Bharat 6G VISION

Taskforce Report
6G Spectrum

सत्यमेव जयते

Government of India
Ministry of Communications
Department of Telecommunications
March 2023

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

---

[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

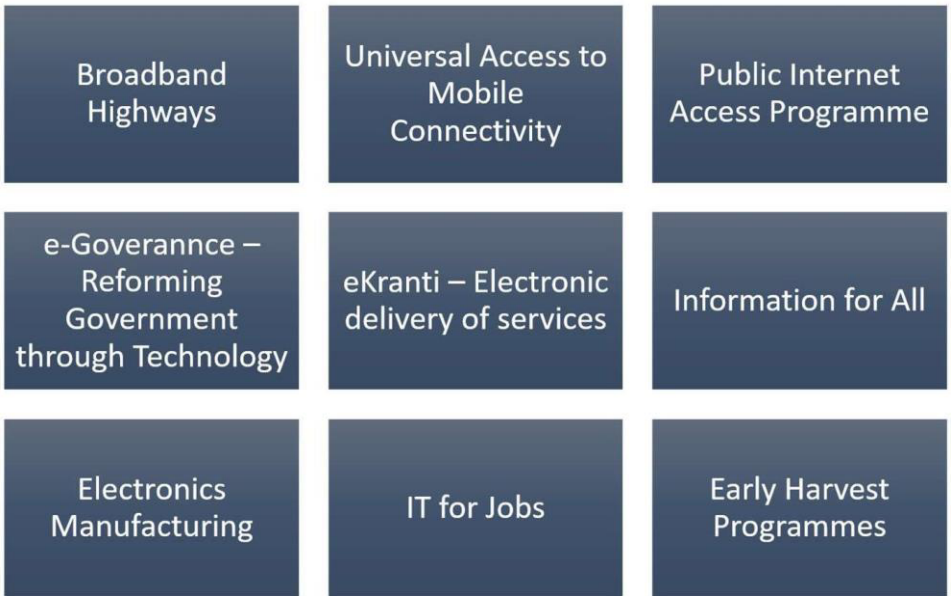

Figure 1: Digital India

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.

