Bharat 6G VISION

सत्यमेव जयते

Government of India
Ministry of Communications
Department of Telecommunications
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Bharat
6G Vision Statement

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"Design, develop and deploy 6G network technologies that provide ubiquitous intelligent and secure connectivity for high quality living experience for the world"

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Executive Summary

Every decade, the world bears witness to yet another, highly improved, generation of wireless cellular technology that changes the way the future of communication is perceived. Each new generation provides an almost disruptive impetus to the state of technological advancement, spearheads societal change, and leaves the world wondering if we have truly understood how limitless communication technology can be.

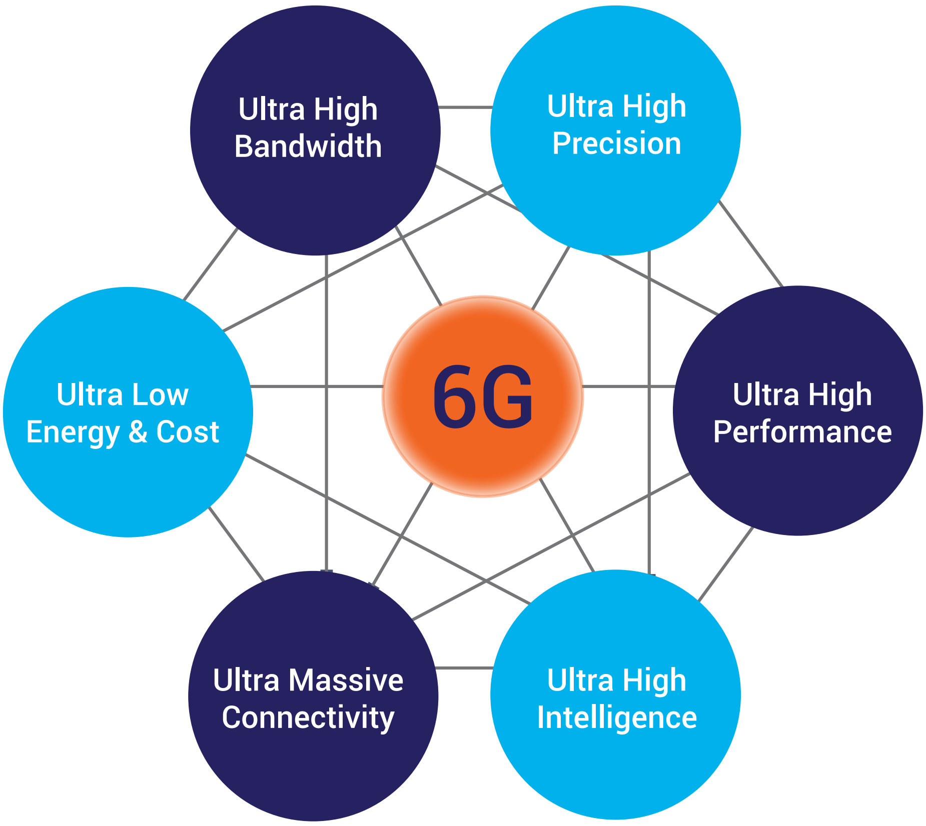
During the last decade, more than 700 million Indians, representing 75% of both rural and urban adult population, became users of mobile and fixed broadband services. Broadband connectivity has transformed lives and livelihoods, particularly of the poor. During the last five years, India has also ramped up telecom equipment manufacturing and exports in a decisive move towards an Atmanirbhar Bharat. During this period, India has also made important contributions to global telecom standards to ensure that its dispersed rural population clusters are as well served as its urban population. The Low Mobility Large Cell rural use case proposed by India is now a mandatory requirement to be met by mobile communication technologies adopted as International Telecommunications Union (ITU) standards.

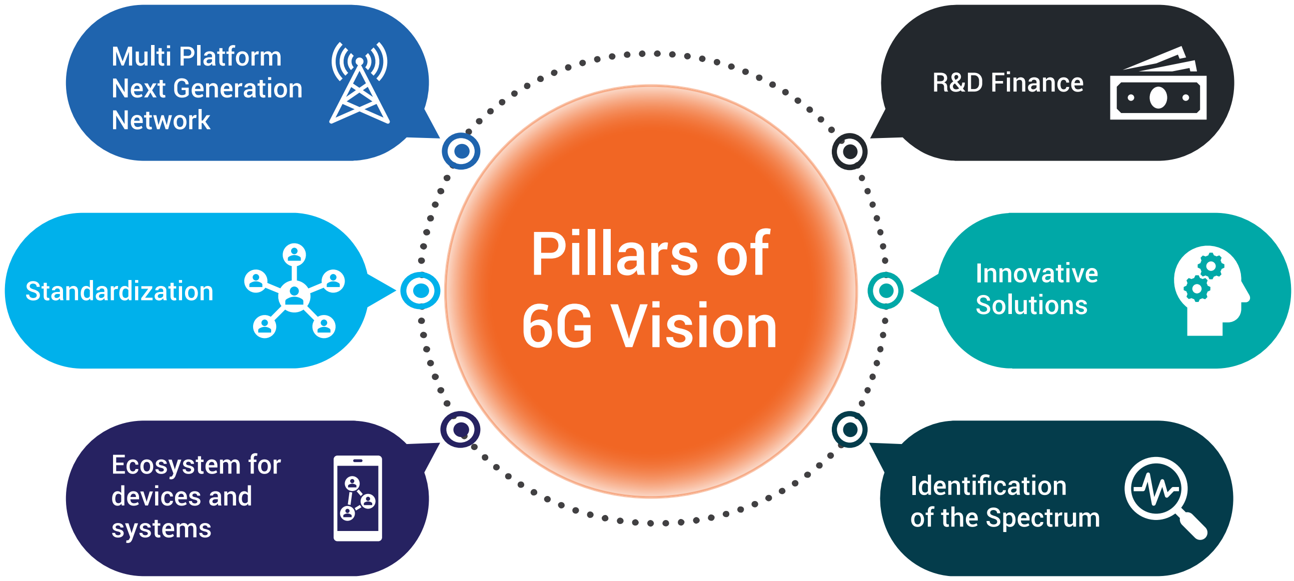
Communication technology is ever evolving, from the early days of fourth generation (4G), when the newfound gaming graphics bowled the world over, to the recent promise that 5G brings to us in terms of heightened connectivity. Today, as India embarks upon its own unique 5G journey, the global telecom sector has already initiated strides towards creating 6G or sixth-generation communication technology as the next big thing on the communication horizon. Despite being at a concept stage, 6G is already making waves with its promise of unified human-machine and machine-machine connectivity and offers a glimpse of what lies in store for the world as the next decade draws closer.

6G will build upon 5G technology and provide more reliable, ultra-low latency and affordable solutions with speeds almost 100 times faster than 5G to enhance and drive new communication applications. These technological advances will impact not just user experience but also transform economies and lives everywhere. It will very likely include intelligent network management and control, and integrated wireless sensing and communication while balancing the potential consequent carbon footprint with reduced energy consumption and a myriad of sustainable and eco-friendly initiatives.

With a Vision of 6G as of today, we need to take stock of where we are with the resources at our disposal and where we ought to be to ensure achievement of Mission 6G. Accordingly, India must focus on aligning its research on technologies in the coming decade that would bolster and propel the implementation of 6G in India in a highly customized manner. Hyper-connectivity and advanced user experience delivered by 6G will improve and enable access to required information, resources (both virtual and physical), and social services without constraints of time and physical location. The advent of 6G will significantly reduce differences in regional and social infrastructure and availability of economic opportunities and will thereby provide alternatives to rural exodus, mass urbanization, and its related problems.

To further explore the impact of 6G in India and to investigate how India can realise its Mission of becoming a global leader in this space, the Technology Innovations Group set up six task forces in India to explore the major pillars of the 6G Vision.



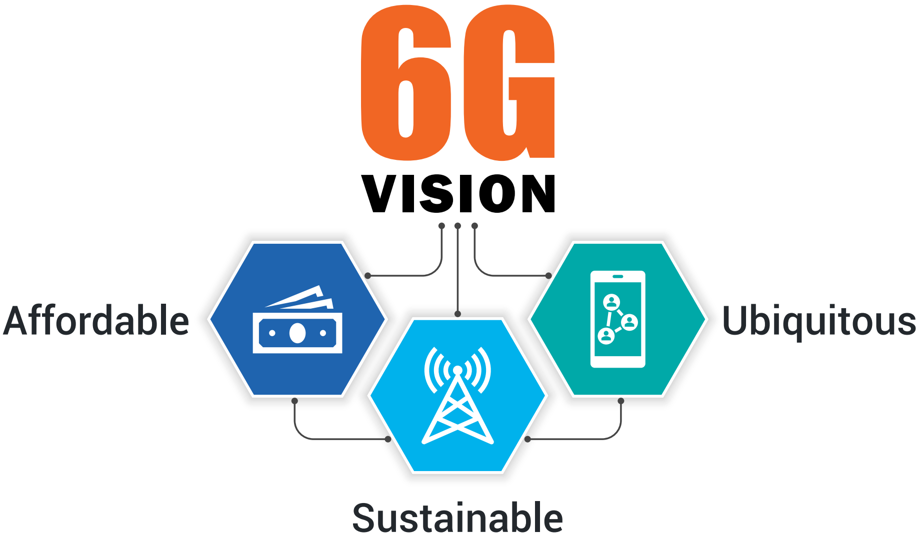


Six task forces formed under the Technology Innovations Group

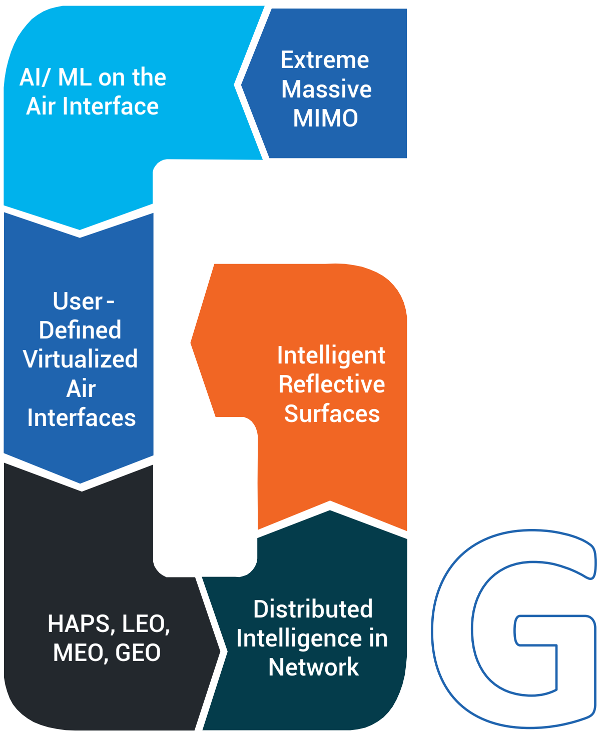
Technology Innovations Group, based on their deliberations on the complete 6G ecosystem, have recommended extensive research in mmWave and Terahertz communications, fiber-broadband, Tactile Internet and Remote Operations, multi-sensor man-machine interfaces and devices leveraging edge cloud computing resources. Well-placed headways into AI, Space-Terrestrial Integration, combined communication and sensing in (Sub) Terahertz bands, SoCs, and innovative solutions emanating from CoEs can further be accentuated by participation in and contribution to global standards forums and leveraging of the start-ups of today. All this and more can be achieved with a robust and much-needed Research & Development (R&D) funding mechanism.

India will identify priority areas for research by involving all stakeholders including industry, academia, and service providers, spanning theoretical and simulation studies, proof-of-concept prototypes and demonstrations, and early market interventions through start-ups, to take the lead. To accomplish the end-state of smart traffic management, virtual reality (VR)/ virtual navigation, smart and highly accurate environmental monitoring, and other fantastical promises of 6G, India will launch a 6G Mission that holistically combines all associated technologies, supported by an adequate financial backup. The Mission can be divided into two phases – the first being the ideation phase to understand the inherent potential and risk associated with the pathways ahead and test proof-of-concept implementations, while the second phase will be dedicated to conceptualizing and delivering potential technology solutions to serve India and the global community. While the basic objective for India will be a customised 6G implementation plan, acceptance and support from the global community can fast forward our commercialization drive and pave the way for further newer technologies.

India has the necessary wherewithal to drive the 6G wave globally and leverage this powerful force multiplier to transform itself into a leading global supplier of advanced, relevant, and affordable telecom systems and solutions. Our primary focus must be on multi-platform next-generation networks like Dense optical networks, AI/ML on the air interface and for network optimization, tactile Internet, Intelligent network operation, Intelligent Reflective Surfaces, Efficient Low Earth Orbit satellites, High-altitude platform systems (HAPS), User-defined virtualized air interfaces, and the like. Further, initiatives into investigating and implementing methods to standardize such technology and devices can provide additional structure and foresight to our 6G roadmap and assist us in efficiently allocating resources to ensure that India becomes a key role player in 6G technology implementation and adoption.



In conclusion, we expect that 6G will play an important role in filling the gap in the provisioning of e-services for urban and rural populations, help in the achievement of the United Nations (UN) Sustainable Development Goals (SDGs), and contribute tremendously towards improving the quality and opportunities of life. These will embody innovations that specifically address the country's needs and improve the productivity of its people, particularly of those in rural areas for whom telecommunications is critical to overcoming the tyranny of distance. These technologies will also provide immense opportunities for India's entrepreneurs to innovate and develop new products based on their Intellectual Property (IP) not just for the Indian market but also for the entire world, transforming India into a global leader providing life- and livelihood-transforming solutions.



2

India and the Telecom Revolution

Mobile wireless telecommunications have, without a doubt, transformed the lives of people and the global economy over the last three decades. Wireless technology harnessed the power of the Internet to morph the daily lives of people and intertwined them into a digital world. From the first generation of analogue technology to the fifth generation of wireless broadband technology, the advancement of seamless Internet has made accessibility and affordability well within the reach of the common people. The results can be seen in India too, which went from a country with less than 20 million landline connections (in 1998) to more than a billion mobile telephone subscribers today with 75% of subscribers always having broadband connectivity irrespective of their location.

At present, the total annual purchase of smartphones is greater than 16 crore smartphones for about 30 crore Indian households. This means that every household today is buying smartphones at an average of one phone every 2 years. A similar amount is being spent annually on two-wheelers, while the annual spend on other household appliances is a lot less. It is interesting to note that an average Indian finds a personal smartphone as valuable as a personal vehicle. Smartphones have evolved from being a means for calling, entertainment, snapping pictures and videos, payments, e-commerce, navigation, etc., to aiding the enhancement of livelihoods.

Affordable telecom technology has enabled Indian citizens to develop their lives and livelihoods at a speed unseen in previous generations. Now, with the imminent deployment of 5G technology bringing in advanced broadband services, higher data rates, better video quality, etc., the experiences of the citizens are only going to improve further. The new machine-type communication capabilities in 5G driving the Mission of Industry 4.0 will impact livelihoods significantly. Many Indians are self-employed or run small enterprises. Their ability to support their customers better through online tracking of their products/ sales, or to monitor critical business activities even as they are on the move, will improve greatly. With the assured low-latency data transfer capability offered for the first time in 5G, professionals can even perform some tasks remotely through tactile Internet.

As India progresses into the centenary of its independence, the next two decades are a critical growth phase that will determine the country's future. It is crucial to seize this opportunity of the latest generation in wireless technology even as the technology is still fresh "from the oven". As the world's second-largest telecom market, India must evolve to become a net technology provider and manufacturer to the world. This means that we must actively participate in defining the contours of the next sixth generation (6G) and drive the innovations such that we address the pressing needs not only for India but for every other country with similar requirements. We must pivot to the position of a leading global provider of technology and solutions for the greater good.

3

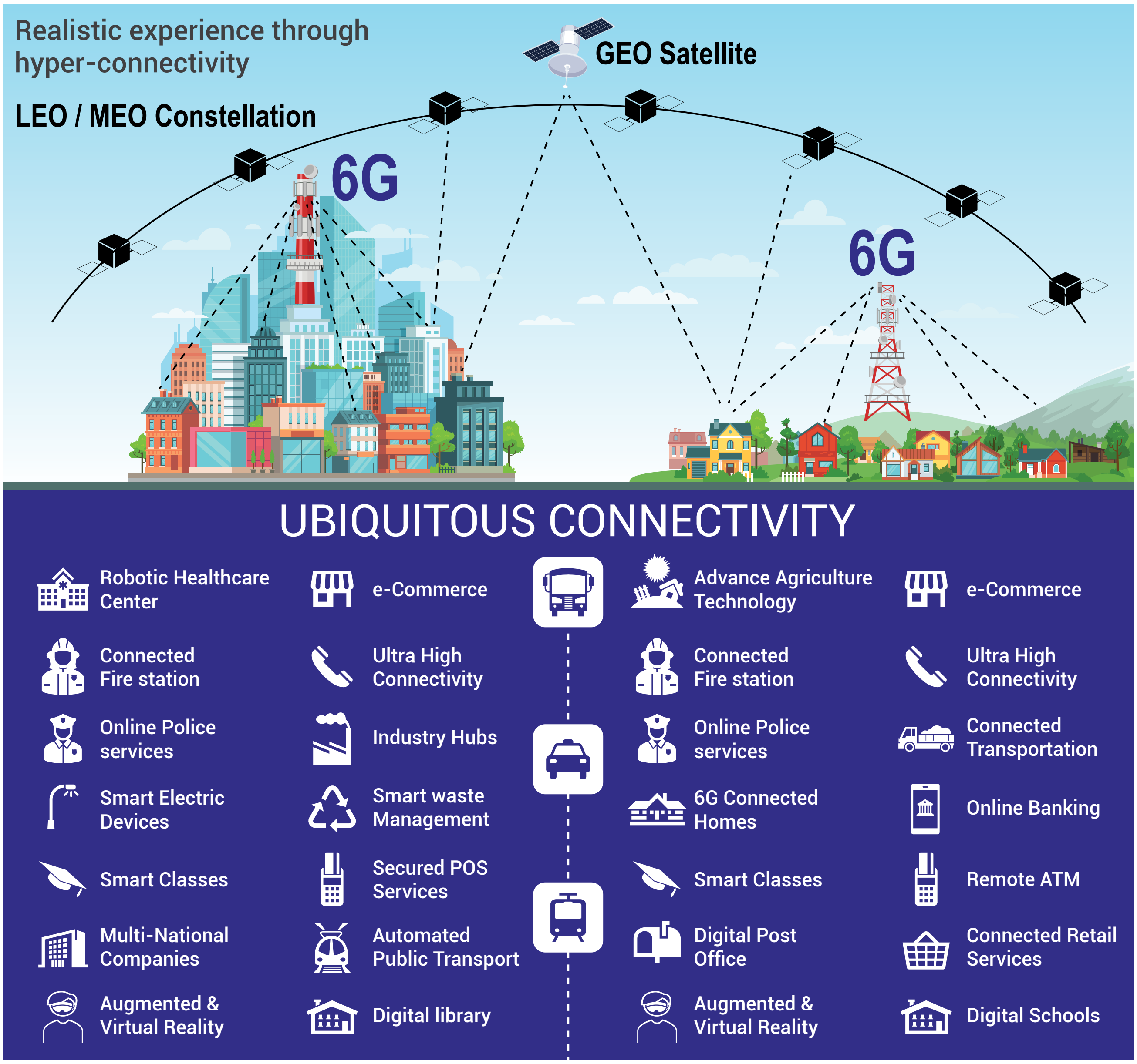
The 6G Promise

As India recently concluded the highly anticipated spectrum auctions, the implementation of 5G mobile services has finally been set in motion in the country. While the full potential of 5G will take shape over time, we already have a clear understanding of how it can impact and change the Indian and global telecommunication landscape for the better. 6G will build extensively on this enhanced state of technology. The global community has already begun exploring its potential in a bid to push the frontiers and stay abreast of the high-paced technological advancements that symbolise the telecom sector.

Although technically 6G does not exist today, it is already conceived as a much superior successor to the widely anticipated 5G. It promises a world of unimaginable speeds, connective intelligence and a highly mature IoT model that will enable and empower automated cars and smart home networks and will heighten the already existing interplay between everyday life and the internet. The global vision is to further transform connectivity to make big data analytics and holographic displays a norm when 6G technology is finally implemented in the 2030s.

The current cell-phone technology is the ubiquitous 4G which supports our current way of life by providing us with seamless streaming and gaming experiences. The new 5G technology promises a speed range of 40 – 1,100 Mbps with the potential to hit maximum speeds of 10,000 Mbps through technologies such as millimeter-wave spectrum and beamforming. While 5G itself seems very futuristic as of now, 6G will offer ultra-low latency with speeds up to 1 Tbps that will amp up the machine-to-machine and human-to-machine interactions to unprecedented heights and transform the development and use of virtual and augmented reality (VR/AR), mobile edge computing, Artificial Intelligence (AI), etc. 6G use cases will include remote-controlled factories, constantly communicating self-driven cars and smart wearables taking inputs directly from human senses. While 6G promises growth, it will simultaneously have to be balanced with sustainability since most 6G supporting communication devices will be battery-powered and can have a significant carbon footprint.

This report further elaborates on India's 6G Mission which aims to provide all these high-speed and ultra-low latency solutions at affordable prices to urban and rural areas alike, irrespective of external factors such as terrains, weather, and environmental conditions.



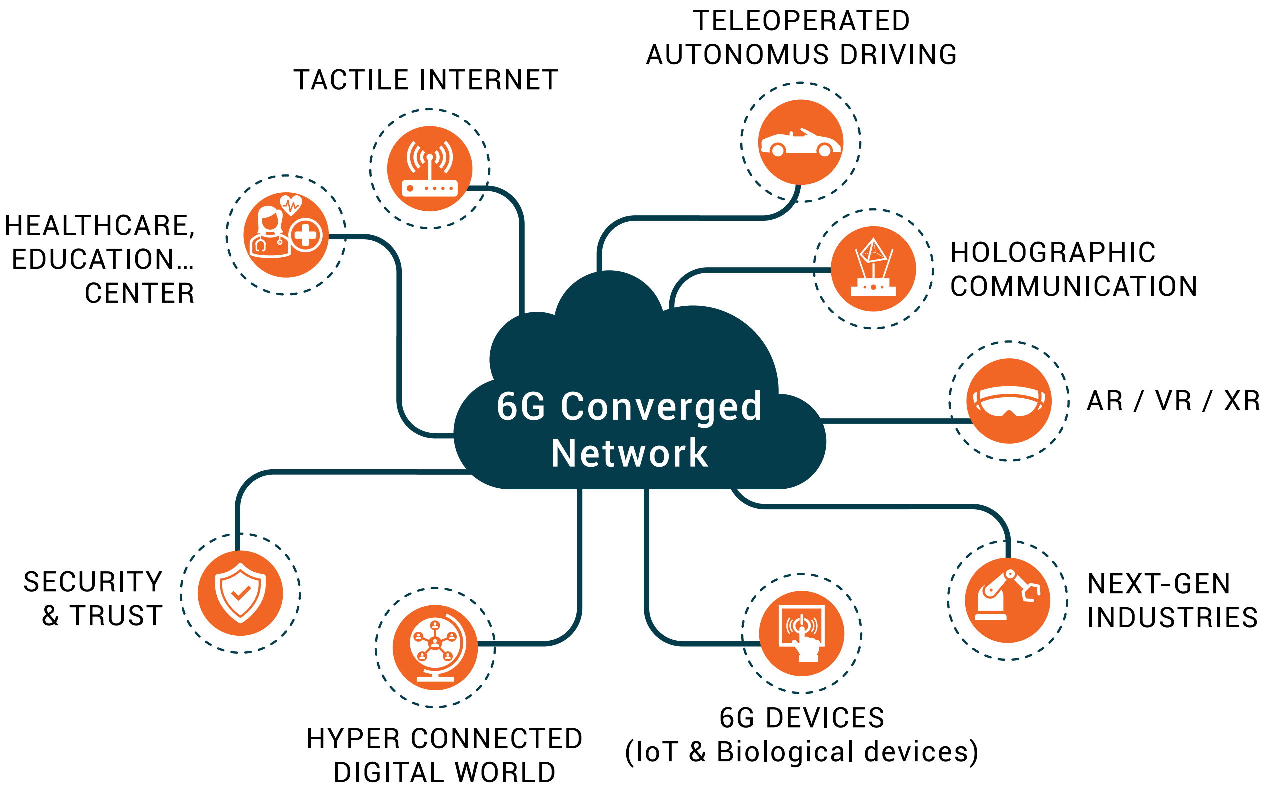
4

The 6G Roadmap

4.1 Global 6G Scenario

The lifestyle of modern society made a drastic shift when broadband access became ubiquitous with smartphones that were powered by the fourth generation (4G) of wireless technology. People were able to connect with their peers 24x7 instantaneously and at high speed with the tap of one's fingers. The need for physical presence in business settings is reduced enabling a boost in efficiency and productivity in all sectors of society.

As we come to grips with the wave of changes that 4G has wrought, the fifth generation (5G) of wireless technology is being rolled out from 2020 onwards. The Internet of Everything is enabling an explosion in remote human-machine and machine-machine interaction. Technology that could only be imagined during the 4G era is being manifested during the 5G wave. And yet every day, we keep discovering, creating, and developing technologies that are of much higher capability than 4G technology. Vehicles can communicate with each other and with us to enable a safer and better transportation experience, machines in factories are interacting with the smart controller as well as with each other to improve productivity, urban and rural utilities are becoming smarter in fulfilling their functions, and so on.



Now that 5G is rolling out, the question for the next decade is what the sixth generation (6G) of wireless technology will look like and how can we convert our vision into reality. What can we expect to become feasible and available in the next decade? Given the impact it will have on lives, livelihoods, and productivity, it is important for everyone across the world, particularly those in growing economies, to ponder over what they would like 6G to deliver and how they can shape it to suit their needs. Many countries and consortiums are actively addressing this question through research efforts and realizing their Vision for 6G. The following discussion summarizes the major efforts that are being pursued worldwide in 6G.

A

A major effort in North America has been launched by the Next G Alliance[1] of stakeholders who range from service providers and vendors to universities and start-ups. The main drivers of their Vision are classified into four foundational impact areas – Everyday Living, Experience, Critical Roles, and Societal Goals. They include four categories of use cases: Network-Enabled Robotics and Autonomous Systems, Multisensory Extended Reality, Distributed Sensing and Communications, and Personalized User Experiences. Based on this classification, the alliance has identified high-level functional and performance requirements based on both audacious and incremental objectives. These goals cover trust, security and resilience, an enhanced digital world experience, affordable solutions that span all aspects of the network, distributed cloud and an AI-native network, and sustainability concerning energy efficiency and life cycle costs. Due to these requirements, nearly fifty technological areas have been identified within the domains of system components, radio technologies, network architecture, Operations, Administration, and Maintenance (OA&M) and provisioning, security, reliability, privacy, and resilience.

1. https://nextgalliance.org/

B

South Korea has outlined a 6G R&D Plan with Rs. 1200 CR investment in the first phase running till 2025, for attaining global leadership, developing key original technologies, making significant contributions to international standards and patents, and building a strong foundation for 6G research and industry.[2] Six focus areas have been identified for attention: terabit speeds, operation in 100-300 GHz band, 3D-coverage integrating LEO satellites with a terrestrial network extending up to 10 km airspace for drones, 10% of the latency in 5G, ubiquitous AI, and security designed into every element of the network. Several key technologies are being pursued to achieve the desired goals: Terabit wireless and Terabit optical communications, RF components and spectrum studies in the THz band, mobile communications in space, ultra-precision networking, intelligent wireless access and network, and real-time network monitoring. A total of 14 LEO satellites are proposed to be launched before the end of the decade. Three 6G research centres have been established in universities in 2021, and 6G capabilities of working-level researchers are being enhanced by scaling up joint R&D by small and medium enterprises, universities, and research centres in Korea. Working together with Korean Intellectual Property Office, R&D funding, a strategy for the key fields of space networking and intelligent high-precision networks having high potential for obtaining pre-emptive standard-essential patents are being put in place. To create global collaborative networks, South Korea is also promoting joint studies on core 6G technologies and 6G spectrum with foreign countries that are carrying out government-led research on 6G technologies.

C

Europe has been in the vanguard of telecom research since the era of 2G. The European 6G Vision[3] identifies key features of 6G including intelligent network management and control, integrated wireless sensing and communication, reduction of energy consumed, trustworthy networks, scalability, and affordability. The 6G architecture is envisaged as a flexible and efficient network of networks including non-terrestrial networks, encompassing novel AI-powered enablers to enhance network performance and provide AI-as-a-Service using a distributed cloud. AI and Machine Learning are expected to play a key role in human-digital-physical interaction to automate certain levels of decision-making. Network capacity is expected to expand to approach and even exceed Shannon and Moore's limits. Smart optical transport is being pursued to ensure an intrinsically secure, green, and scalable network. Photonics integration is being pursued to integrate optical, radio and digital electronic functions. Quantum technologies are being explored to understand their potential for unprecedented performance in quantum sensing, communication, security, and computing. The overarching Vision is to ensure leadership in strategic areas and establish secure and trusted access to key technologies making Europe a sovereign, independent, and reliable source for 6G public and private network solutions and services. A parallel objective is to foster entrepreneurship with private and public participation, complemented with tax policies for start-ups to avoid the relocation of promising businesses. Sovereignty and security requirements are being identified and enforced.

In the first explorative phase (Hexa-X The European 6G flagship project[4] of research), running from 2021 till 2023, the critical technology enablers for 6G being studied are: sub-THz transceiver technologies, accurate stand-alone positioning and radio-based imaging, improved radio performance, artificial intelligence (AI) / machine learning (ML) inspired radio access network (RAN) technologies, future network architectures, and special purpose solutions including future ultra-reliable low-latency communication (URLLC) schemes.

2. https://www.msit.go.kr/eng/bbs/view

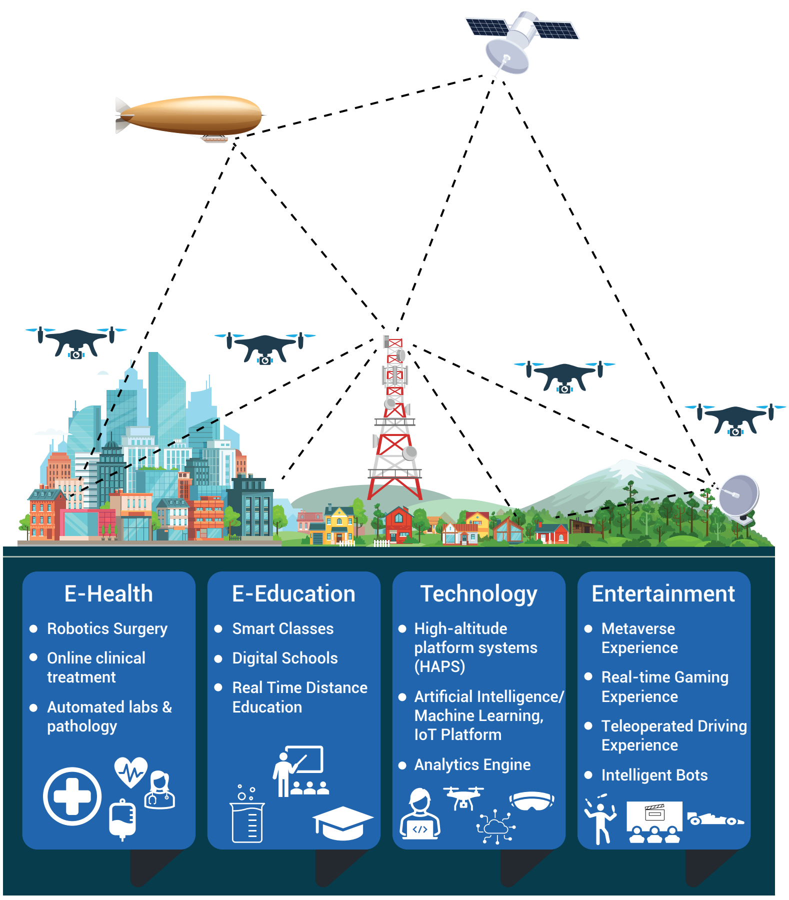
3. https://www.researchgate.net/publication/352226800_European_Vision_for_the_6G_Network_Ecosystem

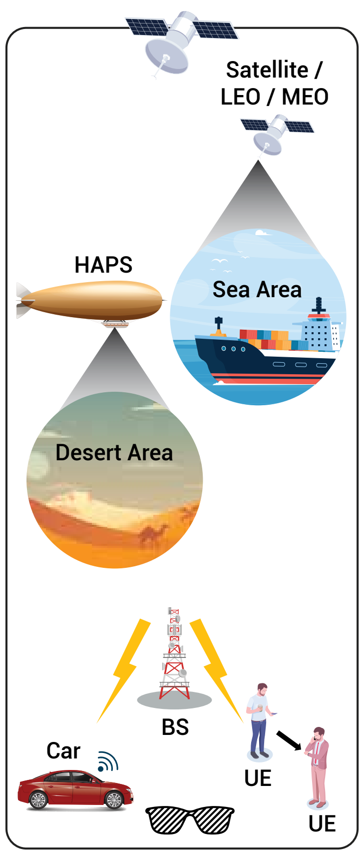
4. https://ieeexplore.ieee.org/document/9482430)

D

In Japan, the Integrated Optical and Wireless Network (IOWN) Forum[5] published its Vision 2030[6] white paper, which laid out key technology directions for infrastructure evolution in four dimensions: cognitive capacity, responsiveness, scalability, and energy efficiency. Phase 1 work was started to identify use cases and technical requirements. Cyber-Physical Systems and AI Integrated Communications Use Cases have been spelled out. Functional architectures have been defined for an Open All Photonics Network (APN), a Data-Centric Infrastructure, (DCI), a Data Hub, and fibre sensing for the APN. Requirements and proposed solutions for the transport backbones to support the 6G wireless network and a reference end-to-end implementation model have been developed. Open APN, DCI, and Data Hub will evolve with the progress in optical/radio communication and photonic-electronic technologies. IOWN proposes to build liaison relationships with other 6G fora and SDOs to complement their efforts.

The following 6G technology areas have been highlighted[7] for research in Japan: high-density distributed antennas, spectrum sharing and integration with non-terrestrial networks, THz band propagation studies, THz band devices, THz radio technologies, Extreme Massive MIMO, Next generation of HAPS communications with improved reliability and lower latency, integrated wireless sensing and communication, use of AI across the telecom network, flexible and intelligent networks, RAN-Core convergence, integrated multi-technology networks, advanced security and distributed cloud.





5. https://iowngf.org/
6. Vision 2030
7. https://www.docomo.ne.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v4.0.pdf

E

ITU's Focus Group on Network 2030[8] foresees high-resolution immersive multimedia over the Internet, smart IoTs, factory automation, and autonomous vehicles, in other words, the fusion of the real and digital worlds, to become commonplace with 6G. Internet of Things operating at hyper-scale at the system level, not in isolated environments such as private networks, will require distributed intelligence all over the connectivity fabric. Information transfer must occur with much lower latency between machines, robots, and their virtual counterparts to support autonomous operations. The proliferation of public and private networks created using Converged Service Platforms will require network intelligence to integrate and manage. Proof-of-concept trials will require access to at-scale physical and virtual testing facilities with embedded measurements. The Focus Group has published reports on Use Cases and Key Network Requirements, New Services and Capabilities, Architectural Framework, and Technology, Applications and Market Drivers for the 6G Network of 2030.

F

Key developments in 6G have been identified and are being pursued in China[9]. It is forecasted that the next generation 6G network will support connectivity plus sensing plus AI, with security implemented by design throughout the network. The network will employ model and data-driven algorithms to leverage AI and ML to deal with analytically intractable conditions better. Such a complex network will be managed without "touch" in a heavily automated manner. AI will also be provided as a service through a converged distributed cloud and network architecture. Further, the network will extend into space through mega-LEO constellations.

From a more theoretical point of view 6G must provide an infrastructure to enable remote-controlled mobile robotic solutions for everyone—the Personal Tactile Internet – and not just for businesses. While some enhancements will appear as "5.5G" or advanced 5G standard, more disruptive advances in the radio technology such as switched Physical Layers (horses for courses) referred to as a "Gearbox PHY[10]" will be possible only in 6G. Seventy-five years after Shannon advanced fundamental information theory concepts, several issues remain open to be addressed on the way toward 6G. Creating the Tactile Internet while simultaneously reducing the energy consumed and operating under constraints imposed by semiconductor technology throws up a wide variety of challenges. These mostly cannot be solved using analytical techniques alone and require one to one account for the reality of networks and hardware. A true system understanding is a sine qua non for advancing the role of information theory in 6G.

8. https://www.itu.int/pub/T-FG-NET2030
9. https://www-file.huawei.com/-/media/corp2020/pdf/tech-insights/1/6g-white-paper-en.pdf?la=en
10. 6G: The Personal Tactile Internet—and Open Questions for Information Theory in IEEE BITS Sep 2021 (https://ieeexplore.ieee.org/document/9568233

4.2 6G Telecom Network in India

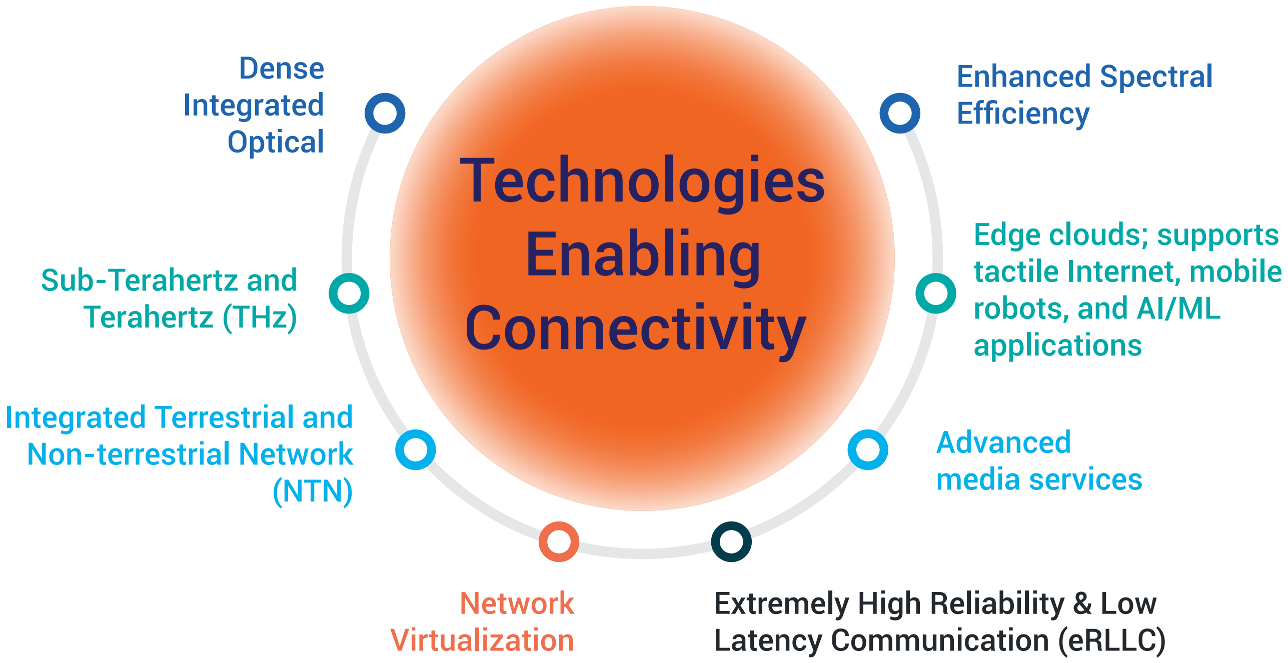
India, along with the world, is contemplating the next generation of telecom technologies and the transformations likely to be wrought by them. This paper presents a Vision for India's journey towards empowering its people with the most advanced, relevant, and affordable next-generation (6G) telecom technologies.

Hyper-connectivity and better experience delivered by 6G mobile communication technology will improve and enable access to required information, resources (both virtual and physical), and social services without constraints of time. Broad deployment of 6G technology will reduce differences in regional and social infrastructure, and in economic opportunities, thereby providing alternatives to rural exodus and metro-driven urbanization. We expect that 6G will play an important role in filling the gap in the availability of e-services between urban and rural communities. This will subsequently fulfil the UN's SDGs and tremendously contribute to improving the quality and opportunities of human life.

By harnessing 6G to embody innovations as per our requirements, we can specifically address the country's needs and improve the productivity of its people, particularly of those in rural areas for whom telecommunications is critical to overcome the tyranny of distance created by modern society. These technologies will provide immense opportunities for India's entrepreneurs to deliver new products based on their IP, for both domestic and global markets, thus transforming India into a leading global manufacturer and provider of telecommunications solutions with the power to transform lives and livelihoods.

This Vision document identifies key research pathways that are being pursued globally and that are particularly relevant for ideating new possibilities in the Indian context. These pathways straddle multiple platforms involving new hardware, software, hitherto unutilised spectrum at very high frequencies, AI and ML engines, quantum photonics and computing technologies, space-based assets, and devices with new user interfaces, sensors and displays that promise to unleash the so-called Tactile Internet.

Terahertz communication with ultra-high speeds will be essential for indoor and outdoor (worksite/factory) tether-less applications. Coupled with Intelligent Reflective Surfaces to overcome propagation hurdles, wireless communication at these frequencies is an important focus area to investigate. A flexible, seamless integrated optical and wireless network reaching each household, even in remote villages, is what we should aim for by the end of this decade. The varied demands from wireless communications in terms of speed, latency, and energy efficiency will require us to leverage the ever-expanding capabilities of semiconductor technology to innovate on a highly adaptable set of waveforms and protocols that can deliver the needed variety. Apart from moving into the new spectrum of the Terahertz band, India should also explore new avenues in cell-free communications and extreme MIMO to utilize the available spectrum in the lower bands much more efficiently. The oncoming integration of Space and Terrestrial networks into one seamless unified whole provides an opportunity for India to leverage her capabilities in space technology to plug the gaps in coverage of its vast rural hinterland and ensure that all Indians have broadband connectivity no matter where they are.



The impressive strides being made in telecommunications are with the help of ongoing technological leaps in semiconductors, photonics, devices, computing and display technologies. The time is ripe for the Indian telecommunication industry to leverage its capabilities in optical networking and develop robust, cost-effective techniques to take fibre to the nooks and corners of the country. The industry needs to utilize its prowess in software to rapidly expand edge computing clouds so that any citizen can inexpensively deploy compute-intensive AI and other applications on the go, and make a mark in new areas such as emerging display, wearable, sensor technologies to address specific UI needs of our applications. Innovations in these spheres can be leveraged by Indian manufacturers to deliver cost-effective competitive products to the entire world. We should focus on sensors and tactile interfaces that enable skilled tasks to be carried out remotely. This will be a game-changer for crafts-persons and technicians who often travel long distances to reach their workplaces and complete their tasks.

By nature, telecommunication is standards-based, which ensures that equipment manufactured by multiple entities communicates seamlessly with each other across national boundaries. Therefore, research into next-generation wireless and optical technologies, next-generation protocols and network architectures that are key to enabling and bolstering 6G implementation and adoption, must follow global standards to be considered as global products. The entire Indian 6G research effort should therefore dovetail into an equally strong and well-orchestrated standardisation drive. India has made rapid strides in standards-related research in recent years, and this trend should be amplified. We need to ensure that global standards adequately incorporate our innovations and address our specific needs. In this regard, telecommunication standards bodies of our country such as TSDSI working in tandem with TEC and other telecommunications forums have a major role to play.

India is one of the largest telecom markets in the world with a high dependency on wireless technology for broadband connectivity. Right now, the spectrum is congested, particularly in the low and mid-bands where the propagation characteristics are favourable. Apart from innovations in spectrum-efficient communications mentioned earlier, we also need to decongest the spectrum and innovate on ways to permit the co-existence of mobile broadband networks with other users in the same bands. Backed by a strong suite of co-existence studies, field measurement campaigns, and pilot trials, India can lead in such efficient shared use of spectrum across many bands. We must also deploy our resources in advanced monitoring and management of spectrum with real-time sensor-driven cognitive spectrum sharing enabled in some bands. Besides, as devices move beyond mm-wave to the terahertz bands, they can adopt the same bands for ambient sensing as well, which is very useful for mobile robotic applications.

While smartphones with their built-in cameras, touch screen and other sensors have delivered enormous value to their human users, the next generation of devices will seek to fuse inputs from multiple sensors and multiple devices to obtain a dynamic representation of the ambience of users or a machine/robot. It will extensively leverage AI and ML in this task with some heavy computing on user devices and some in twhe edge cloud. Like humans, machines will also be "users" who communicate amongst themselves to act in unison as desired by their human operators. The compute engines at the user end as well as in the edge cloud can be innovatively developed around the DIR-V Indian microprocessor program, with an impregnable security layer inbuilt to protect users and applications from cyber-attacks. While the primary device has been the smartphone until now, the next generation will witness an explosion of all kinds of user devices as well as devices that are connected to machines. This vast diversity of devices calls for a healthy ecosystem for developing SoCs by fabless companies/start-ups, new user interfaces particularly wearable ones, and a variety of form factors that suit every application. This presents a big opportunity for India to take a head start in this emerging family of devices and emerge as a global supplier.

5

Summaries of 6 Task Forces & their recommendations

5.1 Multi-Platform Next Generation Networks

The task force dedicated to multi-platform next-generation networks deliberated extensively on the current global thinking regarding the evolution of the telecom network in the year 2030 and beyond. The strands were evaluated in the context of India's own future needs and growth trajectory over the next decade. Depending on the degree of relevance of each of these strands in our context, the Task Force has emphasized some of the possible evolutionary paths over others. While evaluating the strands, it emphasized those that appeared more realistic and promising in a ten-year timeframe. The importance of a dense optical network right up to the homes and offices cannot be over-emphasised. Building the wireless network consumes time and resources but it not only serves the needs of the mobile users but also of the nomadic or the static users as well. Going forward, a seamless integrated optical and wireless network, with wireless fiber-like segments wherever appropriate, is imperative. Sufficient attention will have to be paid to GPON network engineering in rural areas.

The explosive growth in data volumes, the multiplicity of access technologies, the deepening of the optical access network, the proliferation of edge clouds, and the increasing need for content- and user-awareness in networks will lead to a more decoupled core network architecture and will increase the use of AI/ML in optimization and intelligent network operation. As spectrum gets more heavily used, ever-higher frequency bands are being explored primarily due to the large bandwidths available and ever-improving operating frequencies of semiconductor technologies, despite the challenging propagation conditions at these frequencies. Mitigatory techniques such as Intelligent Reflective Surfaces may provide some workaround to the poor propagation at very high frequencies as will massive MIMO with the cell-free operation. The air interface may move radically to a virtualized user-defined mode enabling the radio to support the specific user requirements for a given wireless channel, moving away from the hitherto conservative design for the worst-case wireless channel. The wireless transceiver in many cases may additionally play the role of a radar sensor to capture the ambient environment around the transceiver.

While the remote operation of machines and robots may be attempted even with 5G networks in the coming years, the Tactile Internet for Remote Operations is a serious possibility a decade from now. This capability may be used not just for high-end applications such as remote robotic surgery, but also for a host of mundane applications in much the way multimedia communications is used today with the smartphone for all kinds of applications. This may require good support from edge computing clouds that run /AI/ML algorithms and will leverage a user-defined radio interface to ensure high reliability. The growth of Industrial IoT in the coming years will drive the growth of remote operations even if much of it is simply automation and not tactile. Digital Twins of complex, real physical systems and networks running in the edge clouds will enable automated control of the real system by predictive analysis of future events based on AI and other techniques.

With the increasing cost-effectiveness of Low Earth Orbit satellites and new technologies such as HAPS, it is increasingly likely that non-terrestrial wireless networks will finally get integrated with the terrestrial network to offer ubiquitous coverage not only on ships and aircrafts, but also in rural areas under-served by the terrestrial network in the Indian context. The explosive growth forecast in drone usage will necessitate drone communications to be supported by the integrated space-terrestrial network more reliably and securely.

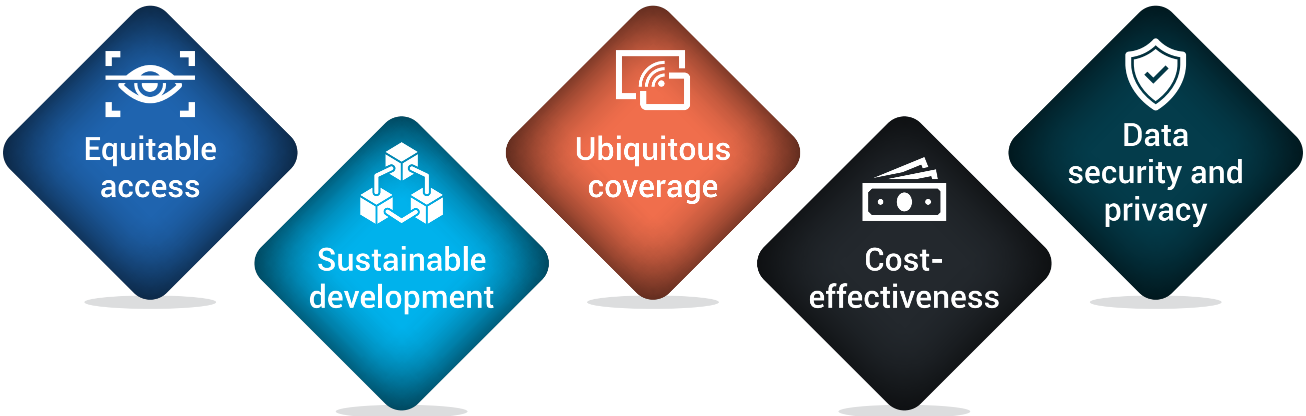
The very high data rates supported by 6G will likely provide a platform for realistic e-meetings where holographic-type or AR/ VR technologies are deployed along with multi-gigabit-per-sec tether-less links to provide a near-physical experience. User-defined virtualized air interfaces will enable such platforms to be invoked even by a mobile user based on the ability to set up a sufficiently fast, low-latency, low-jitter, reliable link, leading towards what could be described as hyper-personalised wireless networks.

The research efforts over the next few years should be aligned toward realising one or more of the highly promising, scalable and feasible (with high probability) technologies/platforms outlined herein. All of these are of great relevance in the Indian context and also have global applicability. Advances made in any of these areas will not only serve our needs but also give India an edge globally. India can use this decade to realise its aspiration of being a net global provider of telecommunications technology.

5.2 Innovative Solutions

6G will push the boundaries of communication technology by ushering in bandwidths of 1Tbps (about 100 times that of 5G). With latencies of less than a millisecond, it can revolutionise all interactions, like human-to-human, machine-to-machine, and human-to-machine, and change the way data is stored, processed and used in the future. In addition, 6G will also incorporate "sensing" as an inherent service - which will also have a profound impact on the design and delivery of new technologies and services in diverse areas such as education, medicine and gaming. While it is difficult to fully understand the implication of these capabilities currently, we need to identify and create a road map to explore various use cases to discover the full potential of 6G as well as pave the way for the 6G technology and standards development to ensure that they meet the needs of all identified future use cases.

