REPORT ON
FIRST INTERNATIONAL QUANTUM COMMUNICATION CONCLAVE

27 – 28 MARCH, 2023

Vigyan Bhawan, New Delhi

TEC 91008: 2023

TELECOMMUNICATION ENGINEERING CENTRE
Department of Telecommunications
Ministry of Communications
Government of India

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1. INTRODUCTION

1.1. Telecommunication Engineering Centre is a technical arm of the Department of Telecommunications and is responsible for the formulation of standards, specifications, test procedures, service specifications and technical regulations for communication sector. TEC seeks to promote and ensure standardisation in the telecom sector to ensure development of world class telecom network and smooth interconnection of individual networks. TEC actively participates in the meetings of standards development organisations, viz., ITU, ETSI, APT, WRC, etc. and also interacts with other international forums, viz., 3GPP, ETSI, IETF, One M2M, etc.

1.2. Quantum technology is opening up new frontiers in computing, communications, sensing and metrology with widespread applications. It may impact many sectors, including healthcare, energy, finance, security, energy, etc.

1.3. TEC has been working towards the development of standards for the Quantum Technologies products and has been entrusted with the task of providing an 'Anchoring Role' to synergize the efforts of academia, R&D institutions, and startups for the development of ecosystem in the country in the niche areas of Quantum Technology. It is in the process of setting up a testing and certification framework for Quantum Technology products. In the process, Generic Requirements (GR) for Quantum Key Distribution (QKD) systems and Quantum-safe Cryptographic systems have been developed by TEC.

1.4. The **"First International Quantum Communication Conclave"** was conceptualised and conducted by TEC with the goals:

a) To bring together the researchers and the industries working in Quantum Technologies and foster the creation of a community among academia, R&D Institutions, and industries.

b) To create awareness among all the stakeholders about the significant works/research being carried out in the areas of Quantum Communication and motivate them to contribute in the area.

c) To identify the challenges and opportunities for India to take the lead in the development of Quantum Technologies.

d) To focus on the importance of standardisation and testing framework and push for contributions towards the standards development and IPR creation in the areas of Quantum Technologies.

e) To identify gaps in the standardisation of the existing and upcoming Quantum products and the areas where standardisation would be required.

f) To identify the application areas and use cases of Quantum Technologies in the communication networks (eg. Integration of Quantum Technologies in 6G, Space, Defense, etc).

g) To identify the challenges in the deployment of Quantum products in the communication networks and devices.

2. EXECUTIVE SUMMARY

2.1. Telecommunication Engineering Centre (TEC) organised the First International Quantum Communication Conclave in collaboration with Centre for Development of Telematics (C-DOT) and Telecommunications Standards Development Society, India (TSDSI) and IEEE Communications Society, Delhi Chapter on 27th and 28th March 2023 at Vigyan Bhawan, New Delhi.

2.2. As quantum computers become more powerful, they threaten to break many of the cryptographic algorithms that are currently in use. To address this issue, many research organisations, academic institutions, and companies are actively working on developing quantum-safe communication technologies that can ensure the security of our communication and data storage systems. The objective of the conclave was to create awareness about quantum technologies in general and Quantum communication in particular, bringing together the national and international experts from academia, research institutions, industries, start-ups and Government Organisations working towards the development of Quantum Technologies. The users of these technologies across various sectors viz. Defense services, Banking and Fintech Sector, Telecom/ICT sector were also invited with an aim to strengthen the security of the communication infrastructure against the threats posed by the Quantum computers.

2.3. The Conclave was a great success attracting a huge participation with around 600 members joining in-person, around 300 persons joining online and gathered more than 5000 views on the live casting on YouTube and Twitter.

2.4. The Conclave presented keynote speeches, panel discussions, and demonstrations by national and international experts from Industries, Start-ups, Government Organisations, Academia, and Research institutions focusing on the recent developments in quantum communication technologies, global trends, standardization efforts, and possible applications of Quantum Technologies to build a secure communication infrastructure.