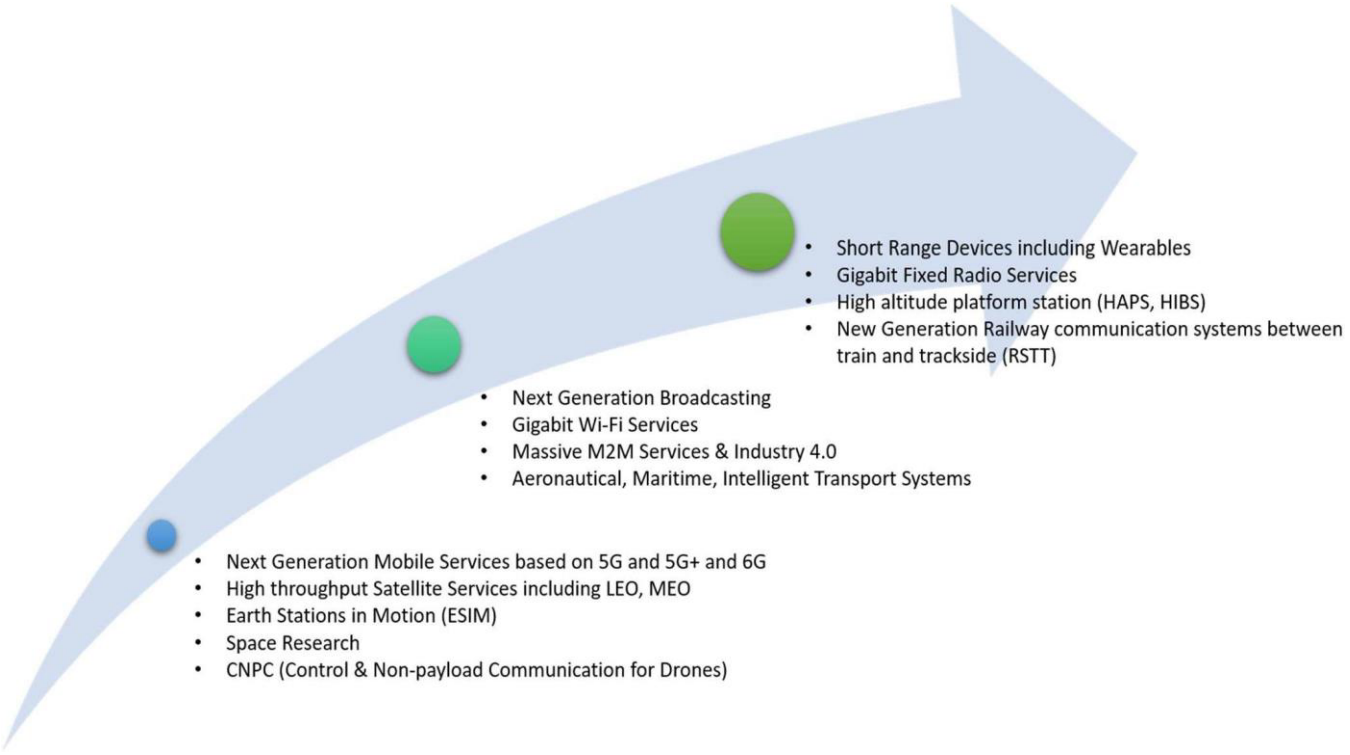

Figure 2: New Era of Services by 2030 from 5G+ and 6G Technologies

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

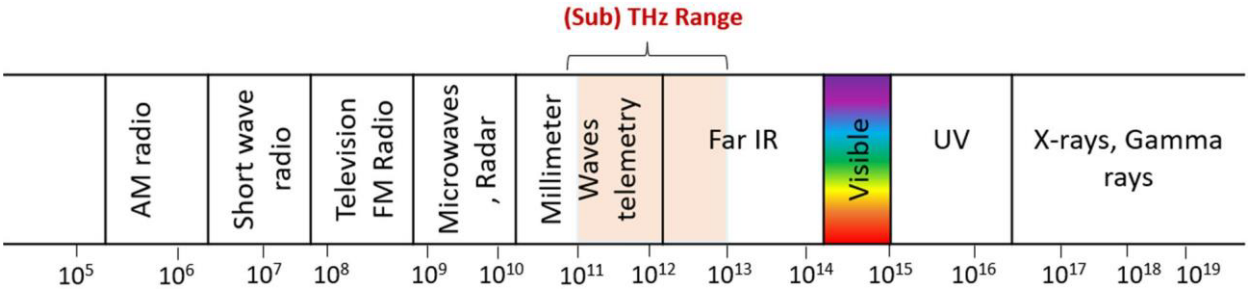

Figure 4: Source – Samsung Research