From a 6G implementation perspective, certain key guiding principles for us to keep in mind are as follows:



The task force recommends the strategy of meta-use cases to drive the actual 6G use case selection process from an indicative list given in the report. Four guiding questions that will help the selection process are also discussed in the report. Identification of marquee use cases from various sectors and forming a consortium of partners who can bring an interdisciplinary approach, will help further our understanding of the needs of 6G as well as holistically guide its further development. These use cases can be identified keeping various considerations in mind and especially evolving from ongoing or planned work for 5G.

Allocation of reasonable financial resources is recommended in a public-private partnership model, over three phases:

1. Basic research in some well-chosen key areas leading to the creation of new IP in Phase I
2. Translating these into potentially commercialize technologies and contributing to allied standards in Phase II
3. Finally, supporting commercialization and product roll-outs in Phase III

Activities are recommended to be carried out via consortium groups involving a judicious mix of academia, industry and appropriate government institutions, through centres of excellence for both "horizontal" technology creation as well as for "vertical" applications and use cases.

5.3 Spectrum

Society's increasing use of radio-based technologies, and the tremendous opportunities for social development that these technologies provide, highlight the importance of radio-frequency spectrum and national spectrum management processes. To better drive spectrum management initiatives for 6G, the following objectives were set out by the 6G Spectrum Policy Task Force -

- Identify various spectrum needs to enable 6G in the coming years with a focus on spectrum availability and allocation among various radio services with reasonable certainty to bridge adoption lag, maximize socioeconomic benefits and provide high-speed broadband through various access technologies to address the digital divide
- Signal the identified 6G spectrum bands for the industry to efficiently plan and build wireless infrastructure across sectors and introduce new wireless technologies in a systematic manner
- Make spectrum available for 6G technology innovations and facilitate ease of doing R&D
- Deployment of spectrum efficient technologies by all stakeholders including Government, TSPs, Enterprise users
- Encourage spectrum sharing and optimal coexistence among various radio services
- Position India as a hub of 6G wireless technology R&D and manufacturing
- Facilitate enhanced use of wireless technologies in enhancing productivity and operational efficiency through Industry 4.0 and enterprise digitalization

The table below summarizes an indicative list of Digital India 2030 Mobile and Broadband Policy objectives along with tentative spectrum bands to be made available.

Three Dimensions of 6G Spectrum

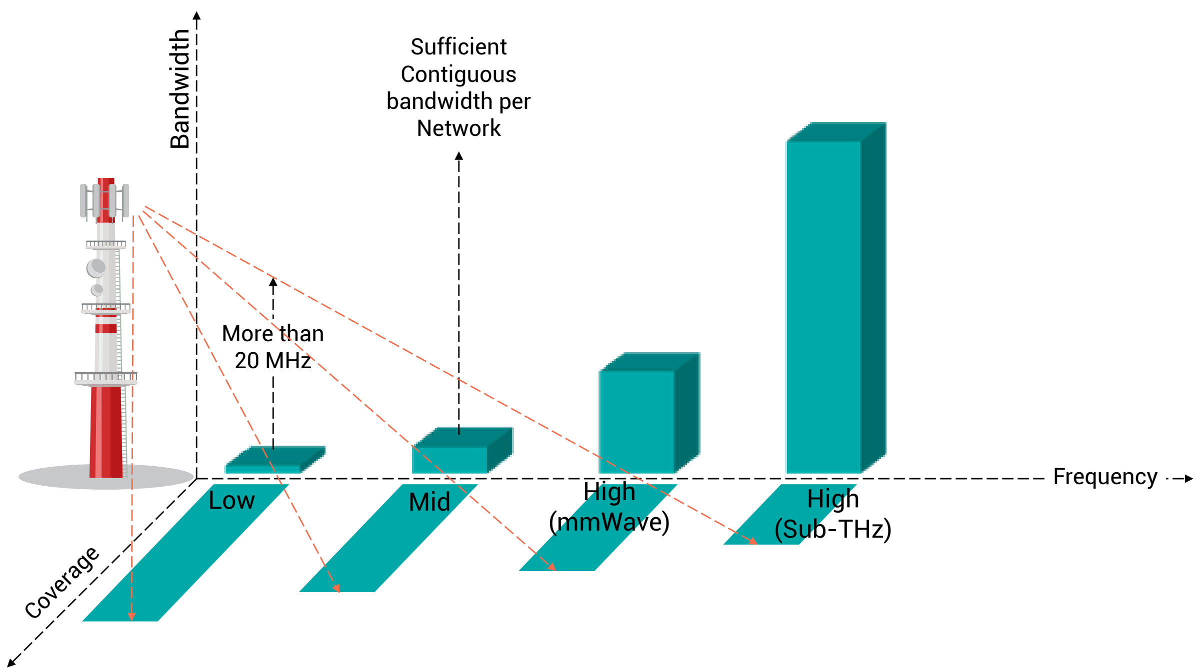


Table 5.3.1: Digital India 2030 Mobile and Broadband Policy Objectives (indicative)

2022 Roadmap		2030 Roadmap		Spectrum Requirements 2030 (5G+ and 6G)		Spectrum Bands to be made available
High speed broadband to citizens, Enterprises, public services. Connect all villages	→	100 Mbps to every citizen (large coverage of 5G and beginning of 6G)	→	Likely to double from the current planned spectrum quantities (covering lower, mild, millimeter and Tera Hz bands) Diverse access technologies Mobile, GSO, NGSO, HAPS, HIBS, etc.	→	<1 GHz Bands Mid Band: up to 10 GHz 6.425-24 GHz Bands Millimetre Bands: 26, 28, 40, 66, 70, 90 GHz, etc. Tera Hz bands
10 Gbps to every GP	→	500 Gbps to every GP	→	High speed backhaul to complement Fibre connectivity	→	Q, V, E, D, W Bands Free Space Optics 6.425-24 GHz Bands Free Space Optics
50% Households with Broadband	→	90% Households with High-speed Broadband	→	FWA – Fixed Wireless Access (would be a cost-effective option) using 5G and E, V Band links & other access technologies including fibre	→	Millimeter bands of 37, 50, 66 GHz V Band (57-66 GHz) 6.425-24 GHz Bands Free Space Optics
10 Million public Wi-Fi Hotspots	→	50 Million public Wi-Fi Hotspots	→	New License Exempt Spectrum Bands	→	6 GHz, V-Band, > 95 GHz Tera Hz Bands
5 Billion IoT Devices; Enterprise Digitization (ITS, Urban Management)	→	25 Billion IoT Devices Smart Enterprises & Factores (Smart Infrastructure Rural and Urban)	→	New License Exempt Spectrum for M2M connectivity to power smart cities and communities	→	915-935 MHz V Band 95 GHz bands Thz bands
Personal and Home Connectivity (SRDs)	→	Connected and Intelligent Living	→	Extremely low power intelligent devices of all kinds connecting everything around	→	Hundreds of bands to be identified continuously based on innovation
UAVs with limited action	→	UAVs in Delivery Services, Logistics, Disaster Management	→	Defined IMT and unlicensed bands with ultra-reliability and control (application specific)	→	1 GHz Bands Band: up to and above 10 GHz

In accordance with the above objectives, the 'spectrum for 6G' has been comprehensively analyzed from bands, services and ecosystem perspectives including current gap areas in the system. As spectrum is a resource with an interplay of different generations of technologies, all spectrum bands require a review of its efficient use among radio service users to enable sufficient spectrum for new-era services.

To enable the above, specific band-wise recommendations have been made taking note of global developments and the Indian opportunity to use spectrum as a key resource to attract R&D investments and to maximize spectrum use in line with NDCP-2018 objectives. Building demand in new bands is an important aspect, which is also critically studied as part of the activity. The following are some of the key recommendations-

- Review the spectrum bands in lower, mid and mmWave bands and announce respective actions to enable maximization of the spectrum and use and socioeconomic benefits.
- Open up a few bands to generate demand (for example 450-470 MHz, 526-612 MHz, 31-31.3 GHz, etc.).
- Expand and position a larger mid-band to meet the requirements of 5G+ and 6G technologies. This requires initiating a new inter-ministerial process of repurposing several bands like that has been done earlier.
- Enterprise use of 5G, 5G+ and 6G services is going to be mainstream and the spectrum Vision needs to be expanded in making spectrum available across the bands and for various use- cases. Assigning spectrum to private captive networks including coexistence bands is the need of the hour.
- Delicensed or license-exempt bands are key as a public good to enable innovation and gigabit public Wi-Fi by exploiting technology innovation for example Wi-Fi 6E or WiGig etc. In line with this, the lower part of the 6GHz band and at least 4.32 GHz in the V band should be delicensed.
- Tera Hz research should be encouraged considering the large swath of spectrum from 90 GHz to 3000 GHz. Industry and academia-driven research testbeds should be established to bring focus on 5G+ & 6G driven active antenna systems and Intelligent Reflector Surfaces (IRS) using mmWave and THz bands. A few countries such as the USA, UK, etc. have made some of the THz bands' licenses exempt for some periods both for commercial deployment and R&D.
- Set up spectrum sandboxes as envisaged in NDCP as a way forward to enable R&D and testing freely outdoors.
- An opportunity to take lead in new technology domains such as sensing, orthogonal sharing, broadband-broadcast convergence, etc., where there is significant research work in progress and some products are also being piloted.
- Strengthen WPC with state-of-the-art spectrum management software to enable spectrum audit, interference management and dynamic database systems. Capacity building is another important area to enable necessary competencies in spectrum management.

Structural mechanisms for coexistence studies, spectrum technology infrastructure and capacity building are critical to creating a systematic approach. This will not only help in studying the bands in an ongoing manner but will also make them available on time to minimise the adoption gap. These aspects are elaborated on as part of the Task Force report. Apart from the need for representation in WRC-23, there is a need to have an institutional mechanism to enable coexistence studies in an ongoing manner. Going forward, a participatory and transparent mechanism is proposed to be taken going forward considering its critical need to build consensus quickly on different bands and the feasibility of the coexistence of different radio services and users.

Further, generation of demand in new and greenfield bands (such as 450-470 MHz, 612-703 MHz and new IMT bands including 37-43.5 GHz, 47.2-48.2 GHz, 66-71 GHz) is necessary, similar to spectrum horizon program. This will ensure that the industry is incentivized to carry out R&D and build systems to commercialize them. This will subsequently enhance the value of the band and will help create business models out of it. Some of the bands mentioned in this executive summary form only part of the recommendations and the Taskforce report comprehensively presents all the bands and specific actions.

5.4 Devices

6G technology will have significant advancements in imaging, presence technologies, and location awareness and the computational infrastructure of 6G will automatically select the ideal place for computing, including artificial intelligence (AI) driven decisions regarding data storage, processing, and sharing. Future networks will be pervasive components of our life, fulfilling the communication needs of humans as well as intelligent machines. 6G will contribute to an efficient, human-friendly, and sustainable society through ever-present intelligent communication. The following four main drivers will emerge for the 2030 era:

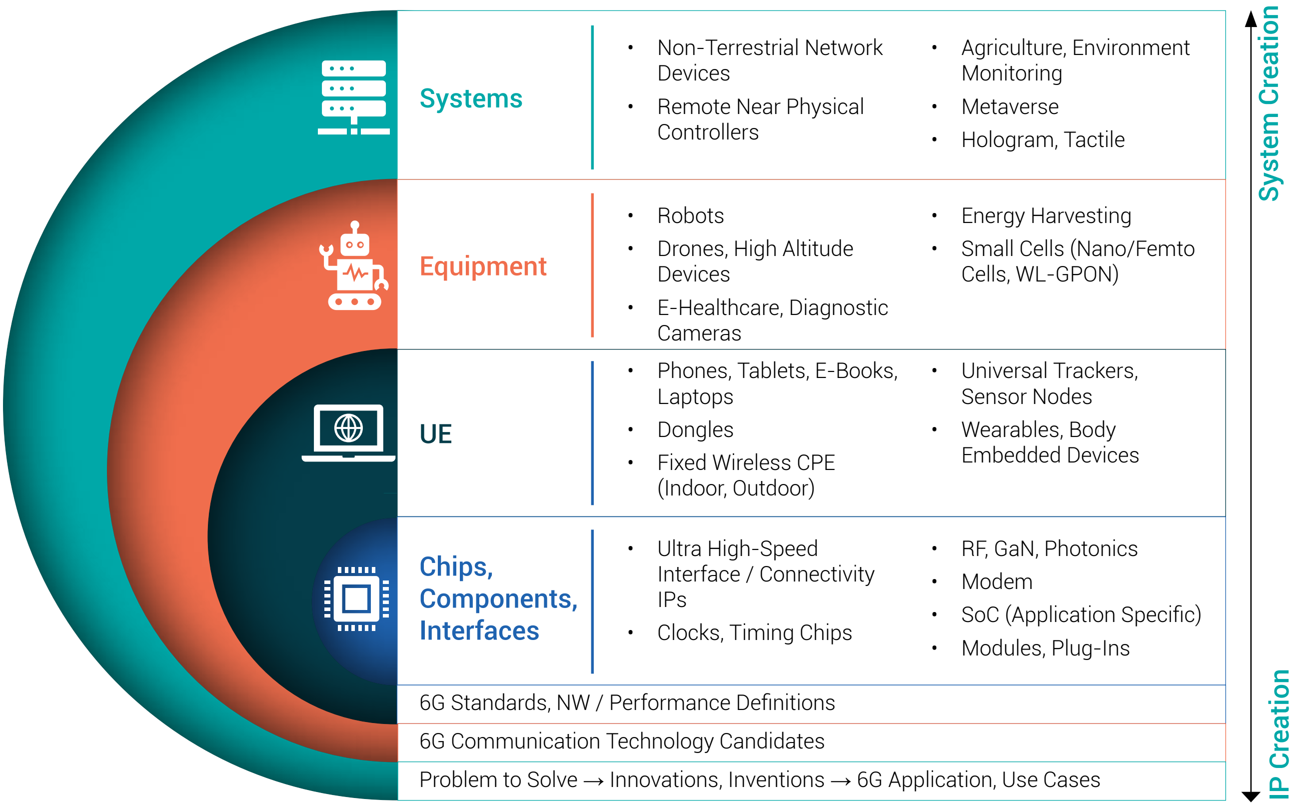
1. Trustworthiness of the systems that will be at the heart of society,
2. Sustainability through the efficiency of mobile technology,
3. Accelerated automation and digitization to simplify and improve our everyday lives, and
4. Limitless connectivity for meeting the demands of intensifying communication anywhere, anytime, and for anything.

It is expected that 6G will provide the ultimate experience for all through hyper-connectivity involving seamless interactions between humans and machines. New themes are likely to emerge that will shape 6G devices, such as:

- New man-machine interfaces created by a set of multiple local devices acting in unison; We will have more intuitive interfaces, with access through gesturing rather than typing
- Ubiquitous universal computing distributed among multiple local devices and the cloud
- Multi-sensory data fusion to create multi-verse maps and new mixed-reality experiences
- Precision sensing and actuation to control the physical world
- A certain class of devices will be extremely low-power and potentially battery-less, relying on the network to power the device
- The end device will evolve in many scenarios to be a network of devices or a sub network. As examples, we can imagine a machine-area network or a robot-area network involving connecting multiple parts of a machine such as a controller and its drives
- With the targeting of (Sub-)Terahertz spectrum, 6G devices will not only be communication endpoints; but will also be able to act as active network nodes in a data path and, ultimately, form standalone networks
- Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviours, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application–network collaboration, resilience mechanisms, the evolution of the end-to-end transport protocols, and ways to deal with latency
- Future services will require connectivity everywhere and in everything. 6G networks can support trillions of embeddable devices and provide trustworthy connections that are available all the time

- 6G connectivity can help India to leapfrog to become a highly industrialized society. While the technology adoption improves productivity, and quality of life for rural and urban citizens, achieving leadership in the development of technology will create immense job opportunities in the country
- 6G Connectivity can help India address many social issues like law and order, healthcare, knowledge-led job creation, improvements in living standards of the citizens in the urban and rural areas, improvements in government and citizen interaction through smart cities, internet of things, digitalization and G2C services, better governance of urban, rural, border areas, islands, forests, and animal kingdoms, vast ocean geography, sovereignty and security, cyber and physical integration among many others. In particular, disaster management with improved resilience, intelligent transportation for de-congestion, and efficient use of waterways are relevant in the Indian context
- New industry verticals will emerge driven by 6G technologies. These may include Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) Communication across road transport, trains, airlines, personal, community and public transport sectors, holographic communications, tactile and haptic internet applications, telehealth including diagnosis, surgery and rehabilitation activities, extremely high-rate information access, connectivity for everything, convergence of networking and computing among others.

Vision of 6G Device Universe



Our Vision for developing 6G devices is based on 6G standards, network and performance expectations and the use cases that the devices are expected to support. We propose an inside-out approach involving developing the required silicon level IPs, interfaces, and chips and enabling the leading applications to use the existing semiconductor and devices ecosystem. We may also own and steer a couple of strategic and mission-critical components, chips, devices and applications to showcase end-to-end capabilities as part of the 6G test bed program.

Regarding R&D funding for this purpose, a majority of the MEITY R&D funding in the semiconductor domain is limited to processor design. There is limited R&D push towards indigenization of 5G-adv/6G modem chipset. Considering the current domestic scenario, significant R&D investments are essential to achieve an Atmanirbhar Bharat in the 5G-adv/ 6G device space with the following key considerations.

- 6G R&D funding to have a 10-year horizon with the outcomes aligned with the IMT-2030 6G standards. However, the intermediate deliverables should target compliance with 5G-advanced specifications, viz. 3GPP Rel-17/18 and beyond
- The funding should cover the development of modem chipsets and end-to-end systems including software/firmware, security elements and applications. Adequate funding should also be given to emerging technologies such as AR/VR, next-generation sensors, human-machine interfaces, etc.
- The funding should be prioritized for the development of

i. SOCs: Modem, RF ICs (Sub 6, mmWave and higher frequencies)

ii. Multiple classes of SOCs to address low-end and high-end IoT applications

iii. AI processors

iv. End-to-End Devices including the applications.

5.5 Standardisation

6G technologies are likely to become viable and impactful over the next ten years and will support ubiquitous instant communications, pervasive intelligence, immersive experiences, and the Internet of Things & Senses. 6G is expected to play a key role in the evolution of society towards the 2030s and shall also play a role in supporting the global sustainability goals, including India's objective to contribute towards climate emergencies. In this context, developing a strong technology that meets Indian interests and values, as well as economic and global societal goals, is the key. Secure and trustworthy India-based 6G infrastructure will help to ensure the sovereignty of India in terms of critical technologies and systems on one hand and will make sure that our primary values such as privacy, trust, transparency, accountability, security, and societal interests are considered on the other hand.

6G is also expected to integrate terrestrial, aerial and maritime communications into a robust network that would be more reliable, faster, and can support a massive number of devices with ultra-low latency requirements. Researchers around the globe are proposing the following cutting-edge technologies as the key technologies in the realization of beyond 5G (B5G) and 6G communication:

i. Quantum Communication/ Quantum Machine Learning (QML),

ii. Immersive XR,

iii. Tera-Hertz Communication

iv. Advanced Artificial Intelligence (AI)/ Machine Learning (ML),

v. Advanced Distributed Ledger Technologies (DLT) like blockchain etc.,

While contributing to the development of global 5G standards in 3GPP, ITU, etc., India as a nation has gained relevant experience with Indian companies also having developed core competencies in certain areas. During this period, there is also a greater understanding of the Standards Development Lifecycle especially that followed within 3GPP including aspects related to its workflow and working procedures. By leveraging this experience, India can contribute to the development of 6G standards in various international bodies such as 3GPP, ITU, IEC, IEEE, one M2M, etc., and can make its mark in the global standardization space and ensure a good number of key innovations are from India. To assess the ability of Indian Telecom and Technology Companies entities to participate in 6G standards development, inputs were collected from a select set of Indian entities based on a survey (provided by VoICE). Based on the inputs recevied, it is felt that R&D may be promoted in specific areas of competencies available in India, prioritizing the softwarisation of networks especially leveraging India's strength in AI/ML.

An Indian initiative led by industry and with support from the government will be essential for balancing the efforts and ensuring our 6G leadership. Government, industry, and academia will need to coordinate more closely in identifying research priorities. This should begin with a concerted effort by industry, academia, and government to develop a research agenda for 6G leadership in areas of shared interest. As a first step in the process, the government should facilitate a stakeholder's session jointly with industry and academic members to engage in a dialogue identifying mutual 6G research priorities.

This task force proposes a 6G program with the following attributes:

- A 6G program be created with a broad category of ecosystem partners including operators, vendors, hyper scalers, academia, and Government research labs, that is agile and quickly adaptable to the evolving needs for driving 6G research and innovations, building on and strengthening India's competencies. (e.g., Next Gen Alliance was set up outside the ATIS, with its own working procedures)
- The program should identify through a consensus-driven approach, the topics/themes of interest in 6G based on business and societal needs. The program should cover all aspects of technology development including early research on ideas, proof-of-concept, standardization, trials & testbeds, etc.
- Govt. of India should take a lead in streamlining the process and fund research programs on the themes identified.
- The program should take a lead in preparing well-defined measurable KPIs to assess the success of these program fundings.
- The program should have cohesive policies to meet the common goal of national leadership, national 6G Roadmap, Sustainability goals, etc.
- The program should have a timeline that aligns with the timeline of various 6G standards efforts across the globe.
- The program should take a lead in developing consensus on solutions of interest and pursue the standardisation efforts at the corresponding international standardization bodies.
- The program should facilitate early trials and prototype development, aimed at developing proofs-of-concept and supporting the domestic manufacturing process.
- The infrastructure including the optical fiber network should be made ready before deployment of 6G keeping in mind the hyper capability of the technology

5.6 R&D Finance

On the whole, telecommunication technology products require significantly large funding and long gestation periods for R&D and commercialization. The stages move from ideation, research, incubation, prototyping, lab testing, miniaturization, field testing, hardening, securitization, outdoor readiness, licenses for background IPs, Standardization, etc. In the cases of deep tech SoCs (System on Chips), funding needs tend to be higher due to multiple layers of prototyping.

India has been witnessing the emergence of several small companies, start-ups and academia in niche areas which are adding newer avenues for positioning India on the global digicom technology landscape. The outcome of the supply-based assessment carried out by DoT a few years back reflects on the available competencies across industry and academia (indigenous 5G Testbed). It firmly established that with suitable and sufficient funding, policy handholding can enable Indian players to play an important role in global partnerships in 6G and beyond programs with significant value add to the global value chain.

R&D funding in telecom will be focused on strengthening the following enablers of the 6G technology:

- Promote the ecosystem for research, design, prototyping, development, proof of concept testing, Intellectual Property Rights (IPR) creation, field testing, security, certification, and manufacturing.
- Develop and establish relevant standards to meet national requirements as well as those of international standardization bodies.
- Enable proliferation of affordable broadband and mobile services and positioning state-of-the-art communication technologies for rural and remote areas to bridge the Indian digital divide.
- Create synergies within the Academia, Research Institutes, Start-ups and Industry for capacity building and development of the telecom ecosystem focusing on relevant technologies and solutions required for 6G implementation.
- Bridge the gap between R&D and commercialization of products and solutions with assistance from government bodies and the start-up ecosystem.
- Enable commercialization of developed technologies for domestic and global markets to ensure a distinctive presence in the telecom sector both today and in the coming years
- Build competencies far beyond 6G communication technologies.
- Identify or constitute an agency to engage in IPR management and obtaining licenses from licenser for the domestic industry to facilitate affordable and timely licenses for technology development.

The key recommendations to promote R&D in this regard and realise the above state are as follows:

- The programs under 6G should be planned to encourage building technology ownership, developing IPRs and SEPs, and moving from prototyping to commercialization as part of the project roadmap. CDoT, along with other research institutions, are envisaged to play a significant collaborative role.
- Funding needs are diverse for academia, industry, and research organizations to build capacities and competencies in different stages of R&D for the 6G program in the coming ten years. Different funding mechanisms and instruments should hence be adopted with flexibility and liberal norms to suit the unique requirements of all without adding to the complexity of the funding structure/ mechanism
- Funding must also cover different activities under research, design, prototyping, development, proof of concept testing, IPR creation, standardization (including pre-standardization) standards participation, field testing, security, and certification in the R&D process so that a clear identification and breakdown of involved costs can be mapped and planned accordingly

- The projects may include Research Testbeds, R&D in products such as network elements, antennas, reflectors, systems, devices, SoCs, etc and at a later stage, may extend to large-scale trials, CoEs for use cases, etc. As part of the funding, seed funding for joint international projects may be explored on bilateral and multilateral platforms. The CoEs should have sufficient autonomy to collaborate with the industry to deliver market-ready solutions with clear KPIs to measure success.
- Since the inception, i.e., the research stage, industry participation from technology companies and system integrators should be envisaged to enable swift and agile scaling of R&D to higher TRL levels.
- Apart from technologies that are upgrades of 5G+, several new research projects may be necessary to work on cross-platform projects requiring, and ultimately triggering, significant funding to contribute to IPRs in 6G research.
- A program to identify industry champions to facilitate funding on liberal terms may also be initiated. It should also identify "academia clusters" for taking up programs based on competencies in different verticals and 'system integrators' for orchestrating new generation products.
- Constitute an Apex Level Advisory board, with experts from India and across the world, for advising on programs and funding needs with members from relevant ministries to enable global and political synergies in funding-related programs.
- Create a large corpus of R&D funds to facilitate various funding instruments such as grants, loans, VC fund, fund of funds, etc. A pool of Rs. 10,000 Cr is envisaged to be created to service these requirements for the next 10 years. The government may take lead in creating this fund, considering the budding technology ecosystem in the country, to strengthen it for 6G and beyond technologies.
- Two tiers of grants are proposed i.e. up to Rs. 20 Cr to service funding requirements ranging from small to medium and grants above Rs. 20 Cr for High Impact projects.
- Administrative setup for vetting R&D projects may include the following depending on the size and scope.

a. Inter-ministerial committee: The mechanism could commence its work in line with other R&D funding schemes like DCIS etc., with TCOE India as its PMU.

b. Set up 6G Mission Apex Body and Directorate to take Bharat 6G Vision forward for its implementation

c. A Section 8 Company or Society may be set up exclusively as a delivery mechanism for 6G and other telecom-related programs; Alternatively, existing agencies of other ministries may also be considered on a need basis.

d. Telecom-focused VC funds and Fund of funds are envisaged for large-size high-risk funding needs. Define measurable KPIs to assess the success of these program funding.

Entities eligible for R&D funding, indicative process, and administrative structure are also identified to enable early take off of the program.


R&D
Research & Development

6

Key Recommendations to Enable Bharat 6G Mission

The Six Task Forces deliberated on various aspects of emerging telecom technologies and platforms in the next decade. They focused on innovations that leverage these new technologies to deliver solutions, the device ecosystem that will support these innovations, a spectrum policy that will enable the ongoing and oncoming explosion in wireless communications, the need to contribute our innovations to global standards and ensure interoperability, and requirement of adequate financing to carry out the Bharat 6G Mission.

The Task Forces' key recommendations to pursue to enable the 6G Mission have been summarised below:

- Innovative funding mechanisms to support industry, startups, academia, and national laboratories to undertake R&D and pursue select risky pathways in search of breakthroughs with clear KPIs and roadmap and partnerships for commercialization
- Innovative solutions through startups and CoEs that leverage the emerging 6G technologies to address key verticals such as transport, water, power grid and renewables, healthcare, education, digital twins and smart cities
- Shared use of spectrum, particularly in the higher frequency bands where the propagation is more akin to that of light
- Reassessment and rationalisation of congested spectrum bands, and adoption of captive networks for Industry 4.0 and enterprise use cases in hitherto less used bands
- New multi-sensor man-machine interfaces and devices leveraging edge cloud computing resources and AI to deliver tactile Internet, ambience awareness and realistic 3D experiences
- mmWave and (Sub-) Terahertz (THz) wireless communications at scale and very high data rates along with adaptive radio interfaces, advanced/ novel antenna techniques (Ultra massive MIMO) and increased virtualisation
- Participation and contribution to global standards forums to ensure interoperability and global reach of our innovation
- Fiber-broadband to every home and integrated dense wireless and optical network, with wireless communications primarily serving mobile users
- Tactile Internet and Remote Operations of machines/ robots, along with near-realistic 3D rendering of virtual participants in meetings
- Space-Terrestrial Integration for ubiquitous coverage
- Combined communication and sensing in (Sub-) Terahertz bands
- SoCs for modems, radios, AI processors

The Task Force Reports in the annexures provide details of the background and thought processes leading up to these recommendations.

7

Bharat 6G Mission

The 6G TIG has enunciated a clear Vision for India in a 6G-driven world. The importance of the impending innovations and developments in 6G cannot be overstated for a country poised to become a global leader in the 6G revolution and one of the top three global economies. It is critical for India to be among the drivers of these new technological developments to best address the country's unique needs, as well as to become a leading supplier of affordable and transformative solutions globally. A Mission-oriented approach is thus imperative to take up the diverse technology development initiatives, studies and innovation efforts necessary to achieve this objective. Based on the Vision 6G outlined herein, a Mission 6G shall be launched with the requisite organisational and financial resources to realise the Vision. Existing organisational strengths will be leveraged to the maximum and new governance structures will be kept lean to ensure agility and speed of execution. The research and start-up ecosystem will be tapped to bring innovations and new ideas to the table. Adequate provision for financial support will be made through explicit budgetary allocation to ensure that the efforts undertaken are not hobbled for want of funds.

The Mission can be divided into two phases:

i. Phase 1 from 2023-2025 (2 years)

ii. Phase 2 from 2025-2030 (5 years)

In Phase 1, support will be provided to explorative ideas, risky pathways, and proof-of-concept tests. Further, ideas and concepts that show promise and potential for acceptance by the global peer community will be adequately supported to develop them to completion, establish their use cases and benefits, and create implementational IPs and testbeds leading to commercialization as part of Phase 2.

An apex body is to be constituted to lay down the Phase-wise objectives, select the research and innovation pathways to be explored, and approve financial support for them. Towards this, the apex body may constitute expert groups to generate the calls for proposals or address technical challenges. This will be followed by the technical assessment of research and innovation proposals and will be rounded off with appropriate review mechanisms for assessing progress and milestones. The apex body shall approve and fund proposals and initiatives with the help of the technical groups.

Proposals and initiatives will leverage the creative impulses of the widest cross-section of the country, ranging from leading academic and research institutions to companies and start-ups, to young students who are unburdened by the wisdom of "what will not work". A thorough appraisal and review process as described above will separate the proposals that are well thought through from those that are based on the flavour of the day.

The apex body will also set up coordination efforts between the research initiatives being undertaken and the sectoral organisations such as TSDSI, TEC, WPC, Start-up India, TDB and others that provide support for standardization, representation and participation at ITU, spectrum needs, incubation, technology development support, etc. Such coordination is critical for an all-of-nation approach to the Mission, without which the Vision outlined cannot be realized. It will also ensure sufficient visibility to the Bharat 6G Mission globally through participation in international forums and meetings and collaborations with similar Missions worldwide.

The apex body will also assess the procedural roadblocks that often come in the way of Mission-mode research, such as processes for timely approval and release of funds and permits for global procurement when justified, well-orchestrated support at international forums when needed, as well as support for IP and value creation. It will also provide assessments and feedback to the government to fine-tune the budgetary and policy support for the Mission and provide corrective actions as necessary. The body will create a governance structure that is as lean as possible while leveraging existing organisational capabilities in the entire telecom sector, both within government as well as in industry and academia-driven sectoral bodies. This structure must be entirely Mission-based and should dissolve itself once the Mission is complete.

As a prelude to the launch of Bharat 6G Mission, the government may consider the recommendations of the 6G TIG for approval in full or in part. It may also constitute the apex body to oversee the Mission and approve the budget for the Mission split into two phases. Timeliness is the overarching requirement while executing this Mission. A successful effort or project may yet yield minimal or no returns if delayed in execution. Given the criticality of timeliness, the apex body must be tasked with ensuring this and empowered to modify processes and procedures as needed to remove roadblocks.

Bharat 6G Mission is fully aligned with the national Vision of ***Atmanirbhar Bharat*** and it seeks to empower every Indian to become ***Atmanirbhar*** (self-reliant) in their lives. At the same time, it ensures that India takes its rightful place in the world as a leading supplier of advanced telecom technologies and solutions that are affordable and contribute to the global good. Bharat 6G Mission is thus timed just right for India's ***Aazadi ka Amrit Kaal***.

Annex: 1
Task Force Reports

6G Taskforce Report:

Multi-platform Next Generation Networks

Chairperson: Prof. Bhaskar Ramamurthi
Member Secretary: Shri Abhay Shankar Verma

1. Background

Task Forces under Technology Innovation Group on 6G (TIG-6G) were constituted vide DoT Letter No.6-1/2021-IC dated 30th Dec 2021 for inputs to TIG-6G. One of the Task Force was on "Multi-platform Next Generation Networks".

The terms of reference of this Task Force are as follows:

- Development of Network Elements of Multiplatform Next Generation Networks
- Integrated Optical and Wireless Network (referred to as Wireless GPON)
- Spectrum Hyper-Efficiency in Networks
- Tactile Internet Remote Operation (referred to as remote near-physical activity)
- Space-Terrestrial Integrated Network (referred to as LEO Satellite Overlay/ Geo Synchronous Satellite based Overlay)
- Drone Communications/ High Altitude Platforms technology
- Any other items in the scope of 6G activities and overall deliverables

2. Executive Summary

The Task Force deliberated extensively on the current global thinking regarding evolution of telecom network in the year 2030 and beyond. The strands were evaluated in the context of India's own future needs and growth trajectory over the next decade. Depending on the degree of relevance of each of these strands in our context, the Task Force has emphasized some of the possible evolutionary paths. While evaluating the strands, it emphasized on those that appeared more realistic and promising in a ten-year timeframe.

The importance of a dense optical network in homes and offices cannot be over-emphasized. This takes time and resources to build, and the wireless network continues to not only serve the needs of a mobile user but nomadic or static user as well. Going forward, a seamless integrated optical and wireless network, with wireless fiber-like segments wherever appropriate, is imperative. Sufficient attention will have to be paid to GPON network engineering in rural areas.

The explosive growth in data volumes, multiplicity of access technologies, deepening of the optical access network, proliferation of edge clouds, and increasing need for content and user-awareness will lead to a more decoupled core and network architecture, and increased use of AI/ML in optimization and intelligent network operations.

As spectrum gets more heavily used, ever-higher frequency bands are being explored primarily due to the large bandwidths available and ever-improving operating frequencies of semiconductor technologies, despite the challenging propagation conditions at these frequencies. Mitigatory techniques such as Intelligent Reflective Surfaces may provide some workarounds of poor propagation at very high frequencies as well as massive MIMO with cell-free operation. The Air Interface may move radically to a virtualized user-defined mode enabling the radio to support the specific user requirements for a given wireless channel, moving away from the hitherto conservative design for the worst-case wireless channel. The wireless transceiver in many cases may additionally play the role of a radar sensor to capture the ambient environment around the transceiver.

While the remote operation of machines and robots may be attempted even with 5G networks in the coming years, the Tactile Internet for Remote Operations is a serious possibility after a decade from now. This capability may be used not just for high-end applications such as remote robotic surgery, but for a host of mundane applications in a similar way to multimedia communications is used today with the smartphone for all kinds of applications. This may require good support from edge computing clouds that run ML/AI algorithms and will leverage a user-defined radio interface to ensure high reliability. The growth of Industrial IoT in the coming years will drive the growth of remote operations even if much of it is simply automation and not tactile. Digital Twins of complex, real physical systems and networks running in the edge clouds will enable automated control of the real system by predictive analysis of future events based on AI and other techniques.

With the increasing cost-effectiveness of Low Earth Orbit satellites and new technologies such as HAPS, it is likely that non-terrestrial wireless networks will finally get integrated with the terrestrial network to offer ubiquitous coverage not only on ships and aircraft but in the Indian context, to rural areas under-served by the terrestrial network. The explosive growth forecast in drone usage will necessitate drone communications to be supported by the integrated space-terrestrial network in a reliable and secure manner.

The very high data rates supported by the next-generation network are likely to provide a platform for realistic e-meetings where holographic-type or AR/VR technologies are deployed along with multi-gigabit-per-sec tether-less links to provide a near-physical experience. User-defined virtualized air interfaces will enable such platforms to be invoked even by a mobile user based on the ability to set up a sufficiently fast, low-latency, low-jitter, reliable link, leading toward what could be described as hyper-personalized wireless networks.

The research efforts over the next few years should be aligned toward realizing one or more of the highly promising, scalable, and feasible (with high probability) technologies/platforms outlined herein. All of these are of great relevance in the Indian context and also have global applicability. Advances made in any of these areas will not only serve our needs but also give India an edge, globally. India can use this decade to realize its aspiration of being a net global provider of telecommunications technology.

2.1 Development of Network Elements of Multiplatform Next Generation Networks

The 5G core network architecture having well-defined virtualized network elements enables support for increased throughput demand, reduced latency, and increased reliability as per requirements of various applications and services that 5G must support. The new 5G core utilizes cloud-aligned, service-based architecture (SBA) that spans across all 5G functions and interactions including authentication, security, session management, and aggregation of traffic from end devices. The 5G core network has been designed from scratch to include Service Based Architecture, network slicing, mobile edge computing, etc. that bring flexibility, easy integration with third-party software, easy provision of services belonging to different verticals, improved QOS, etc. It will enable mobile operators to serve IoT (Internet of Things) use cases, ultra-reliable, low latency connections as well as use cases pertaining to enhanced mobile broadband.

The 5G Radio Access Network caters to multiple categories of applications that require high reliability and low latency using the Ultra-Reliable Low-Latency Communication (URLLC), Massive Machine Type Communications (mMTC), and Ultra Mobile Broadband (eMBB). It employs massive MIMO extensively to achieve high spectrum efficiency. For the first time, the 5G network forays into the mm-wave band with wideband channels having a bandwidth of 400 MHz While the radio propagation characteristics in this band are not as favorable as in the lower bands, the antennas do become smaller enabling very large number to be deployed in an array, and the data rates achievable are impressive.

The next-generation (6G) network is anticipated to make several major leaps forward, and the network elements belonging to multiple platforms such as RAN, Cloud, Edge Cloud, optical network, terahertz wireless nodes, and new user device types will be required to inter-operate seamlessly to make the new applications and use cases a reality. In 6G, Multi-platform Network elements have to work at very high frequencies, bandwidths, and data rates, provide ultralow latency where needed, support programmability, and provide high computational power, high reliability and security. These are dealt with extensively in the following sections dealing with specific capabilities envisaged in the next-generation 6G network.

2.2 Integrated Optical and Wireless Network

The network architecture currently in vogue uses an optical fibre network for backhauling the data to the routers and data centres, and a wireless network for mobile subscriber access. Optical fibre is increasingly being extended for providing higher data-rate connectivity not just in offices, but in homes too using Gigabit Passive Optical Network (GPON) technology. Within offices and homes, Wi-Fi provides tether-free access to users. While optical fiber backhaul from cellular base stations is the preferred mode due to the ever-increasing data rates supported by the wireless systems, wireless backhaul continues to be used where optical fiber connectivity has not yet been provided.

As data consumption by users grows exponentially, the desired network configuration is an optical fiber in every office/home and ultra-high-speed / reliable / low-latency (all three desirable features or some combination thereof) wireless access for mobile users. Given the ever-increasing user appetite for data, it is wise not to overload the mobile access network with indoor users who could very well be served by an optical network reaching into the office/home. Since densification of the optical network takes time, wireless access continues to serve indoor users as well in many homes and offices.

One of the thrust areas for the future network is maximal optical fiber penetration in offices, shops, and homes. When water, electricity, and even gas are being piped to every home, there is no reason not to extend optical connectivity too. However, the outdoor plant engineering for the last-mile OFC with terminations every 10-15m, and with sufficient robustness against frequent digging, construction activities, etc, remains to be fine-tuned. Just as electricity is supplied with overhead cables in certain areas, the last-mile overhead OFC deployment option must also be engineered in a robust fashion (e.g., new fiber designs with a low bending radius could be developed). A decision has been made to take OFC to every village in the country. It is the right time to work out the best-engineered solution to extend GPON to every home in the village including the dwellings build under the Pradhan Mantri Awas Yojana.

While building such a deep and dense OFC network, it is to be expected that providing 100% Optical connectivity may not be technically or economically feasible in certain areas or sections at a given point of time. This is where tightly integrated optical and wireless networks play an important role. New wireless technology in the mm-wave, E, V, and terahertz bands is expected to provide multi-gigabit speeds akin to optical systems. It is also fairly easy to “drop” multiple links on a wireless “bus” similar to GPON. It is worth noting that GPON itself is evolving to higher rates such as XGSPON (10 Gbps) and HS-PON (50 Gbps). There is great interest globally in an integrated optical and wireless network (see, for example, https://iowngf.org/) which is managed and re-configured intelligently along with a host of distributed computing resources. Thus, a judicious combination of ultra-high-bitrate wireless technology in new mm-wave and terahertz bands and optical technology, designed to interoperate seamlessly, can provide India with the flexible and cost-effective solution to take broadband to every home and office within the next ten years.

It is also anticipated that quantum communication techniques will become more common-place in the ever-expanding optical network to provide an enhanced level of security.

2.3 Core Network

In conjunction with the proliferation of the mobile cellular network in the country, there also has been tremendous growth in mobile data consumption. The key factors that drive this growth in the country are increased usage of smartphones, availability of a variety of mobile applications, and limited deployment of fixed-line infrastructure. Mobile phones are the primary or only means of data consumption even from the home or workplace. Even a conservative estimate indicates a huge consumption to the tune of a few exabytes per day by 2030, when the deployment of IMT-2030 or the

6th Generation mobile communications system (6G) may start. In order to support the very large number of users including machines, and to support extremely large data transfer volumes, we will need an immensely flexible and scalable core network as an integral part of the 6G system.

The 5G core network has been designed from scratch incorporating technologies and design principles such as Software-Defined Networking (SDN), network function virtualization (NFV), network slicing, service-based architecture (SBA), and control and user plane separation. Among other capabilities, these technologies and principles bring flexibility, platform independence, cloud-native deployment, easy integration with third-party software, provisioning of services belonging to different verticals, and support for diverse QoS requirements of applications and services. The 5G system also has a converged core with a common interface between the access and the core network enabling easy integration of diverse access technologies within a single 5G network. While these techniques would continue to be the bedrock of the 6G core, the core network may need to evolve further in order to support the emerging diversity and the required data volume in the 6G network.

The recent advent of cloud computing and network functions virtualization has resulted in the emergence of network cloudification. Furthermore, with the proliferation of edge computing, computing resources inside a network now extend from a centralized cloud to the network edge, providing almost ubiquitous computing power. However, the computing capability of a single network edge site is normally limited and cannot be flexibly expanded. Future networks may require multiple distributed network edge sites to interconnect and collaborate with each other. Orchestration capabilities that are computing-aware will need to be supported.

With the advent of social media platforms, AR/VR use cases, etc., the users are also more content-aware. IETF has proposed Information-Centric Networks (ICN) as a paradigm to make networks content-centric than the current approach of being host-aware networks are expected to improve the network efficiency and satisfy ever-growing data demands of the users.

Design principles and technologies such as disaggregation, edge computing, incorporation of diverse and complementary access technologies, user-centric design enabling concurrent usage of a large number of access links/technologies, and usage of AI/ML techniques are likely to play a significant role in this evolution. The 6G core is likely to be integrated with an ever-larger number of access technologies, terrestrial and non-terrestrial, unicast and broadcast, licensed and unlicensed access, etc. The usage of technologies, that support network softwarization, such as SDN, NFV, SBA, network slicing etc. will gain further momentum. These will be complemented by AI/ML technology, which is likely to play an important role in the performance optimization of the 6G core. AI/ML-driven protocol and network design will impart greater flexibility. In addition, the enablement of localized (or edge-based) service delivery with a reduced number of network functions in the data path (possibly involving only access network functions) is expected to be an important design principle for the 6G core. It leads to a decoupled access and core network architecture, unlike the existing 5G architecture, and may bring immense benefits both in terms of reduced end-to-end latency and improved scalability of the core network.

As networks become increasingly flexible and the complexity of network functions grows, the introduction of intelligent operation capabilities in future networks will be of great importance.

In the scenario where we are monitoring a network for impairment (or potential impairment) for example, it is common that multiple sensors will be measuring numerous parameters and the key performance indicator is 'network health'. These sensors tend to measure independently of one another and are not always working together in a system wide manner. Thus, a comprehensive unified, multi-level, and deeply correlated analysis of measurements is needed to accurately pinpoint root causes of alarms and instantly invoke automatic recovery mechanisms

2.4 Spectrum Hyper-Efficiency in Networks

Deploying nano/dense small cell networks overlaying the conventional macro cell networks is widely regarded as a key step towards network architecture revolution for improved spectrum and energy efficiency. This includes evolution of transport network to support such dense deployments. Obviously, if there is dense cellular network with small cells that are sized in the tens of meters range, one needs a dense optical network for the backhaul aided by ultra-high bitrate wireless links in the mm-wave bands and beyond (see Section 2.2). With such a dense network of small cells, the concept of cell-free communications between handset and base stations using massive MIMO, with a very large number of antennas that are not co-located, becomes attractive. Here there is no geographically contiguous cell served by a single base station. Rather each handset sends to and receives signals from multiple cell sites based on the channel conditions. Both capacity and coverage can be enhanced greatly using this approach.

Another holy grail in improving spectrum efficiency is full-duplex communication, which has been around for a long time in wired telephony. It is much harder to implement in wireless systems, but the reward is a doubling, over and above all other improvements, in spectral efficiency. Steady progress has been made over the years, and it is expected to become a reality sooner than later.

Despite the advances made in every generation of cellular wireless technology leading to Gigabit-per-sec speeds in 5G, the cellular system continues to be designed to ensure a minimum acceptable level of service to the worst-situated user in a cell. All the mandatory requirements to be met by the system are specified in terms of this worst-case performance, with opportunistic best-effort enhanced performance for the users who have better links to the cell site. Taking advantage of the vastly improved processing and computing power at the base station and handset, one can conceive of a "horses for courses" approach in the future, wherein multiple waveforms and link protocols are made available to users. Each handset will select the waveform and protocol best suited for its instantaneous channel conditions and user requirement (reliability/data rate/latency). This concept is being explored by several research groups (see, for example, 6G: The Personal Tactile Internet—And Open Questions for Information Theory in IEEE BITS Sep 2021), as provisioning in the same system of an optical-fiber-like high data-rate, low-error-rate, low-latency wireless connection over a relatively benign channel differs considerably from that of a low bit-rate, low-energy-consuming, robust link over widely-varying channel conditions. This idea can be refined further, and one can migrate to a completely "user-defined" dynamic radio layer determined by the current radio environment experienced by the user and the performance attributes sought by the user. This is explored further in Section 2.8.

As optical-fibre-like speeds are being approached in wireless systems, and the semiconductors used to build the systems perform better and become most cost-effective and reliable at ever increasing frequencies. there is great interest in moving to higher frequency bands where spectrum is also more easily available. In 5G, the first foray was made into the mm-wave band and over the next few years we will learn about the nuances of deploying in this band, outdoors in the rain and fog, as well as indoors, particularly in factories and stadiums. Similarly, the E-band and V-band at still higher frequencies are attractive, particularly for integrated optical and wireless networking. These bands are roughly at twice the frequency of the 5G mm-wave bands, and the learnings from the mm-wave band can be carried over in time to these bands.

Even as the semiconductor frontiers at very high frequencies are conquered, the challenge of overcoming the channel conditions at these frequencies remains. Wireless propagation at mm-wave and beyond suffers from high rain and fog attenuation and is more ray-like and less diffractive than at lower frequencies. The built environment, therefore, poses a significant challenge to the deployment of wireless systems in these bands. In an attempt to convert the light-like characteristic of propagation at terahertz frequencies to an opportunity, Intelligent Reflective Surfaces are being investigated as a way of "channelling" the signal toward the desired direction. These surfaces are massive reflective arrays placed on building facades with individual control of the reflective elements. By forming the beam appropriately, it is proposed to steer the terahertz signal around buildings, for example, and overcome one of the limitations of mm-wave-and-above propagation.

Many emerging applications (autonomous driving, but more generally situational awareness for any mobile robot) need radar sensing to comprehend the local physical environment. With spectrum becoming scarce, and the very high frequencies (>70 GHz) typically used for radar imaging also being explored for communications, one could conceive of user devices that combine radar sensing and communications functions using the same spectrum. Just as all smartphones today are location-aware using navigational aids such as NAVIC and GPS, tomorrow's devices may become ambient-aware by using its radio for radar function in addition to communications.

2.5 Tactile Internet Remote Operation

The title of this section is based on the nomenclature introduced in Representative use cases and key network requirements for Network 2030", a document produced by the ITU Focus Group on Technologies for Network 2030. It refers to use of the Internet, including mobile Internet, to remotely control a device based on real-time feedback from the device thus establishing a feedback control loop over great distances and time-varying communication link characteristics. This is a considerable challenge compared to the highly reliable, low-latency, wired local feedback loop in most control applications today.

As 5G deployment grows, Internet of Things (IoT) is expected to grow exponentially with billions of devices connected to the Internet. These will include machines in factories, hand-tools, industrial fixed and mobile robots, vehicles, drones, fixed and mobile sensors among other things. With the URLLC service in 5G, it is possible to limit the latency on certain links to less than a millisecond, though this comes at the cost of bandwidth and energy. In private 5G networks, it may be possible to limit the latency even on eMBB links to a few milliseconds. Thus, it is possible to conceive of remote control of robots /machines based on sensory feedback to the operator either from sensors on the robot / machine or around it. While automated remote-control loops may need sub-millisecond feedback, human-in-the-loop remote control systems may work quite well with multi-millisecond feedback delay. Low jitter and link reliability are important attributes that the link must possess for such remote control to work effectively.

The demand for such remote tactile control operations will grow once the techniques become robust and well publicized, even though the initial breakthroughs will come in the B2B space. Most likely, major enhancements in the QoS provided by the wireless connectivity will be identified and implemented in the next-generation wireless network before such remote tactile operations become commonplace and are used by the wider population. The potential for such technology to impact personal productivity is high, as well as its ability to make skilled expertise available remotely when it is not available locally. While the iconic application is remotely assisted surgery, there are many more mundane but economically critical use cases where the personal skills of an expert can be productively engaged remotely. A straightforward example is remote operation of rented farm equipment such as tractors and harvesters or of tower cranes at construction sites. The productivity of the expert also increases manifold as she/he wastes much less time transporting oneself from one spot to another that needs her/his expertise.

In addition to the tactile human-in-the-loop remote operations, there is an expanding need for remote control loops in Industrial IOT (IIOT). Industrial networks enabled by the Internet of things (IoT) are fundamentally different from information technology (IT) networks in terms of performance and reliability requirements. They go beyond connecting back offices to factory floors, moving towards integration from device level all the way through to enterprise business systems, resulting in the automatic operation and control of industrial processes without significant human intervention. These networks therefore need to deliver superior performance and mandate a real-time, secure, and reliable factory-wide connectivity, as well as inter-factory connectivity at large scales in the future. Factory automation and machine control applications typically demand low end-to-end latency ranging (from sub-ms to 10 ms), and small jitter (at 1μs level), to meet the critical closed loop control requirements.