2.5. It featured talks from international experts from the different countries: ID Quantique, Geneva, **Switzerland**; SK Telecom, **South Korea**; National Institute of Standards and Technology (NIST), **USA**; European Telecommunications Standards Institute (**ETSI**); Institute of Quantum Computing, University of Waterloo, **Canada**; Xiphera, **Finland** ; Amazon Web Services Cryptography, **USA**; Quintessence Labs, **Australia**; Zurich Instruments AG, **Switzerland** and Quantum Communications Hub, **United Kingdom**.

2.6. Further, the following experts from the Indian industries/start-ups, premier academic and research institutions, Government Organisations, Defense services, etc. involved in the research, development, policy making and deployment of Quantum Technologies presented their views:

a) **Industries/Startups:** QuNu Labs, Taqbit Labs, Qulabs, Qbit Labs, QpiAI, Thales

b) **Academia:** IISc Bengaluru, IIT Delhi, IIT Madras, IIT Bombay

c) **Research Institutions:** Raman Research Institute, Physical Research Laboratory, IISER Pune, C-DOT, C-DAC, IDRBT, Amrita Centre for Cyber Security

d) **Government Organisations:** Indian Armed Forces, DRDO, ISRO, National Security Council Secretariat, DoT, TEC

2.7. The keynote addresses were well received by the attendees, who appreciated the speaker's insights and thought-provoking ideas. The panel discussions generated a lively debate, providing valuable insights for the attendees and the follow-up Q&A sessions were very interactive, allowing attendees to engage further with the panelists. The event offered a valuable opportunity for attendees to learn about the latest developments in Quantum technologies at both the national and international levels. It

also allowed them to engage and connect with their peers in the industry, fostering innovation and visualization of government roles and facilitations for converting technology into commercialization.

KEY HIGHLIGHTS OF THE CONCLAVE

2.8. Inauguration by Hon'ble Minister of Communications, Railways, Electronics and IT

Shri Ashwini Vaishnaw, Hon'ble Minister of Communications, Electronics & IT and Railways inaugurated the conclave in the august presence of **Shri Devusinh Chauhan**, Hon'ble Minister of State for Communications; **Prof. Ajay Kumar Sood**, Principal Scientific Adviser to Govt. of India; **Shri K Rajaraman**, Secretary(Telecom), **Shri Sunil Gupta**, CEO, QuNu Labs and **Shri Ritu Ranjan Mittar**, Sr. DDG and Head, TEC.

2.9. Release of TEC Standards on Quantum Communication Systems

For enabling Indian companies to access national and international markets, it is important that quantum products are tested and certified to ensure their functional capabilities, reliability, security, and interoperability with other subsystems and compatibility in multi-vendor environment.

To achieve this objective, the following standards developed by TEC on Quantum Communication products were released:

(i) **Test Guide for "Quantum Key Distribution System"** (TEC No. 91001:2023)

(ii) **Generic Requirements on "Quantum-safe and Classical Cryptographic Systems"** (TEC No. 91010:2023)

These standards would help to validate the Quantum Key Distribution Systems and Quantum-safe cryptography systems developed by Indian entities.

2.10. Announcement of Quantum Hackathon

Shri Ashwini Vaishnaw, Hon'ble Minister of Communications, Electronics & IT and Railways highlighted the Proof-of-Concept Quantum Key Distribution (QKD) Trials successfully completed using the systems developed by C-DOT and announced the Quantum Hackathon with a prize money of ₹10 Lakh for each break in the Quantum-safe systems developed by C-DOT.

Quantum India: Pioneering Developments in Quantum Communication Technologies and Way Forward

2.11. During the event, the experts from Indian academia, research institutions and industries/start-ups presented about the research and development being carried out in India in the area of Quantum Communication Technologies and the supporting technologies, offering valuable insights into the current state and future prospects of Quantum Communication in India.