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

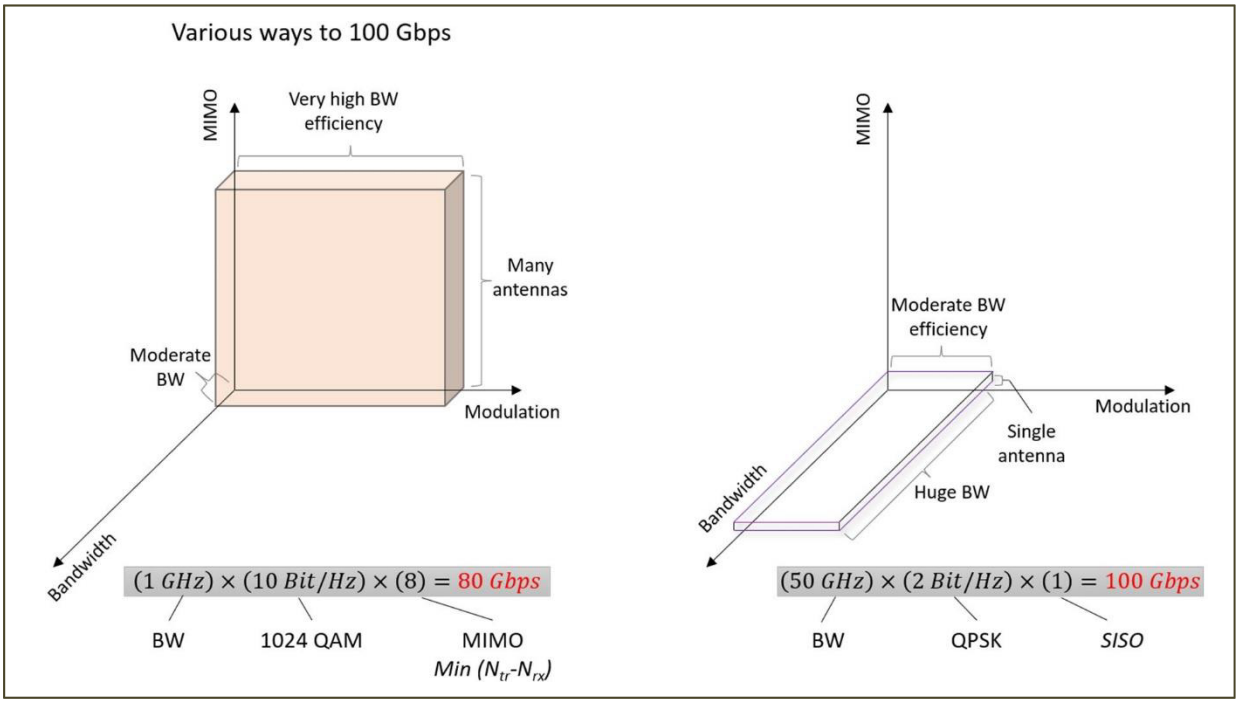

Figure 6: Source MTT-S, 6G Flagship

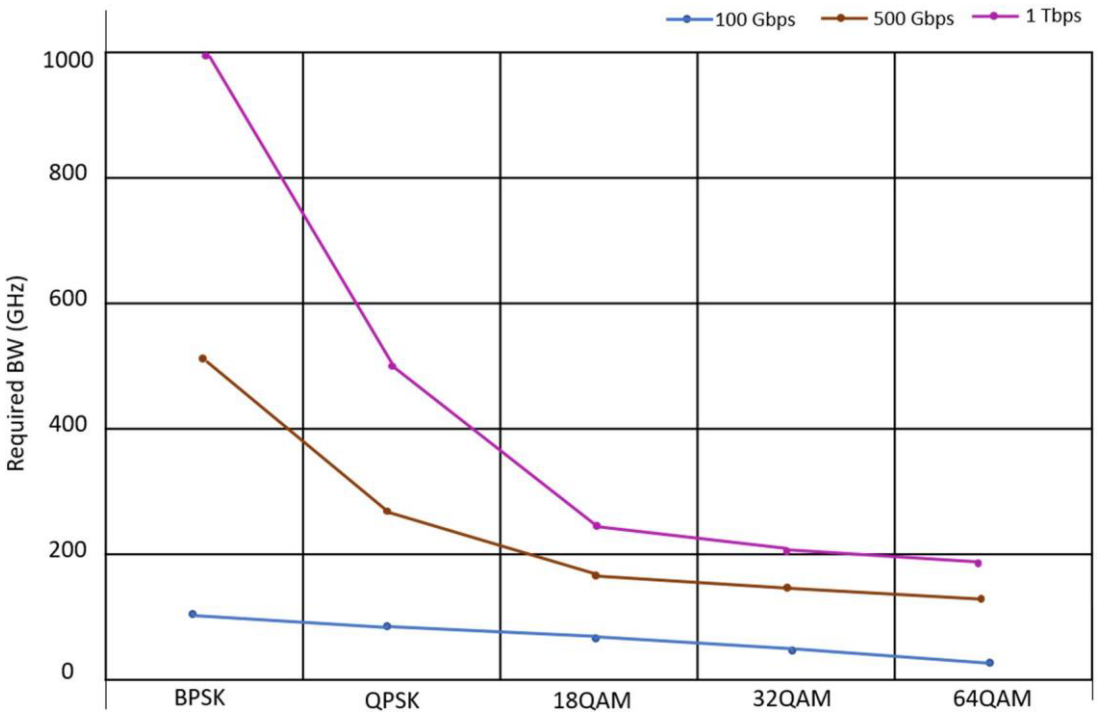

Figure 7: Source MTT-S, 6G Flagship