At the same time, as part of the fourth industrial revolution, or Industry 4.0, operational technologies (OTs) and IT are converging. Control functions traditionally carried out by customized hardware platforms, such as programmable logic controllers (PLC), have been slowly virtualized and moved onto the edge or into the cloud in order to reduce the capital expenditure (CAPEX) and the operational expenditure (OPEX) of the system, and to provide increased system flexibility and capability to handle and analyse 'big data'. This industrial cloudification places even higher requirements on underlying networks, as the same latency, jitter, security, and reliability requirements need to be implemented at larger scales.

It is anticipated that several of these sophisticated remote-control loops will require compute-intensive AI algorithms. For example, the remote controller may need to get a picture in real-time of the operating environment of a mobile robot or vehicle based on multiple sensor feeds. Such a picture may be obtained by data fusion using AI/ML techniques. These algorithms may run at the remote location, but this will require huge data transfers to the remote controller. A more efficient alternative would be for the remote controller to offload the AI engine to an Edge-Computing cloud provided by the network nearer the mobile robot or vehicle. Mobile Edge Computing is supported in 5G itself and will mature in a major way over the next decade.

In addition to remote control loops, there is another application with similar characteristics involving predictive analysis followed by evasive actions. A digital twin (DT) is defined as a real-time representation of a physical entity in the digital world. DTs add value to traditional analytical approaches by improving situational awareness, and further enable better responses for physical asset optimization and predictive maintenance. Facilitated by vastly deployed DTs, the digital world and the physical world have the potential to be fully intertwined, contributing to formulate a new norm of DT-enabled cyber-physical world in the near future. It is anticipated that the DTs will reside in the edge cloud, with sensor data from the physical world fed to it in real-time. It is also anticipated that ML algorithms implemented in the edge cloud will play a big role in predictive analysis at the DT to take anticipatory action in the physical world to avoid undesired situations (power tripping, traffic snarls, mob formation, are examples) from developing.

2.6 Space-Terrestrial Integrated Network (STIN)

Space-based repeaters have been used for a long time to provide communication links over great distances. While this technology overcomes the tyranny of distance, it suffers from poor spectrum re-use as the footprint of the satellite, even with modern beam-formed antennas, is quite large. Geo-synchronous satellites provide 24x7 service, but the link budget tends to be tight and the latency high. Low-earth orbiting (LEO) satellites overcome both these limitations to an extent but have to be flown in constellations since only a subset will be visible over the service area at any given time. With LEO satellites, one can even conceive of orbiting base stations and not just repeaters. Such base stations are mobile, in contrast to the fixed ones on terra-firm, and calls have to be handed over even if the user is stationary. Besides, base stations may have to serve in multiple networks as they orbit the earth to not idle most of the time.

As these technological challenges are overcome and it becomes feasible for mobile handsets to communicate with space-based base stations, one could leverage inter-connected low earth orbit (LEO) satellites and other non-terrestrial networking nodes and platforms to build a parallel Internet network that can peer with its terrestrial counterpart. With such an integrated framework, the envisaged key benefits include: (i) ubiquitous Internet access at a global scale, including rural areas like oceans, deserts, as well as moving platforms such as ships and planes; (ii) enriched Internet paths that could lead to better data delivery performance compared to those over the terrestrial Internet determined by border gateway protocol (BGP) configurations across domains; (iii) ubiquitous edge caching and computing services provided by lightweight, on-board computing and storage resources on LEO satellites.

In the Indian context where 900M users live in rural areas, and terrestrial cellular coverage remains patchy in some parts of the hinterland, a STIN can provide the ubiquitous coverage that has been sought by the country for more than two decades now. Calls from a mobile can be handed over to the space segment whenever terrestrial coverage disappears and handed back when it re-appears as one moves. Areas not served by terrestrial systems can be permanently served by the space-based network.

India has a strong space technology base, and this approach could be pursued vigorously to provide 100% universal coverage once and for all. India is also one of the few countries developing a High-Altitude Platform System (HAPS) for various applications. HAPS fly at around 20 km altitude for months together using only solar energy. They can hover (circle) over a geographical area if desired. Thus, HAPS combines the high-link-budget and low-latency benefits of LEO satellites (better actually) and the geostationary benefit of GEO satellites. HAPS platforms could be placed to serve one or more rural districts each across the country. The platforms are also immune to weather and other terrestrial disturbances and can serve the dual purpose of providing vital communications during disasters.

2.7 Drone Communications

Piloting of drones is an application in the category of Remote Tactile Operations, though the clear line-of-sight radio link in this application makes the wireless communication less challenging. While drone communications in an exclusive frequency band is fairly straightforward, implementing the same using cellular technology (4G, 5G or next generation) is a challenge. The interference environment above the cell towers is very severe though the antenna down-tilt does minimize interference among neighboring cells to an extent. By the same token, the down-tilt also makes communication with high-flying drones difficult. If the next-generation cellular systems are to be used for drones as well, these issues must be specifically addressed. Drones cannot be simply treated as one more set of mobile “users” who happen to be flying above the towers. Being an application requiring specific QoS guarantee on reliability and latency, this “above the tower skyline” application needs to be catered for with specific supporting features in the next-generation networks.

2.8 Hyper Personalized Networks

Network designs so far have focused on the Spectral efficiency improvements arising out of better coding, massive MIMO and others. As we fundamentally hit the Shannon limit (with 5G almost reaching Shannon’s capacity limit for single-antenna systems) the only way to improve speeds further is to employ more spectrum, and this is available only at very high frequencies with their associated issues, as discussed above. The design-for-the-worst-case approach alluded to earlier suffers from the following infirmities:

Static and worst-case provisioning: Networks today are primarily designed for cell edge performance. The cell boundaries are static in nature since the transmit power of the power amplifiers used is typically fixed for a given base station. Since 80% of the users are never on the cell edge, the network design is thus mostly pessimistic and does not consider the average conditions. It is estimated that there is approximately a wastage equivalent to 25% of the spectrum on an average.

Limited or no sharing of spectrum: We need to leapfrog to unlock a lot of under-utilized “statically” allocated spectrum. The benefits of dynamic spectrum sharing have not been realized due to poor cognitive abilities of the transceivers to ascertain under-utilized spectrum in their respective vicinities. There is also no real-time intelligence provided to the transceivers from the spectrum licensor to better utilize the available spectrum. Since most of the communications is happening in an interference-dominated regime, the overall spectrum utilization continues to be poor. This needs to be addressed with significant changes in the regulatory and wireless system architectural frameworks.

Limited observability of the network: The common Radio Layer metrics which are observable today are not sufficient for Network Optimization. If additional metrics such as channel impulse response seen by the handset and Base Station are made observable, then it opens possibilities to perform new types of Network Optimization. The availability of such Radio Link metrics, when studied and correlated over large sample sets, can set in useful ways to exploit Machine Learning at Layer 1 and Layer 2 of the wireless network to significantly impact performance.

Instead of a fixed protocol and waveform or a limited set of waveforms, as has been the case till now, the protocol and waveform ought to be based on the specific user's location and needs, which can vary over time and space. This will result in a hyper-personalized network that has a virtualized air interface running on Software-Defined-Radios (SDR). Two possible models are envisioned for virtualization: static OpenGL-like API (as is done for Graphics), or a Java-like Virtual Machine. The different components of the Air Interface are abstracted as virtual machines on an SDR, each doing a specific radio implementation task. The advantage with either of the two approaches is that the APIs or the virtual machines are pretty much agnostic to the underlying hardware which implements them. One can visualize every waveform defined so far in 2G/3G/4G/5G as a Virtual Machine which in turn encapsulates all the required virtual machine calls.

With this approach, the RAN of the future can be enabled by defining the Virtual machine and not the waveform. Waveform synthesis is left to the Cognitive RAN synthesizer based on the local instantaneous conditions and requirements. The desired VMs are either invoked from a library or defined on the fly and uploaded to the peer entity for use to set up the link. This approach enables dynamic and localized network optimization which a digitized architecture is amenable to, rather than force-fitting on every user a design dictated by the worst-case. It opens up the doors for implementation of AI/ML algorithms based on a rich set of observable radio metrics. Some more details of the proposed Cognitive RAN approach are provided in Annexure 1.

2.9 Holographic-type communications (HTC)

The title of this section is also based on the nomenclature introduced in Representative use cases and key network requirements for Network 2030" (January 2020) referred to in Section 2.5. It alludes to an application foreseen when data rates supported by the mobile Internet reach one or two orders of magnitude higher levels than even in 5G, and when very high frequency (mm-wave and higher) wireless systems support Gigabit-per-sec links each to multiple devices in a room. While holography is a method for producing a three-dimensional image of a physical object by capturing (on a plate or film) the pattern of interference formed by a split laser beam and then illuminating the captured pattern either with a laser or with ordinary light by diffraction. However, holography technology and ecosystem are presently not mature enough for mass usage. In the next decade, the motivation of enabling a fully immersive experience will lead to the adoption of various technologies that produce augmented reality (AR) and virtual reality (VR) via head-mounted display (HMD) devices. Holographic type communications (HTC) is expected to digitally deliver 3D images from one or multiple sources to one or multiple destination nodes in an interactive manner. The ultimate aim is to produce the next generation of virtual meeting experience. Fully immersive 3D imaging will impose great challenges on future networks in terms of data rates, jitter and latency requirements.

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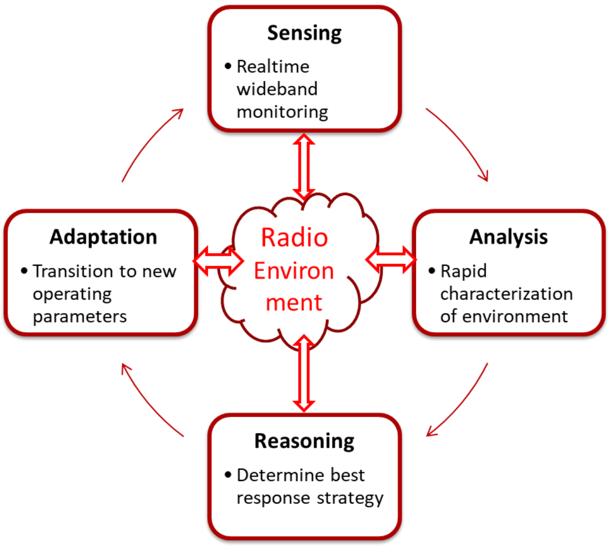
Annexure 1: Cognitive RAN - Some Details



The Cognitive RAN proposed has 4 phases of functionality comprising of Sensing, Analysis, Reasoning and Adaptation as shown in the diagram.

- Sensing Phase: In the Sensing phase the radio environment is sensed via wideband sensing/scanning as well as monitoring. In addition, the previously captured data is also utilized to find out various aspects of ambient conditions expected in the radio environment at a given time instant.
- Analysis Phase: The radio environment sensing provides information which goes through the Analysis phase to characterize and extract information on various aspects like the available radio frequency bands, licensed or unlicensed, interference power in various frequency bands, adjacent channel interference, co-channel interference, and far-off channel rejection, impulse noise, Signal to Noise Ratio, Carrier to Noise Ratio etc. It must be noted that learning algorithms can find significant use here to make use of previously existing data to infer about the radio environment.
- Reasoning Phase: In this phase the inputs from the Analysis phase are utilized to determine the best communication scheme and associated parameters required to establish successful radio links. The radio links are derived based on a chosen cost function. For a given region based on local RF terrain and geography the operator can choose the cost function of choice. As an example, some of the cost functions that can be chosen are Spectral Efficiency (Bits/Hz), Latency, reliability/graceful degradation or data security or in a combination of many different priorities like QoS/service level agreement requirements, or a certain target Bit/Packet Error rate or even frame error rate allowable by an application. Some of these cost functions could be dictated by nature of the end application which could be a voice, video, data, or a combination of those, maximum propagation distance, terrain conditions, initial hand-shake communication channel, and modulation details. Based on the chosen cost function, the reasoning phase runs an optimizer that considers the various operational constraints and then designs a modulation scheme with a desirable frame structure that can satisfy the radio link conditions. As an example, one of the operational constraints could be the spectral mask that needs to be enforced by the wireless regulatory bodies.
- Adaptation Phase: This phase takes care of transitioning the different radios on the Base Station and User Equipment side to change the existing radio link to that designed by the new radio link design and modulation scheme as designed by the output of the Reasoning Phase.

This type of RAN ensures optimal radio performance all the time for all users. The modulation and corresponding demodulation schemes are designed on the fly based on cost functions that capture the specific user's needs. In addition, this method leverages Deep Learning methods to determine the optimal use of resources to realize a waveform at Base Station and handset at a given instant. Overall, this results in a hyper-personalized network for users, rather than a one-size-fits-all approach.

6G Taskforce Report: Multi-Disciplinary Innovative Solutions

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Executive Summary

6G is expected to push the boundaries of communication technology by ushering in bandwidths of 1Tbps which will be 100x that of 5G. With latencies of less than a millisecond, it can potentially revolutionise the way people interact with other humans, machines, and data. In addition, 6G will also incorporate sensing as an inherent service - which will also have a profound impact on the design and delivery of new technologies and services in diverse areas.

We will have to evolve a road map to explore various use cases to discover the full potential of 6G as well as inform the 6G technology and standards development to ensure that they meet the needs of future use cases. We can broadly classify the use cases for 6G under these four categories, as described by Next G Alliance of North America:

- **Living**: Use cases that improve the quality of everyday living, especially in the context of an aging population, and support them in everyday activities. Geriatric care via telepresence and remote nursing, assistive and rehabilitation care to patients, etc.
- **Experience**: Use cases that enhance the quality of experience in areas like entertainment, healthcare, and education, by utilizing the significant advances in bandwidth and latency and incorporating new interfaces such as touch. 6G can be expected to change the way stories are told, training delivered, ailments are diagnostics and health care provided, and more generally, the way experiences are delivered and shared.
- **Critical**: Use cases that improve the quality of critical services in sectors like health care, manufacturing, agriculture, transportation, public safety, disaster response, defence, etc. We expect humans and robots will work together in many sectors. 6G capabilities of high bandwidth, low latencies, differentiated service levels, inherent sensing capabilities, and attention to security and reliability of the communication technologies will become necessary and key features to build very reliable critical services.
- **Societal**: Use cases that improve and attain high level societal goals like sustainability and equitable development. Equitable access to communication, ubiquitous coverage and green technologies will be key foundational pillars for sustainable and just societal development, without compromising the environment. In addition, security and privacy will be key pillars to be considered from ground up in the technology specifications, to ensure trust in the system.

Identification of marquee use cases from various sectors and forming a consortium of partners who can bring to bear an interdisciplinary approach, will help further our understanding of the needs of 6G as well as guide its further development in a holistic manner. These use cases can be identified keeping various considerations in mind and especially evolving from ongoing or planned work for 5G,

We recommend setting up of a 9-year national mission for 6G, with a clear goal of creating some minimum indigenous IP which becomes part of the 6G standards and leads to creation of commercial products made in India by 2030. It should have reasonable funding allocation with freedom to foster public-private collaboration partnership, with funds disbursement and mission objectives accomplished over three phases:
Phase I (Years 1-4): Setup horizontal centres of excellence focusing on new breakthrough technologies, that can lead to creation of new IPs, with a view to make them a basis for

standardization and eventual commercialization. Simultaneously, vertical centres of excellence (or field labs) should be setup to focus on implementing use cases at a reasonable scale, beyond that of a pure research laboratory. These can start with using 5G technologies and should focus on identifying and measuring KPIs for each use case. We recommend the government to largely fund this phase (through the mission), with amounts in the range of 8k-16k Crores (USD 1-2Billion).

Phase II (Years 4-6):, The horizontal centres should focus on translation of lab scale technologies to pilot scale validation and field trials in the various vertical use case Labs. This will also lead to participation and contribution to international and national standards. The vertical centres (use case labs) should keep upgrading their installations to keep pace with advances in 5G and eventually transition to testing early versions of 6G being developed in horizontal centres. This will enable a solid validation of 6G technologies which can then form a good foundation for proposals for standardization and eventual commercialization. We expect a significant contribution from industry to fund this phase of the activity. The government can provide partial funding in the range of 8k-16k Crores, with the industry putting in the rest.

Phase III (Years 7-9): The centres (especially the horizontal ones) could transition into skilling as well as incubation activities. We expect most of the funding to come from industry and venture communities in this phase. The goal will be for the start-ups and other industries to transition to full 6G based commercialization along with the expansion of the ecosystem to support manufacturing and supply chains. The government may provide seed funding for venture funds to catalyse co-investments in start-ups.

1. Introduction

The current internet penetration in India is largely through smart phones with about 45% of the population having internet access with about 13GB monthly data consumption per user. Most of the current usage is for online video and hence is dominated by download speeds. The expectation with 5G and eventually 6G is that upload bandwidth will also increase as there will be many use cases involving tele-interactions where high bandwidth will be required for both directions.

Though 5G roll out is imminent, it will only provide about 10Gbps bandwidth with 1mS latency. However, many applications that involve immersive presence or haptics interaction like tele-surgery, will require bandwidths of 10Gbps/user[1] or sub-millisecond latency[2]. To address these applications, the targeted capability for 6G is 1Tbps with sub-1 ms latency, with almost ubiquitous coverage across the entire planet. To achieve these high bandwidths, the carrier frequency will move to 0.1-1THz with bandwidths of 7-35GHz. Such high frequencies will also enable the capability for sensing hence 6G is also expected to converge communications with some sensing capability[3].

While researchers and technologists will work towards realising these capabilities, it is paramount that we also start exploring use cases in parallel, especially those that get enabled via innovative applications of these 6G capabilities. This will lead to a collaborative innovation process - where the use cases and capabilities can iteratively push each other, thus leading to practical and useful technologies with readymade applications.

With this broad context, we will next describe the key aspects of this report.

1.1. Terms of Reference

This report covers the following aspects, which form the terms of reference for this task force:

- Use-case definition
- Developing indigenous globally competitive `ahead of state-of-art` solutions and piloting them in real field environment
- Creating inputs for advanced research by practically establishing the limitation of available technology
- Providing substantial implementation inputs for global standardisation
- Pilot-Trials
- Other items in the scope of 6G activities and overall deliverables.

2. Use-case definition: approach, identification, definition.

While we still don't have 5G deployed, it requires quite a leap of imagination and further exploration and understanding to describe use cases for 6G

[1] E Bastug, et. al., "Towards interconnected Virtual Reality", IEEE Communications Magazine 2016
[2] Qi Zhang et. al., "Towards 5G enabled Tactile robotic telesurgery", CoCoNet 2019
[3] Carlos Lima et al., "Converged Communications, Localization & Sensing for 6G", IEEE Access 2021

2.1. Global Actions on probable 6G Use cases

2.1.1. European Union

Hexa-X[4] is EU's flagship 6G consortium created with a selective and well-composed choice of participants to lay the foundations for 6G systems and with the goal to enable EU leadership in B5G/6G research and development. Hexa-X has published a number of documents sharing the outcomes of deliberations in its different working groups and the deliverable D1.2 captures the 6G vision, use cases and societal values – including aspects of sustainability, security and spectrum.

The use cases for the 6G era defined by Hexa-X have been identified combining two approaches. Firstly, driven by the Hexa-X vision of combining the Digital, Physical and Human worlds while keeping Sustainability, Inclusion and Trustworthiness as the key values driving the future society. Secondly, collecting views from the partners and the ecosystem.23 use cases have been identified and broadly classified into 5 categories.

- Sustainable development
  - E-health for all
  - Institutional coverage
  - Earth monitor
  - Autonomous supply chains
- Massive twinning
  - Digital Twins for manufacturing
  - Immersive smart city
  - Digital Twins for sustainable food production
- Immersive telepresence for enhanced interactions
  - Fully merged cyber-physical worlds
  - Mixed reality co-design
  - Immersive sport event
  - Merged reality game/work
- From robots to cobots
  - Consumer robots
  - AI partners
  - Interacting and cooperative mobile robots
  - Flexible manufacturing
- Local trust zones for human & machine
  - Precision healthcare
  - Sensor infrastructure web
  - 6G IoT micro-networks for smart cities
  - Infrastructure-less network extensions and embedded networks
  - Local coverage for temporary usage
  - Small coverage, low power micro-network in networks for production & manufacturing
  - Automatic public security

[4] Hexa-X D1.2: Expanded 6G vision, use cases and societal values, https://www.google.com/url?q=https://hexa-x.eu/wp-content/uploads/2021/05/Hexa-X_D1.2.pdf&sa=D&source=docs&ust=1649135784835864&usg=AOvVaw1OuR_5X886It3aOguwGrPa

In addition to the Use cases, enabling services harnessing new capabilities have been identified

- Compute-as-a-Service (CaaS)
- AI-as-a-Service (AIaaS)
- AI-assisted Vehicle-to-Everything (V2X)
- Flexible device type change service
- Energy-optimised services
- Internet-of-Tags
- Security as a service for other networks

The following research challenges were identified

- Connecting intelligence
- Network of networks (e.g., millions of (specialised) subnetworks)
- Sustainability
- Global service coverage
- Extreme experience
- Trustworthiness.

Each use case family addresses multiple of these research domains and is analysed for the different Key Performance Indicators (KPIs), and a set of Key Value Indicators (KVIs) featuring the trustworthiness, inclusiveness, and sustainability abilities. Please refer to D1.2 for details

2.1.2. North America

The US SDO ATIS launched the Next G Alliance[5] as a consortium of stakeholders from Industry - Academia - Government to North American technology leadership in the 6G era with a strong emphasis on technology commercialization including full lifecycle of research and development, manufacturing, standardisation, and market readiness. One of the key stated goals is to leverage the deliverables to "*influence U.S. government funding priorities and actions that will incentivize the technology industry, laying the foundation for a vibrant marketplace for North American products and services globally.*"

The Next G alliance is organised into 6 working groups, namely - Roadmap, Technology, Green, Societal Needs and Economic Drivers, Spectrum, Applications.

In terms of the broad technology roadmap for 6G, the forum has published the roadmap whitepaper, which indicates the following areas as top priorities for technical leadership and contributions.

- Trust, Security and Resilience
- Sustainability
- AI Native Wireless Networks
- Distributed Cloud and Communications systems
- Digital World Experiences
- Cost Efficient Systems

[5] Road map to 6G: Building the foundation for North American Leadership in 6G and beyond. https://www.google.com/url?q=https://nextgalliance.org/&sa=D&source=docs&ust=1649135784837377&usg=AOvVaw2N3T1WCKScdDaVxLKAcqZN

The alliance has identified four key foundational areas under which they have studied various use cases. These are:

- Living: how to improve quality of everyday living?
- Here they are particularly concerned about the ageing population and envision how robotics technologies can benefit from 6G capabilities to allow better support in everyday activities.
- Experience: how to enhance quality of experience in areas like entertainment, healthcare, and education?
- Here, novel, bandwidth hungry user interfaces like 16k and even 32k displays along with haptics technologies - which will be very latency sensitive, will enable creation of new mixed reality content to be delivered. These are expected to change the way stories are told, training delivered, health diagnostics and care provided and in general way experience is delivered and shared.
- Critical: How to improve quality of critical roles in sectors like health care, manufacturing, agriculture, transportation, public safety etc.?
- A key observation they make is that the humans and robots will work together in each of these use cases, where robots will serve to augment/complement the humans. Hence human robot interfaces and interactions will be critical and 6G capabilities of high bandwidth, low latencies, differentiated service levels, inherent sensing capabilities, and attention to security and reliability of the communication technologies will become necessary features to build upon in these use cases.
- Societal: how to improve and attain high level societal goals?
- Equitable access to communication, ubiquitous coverage and green technologies will be key foundational pillars for sustainable and just societal development, without compromising the environment. In addition, security and privacy will be key pillars to be considered from ground up in the technology specifications, to ensure trust in the system.

Finally, the alliance recommends that inter-disciplinary approaches to the use case studies will extract functional, performance and value requirements that will in turn help inform technologists as they proceed with 6G development.

2.1.3. Japan

The Japan Beyond 5G (B5G) consortium was established in December 2020 to achieve early and smooth introduction of communication networks evolving Beyond 5G and to strengthen the international competitiveness of Japan in “Beyond 5G” domain to realise the strong and vibrant society expected in the 2030s.The consortium consisting of all stakeholders of the Japanese ecosystem - Govt., Industry (both telecom and other verticals) and Academia has been organised into 2 committees.

- Committee for Planning and Strategy
    - Study comprehensive strategies to promote B5G and prepare B5G whitepaper
- International Committee
    - To identify international trends for promoting B5G and international dissemination

The first version of the B5G whitepaper was released in March 2022 and summarises needs from different industry verticals that are consumers of B5G, capabilities required, and technological trends.

For each of the industry verticals, the report captures the current challenges, future vision. To realize that future vision, the use cases that are achievable with B5G technology are identified. With this perspective in mind, the following industries are surveyed leading to many use cases and their specific requirements on B5G:

- Finance
- Construction and Real Estate
- Logistics and Transportation
- Telecommunications and IT
- Media Industry
- Energy resources and Materials
- Automotive Industry
- Machinery industry
- Electronics and Precision electronics industry
- Living, Food and Agriculture Industry
- Retail, Wholesale and Distribution sectors
- Services, Public services, and Corporate Services
- Restaurant Industry
- Entertainment and Leisure
- Academic and others

From the gaps and KPI study the following B5G technology trends are arrived at

- System platforms and applications for X-As a Service, where X = [R] Robots, [M] Mobility, [XR] extended Reality
- Trustworthiness - Security, Privacy and Resilience with DLT, Confidential Compute systems, AI based security, etc.
- Network Energy Efficiency Enhancement including network energy savings, use of renewable energy and architectural framework to solve AI power consumption issues
- Network coverage extension including Non-Terrestrial Networks and High-Altitude Platform Stations
- Architectural enhancements to improve overall user experience, and performance of ubiquitous sensors and AI systems
- Future Wireless and Optical Network technologies like Reflective Intelligent Surfaces, Large Scale MIMO, Evolved Air Interface for new bands and improved energy efficiency, Integrated Sensing and Communication, and Optical Wireless and Acoustic communications

2.2. Strategy for the development of Indian specific scenarios and setting up of CoEs

The main purpose of identifying potential use cases at this early juncture in 6G development is to help push and refine the technical capabilities for 6G which will eventually lead to practical solutions, and simultaneously result in valuable IP creation as well as a better chance for getting accepted in international standards. Hence the use cases should be demanding of the communication technologies and should be asking for capabilities beyond 5G.

The process to select the Use Cases can consider the following questions to test their suitability for adoption as part of 6G R&D

- **Is the use case supported by any planned 5G Application layer standards?**
  The final revision of the 5G Application Layer Standards (ALS) Report has been submitted to the DOT last year. In it, two verticals were accorded priority over all others. These were Smart City & Banking Financial Services. Agriculture & Healthcare were close but lower in the priority order.

- **Is there an availability of Nationally published reports for KPI metrics data?**
  Availability of any ground level KPI data for the Use case from Nationally published reports will help create benchmarks for quantifying the efficacy of achieving the use cases and the impact of communication technologies. This data can be baselined over which improvement can be targeted by 6G capabilities like "Sensing" of both active and passive vulnerable road users for collision avoidance. e.g.: for Intelligent Transport Systems: Yearly Road Safety Reports show India in the lowest bracket of Road safety globally. [Refer [8] in Appendix for Report]
  The purpose will be to serve as the baseline against which the Govt can set targets for the technology to prove itself.

  Other reports can point to Net Energy consumption by current 4G/LTE systems in India. This should also include the device ecosystem plus Data Centres. As per Mckinsey report on Green Telecom, currently, each 5G site requires two to three times more energy than an equivalent 4G site. Further, with more services at the edge the number of Data Centres will increase. With the advent of 6G the Energy requirement will be astronomical. Therefore, Green Energy, net energy reduction will be of paramount importance [see reference 26 for more details].

- **Is there an Assessment of the 5G use cases experimented in 5G Innovation Hubs, specifically the horizon 2 and 3 use cases?**
  Availability of performance test results of varied 5G use cases, specifically horizon 2, 3 use cases helps to map and explore further with 6G. The existing 5G Innovation Hubs can be extended for 6G research.

- **Is there a report available on the 5G use cases planned, experimented in the STPI COEs, Centre of Entrepreneurship (https://stpi.in/index.php/stpi-coe) established at National level on varied technologies?**
  Out of 25 COEs planned (e.g., Quantum, Image, IOT), 20 are established at the national level for varied technology areas. These COEs are aligned with vertical industries, for e.g.,
  - IOT Open Lab at Bengaluru for multiple industries (Industrial IoT, Automotive, Wearables, EduTech, AgriTech, NanoTech, Mobility & Home Automation, and Smart City)
  - Motion (Autonomous Connected Electric Shared (ACES) Mobility) at Pune for Auto Industry
  - Establish new COEs that are needed for 6G to explore new use cases.

The purpose will be to serve as the baseline against which the Govt can set targets for the technology to prove itself.

2.3. Sectoral Engagement Strategy

[Each sector like Agriculture, Manufacturing, Disaster Response, Finance, Education, Logistics, Mobility, Entertainment etc could potentially contribute to 6G use cases. We would need to have a champion for each sector - could be a line ministry or a reputed organisation, which drives the articulation of the use case looking 10-15 years into the future, via consultation with appropriate stakeholders. These could then form the basis of setting up centres of excellence (COE) for the said use cases for each sector, with appropriate allocation of funding. The use case (or "Vertical") COEs can first identify and realise their solutions via existing 4G and upcoming 5G technologies. As 5G technologies are expected to bring digital change to a variety of other sectors]. To promote and smooth adoption of 5G potential use cases, the Department of Telecommunication has constituted an inter - ministerial committee with representatives from 17 ministries. The existing 5G use case engagement experience will be extended on to the 6G engagement. The KPIs and benchmarking will serve as a starting point for future enhancements to the use cases, some of which may require 6G.

2.4. Indigenous IP Creation Strategy

We should also create "horizontal" COEs which focus on foundational technology creation to enable 6G capabilities. This will lead to creation of fundamental IPs and contributions to international standards, as well as support for indigenous manufacturing. However, the funding requirements will be substantial and hence a strategic approach will be required to achieve these aspirations. Some of the key points for this will be:

- Generating IPs to the extent maximum in next 3-4 years
- Focus on strengths due to limitations in budget
- Form Consortiums of entities (Academia & industry) and include strategic international partners
- In the initial research phase, provide funding support to the private sector (including large and SMEs).
- Incentivization contribution of R&D funding from the private sector through tax breaks etc. especially for the productization and standardisation phase.

3. Potential 6G Use cases of relevance to India

3.1. Healthcare

Ambulance services will get augmented to provide continuous high-quality care from home-to-hospital to enable Hospital-to-Home (H2H) services. 6G will enable hospitals to reach home on demand and in an emergency. The future ambulance vehicles will be fully AI enabled and connected with the infrastructure. Therefore, H2H will be realised as a mobile hospital on an intelligent vehicle platform that will have a minimum dependence on hospitals including doctors and nurses. This mobile hospital will replace ambulance services.

Intelligent Wearable Devices (IWD) that are connected to the Internet will transmit psychological and physiological data to test and monitoring centres. These devices will monitor all vitals like, heartbeat, blood pressure, blood tests, health conditions, body weight and nutrition. This data will be available in real-time at the diagnostic centres. IWD data will enable personalised treatment and care plan and advise the person for the next action, for instance, advising for walk or running. IWD will allow maintaining a digital twin of the individual for health, nutrition, and habits.

Tele-diagnosis, remote surgery and telerehabilitation are just some of the many potential applications in healthcare. We have already witnessed an early form of this during the ongoing COVID-19 pandemic, whereby a huge number of medical consultations are via video links. However, with the aid of advanced tele diagnostic tools, medical expertise/consultation could be available anywhere and anytime regardless of the location of the patient and the medical practitioner. Remote and robotic surgery is an application where a surgeon gets real-time audio-visual feeds of the patient that is being operated upon in a remote location. The surgeon operates then using real-time visual feeds and haptic information transmitted to/from the robot. This will definitely create a significant impact on Rural medical arrangement and overall cost of treatment will be drastically reduced.

A smart pharmacy box (cabin) installed in rural areas where patients can enter and describe the symptoms to an interface (virtual), accordingly the pertinent doctor (virtual doctor or holograph) can prescribe the medication and the medicines are dispatched by the box thus realising an ATM using a health card. Connectivity provided by 6G will make the box portable.

3.2. Agriculture

Agriculture use cases can consider smart and precision agriculture with connectivity to every square metre in the country. 100 Kisan Vigyan Kendra's run by ICAR can provide the testbed or living labs to experiment with communication technology evolutions for agriculture over this coming decade.

For vertical farming and green houses, highly dense and large-scale sensor network can be deployed where connectivity is provided using a set of 6G micro base stations, including drones working as wireless access points.

3.2.1. Smart Agriculture using 6G-IoT and AI

Objective is to develop an intelligent predictive system fusing IoT and AI/ML techniques to forecast yield, irrigation schedule, pesticide schedule and crop health information with specific goals as listed below:

- Development of a sensor network to collect location specific soil, weather, and plant health data for the purpose of precise management of soil and crop.
- Design of communication framework and Protocols.
- Building of Rice specific analytics model and development of PC / mobile based application software
- Pilot implementation.

It is required to develop Message Exchange Middleware (MEM) for exchange of data between the devices which is fast and reliable after finalisation and deployment of the selected IOT devices and finalisation of protocol. Two standard and frequently used protocols, namely, MQTT and CoAP are being proposed; any one of them can be selected based on mutual acceptability.

MQTT is preferred over CoAP for mission-critical communications because it can enforce quality of service and ensure message delivery. CoAP, for its part, is preferred for gathering telemetry data transmitted from transient, low-power nodes like tiny field sensors. Despite fulfilling different needs, both protocols are fundamental in IoT and IIoT deployments, where fast and flexible data exchange is a basic operational requirement. After evaluation of the field situation, the most appropriate protocol out of the two will be selected and implemented.

3.3. Defence & Internal Security

The following use case scenarios are recommended

(i) **Battlefield Surveillance**

With integration of sensors, drones and Satellites, an unmanned surveillance grid mapping every inch of border (high accuracy localization) will enhance the operational efficiency by providing real time inputs to the commanders in the field formations.

(ii) **Security protocol**

A Novel protocol exclusively for defence may be developed in conjunction with academia and industry for authentication and key management in 6G. This can be leveraged to exploit the same network infrastructure for providing communication to local population and armed forces in the given area. The concept can be akin to a Military grade network slice.

(iii) **Dynamic Radio Illumination of Battlefield**

With advanced beamforming techniques already available in 5G, the 6G should look at dynamic radio coverage in the heterogeneous environment based on the progress of operations.

(iv) **Digital Twin of Battlefield**

The real-time dynamic interaction between the virtual and the real battlefield can be simulated using the digital twin to provide automated flow of info in ops. This will enable commanders to take timely decisions and shape the response in battle.

3.4. Disaster Response

Wildfires are associated with human evolution and almost all forests across the world have faced incidents of wildfires, however, when these fires become uncontrollable, they often turn into disasters. Raging wildfires results in loss of natural resources, biodiversity, property, and often human lives.

In Indian context significant wildfires have been reported in some of the states like Uttarakhand, Nagaland, Odisha, Tamil Nadu and in the other states in the last couple of years. Many extreme climate events have occurred in India in the last decade which have resulted in occurrence of significant wildfires. The higher number of wildfires in the year 2009 and 2012 have resulted due to the effect of El-Nino which brought in significant dryness.

Key Challenges: Fire can be detected through satellites, ground sensors, unmanned aerial vehicle (UAV), and physical observation by public and forest officials. However still there are gaps in accurate and timely reporting of wildfire.

- One of the major challenges in managing the wildfires is early detection of the same. Early detection of wildfires is important for timely deployment of resources towards control the spread and to take mitigation steps.
- MODIS and VIIRS sensors can report the wildfire at 1km and 375m spatial resolutions respectively six times a day, however, small wildfires (which may turn into large fires) remain undetected.
- Depending on the satellite pass, fire alert data can be obtained for a limited duration. Also there exists latency to the tune of one to one and half hours before data reaches the end user.

It is therefore important to deploy sensor networks at strategic locations so as to have continuous data collection on the remote server. Whenever some sensor records value more than a specified threshold it may enable early detection of wildfire. Also, it may be required to deploy the UAVs in sync with satellite and ground sensor networks to monitor the occurrence of wildfire. In addition, crowd-based systems are also required to collect instant geotagged locations of wildfire along with text, audio, image, and video data of that location.

Multi-source Data Analysis & Visualization: Wildfire management required real-time response to dynamically evolving situations, spread over many hectares. Use real-time data feeds from multiple sources: satellite, on-ground sensors, drones, meteorological services etc., and combine these with other contextual data (terrain maps, vegetation type and cover etc) to analyse with high fidelity scientific models on HPC systems to predict spread of fire and allow visualisation. This visualisation can be communicated in real-time to on-field personnel to enable them to make more effective decisions. The resulting latency and data bandwidth requirements is potentially a good use case for 6G (along with its inherent sensing capability). CDAC (HPC Capability) and IITKGP (Fire Dynamic Scientific Model and Simulations) are working together for this use case. Test site can be in Sikkim.

The low latency 6G technology will enable development of advanced real time fire danger rating systems, which will be based on data streaming not only from ground sensors but also from satellites, UAVs, IoT network, crowd, and climate models. Therefore, considering the future challenges it is inevitable to carry out targeted research now to define the strategies for handling the big data towards very optimum handling of the fire disaster.

Other similar use cases in Civilian (disaster management for flooding, landslides, etc.) and Defence for communicating and rendering in real-time, situational awareness and what-if predictions.

3.4.1. 6G Offerings specific to Disaster Management

- Very Large Volume & Tiny Instant Communications
- Beyond best effort and High-Precision Communications and lossless networking and latency guarantee
- Many Nets (Satellite, MEC, Dense network)
- Intelligent Connected Management and Control functions, Programmability and Integrated sensing and communication

3.4.2. Other Disaster Management Use cases

Almost all large spatial scale disasters such as flood, air pollution, GLOF require significant data processing power and dissemination protocols so as to enable governments to take mitigative measures in good time. The development of grid consortium for very high-speed collaborative computing, data transfer will be required in future for effective decision making considering the deluge of data from different sources. In India many times potential cyclone related disasters have been averted by collaborative coordination among different stakeholders. Such type of collaborative, spontaneous, real time disaster control measures also need to be taken for forest fires. 6G technology has the potential to bring revolution in disaster alert, processing and information dissemination activities, thus strong research needs to be carried out for future disaster management activities.

There are also potential applications in other environmental use cases - rope in Ministry of Environment to explore applications for reducing carbon footprint and meet India's commitment

The mining sector needs smart technology for real-time monitoring for worker's safety as well as allow remote-tele operation of mining equipment. Difficult wireless propagation medium, including need for ad-hoc network setup, good localization capabilities, sensing capabilities etc.

There are also potential applications in other environmental use cases - rope in Ministry of Environment to explore applications for reducing carbon footprint and meet India's commitment
The mining sector needs smart technology for real-time monitoring for worker's safety as well as allow remote-tele operation of mining equipment. Difficult wireless propagation medium, including need for ad-hoc network setup, good localization capabilities, sensing capabilities etc.

3.5. Transportation/Air mobility

Unmanned Aerial Vehicles (UAV) is one of the prominent use cases for 5G which has exponential growth of the market owing to numerous applications that have been facilitated by advances in battery technology and wireless communications. Given the successes of UAVs thus far, researchers are already gearing towards aerial transport systems that consist of dense deployment of both UAVs and Personal Aerial Vehicles (PAVs) with human passengers. However, future aerial transport systems will require stricter network key performance indicators to support the expected massive deployment of aerial vehicles considering network capacity and distance between the base station and the aerial vehicles, among others. Hence 6G will be required for Urban Air Mobility (UAM). These electric vertical take-off and landing (eVTOL) aircraft for passengers will be very much applicable for cities like Mumbai and Bangalore where peak hour traffic is one of the biggest challenges. It is expected that the market for eVTOL Air Taxis to Grow to $14.7 Billion by 2041.

Safe ITS
"Safe" Intelligent Transport Systems (ITS) that protect the Vulnerable Road Users.
Innovations in Location/Speed Sensing will be required for improving Safety metrics.

The technology can be applied to all transport modes including Robots.

3.6. QKD and integration with 6G

Quantum technology (QT) is envisioned to play a critical role in the 6G framework [9 - 12]. Considering the spectra of utilities and applications that is brought forth by 6G technologies, security will be one of the greatest challenges. This can be primarily addressed by secure quantum communication. The technology has been demonstrated globally and has many commercial players as well. However, another important aspect is Quantum computing which can contribute to solving computationally difficult optimization problems in 6G, the problems that are computation-intensive can be expedited and several protocols are explored which can contribute to privacy-preserving applications.

In quantum communication we use the quantum property of light to communicate between remote parties. We generate spontaneous secure symmetric encryption keys through a quantum process and the quality of the keys are high in entropy and generated via true random process. This methodology has elevated the nature of security from computational security in modern cryptography to information theoretic security in the Quantum era. As a matter of fact, the resources of QT like superposition, coherence and entanglement serves dual purpose. On one hand it strengthens the cryptography and on the other hand it provides unprecedented computational power. The laws of quantum mechanics like no cloning theorem, Heisenberg uncertainty principle and non-locality principles forms the basis of provable security of Quantum Key distribution (QKD).

Quantum Key distribution: In Quantum Key distribution [14], we begin by selecting a protocol which has a proven information theoretic security guaranteed by the laws of quantum physics. The BB84 with single photons is the most secure QKD protocol having security proven for most general eavesdropping attacks on the quantum channel. We can categorise the QKD protocols into discrete variables DV-QKD and continuous variable CV-QKD based on the nature of detection. We have a quantum transmitter and receiver connected with quantum and classical channels. Once we identify the QKD protocol, the QKD transmitter will generate quantum states, encode the quantum states, and transmit it either by free space or by fibre-based channel. The QKD receiver will receive the states and proceed to sifting and post processing the detected states according to the protocol. The quantum states being fragile will suffer from vulnerabilities in implementation, transmission, reception, and environmental factors giving rise to errors. If the error rate of the system exceeds the threshold, then we drop the generated encryption keys, otherwise we accept the keys as tamper free and proceed with generating symmetric keys on either end. The future quantum secure network and a quantum network will require QKD nodes easily provided by free space and fibre-based quantum communication (QC). This can be achieved using three approaches (1) direct ground-to-ground free space/fibre-based QC, (2) satellite QC and (3) Drone based QC. An integrated model would combine the satellite communication networks, aerial networks, terrestrial networks, and marine communication networks

Space-air-ground-sea integrated network (SAGSIN), which provides a promising network architecture for 6G [11]. In Figure 2, we have presented different components of quantum communication which will play a critical role in boosting the security of 6G. This includes a hybrid communication system which will encompass PQC, QRNG and different forms of quantum communication i.e., QKD and QSDC as presented in the figure. This will further lead to establishing a quantum internet across PAN country quantum network supporting several applications using entangled photons as a resource.

In QKD, the adversarial model encompasses the present and future attacks by quantum adversaries (with quantum computer and quantum memory) and classical attacks with present state of art technologies obeying the laws of quantum physics. The keys are obtained from a composable security framework ensuring further usage of keys for cryptographic purposes. Another important application of QT is the quantum random number generator (QRNG). These RNG are quantum based TRNG providing high entropy and Information theoretic quantum certified random numbers for conventional cryptography. Post quantum cryptography (PQC) is another aspect of quantum safe cryptography where the mathematical problems used in cryptography are believed to be quantum safe. Recently, NIST [13] has shortlisted in round 3 (2020) the finalists of the NIST Post-Quantum Cryptography Standardisation Process, three PQ algorithms for use in digital signatures and four PQ algorithms in Key encapsulation mechanism (KEM) along with alternate candidates for each.

Recent achievements

QKD Network

- The Cambridge Quantum Network [15] is another such example, this network has been operating for several years with secure key rates of about 1 Mb/s and interestingly the network operates in the presence of 100Gb/s classical traffic.
- Toshiba [16] breaks quantum communication record with 600 km of optical fibres.
- An integrated space-to-ground quantum communication network [17] over 4,600 kilometres consisting of (1) fibre network of more than 700 fibre QKD links and (2) two satellite-to-ground free-space QKD links.

QKD in 5G:

- SK Telecom has deployed a form of QKD in its 5G mobile networks to provide increased security in its 5G network [18].
- In 2020, Verizon tested QKD over fiber optic links in its network, encrypt live video streams over a fiber network between three locations, which are the Washington D.C. Executive Briefing Centre, the 5G Lab in D.C., and Verizon's Ashburn [19].
- It is reported that the first demonstration of quantum-secured, inter-domain 5G service orchestration and on-demand NFV chaining over flexi-WDM optical networks was performed by the University of Bristol [20]. software-defined
- A software defined QKD network (SDQKDN) was demonstrated using (1) CV QKD by Huawei Technologies Duesseldorf GmbH (HWDU), Munich Research Centre, and (2) SDN by UPM and Telefonica on a production-level optical fiber infrastructure of Telefonica to demonstrate [21].

Global initiatives:

- In the US, The National Quantum Initiative Act was signed into law in 2018.
- The EU also launched its Quantum Technologies Flagship in 2018.
- India has announced a National Mission on Quantum Technologies & Applications (NM-QTA) in 2020.

- The Quantum Internet Alliance (QIA) [22] is preparing for a pan-European Quantum Internet towards implementing a fully integrated network stack running on a multi-node quantum network.

Standardisation and certification

At present there is a parallel global effort on standardisation and certification. In this direction ITMO University and Kazan Quantum Centre launched Russia's first multi-hub quantum network which will form the basis for development of quantum communication in Russia. China Communications Standards Association CCSA-ST7, and it has several related contributions to international SDOs including ITU and ISO/IEC. The ETSI-QKD/ISG [23] has developed testing and evaluation methods and methodologies, system test, interfaces, component specifications which have been released for commercial quantum communication. The ISO group [24] developing two standards: "ISO/IEC 23837-1 Information security—Security requirements, test, and evaluation methods for quantum key distribution—Part 1: Requirements (containing predefined security functional requirements for use in QKD PPs) and ISO/IEC 23837-2 Part 2: Test and evaluation methods. Both are currently in advanced committee draft (CD) stage and publication is planned for spring 2022.

Advantages of QKD in 6G: Hardening of the 6G security

- QKD may be deployed over the backhaul connecting radio access networks and the core network.
- Quantum communications can also be leveraged for securing communications between an SDN controller and SDN enabled devices as successfully demonstrated by Telefonica and its partners in 2020.
- In future, we can expect mesh-like Space Information Networks (SIN) under 6G. In this regard Quantum Space Information Network (qSIN) is a reality today and several demonstrations and this will offer novel methods of key relay which will have its own advantages. For example, Huang et al. [25] demonstrated a double-layer quantum satellite network architecture based on a trusted repeater and implemented a quantum key pool (QKP) showing an improvement of the success probability of key relay services.
- The security can be approached in a hybrid manner leveraging QNRG, QKD, PQC and state of art communication techniques.
- Quantum-Assisted Blockchain (qChain) can use quantum communications to address the security in blockchain nodes. There is a good opportunity to evolve new protocols based on quantum entanglement to assist the technology.
- The 6G system will involve application of AI algorithms such as deep learning, deep reinforcement learning, etc and the communications among participants can be secured using quantum secure communication.

3.7. Education

There are so many opportunities in the Education sector like Remote learning. However, another prominent area is robust infrastructure for exam conduction. Total 1,26,30,885 applications were received for the RRB CEN NTPC 2021 exam. Online examinations have always a potential to save cost in exponential factor, however that requires robust infrastructure. If Person needs to appear from home or remote centre, then 6G will play a significant role.6G will allow the video to transmit at such a high speed and nearby edge processing will help in managing the compliance. All major examinations like JEE, NEET, State Government, Banking, Defence, and other related sectors can leverage 6G in exam conduction.

3.8. Metaverse

Metaverse bridges the physical world and the avatars in the virtual world built by human imagination, leveraging Extended Reality, AI, Spatial Computing, IoT, Wearable Technologies, Decentralized, Crypto Currencies and 5G / 6G and brings in next generation User Experience.

The Metaverse requires real time experience between what a person does and what their avatar does without lag, hence very low latency. This requires, the network connections to be super-fast, super-reliable and available everywhere. Also support the processing power leap as there is a move from 2D to 3D, holographic displays.

Holographic displays used for real-time multi-dimensional interaction, requires a very high throughput. This increases further with concurrent data streams, hence requires Tbps, and latency to be less than 1ms.

Use Cases extends from

- Digital Twin, with physical and digital world interactions across industry sectors
- Immersive product design, reviews with 3D models, VR in manufacturing with distributed teams
- Media, Entertainment & Sports for interactive immersive experiences
- Collaborative Learning and remote working through' Virtual Spaces

4. Roadmap for Infrastructure/funding Support

- GoI will need to allocate good funding for basic and applied research for the next three to four years (Y1-4) - with the setting up of "Horizontal" Centres of Excellence across the country. (~USD 1-2B)6. These could be anchored in academia - but have industry partners. We can choose to focus on a few key foundational areas, where we might have inherent strengths and capabilities
- GoI can set up "Vertical" use case field labs across the country for various verticals (Agri, Industrial Automation, Logistics (transportation), Health, Security, Education) (~USD 1-2B). These could be anchored in industry/other domain specific institutions - but have academic and international partners . The R&D money should allow co-innovation from academia/industry consortiums (which means industry should also be eligible for a slice of the R&D grants - in the first phase).
- GoI can also create a venture fund of funds to co-invest in translation and start-up creation (Y7-9) (USD 1-2B) through accelerators in academic and other institutions.

[6] Numbers are indicative. As a comparison, the EU has invested USD2B (with countries/companies putting in additional money).

5. Key Recommendations

- Create a National Mission for 6G which has a 9-year tenure (2022-2031), with funding allocation in three tranches - phase 1 for Years 1-4 and Phase 2 for Years 4-7 and Phase 3 for years 7-9. The mission's purpose will be to catalyse
    - Coordination and interactions between various stakeholders in Central and State governments and their respective line ministries as well as with industry and academia.
    - Fundamental and applied research for 6G technologies, leading to creation of new IP, knowledge, and skilling.
    - Pilot scale demonstration and validation of these technologies in field trials for various use cases.
    - Participation and contribution to national and international standards. This is expected to start from 2025 onwards.
    - Creation of start-ups and other translation mechanisms to convert these technologies to products designed and manufactured in the country for the global market.
    - Formation of consortia between academia, industry, and government agencies nationally and internationally for various activities in each of the phases.
    - Competitive selection of consortiums for funding support to undertake various activities of the mission to realise its objectives in each of the phases.

- Invite proposals from consortia of Academia, Industry and Government agencies to set up "Horizontal" Centres of Excellence across the country. These could be anchored in academia - but have industry and other partners.
    - In phase I (Y1-3), these centres will focus on basic and applied research, with lab scale validation.
    - In phase II (Y4-6), these centres will focus on translation to pilot scale validation and field trials in the various "Vertical" Use case Labs. This will also lead to participation and contribution to international and national standards.
    - In Phase III (Y7-9), these centres will largely focus on large-scale skilling and manpower development.