2.12. **Quantum Key Distribution:** Sh. Atul Kumar Gupta from C-DOT presented the Measurement Device Independent QKD system developed by C-DOT and mentioned about the applications being invited by C-DOT from Indian entities for collaborative development of Continuous Variable Quantum Key Distribution CV-QKD. For the future scope of development, he suggested Twin-Field (TF) QKD, which overcomes the PLOB bound on rate-distance limit can be explored for long-distance QKD and Chip-based miniaturized QKD for rapid adoption and affordable deployment.

2.13. Sh. Sunil Gupta, CEO of QuNu Labs presented the multi-point QKD system with Hub and Spoke Solution developed by QuNu Labs. He talked about developing Inter-State Hub and Spoke QKD Network in India where Inter-state spokes can communicate using the common spoke and the Hub of another configuration as trusted node.

2.14. Sh. Dilip Singh from QuNu Labs presented the implementation of Drone based Free Space QKD system and Satellite QKD System in Low Earth orbit being developed by QuNu Labs using high precision Pointing, Acquisition and Tracking (PAT) System and Atmospheric Compensation.

2.15. **Post-Quantum Cryptography:** Sh. Prashant Chugh from C-DOT talked about the C-DOT's PQC-based IP layer Encryptors and PQC-enabled Quantum Secure Smart Video IP Phone developed by C-DOT with NIST PQC key exchange algorithms and supporting both Classical and PQC Algorithms in hybrid mode.

2.16. Sh. Swami Saran from Thales presented the Hardware Security Modules developed by Thales providing Post Quantum crypto agility and Quantum Randomness using QRNG from ID Quantique. The various speakers emphasized migration to Quantum-safe infrastructure maintaining backward compatibility between Classical and Quantum-safe Public Key Infrastructure.

2.17. **Quantum Random Number Generator:** Prof. Kausik Majumdar from IISc, Bengaluru presented about an all-electronic van der Waals heterostructure-based device developed by Quantum Electronics Laboratory at IISc, Bengaluru generating a random sequence with record-high value (>0.98 bits/bit) of min-entropy through the detection of discrete charge fluctuation in a quantum dot embedded in a tunnel junction. The generated high quality random sequence passes tests such as NIST SP 800-90B and NIST SP 800-22.

2.18. Ms. Suma Varughese, Director General (MED & CoS) briefed about the Quantum Random Number Generator developed by DRDO and it's Transfer of Technology (ToT) to Industry. Shri Sunil Gupta, CEO, QuNu Labs also talked about the QRNG developed by QuNu Labs.

2.19. **Single Photon Source and Detector:** Prof. Bijoy Krishna Das from IIT Madras explained about the Photon Source integrated with Pump Rejection Filter as the approach to generate an efficient photon source. Prof. Kausik Majumdar from IISc, Bengaluru also briefed upon the works being carried out by Quantum Electronics Laboratory at IISc Bengaluru on chip-scale solutions of Single Photon Source and Single Photon Detector.

2.20. Shri Nilesh M. Desai, Director, SAC, ISRO presented the Development of a Quantum-Dot Single/ Entangled Photon Source and Single Photon Avalanche Detector (SPAD) at ISRO.

2.21. Prof. Joyee Ghosh from IIT Delhi presented about the projects funded by DST-QuEST and DRDO for development of entangled photon sources. She also briefly talked about the Integrated architectures generating entangled and hyperentangled photons and Telecom-Band Quantum Light Sources Using Dispersion-Engineered SOI Waveguides.

2.22. **Quantum Memories:** Dr. Nixon Patel from Qulabs explained about the Table-top Proof of Concept of Rb-based EIT Quantum Memory carried out in collaboration with IIT Roorkee. He also highlighted that Warm Rb vapor-based Quantum memories could provide a field deployable solution towards building a scalable quantum repeater network.

2.23. **Quantum Simulators:** Prof. Urbasi Sinha from Raman Research Institute, Bengaluru presented about the development of a novel, indigenous QKD simulation toolkit that can precisely model and analyse any generic QKD protocol.