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

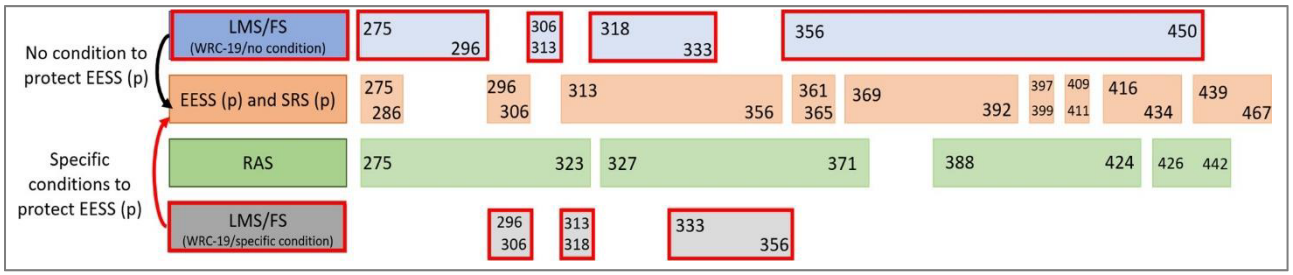

Figure 8

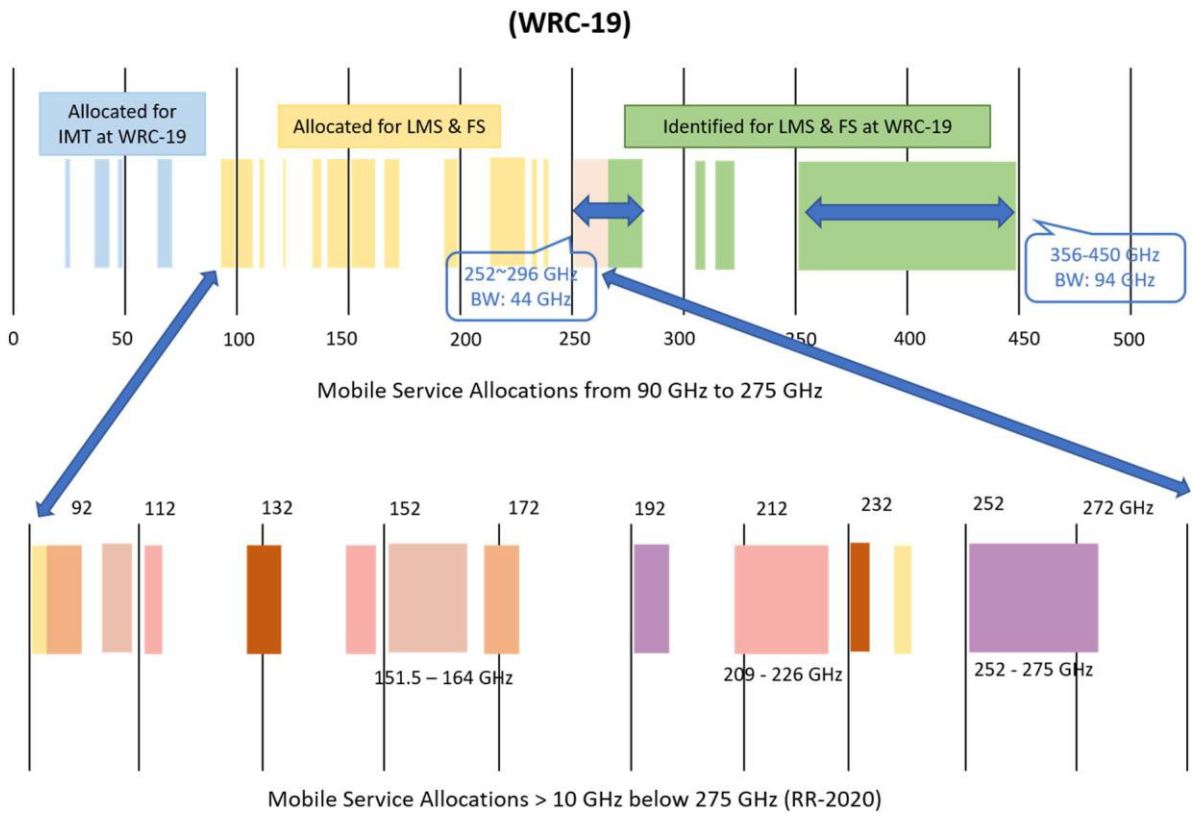

Figure 9: Spectrum above 30 GHz allocated to MOBILE services as per Radio Regulations (source: IAFI)