- Invite proposals from consortia of government agencies, industry, and academia to set up "Vertical" use case field labs across the country for various verticals (Agri, Industrial Automation, Logistics (transportation), Health, Security, Education).
    - In phase I (Y1-3), these field labs will start with field scale deployment of 5G and focus on KPIs for each use case. They will keep upgrading their installations to keep pace with advances in 5G.
    - In phase II (Y4-6), these field labs will start adopting components of 6G technologies - with an aim to validate and contribute to standards. These will also allow the eco system to mature to enable targeting of productization for next phase.
    - In phase III (Y7-9), start-up and other industries will work towards transitioning to full 6G based use cases (where needed) and will allow the ecosystem to expand its manufacturing and supply chain footprint, to plan for full deployment.

  - Each consortium, running these use case field labs, will work together with concerned stakeholders to define the scope of the pilot trials for evolving the use-cases in phases.
  - The consortia will also Invite other solution providers who are ready for pilot testing of their technologies and provide all necessary support for successful testing.
  - The results of all pilot trials in these use case field labs, will provide feedback to research teams, Standardisation teams and solution development teams for further capability enhancement and solution optimization.
- Phases II & III can focus on creating a national ecosystem (including start-ups, MSMEs, and large Industries) of developing and mass manufacturing of solutions and helping manufacturers with appropriate incentive schemes.
- Plan and organise adequate funds with firm commitment of timely, inclusive, and merit-based support based on delivery and progress.
- Partial/Seed funding for Use Case Field Labs should be obtained from appropriate line ministries.
- We anticipate about 1-2B USD for Phase I (Y1-4), 1-2B USD for Phase II (Y4-7) and USD 2-10B for Phase III (Y7-9).

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7. Appendix: Detailed Use cases

7.1. A detailed study of a Health care use case

The 6G revolution is envisioned to connect everything and control trillions of devices—macro to micro to nano—for the digitization future. Time-sensitive healthcare applications such as haptic (involving touch, sight, and sound) actions and holographic connections displaying three dimensional images assist healthcare professionals using emotion-sensing wearable devices to monitor mental health, heartbeats, oxygen level, glucose, blood pressure, and much more, as shown in below.

At present, the healthcare sector is facing numerous challenges. The deficiencies of the 5G mobile system as an enabler of IoE (Internet of Everything) have inspired global research activities to focus on the 6G wireless system.

The requirements of 6G communication technology for future healthcare are high data rate (≥1 Tbps), high operating frequency (≥1 THz), low end-to-end delay (≤1 ms), high reliability (10^{-9}), high mobility (≥ 1000 km/h) and wavelength of ≤300μm. Telesurgery requires real-time communications. Also, holographic communication and augmented/virtual reality will boost up the intelligent healthcare systems. However, 5G and B5G will be unable to support intelligent healthcare. In the 5G communication era, intelligent healthcare will be implemented partially which will push forward a step ahead.

6G communication technology requires supporting technologies to fulfil the promises. 6G is truly AI-driven communication technology, and thus, it requires AI to integrate its communication technology. Moreover, 6G will enable Internet of Everything (IoE), and it will boost up many fields. Also, edge technology is necessary for 6G technology for bringing the Cloud features closer to intelligent devices. Thus, 6G communication technology comprises of many technologies. Some of the technologies that are vital for healthcare industry is listed below.

- **Edge Intelligence:**
  6G will rely on Cloud computing for storage, computing and analysis of Big Data. Data produced by the intelligent devices are transferred to Cloud for storage, however, it consumes communication resources and bandwidth. Off late, the technologies are brought closer to the data source due to the exponential growth of data. This technology is Edge technology. 6G is claiming to have a high capacity to provide
  smooth services to billions of intelligent devices. 6G will rely on Edge technology to provide the smooth and high-speed Internet services to the intelligent devices which is vital for healthcare.

- **Artificial Intelligence**
  6G will be a truly AI-driven communication network. 6G will make every aspect of network communication intelligent to make the system self-aware, self-compute and self-decide on a situation. The goal of 6G is to provide global coverage, including space-air-water. This is achievable only by making the different aspects of communication "intelligent. Implementation of AI algorithms is generating high accuracy and performance in communication networks. Truly AI-driven communication can offer real-time communication which is very important for modern healthcare.

- **Holographic Communication**
  Hologram is a physical recording of an interference pattern that uses diffraction to generate a 3D light field. The image generated has parallax, depth, and other properties of the original object. Holographic communication uses cameras from different angles to create a hologram of the object. It will use the core service of 6G. It will require high data rates to provide good quality of service and streaming high-definition videos. Moreover, very low latency is required for real-time voices and immediate control responses. Holographic communication will be a breakthrough for healthcare.

- **Augmented reality and virtual reality**
  Augmented reality (AR) helps to include virtuality to real objects. Moreover, it is combined with multiple sensory abilities such as audio, visual, somatosensory, haptic etc.
  AR also provides real-time interaction and presents 3D images of virtual and real objects accurately. Virtual reality (VR) refers to presenting an imaginative or virtual world where nothing is real. AR and VR will use the core service of combined and enhanced 6G features.

- **Tactile/Haptic Internet**
  Haptic technology creates a virtual touch using force, motion, or vibration on the user. Tactile Internet is used to transfer the virtual touch to another user, maybe human or a robot. Tactile Internet requires high speed of communication to grab the tactile in real-time. This technology will be used for remote surgery, i.e., telesurgery. It will also help doctors for diagnosis using touch without being physically
  present. Haptic human-computer interaction (HCI) is classified into three types, namely, desktop, surface, and wearable.

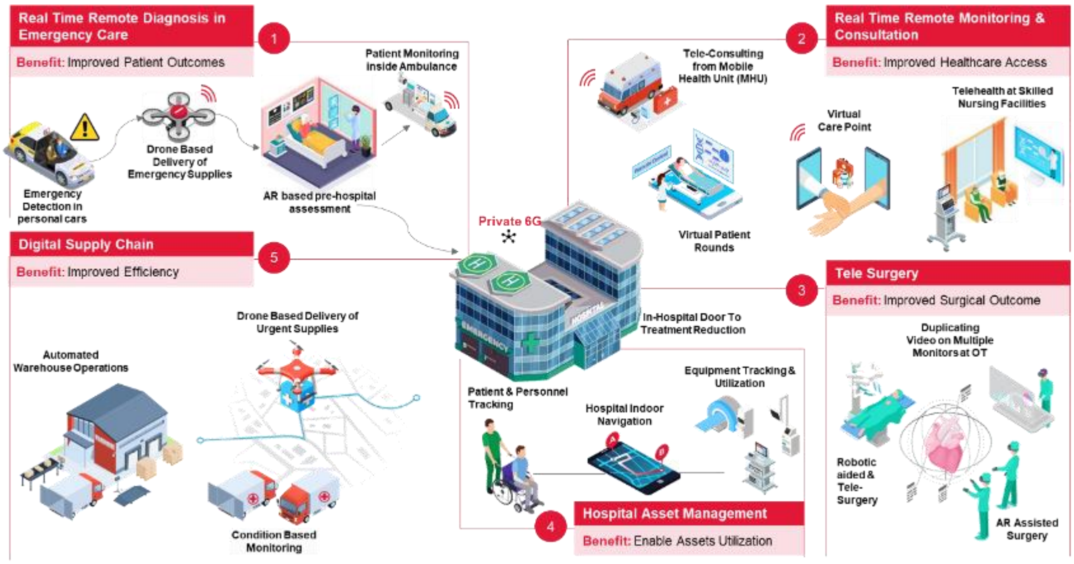
- **Intelligent Internet of Medical Things**
  In 6G communication paradigm, Intelligent Internet of Medical Things (IIoMT) will evolve and serve many purposes for well-being of humankind. IIoMT are intelligent devices that are AI-driven that makes its own decision using communication technology. IoE will also emerge along with IIoMT, and thus, medical things can connect to the Internet. For instance, MRI and CT scan. The scanner will scan the devices and send the data to remote locations through 6G technology.

- **HOSPITAL-TO-HOME SERVICES (H2H)**
  Currently, the ambulance services are just a transporter of patients with oxygen and road traffic priority. It does not serve the purpose of emergency service due to absence of intelligence. Therefore, the ambulance services are not impacting on our lives. Any normal car can also solve the same purposes if we keep oxygen and emergency signal. Therefore, a new kind of ambulance service is required to improve lifestyle.

  To replace ambulance services, the Hospital-to-Home (H2H) services will be emerging. Due to the advent of communication technology, hospital can reach to home on demand and in an emergency. The future vehicles will be fully AI driven to make intelligent vehicles. Therefore, H2H will be implemented upon mobile hospital on an intelligent vehicle platform that will have a minimum dependence on hospitals including doctors and nurses. This mobile hospital will replace ambulance services.

- **Intelligent Wearable Devices**
  Intelligent Wearable Devices (IWD) are connected to the Internet and transmit psychological and physical data to test centres and monitoring centres. This device will monitor heartbeat, blood pressure, blood tests, health conditions, body weight and nutrition. The test result will be received quickly.
  Also, IWD learn from the personal body history and advise the person for the next action, for instance, advising for walk or running. IWD will maintain a personal history of health, nutrition, and habits.

Based on the above technology that enhances / uses the underlying 6G Core services, probable use cases are depicted below.



A landscape of intelligent healthcare systems. This figure includes Intelligent Internet of Medical Things sensor, Intelligent Wearable Devices (IWD), Online Prescription, MRI, CT scan), Hospital-to-Home (H2H) Services implements mobile hospital, Pathology, Local Doctors, Remote Doctors, and Data Scientist.

- **Use case 1: Real Time Remote Emergency Care:**
  Emergency detection in personal cars: Acquisition of vitals through Bi-directional Tactile / Haptics Internet, Alert to Driver, Notification to Emergency Control Centres

  Drone based delivery of emergency supplies: Timely emergency medical supply to remote location, receive emergency notification, Determine emergency location, Dispatch emergency supplies

  Telepresence / Holographic based pre-hospital assessment: Remote trauma assessment, Telepresence / Holographic examination, Remote Annotation, Receive AR based instruction

Patient monitoring inside Ambulance: Pre-hospital remote diagnosis and treatment, Monitoring of vitals, Acquisition of medical images.

- **Use case 2: Real Time Remote Monitoring and Consultation**
  Virtual Care Point (Rural, Public Space, Clinics): Remote Telepresence / Holographic consultation and collaboration, Real time acquisition of Vitals through Tactile / Haptics Internet,

  Tele-Consulting from Mobile Health Unit (MHU): Remote Telepresence / Holographic consultation and collaboration, Real time acquisition of Vitals through Tactile / Haptics.

  Telehealth at Skilled Nursing Facilities (SNF): Teleconsultation and remote monitoring, Remote Telepresence / Holographic consultation and collaboration, Real time acquisition of Vitals through Tactile / Haptics, Generate alerts and notifications

  Virtual Patient Rounds: Examine and treat inpatients remotely, Real time acquisition of Vitals through Tactile / Haptics, Remote Telepresence / Holographic consultation and collaboration, Remote diagnosis, and treatment
- **Use Case 3: Tele Surgery**
  AR/VR Assisted Surgery: AR projection of diagnostic imaging during surgery: Rendering and projection of imaging using AR/VR, Uncompressed real time video stream using holographic techniques, AR/VR content caching

  Duplicating Video on Multiple Monitors at OT: Optimize OT layout to increase efficiency Telepresence / Holographic consultation and collaboration, Broadcasting video to multiple screens

  Robotic Aided and Tele Surgery: Improve accuracy to improve surgical outcomes, Haptic feedback & motion control data stream, Telepresence / Holographic consultation, and collaboration.

- **Use Case 4: Supply Chain, Asset Mgmt., Vision Controlled Access**
  Equipment Tracking & Utilization: Increase efficiency, reduce shrinkage: Track and trace of assets, plan scheduled maintenance and reduce downtime

  Patient and Personnel Tracking: Utilization of personnel, safety of patients, Wearables used for tracking, Safety of patients and hospital staff, Geo-fencing of vulnerable patients

  Compliance, Access & Navigation: Control Access, Verify Compliance & help navigation, PPE
  Compliance, Video based Secure Access, Mobile app based indoor navigation

  Drone based delivery of urgent supplies: Timely emergency medical supply to remote location, Receive notification & dispatch medical supplies.

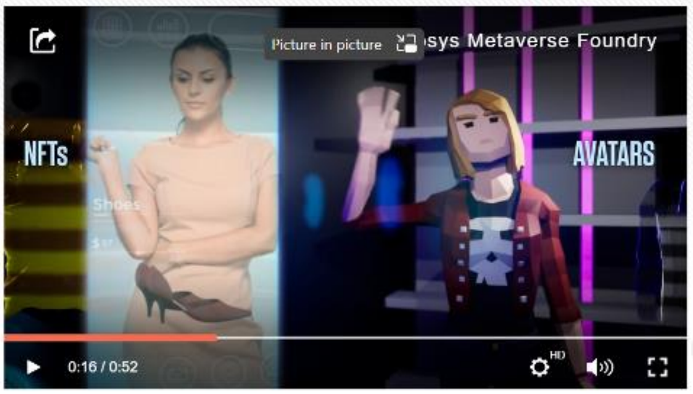
7.2. A detailed study of Remote Education Use case

Remote Education provides a new approach for engaging teachers and students in India's rural areas seamlessly providing live classroom sessions, interactive immersive experiences, digital content, exams, and assessments by leveraging the benefits of 5G and 6G technologies.

This digital collaboration can bring in varied capabilities,

- ***Omni-Channel Experiences***, focused on engaging with students where they are
- Capability to schedule ***real-time classroom sessions*** for subjects where volunteers and SMEs can conduct classroom sessions and live interactions
- ***Quality content available*** for students and teachers to access it on demand through their smart devices and tablets.
- Evaluation capability to ***conducting assessments*** on the subjects for students with remote monitoring of distributed students taking up national level exams
- Capability for the students to experience ***industry interactions and virtual visits*** to gain knowledge via immersive experiences. Holographic displays for real-time multi-dimensional interaction, that requires a very high throughput.
- Enhanced video experience using content ***Caching at Edge*** and levering ***5G network Slicing (eMBB) and future 6G technologies***
- ***Gamification techniques*** to monitor and track the progress of Students and Teachers.
- Partnership with various content providers to democratize the content creation and ***bring in the best of the content*** to the students and teachers.
- ***Video Analytics at Edge*** for better student engagement and ***real time attention dashboard.*** Also, for ***online assessments with real time video monitoring with 6G***
- Ability for students to ***learn and develop expertise*** in areas based on their interest, capability, and passion
- ***Interactive voice-based chat bots*** to assist students in their learning journey.
- ***Predictive analytics and insights*** to track student behaviour and performance to enable success of students
- ***AI/ML based language conversion in local languages*** for learning content and live course delivery
- Collaboration via '***Virtual Spaces'***


Remote Education: Interactive Expert Sessions
Powered by Infosys Education Platform
Rural classrooms attends interactive live expert sessions from urban classroom, remote
Infosys Education Platform helps in engaging teachers and students in India's rural areas leveraging 5G and Edge technologies
Live classroom sessions, deliver on demand digital content (Content Caching @ Edge)
Assessments across various channels including Edge analytics for 'Student Engagement'
Gamification for Q&A, tracking students' progress
AR / VR enabled teaching
Network API integration for on demand QoS upgrade, Charging party change, sponsored events..
1
Live urban classroom session to the rural school
2
Leveraging AI driven Chat Bot for Q&A Sessions
3
Student Engagement Analytics
4
Industry interactions, Industry visit using AR/VR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Education and other Metaverse Use Cases

- **Augmented, Virtual and Extended Reality**
  Usage of immersive experiences, with XR helps students to gain better experience specifically in medical field. Remote access to surgeons in theatre can be provided to students which expands the reach to medical consultants in teaching hospitals. Similar scenarios in bringing industry experiences and real, interactive experiences with manufacturing industries which brings in more practical experiences.

- **Edge and Video Analytics**
  Recent pandemic has pushed many educational institutions to adopt remote and online learning and assessments. It's important to get a real time view on students' engagements to bring in varied interventions like immersive experiences, industry views and interactions as part of the learning process. To analyse the student engagement levels, edge and video analytics are performed on these video streams. Similarly, if a large-scale assessment remotely is required, there is a need for video analytics to make sure assessment happens in a fair manner without any malpractices.

- **Transformation in Global Education**
  With 6G, networks evolve to support immersive, multi-dimensional interaction and collaboration that can remove distance as a barrier to interaction. Educational institutions can re-imagine the bring in more global university collaboration that helps our students and faculty to gain global education from varied universities, from digital content, living labs, to expert sessions.
  This further helps students to be more prepared with varied skills that industry needs and be ready to take up variety of jobs, research programs and many more.

- **Metaverse & Education**
  Metaverse bridges the physical world and the avatars in the virtual world built by human imagination, leveraging Extended Reality, AI, Spatial Computing, IoT, Wearable Technologies, Decentralized, and 5G / 6G and brings in next generation User Experience. This can re-imagine the learning experience with more collaboration, industry-academia interactions, global connects.
  The Metaverse requires real time experience between what a person does and what their avatar does without lag, hence very low latency. This requires, the network connections to be super-fast, super-reliable and available everywhere. Also support the huge processing power as we move from 2D to 3D, holographic displays.
  Complex topics e.g., Medical, Manufacturing can be addressed through' Holographic displays used for real-time multi-dimensional interaction, requires a very high throughput. This increases further with concurrent data streams, hence requires Tbps, and latency to be less than 1ms.
  Extend across varied other industry learning,
  - Digital Twin, with physical and digital world interactions across industry sectors
  - Immersive product design, reviews with 3D models, VR in manufacturing with distributed teams

- Collaborative Learning and remote working through' Virtual Spaces
- References
    - https://infyspringboard.onwingspan.com/
    - Infosys Metaverse Foundry
    - https://hexa-x.eu/wp-content/uploads/2021/02/Hexa-X_D1.1.pdf
    - 5G | Infosys

6G Taskforce Report:
6G Spectrum

Chairperson: Prof. Abhay Karandikar
Member Secretary: Shri. Bhagirath

Executive Summary

Society's increasing use of radio-based technologies, and the tremendous opportunities for social development that these technologies provide, highlight the importance of radio-frequency spectrum and national spectrum management processes. Technological progress has continually opened doors to a variety of new spectrum applications that have spurred greater interest in, and demand for, the limited spectrum resource. Increased demand requires that spectrum be used efficiently and that effective spectrum management processes be implemented.[1] (ITU Spectrum Management Handbook).

Objectives

- Identify various spectrum needs to enable 6G in the coming years
- Spectrum availability and allocation among various radio services with reasonable certainty to bridge adoption lag and maximize socioeconomic benefits
- Provide high speed broadband through various access technologies to address digital divide
- Signal 6G spectrum bands for industry to enable efficiently plan and build wireless infrastructure across sectors and introduce new wireless technologies in a systematic manner
- Make spectrum available for 6G technology innovations and facilitate ease of doing R&D
- Deploy spectrum efficient technologies by all stakeholders including Government, TSPs, Enterprise users
- Encourage spectrum sharing and optimal coexistence among various radio services; Provide soutline for national studies related to radio frequency spectrum
- Position India as the hub of 6G wireless technology R&D and Manufacturing; Attract investments in exploiting spectrum

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[1] ITU's Spectrum Management Handbook
According to the ITU's Spectrum Management Handbook, spectrum planning can be classified by time (short term, long term and strategic) and the areas covered (spectrum use and spectrum management systems). And 'long term planning' means planning that considers issues needing resolution or systems to be implemented within five to ten years, whereas 'short term planning' is to be implemented within three to five years. In comparison, strategic planning is involving the identification of a limited number of key issues, which require concentrated spectrum management attention for solutions that need more than ten years to be implemented. Therefore, long-term strategy is about a defining vision and mission to solve key issues which will be implemented over ten years related to spectrum management for spectrum utilization.
At present, most spectrum planning is relatively short-term. However, if spectrum resources are to adequately support national goals and objectives, long-term planning is essential. It can provide a basis for effective spectrum management to ensure that spectrum is efficiently allocated and assigned, to accommodate constantly evolving spectrum requirements by new systems and their applications. It also facilitates decision-making by providing a basis for the practical consideration and evaluation of alternative courses of action. Long-term planning should endeavor to:

- make today's decisions on spectrum planning strategies in view of their consequences for the future
- identify the impact of past decisions on the future
- periodically adjust decisions to changing circumstances

It should be sufficiently comprehensive to accommodate the national spectrum requirements of both known and anticipated radiocommunication systems within its stated timeframe.

- Facilitate enhanced use of wireless technologies in enhancing productivity and operational efficiency through industry 4.0 and enterprise digitalization
- Be flexible and dynamic to incorporate new kinds of radio services in the existing bands and inter se allocation of bands to prioritize relevant radio services.

Accordingly, the subject, ‘spectrum for 6G’ has been comprehensively analyzed from bands, services, current gap areas in the system and ecosystem perspective. As spectrum is a resource with interplay of different generations technologies, all spectrum bands require a review of its efficient use among Radio service users to enable sufficient spectrum for new era services.

Specific band-wise recommendations have been made taking note of global developments and Indian opportunity to use spectrum as a key resource to attract investments in R&D and maximize spectrum use in line with NDCP-2018 objectives. Building demand in new bands is an important aspect, which is also critically studied as part of the activity.

Structural mechanisms for coexistence studies, spectrum technology infrastructure, and capacity building is critical to creating a systematic approach in not studying the bands ongoingly but also making them available in a timely manner, so that adaption gap is minimized. Even these aspects are elaborated as part of the Taskforce report.

We are confident that the recommendations would be useful for DoT in its visionary effort to work on 6G program from the beginning. The expert team under the Taskforce would continue to engage in key deliberations on the subject as discussions progress in harmonizing various bands across the regions taking note of Indian objectives.

1. Introduction

National Broadband Mission: Spectrum for Rural and Urban Needs.

The Spectrum is a key natural resource to achieve India’s socio-economic goals and maximize its utility for common good.

A few crucial elements for Digital India include the following:

1. Real-time Governance
2. Precision Agriculture
3. Smart Villages
4. Smart Cities' & Smart Communities
5. Tele Medicine and Digital Health
6. Intelligent Transport Systems
7. Bullet Trains
8. AR/VR Based e-Education
9. Smart logistics and Export Hubs
10. Security & Surveillance
11. Industry 4.0
12. Drone based services
13. Smart / Assisted Driving
14. Real-time Public Protection and Disaster Relief

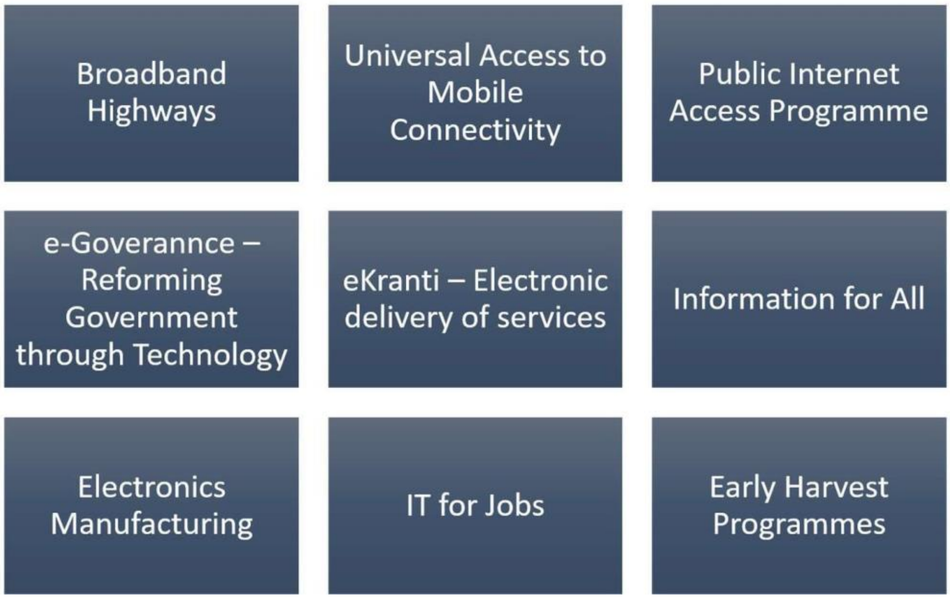

Figure 1: Digital India

Figure 2 shows the potential of new services by 2030 from 5G+ and 6G Technologies. These include convergence of multiple access technologies (e.g., terrestrial and satellite), complementary technologies of broadband and broadcast, universal coverage & high capacity for improved user experience, and improved usage to multiple industries.

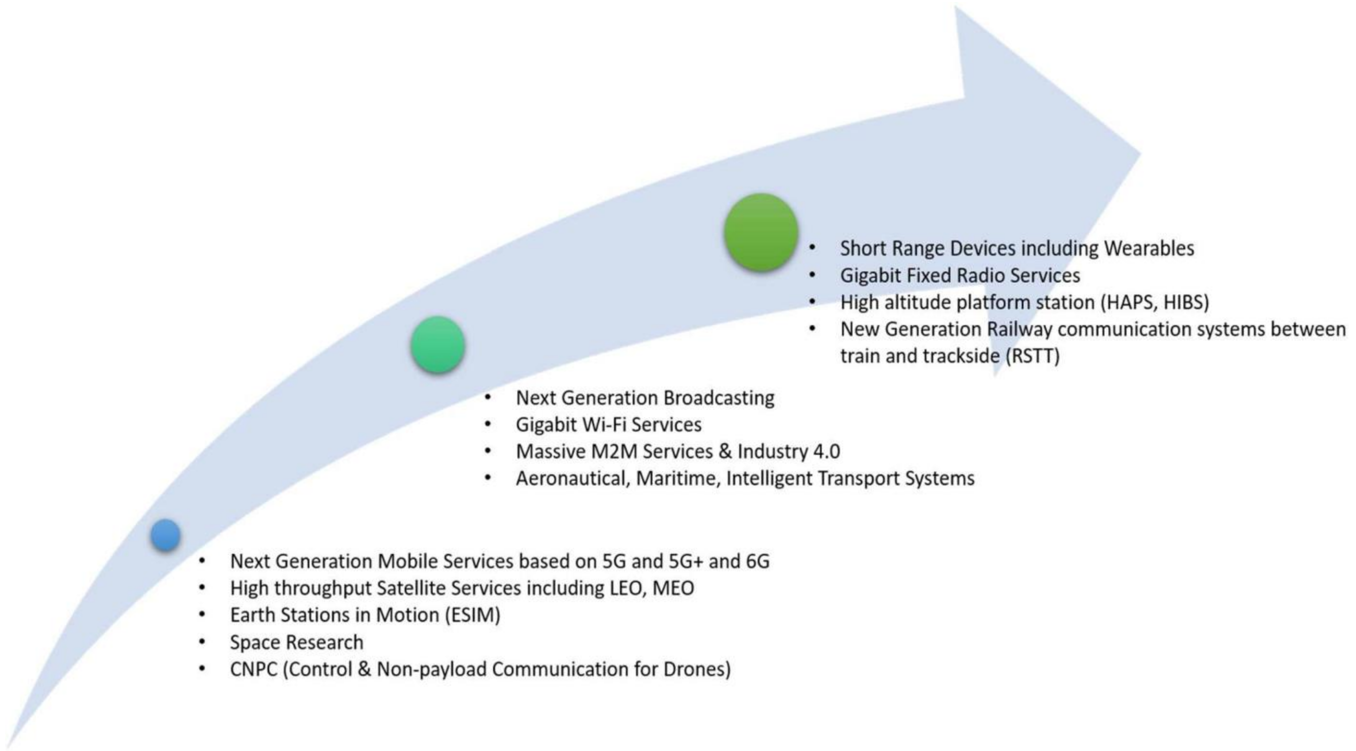

Figure 2: New Era of Services by 2030 from 5G+ and 6G Technologies

The below table summarizes an indicative list of Digital India 2030 Mobile and Broadband Policy Objectives.

Table 1: Digital India 2030 Mobile and Broadband Policy Objectives (indicative)

2022 Roadmap	2030 Roadmap (?)	Spectrum Requirements 2030 (5G+ and 6G) (?)	Spectrum Bands to be made available
• High speed broadband to citizens, Enterprises, public services. Connect all villages • 10 Gbps to every GP • 50% Households with Broadband • 10 Million public Wi-Fi Hotspots • 5 Billion IoT Devices; Enterprise Digitization (ITS, Urban management) • Personal and Home Connectivity (SRDs) • UAVs with limited action	• 100 Mbps to every citizen (large coverage of 5G and beginning of 6G) • 500 Gbps to every GP • 90% Households with High-speed Broadband • 50 Million public Wi-Fi Hotspots • 25 Billion IoT Devices Smart Enterprises & Factories (Smart Infrastructure Rural and Urban) • Connected and Intelligent Living • UAVs in Delivery Services, logistics, Disaster management	• Likely to double from the current planned spectrum quantities (covering lower, mid, millimeter and Tera Hz bands) • Diverse access technologies Mobile, GSO, NGSO, HAPS, HIBS etc. • High speed backhaul to complement Fibre connectivity • FWA - Fixed Wireless Access (would be a cost-effective option) using 5G and E, V Band links & other access technologies including fibre • New License Exempt Spectrum bands • New License Exempt Spectrum for M2M connectivity to power smart cities and communities • Extremely low power intelligent devices of all kinds everthing around • Defined IMT and unlicensed bands with ultra-reliability and control (application specific)	• <1 GHz Bands Mid Band: up to 10 GHz 6.425-24 GHz Bands Millimetre Bands: 26, 28, 40, 66, 70, 90 GHz etc. Tera Hz bands • Q, V, E, D, W Bands Free Space Optics 6.425-24 GHz Bands • Millimeter bands of 37, 50, 66 GHz V Band (57-66 GHz) 6.425-24 GHz Bands Free Space Optics • 6 GHz, V-Band, >95 GHz Tera Hz Bands • 915-935 MHz V Band >95 GHz bands THz bands • Hundered of bands to be identified continuously based on innovation • <1 GHz Bands Band: up to and above 10 GHz

1.1 Summary of Recommendations

1. Review the spectrum bands under key recommendations and announce respective actions to enable maximization of spectrum and use and socioeconomic benefits. There are a few bands that need be opened-up for generating demand for example 450-470 MHz, 526-612 MHz, 31-31.3 GHz etc.
2. There is a significant need to expand and position a larger mid-band (7-24 GHz) to meet requirements of 5G+ and 6G technologies. This requires initiating an inter-ministerial process of repurposing several bands like that has been done earlier.
3. Apart from the need of WRC-23, there is a need to have an institutional mechanism to enable coexistence studies in an ongoing manner. A participatory and transparent mechanism is proposed to be taken going forward considering its critical need to build consensus quickly on different bands and feasibility of coexistence of different radio services and users.
4. Enterprise use of 5G, 5G+, 6G services is going to be mainstream and the spectrum vision needs to be expanded in making spectrum available across the bands and for various use-cases.
5. Spectrum assignment models shall embrace a flexible paradigm to enable allocations in a platform/application agnostic manner enabling its maximum spectrum reuse if they can coexist.
6. Delicensed or license-exempt bands are key as a public good to enable innovation and gigabit public Wi-Fi by exploiting technology innovation for ex. Wi-Fi 6E or WiGig etc. In line with this, the lower part of 6 GHz band and at least 4.32 GHz in V band should be delicensed.
7. Tera Hz research should be encouraged considering the large swath of spectrum from 90 GHz to 3000 GHz. An industry and academia driven research testbed should be established to bring focus on 5G+ & 6G driven active antenna systems and Intelligent Reflector Surfaces (IRS) using mmWave and THz bands. A few countries such as USA, UK have made some of the THz bands license exempt for some periods both for commercial deployment and R&D.
8. Spectrum Sandboxes as envisaged in NDCP is a way forward to enable R&D and testing freely in outdoors.
9. There is an opportunity to take lead in new technology domains such as sensing, orthogonal sharing, broadband-broadcast convergence etc., where there is a significant research work in progress and some products are also being piloted.
10. Strengthen WPC with state-of-the-art spectrum management software to enable spectrum audit, interference management, dynamic database systems. Capacity building is another important area to enable necessary competencies in spectrum management.

2. Spectrum considerations

2.1 Immediate considerations in WRC-23 agenda items

WRC-23 AI 1.1 (Resolution 223 Rev.WRC-19) Additional frequency bands identified for International Mobile Telecommunications

- 4 800 – 4 990 MHz

WRC-23 AI 1.2 (Resolution 245 WRC-19) Identification of frequency bands for IMT in 3 300-3 400 MHz, 3 600-3 800 MHz, 6 425-7 025 MHz, 7 025-7 125 MHz and 10.0-10.5 GHz

- 600-3 800 MHz and 3 300-3 400 MHz (Region 2)
- 300-3 400 MHz (amend footnote in Region 1)
- 7 025-7 125 MHz (globally)
- 6 425-7 025 MHz (Region 1)
- 10.0-10.5 GHz (Region 2)

WRC-23 AI 1.3 (Resolution 246 WRC-19) Consideration of possible allocation to Mobile on a primary basis in Region 1

- 600-3 800 MHz (Region 1)

WRC-23 AI 1.4 (Resolution 247 WRC-19) mobile connectivity in certain frequency bands below

2.7 GHz using high-altitude platform stations as IMT base stations

Use of high-altitude platform stations as IMT base stations (HIBS) in the mobile service in certain frequency bands below 2.7 GHz already identified for IMT

- 694-960 MHz;
- 1 710-1 885 MHz (1 710-1 815 MHz to be used for uplink only in Region 3);
- 2 500-2 690 MHz (2 500-2 535 MHz to be used for uplink only in Region 3, except 2 655-2 690 MHz in Region 3);

WRC-23 AI 1.5 (Resolution 235 WRC-19) Review of spectrum use of the frequency band 470-960 MHz in Region 1

- 470-694 MHz

Key WRC-23 agenda items related to IMT/Mobile are listed below:

Bands	470-960 MHz	3300-3400 MHz	3600-3800 MHz	4800-4990 MHz	6425-7025 MHz	7025-7125 MHz	10-10.5 GHz	IMT FS
Region 1	AI 1.5 (IMT)	AI 1.2 (IMT)	AI 1.3 (MS)	AI 1.1 (IMT)	AI 1.2 (IMT)	AI 1.2 (IMT)		9.1 c
Region 2		AI 1.2 (IMT)	AI 1.2 (IMT)	AI 1.1 (IMT)		AI 1.2 (IMT)	AI 1.2 (IMT)	9.1 c
Region 3				AI 1.1 (IMT)		AI 1.2 (IMT)		9.1 c

Figure 3: WRC-23 IMT agenda items (Source GSMA)

2.2 Spectrum and Tbps communications

- THz range: 100 GHz ~ 10 THz
    - ITU-R: 300 GHz ~ 3 THz

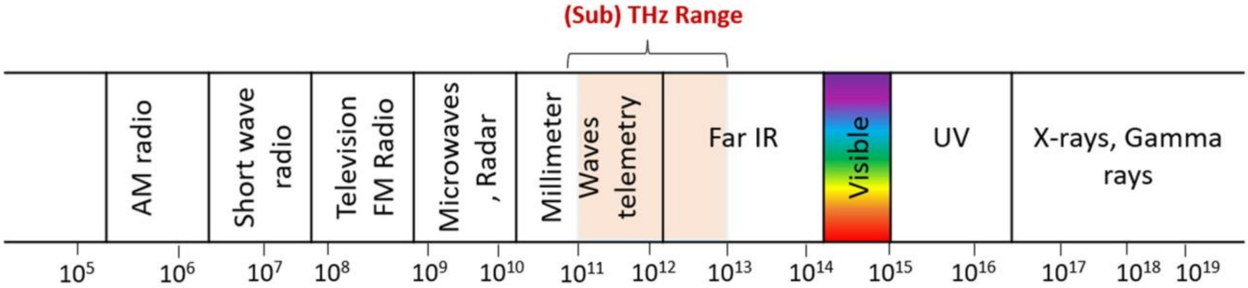

Figure 4: Source – Samsung Research

Consideration: Supporting "contiguous tens of GHz or more" bandwidth

- Necessity of studies on frequency range up to 3 THz

Figure 5: Source - Samsung Research

2.3 Other WRC-19 outcomes related to >100 GHz

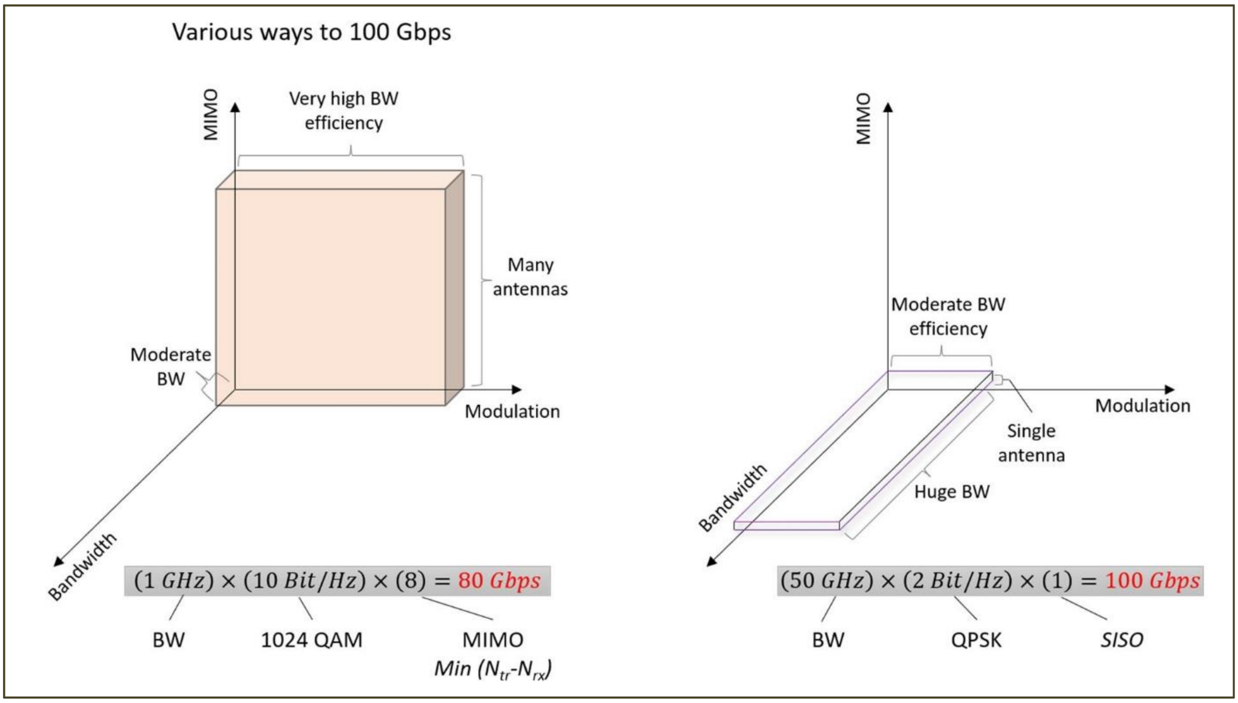

Figure 6: Source MTT-S, 6G Flagship

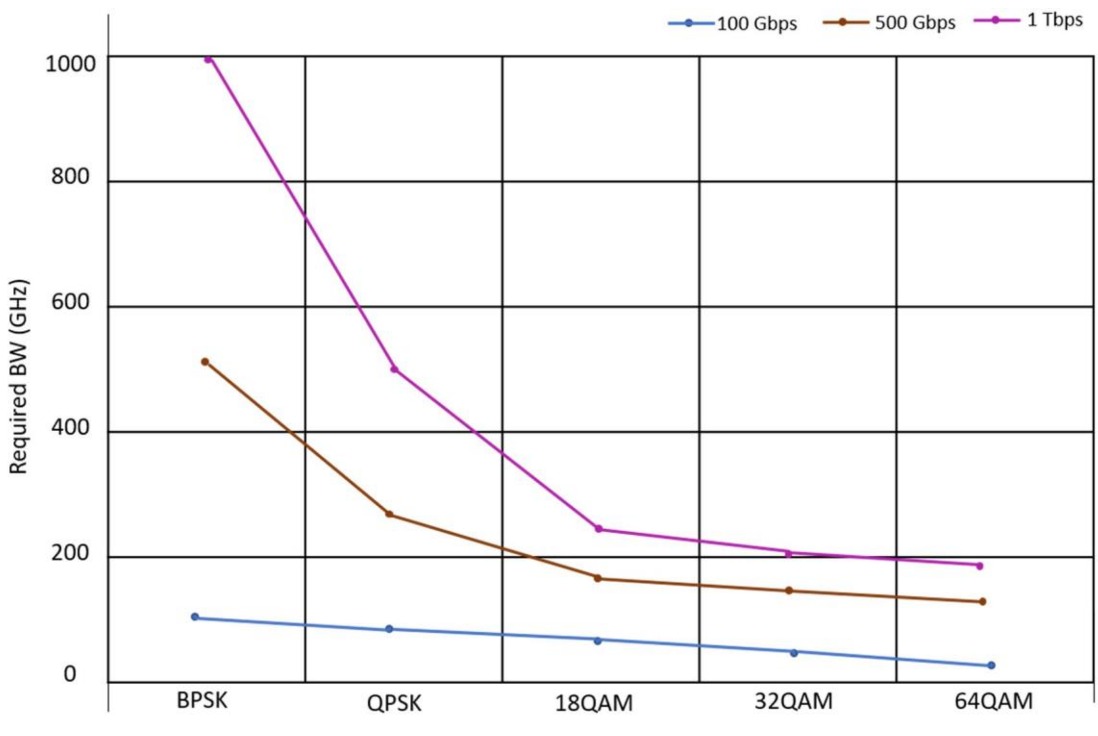

Figure 7: Source MTT-S, 6G Flagship

2.4 Spectrum above 30 GHz and 7.125-24 GHz

2.4.1 Spectrum above 30 GHz allocated to MOBILE services as per RR

WRC-19 Agenda Item 1.15 (APT and CEPT proposed this agenda item as candidate WRC-19 agenda item at WRC-15)

- To consider identification of frequency bands for use by administrators for the land- mobile service (LMS) and fixed services (FS) applications operating in the frequency range 275-450 GHz, in accordance with Resolution 767 (WRC-15);
- Study scope (Res. 767, WRC-15): Technical and operational characteristics in the LMS and FS operating at frequencies above 275 GHz, Spectrum needs, Propagation model within 275-450 GHz, Sharing & compatibility studies considering protection of the passive services and Candidate bands

Outcome of WRC-19 Agenda Item 1.15

- Identification for LMS and FS in bands between 275 and 450 GHz
  - No specific condition to protect EESS passive applications: 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz
  - Specific conditions to protect EESS passive applications: 296-306 GHz, 313-318 GHz and 333-356 GHz
  - Specific conditions (e.g., minimum separation distance and/or avoidance angels) to protect RAS in portions of range 275-450 GHz

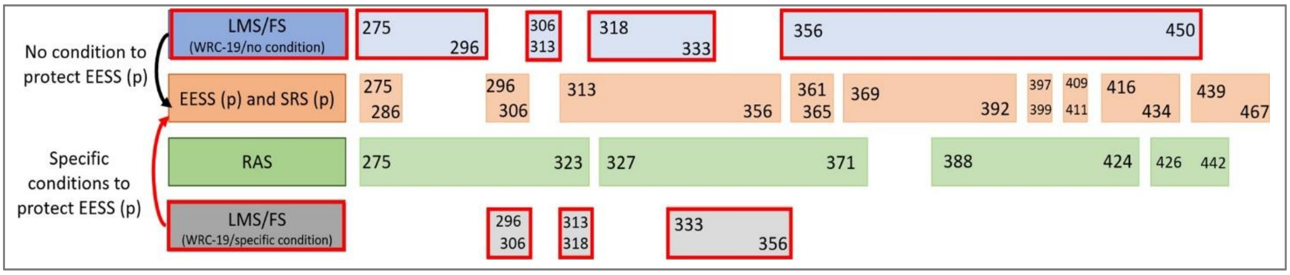

Figure 8

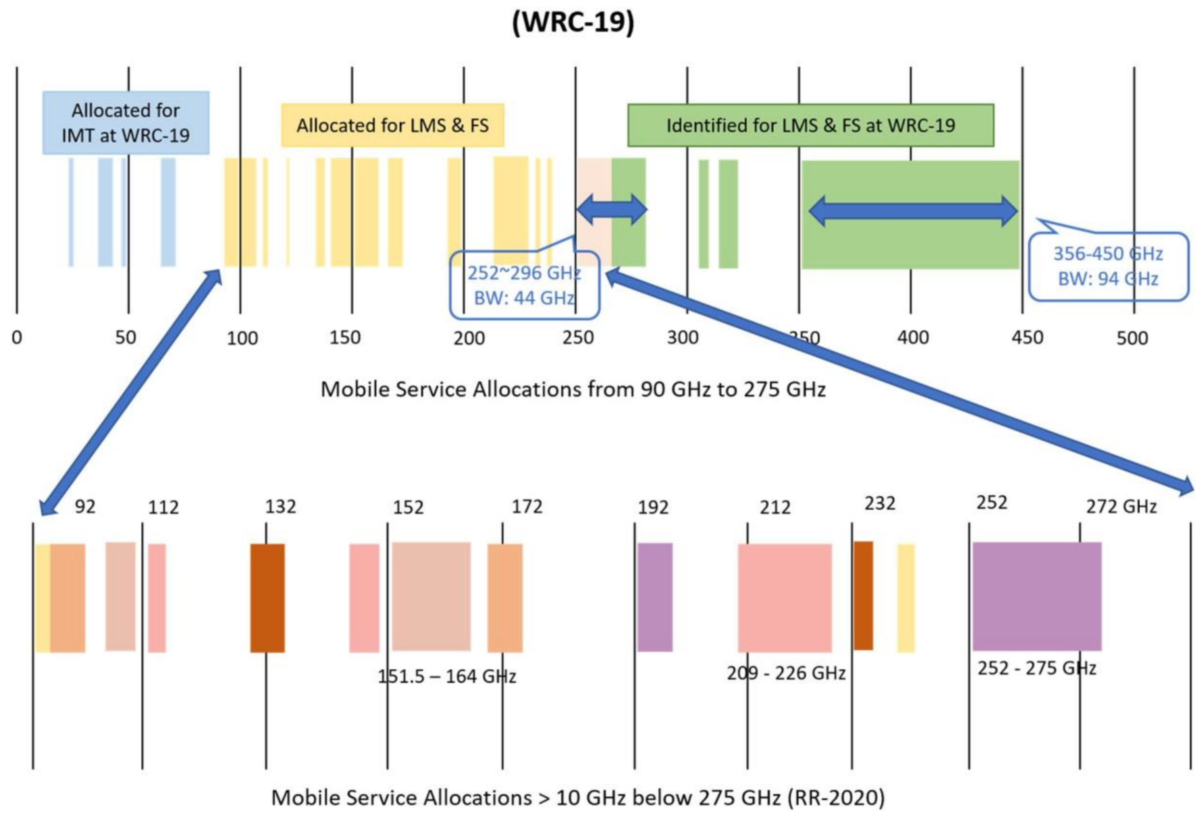

Figure 9: Spectrum above 30 GHz allocated to MOBILE services as per Radio Regulations (source: IAFI)

2.4.2 Spectrum between 7.125 GHz and 24 GHz allocated to MOBILE services on Primary basis as per RR

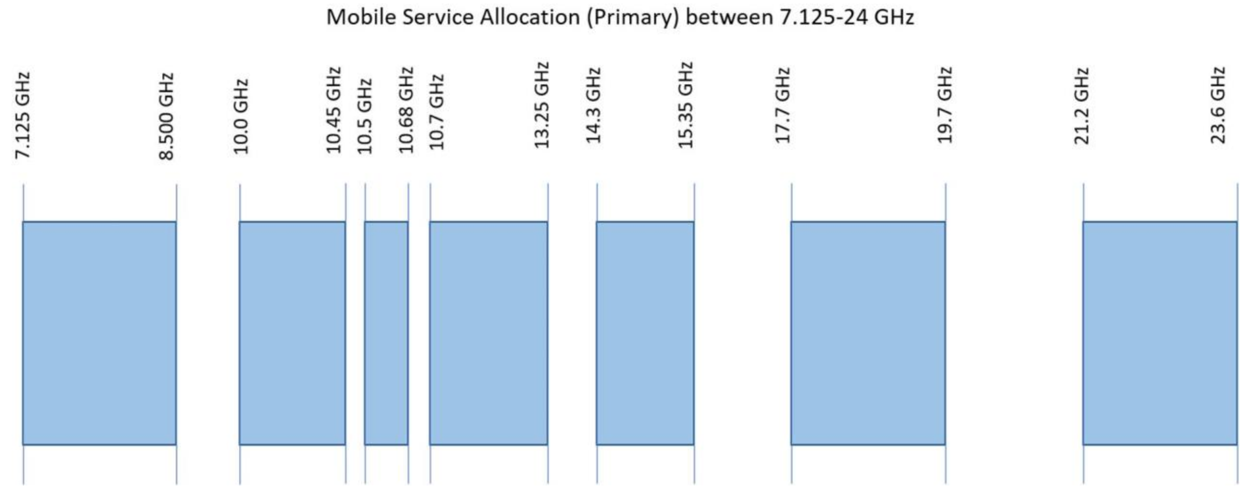

Figure 10: Spectrum between 7.125 GHz and 24 GHz allocated to MOBILE services on Primary basis as per Radio Regulations

2.5 Leveraging Indigenous 5G Testbed Experience for 6G

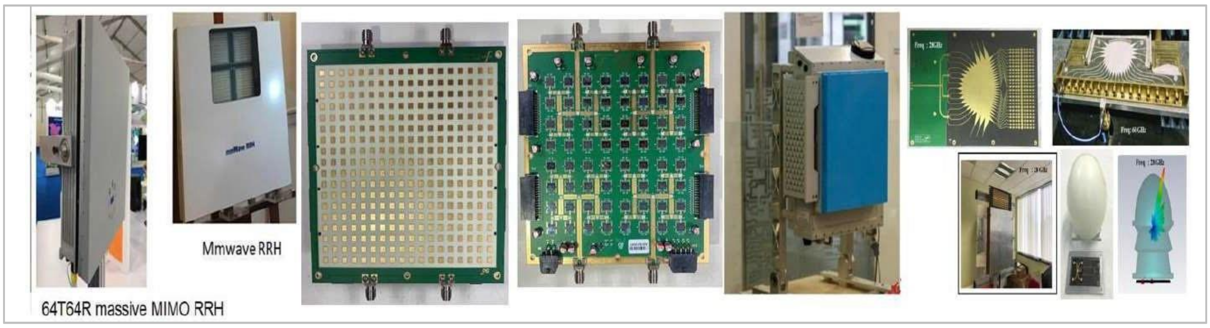

Figure 11: 5G Antenna Development and Massive MIMO (Source SAMEER, CEWiT)

India has successfully executed a multi-institute collaborative program "Indigenous 5G end to end test-bed" meeting 5G standards. This may be continued for fostering continued 6G researching

- The expertise and the knowledge gained during 5G project may be leveraged to develop 6G systems.
- To explore the potential impact that THz could have on next generation 6G technology, design, development, and demonstration of an end-to-end THz links may be considered.
- The demonstration can be a major milestone in exploring the feasibility of using the THz spectrum for 6G wireless communications.