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

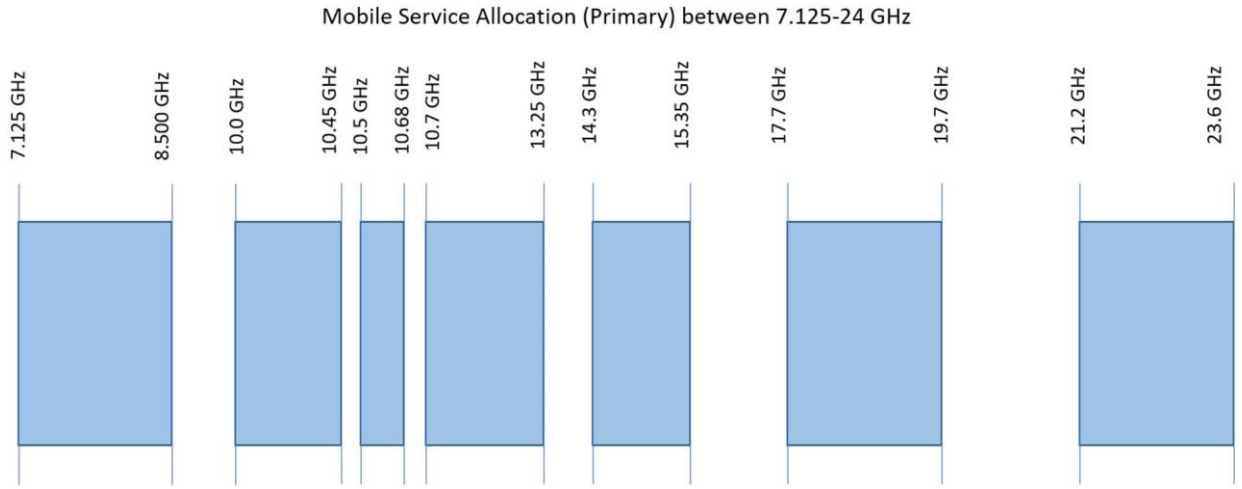

Figure 10: Spectrum between 7.125 GHz and 24 GHz allocated to MOBILE services on Primary basis as per Radio Regulations

2.5 Leveraging Indigenous 5G Testbed Experience for 6G

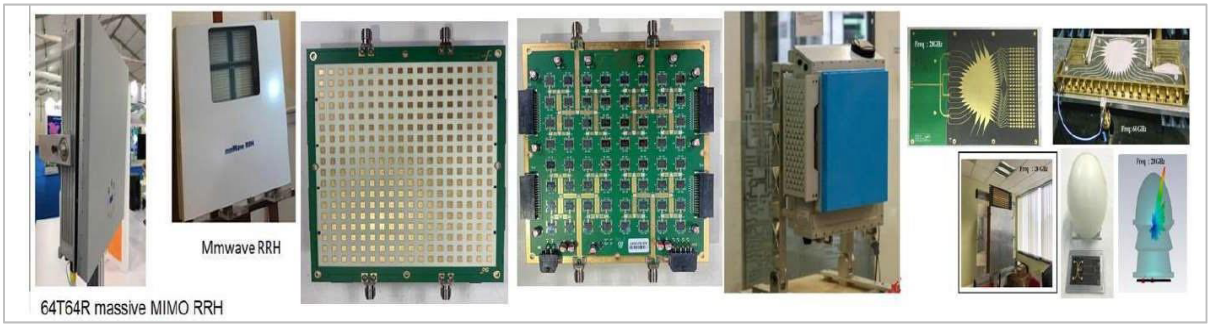

Figure 11: 5G Antenna Development and Massive MIMO (Source SAMEER, CEWiT)

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.

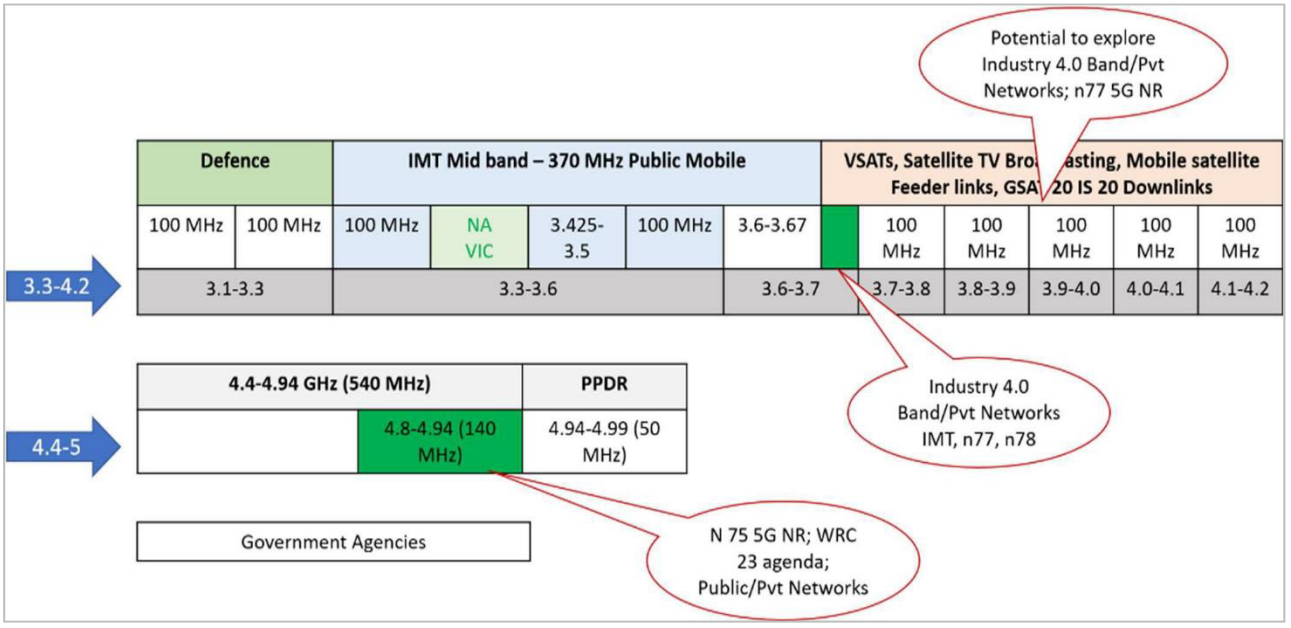

Figure 12: Need to expand mid-band for 5G+, 6G services

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.

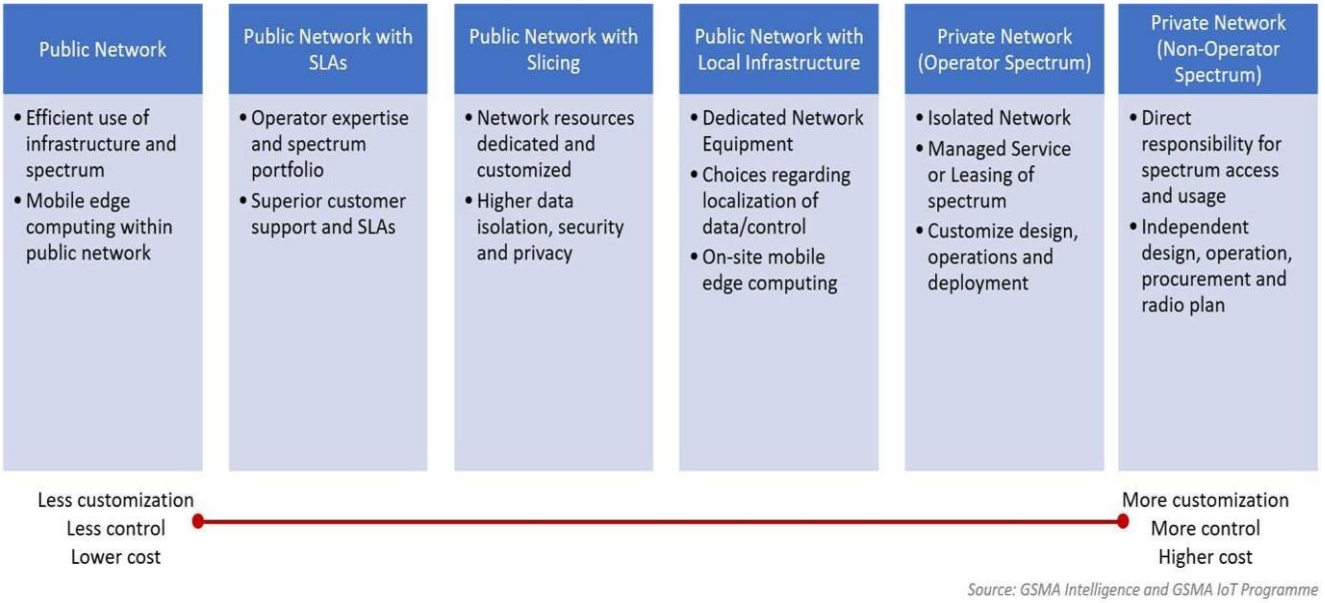

Figure 14

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.