2.6 ITU-R and World Radio Conference 2023

- ITU-R WP5D has started working on a report on Technical Feasibility of IMT in Bands Above 100 GHz which includes propagation models, enabling technologies, deployment scenarios, and use cases.
- ITU-R WP5D is also developing the Future Technology Trends report (started work from the 36th meeting of WP5D and the report will get finalized in the 41st meeting of WP5D)
- ITU-R WP5D is developing 6G Vision Recommendation (2021 – June 2023) which will also provide an overall timeline for 6G (Standardization, Spectrum, and Deployment).

3. Existing National Regulations

The Indian Telegraphy Act 1885 and Indian Wireless Telegraphy Act, 1933, enables the Central Government to manage the radio waves, issue wireless apparatus license under the law and prohibit certain apparatus to operate.

NDCP: Department of Telecommunications has prescribed National Digital Communication Policy in 2018 which is a roadmap for next 5 years. Policy Objective on Spectrum Management as per National Digital Communication Policy (NDCP) 2018 mainly is *Recognizing Spectrum as a key natural resource for public benefit to achieve India's socioeconomic goals, ensure transparency in allocation and optimize availability and utilization*. The NDCP needs to be revised keeping in view the progress made and with new global developments.

NFAP: From time-to-time National Frequency Allocation Plan (NFAP) is reviewed and updated to accommodate the spectrum requirements for latest technological developments keeping the global harmonization in mind. Latest NFAP is effective from 25.10.2018. The NFAP is already under revision taking note of WRC-2019 outcomes.

4. Recommendations

4.1 New bands are critical for India

Unlike several other countries, who have an extended mid-band from 3.400-4.200 GHz and 4.400-5.000 GHz, India has a very limited mid-band i.e., 3.300-3.670 GHz. Apart from 5G, 5G+ even 6G and futuristic mobile technologies need mid-band as they will have several applications which may need different spectrum bands. Despite the announcement of WRC-19 that a spectrum of 17.25 GHz is made available for IMT, it is to be noted that all these bands are in millimetre zone, and they have high space losses and regulations to protect adjacent bands (24.25-27.5 & 37- 40.5 GHz band) (additional restrictions offing from 2027). Further, the band, 45.500-47.000 GHz is not applicable to India.

A few mid-band segments have been identified as below for further timebound studies to enable efficient use of spectrum through enhanced coexistence options. The objective is to ensure sufficient spectrum is made available for 6G while efficiently taking care of spectrum provisioning for other services.

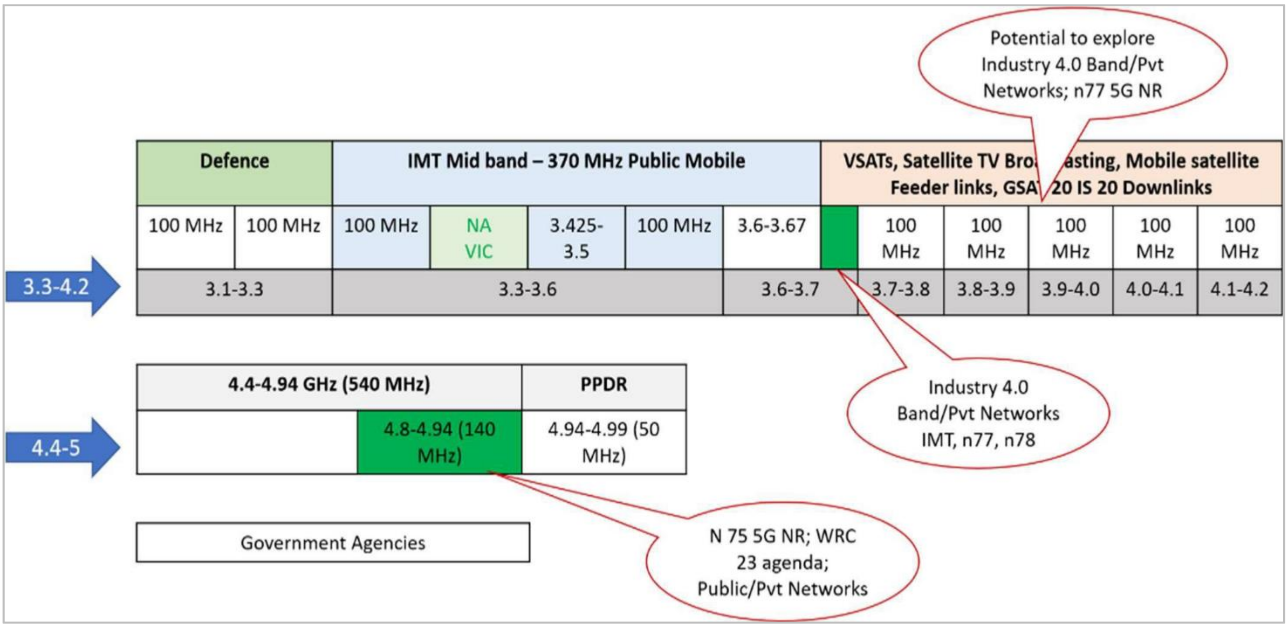

Figure 12: Need to expand mid-band for 5G+, 6G services

While the newly created IMT bands in millimetre wave, would be a valuable resource, significant benefits economic impact can be derived from mid- band and sub 1 GHz bands. This is more so considering the developed device ecosystem and capex involved in providing a wider coverage. Most of the initial global deployments in 5G are in mid-band considering its reasonably large coverage and capacity characteristics. Whereas the millimetre band is envisaged to cover hotpots and Fixed Wireless Access (FWA) kind of applications. A few bands are identified as below for coordination, repurposing and further study to prepare for the 6G era in the mid band.

4.1.1 Specific Actions – Low and Mid-band

Table 2

Sl. No	Status	IMT Bands	Quantity (MHz)	Potential for 5G, 5G+. 6G and BWA	Remarks
1	Announce	450-470 MHz[2]	As per ITU-R M.1036 (Section 2)	Sub 1 GHz band for IMT	This is an existing IMT band (IND 16 of NFAP). May take five or more years to mature. **Option 1**: Offer the band at Zero cost for all TSPs for 5 years to build and offer the applications commercially *only* for mMTC, uRLLC. **Option 2**: Offer the band for Railways to use in IMT to trigger indigenous product development. Band 31 (3GPP) **Option 3:** Offer the band for Rural connectivity using indigenous products
2	Announce	582-612 MHz	30	M2M/IoT / Rural links	Low power IMT Pvt Networks based on indigenous technologies and Rural Connectivity links
3	Announce in consultation with MIB	526-582 MHz	56	Next Generation Broadband & Broadcasting /	Low power IMT Networks in convergence use in coordination with MIB services; (Analog TV

[2] NDCP envisages maximization of socio-economic benefits using spectrum as a resource. The band 450-470 MHz is one of the IMT and 3GPP bands. It may be recalled that the commercial band

700 MHz segment is idle for over six years. Apart from 700 MHz band, a new 600 MHz band is also carved out from broadcasting and government use bands. Further, the 2G bands may become 4G bands in subscribers migrate and subject to business decisions. Hence, considering the opportunity cost, we may consider offering the spectrum band 450- 470 MHz to either Railways or TSPs free for initial 5 years to build demand in the virgin band. As the applications proposed are IMT services including uRLLC, mMTC, the proposal will enable digitalization of strong industry 4.0 applications using 5G enhancing productivity for Indian products in global market.
2 ibid. Considering the opportunity cost, we may consider offering the spectrum 526-612 MHz band free for initial 5 years to build demand in the virgin band between 500- 600 MHz as 700 MHz band itself is yet to be exploited.

				mMTC, uRLLC of 5G Sub 1 GHz band for IMT	Transmitters announced to be shut down) Offer the band at Zero cost for all TSPs for 5 years to build and offer the applications commercially for mMTC, uRLLC and other convergence applications.
4	Announce	612-703 MHz APT 600 MHz band plan	40 (FDD)	mMTC, uRLLC of 5G Sub 1 GHz band for IMT	This is a green field band. Also recommended by TRAI for commercialization in the current recommendations. Subject to the outcome of the auction process, take measures to generate demand.
5	Announce	1.427-1.518 GHz	91	Mid-band for IMT	WRC 15; ITU R M.1036-5 (under revision); Part with government agencies; Broadcast Studio links require Relocation: dependency is on Resolution 223 (WRC-19)
6	Study with DoS	2.500-2.535 2.655-2.690 GHz	70	Band n41 TDD is an option	Current MSS services are affected due to interference from foreign IMT stations. ISRO planning to migrate MSS to another band. Only India is said to be using the band for MSS, so interference may continue to affect.
7	Study with DoS	2.555-2.635 GHz	80	Band n41 TDD is an option	Subject to precious orbital allocations vis a vis efficient use of the S band

8	Study with Government Agencies for relocation or coexistence	4.400-4.800 GHz	400 MHz	Potential band for 5G, 6G services	3GPP band with device ecosystem (with other government agencies 4.400-4.940 MHz).
9	Study with Government Agencies for relocation or coexistence	4.800-4.940 GHz	140	Potential band for IMT or IMT based Private networks	IMT band (4.800-4.990). Part under other government agencies 4.400-4.940 MHz).
10	(May be decided along with the above band)	4.940-5.000	60	Potential band for IMT or IMT based Private networks	3GPP 5G Band; To maximize the value, a view may be taken in tandem with the outcome of the coordination on the band 4.8-4.94 GHz above.
11	Study with DoS	6.425-7.025 GHz	600	Mid-band for IMT	WRC-23; Res 245[3] WRC-19 (Region 1 studies); We may await study results
12	Study	7.025-7.125 GHz	100	Mid-band for IMT	WRC 23; Res 245 WRC-19 (Global studies); We may await study results
13	Study with MoD for coexistence	10.000-10.500 GHz	500	Mid-band for IMT	WRC 23: Res 245 WRC-19 (Region 2 studies); We may await study results
14	Study with DoS	5.925-6.425 GHz	500	Mid-band for BWA or Lowe power Wi-Fi services	Consider for delicensing to enable Wi-Fi 6 in line with global Developments

[3] Res 811 WRC 19: 1.2 to consider identification of the frequency bands 3 300-3 400 MHz, 3 600-3 800 MHz, 6 425-7 025 MHz, 7 025-7 125 MHz and 10.0-10.5 GHz for International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution 245 (WRC-19).

4.1.2 Specific Actions Millimetre bands:

Table 3

Sl. No	Status	IMT Bands	Quantity (MHz)	Potential for 5G, 5G+. 6G and BWA	Remarks
1	Announce	31.000 – 31.300 GHz	300	Indigenous technologies	Green field Mobile Band; Low power Mobile Pvt Networks based on indigenous technologies
2	Band segmentation	37.000-39.500 GHz			WRC-19 IMT Band- We may announce it for FSS and other services, subject to efficient deployment of satellite systems. Otherwise, it may be reviewed for IMT requirement after 5 years.
3	Band segmentation	39.500-40.500 GHz		Potential band for low power IMT based Private networks	WRC-19 IMT Band-Reserved for MSS (39.500-40.500) and Low power Pvt Networks subject to feasibility.
4	Announce	40.500-43.500 GHz	3000 (TDD)	Millimetre-band for IMT	WRC-19 IMT Band; Open the band for Commercial use @ ZERO Cost for 5 years to generate demand to all TSPs
5	Push for Indian need in foot notes	45.500-47.000 GHz			WRC-19 IMT Band; Proposed for MSS and NGSO

6	Study	47.200-48.200 GHz			WRC-19 IMT Band; Proposed for MSS and NGSO
7	Announce	66.000-71.000 GHz	5000	Millimetre-band for IMT	WRC-19 IMT Band This is a green field band. May take five or more years to mature. Offer the band ZERO cost for all TSPs for 5 years to build and offer the applications in uRLLC, MMTC and FWA commercially

4.2 Private Networks/Non-Public Networks/Industry 4.0 in 5G, 5G+, 6G Era

Non-public networks are intended for the sole use of a private entity such as an enterprise as per 3GPP TS 22.261. First step towards the Industry 4.0 (IR 4.0) is the digitalization of asset- intensive industries to have connected ecosystem to improve business efficiency and automated processes. To realize the full vision of Industry 4.0, the next generation of industrial wireless, based on 3GPP mobile technologies such as 4.9G/LTE and 5G, are essential. And to develop device ecosystem, identification of frequencies is necessary as Radio frequencies are significant importance to a country's economy and society because they allow all wireless communications devices, including mobile phones and wireless broadband, to operate.

To enable new usage of the spectrum and to support innovation in order to meet the local wireless connectivity demands of Industry 4.0, timely identification and allocation of spectrum is necessary.

Advantages:

- This will support growth and innovation across a range of sectors such as manufacturing, enterprise, logistics, agriculture, mining, and health.
- It could enable organizations to set up their own local networks with greater control over security, resilience, and reliability than they may have currently.

Global trend and spectrum consideration are placed at Annexure. As can be seen from the annexure, most countries have made spectrum available in mid-band & in millimetre bands. To reap the benefits of the already available device ecosystem in these bands, similar bands may be provided for the purpose of deployment of private networks in India also. Further, a few new bands in IMT and other mobile bands, as part of coexistence with other services could be considered for study on developing indigenous technologies for Private networks as well.

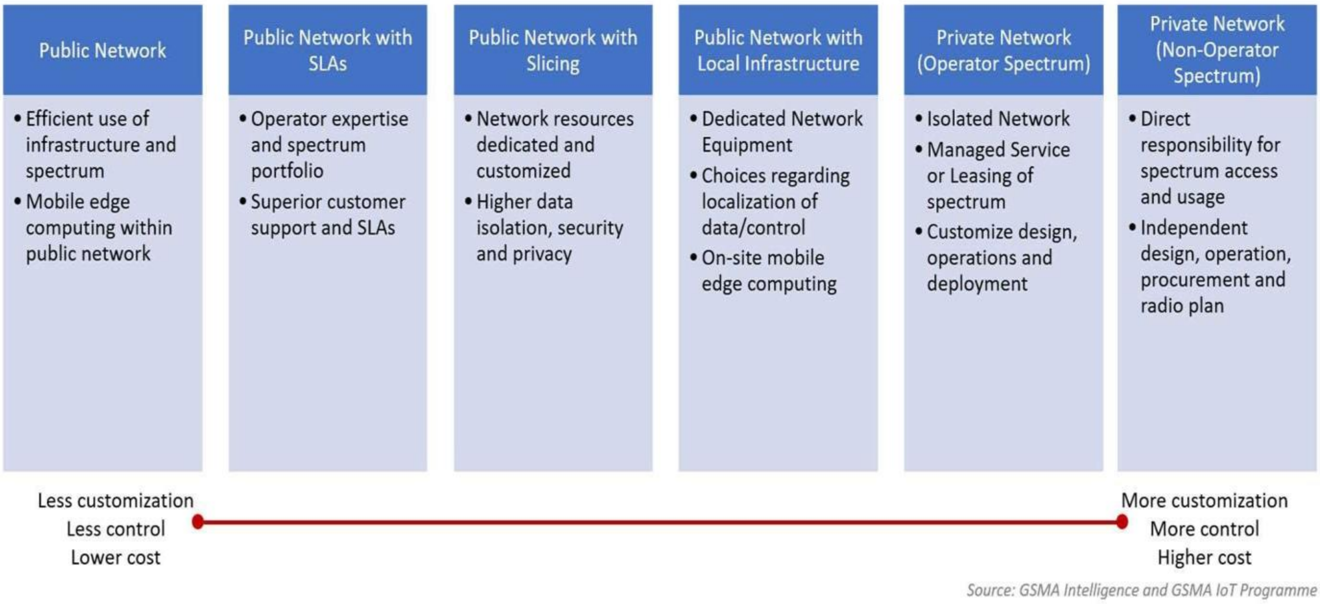

Figure 14

Globally in this direction, many countries have already assigned spectrum bands for the innovation and proliferation of the private 5G services as shown in below table:

Table 4

S. No.	Country	Mid band (1-6 GHz)		mm Wave bands	
		Non-Public Network	Quantity (in MHz)	Non-Public Network	Quantity
1	UK	3800-4200 MHz 2390-2400 MHz 1781.7-1785 MHz/1876.7-1880 MHz	400 MHz 10 MHz 3.3 MHz	24.25-26.5 GHz (shared, Indoor use)	2250 MHz
2	USA	CBRS band-3.5 GHz (3550-3700 MHz) EBS band-2.5 Ghz (educational purposes)	150 MHz		
3	Germany	3700-3800 MHz (for regional and local 5G networks)	100 MHz	24.25-27.5 GHz (Technology and Service-neutral basis)	3250 MHz
4	Japan	Planned for Future: 4.6-4.9 GHz	300 MHz	28.2-28.3 GHz* (for indoor & Campus- for Broadband fixed wireless services) Planned for Future: 28.2-29.1 GHz	100 MHz 900 MHz
5	Sweden	3720-3800 MHz (Local and regional licenses)	80 MHz	24.25–25.1 GHz (Local 5G)	850 MHz
6	Netherlands	3450-3500 MHz/3750-3800 MHz (Year 2026)	50 MHz	26 GHz (for local and shared use)	
7	France	2570-2620 MHz	50 MHz		
8	Russia			24.25-24.65 GHz	400 MHz
9	Norway	2300-2400 MHz 3600 MHz	100 MHz	23 GHz band 26 GHz band	
10	New Zealand	2575-2620 MHz	45 MHz		
11	Malaysia			24.9-26.5 GHz (beauty contest, national basis) 26.5-28.1 GHz (first come-first serve)	1600 MHz 1600 MHz

4.2.1 Specific Actions: Private Networks

Table 5

Sl. No.	Status	Potential IMT Bands	Quantity (MHz)	Remarks
1	Announce	3.670-3.700 GHz	30	Low power IMT Pvt Networks
	Study	3.700-3.800 GHz	100	TRAI recommendation
2	Announce	24.25-24.750 GHz	500	24.25-24.65 GHz - Currently reserved for BSNL; More suitable for low power campus networks considering its proximity for EESS Passive service spectrum. It is required to protect 23.8 GHz from out of band emissions from these segments.
3	Announce	582-614 MHz	32	Low power IMT Pvt Networks based on indigenous technologies
4	Announce in consultation with MIB	526-582 MHz	56	Low power IMT Pvt Networks in coordinated use with MIB services on non-interference and non-protection from TV transmission
5	Study with MoD	4.800-4.940 GHz	140	Option 1: IMT Option 2: Low power IMT Pvt Networks
6	Announce	4.940-5.000 GHz	60	
7	Study with DoS	3.700-4.200 GHz	As available	Segments to be identified
8	Study with DoS	28.500-29.500 GHz		TRAI recommendation
9	Study with DoS	39.500-40.500 GHz	1000	DoS MSS service would be predominant user. Co-sharing with Low power IMT Pvt Networks
10	Study	31.000 – 31.300 GHz	300	Low power Mobile Pvt Networks based on indigenous technologies

4.3 Unlicensed/License Exempt Operations

The BIS study report[4] on spectrum needs for smart infrastructure stresses the need for delicensed /unlicensed spectrum to service various infrastructure needs.

The report mentions that the world is undergoing an unprecedented pace of urbanization, and so is India. This **rapid scale of urbanization** will need smarter, sustainable cities based on smart infrastructure that are able to **manage city utilities and services effectively and efficiently** for its citizens.

With the Government of India initiative of developing 100 smart cities as light house projects being already underway, the technology adoption and smart infrastructure deployment in Indian cities has accelerated like never before. Internet of Things (IoT) and Machine to Machine (M2M) communications have become buzz words in the technology domains. The Ministry of Urban & Housing Affairs (MoUHA) in its initial concept note on Smart Cities have identified Social Infrastructure, Physical Infrastructure, Institutional Infrastructure and Economic Infrastructure as the four pillars of a smart city.

Beyond leveraging ICT in the digitization of Institutional, Economic, Social & Governance Infrastructures of a city, a glimpse into the physical infrastructure brings out a few staggering numbers on the business aspect of this ICT Infrastructure paradigm and its intervention in a smart city. Consider the scenario in India, as an example:

- In next five years, more than 350 million Smart Electricity Meters are going to be procured & deployed under the NSGM (National Smart Grid Mission). All these 350 million Smart Meters are going to use Communication Modules and Gateways/DCUs (Data Concentrator Units). At a conservative figure of One DCU/Gateway to 500 Smart Meters, 250 million Communication Modules & 0.5 million DCUs/Gateways shall be needed for the last mile communication in the Smart Metering (AMI) Deployments alone
- Smart Streetlights in next five years, are going to use more than 150 million Communication Modules and at least half a million of DCUs/Gateways.
- Smart Buildings are going to deploy more than 50 million smart Sensors and at least 500K- 800K DCUs/gateways.
- Similarly, various applications of the Smart Infrastructure paradigm like Smart Water, Smart Gas, Smart Traffic, Smart Environment, Smart Waste Management, Smart Sewage Disposal etc. are going to use a few billions of Smart Sensors with Communication Modules and DCUs/Gateways correspondingly with at the least worst-case ratio of 1:100 to 1:500.

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[4] https://www.services.bis.gov.in:8071/php/BIS_2.0/eBIS/wp-content/uploads/2020/11/Spectrum-Requirement-for-Smart-Infrastructure- 20200924-FINAL-1.pdf

- Even if the unified Communication Infrastructure is deployed, the number of sensor Communication modules is not going to reduce; only the DCUs/Gateways needed shall reduce but shall need enhanced features and design complexities.

To summarize, it is reported that India is going to need a minimum of 8-10 billion Communication Modules to be integrated into the Smart Sensors and Controllers and 10-50 Million Gateways that shall be needed to operate and maintain the Nation-wide Critical Infrastructure that needs to be deployed to enable and empower the citizens to lead a sustainable, safe, and secure life.

Further, there is a strong appetite for mobile accessories considering India's billion mobile ecosystem. Device accessories including headphones, wireless charges, smart devices connecting to mobiles, smart devices connecting household devices and appliances are envisaged to transform the quality of experience for the consumer.

As many devices are expected to be connected in near future, present allocation of frequency band of 3 MHz (865-868 MHz) in the Sub Giga Hertz Frequency Bands may not be sufficient for the entire M2M/IoT/Smart Cities ecosystems requirements to offer seamless services.

Unlicensed spectrum is going be key in serving the following smart infrastructure needs for the public in a big way in next ten years.

- Energy
- Water
- Waste Management
- Intelligent Transport System – Smart Parking, Traffic Congestion Management…
- Manufacturing, SCADA & Industrial Automation
- Health – Active Assisted Living
- Agriculture o Environment
- Smart Homes & Buildings
- Personal devices and accessories
- Household appliances

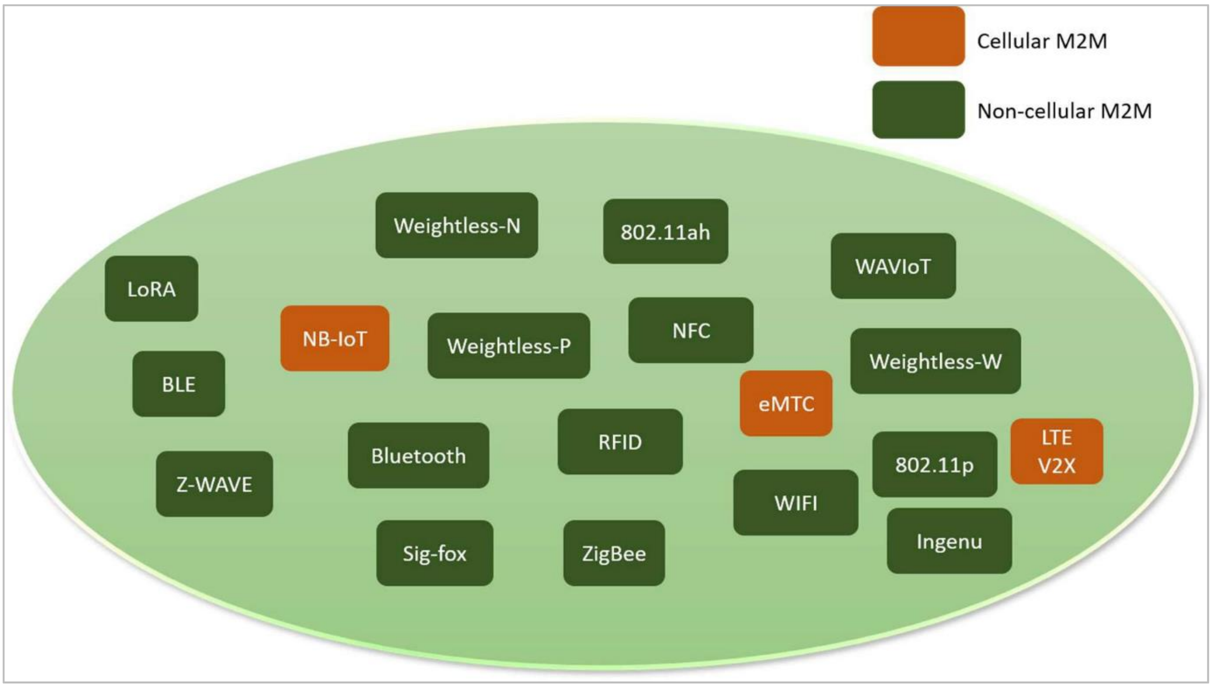


Figure 15: Source ITU

The BIS report recommends 18 MHz of contiguous unlicensed spectrum to meet the target of 5 billion IoT devices as per NDCP 2018 either in 850 MHz band (851-869 MHz) or in 900 MHz band. Considering that, the report is for the next ten years, the separation band i.e., 915-935 MHz should be considered for operating low-power SRDs considering the globally developed device ecosystem.

About spectrum for short-range devices (SRD), the device ecosystem is present in several small bands across the radio spectrum. These devices range from audio assist devices, hearing aids, traffic and telematics devices, active medical implant devices including pacemakers, wearable devices, wireless chargers, and inductive devices, among others. A whole list of the product range is requested from the industry from time to time. Though several bands are delicensed, there is a need to continuously scan the landscape and take necessary action to make available world-class equipment and devices to the Indian public in a timely manner.

Hence, a standing committee under Member (Technology) is envisaged to be constituted with members from DoT, WPC, Academia, and Industry to periodically review on a quarterly basis and make recommendations to DoT for delicensing these very low power devices ranging from nanowatts to milliwatts

To begin with, as done earlier, the recommendations/ decisions of the European Commission, FCC, and ETSI could be taken into consideration who primarily contribute to the development of the device ecosystem.

4.3.1 Specific Actions: Unlicensed / License-Exempt operations

Table 6

Sl. No.	Status	Band	Quantity (MHz)	Proposal	Remarks
1	Announce	915-935 MHz	20	Delicense for low power IoT / M2M Operations	The band is part of government agency' spectrum. However, the proposed use of IoTs is at very low power levels, no interference is envisaged. Similar to the case of 24.0-24.25 GHz (NFAP-18 footnote IND 34)
2	Announce	5.875-5.925	50	Delicense for use of C-V2X systems (Cellular Vehicle to Everything) for intelligent transport in smart city / highway safety and other applications	Current allocation for Dedicated Short Range Communication (DSRC) for Intelligent Transport Systems (IND 30). DSRC has not taken off and the band is lying idle. Replace DSRC with C-V2X.
3	Announce	57.000-61.560 GHz (2*2.16 GHz)	4560	Delicense for indoor and outdoor low power operations (Opportunity to connect Households and Enterprises	Wi-Fi services based on 802.11.ad, ay would enable Gigabit Wi-Fi services. The band is suitable for delicensing due to peaking oxygen absorption in this range even within V Band.
4	Announce	5.925-6.425 GHz	500	Potential for gigabit Wi-Fi services	Delicense for Wi-Fi 6E

4.4 Spectrum for Innovation and Experimentation – THz Research

Spectrum for innovation and experimentation is attracting investments globally considering the available facilitation from a country. Indian start-ups and SMEs are gearing up well in wireless technologies and this provides an opportunity to open unused and new bands to enable innovation blossom in line with global trends. Some segments would be permitted with unlicensed operations and the rest under special innovation program.

New bands for Experimentation and delicensing

Open spectrum bands > 95 GHz bands to trigger innovation and Experimentation to take lead in the development of innovative Wireless products under Make in India in new bands.

- Offer experimental licenses (like that of FCC)[5] for the 95 GHz to 3 THz range to promote innovation and new product development.
- Maximum 10 years experimental license
- These licenses would offer increased flexibility compared to conventional experimental licenses by providing for longer license terms, license transferability, and the ability to sell equipment during the experimental term.
- Permitted to market experimental devices designated to operate in the bands above 95 GHz via direct sale. (i.e., To allow direct sales to members of the general public)
- Delicense 4 segments of bands for unlicensed operations to enable new product innovation and development.

4.4.1 Specific Actions: Spectrum for innovation and experimentation

Table 7

Sl. No.	Status	Band	Quantity (MHz)	Proposal
1	Announce	95 GHz – 3 THz	As per experimental needs	Offer experimental licenses with enabling conditions for commercial sale and operations
2	Announce	116.000-123.000 GHz	7000	Unlicensed operations in Indoor and outdoor for TEN years
3	Announce	174.800-182.000 GHz	7200	As above

[5] FCC Order Spectrum Horizons: First Report and Order – ET Docket 18-21

4	Announce	185.000-190.000 GHz	5000	As above
5	Announce	244.000-246.000 GHz	2000	As above

4.5 Measure to promote Experimentation in Satellite-based products and services

Suitable Experimental License rules should be developed for satellite-based experiments and trials and granted Experimental License in a time-bound manner at affordable costs. A detailed policy should be worked out in consultation with all stakeholders, especially the department of space on how to facilitate experimental use of the spectrum.

4.6 Experimental Test Zones

Wireless product development involves rigorous testing of product functions under real radiating conditions subjecting to seasonal variations, varying characteristics of radiating resources, and mitigation of potential interference issues. This requires outdoor testing as part of maturity cycle in real field conditions. There is a need to enhance ease of doing business by reducing transaction costs involved in obtaining such outdoor testing permissions and coordination involved with licensed users especially if the products are being developed in licensed bands. DoT has already facilitated spectrum framework for experimentation, R&D, Manufacturing, Technology Trials and Demonstrations primarily for indoor through self-declaration and for outdoor cases through coordination as applicable. However, there is a strong need for facilitating such outdoor testing **in 'Spectrum Regulatory Sandboxes'**, so that innovators could access these test zones quickly facilitating ease of doing R&D.

It is proposed to establish outdoor / radiating testing facilities under two categories in demarcated zones:

- Outdoor Testing in Unallocated, Unallotted, Unassigned, Unsold bands which are literally available but NOT being used in the country and currently not offered to enable R&D and experimentation.
- Outdoor Testing in assigned bands (which generally can't be offered for testing as they are being used by the telecom licensees) in interior and remote areas where such bands are not being used.

The central theme of Spectrum Test Zones is to set up 'Spectrum Regulatory Sandboxes' in different Geographical zones (remote), Campuses, Academic institutes, R&D Lab campuses, Government campuses (e.g., CDoT, CDAC, ITI, BEL, SAMEER etc.), Telecom Service Providers, etc., wherein Startups, SMEs, Organizations, etc., could test their wireless products/ technologies I the bands for various radio services as identified in the Radio Regulations for R&D, Experimentation, etc.

4.6.1 Specific Action: THz Testbed

DoT should invite proposals to establish a THz test bed in partnership with industry and academia to enable state-of-the-art R&D in THz research and technologies.

4.7 Spectrum studies enablement

4.7.1 Spectrum Center of Excellence for Competency and Capacity building in Spectrum Management

The recent times have seen more and more dependency on wireless systems for various communications requirements in almost all sectors. This is specifically so in cellular and broadband wireless networks. With the explosion in the use of wireless broadband, the radio frequency spectrum has become a very valuable resource. Various stakeholders like the government departments, operators, and technology developers are looking for the right technologies and policies to make the best of the available spectrum to meet the current and future demands of wireless communications.

Due to the ever-increasing need for spectrum, the frequencies being licensed are also increasing rapidly. In the case of broadband wireless networks, as the networks evolved from 2G to 3G to 4G, the frequency bands also moved from 0.8 GHz to 1.8 GHz to 3.3 GHz, and now towards millimeter wave bands in 5G. The computing platforms are also becoming powerful enough to handle the demands of higher frequency bands. Many of these bands are new to the applications and technologies that they will be subjected to.

Broadband networks are considered as critical infrastructure in India like anywhere else in the world. Many government services are run over broadband networks. The whole economy and the national GDP itself depend on how good the communication infrastructure is established across the country.

Spectrum, though the most critical element to meet this requirement, is however considered a scarce natural resource. It needs to be utilized optimally and in a very efficient manner. The Government policies need to ensure the best use of the spectrum by various agencies that fulfill the national requirements and the need of its citizens. The technologies implemented should be the most efficient and suitable for that spectrum band. There is a need to understand various aspects of the radio spectrum while arriving at policy and technological decisions. For example, the propagation characteristics change dramatically as we move to mm-wave frequencies, and one must revisit the existing spectrum licensing model to ensure high spectrum efficiency. One also needs to explore spectrum-sharing modes of licensing. Finally, with so much spectrum being licensed, monitoring for compliance and unauthorized use becomes equally important. All of this calls for entirely new studies on propagation and coverage regions of different types of antennas at high frequencies, real-time geospatial databases for licensing and monitoring, dynamic opportunistic use of white spaces as determined from the database, IoT sensors for nation-wide monitoring of spectrum, simulators for multi-antenna wireless links, etc.

To cater to these, the proposed Institute of Advanced Radio Spectrum Engineering and Management Studies (IARSEMS) should draw a roadmap for 6G spectrum research.

4.7.2 Spectrum Infrastructure for Coexistence studies

Spectrum is going to play a more critical socioeconomic role in forwarding the Digital India program. However, the Indian market poses a quite challenging and potential environment for the deployment of wireless technologies and services. It is challenging because of limited technological competencies in government agencies to appreciate the coexistence opportunities involved in spectrum sharing, and identification of new bands among different stakeholders, especially the government agencies. This presents a big challenge for the deliberations at ITU, APT, and stakeholder discussions with the government. It further gets aggravated with the arguments ranging from 'global studies don't apply to India-specific uses' to 'there are no ITU studies yet' or 'it is not possible to share' etc. On another side, the Indian market presents a tremendous opportunity due to the imminent need for wireless technologies due to its sheer size in terms of population, largely middle class, geography, rapidly growing appetite for internet services, economic ambition to reach $5 trillion by 2025 ($1 trillion from the digital economy) and large unconnected segments (enterprises, infrastructure, villages).

In view of the explicit need to promote coexistence opportunities by taking note of country-specific requirements, identifying new bands, to develop clarity & take a position in global spectrum discussions there is a demand to institutionalize coexistence testing mechanisms and build spectrum testing infrastructure. The time lag between the identification of bands necessary for the country's needs and the rolling out of services needs to be minimized to minimize the opportunity cost.

Creating an institutional framework to 'enable ongoing studies on coexistence of spectrum, identification of new bands' on a neutral platform is critical to address the above challenges and reap the opportunities for the industry and public.

It is recommended to set up a "Spectrum Studies Council" (SSC) on priority under a collective engagement with premium academic institutions with spectrum expertise in PPP mode. Considering the size of the studies, it is going to be a mammoth task unless multiple expert institutions and industries come together with stakeholders in partnership with DoT. This is more so because WRC is scheduled for next year (2023), and several countries are carrying out on-ground studies since 2019.

The studies should invariably take note of models considering key technology components, deployment scenarios, system parameters, channel model, propagation model, and updated protection requirements. Create on-ground sharing study groups by involving the stakeholders. Timelines of deliverables should be harmonized globally while keeping the focus on national and regional requirements.

4.7.3 Spectrum Management Software; Dynamic Database Systems; Wideband sensors for Spectrum Monitoring

If the spectrum is to be used efficiently, its use must be coordinated and regulated through both national regulations and the Radio Regulations of the International Telecommunication Union (ITU). The ability of each country to take full advantage of the spectrum resource depends heavily on spectrum management activities that facilitate the implementation of radio systems and ensure minimum interference. To this end, administrations should, as appropriate, make use of computerized spectrum management systems (Handbook on National Spectrum Management Edition of 2015)

4.7.3.1 Spectrum Management Software

Industry inputs convey the need for state-of-the-art spectrum management software, which would enhance the effectiveness and efficiency of WPC operations.

"WPC to source appropriate and advanced spectrum management SW tools to enhance efficiency in allocation, monitoring, technology adoption and help further interference, capacity studies from ITU/GSMA/ETSI or others, similar to Regulators like Ofcom, FCC, etc. This will also help promote new spectrum allocations for innovations, new technologies and existing spectrum deployments, monitoring and efficient use, at par the developed world."

The current IT modules deployed on Saral Sanchar are administrative modules and it needs to be complemented with spectrum management software, which is critical to enable professional and technical management of the spectrum. Apart from a few global vendors, even ITU offers software called SMS4DC (Spectrum Management Software for Developing Countries) at a nominal cost.

The Spectrum Management Software has several tools for spectrum engineering, allocation, interference assessment, etc., as below.

1. Engineering tools
2. Administrative database and licensing system
3. Graphical information system
4. Links to monitoring software
5. Information on Geographic Information Platform etc.

A state-of-the-art Spectrum Management Software should be deployed in DoT in the next 12 months.

4.7.3.2 Dynamic Database System (DDS)

Dynamic database systems for allocation/ interference management are gaining popularity in developed countries to enhance the efficient use of the spectrum across user segments. As per the FCC regulations, the popular CBRS band in the USA is offered to three categories of users depending on their priority use.

A technical committee would be formed to assess the relevance of dynamic database systems, since there are licensed users in certain bands, the band utilization may be very limited impacting the opportunity cost to maximize the socioeconomic benefits, especially in sub 1 GHz and mid-band spectrum bands.

4.8 Spectrum Availability for 6G

Spectrum is one of the key enablers for new technology development and rollout. Different countries had considered spectrum availability and regulatory readiness as key strategic steps for early adoption, enabling the ecosystem and leading the technology development and rollout. E.g., USA 5G FAST[6] program enabled early availability and roadmap for the 5G spectrum, including joint coordination among various users and a strategy for vacating incumbent users to make space for 5G.

A similar approach is key for India to take lead in 6G at the same time taking steps to ensure early availability of spectrum already identified for 5G (e.g., 5G HLF recommendations). Spectrum is a scarce resource; therefore, all efforts should be made to maximize the usage of spectrum by allowing sharing among contending services. The below-given approach could be considered for the identification of spectrum, when to share and how to share.

To ensure the readiness of the spectrum for 6G, a systematic and focused approach geared towards making the frequency ranges available is essential. The proposed approach is shown in the Figure below.

[6] The FCC's 5G FAST Plan, https://docs.fcc.gov/public/attachments/DOC-354326A1.pdf

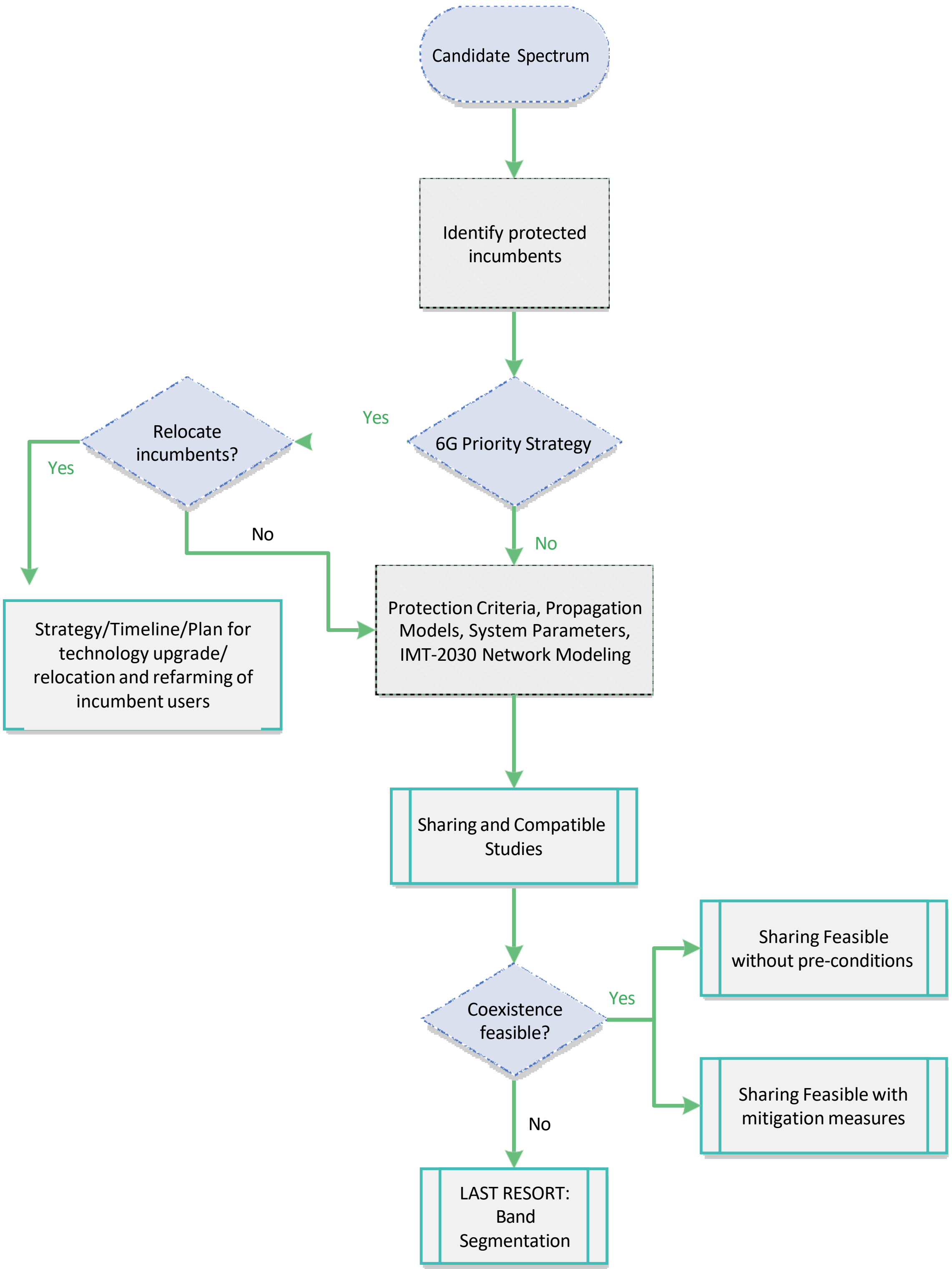


Figure 16: An approach towards ensuring timely and predictable availability of 6G spectrum (Source: 5GIF)

5. Annexure

A.1 Term of Reference of Task Force

- To reform mid-band and sub-1-GHz spectrum
- To consider the feasibility of 6 GHz and 10 GHz bands
- To consider more candidate bands in mmWave bands
- To explore the feasibility of the THz band
- To recommend options on secondary use of spectrum
- To consider new spectrum ownership and sharing models enabling flexible spectrum allocation
- To consider the integration of emerging coverage solutions like Satellites, Drones, unmanned aerial vehicles etc. and consider their spectrum requirements
- To provide a roadmap for channel measurements and new channel models for mmWave and THz bands
- To identify co-existence and dynamic spectrum sharing study items
- Any other items in the scope of 6G activities and overall deliverables

A.2 Major decisions of WRC-19 w.r.t. ITU Region 3

A.2.1 Mobile Broadband

- IMT-Additional bands for International Mobile Telecommunications (IMT) identified in the 24.25-27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2, and 66-71 GHz bands, facilitating the development of fifth generation (5G) mobile networks. A total of 17.25 GHz was identified for IMT in comparison with 1.9 GHz available before WRC-19 with certain regulatory conditions and exceptions.
- Wi-Fi networks – Regulatory provisions revised to accommodate both indoor and outdoor usage and the growth in demand for wireless access systems, including RLANs for end-user radio connections to public or private core networks, such as Wi-Fi, while limiting their interference into existing satellite services.
- High-altitude platform stations (HAPS) – Additional frequency bands Identified for High Altitude Platform Systems – radios on aerial platforms hovering in the stratosphere – to facilitate telecommunications within a wide coverage area below for affordable broadband access in rural and remote areas.

A.2.2 Satellite Services

- **Earth exploration-satellite (EESS) service** – Protection accorded to EESS with the possibility of providing worldwide primary allocation in the frequency band 22.55-23.15 GHz to allow its use for satellite tracking, telemetry, and control.
- **Non-Geostationary Satellites** – Regulatory procedures established for non-geostationary satellite constellations in the fixed-satellite service, opening the skies to next-generation communication capabilities. Mega-constellations of satellites consisting of hundreds to thousands of spacecrafts in low-Earth orbit are becoming a popular solution for global telecommunications, as well as remote sensing, space and upper atmosphere research, meteorology, astronomy, technology demonstration and education.
- Regulatory changes introduced to facilitate rational, efficient, and economical use of radio frequencies and associated orbits, including the geostationary-satellite orbit.
- **Broadcasting-satellite service (BSS)** – Protection of frequency assignments, providing a priority mechanism for developing countries to regain access to spectrum orbit resources.

A.2.3 Transport

- **Railway radiocommunication systems between train and trackside (RSTT)** – Resolution approved on Railway radiocommunication systems to facilitate the deployment of railway train and trackside systems to meet the needs of a high-speed railway environment in particular for train radio applications for improved railway traffic control, passenger safety and security for train operations.
- **Intelligent Transport Systems (ITS)** – ITU Recommendation (standard) approved to integrate ICTs in evolving Intelligent Transport Systems (ITS) to connect vehicles, improve traffic management and assist in safer driving
- **Global Maritime Distress and Safety System (GMDSS)** – Expanded coverage and enhanced capabilities for GMDSS.
- **Earth stations in motion (ESIM)** – The decision on ESIMs will connect people while in planes, ships, and trains to communication links with geostationary satellites.

A.3 Global Focus on Tera Hz

- About 10 years, a considerable amount of time to use spectrum
- Necessity and Demand, Global movements on THz

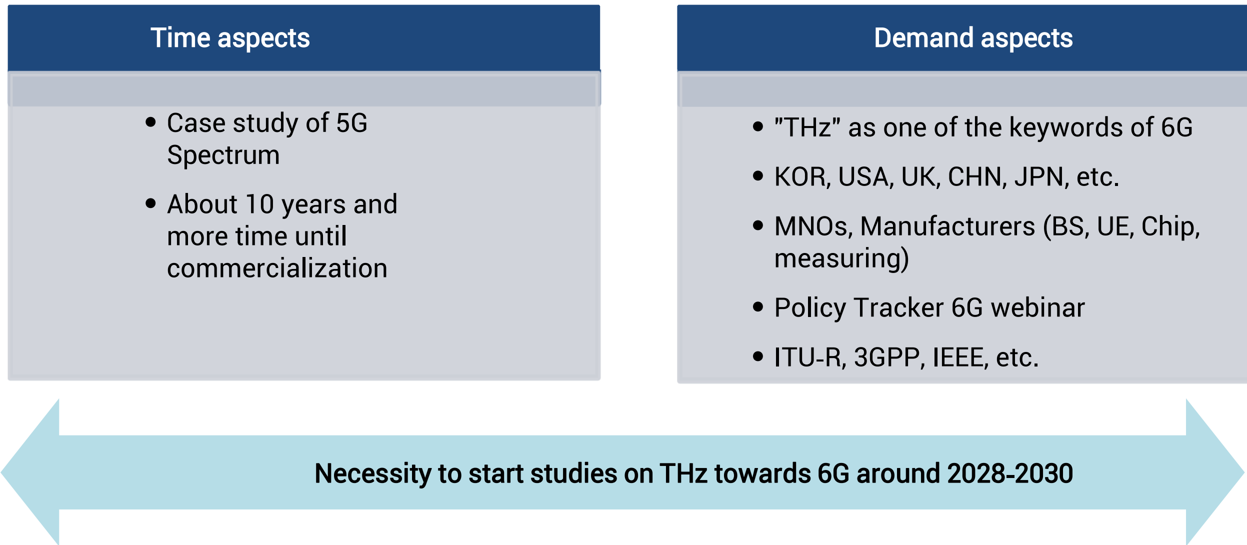


Figure 17: Samsung Research

6G Taskforce Report: 6G Devices

Chairperson: Prof. Kiran Kumar Kuchi
Member Secretary: Shri. Sunil K Singhal

1. Executive Summary

6G technology will have significant advancements in communication, sensing, imaging, presence technologies and location awareness. The computational infrastructure of 6G will automatically select the ideal place for computing, including artificial intelligence (AI) driven decisions regarding data storage, processing, and sharing. Future networks will be pervasive component of life, society, and industries, fulfilling the communication needs of humans as well as intelligent machines. 6G should contribute to an efficient, human-friendly, sustainable society through ever-present intelligent communication.

1. Four main drivers will emerge for the 2030 era

- Trustworthiness of the systems that will be at the heart of society,
- Sustainability through the efficiency of mobile technology,
- Accelerated automatization and digitalization to simplify and improve our lives, and
- Limitless connectivity meeting the demands for intensifying communication anywhere, anytime, and for anything.

It is expected that 6G will provide the ultimate experience for all through hyper-connectivity involving humans and everything. New themes are likely to emerge that will shape 6G system requirements and technologies, such as:

- New man–machine interfaces created by a set of multiple local devices acting in unison; We will have more intuitive interfaces, with access through gesturing rather than typing.
- Ubiquitous universal computing distributed among multiple local devices and the cloud;
- Multi-sensory data fusion to create multi-verse maps and new mixed-reality experiences;
- Precision sensing and actuation to control the physical world.
- A certain class of device is one that will be extremely low-power and potentially battery-less, relying on the network to power the device.
- The end device will evolve in many scenarios to be a network of devices or a sub network. As examples, we can imagine a machine-area network or a robot-area network involving connecting multiple parts of a machine such as a controller and its drives
- With 6G targeting to enable ubiquitous mmWave coverage and going further to exploit even higher spectrum (~THz), there comes an inherent need for compact network densification to build coverage, and with this, a vital need to contain deployment costs. In such a context, 6G devices will not only be communication end-points; 6G devices will be able to act as active network nodes in a data path and, ultimately, form standalone networks.