[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

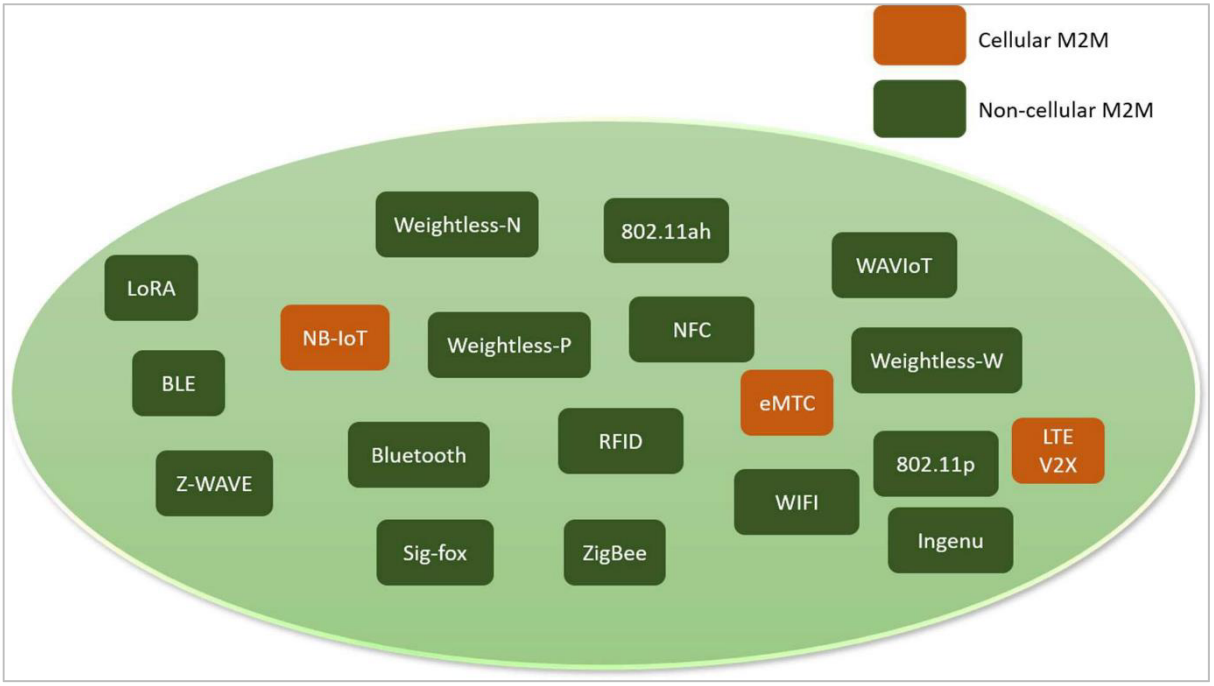

Figure 15: Source ITU

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

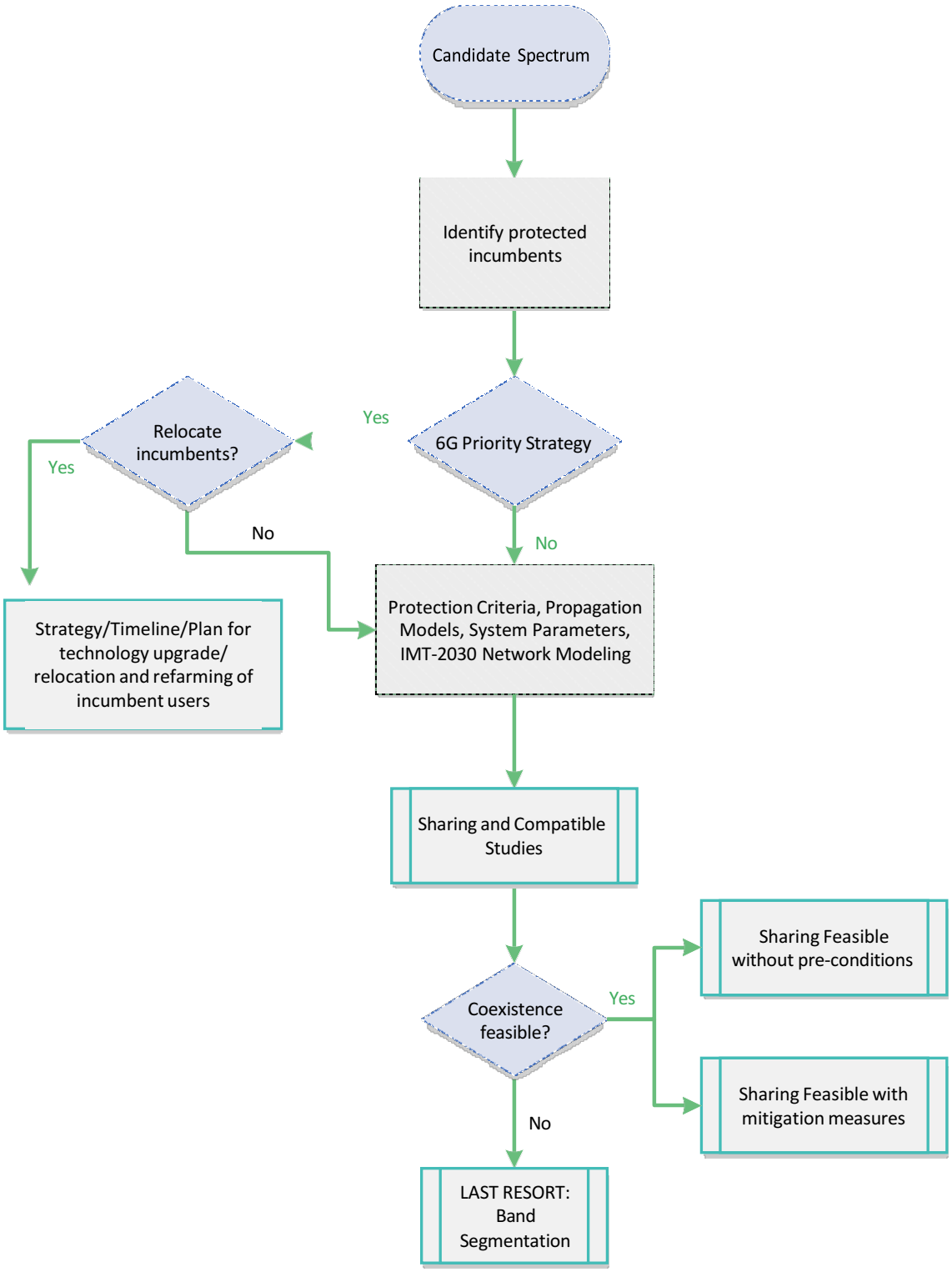

Figure 16: An approach towards ensuring timely and predictable availability of 6G spectrum (Source: 5GIF)