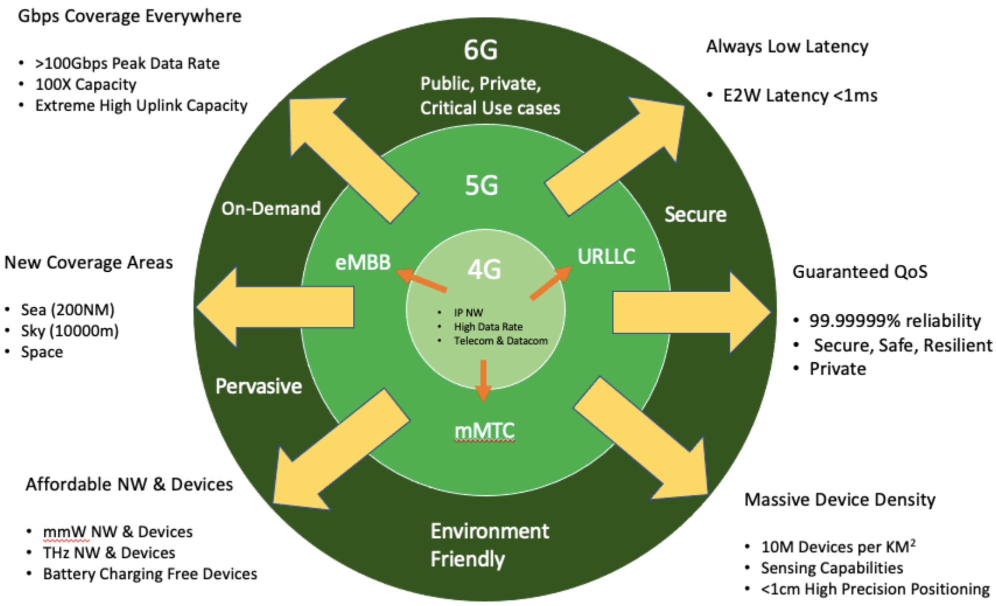
- Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviours, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application–network collaboration, resilience mechanisms, evolution of the end-to-end transport protocols, and ways to deal with latency.

- Future services will require connectivity everywhere and in everything. 6G networks can support trillions of embeddable devices, provide trustworthy connections that are available all the time.

- 6G connectivity can help India to leapfrog to become highly industrialized society. While the technology adoption improves productivity, quality of life, for rural and urban citizen, achieving a leadership in the development of technology will create immense job opportunities in the country

- 6G Connectivity can help India address many social issues like law and order, healthcare, knowledge led job creation, improvements in living standards of the citizens in the urban and rural areas, improvements in government and citizen interaction through smart cities, internet of things, digitalization and G2C services, better governance of urban, rural, border areas, islands, forests and animal kingdoms, vast ocean geography, sovereignty and security, cyber and physical integration among many others.

- New industry verticals will emerge driven by 6G technologies, these may include Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) Communication across road transport, trains, airlines, in personal, community and public transport sectors, Holographic communications, tactile and haptic internet applications, tele health including diagnosis, surgery and rehabilitation activities. Extremely high-rate information access, connectivity for everything, convergence of networking and compute among others.



Our Vision for developing 6G devices will be based on 6G standards, network and performance expectations, use cases the devices are expected to deliver. We would start with Inside out approach developing needed silicon level IPs, interfaces, chips and enable the leading applications using the existing semiconductor and devices ecosystem. We may also own and steer couple of strategic and mission critical components, chips, devices and applications to show case end to end capabilities as part of the 6G test bed program.

Regarding R&D funding, there is limited R&D push towards indigenization of 5G-adv/6G device modem chipset. Considering the current domestic scenario, significant R&D investments are essential to achieve Atmanirbhar in the 5G-adv/6G device space with following key considerations.

- 6G R&D funding to have a 10-year horizon with the outcomes aligned with the IMT-2030 6G standards. However, the intermediate deliverables should target compliance with 5G-advanced specifications, viz. 3GPP Rel-17/18 and beyond.
- The funding should cover development of modem chipsets, end-to-end systems including software/firmware, security elements and applications. Adequate funding should also be given to emerging technologies such as AR/VR, next generation sensors, human-machine interfaces etc.
- The funding should be prioritized towards the development of
    - SOCs: Modem, RF ICs (Sub 6, mmWave and higher frequencies)
    - Multiple classes of SOCs to address low end and high end IoT applications
    - AI processors
    - End-to-End Devices including the applications

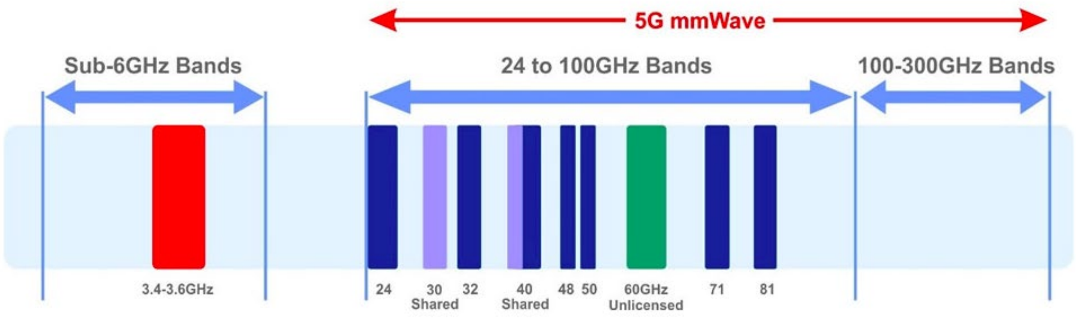
2. Societal View

- Let us imagine India in 2040. With Global population at 9.2 Billion people, India would be the most populous country with 1.5 Billion people living in the subcontinent. Young India is aspiring to grow it's per capita income from current 1900$ to 5000$ in 2030 and 12000$ in 2040. India will be the third largest economy in the world by GDP ranking having overtaken Japan.
- India would be the world's largest democracy with 100% of its citizens having home, food, water, sanitation, education, job and income sources, electricity, connectivity, television, mobile, and most of the Govt to citizen services through digital platforms.

- India is expected to increase its literacy rate from current 77.7%, closer to triple digits, add few more years to current average life expectancy of 69.8 years, see leapfrogging increase in human capital ranking, innovation ranking, standards of living and happiness index.
- India is expected to continue its position at the top, in terms of mobile subscriber base, increase it's internet penetration and broadband penetration closer to 100% by 5G Broadband and Fibre to Home connectivity. 2G/3G would have been switched off, main connectivity is 5G and some 4G connectivity to support the needs of the society. There would be telecom services, private networks, community networks everywhere based on 5G/4G. All critical networks would be secure, protected and indigenous.
- India would have achieved its smart cities mission with 100+ cities offering smart city services to its citizens through digital platforms. All 600000 villages in India would have got internet connectivity and people access to information, entertainment and services through mobile and fixed broadband.
- 1.5B people interacting with Government and among each other through Digital platforms, availing Government to Citizen (G2C) services, Tele-Health Services. 500M+ students using Tele-Education platforms across India including primary, secondary, higher and advanced studies. All Hospitals would be interconnected, all doctors and health professionals would be available on National Health Network for consultation, diagnostics, and patient dialogue. Entertainment would be available at the home, in vehicles, in public areas and on the move.
- Smart Agriculture will be everywhere, with use cases like drone usage for pesticide dispensing, smart monitoring, smart storage systems, smart transportation systems and farm to plate traceability.
- Security, Surveillance, Public Safety, Policing, litigation and justice systems, courts all moved to digital platforms with real time access to previous case studies, evidence, real time tele-hearings. Body cameras for policing, surveillance, evidence collection, traffic management will be prevalent in urban areas. Road tolling will be satellite based, with V2V and V2I technologies deployed across the personal and public transport systems. There will be instantaneous identification and verification at Police stations, passport offices, courts, government offices, G2C service centres, Hospitals, Airports, Bus/train stations to avoid procedural delays and physical paper-based systems.
- Future technologies should help contribute further to the success of a number of UN SDG goals including environmental sustainability, trust and inclusion, efficient delivery of health care, reduction in poverty and inequality, improvements in public safety and privacy, support for ageing populations, and managing expanding urbanization.
- 6G connectivity can help India to leapfrog to become highly industrialized society. While the technology adoption improves productivity, quality of life, for rural and urban citizen, achieving a leadership in the development of technology will create immense job opportunities in the country
- 6G Connectivity can help India address many social issues like law and order, healthcare, knowledge led job creation, improvements in living standards of the citizens in the urban and rural areas, improvements in government and citizen interaction through smart cities, internet of things, digitalization and G2C services, better governance of urban, rural, border areas, islands, forests and animal kingdoms, vast ocean geography, sovereignty and security, cyber and physical integration among many others.
- New industry verticals will emerge driven by 6G technologies, these may include Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) Communication across road transport, trains, airlines, in personal, community and public transport sectors, Holographic communications, tactile and haptic internet applications, tele health including diagnosis, surgery and rehabilitation activities. Extremely high-rate information access, connectivity for everything, convergence of networking and compute among others.

3. Radio centric view

In the last few decades every new generation of cellular technology until 5G brought significant improvements in data speeds (that spurred many new applications) but the operational frequency range was limited to sub 6-Ghz frequencies where the radio propagation conditions are conducive to cellular network deployments. 5G is the first radio access technology that extended the frequency of operation beyond 6GHz (expanded the operation to milli-meter wave or mmWave). While defining 6G vision and use cases, it is therefore important to clearly differentiate and outline the vision, network evolutions and the operational scenarios for sub 6Hz, mmWave and beyond mmWave frequency ranges.



3.1 Sub 6GHz

For frequencies below 6GHz, where the signal propagation characteristics are conducive to small and large cell deployments, 6G radio access technology is likely to evolve as an enhanced radio access technology that leverages the key components and features of 5G while ensuring backward compatibility.

3.2 Beyond mmWave

However, for extremely high frequency operation, especially T-Hz range where the data rates and latencies are beyond the conventional cellular range (use cases are more like fiber replacement) 6G requires a completely new radio definition that requires grounds up development. While commercial use cases and deployment feasibility is not clear in this operational frequency range, the landscape will be clear only after a few years. India should make the necessary R&D investments in order to be able to compete with the rest of the world.

3.3 mmWave

For frequencies above 6GHz and below 52.6 GHz (the mmwave range), the ongoing network deployments around the world indicate that achieving contiguous network coverage in this frequency range remains significant challenge, and therefore, further R&D aimed at enhancements to mmwave operation are being envisioned as part of the 5G -advanced standards. Therefore, development of reliable mmwave networks will be an important consideration for 6G standards.

3.4 5G-Advanced vis-à-vis 6G

While 6G is an IMT-2030 technology (specifications to be available by 2030), 5G advanced (5G-A) that includes rel-18 and beyond may play a significant role in fulfilling many 6G use cases and applications. Therefore, 5G-A may be viewed as a pre-6G standard. In such a scenario, most 6G applications would ride on 5G and 5G-adv radio technology with innovations mainly introduced in the development of new types of devices, applications, network architectures rather than relying solely on improvements made in physical and MAC layers (exception will be for the T-Hz use cases)

3.5 New Services

5G Supports eMBB (very high data rate, moderate latency), mMTC (low-to-medium data rate, moderate to high latency, ultra-high connection density), URLLC (medium data rate, very low latency, very high reliability), as three distinct services. 6G will provide many more new services that will include various combination of the aforementioned three services that will cater to the new use cases envisaged for 6G.

3.6 Beyond cellular uses cases

5G and 5G-advanced specifications cater to new uses and verticals that go well beyond the capabilities offered in the previous generations: examples include Non-Terrestrial-Networks including Satellite (GEO/LEO), HAPS (High Altitude Platforms). Combined with terrestrial services, 6G would offer universal connectivity anytime, anywhere on the earth including land, sea and air. Therefore, 6G will eliminate/minimize the rural-urban digital divide. This is feasible when the available spectrum in both sub 6 and mmwave frequency range is leveraged to the full extent.

4 6G Global view

	2G	3G	4G	5G	5G Advanced	6G
Introduction Year	1992	2000	2010	2020	2025	2030
Key Features	Voice, SMS	Broadband Data	MTC, Video	Industrial IOT Interactive Video	mMTC+ URLLC+ eMBB+	Connecting Worlds Massive Scale AI & Sensing Holographic Video
Broadband Data Rate Device MIMO		1-10Mbps 1Tx/1Rx	10Mbps-1Gbps 1Tx/2+Rx	100Mbps-20Gbps 2Tx / 4+Rx		1GBps -1Tbps+ 4Tx/8+Rx
Spectrum		FDD+ 2.3Ghz TDD ~100MHz+	+2.5GHz TDD+ Unlicensed 5GHz ~600MHz+	+3.5 – 7 GHz +mmW ~3+GHz		+7 – 24GHz +Sub THz ~50 GHz+
Network Densification		Nominal	+	+device		++device
User Plane Latency			50ms	4 ms (eMBB) 1ms (uRLLC)		25 us – 1ms
Mobility			350 KMPH	500 KMPH		1000 KMPH (Multiple moving platforms)
Killer Use cases	Voice, SMS, VAS	Mobile Web	Mobile Video/TV Social Media Video Call	V2X Smart City/Factory/Home Cloud Gaming, XR UHD Video	Telemedicine Wearables	N-D Holographic Comm AI efficient System NTN Systems Tactile/Haptic/Digital Sensing Automated Driving Internet of bio-nano things

The market for 6G technology is predicted to enable significant advancements in imaging, presence technologies, and location awareness. The computational infrastructure of 6G will automatically select the ideal place for computing, including decisions regarding data storage, processing, and sharing, using artificial intelligence (AI).

Future networks will be a fundamental component for virtually all parts of life, society, and industries, fulfilling the communication needs of humans as well as intelligent machines. To make the best out of it, we – the industry and research community — should contribute together towards a common vision. 6G should contribute to an efficient, human-friendly, sustainable society through ever-present intelligent communication.

Four main drivers will emerge for the 2030 era:

- Trustworthiness of the systems that will be at the heart of society,
- Sustainability through the efficiency of mobile technology,
- Accelerated automatization and digitalization to simplify and improve our lives, and
- Limitless connectivity meeting the demands for intensifying communication anywhere, anytime, and for anything.

It is expected that 6G will provide the ultimate experience for all through hyper-connectivity involving humans and everything. New themes are likely to emerge that will shape 6G system requirements and technologies, such as:

- New man–machine interfaces created by a set of multiple local devices acting in unison; We will have more intuitive interfaces, with access through gesturing rather than typing.
- Ubiquitous universal computing distributed among multiple local devices and the cloud;
- Multi-sensory data fusion to create multi-verse maps and new mixed-reality experiences;
- Precision sensing and actuation to control the physical world.
- A certain class of device is one that will be extremely low-power and potentially battery-less, relying on the network to power the device.

- The end device will evolve in many scenarios to be a network of devices or a sub network. As examples, we can imagine a machine-area network or a robot-area network involving connecting multiple parts of a machine such as a controller and its drives
- With 6G targeting to enable ubiquitous mmWave coverage and going further to exploit even higher spectrum (~THz), there comes an inherent need for compact network densification to build coverage, and with this, a vital need to contain deployment costs. In such a context, 6G devices will not only be communication end-points; 6G devices will be able to act as active network nodes in a data path and, ultimately, form standalone networks.

5 Enhanced end-to-end connectivity

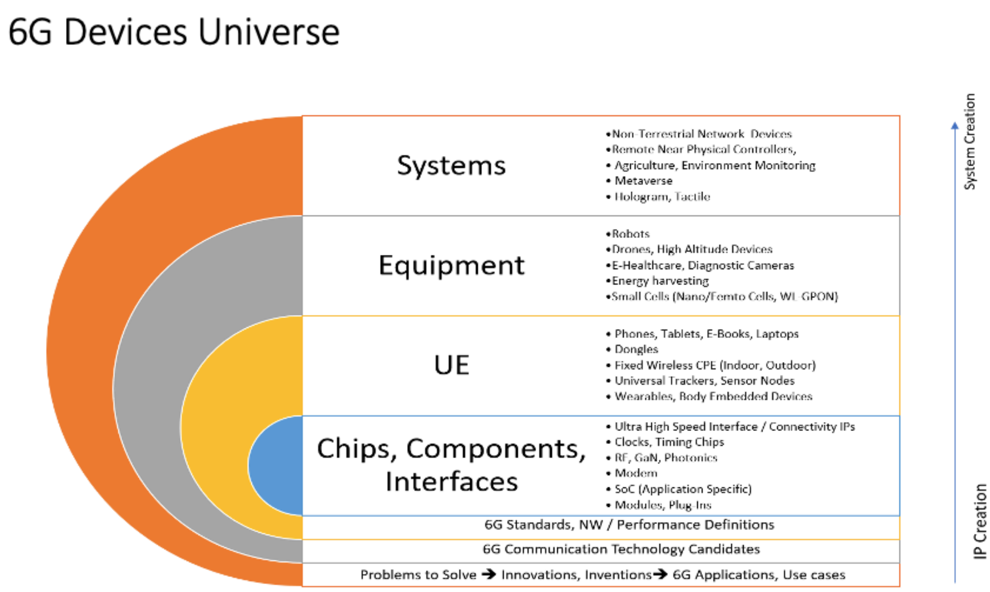
Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviours, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application–network collaboration, resilience mechanisms, evolution of the end-to-end transport protocols, and ways to deal with latency.

6 Embedded devices everywhere

Future services will require connectivity everywhere and in everything. 6G networks can support trillions of embeddable devices, provide trustworthy connections that are available all the time.

7 Global 6G activities in area of Device

6G Device universe is expected to be built on the user problems to be solved, fulfill user needs and wants, bring in new inventions and innovations in experiences, applications and use cases. There are several possible communication technology candidates which will be further evaluated, developed and matured. The best candidate would eventually evolve into 6G Standards including network requirements and key performance Indicators.



In terms of devices evolution, the ecosystem is expected to take two approaches

7.1 Inside out approach

IP Creation, Interfaces, Components, SOCs, Modules, UE devices, Equipment Subsystems, Systems. This approach will be taken by mainly semiconductor players and component suppliers.

7.2 Outside in approach

Which basically focuses innovations at the software and system level and integration of various subsystems to bring in efficiencies, lower cost and provide better user experiences. This approach is expected to be taken by high-tech / consumer tech / Software / AI developers and system suppliers.

Both approaches are expected to meet and harmonize over the next few years of evolution towards 6G.

8 Modem and Application Processor Evolution

It is expected that Modem and Application Processors will continue to remain separate in the 6G device architecture. Individually Modem will continue to evolve from being a 5G Modem to a 5G Advanced Modem and will work with the available frequency bands with 5G Advanced use cases. Application processors will evolve based on the application and likely to include parallel processing, increased performance of Neural processing units able to support Machine Learning and Artificial Intelligence based software architectures, operating systems that will work across different device classes and applications.

We expect to have discrete modems being preferred over those integrated along with main SOC.

In terms of device universe, the following devices are expected to be available in 6G era as well.

8.1 Communication Interfaces

This includes module or dongle for laptop, gaming devices or other devices needing ultra high speed 6G connectivity

8.2 Timing, Clock Chips

Very high-performance timing and clock chips are essential to ensure proper working of very low latency, ultra-high speed communication systems, devices, applications.

8.3 RF Front end chips and modules

These include RF Transceivers, power amplifiers, GaN devices, antenna arrays, front end modules needed for 6G devices.

8.4 IoT/Industrial IoT/Trackers

Location Tracking: Future 6G communications will be dependent on satellite technology to attain global coverage. 6G will connect telecommunications, earth imaging, and navigation satellites in the future to provide cellular users with location services, broadcast and Internet connection, and weather forecasting data. The provision of high-speed Internet connectivity onboard fast trains and planes is one example. Precision ranging techniques like UWB are likely to find even more relevance.

8.5 Universal IoT Chip

- The one which works both indoor as well outdoor, uniquely identifiable, includes all wireless connectivity standards and interfaces, on software defined radio architecture.

8.6 Sensor Nodes & Energy Harvesting

- Combination of different sensors in on a silicon or in a module

- Energy harvesting devices which can power ultra low power sensor nodes.

8.7 Smartphone

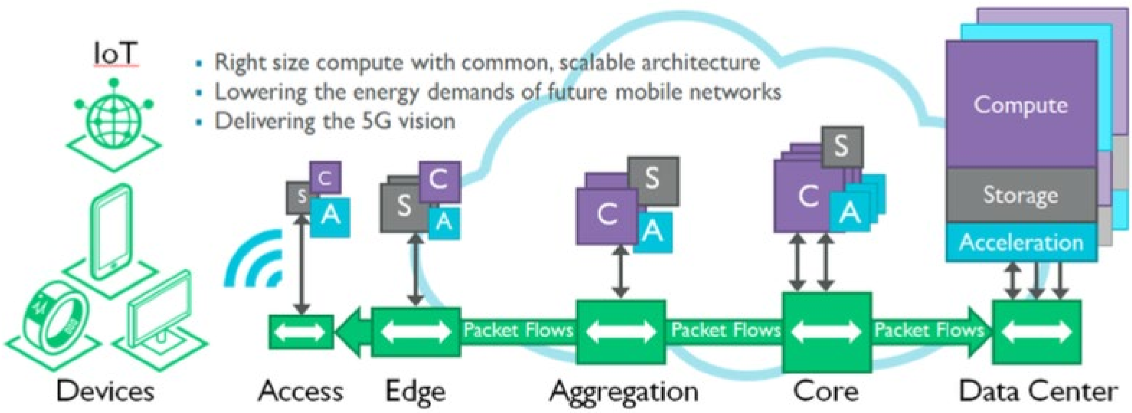
- 6G will hopefully fulfill and surpass a variety of standards, including delivering high-energy performance, particularly in the context of extensive IoT use and an eco-system of innumerable minute sensors. Additionally, it is required to lengthen the battery life of smartphones, based on the notion that their skills and capacities to cope with sophisticated multimedia signal processing grow exponentially as their power consumption increases. Low energy consumption and a longer battery charge life are two research topics in 6G that attempt to overcome the majority of communication equipment's daily recharging issues while still meeting communication goals.

8.8 Cellular Cameras, Body Cameras, Dash Cameras

There are two possible evolution paths viz.

- Cellular connectivity driven device architecture, which assumes that a broadband connectivity of 1Gbps+ would be available, which reduces need for processing power and storage in the device and
- Application Centric where the storage & processing power at the edge, decision with analytics at the edge will decide how to communicate the video clips or streams back to the storage in the cloud or at the base station or in the device.

Scalable processor cores will support different device classes based on compute, storage and acceleration needed by the application/use case.



Source: ARM

8.9 Wearable and Body embedded Devices

Wearables are expected to evolve from current smart watches, smart glasses and ear buds to include the personal global navigation devices, help humans to interact with different types of experiences, utilities and services like smart home, workplace, factory, retail, healthcare, travel, business among others.

Another category of products would be body embedded devices, for animals, plants, patients with specific ailments and need critical monitoring etc. these devices need body safe materials, power sources, fail safe mechanisms.

8.10 Connectivity devices

- Indoor CPE
- Outdoor CPE
- Mobility CPE-Train, metro

8.11 NTN devices- Aircraft, ships, drones

6G research is currently focusing on the development of non-terrestrial networks (NTNs) to promote ubiquitous and high-capacity global connectivity. The potential of NTNs has been acknowledged in the standard activities. A work item for 3GPP Rel- 17 has indeed been approved in December 2019 to define and evaluate solutions in the field of NTNs for NR. Study items have also been identified for Rel-18 and Rel-19, thus acknowledging long-term research within the timeframe of 6G.

Existing handheld satellite communication terminals are generally bulky, unattractive and costly when compared to terrestrial cellular devices. The combination of a common TN/NTN air interface and TN frequency band re-use can virtually suppress any device incremental complexity at any level (RF front end, RF transceiver, baseband, form factor, etc.). NTN/TN technology alignment can then be combined with a single subscription covering both TN/NTN, and turn NTN into a mass-market mainstream feature of the existing vast, dynamic and highly innovative smartphone ecosystem. Crucially, 6G TN/NTN device capability can become one additional feature widely available by default to all consumers, with the same form factor and cost structure as before this feature is introduced. 6G TN/NTN capable devices can also be delivered through already well-established OEM manufacturing and existing retail channels. Further to this, the combination of NTN technology with 6G device mesh/relay capability can be used to provide deeper indoor coverage in remote areas.

8.12 Sensors- Diagnostics, Robots, cameras, actuators, Digital/bio sensing and e-health

With the rising frequency of COVID-19 infections, biosensors that are precise, accurate, sensitive, easy-to-use, and specific to detect and monitor infectious illnesses are in high demand. These biosensors can be incorporated into cell phones with the introduction of 6G to provide early warning and control of pandemics .6G networks might be capable of a lot more with the integration of quality control, machine learning, and biotechnology. Detecting viral illnesses effectively by examining the body temperature of affected individuals. Optical biosensors may also be used to monitor the pathological function of bio recognition molecules including antibodies, enzymes, entire cells, and DNA zymes in order to better identify a variety of disorders. 6G can also be useful in other fields of electronic health (e-health), such as controlling ambient conditions (temperature, proportion of gases, and light condition). Autonomous robots can be employed in a variety of health activities, including emergency treatment, medical exams, cleaning polluted floors, and drug delivery in remote locations.

9 Agriculture

According to estimates, present agricultural productivity would need to grow by 60–70% by 2050 to meet the demands of the entire population; to do this, widespread deployment of high-precision wireless technologies will be critical. Autonomous cars, augmented reality for training, sensors for detecting factors on the farm, and data are some examples of application cases. An automated irrigation control is another use of precision agriculture. Precision agriculture, also known as smart farming, will make this possible by using wireless sensor networks to track agricultural factors and make intelligent decisions. (I) data collection, (ii) diagnosis, (iii) data analysis, and (iv) precision field operation and assessment are the steps of precision agriculture identified in. This opens up the possibility of carrying out agriculture activities. It has been proposed that AI be infused into precision energy in 6G to increase agricultural efficiency.

10 Metaverse Devices- AR/VR/XR

THz communication in submillimeter bands can be supported by 6G networks with exceptionally low latency. 6G supports virtualized service sets, which ease holographic communications across physical boundaries and improve management. This enables autonomous, real-time experienced reality (XR) for 3D pictures. 6G communication will be designed to offer dense network connectivity, large coverage, low-power nodes, and effective AI capabilities for mIoT. 6G can accommodate up to 106 parallel sensor connections per square kilometre of range. 6G will enable computational intelligence to improve AR/VR perception models with extraordinary reliability and range. 6G is expected to support smart city verticals such as vehicular-to-anything networks, internet-of-bio-sensory-things, supermassive edge computing, AR/VR use-cases (for example, remote surgery, holographic mind-mapping, immersive gaming experience, haptic communication via sub-millisecond (1 ms TI service), optical radio access cores with photonic communication for super-dense visible light communication.

Example: Metaverse experience at MWC 2022

11 Hologram

Hologram is a next-generation media technology that can present gestures and facial expressions by means of a holographic display. In order to provide hologram display as a part of real-time services, extremely high data rate transmission, hundreds of times greater than current 5G system, will be essential.

Japan recently introduced 7-eleven stores with touch free holographic self-checkouts. The holographic interface, called the Digi POS (Point of Sale), projects an image of a touch screen floating in air when a shopper directly faces the self-checkout register and scans the items they want to purchase.

The Digi POS was developed by six different companies, including 7-Eleven Japan, Toshiba Tec, Asukanet, Kanda Kogyo Development, Mitsui Chemicals Development and Mitsui Bussan Plastic.

12 Energy Efficiency or Zero Energy Devices

Although the battery life of NB-IoT/LTE-M devices can be up to ten years in some cases, battery replacement or charging limits the applicability of these devices.

Fast forward ten years into the future and imagine similar use cases but without the hassle of replacing or charging the battery. Enter the era of zero-energy devices, devices that from the end-user perspective operate without a battery. Instead, the energy necessary for communication is harvested from the surroundings – from vibrations, from light, from temperature gradients, or even from the radio-frequency waves themselves.

Packages in a warehouse can be tracked by using low-cost, zero-energy devices, potentially printed directly on the boxes –this could work even if the box is behind other boxes, avoiding the use of optical bar codes. The box may even provide information on, for example, temperature or humidity in the box, something which is not possible with a passive bar code. Monitoring the environment is another scenario where miniaturized, low-cost, zero-energy devices can play a role.

Source: Ericsson: Example of Zero Energy Device for environment monitoring

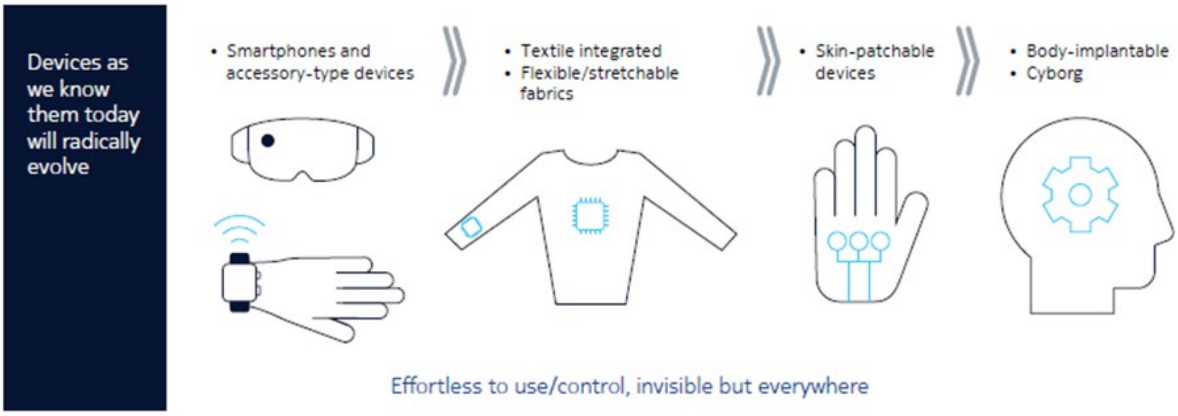
In the future, ubiquitous zero-energy devices will help us monitor pollution, weather or even disease prevalence. Zero-energy devices could also transform the retail industry. Imagine you're in a department store shopping for a shirt. As soon as you pick one up from a shelf, the zero-energy device embedded in the shirt's tag tells the store network that you're interested in that particular shirt style or model. With that information, the TV screens in your vicinity could offer you additional options for similar shirts and accessories. All this without the user having to bother charging or replacing batteries in the thousands or even millions of zero-energy devices around!

As a result, 6G will need to develop a comprehensive strategy for energy-efficient wireless communication. A fundamental aim of 6G communication is to run without the need of batteries whenever and wherever feasible, with a target efficiency of 1 pico-joule per bit. Aside from the advantages of high-power THz waves, 6G communication also allows for directed beam communication through MIMO antenna arrays, which allows devices to transmit power beams in a specified direction. This technology has the capability of providing adequate energy to networked devices. One example is:- Packages in a warehouse can be tracked by using low-cost, zero-energy devices, potentially printed directly on the boxes –this could work even if the box is behind other boxes, avoiding the use of optical bar codes.

13 New 6G Man-Machine Interfaces

While the smartphone and the tablet will still be around in 2030, we are likely to see new man-machine interfaces that will make it substantially more convenient for us to consume and control information. We expect that:

- We will have multiple wearables that we carry with us, and they will work seamlessly with each other, providing natural, intuitive interfaces. Not only, wearable devices, such as earbuds and devices embedded in our clothing, will become common, but also skin patches and bio-implants will become prevalent. We might even become reliant on new brain sensors to operate machines. The figure below shows the potential evolution of devices.



- Touchscreen typing will likely become outdated. Gesturing and talking to whatever devices we use to get things done will become the norm.
- The devices we use will be fully context-aware, and the network will become increasingly sophisticated at predicting our needs. This context awareness combined with new human-machine interfaces will make our interaction with the physical and digital world much more intuitive and efficient.

The computing needed for these devices will likely not all reside in the devices themselves because of form factor and battery power considerations. Rather, they may have to rely on locally available computing resources to complete tasks, beyond the edge cloud. Networks will thus play a significant role in the man-machine interface of tomorrow.

14 Other Advanced 6G Devices

- Integrated spectroscopy- health, agriculture, forensics, meteorology
- Observability, Learning, edge & fog compute
- Remote sensing, Local sensing through terrestrial network
- Split computing-multiparty computing
- Security- Device and applications
- Human-Machine Interface

15 Terahertz and Si-Photonics

Conventionally, terahertz circuits, including those in the 300 GHz band, have been realized using compound semiconductors and BiCMOS circuits. However, it is not only the transistors that determine the performance of communication. Terahertz communication is expected to blossom in the very near future. The development of optoelectronic terahertz devices will greatly influence the pace to bridge the technology and application gap of terahertz communications. The transmitting power, energy consumption, and chip size are among the key aspects to attract effort in development for the near future.

Photonics integration technology is progressing rapidly, which could push optoelectronic terahertz communication toward the terabit-on-chip target. Photonics integration is a feasible approach to improve transmitting power and reduce energy consumption. The progress of Si photonics integration technology paves a new way for development of optoelectronic terahertz communications. The Si photonics integration technology also makes its integration with Si electronics and low-loss waveguides easier, which is expected to further improve the system efficiency.

16 Security

5G has following security enhancements compared to previous generation technology

17 Zero Trust

3G employed mutual authentication between devices and base station, same level of distrust continued in 4G. 5G has implemented the Security Edge Protection Proxy (SEPP), a gatekeeper that prevents any traffic that isn't authorized and verified from entering the network carrier's network. For implementing the separation of duties, components from previous cellular standards have been broken up with gateways in between them to ensure that the data received is valid. To help facilitate this is an updated cryptographic key hierarchy. Effectively, these sub-components now have specific encryption keys between them. In the event that one sub-key is compromised, the rest of the 5G environment remains protected.

18 Data Transmission Security

The encryption and integrity controls have slowly been increasing over the generations of technologies. The second-generation (2G) added encryption between a user device and base station but left the rest of the network lacking. The 3rd and 4th generations effectively added another hop of encryption to their standards.

The situation was made worse by the fact that critical vulnerabilities due to lack of cryptographic and integrity controls were found in the signalling protocols leveraged by those cellular generations. Signalling protocols are what's leveraged to manage telephone calls, route text messages, and perform roaming. The abuse of these protocols allow adversaries to intercept and listen in to phone calls, perform fraudulent cellular activity, track users, and more.

With 5G, the standard has finally reached a point where all signalling traffic is encrypted and integrity protected. And user traffic is encrypted with optional integrity protection. The SEPP ensures that traffic sent from one network operator to another is encrypted.

19 Privacy

The previously discussed enhanced authentication, encryption, and integrity controls help to address privacy concerns. But 5G also directly addresses privacy concerns discovered with the 4G/LTE standard.

In order for a device to leverage the cellular network, it has to perform an attaching procedure. In 4G/LTE, the device will continuously beacon out an identifier that the cellular network uses to identify and authorize the user. This value is called the International Mobile Subscriber Identity (IMSI). During the attachment procedure, the device and base station authenticate each other and agree on security controls they will use to communicate.

Because the IMSI is beaconed out before security controls are agreed upon, the attribute is transmitted in plaintext, allowing users to be tracked and, in some cases, even for adversaries to perform fraudulent cellular activity on a victim's behalf. Vulnerabilities related to the IMSI have been discussed in many security conferences around the world

5G addresses the weaknesses of the plaintext IMSI by taking the 5G equivalent, now called the Subscription Permanent Identifier (SUPI), and encrypting it with that device's home carrier's public key. The encrypted SUPI is called a Subscription Concealed Identifier (SUCI). The SUCI is then leveraged to initiate the attachment procedure.

20 Virtualization and Software-Defined Networking — 5G Deployment Dangers

Because 5G is implemented in the cloud, all components are virtualized. As such, 5G networks can be constructed like Lego pieces, hot-swapping components as needed. Instead of having a flat network where all internal components can talk to each other, 5G can ensure that the only areas of a network that should be able to communicate can. Also, in the case where vulnerabilities are found, machines can be updated or mitigations can be put in place instantly to address the concerns. The cloud also enables resiliency not found in previous generations of cellular technologies. Cellular components can scale to address communication surges.

On top of the overall virtualization that's achieved by being in the cloud, internal networks are similarly virtualized with network slicing. Network slicing enables mobile network operators to ensure that each type of data flowing through the mobile network is treated in the way that best suits it. For example, payment card data flowing over the cellular network can be configured with more secure encryption and integrity algorithms. In cases where availability is more important than security, network slicing can ensure that fast response times are enforced.

21 5G Security Risks and Concerns

As 5G becomes more ubiquitous across the globe, the security community is taking the opportunity to review and understand the potential security risks associated with implementing the standard. These security risks fall into the following categories viz. Inherited flaws and Out-of-specification issues

22 Inherited Flaws

22.1 Legacy Protocols

The legacy protocols that possess the most vulnerabilities are the aforementioned signaling protocols. A brief summary of what each protocol does and its vulnerabilities are summarized below:

SS7: Used in 2G/3G to exchange information needed to transmit voice and text messages between parties. This protocol lacks authentication and integrity controls resulting in any party being able to establish man-in-the-middle connections, allowing communications to be intercepted. Abusing this protocol also allows an attacker to perform telephone spam, spoof numbers, and track a user's location.

Diameter: With the transition from 3G to 4G/LTE, the Diameter protocol was brought in to replace SS7. Diameter provides authentication, authorization, and even encryption. Weaknesses were discovered in this protocol that allow adversaries to send spoofed messages that can leak information about a cellular user such as their location.

GTP: Recently, Positive Technologies released research into another vulnerable protocol leveraged in 4G/LTE and 5G: GTP. GTP is used to transmit user traffic on all generations of mobile technologies from 2G to 5G. Abusing this protocol can result in a bad actor being able to impersonate a user, perform fraudulent cellular activity, and achieve denial of service. Unlike the other two protocols, GTP is defined for use in 5G standalone architectures.

22.2 Downgrade Attacks

Because of how fast technology moves forward, it can be difficult even for tech enthusiasts to keep up-to-date, let alone non-technical people. To ensure that everyone has sufficient time to upgrade, new standards are typically made to support older ones as well. However, in allowing support for older generations, there's the potential that downgrade attacks can be performed.

Downgrade attacks trick users into leveraging the insecure and out-of-date versions of a protocol. These types of attacks can be found everywhere. For instance, the Transport Layer Security (TLS) protocol that a browser leverages to securely surf the internet. Even the latest TLS version published in 2018 has been found to be vulnerable to downgrade attacks [15]. But, there's an easy fix. A web browser can be configured to limit access to websites that leverage the latest, most secure protocols, disabling anything deemed insecure. With those protocols disabled, if someone attempts a downgrade attack against it, the browser will simply refuse.

Cellular devices don't have the same flexibility that web browsers do. When a mobile device connects to a cellular network, the user has no control over the process. There's no setting in an iPhone or a Pixel that can be configured to prevent a phone from connecting to out of date and insecure cellular networks (like 2G). The Electronic Frontier Foundation (EFF) is actively lobbying tech giants, namely Apple, Samsung, and Google, to allow users the ability to disable insecure cellular standards within their devices [16]. Until these changes are implemented, adversaries have the potential to side-step all the security controls implemented by 5G by performing downgrade attacks.

22.3 Out-of-specification Issues

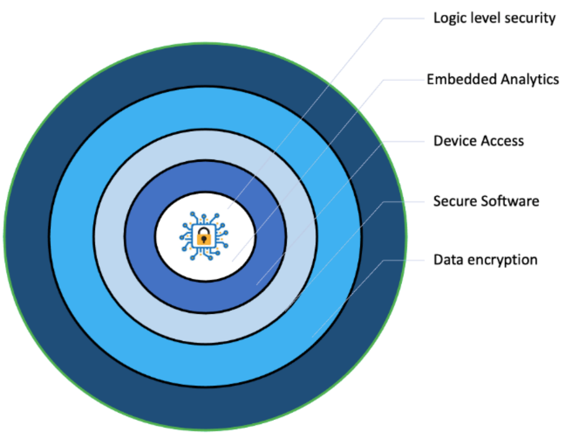
3GPP has defined very explicit details on the 5G standard in their releases, but there's a number of areas of 5G that they deem out-of-scope. It's these areas that companies and network operators have to figure out on their own and therefore where there is the highest probability of something going wrong. This includes security problems with the cloud, web application vulnerabilities, and privacy concerns.

22.4 Complications Managing User Privacy

Mobile network operators will need to work with cloud providers and third-party developers to define who has what responsibilities in terms of user privacy, and how each player will be held responsible. One might suspect that current privacy regulations help provide assurance here. But 5G networks do not stop at a country's border since radio waves have no comprehension of political jurisdictions. So it is entirely possible for overlapping laws to conflict. The situation becomes even more convoluted when an incident occurs because it's not possible to predict which law(s) will take precedence when a victim, an attacker, and the service provider are from different locations.

And all of this is assuming that a nation-state has implemented 5G with industry best practices. To ensure confidentiality and integrity of over-the-air communication, 5G leverages the New Radio Encryption Algorithm (NEA) and New Radio Integrity Algorithm (NIA), respectively. Both algorithms support the highly secure Advanced Encryption Standard (AES). However, in both cases, these algorithms also support weaker algorithms (like SNOW 3G [18]) and can be disabled entirely so no protections are in place.

As 5G becomes ubiquitous, Indian lawmakers will need to devise adequate policies to address security concerns to ensure there are no gaps in protecting end-user data. When one looks at a secure, embedded system built using a chip , includes layers of protection starting with the logic level.



As 5G becomes ubiquitous, Indian lawmakers will need to devise adequate policies to address security concerns to ensure there are no gaps in protecting end-user data.

When one looks at a secure, embedded system built using a chip , includes layers of protection starting with the logic level.

At a device level we should focus on logic level security that monitors specific operations at the logic transition level. The logic level is integral to the silicon so that it cannot be hacked or removed. In older generation systems, the NW element is considered to be trusted and device could be / can go rouge. In the next generation systems eve device should have an ability to authenticate and then only initiate data sharing process. As devices become powerful and capable to collect, process and stream large amount of data, this ability to ensure that the recipient is a trusted one is a much needed ability in the device silicon. A dedicated analytics engine for on-chip analysis uses real-time data from the hardware monitors. This engine has to be separate and cannot be impacted by the functional software stack. As data need to move off the chip, access to the chip has to be secure. This requires silicon based root of trust including a level of authentication before another system can connect. Once the device/chip is accessed, as data is sensitive, secure software and data encryption is necessary.

23 Domestic Capabilities

Indigenous development of 5G UE chipset is a nascent stage. Capabilities listed by MEITY as part of the semicon India deliberations have been listed here:

- India Semiconductor Mission has announced an MoU between Cyient, WiSig Networks and IIT Hyderabad to enable mass production of "5G Narrowband-IoT- the Koala Chip, Architected and Designed in India".
- MoU between Signal chip Innovations, MeitY and Centre for Development of Advanced Computing (C-DAC) for not only design and manufacture but also deployment and maintenance of 10 Lakh Integrated NavIC (Navigation with Indian Constellation) and GPS Receivers. Signalchip, an Indian Fabless semiconductor company has developed “Agumbe” series of baseband, modem and radio frequency (RF) chipsets for 5G/4G networks with integrated support for global navigation satellite systems including NavIC.
- Partnership was announced with Synopsys, Cadence Design Systems, Siemens EDA and Silvaco for making available their Electronic Design Automation (EDA) tools & design solutions for Chips to Startup (C2S) Programme being implemented by CDAC, a scientific society under Ministry of Electronics and IT, Govt. of India at 100+ Institutions for 5 years.
- An MoU was announced between Semiconductor Research Corporation (SRC) USA and IIT Bombay to focus on bringing together SRC's industry experts and India's R&D talent to create a compelling industry driven world-class R&D program.
- MoU between Global Institute of Electrical and Electronics Engineers (IEEE India) and Centre for Development of Advanced Computing (C-DAC) was announced for skill and technical standards development in semiconductor electronics focusing on VLSI design and Electromagnetic interference (EMI)/ Electromagnetic compatibility (EMC).
- MeitY announced an MoU between Atal Community Innovation Center Kalasalingam Innovation Foundation (ACIC-KIF) and Centre for Development of Advanced Computing (C-DAC) for collaborative R&D, Product development and Trainings in the areas of semiconductor technologies, Power electronics, Energy harvesting, Electric vehicles etc.
- DIR-V has announced Five MoUs for the use of indigenously developed RISC-V Processors - SHAKTI and VEGA.
- MoU between SONY India and DIR-V SHAKTI Processor (IIT Madras) for the Systems/Products developed by SONY.
- MoU between ISRO Inertial Systems Unit (IISU), Thiruvananthapuram and DIR-V SHAKTI Processor (IIT Madras) for development of high performance SoCs (System on Chip) and for Fault Tolerant Computer Systems.
- MoU between Indira Gandhi Centre for Atomic Research (IGCAR), Department of Atomic Energy and DIR-V SHAKTI Processor (IIT Madras) for the Systems/Products developed by IGCAR.
- MoU between Bharat Electronics Limited (BEL) and DIR-V VEGA Processor (C-DAC) for Rudra Server board, Cyber security, and Language Solutions.
- MoU between Centre for Development of Telematics (C-DOT) and DIR-V VEGA Processor (C-DAC) for the 4G/5G, Broadband, IOT/ M2M solutions
- Additionally, an intent of MoU was announced between IISc Bangalore and SEMI, USA for building core competence of quantum technologies - multi-qubit superconducting quantum processors, photonic processors, diamond-based magnetometers, lab-level quantum-secured communication network etc.
- SEMI, USA and IESA also announced an MoU for exploring the potential for growth of Electronics and Semiconductor industry in India and thereby bring global major players in semiconductor to leverage the opportunities for catalysing the semiconductor ecosystem in India.

24 6G Devices R&D Funding

There is limited R&D push towards indigenization of 5G-adv/6G device modem chipset. Considering the current domestic scenario, significant R&D investments are essential to achieve Atmanirbhar in the 5G-adv/6G device space. The key considerations for the R&D funding agencies are:

- 6G R&D funding should have a 10-year horizon with the outcomes aligned with the IMT-2030 6G standards. However, the intermediate deliverables should target compliance with 5G-advanced specifications, viz. 3GPP Rel-17/18 and beyond.
- The funding should cover development of modem chipsets, end-to-end systems including software/firmware, security elements and applications. Adequate funding should also be given to emerging technologies such as AR/VR, next generation sensors, human-machine interfaces etc.
- The funding should be prioritized towards the development of
    - SOCs: Modem, RF ICs (Sub 6, mmWave and higher frequencies)
    - Multiple classes of SOCs to address low end and high end IoT applications
    - AI processors
    - End-to-End Devices including the applications

25 Academia and Industry Cooperation

- Fundamental R&D and blue sky research should be encouraged.
- Projects are carried out through academia where industry is encouraged to participate in the co-development mode at an early stage. Industry contributions can come in the form of expert resources, access to labs and test instruments, outcome linked financial aid, subsystem components etc.
- Some projects may provide seed funding to the academia, and upon delivery of successful initial prototypes, industry/start-ups may take the outcomes forward with additional investment by the industry/VC.

6G Taskforce Report:

International Standards Contribution

Chairperson: Shri. N G Subramaniam
Member Secretary: Shri. Ashutosh Pandey

Executive Summary

The Sixth Generation (6G) technologies are likely to become viable and impactful over the next ten years and will support ubiquitous instant communications, pervasive intelligence, immersive experiences, and the Internet of Things & Senses. The 6G is expected to play a key role in the evolution of the society towards the 2030's and shall also play a role in supporting the global sustainability goals, including India's objective to contribute towards climate emergencies.

In this context, developing a strong technology that meet Indian interests and values, as well as economic and global societal goals, is key. Secure and trustworthy India-based 6G infrastructures will help on the one hand to ensure the sovereignty of India in terms of critical technologies and systems, and on the other hand to make sure that our primary values such as privacy, trust, transparency, accountability, security, and societal interests are considered.

The Sixth Generation (6G) wireless communication network is also expected to integrate the terrestrial, aerial, and maritime communications into a robust network which would be more reliable, faster, and can support a massive number of devices with ultra-low latency requirements. The researchers around the globe are proposing cutting edge technologies such as Artificial Intelligence (AI)/Machine Learning (ML), Quantum communication/quantum Machine Learning (QML), Distributed Ledger Technologies (DLT) like blockchain, Immersive XR, Tera-Hertz communication, etc., as the key technologies in the realization of beyond 5G (B5G) and 6G communications.

With the contribution in development of global 5G standards in 3GPP, ITU etc., India as a nation has gained good amount of experience. Over the years, Indian companies have also developed core competencies in certain areas. During this period, there is also a greater understanding of the Standards Development Lifecycle especially that followed within 3GPP including aspects related to its workflow and working procedures. By leveraging this experience, India can contribute to the development of 6G standards in various international bodies such as 3GPP, ITU, IEC, IEEE, one M2M, etc. and can make its mark in global standardization space and ensure good number of key innovations are from India.

To assess the ability of Indian entities to participate in 6G standards development, inputs were collected from a select set of Indian entities. Accordingly, a set of questions were asked to these representative companies to assess the capability of these Indian Comm Tech Companies on Product, R&D and 6G Standards contribution. This forms a good basis for promoting R&D in specific areas of competencies available within India, prioritizing software-ization of networks especially leveraging India's strength in AI/ML.

We had also compiled a list of global initiatives on 6G, their focus areas, how they are structured for the purpose of our learning. NextG Alliance in USA and Europe's 6G-IA are those among the many globally, we had the benefit of interacting with.

An Indian initiative led by industry and with support from government will be essential for balancing the efforts of these other regions and ensure our 6G leadership. Government, industry, and academia will need to cooperate more closely in identifying research priorities. This should begin with a concerted effort by industry, academia, and government to develop a research agenda for 6G leadership in areas of shared interest. As a first step in the process, the government should facilitate a stakeholder's session jointly with industry and academic members to engage in a dialogue identifying mutual 6G research priorities.

This task force proposes the following:

- A 6G program be created with a broad category of ecosystem partners including operators, vendors, hyper scalers, academia, and Government research labs, that is agile and quickly adaptable to the evolving needs for driving 6G research and innovations, building on and strengthening India's competencies (e.g., Next Gen Alliance was setup outside the ATIS, with its own working procedures).

- This set of stake holders through a consensus driven approach recommend topics/themes of interest in 6G based on business and societal needs. The program should cover all aspects of technology development including early research on ideas, proof-of-concept, standardization, trials & testbeds, etc.
- Government of India taking a lead in streamlining the process and fund research programs on the themes identified.
- The 6G program to take a lead in preparing well defined measurable Key Performance Indicators (KPIs) to assess the success of these program funding.
- The objective of this framework is also to have cohesive policies to meet common goal of national leaderships, national 6G Roadmap, Sustainability goals, etc.
- It is important that this initiative gains momentum immediately and aligns to the timeline of various 6G standards efforts across the globe.
- The 6G program should take a lead in developing consensus on solutions of interest and pursue the standardization efforts at the corresponding international standardization bodies.
- Concurrently, the program should facilitate early trials and prototype development, aimed at developing proof-of-concepts and support the domestic manufacturing process.

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1. Background

In the quest for higher data rates and lower latencies to end users, work has already begun globally at a fast pace to identify and develop new 6G wireless communication technologies. 6G technologies are likely to become viable and impactful over the next ten years and will support ubiquitous instant communications, pervasive intelligence, immersive experiences, and the Internet of Things & Senses.

6G is expected to play a key role in the evolution of the society towards the 2030's, as the convergence between the digital, physical, and personal domains, will increasingly become a reality. It shall also play a role in supporting the global sustainability goals, including India's objective to contribute towards climate emergencies. Some organizations are already considering defining 6G targets to include improving energy efficiency, reducing carbon emissions, and increasing the use of recyclable materials. This will greatly contribute to the United Nations Sustainable Development Goals.

One of the biggest promises of the next decade is that immersive communication, holographic telepresence, and AR/VR will become our default means of communication. With 6G, we should expect to approach a fully connected world, where the physical world is represented in high detail in the digital domain, where it can be analysed and acted upon. The network would provide the links between the domains by devices embedded everywhere, as well as provide the infrastructure and the intelligence of the digital domain. Just like 5G helped the industry 4.0 attempts to make digital twin of machines, 6G will enable humans to be placed in the middle of this cyber-physical continuum and remain fully interconnected.

6G will therefore become the basis of societies of the future. To this end, it must continue to address the pressing societal needs and deliver new functionalities at the same time. Privacy by design, trustworthiness by design, and societal fairness, shall be the foundations of the 6G infrastructure.

Digital technologies are more and more considered as critical and essential means for ensuring as one of the foundations of countries' sovereignty. Developing strong technology offers an alternatives, that meet Indian interests and values, as well as economic and global societal goals, is the key. Secure and trustworthy India-based 6G infrastructures will help on the one hand to ensure the sovereignty of India in terms of critical technologies and systems, and on the other hand to make sure that our primary values such as privacy, trust, transparency, accountability, security, and societal interests are considered. At the same time, it is important that we continue to interact with other areas of the world, promoting the adoption of its values, from the perspective of both the society and the environment, and for guaranteeing a level playing field, in which all human beings can hope for a better future.

Global standards and renewed regulations shall play a key role in the development and deployment of 6G and subsequently of services developed using 6G technologies in India and beyond, in many vertical sectors. It is one of the keys to ensure a sustainable and affordable 6G network available everywhere, to everyone. The International Mobile Telecommunications (IMT) systems for 2030 and beyond will be developed as a global standard to better serve communication needs in every continent of the world. Standards will be required in key technologies required for 6G, i.e., system network architecture and control, edge and ubiquitous computing, radio technology and signal processing, optical networks, network and service security, non-terrestrial networks communication, and device and components.

For a developing economy like India with a large population and significant opportunities, the challenge lies in identifying 6G technologies that are likely to make a major impact in addressing the needs of the growing economy in an affordable manner.

In view of the above and considering India's endeavour to take lead in 6G space, Technology Innovation Group (TIG) on 6G was constituted in the Department of Telecommunications (DoT). Six task forces have been constituted on various subjects to assist TIG. This Task Force on International Standards Contribution was constituted for:

- Mapping global 6G activities and capability definition
- Contribution for WP-5D on research views on IMT for 2030 and beyond

- Pre standardization activities on 6G and streamlining the processes to be inclusive of all stakeholders
- Inputs to standardization activities on 6G in TSDSI
- White paper on India's competency and potential pre standardization activities
- White paper on India mission 6G program, vision, mission, objective, and structure.

The task force currently focused on the following areas:

- White paper on India mission 6G program, vision, mission, objective, and structure
- Mapping global 6G programs and activities to recommend similar framework
- Stimulate competency and innovations from India through pre standardization activities
- Recommendations on contributing for WP-5D on research views on IMT for 2030 and beyond
- Formulate inclusive engagement framework for the 6G research areas to create synergy between with industry and academia
- Mobilize increased participation and contributions in various global standardization bodies from national entities/organizations like TSDSI, TEC, BIS

2. A Program for Technology Development and Contribution to Global Standards

The fusion of digital and real worlds across all dimensions will be the driving theme for 6G Networks. A hyper-scale of things will operate at the system level but not in isolated environments such as private networks. This will demand coordination of distributed intelligence all over the entire network connectivity fabric. It will be necessary to deliver information in fractional units of time between machines, robots, and their virtual counter parts to support autonomous operations safely.

The Sixth Generation (6G) wireless communication network is expected to integrate the terrestrial, aerial, and maritime communications into a robust network which would be more reliable, fast, and can support a massive number of devices with ultra-low latency requirements. Researchers around the globe are proposing cutting edge technologies such as Artificial Intelligence (AI)/Machine Learning (ML), Quantum communication/Quantum Machine Learning (QML), Distributed Ledger Technologies (DLT) like blockchain, Immersive XR, Full-Duplex, Tera-Hertz communication, etc., as the key technologies in the realization of beyond 5G (B5G) and 6G communications.

Standards-developing organizations, public-private partnerships, and industry alliances understand the significance of planning ahead with the 6G capabilities and identify opportunities for themselves: they build strategies to innovate and lead new markets; perhaps they use new technologies with 6G for increasing productivity and operations in their business.

With the contribution in the development of global 5G standards in 3GPP,, ITU etc., India as a nation has gained good amount of experience. Over the years Indian companies have also developed core competencies in certain areas. By leveraging the experience and the competencies developed in certain areas, India can contribute to the development of 6G standards in various international bodies such as 3GPP, ITU, IEC, IEEE, one M2M etc. and can make its mark in global standardization space and ensure good number of key innovations are from India.

2.1 The Standards Development Cycle

From the first analog systems to 2G, 3G, 4G and today 5G and beyond, the collaborations of Industry members with telecom operators, regulators and academia have played a crucial role in the developing standards that meet the needs of consumers, different industries, and society. By fulfilling their needs, the tools for a connected, safer, and more environmentally friendly society are provided, enabling an enriched life for consumers and increased efficiency for all industries.

Standardization is a framework of agreements for all relevant parties in an industry to ensure the creation of well-performing systems, products, and services in accordance with set guidelines. The objective is to maximize compatibility, interoperability, safety, repeatability, and quality. Development of a new technical standard within a standardization organization is based on the consensus of different parties, including vendors, operators, end users, interest groups and governments.

Various technology components are involved in the development of technology for devices, networks and interfaces, whose interworking are defined in technical specifications that get defined and developed within multiple standardization bodies, consortiums, industry groups, etc. For e.g., the IETF, ETSI Industry Specification Group on Network Functions Virtualization (ISG NFG), Web3D Consortiums for representing 3D objects over web, VRIF (Virtual Reality Industry Forum), e-CPRI, Open API specifications, 3GPP for the radio and core interfaces, etc. In this report, we focus on 3GPP, a reputed and well-attended engineering organization that develops technical specifications which form the basis of cellular systems1. Due to the complexity of both the cellular system and the fact that 3GPP is a collaborative effort amongst hundreds of different entities with potentially diverse interests/incentives,

[1] Example is reproduced from https://www.qualcomm.com/news/onq/2017/08/02/understanding-3gpp-starting-basics

understanding how work gets done and decisions are made inside 3GPP can sometimes be a mystery. One way to demystify the 3GPP process is to compare it to how any system-engineering effort works in any engineering company across the world. And utilizing this simple analogy helps to breakthrough some of the 3GPP complexity and confusing acronyms.

Let's say that instead of developing new technology specifications for cellular networks, we are instead a company that desires to build a new jet airplane, as depicted below in Figure 1.

Figure 1: High-level system-engineering steps for building a plane (source: Qualcomm).

Step 1: We would be likely to begin the process by conducting some early R&D to specify requirements, assess constraints, and gather other useful data for the project before bringing the proposal to management. These initial efforts can be instrumental in setting the project in the right direction, or even allowing it to see the light of day. We would be then likely to enter a project proposal phase where we present the project to management for approval. This may require multiple iterations, where management requires us to go back and collect further data before being approved to proceed.

Steps 2 and 3: If approved, a jet plane would obviously need to be broken down into different sub-systems to allow different, specialized groups within (or outside) our company to work on it, for example, the jet engine or the cabin/seat design. Within each of those specialized areas, engineers would likely begin by conducting feasibility studies to test various potential solutions before proceeding with development.

Step 4: Once an agreed-upon solution was selected, development work would then proceed. Within a company-driven effort, it is likely someone or some group would be responsible for overseeing the overall project to ensure the different sub-systems come together as planned on time and within budget.

Although the nuances may change from effort to effort, and company to company, this process is relatively consistent for most system-engineering efforts. 3GPP's development of technical specifications is very much analogous to this. The only fundamental differences are that 3GPP develops technical specifications (vs. jet planes), is constrained by meeting time (vs. OPEX $ and resources) and is a collaborative effort across hundreds of different entities with potentially diverse interests/incentives. Furthermore, 3GPP has tens, if not hundreds of these system-engineering efforts going on at once. Some are more minor projects and some of them are very big projects — like designing a jet airplane.

3GPP is a collaborative, system-level engineering effort, and thus, the 3GPP workflow and working procedures reflect this. Figure 2 depicts a high-level view of the 3GPP process where you will notice a lot of similarities to the jet plane analogy above.

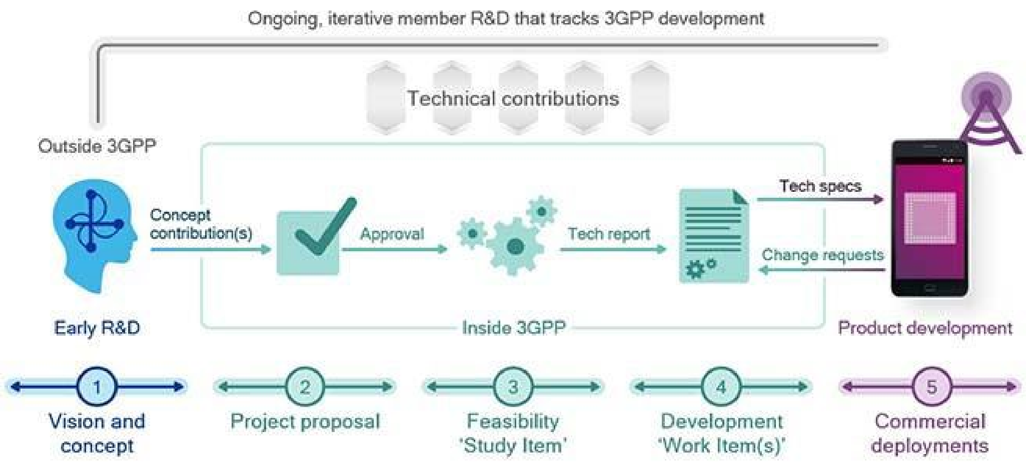


Figure 2: 3GPP working procedures and process.

A quick summary of the 3GPP process can then be listed as follows:

- Project proposals (Step 2 above) introduce new technical features/services into the cellular system and are initiated by individual members based on early development work (Step 1 above) done outside of 3GPP. In other words, there is no "Mr. 3GPP" deciding or driving what the next big cellular feature will be — it relies on the leadership of individual 3GPP Members (also called IMs).
- All new 3GPP work activity must be approved at the plenary meetings, which take place quarterly. Approval of significant features usually results in one or more approved Study Item(s) to conduct feasibility on multiple technology options/solutions (Step 3 above) based on the technical contributions of individual 3GPP members. The output of a Study Item is a Technical Report (TR) that details the agreed-upon concepts from the feasibility study.
- Once the Study Item is complete and TR approved, this may result in corresponding Work Item(s)2 to begin development work on the feature implementation details based on the agreed-upon concepts from the Study Item TR, as well as continued technical contributions from 3GPP members (Step 4 above). Agreed-upon implementation details are executed in 3GPP Tech Specification(s) — either creating new specifications or making updates to existing specifications. Once Technical Specifications are released, it kicks-off a race to deliver standards-compliant devices and infrastructure to enable wide-scale commercial deployments (Step 5 above).

There is one final and essential point on the way decisions are made in 3GPP. Decisions in 3GPP are technology-driven and result from a consensus-based process open to all members. 3GPP members submit technical documents, often referred to as contributions, to propose solutions and technologies. These contributions are discussed publicly in 3GPP meetings (time permitting). Any member can reject a contribution at any time, in which discussions about the contribution (and related alternative contributions) continue well beyond the 3GPP agenda and the 3GPP meeting in which the contribution(s) were originally presented. Thus, the 3GPP decision-making process is iterative and non-linear. Very few of the agreed-upon concepts in a Technical Report resulting from a Study Item or agreed-upon implementation details in Technical Specifications resulting from a Work Item are untouched from the initial member contribution(s). The agreed-upon concepts and implementation details instead come from a collaborative effort that involves iteration and negotiation between 3GPP members. One of the main reasons as to why 3GPP remains successful to date.

[2] Not all Work Items are the result of a Study Item — smaller, more evolutionary efforts may start directly and may have some study phase at the start of the Work Item

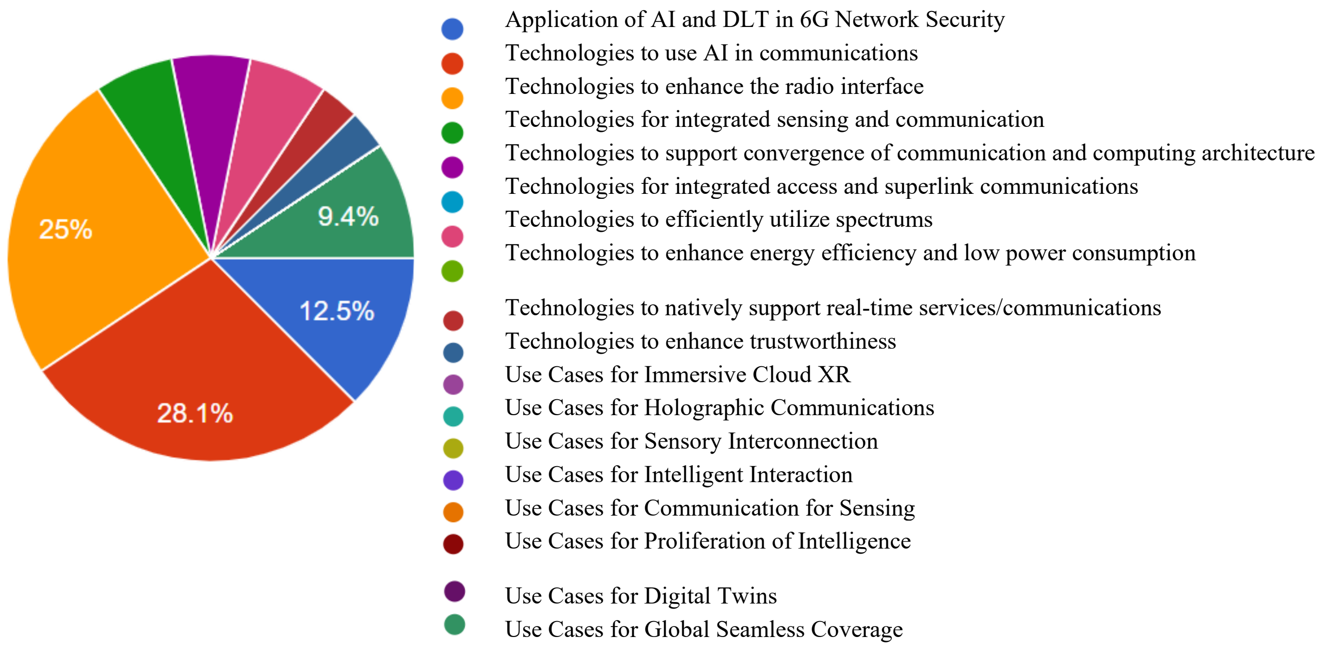
2.2 Classification of Industry Standardization

Industries worldwide that have an active Standardization engagement plan their engagements into the following four areas of standardization, which are critical to the development of communication systems and corresponding ecosystems:

- Spectrum and technical regulations: The timely availability of globally or regionally harmonized radio spectrum is a key requirement for the successful deployment of radio systems, including terrestrial mobile networks. Decisions are made by the International Telecommunication Union (ITU), regional regulatory bodies, or local bodies on a per country basis – all of whom place technical requirements on equipment to avoid inter-system interference. Additional technical regulations, including physical restrictions on the deployment of equipment, electromagnetic field matters (EMF), and cyber and physical security aspects must also be in place to ensure the successful rollout and use of mobile networks.
- Connectivity networks: Here, the rules dictating how to interact in the ecosystem of connectivity networks are set. These encompass, for example, the multivendor interfaces and application program interfaces (APIs) that ensures global connectivity across networks and enable the unprecedented scaling of products.
- Ecosystem expansion: Ecosystem expansion standardization ensures that markets using mobile technologies – especially those new to the industry – fully understand and can properly utilize connectivity networks. Activities within this area also include harmonizing the requirements of such markets within the standardization of connectivity networks.
- Implementation components: The standardization of implementation components ensures the availability of the components and technologies needed to implement connectivity network products and services worldwide.

2.3 Intent to contribute to 6G Standards

To assess the ability of Indian entities to participate in 6G standards development, inputs were collected from a select set of Indian entities(list available in Annex 1). Accordingly, a set of questions were asked to these representative companies to assess the capability of these Indian Comm Tech Companies on Product, R&D and 6G Standards contribution. Based on the information provided by them these Indian Communication technology enterprises have an intention to contribute to the following areas for 6G Standards:



Starting with the research above, India needs to put together a roadmap and vision for 6G technology development and Standards contribution.

2.4 Regional Research Initiatives on NextGen Networks

Various countries and regions have already announced formal plans of government support for their research and development efforts that will define 6G. They all have the goal of firmly establishing themselves as the epicentre for the next generation of innovation and economic growth.

Funding for such national programs is happening throughout the world today. Some programs worth mentioning are as follows:

- Europe
  - Smart network & services joint undertaking (EU - research program)
  - Hexa-X (EU - research project)
  - 6G Genesis (Finland – research project)
  - BMBF (Germany – funding body)
  - KTH Digital Futures (Sweden – research center)
- China
  - Promotion groups by the Ministry of Industry Information Technology (MIIT) and National Key R&D Program by Ministry of Science and Technology (MOST)
- USA
  - NSF Project (see details below)
  - RINGS
  - NextG Alliance
- Canada
  - NSERC, Mitacs, SIF
- Japan

    - B5G Consortium (MIC)
    - NICT
- Korea
    - 6G R&D strategy (Ministry of Science & ICT)
    - ETRI

US National Science Foundation funds research on Advanced Wireless Next Generation Systems, which involves a broad participation across industries. Some of their ongoing projects include:

- Resilient and Intelligent NextG Systems (RINGS): Accelerate research in areas with significant impact on next generation (NextG) wireless and mobile communication, networking, sending and computing systems
- Platforms for Advanced Wireless Research (PAWR): Research to enable experimental techniques, networks, systems, and devices
- Spectrum Innovation Initiative (SII-Center): New advanced and automated spectrum management techniques
- Spectrum and Wireless Innovation Enabled by Future Technologies (SWIFT): New technology or significant enhancements to existing wireless infra for improving spectrum utilization, beyond spectrum efficiency
- Machine Learning for Wireless Networking Systems (MLWiNS): Wireless specific ML techniques for dynamic spectrum access, improve radio/network resource efficiency, scale to address diverse and stringent QoS of future wireless applications.

The importance associated with programs around 6G cannot be underestimated and would revolve around the following aspects:

- Significant Global economic value expected from mobile / cellular industry
- Connectivity remaining crucial for economic and societal development
- Critical communications infrastructure increasingly dependent on mobile connectivity
- Indian leadership in key technologies and ensuring security and resiliency of Next G is important

An Indian initiative led by industry and with support from government will be essential for balancing the efforts of these other regions and ensure our 6G leadership. Government, industry, and academia will need to cooperate more closely in identifying research priorities. This should begin with a concerted effort by industry, academia, and government to develop a research agenda for 6G leadership in areas of shared interest. As a first step in the process, the government should facilitate a stakeholder's session jointly with industry and academic members to engage in a dialogue identifying mutual 6G research priorities.

3. Global Initiatives on 6G

Worldwide interest has also started among the industry members on aligning research outcomes to the standards development processes.

- North America: NextG Alliance
- Europe: 6G IA
- China: IMT 2030PG initiative Future Forum
- Japan: B5G Consortium
- Korea: 5G Forum (MoU with Next G Alliance)
- India: TIG-6G (in the formation stage)

A key to fast and seamless adoption of new technologies across the globe is a timely and effective standardization, performed by Standards Developing Organizations (SDO), aligned among all relevant stakeholders. Several SDOs are expected to work on 6G, e.g., 3GPP, ETSI, IETF and IEEE, in a much tighter way than they did for 5G, as 6G intends to merge and make work together different technologies, which have been taken care of, so far, by different SDOs.

Effective standardization requires sound regulation and governance that surround the technical work of the SDOs and ensure proper legal frameworks among different geo-areas. The national approach to regulation is an artifact of technological opportunities and institutional and social acceptance models. As 6G becomes pervasive the challenge of how and what to regulate becomes ever more intense.

3.1 Timeline

Standardization work on 6G is not expected to start till 2025. Initial efforts on identifying future service needs for the next decade, as the ones performed by ITU-T with the Focus Group on Network 2030, have fostered the definition of evolutionary steps from 5G networks being deployed nowadays. The International Mobile Telecommunications (IMT) systems for 2030 and beyond will be developed as a global standard to better serve the communication needs in every continent of the world.

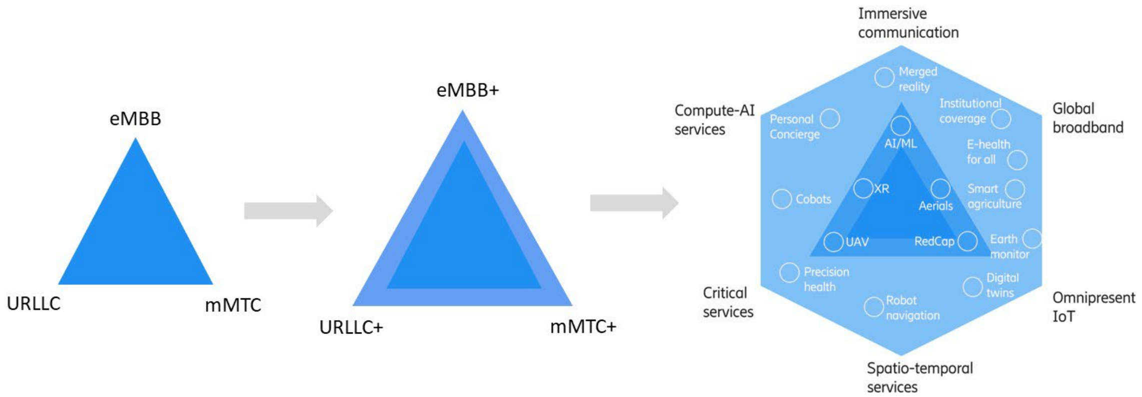


Figure-3: The evolution of usage scenarios from IMT-2020 to IMT for 2030 and beyond (source: ITU-R)

The overall usage scenarios in 6G are envisaged to emerge further from the three basic categories in 5G i.e., eMBB, mMTC and URLLC. These three basic categories are expected to expand into 6 different service categories based upon use case requirements. These usage scenarios can further be mapped into various key user applications and capabilities (Figure 3).

The 6G timeline is under development by SDOs, 3GPP, ITU, and other interested organizations. ITU-R Working Party 5D (IMT Systems) is responsible for overall planning for IMT (International Mobile Telecommunications) systems and develops its schedule based on input from SDOs, specification groups, and industry. The current timeline being discussed in the related ITU-R WP 5D group is made available in Figure 4.

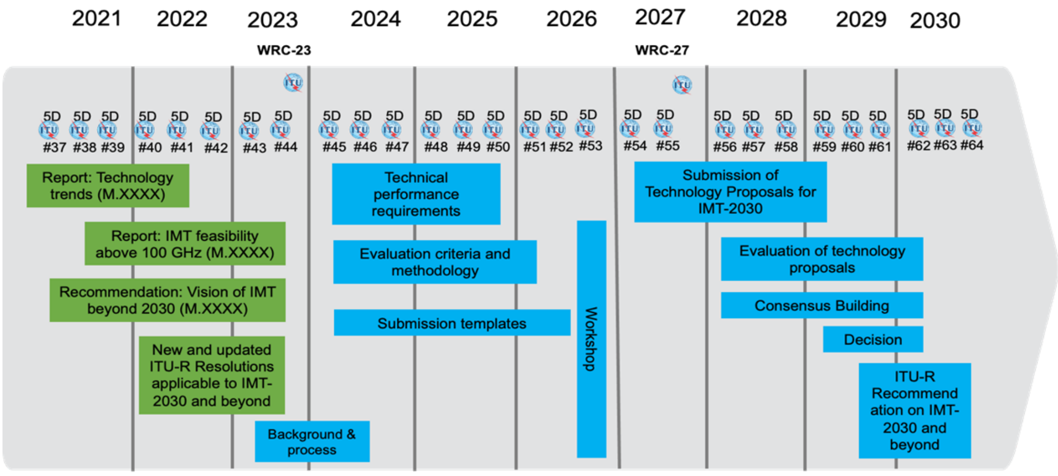


Figure 4: Current timeline consideration at ITU-R WP 5D on IMT specifications for 2030 and beyond

To achieve global interoperability, mobile systems are specified and standardized in international forums, such as ITU and 3GPP. The ITU approach is for external organizations and members to submit their 6G technical proposals for consideration. It is expected that the main technical specification of 6G systems will be done in 3GPP to maximize global harmonization. It is critical that India takes a leadership role in the development of 6G specifications and standards. While standards should continue to be private sector led, alignment between industry and government on key drivers for Indian success will ultimately deliver standards that meet the worldwide marketplace needs and values.

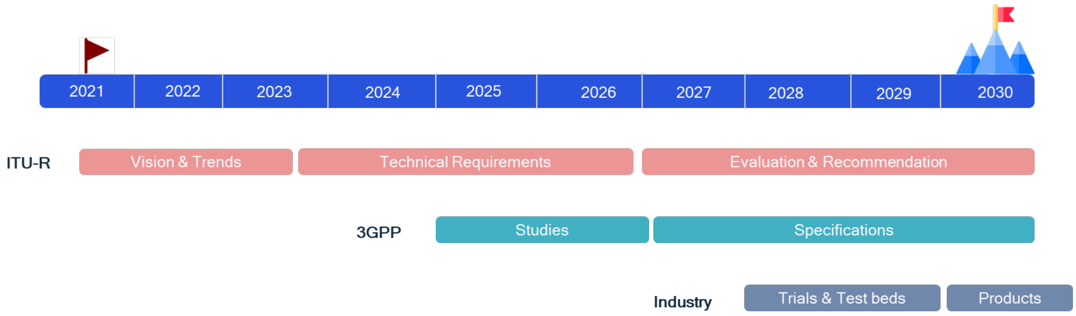


Figure 5: Overall roadmap for 6G development (tentative)

The development of 6G systems is expected to happen in parallel to various stages of the standardization effort; testbeds and trials can be used to validate technical choices made during standardization and to obtain experience with implementation options. Additionally, during the deployment and commercial operation, new services requirements will emerge for an evolution of the 6G systems, with input into the research, innovation, and development lifecycle. From 3GPP standards development point of view, there are yet features and capabilities from existing 5G solutions that require full specification, and which are expected to be completed in forthcoming 3GPP Release 18, targeting end of 2023. Next releases, by mid of the decade, i.e., 2025, are expected to be focused on 5G evolution, in parallel to the analysis of 6G, and finally on the proper 6G specification. Figure 5 illustrates the overall roadmap for 6G development.

4. Creating a vision for 6G success in India

The next generation of wireless technology will be woven into the daily lives of society to an even greater degree than today's technology. This role presents tremendous opportunities for 6G to facilitate key public policy objectives in areas such as security, privacy, environment, safety, health, sustainability, and equity, among others. But a policy framework that provides clarity to the industry, balanced with the flexibility necessary to promote competition in innovation, will be critical to create a foundation for key 6G applications and use cases.

Successful implementation of India's 6G vision must include an effort to work with other market-driven partners on common approaches to key policy issues to the extent possible. The very nature of advanced communications technologies facilitates the ability to offer services and social benefits across borders. Identifying areas for consistent societal, legal, and regulatory regimes will enable 6G technologies to achieve their full potential. Additionally, agreement on approaches will promote greater leverage in support of those positions within international bodies establishing standards for 6G.

To achieve the above objective, it is essential that India starts working towards globally harmonized standards to leverage global economies of scale both for network & devices, as it ensures international roaming & interoperability across networks deployed globally. It is pertinent to note that this approach caters to all the segments of stakeholders. Most importantly, it will be beneficial for consumers leading to least cost implication in terms of handsets and service cost, availability of commercial devices, which will work across the networks in India and while roaming outside of India. For the industry, it leads to optimized use of investments, minimal implementation impacts on the evolution of existing networks and economies of scale. This also syncs with the Government's regulatory and policy measures in terms of least implications to prevailing regulatory requirements and attracting investments towards manufacturing in India for the world.

To successfully compete with the aggressive efforts of other countries, the Indian government must provide resources to support a collaborative framework for research engagements jointly led by the industry, academia, and other domestic stakeholders. Such support would include:

- Financial support and incentives for undertaking basic research,
- Access to government test bed facilities,
- Bridging the gap between research and development to promote adoption of early-stage technologies.

Public and private investments shall focus on key 6G technologies, such as programmability, integrated sensing and communication, trustworthy infrastructure, scalability, and affordability, as well as AI/ML, microelectronics (at least in design), photonics, batteries (e.g., for mobile devices), software, and other technologies that may help to reduce the energy footprint. India needs an effective and inclusive program to foster Entrepreneurship with private and public participation, complemented with tax policies, to create new businesses around the creation, development, and delivery of these technologies.

The ultimate completion of 6G requires full interoperability between all entities on all levels, i.e., global standards. This would ensure an affordable and scalable 6G system that may be utilized worldwide. Effective standardization requires sound regulation and governance, which in turn require a common certification process, considering the growing number of vendors that will develop for an ecosystem across the world, plus a lean process that would allow verticals to sell their services from anywhere to everywhere. While India can focus on doing Stage 1 (requirements) and 2 (architecture) standardizations work within the different structures identified (TEC, BIS, WPC, TSDSI, etc.), Stage 3 (normative) standardization work should focus on international bodies including the likes of ITU-R, ITU-T, 3GPP, IEEE, etc., so that there is more global acceptance, nd recognition to the efforts and commitments from India. We need to also do effective coordination among different Indian entities active in 6G and with global counterparts (viz., NextG Alliance, HEXA-X, IMT2030-PG, etc.) through the establishment of MoU's and cooperation agreements, to leverage our skills and avoid duplication of efforts.

To begin with, India needs to put together a roadmap and vision for 6G technology development. The scope of such a document is to provide a foundational vision for 6G that addresses both Indian needs and global alignment goals and to develop priorities and strategies for achieving Indian leadership alongside other regions' leadership. This includes describing the key challenges across social and economic, technical, spectrum, applications, and sustainability (e.g., energy, environmental) considerations, and recommending governmental actions and standardization strategies. Progression in 6G development and standardization should lead to a proactive market readiness stage, where policies and incentivized innovation can set the stage for a robust 6G marketplace. Market-ready spectrum policies and incentives for widespread 6G deployment would lay the groundwork for rapid commercialization and deployment. It is imperative for industry and government to cooperate on policies and actions that facilitate strong market readiness for 6G.

In addition to internal discussions, the task force has also interacted with the representatives from global 6G initiatives like the US[3] Next Gen Alliance (NGA) and the EU[4] SNS-JU to understand the globally prevalent methodologies and best practices. Their presentations are attached as an annexure to this report.

This task force recommends the following aspects:

- A 6G program be created with a broad category of ecosystem partners including operators, vendors, hyper scalers, academia, and Government research labs, that is agile and quickly adaptable to the evolving needs for driving 6G research and innovations, building on and strengthening India's competencies. (e.g., Next Gen Alliance was setup outside the ATIS, with its own working procedures)
- This set of stake holders through a consensus driven approach recommend topics/themes of interest in 6G based on business and societal needs. The program should cover all aspects of technology development including early research, proof-of-concept, standardization, trials & testbeds, etc.
- Government of India taking a lead in streamlining the process and fund research programs on the themes identified.
- The 6G program to take a lead in preparing well defined measurable KPIs to assess the success of these program funding.
- The objectives of this framework are also to have cohesive policies to meet common goal of national leaderships, national 6G Roadmap, Sustainability goals, etc.
- It is important that this initiative gains momentum immediately and aligns to the timeline of various 6G standards efforts across the globe.
- The 6G program should take a lead in developing consensus on solutions of interest and pursue the standardization efforts at the corresponding international standardization bodies
- Concurrently, the program should facilitate early trials and prototype development, aimed at developing proof-of-concepts and support the domestic manufacturing process.

The internal framework that we propose to adopt and to build in India should be consistent with the framework that is being discussed in ITU and 3GPP. All aspects of technology development that we need to pursue should be converging with the universal standardization process happening globally. As independence existence of a country specific technology is not possible in this age, we can observe from the regulatory process, in which direction the wind blows, and accordingly revise our strategies dynamically. This can be realized only by participating in the standardization process actively by influencing in the creation of IMT 2030 framework as well as subsequent standardization process at 3GPP to be dictated by our national R&D activities and as per our tested prototypes. That means our technology development should sync with the progress of the regulation. As we could see, certain countries taking very aggressive approach in ITU-R and steer the discussion in that direction. This way only we can ensure that our technology, if shaped towards the objectives of 6G, is not alienated in the overall scheme of things.

Indian and Atmanirbhar Approach to 6G Standards:

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[3] Next G Alliance by ATIS, https://nextgalliance.org/

[4] EU SNS https://digital-strategy.ec.europa.eu/en/policies/smart-networks-and-services-joint-undertaking

- 6G program imperatives
  - "Big Bets" by investing heavily on development of 6G Standards in defined/ focused areas, as opposed to natural evolution based on market driven forces
  - Evolution of the 'Public Sector model' of the 60s and 70s to the "Public Investment" for Atmanirbhar Bharat
  - "Identifying the process for discovery of prioritised areas for 6G Standards" rather than "Identifying the prioritised areas for 6G Standards"
- 6G Focus areas for India
  - For the Indian Society
  - For the Indian Industry
  - For international market forays/ global market access
- Sustainable Standards driven Research Program must include
  - Sustainable 6G Roadmap R&D/ Standards Contribution Areas
  - Sustainability Capability (Start-ups, Academia, Industry)
  - Sustainable Resource (Academia, Industry)
  - Sustainable Funding (Government, Industry)
  - Sustainable Global 6G Standards Participation program

India must step up to the 6G standards and technologies in a bold and aggressive manner, in order to create the ecosystem and framework for contributing meaningfully to the 6G economy in a sustainable and impactful manner.

Annexure A: 6G Standards Engagement for Atmanirbhar Bharat

Winning in the digital age will require India to demonstrate technical and technology leadership at the international stage. India must make the shift from Services to Products to claim a substantial part of the coming growth for itself. It must also change to its posture to an aggressive proactive contributor to 6G Standards, from being a follower or just a compliance seeker.

Successful implementation of India's 6G vision must include a deep dive to understand the state of art in the country. It must also understand the current state of research capabilities. And then, it must understand the areas in which the Indian ecosystem is committed towards contributing to 6G standards.

A very high-level research summary to this effect is produced below.

A.1. List of Companies participated in the survey

Sl.	Company Name
1	Accord
2	Alif Semiconductor
3	Astrome Technologies
4	Big Cat Wireless
5	CDOT
6	Cientra Techsolutions
7	Coral Telecom
8	DSP Works
9	Dyotis Technologies
10	Easiofy
11	Eigen Technologies
12	ELCOM
13	Enmovil Solutions
14	Frog Cellsat
15	HFCL
16	Indio Networks
17	Infinity Labs
18	Inventum Technologies
19	ITI
20	Kenstel Networks
21	Kotkar
22	Lavelle
23	Lekha Wireless
24	Linking Minds
25	Mannash Solution
26	Matrix Comsec
27	MCBS
28	NEXGE Technologies
29	Nimble Vision
30	Niral Networks
31	Nivetti Systems
32	NMS Works

Sl.	Company Name
33	Resonous Technologies
34	Saankhya Labs
35	Samriddhi Automation
36	Sparsh Technology
37	Sensegiz
38	Sensorise
39	Signaltron
40	Signalchip
41	SNS Softtech
42	Sookhta
43	Sterlite
44	TCS
45	Tejas Networks
46	UTL
47	Valles Marineris
48	VNL
49	Vista Inf.
50	VVDN Technologies
51	WiSig

A.2. Product Capability Areas

The Indian Communication technology enterprises have demonstrable products and capabilities in the following areas, where at least three or more companies provide a viable product portfolio:

Products & Capabilities	Org. count
Small Size LTE/ LTE-R Based Mobile Systems, with its various derivatives including rural & disaster communications, Macro & Micro eNodeB, Small Cells, EPC, NIB C-RAN BBU and RRH, LTE/ LTE-R/ LTE Advanced based broadband wireless access systems (eNodeB, gNB, EPC, etc.) in all standard LTE bands in the country	11
Smart City Solutions	10
IoT Modules	9
LTE/ LTE-R Based Mobile Systems, with its various derivatives including rural & disaster communications, Macro & Micro eNode B, Small Cells, EPC, NIB C-RAN BBU and RRH, LTE/ LTE-R/ LTE Advanced/ based broadband wireless access systems (eNodeB, EPC etc.) in all standard LTE bands in the country	8
Software Defined Radio, Cognitive Radio systems (all bands)	8
Telecom Network Management systems (NMS) with its various derivatives	8
IP/ MPLS Core routers/ Edge/Aggregation/ Enterprise Router	7
M2M/ IOT Subsystems including NB IoT in different verticals	7
Pico eNodeB, Category 2, TEC ENB GR (TDD/FDD)	7
Radio systems (IP/ Hybrid), Mobile Front haul BBU and RRH (CPRI, eCPRI, FlexE, RoE, NGFI)	7
Disaster Communication Systems etc., including backpack satellite products	6
IoT based SCADA Devices	6
IP based Soft Switches, IMS, Unified Communication Systems	6
Telecom & IT Software Solutions	6

Products & Capabilities	Org. count
Telecom Network Management systems (NMS) with its various derivatives including Operation Support System (OSS), Billing Support System (BSS), Trouble Ticketing System (TTS)	6
Ethernet Switches (L2 and L3)	5
GPON equipment (including ONT and OLT)	5
IoT Based Customer Feedback Devices	5
Mesh network of Hardware, Cloud, analytics and Software	5
Remote Device Management & Data Acquisition	5
Satellite based systems	5
Video Conferencing Applications	5
Wireline PABXs / IP PBX	5
Encryption/ UTM platforms (TDM and IP) (Unified threat management)	4
Gateways: GSM, V0IP, Signalling,	4
Home Automation based on Wi-Fi or sub-GHz solutions including sensors, remotes	4
IP audio phones / IP video Phones / Analog adaptor	4
mm Wave Systems	4
Other satellite equipment	4
Outdoor AP (802.11ac - MIMO 2.4 and 5 GHz bands - IP67 Rated	4
Satellite based IoT Systems including location, resources tracking	4
Satellite Communication- Ground/ Earth Station Antennas	4
Space Communication	4
Unified Communications and IP Telephony	4
VoIP and SIP Phones (User Terminals Phones)	4
XGS-PON,	4
Drone Communication	3
Embedded Transaction Device	3
EPC (Enterprise class)	3
Media Gateways	3
NB-IoT Geo Satellite Systems	3
NFV/ SDN CPE	3
NG-PON2	3
Outdoor AP (802.11n/b/g - MIMO 2.4 and 5 GHz bands - IP67 rated	3
Portable RAN Framework	3
Remote management platforms for SIM, Subscription and Device enablement	3
SDN Software Controllers, NVF and CNF software	3
Security and Surveillance Communication Systems (video and sensors based) including Perimeter Security Systems	3
SIM Applets for Subscription Management & Control	3
Telecom Consultancy	3
Telecom OSS with its various derivatives	3
VSAT Systems	3
Wi-Fi based broadband wireless access systems indoor & Outdoor (Including Access Point, Aggregation Block, Core Block)	3

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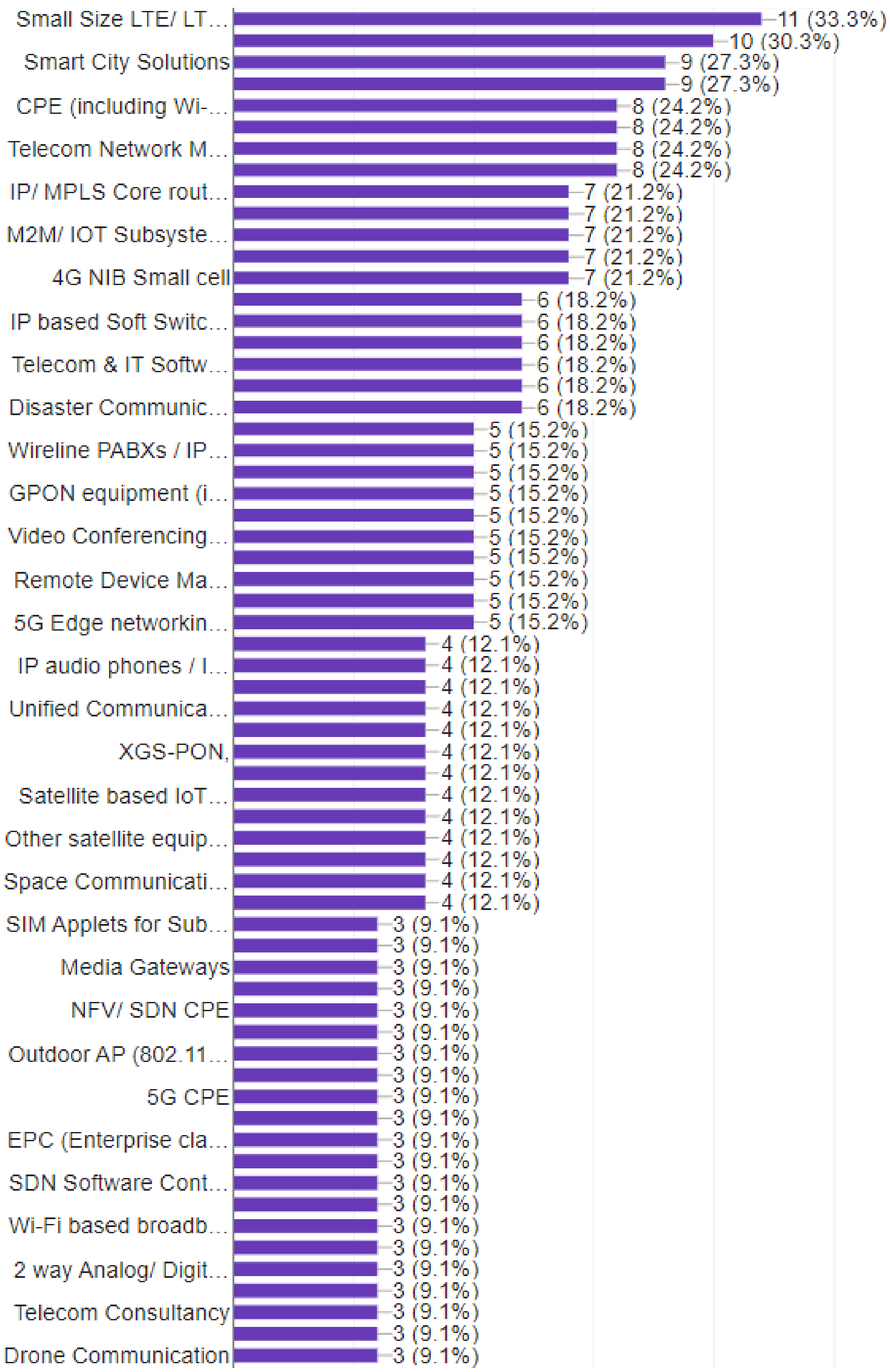
Small Size LTE/ LT…
Smart City Solutions
CPE (including Wi-…
Telecom Network M…
IP/ MPLS Core rout…
M2M/ IOT Subsyste…
4G NIB Small cell
IP based Soft Switc…
Telecom & IT Softw…
Disaster Communic…
Wireline PABXs / IP…
GPON equipment (i…
Video Conferencing…
Remote Device Ma…
5G Edge networkin…
IP audio phones / I…
Unified Communica…
XGS-PON,
Satellite based IoT…
Other satellite equip…
Space Communicati…
SIM Applets for Sub…
Media Gateways
NFV/ SDN CPE
Outdoor AP (802.11…
5G CPE
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SDN Software Cont…
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2 way Analog/ Digit…
Telecom Consultancy
Drone Communication
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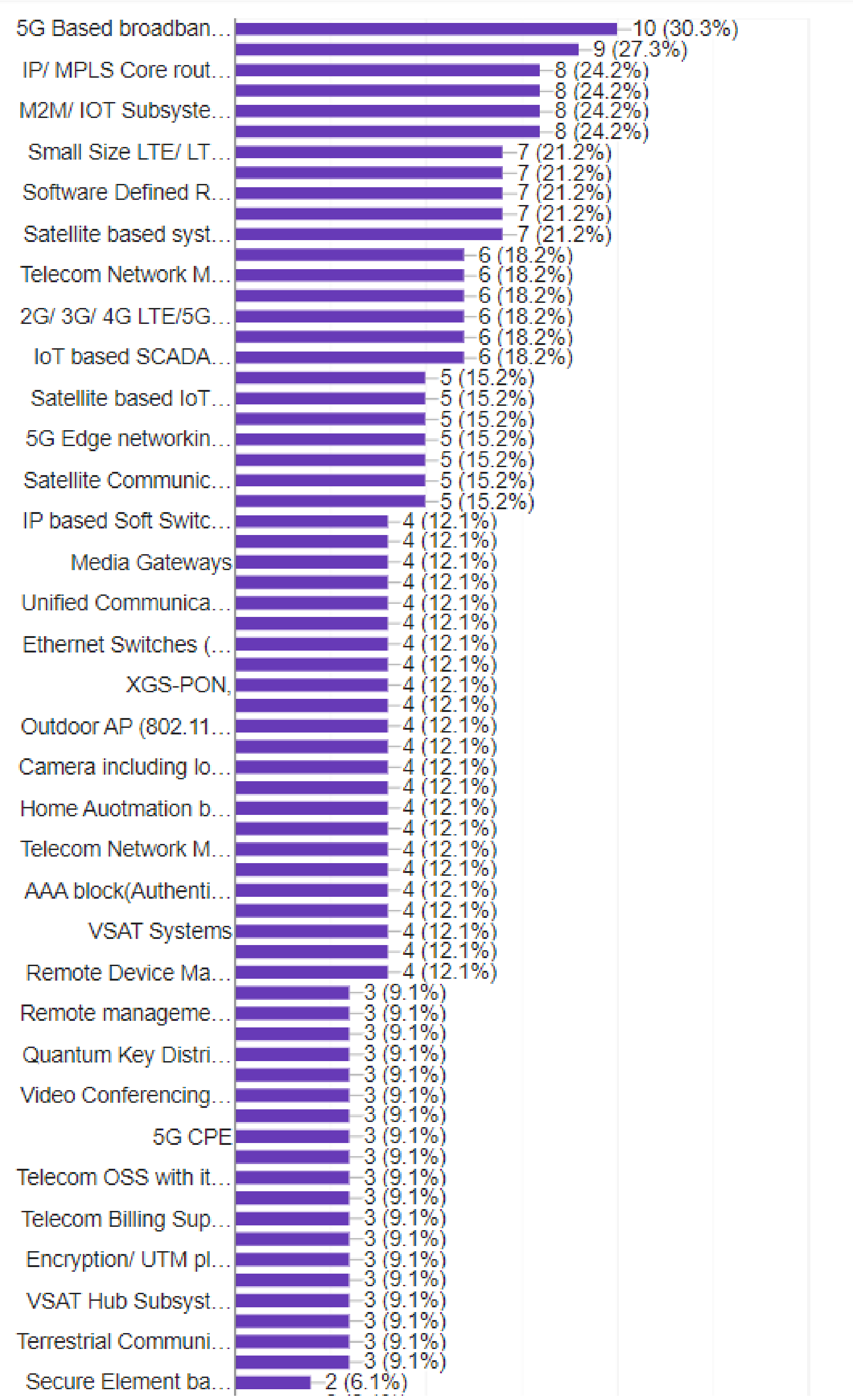
A.3. R&D Capability Areas

The Indian Communication technology enterprises have ongoing research and development in the following areas, where at least two or more companies have a viable investment:



A tabular form of prioritized R&D capabilities is presented below:

Fields	Organisations in R&D
5G Based broadband wireless infrastructure systems including gNodeB, 5G Core	10

Fields	Organisations in R&D
IoT Modules	9
IP/ MPLS Core routers/ Edge/Aggregation/ Enterprise Router	8
LTE/ LTE-R Based Mobile Systems, with its various derivatives including rural & disaster communications, Macro & Micro eNode B, Small Cells, EPC, NIB C-RAN BBU and RRH, LTE/ LTE-R/ LTE Advanced/ based broadband wireless access systems (eNodeB, EPC etc.) in all standard LTE bands in the country	8
M2M/ IOT Subsystems including NB IoT in different verticals	8
Telecom & IT Software Solutions	8
CPE (including Wi-Fi Access points and Routers, Media Converters),	7
Pico eNodeB, Category 2, TEC ENB GR (TDD/FDD)	7
Satellite based systems	7
Small Size LTE/ LTE-R Based Mobile Systems, with its various derivatives including rural & disaster communications, Macro & Micro eNodeB, Small Cells, EPC, NIB C-RAN BBU and RRH , LTE/ LTE-R/ LTE Advanced based broadband wireless access systems (eNodeB, gNB, EPC, etc.) in all standard LTE bands in the country	7
Smart City Solutions	7
Software Defined Radio, Cognitive Radio systems (all bands)	7
2G/ 3G/ 4G LTE/5G Modems	6
4G NIB Small cell	6
Disaster Communication Systems etc., including backpack satellite products	6
IoT based SCADA Devices	6
Telecom Network Management systems (NMS) with its various derivatives	6
5G Edge networking platform	5
mm Wave Systems	5
Other satellite equipment	5
Radio systems (IP/ Hybrid), Mobile Front haul BBU and RRH (CPRI, eCPRI, FlexE, RoE, NGFI)	5
Satellite based IoT Systems including location, resources tracking	5
Satellite Communication- Ground/ Earth Station Antennas	5
Space Communication	5
AAA block(Authentication, Authorization & Accounting)	4
Camera including long range camera, IP camera & Recorders, Night vision cameras	4
Cloud Computing	4
Distributed Unit (DU)	4
Ethernet Switches (L2 and L3)	4
Home Automation based on Wi-Fi or sub-GHz solutions including sensors, remotes	4
IoT Based Customer Feedback Devices	4
IP audio phones / IP video Phones / Analog adaptor	4

Fields	Organisations in R&D
IP based Soft Switches, IMS, Unified Communication Systems	4
Media Gateways	4
NFV/ SDN CPE	4
NG-PON2	4
Outdoor AP (802.11ac - MIMO 2.4 and 5 GHz bands - IP67 Rated	4
Outdoor AP (802.11n/b/g - MIMO 2.4 and 5 GHz bands - IP67 rated	4
Remote Device Management & Data Acquisition	4
Telecom Consultancy	4
Telecom Network Management systems (NMS) with its various derivatives including Operation Support System (OSS), Billing Support System (BSS), Trouble Ticketing System (TTS)	4
Unified Communications and IP Telephony	4
VoIP and SIP Phones (User Terminals Phones)	4
VSAT Systems	4
Wi-Fi based broadband wireless access systems indoor & Outdoor (Including Access Point, Aggregation Block, Core Block)	4
Wireline PABXs / IP PBX	4
XGS-PON,	4
5G CPE	3
Drone Communication	3
Encryption/ UTM platforms (TDM and IP) (Unified threat management)	3
EPC (Enterprise class)	3
Gateways: GSM, V0IP, Signalling,	3
GNSS based Time Servers (including navIC) NTP. IEEE 1588/PTP for Time Synchronisation and Standalone GNSS receiver for location information	3
GPON equipment (including ONT and OLT)	3
Mesh network of Hardware, Cloud, analytics and Software	3
NB-IoT Geo Satellite Systems	3
Quantum Key Distribution (QKD)	3
Remote management platforms for SIM, Subscription and Device enablement	3
SIM Applets for Subscription Management & Control	3
Telecom Billing Support System (BSS) with all its derivatives	3
Telecom OSS with its various derivatives	3
Terrestrial Communication	3
Two-way MSS Data Terminals (Satellite Receivers with location data)	3
Video Conferencing Applications	3
VSAT terminal Subsystem - IDUs	3
VSAT Terminal Subsystem - ODUs	3
Over-the-Air Technology	2
Secure Element based Identity and Encryption Systems	2

A.4. External Presentations

"NextG Alliance" Presentation by Dr. Farrokh Khatibi (Qualcomm)

Next G Alliance.pdf

"EU's 6G Smart Networks and Services (SNS) Joint Undertaking" presentation by Dr. Colin Willcock.