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

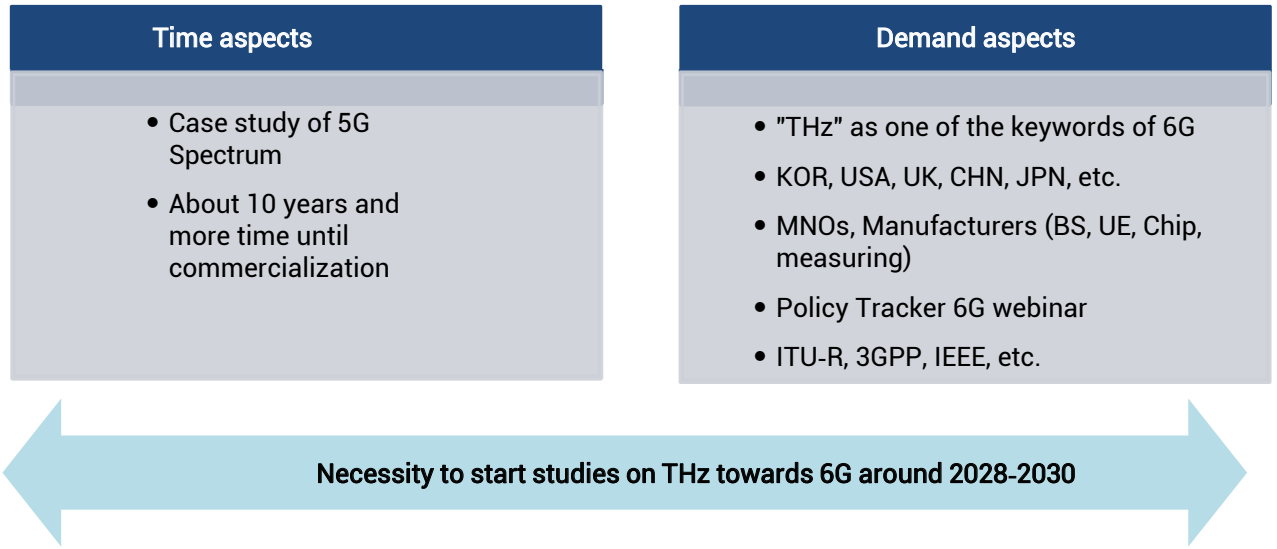

Figure 17: Samsung Research

सत्यमेव जयते

Ministry of Communications
Department of Telecommunications
Sanchar Bhawan, 20 Ashoka Road
New Delhi - 110001
E-mail: ddgic-dot@gov.in