EU 6G-IA
Presentation to TSDSI

6G Taskforce Report: R&D Finance

Chairperson: Shri A K Tiwari

Member Secretary: Shri Kishore Babu

1. Background

Telecommunication technology products require significantly large funding and long gestation periods for R&D and commercialization. The stages move from ideation, research, incubation, prototyping, lab testing, miniaturization, field testing, hardening, securitization, outdoor readiness, licenses for background IPs, Standardization etc. In the cases of deep tech SoCs (System on Chips) funding needs would go further higher due to multi-layers of prototyping. These are some of the factors which enabled only a few global companies to sustain in the market while continuously investing in R&D withstanding aggressive global competition. In this scenario, standardized open interfaces have enabled emergence of small niche companies to develop products to meet various requirements in both public and private networks.

India is in the cusp of emergence of several small companies, start-ups and academia in these niche areas opening new doors for positioning India on global Digi-com technology landscape. The brimming start-up ecosystem is an added strength to in the 6G technology initiative. The outcome of supply-base assessment carried out by DoT a few years back reflects competencies across industry and academia (indigenous 5G Testbed) to firmly believe that with suitable and sufficient funding, policy handholding will enable Indian players to play an important role in global partnerships in 6G and beyond programs with significant value add in global value chain.

As may be seen in the figure-1, patents filed in communication Technologies at Indian Patent office are relatively small.

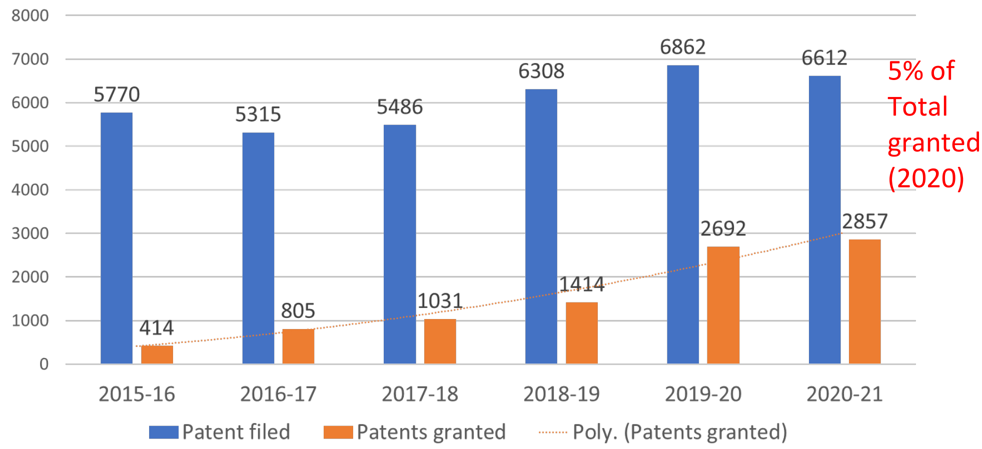


Figure 1: Communication Technology Patents (Indian Patents Office)

Technology ownership and control is transcending over-the normative trade principle of just reducing import bill but is gaining strategic importance in view of geo-political relations. Technology ownership is also being directly related to making affordable technologies across economic verticals for proliferation of technology adoption.

The Taskforce on R&D funding is constituted with the following terms of reference to enable Indian R&D ecosystem leapfrog in the 6G activities with concrete outcomes in terms of the development of technologies, contribution to global 6G standards and commercialization of the developed products for domestic and global markets.

1.1. Terms of Reference

- Develop a roadmap for funding R&D, Pre-standardization, Standardization Activities, Development of 6G Technologies, Products and Applications
- Mechanisms for vetting R&D budget proposals under the 6G Mission
- Funding models and modalities of R&D activities and ecosystem – Academia / Industry / industry-Academia joint partnerships, IPR Development, Standards Development, Proof of Concepts, PPP Projects, Testbeds, Setting up CoEs, Pilot Rollouts etc.
- Any other items in the scope of funding of 6G activities including awareness, capacity building, hackathons, and over all deliverables.

Other taskforce's chairs are also part of the R&D funding taskforce (constitution at **Annex 1**) to bring in respective taskforce plans and programs as part of the larger funding proposition and build synergies.

2. Objectives for 6G R&D Funding

- To promote the ecosystem for research, design, prototyping, development, proof of concept testing, IPR creation, field testing, security, certification and manufacturing.
- To develop and establish relevant standards to meet national requirements and enable their standardization in international standardization bodies.
- To enable proliferation of affordable broadband and mobile services; positioning state of the art communication technologies for rural and remote areas to bridge digital divide.
- To create synergies among the Academia, Research Institutes, Start-ups and Industry for capacity building and development of telecom ecosystem through outreach to build relevant technologies and solutions.
- To bridge the gap between R&D and commercialization of products and solutions.
- Commercialization of developed technologies for domestic and global markets.
- To build competency base for beyond 6G communication technologies.

3. Summary of Recommendations

- The programs under 6G to encourage building technology ownership, developing IPRs and SEPs, moving from prototyping to commercialization as part of the project roadmap. CDoT along with other research institutions is envisaged to play a significant collaborative role.
- Funding needs are diverse for academia, industry, research organizations to build capacities and competencies in different stages of R&D for 6G program in the coming ten years. Hence, different funding mechanisms and instruments to be adopted with flexibility and liberal norms.
- Funding to cover different activities under research, design, prototyping, development, proof of concept testing, IPR creation, standardization (Including pre-standardization) standards participation, field testing, security, certification in the R&D process.
- The projects may include Research Testbeds, R&D in products such as network elements, antennas, reflectors, systems, devices, SoCs. At a later stage, they may extend to largescale trials, CoEs for use cases etc. As part of funding, a seed funding for the joint international projects may be explored on bilateral and multilateral platforms.
- Since from inception i.e., research stage, industry participation from technology companies and system integrators should be envisaged to enable scale R&D to higher TRL levels with agility and velocity.

- Apart from technologies which are upgrades of 5G+, several new research projects may be necessary to work on cross-platform projects, that may require significant funding to contribute to IPRs in 6G research.
- A program to identify industry champions to facilitate funding on liberal terms may be initiated. It should also identify "academia clusters' for taking up programs based on competencies in different verticals and 'system integrators' for orchestrating new generation products.
- Constitute an Apex Level Advisory board with Indian experts from India and abroad for advising on programs and funding needs. Members from relevant ministries to be included to enable synergies in funding related programs.
- There is a need to create a large corpus of R&D fund to facilitate various funding instruments such as grants, loans, VC fund, fund of funds etc. A pool of Rs. 10,000 CR is envisaged to be created to service these requirements for the next 10 years with eye on R&D and commercialization. Government may take lead in creating this fund considering the budding technology ecosystem in the country to strengthen it for 6G and beyond technologies.
- Two tiers of grants are proposed i.e., up to Rs. 20 Cr to service funding requirements ranging from small to medium. Grants above Rs 20 Cr are envisaged for High Impact projects.
- Administrative set up for vetting R&D projects may include the following depending on the size and scope.
  - Inter-ministerial committee: The mechanism could commence its work in line with other R&D funding schemes like DCIS etc.
  - A Section 8 Company or Society may be envisaged exclusively as a delivery mechanism for 6G, and other telecom related programs or existing agencies of other ministries may also be considered on need basis.
  - Telecom focused VC fund and Fund of funds are envisaged for large size high risk funding needs.
- Entities eligible for R&D funding, indicative process, administrative structure are also indicated to enable early take off of the program.

4. Large capital needs for R&D

The figure 2 presents R&D expenditure of global majors including telecom OEMs. It may be seen the kind of investments that may have gone into 5G technology development noting the R&D expenditure in communication technology companies.

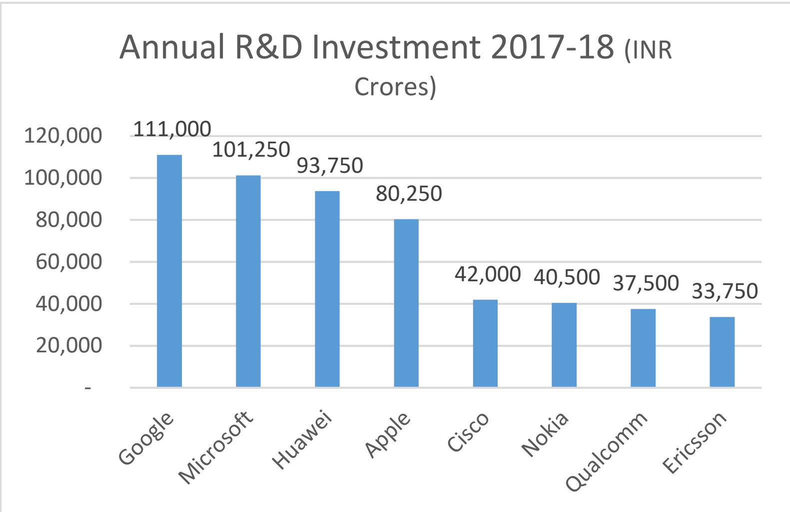


Figure 2 Source: https://spendmenot.com/blog/top-rd-spenders/

The figure 3 presents the role of different agencies including government, academia, small and large businesses in different stages of technology development. In the cases of new technologies development in TRL levels 1-7, the government is envisaged to take a lead role.

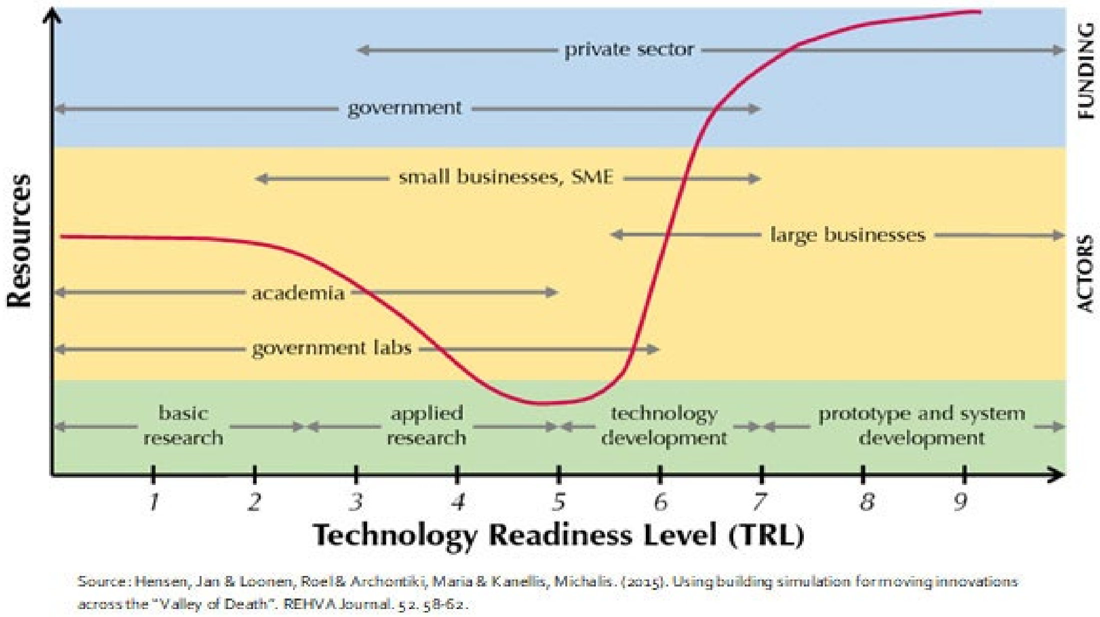


Figure 3 European Commission - EURAXESS

Taking note of strategic and economic needs of technology ownership in Critical and Emerging Technologies (CET), acknowledging the large needs of capital formation for telecom technology R&D and lead role envisaged from government, it is necessary, to create a large pool of capital for R&D in the country, through different financing structures and instruments.

As per the supply base assessment carried out by DoT, there are significant competencies in the country in technology products and platforms cutting across network infrastructure, transport, devices, platforms, SoCs, antenna systems etc. It was also noted many of the technology companies in the strata of SMEs and Start-ups are cash strapped for additional R&D funding despite their demonstrated competencies in 5G technologies. It may also be noted that patents filed by domestic companies is a fraction of total patents filed in telecom technologies.

5. Funding timelines

The following schematic presents a likely unified view of 3GPP, ITU regarding 6G program. While research projects are envisaged to dominate in the initial phases, the middle phase may focus more on standardization, prototyping followed by commercialization beyond 2028.

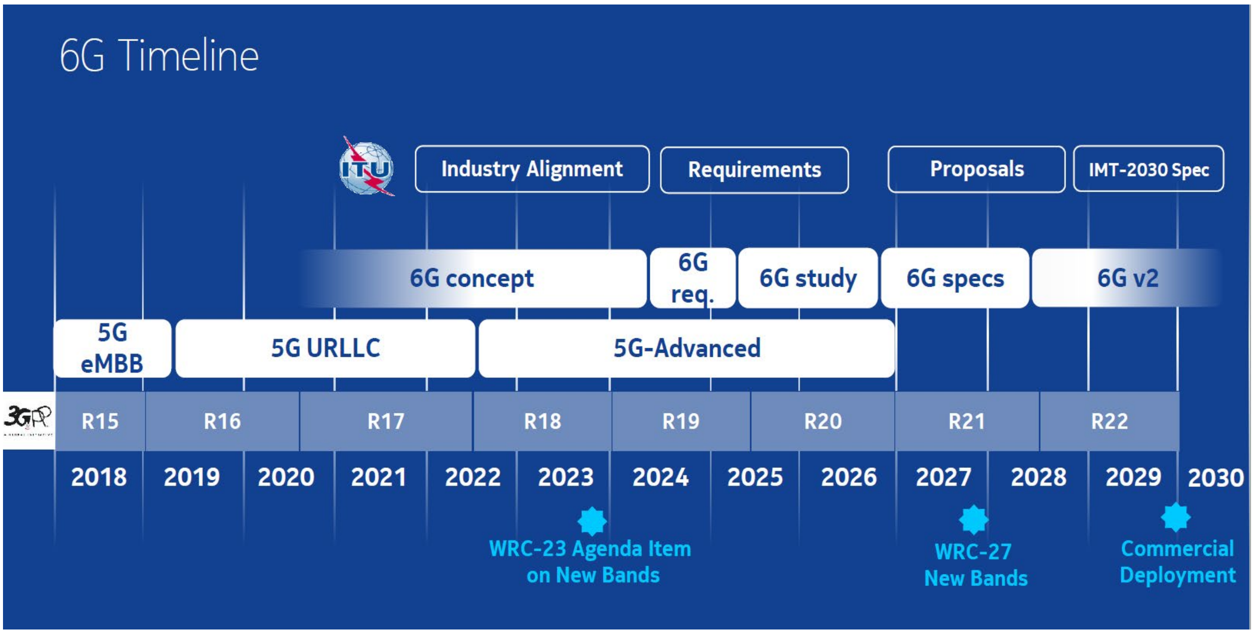


Figure 4 6G Timelines: Source Nokia

So, in line with global timelines, the 6G funding program should synchronize its activities and facilitate R&D stakeholders in a lock stock barrel approach on all fronts.

6. Priorities

6.1 Identifying champions in technology development

As mentioned, funding the industry and academia with focus on start-ups and SMEs who have core strengths and demonstrated capabilities is an important first step before taking a big leap. Considering the limited resource in terms of grants, an exercise to identify champions may be carried out to identify key industry players in terms of individual funding (in the cases of SMEs and Start-ups) and consortium programs (in the cases of academia and system integrators) to avoid thin spread of available funding. A DoT Apex Committee may come out with an expression of interest in a specific format to identify key players in this direction. The facilitation may include waiving the need for bank guarantees, need for collateral etc., for any advances to be paid in technology development and special dispensation under grants and instruments.

- SMEs, Start-ups: IPRs generated in the previous generation technologies, investments made in R&D, TRL levels of products.
- Academia or cluster of academia: IPRs generated in the previous generation technologies, TRL levels of technologies and products.
- The above doesn't preclude any new generation domestic companies emerging in the 6G landscape in applying for necessary funding support.

6.2 System Integration is key

The trend of open interfaces in technology products (e.g., Open RAN) is envisaged to continue triggering several small new companies developing niche products fitting into the technology / product architecture of 6G. These augurs good for Indigenous companies to position their products against competition in global markets.

Cross platform, cross device, cross medium orchestration demands state of the art expertise in system integration of these products from start-ups and SMEs making it a wholesome solution. As successfully demonstrated in the case of BSNL 4G PoC trials, Indian R&D ecosystem needs specialized system integrators in communication technologies to bring different flavours of products and solutions together to frontend, rollout, and support services on ground not only in 5G era but more so in 6G era, especially due to lack of mega technology companies from India, who may bear investments upfront and extend support perpetually during the life cycle of the products.

Building successful partnerships with System Integrators from the beginning in all R&D projects in 6G would reasonably ensure commercialization of technologies.

6.3. Funding in standards participation

In line with INSS (Indian National Strategy for Standardization), funding of experts from industry to enable their full participation in all the standardization process meetings is necessary to build standardization competencies in global platforms to consummate Indian standardization efforts leading to engage in SEP generation from the country.

6.4. Funding through different structure and instruments

Different funding instruments and structures are necessary to realize the objectives set forth under the 6G TIG and these are elaborated in later sections.

6.5. Apex level advisory board for funding direction

It is proposed to have an apex level board with Indian experts from India and abroad under DoT chairmanship to provide guidance and direction to the funding program for largescale projects cutting across ministries.

6.6 Champion initiatives & Programs

The 6G program may initiate champion initiatives taking note of inputs from the taskforce reports. Some of these initiatives include:

- A time-bound 6G Competency assessment program across institutes and industry
- Testbeds for Tera Hz and 5G+
- Advanced IoT Communication Modules and ecosystem
- Quantum Communications and security for 6G
- Fabless design in 6G Communication chipsets
- Photonics based SoCs
- Intelligent Reflector Surfaces
- Spectrum sharing technologies

6.7. Creating mechanisms to sustain R&D in long term

- Ensure flexible and full funding for technology companies through all possible instruments (including grants, loans focused venture capital fund and fund of funds) on flexible and liberate terms
- Incentivize service providers to try domestic technology products ongoingly
- Handhold in access to market for the quality domestic Technology products in Universal Service Obligation Fund (USOF) tenders, public sector procurements in all models

Structure of above programs and initiatives is tabulated in later sections.

7. Global Thoughts on 6G Actions and Funding (Wilson Centre)

The task force explored different funding models in Europe, USA in public and private for global practices especially regarding 6G Technologies.

- Creation of easy-to-use funding mechanisms for research and testbeds to maintain pace within leading countries and secure leadership in 6G technology.
- Driving a 6G eco-system development, leveraging research, industry and university collaboration programs and standardization.
- Incentivize advanced manufacturing in relevant markets, secure integrity of supply chains and decrease concentration of strategic capabilities and dependencies on high-risk countries
- Incentivize operators and vertical industries to adopt 6G.

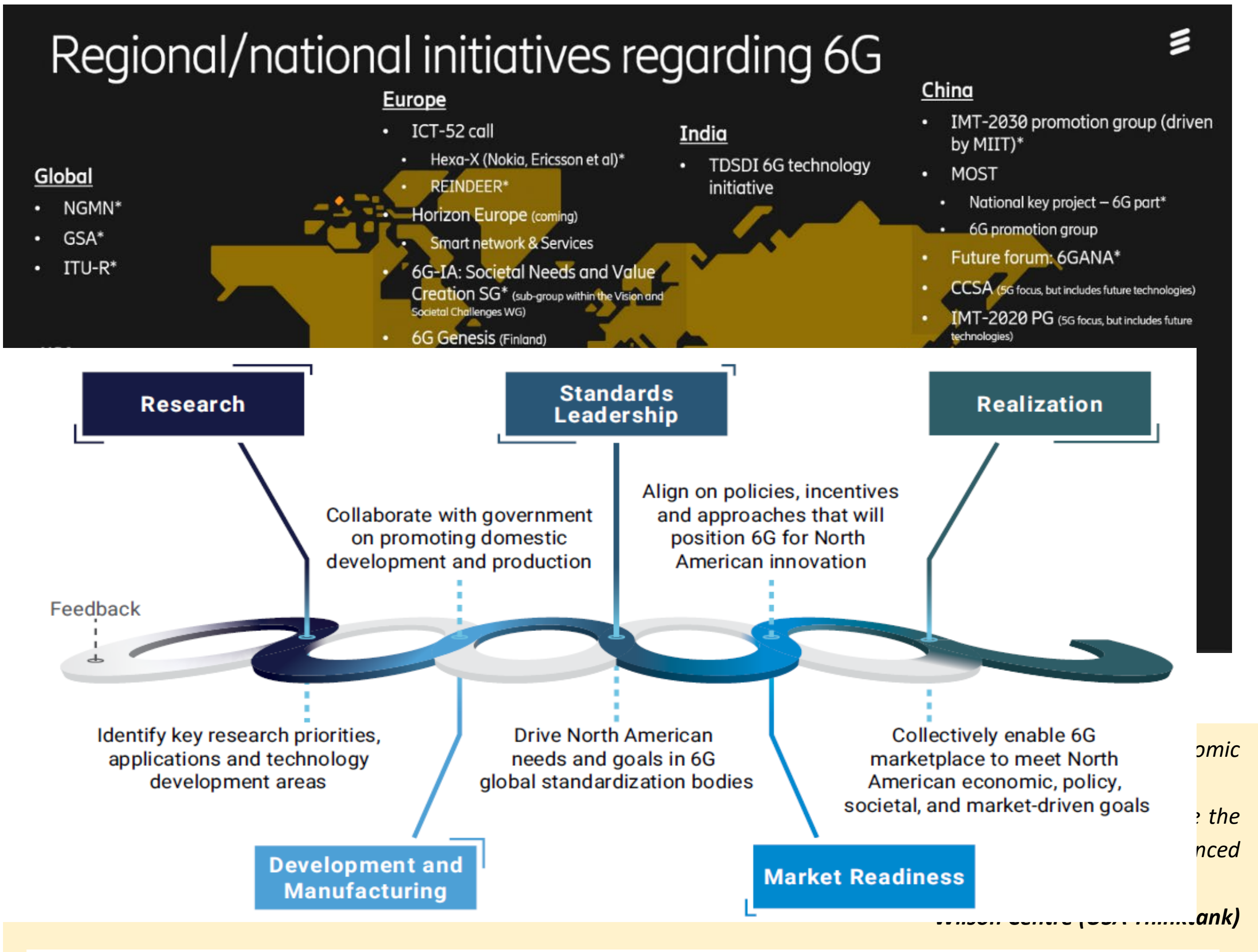


Figure 6 NextG Alliance Roadmap

Some of the specific funding mechanism in EU, USA are presented in Annexure 2, 3.

8. Programs and Funding Models

Phase I: 5-7 Years

- Creation of easy-to-use funding mechanisms for research and testbeds to maintain pace within leading countries and secure leadership in 6G technology.
- Driving a 6G eco-system development, leveraging research, industry and university collaboration programs and standardization.

#	Area	Partners	Remarks
1.0	Workshops and Competency identification exercise	Industry, RI (Research Institutes) and Academia	50 Workshops (over 5 years)
1.1	Research Projects, Prototyping on 6G Technologies	Industry, RI, and Academia	Identify With clarity on IPRs ownership and licensing framework
1.2	International Joint Projects	EU, Japan, Korea, US	Structure & Funding Partnerships (QUAD; EU, Korea, Japan – JWGs)
1.3	Testbeds, Prototypes in Industry with Academia Partnership (Lab, City)	Industry, RI, and Academia	Build SEPs and 'Commercialization'
1.4	PoC, Consortium Program of Technology Development	Industry, RI, and Academia	End to end system development and proliferation
1.5	Standards Development & Participation	TEC, TSDSI, Industry, RI, and Academia	Clear objective to build SEPs. Excluding Startup Activities.
1.6	High Impact / Strategic Projects	Industry, RI, Academia	
1.7	Drafting Program architecture	External Agency	Engage Professional Agency
1.8	Drafting of T&C and Agreements	External Agency	Engage professional legal agency
1.9	6G Program Office	In DoT	Staffed with professionals

Phase II (Post 2025)

- Incentivize advanced manufacturing in relevant markets, secure integrity of supply chains and decrease concentration of strategic capabilities and dependencies on high-risk countries
- Incentivize operators and vertical industries to adopt 6G.

#	Area
2.1	PLI, DLI Schemes to promote and proliferate technologies, products developed
2.2	Incentivize operators
2.3	Set up Use case labs
2.4	Hackathons on Use cases
2.5	Experience Centers
2.6	Incentivize vertical industries to adopt 6G

9. Eligibility for Availing Funding under the Program

Any of the following Indian entities which can contribute to the cause of enhanced and affordable rural connectivity is eligible for support from this fund.

- 'Domestic Company(ies)' with focus on telecom research and development.
- Indian Academic institutions.
- R&D institutions, Section 8 companies / Societies with focus on telecom research and development; or
- Collaborative joint / consortium of above entities with Indian or international partners as the case may be.

Definition of above entities is elaborated in the annexure 5.

10. Funding models Proposed

10.1. Grants in aid up to Rs. 20 Cr

- Grant in aid is envisaged to service funding requirements from small to medium projects in the development of technology, products, research, solutions, integrated proposals, hosting workshops / events / conferences, small size international joint projects, standards participation, participation & collaboration in in 6G product events, standardization activities.
- The grants are aimed to service research and development activity in all TRL levels as the case may be considering that 6G activities could be new or upgradation from earlier capabilities as well.

10.2. Grants in aid for High Impact Projects above Rs. 20 Cr

- These are large projects where funding requirements are high to develop cutting edge technologies with end-to-end solution as the focus. They include high impacting R&D projects such as Testbeds, Communication Systems, Development of System on Chips / AI chipsets for Communications, Deep technologies, large size international joint projects, hosting international conference in India etc.
- Consortium projects which require development, hardening, technology demonstration, product integration and extensive interoperability testing to deliver an end-to-end product portfolio would also be considered under this segment. It may include largescale technology trials to make the products carrier grade and ready for market deployment.
- These high impact projects, generally, are envisaged to be driven in collaboration with industry, Academia, or other agencies such as R&D focused Society / Section 8 company / Research Institutions such as C DoT.

10.3. Partial grants and loans

- These are partial grants where funding requirements are high, to develop cutting edge technologies, high impacting R&D including development of System on Chips / AI chipsets for Communications, deep technologies etc.
- The amount in excess of Rs 20 Cr could be considered as soft loan after commercialization of the technology / product in instalments that are linked to risk-associated milestones. This is in order to facilitate and circulate the available funding for the R&D ecosystem once the products / technologies are successfully commercialized.
- Soft loans as one of the funding options may be considered on very liberal terms without any collateral to enable the creation of working capital for commencing production, execution of

purchase orders, commercialization activities, extension of phased programs and expansion of R&D facilities without any collateral.

10.4. VC Funding for industry

In view of the need for risk funding, such modes also to be facilitated through an exclusive VC fund for 6G and fund of funds (further elaborated under section 10).

11. Mechanisms for vetting R&D budget proposals under the 6G Mission

Different mechanisms are considered for the purpose to make funds available through different instruments as envisaged above. Considering the large outlay, flexibility, transparency, quicker outcomes, expert participation, need for a large capital pool, high risk projects etc., the following models may be considered.

- Inter-Ministerial Committee (IMC) in DoT

An IMC with experts and representatives from relevant ministries could be constituted at appropriate level depending on the quantum of funding to vet, approve and implement the programs. The PMU (Program Management Unit) function could be managed by TCOE India, considering the success of its execution under DCIS funding initiative. An indicative administrative structure of IMC is at Annexure5.

- Restructured TCoE India to manage the programs

There is an opportunity to position TCoE India, a society created under DoT, with suitable accountability structures and professional staffing to manage the fund. Expert Governing committees could be formed in TCoE to provide guidance and direction for different 6G initiatives.

- Separate Section 8 company for 6G

In lieu of option 2 above, considering the size of 6G funding and need to efficiently manage it for the next ten years, a separate section 8 company may also be constituted for 6G and for overall R&D and commercialization program under DoT.

- Leverage any section 8 company of other departments

It may also be considered to identify any other established Section 8 company or public agency, with expertise in managing R&D programs in next generation technologies for the purpose in place of option under 3 above. It is also possible that 6G program cuts across platforms, some initiatives of 6G could also be given to other agencies if they have already developed expertise in similar programs to enable synergies and strengthen the created competencies.

11.1. High Risk Funding Instruments

To promote innovation driven high-risk ventures, a Telecom VC Fund and Fund of Funds are also envisaged as below.

- 6G VC Fund

A focused 6G VC fund with corpus in partnership with public entities may be constituted to enable financing instruments including equity with fund life of 10 years (further extendable by two years) taking note of 2035 timeline for risk funding to develop 6G products and commercialization.

With an anchor contribution from DoT, and the rest from identified public VC fund partners could be envisaged in line with successfully executed MeitY VC fund National Fund for Software and IT.

- ‘Telecom Fund of Funds for Start-ups, MSMEs’

To enable pooling of larger capital necessary for telecom gear development with focus on Start-ups, MSMEs a Telecom Fund of Funds may be considered inviting partnership from industry and private led VCs with an annual anchor contribution from DoT for five (5) years.

Any Public Financial Institution with a successful track record in Promotion, Financing and Development of the Micro, Small and Medium Enterprise (MSME) sector may be identified as the implementation agency to prepare a blueprint and drive the fund of funds. E.g., Start-up India fund of funds.

While the decisions for structures under options 3, 5, 6 above may take time and procedures involved, the options under 1, 2, 4 may be immediately used to invite the projects for 6G initiative.

Indicative process of evaluation for funding needs is indicated under Annexure 6.

Annexure 1: Funding mechanism under other ministries

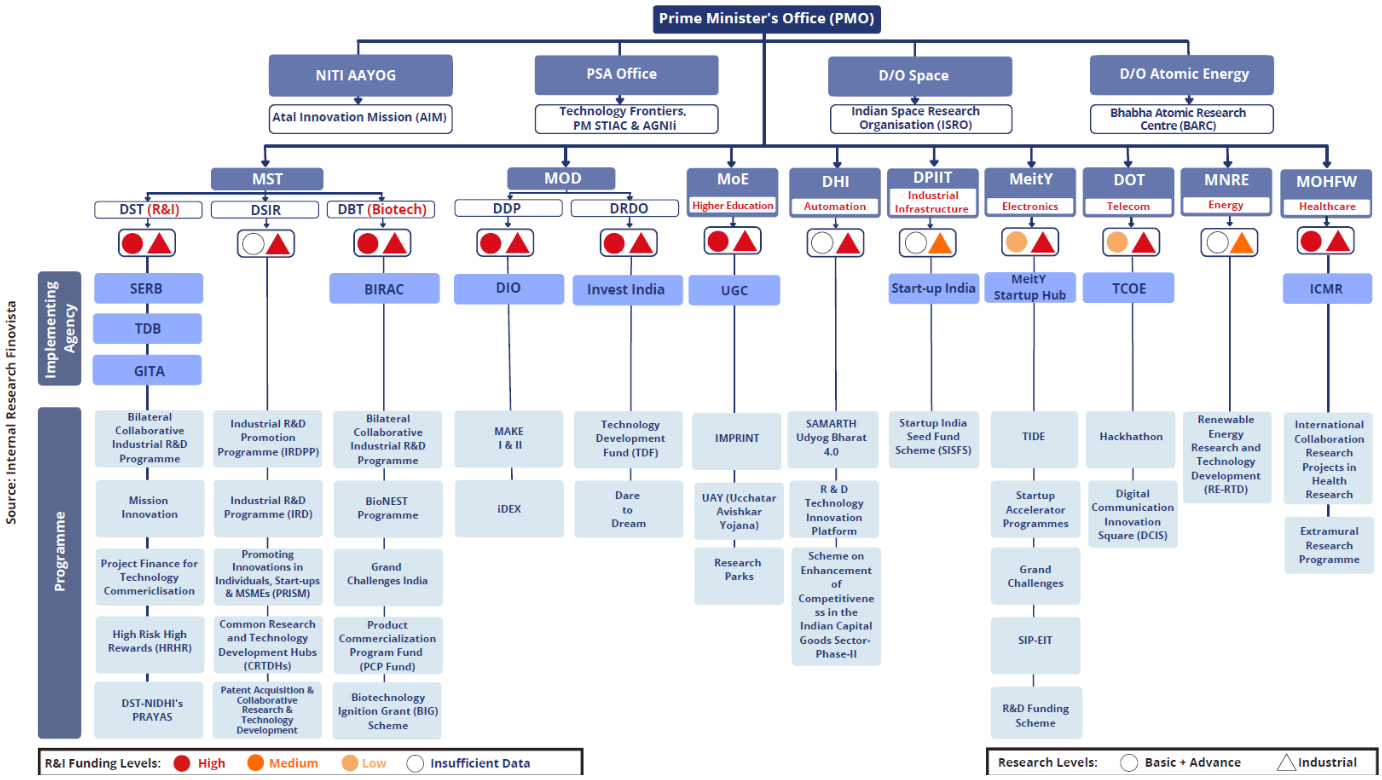


Figure 7: Funding mechanism under different entities

Annexure 2: Europe's first large-scale 6G Research and Innovation Programme

EU created Joint Undertaking on Smart Networks and Services towards 6G (SNS JU) adopted its first Work Programme 2021-2022 with an earmarked public funding of about € 240 million.

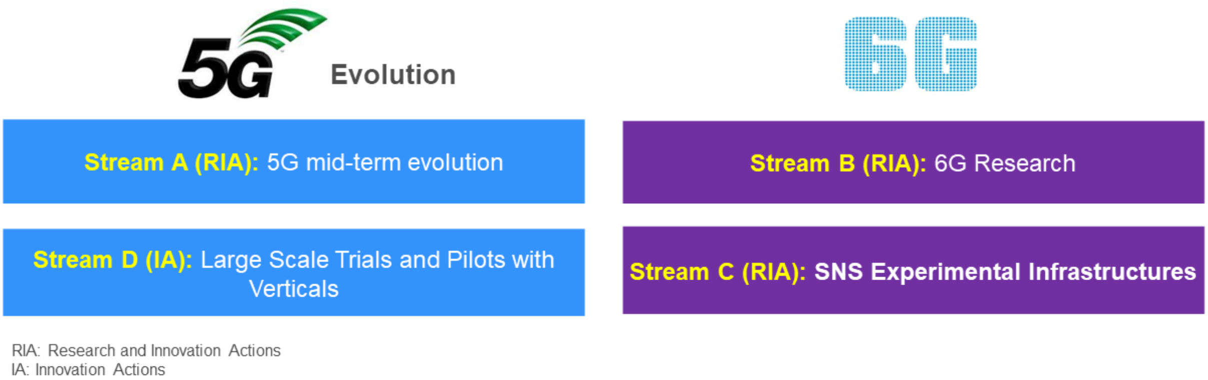
The Work Programme 2021-2022 will fund activities ranging from 5G evolution including large-scale trials and pilots with vertical industries to frontier research towards 6G systems.

The European partnership on Smart Networks and Services (SNS), a Joint Undertaking co-led by industry and the Commission with close involvement of Member States, sets the strategic R&I roadmap for Europe. The initiative builds on an EU contribution of €900 million over the next 7 years to be matched by the private sector with the same amount. The aim is to enable European players to build the R&I capacities for 6G systems and develop lead markets for 5G infrastructure as a basis for the digital and green transformation.

The SNS Work Programme was adopted by the SNS JU Governing Board and will be the basis for Calls for Proposals to be launched early 2022. It sets out four main complementary work streams:

- Stream A (RIA): Smart communication components, systems, and networks for 5G Evolution systems.
- Stream B (RIA): Research for radical technology advancement (in preparation for 6G and radical advancements of IoT, devices and software).
- Stream C (RIA): SNS Enablers and Proof of Concept (PoCs), including development of experimental infrastructure(s) that could be further used during later phases of SNS.
- Stream D (IA): Large Scale SNS Trials and Pilots with Verticals, including the required infrastructure to explore and demonstrate technologies and advanced applications as well as advanced services in the vertical domains.

These four Streams will be complemented by SNS Support Actions (CSA) to support EU wide synergies and directionality as well as international cooperation.



This Work Programme 2021-2022 builds the first phase of the SNS roadmap and will expand the early wave of European 6G projects launched in January 2021 under the 5G-PPP. The four Streams will evolve into new frontier research, proof of concept, standardisation, and deployment in subsequent phases or open new opportunities for technology development across the broader supply chain such as microelectronics or cloud-based service provisioning.

The Council Regulation 2021/2085 establishing the SNS JU entered into force. The SNS JU enables the pooling of an EU contribution of €900 million for the period 2021-2027 with industrial resources of at least the same amount. It also fosters alignment with Member States concerning national funding programmes on 5G and 6G. The SNS JU has the ambitious mission for driving the 5G evolution as basis for the digital and green transition and building Europe's technological capacities for 6G systems, which are expected for commercial launch at the end of this decade.

Deep pockets for 6G

The data also suggest that the EU has become more willing to invest in 6G research in recent years. Between 2017 and 2019, Horizon 2020 provided an average of €3.07 million per programme for 6G. In 2020 and 2021, this figure doubled – on average, each initiative received around €6.13 million in funding. However, more money on the table doesn't mean companies have been given financial resources at the same pace. The EU granted an average of €359,754.64 per participant in projects from 2017 through 2019. The figure grew to €443,756.30 for initiatives launched in 2020 and 2021, a 23% increase.

A two-year journey

This event is the culmination of an interesting journey over the last couple of years:

- We started with initial discussions among a handful of like-minded technical experts in industry about the need to energize and coalesce US research efforts on 6G.
- This was followed with individual contacts with NSF, which became a more structured group preparation for a smaller partnership with four companies. One potential partner had to drop out and we were set to proceed with three, and we settled on the themes of the solicitation, namely resilience and enabling technologies.
- There was a surge of interest at what seemed to be the last moment from both industry and government, and we ended up with a much larger partnership, composed of nine industrial partners (Ericsson, Apple, Google, IBM, Intel, Microsoft, Nokia, Qualcomm, and VMware), and three government partners (NSF, Department of Defence and National Institute of Standards and Technology).
- After another round of discussions to further shape the solicitation content with inputs from all the additional partners, we were finally ready to go. The total funding budget is $40 million, with each project receiving about $1 million over three years.
- The solicitation went out in April 2021, and over 200 proposals were received. After extensive reviews by NSF panels, and further inputs from industry partners, eventually 37 proposals were selected for funding.

Annexure 3: Resilient & Intelligent NextG Systems (RINGS)

National Science Foundation (USA)

The RINGS program seeks to accelerate research in areas that will potentially have significant impact on emerging Next Generation (NextG) wireless and mobile communication, networking, sensing, and computing systems, along with global-scale services, with a focus on greatly improving the resiliency of such networked systems among other performance metrics. Modern communication devices, systems, and networks are expected to support a broad range of critical and essential services, incorporating computation, coordination, and intelligent decision making. Resiliency of such systems, which subsumes security, adaptability, and autonomy, will be a key driving factor for future NextG network systems. Resiliency in both design and operations ensures robust network and computing capabilities that exhibit graceful performance- and service-degradation with rapid adaptability under even extreme operating scenarios. The RINGS program seeks innovations to enhance both resiliency as well as performance across the various aspects of NextG communications, networking, and computing systems. This program seeks to go beyond the current research portfolio within the individual participating directorates by simultaneously emphasizing gains in resiliency (through security, adaptability and/or autonomy) across all layers of the networking protocol and computation stacks as well as in throughput, latency, and connection density.

In this program, NSF is partnering with the Office of the Under Secretary of Defence for Research and Engineering (OUSD R&E), the National Institute of Standards and Technology (NIST) and several industry partners shown above. This program seeks to fund collaborative team research that transcends the traditional boundaries of individual disciplines to achieve the program goals.

Annexure 4: Approval structure

i.	**Secretary, DoT**	**Chairperson**
ii.	Member (Technology), DCC / Member Finance / Additional Secretary, DoT	Members
iii.	JS Level Representative from NITI Aayog	Member
iv.	JS Level Representative from Ministry of Electronics & IT	Member
v	Executive Director, C-DOT	Member
vi	Director, USoF	Member- Convener
vii	Any other JS level representative(s) from Central Government Ministry/ Department/ Organization may be co-opted with the approval of Chairperson	Members
viii	One Member each from Industry, Academia, and VC to be opted by the Chair	Members

- TCoE India as the PMU, applications may be invited for 6G activities.
- The current DCIS guidelines format may be revised to take note of various activities identified for 6G including standards participation.
- It may further be structured depending on the quantum of project fund.

Annexure 5: Definitions

- Applicant for the program is a legal entity including Private Company, Society, Section 8 Company, Academia, Research Institution etc., making an application for seeking fiscal support under the Scheme.
- Domestic Company is defined as those which are owned by resident Indian citizens as defined in the FDI Circular of 2017. A company is considered as 'Owned' by resident Indian citizens if more than 50% of the capital in it is beneficially owned by resident Indian citizens and / or Indian companies, which are ultimately owned and controlled by resident Indian citizens. Having incorporated in India with DSIR approval as an R&D house, it should hold IP ownership in India and majority of team and R&D should be located in India.
- MSME shall be defined as per the Gazette Notification by Ministry of Micro, Small and Medium Enterprises, dated 1st June 2020 or extant norms.

- Start-up shall be defined as per the DPIIT notification dated 19th February 2019 or extant norms.
- Technology Domains: Hardware, Software, Solution development in Telecom sector. Specific products, inter alia, are elaborated under Section 4.
- TRL Level: Technology Readiness Levels (TRL), as per global standards, are a type of measurement system used to assess the maturity level of a particular technology.

Annexure 6: Indicative Process of Evaluation for funding

1. What is the Selection Process for Funds Allocation?

Step 1: Evaluation Committee to be formed – distinguished committee of experts, who can be further supported by experts in niche areas of research

Step 2: Committee to review the following and provide rating

- Correctness of background data and accuracy
- relevance and appropriateness
- originality / validate newness / against existing patents
- clarity of business case or demonstration of concept for R&D funds
- Sustainability
- Credibility of people, their track record

Step 3: Based on review findings and recommendations, the R&D Technical Evaluation Committee will select the proposals.

2. How do we fund thru the phases of R&D?

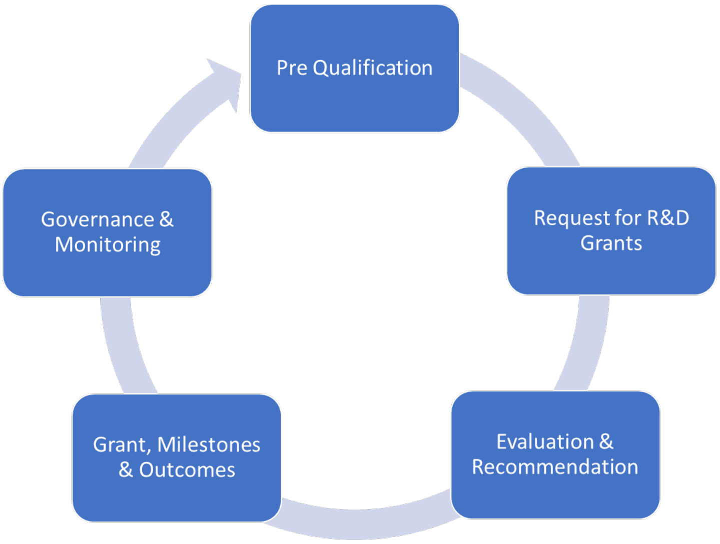
- Allocating funds thru the R&D value chain
  - Idea to Research to Prototype Development to Commercialization
- Agile methodology
  - Phase-wise Backlogs – how are resources expended in the flows between the phase backlogs – idea backlog to research backlog to development backlog to commercialization backlog
- Projects moving to commercialization.

3. How will we monitor the funds utilization?

Implementation and Monitoring can be further digitised based on reports submitted directly in the portal by the grant recipients, augmented by periodic audits facilitated by designated people / sub-committee of the Governance Board.

- Monitoring framework right from inception stage
- Periodic Project performance reports
- Formal mid-term reviews
- Accommodate CRs if it makes sense
- Completion report on project completion to be reviewed and validated against
  - impact created (high speed broadband connectivity)
  - outcomes (affordable and inclusive for rural areas)
  - outputs (quality of services proving at scale)
  - overall Patents/ IPs created.
  - Success of commercialisation.

4. Proposed Grant Management Cycle


Pre Qualification
Request for R&D Grants
Evaluation & Recommendation
Grant, Milestones & Outcomes
Governance & Monitoring

Annex: 2
Constitution of the 6G TIG and Task Forces

With the start of implementation of 5G technology, telecom community in various parts of the world has started to actively look at emerging new use cases, future technologies to support such use cases, and requirements for 6G. For India to effectively achieve its mission and vision of taking a distinct lead in the 6G space, we would require a collaborative effort from the government, industry, TSPs, academia, research institutions etc. to identify the areas of work and build synergies to innovate, standardize, run pilots, manufacture, test and supply at a global scale.

To bring out the vision, mission, goals and a roadmap for India in 6G space, a "Technology Innovation Group on 6G" (TIG6) was constituted with following members:

Sl No.	Designation/Organisation	Position
1	Secretary (Telecom)	Chairperson
2	SS(T)/AS(T)	Member
3	Member (Technology)	Member
4	Member (Services)	Member
5	Advisor/Sr.DDG (TEC)	Member
6	Wireless Advisor	Member
7	JS(T),DoT	Member
8	Signals Officer-in Chief, Integrated Army	Member
9	Chairman, TSDSI	Member
10	Director, IIT, Madras	Member
11	Director, IIT, Kanpur	Member
12	Director, IIT, Hyderabad	Member
13	Director, IIT, Delhi	Member
14	Director, IISc, Bangalore	Member
15	Chairman, COAI	Member
16	ED, C DoT	Member
17	DDG (SRI)	Member
18	DDG (Security Assurance-1)	Member
19	DDG (IR)	Member
20	JS level, MEITY	Member
21	JS level, DST	Member
22	JS level, Department of Space	Member
23	DDG (IC)	Member Secretary

Following terms of reference were given to the TIG6:

a. Define Vision, Mission and Goals for 6G in India

b. Identify the areas of work and build synergies to innovate, run pilots, manufacture, test and supply at a global scale

c. Develop a roadmap for R&D, pre-standardisation, development of products and applications; and

d. Evaluate, approve roadmaps & action plans for 6G.

The Group was asked to constitute Steering Committees with experts from various domains and work towards finalization of the First report on 6G Vision, Mission and Goals by March 2022. This report is a result of all the deliberations and the groundwork conducted by the TIG.

(Office Memorandum dated 1st November 2021, as amended on 26th November and 30th December 2021)

Terms of Reference

Task Forces constituted under Technology Innovation Group on 6G (TIG-6G) for inputs to TIG-6G.

1. **Multi-Platform Next-Generation Networks**
    - Development of Network elements of Multiplatform Next Generation Networks
    - Wireless GPON
    - Spectrum Hyper-Efficiency in Networks
    - Remote Near-Physical Skilled Activity
    - LEO Satellite Overlay
    - Drone Communications
    - Any other items in the scope of 6G activities and overall deliverables

2. **Innovative Solutions**
    - Use-case definition
    - Developing indigenous globally competitive 'ahead of state-of-art' solutions and piloting them in real field environment
    - Creating inputs for advanced research by practically establishing the limitation of available technology
    - Providing substantial implementation inputs for global standardisation
    - Pilot-trials
    - Any other items in the scope of 6G activities and overall deliverables

3. **Spectrum**
    - To refarm mid-band and sub 1-GHz spectrum
    - To consider the feasibility of 6 GHz and 10 GHz bands
    - To consider more candidate bands in mmWave bands
    - To explore the feasibility of THz band,
    - To recommend options on secondary use of spectrum
    - To consider new spectrum ownership and sharing models enabling flexible spectrum allocation.
    - To consider integration of emerging coverage solutions like Satellites, Drones, Unmanned aerial vehicles etc. and consider their spectrum requirements
    - To provide roadmap for channel measurements and new channel models for mmWave and THz bands
    - To identify co-existence and dynamic spectrum sharing study items
    - Any other items in the scope of 6G activities and overall deliverables

4. Devices

- Development of 6G devices ecosystem
- To enable secure, reliable, high speed and low-latency communications links anywhere and anytime in order to connect all things (sensors, machines, people)
- To exploit AI/ML technology to enable Cyber Physical Fusion to advance socio-economic development of the country
- Establish early global consensus on requirements, key technology components, and device architecture
- Any other items in the scope of 6G activities and overall deliverables

5. Standardisation

- Mapping global 6G activities and capability definitions
- Contribution for WP-5D on "Research Views on IMT for 2030 and beyond (3GPP Annex document 5D/886-E)"
- Pre-Standardization activities on 6G and streamlining the processes to be inclusive of all stakeholders
- Inputs to Standardization activities on 6G in TSDSI
- White paper on India's competencies (India, Research Labs and Academia) and potential pre-standardization activities
- White paper on "India Mission 6G program", Vision, Mission, Objectives and Structure.
- Any other items in the scope of 6G activities and overall deliverables

6. R&D Finance

- Develop a roadmap for R&D, pre-standardisation, development of products and applications
- Propose and vet R&D proposals under the 6G Mission
- Research Ecosystem – industry-academia research partnership for IPR development, standards development and proof of concepts through research projects, PPP projects, testbeds and pilot roll-outs;
- Any other items in the scope of 6G activities and overall deliverables

Acknowledgements

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3	Prof. Abhay Karandikar	Director, IIT Kanpur	Spectrum
4	Prof. Kiran Kumar Kuchi	Professor, IIT Hyderabad	Devices
5	Shri N G Subramaniam	Chairman TSDSI	International Standards Contribution
6	Shri A K Tiwari	Member (T), DoT	R&D Finance
Document Drafting			
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2	Shri Vijay Kumar Roy	Director, TEC	Document drafting and finalization
3	Rahul Hakeem	Partner, KPMG India	Document drafting and standardisation
4	Yasharth Srivastava	Associate Director, KPMG India	Document drafting and standardisation
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