2.24. **Metro Area Quantum Access Network:** Prof. Anil Prabhakar from IIT Madras presented "The Metro Area Quantum Access Network "(MAQAN) developed as a collaborative effort between IITM, CDAC, SETS and ERNET. It acts as the testbed to evaluate point-to-multipoint quantum key distribution. MAQAN connects laboratories at IIT Madras, ERNET and SETS in a star topology, and also demonstrates QKD using WDM techniques. The goal of MAQAN is to enable standardization and interoperability of quantum secure hardware, even as we continue to develop indigenous equipment, and newer modalities for quantum key distribution and quantum secret sharing.

2.25. **Quantum Computer:** Sh. S.D. Sudarsan from C-DAC mentioned about the Four qubit quantum computer built at Centre of Excellence in Quantum Technology (CEQT) at IISc, Benglauru. Also, Shri Nagendra Nagaraja, QpiAI mentioned about 25 qubit Quantum computer being developed by QpiAI along with a roadmap to build a Quantum Computer upto 300 qubits.

Demonstrations and POC Trials

2.26. Shri Ashwini Vaishnaw, Hon'ble Minister of Communications, Electronics & IT and Railways mentioned about the successful field trials of Quantum Key Distribution System developed by C-DOT between the Sanchar Bhawan, Department of Telecommunications and National Informatics Centre (NIC's) CGO Complex in Delhi.

2.27. The field trials of secure VC solution with the Post-Quantum Cryptography based system developed by C-DOT between TEC, C-DOT and DoT HQ, Sanchar Bhawan was presented by Sh. Abdul Kayum, DDG(6G), TEC.

2.28. Shri Nilesh M. Desai, Director, SAC, ISRO presented the following trials carried/being carried out by ISRO:

(i) Inter-building Free Space **Single-Photon based** Quantum Key Distribution inside SAC Campus over a distance of 300m.

(ii) Inter-building Free Space **Entanglement based** Quantum Key Distribution inside SAC Campus over a distance of 300m.

(iii) QuantESS Payload (Quantum Entanglement studies in Space) onboard POEM-2 on PSLV-C55 for development of space worthy entangled photon source.

2.29. Ms. Suma Varughese, Director General (MED & CoS) presented about the field testing of the Fiber based QKD done by DRDO and IIT-Delhi over a distance of 100 Km at Praygraj – Vindhyachal.

2.30. Prof. Urbasi Sinha from Raman Research Institute (RRI), Bengaluru presented about the demonstration of free space entanglement based quantum communication between two buildings at RRI through an atmospheric channel.

Quantum Around the Globe: Worldwide Initiatives and Developments in Quantum Technologies

2.31. Mrs. Suma Varughese, Director General (MED & CoS), DRDO mentioned about the Worldwide Quantum efforts with Europe spending $5 billion, U.S. $3 billion, and U.K. around $1.8 billion to become tomorrow's quantum superpowers.

2.32. Shri Timothy P Spiller, Director of Quantum Communications Hub in United Kingdom presented the UK National Quantum Technologies Programme (UKNQTP) and the position of the Quantum Communications Hub within the NQTP. He summarised the successful outcomes of Phase 1 (2014-19) of the Hub work and the expanded portfolio of research and development being carried out during Phase 2 (2019-2024).

2.33. Shri Nilesh M. Desai, Director, SAC, ISRO briefed about the world-wide successful demo missions/programs related to QKD:

(i) **MICIUS** by China demonstrating Decoy state BB84 and Entanglement distribution over 1200 Km using Micius Satellite.

(ii) **SOCRATES** by Japan demonstrating Satellite-to-ground quantum-limited communication using a 50 Kg microsatellite.

(iii) **SpooQY-1** by Singapore demonstrating the operation of a compact, low-power, lightweight, and robust source of entangled photon pairs into low Earth orbit. (Loop-back mode)

2.34. Dr. Dong-HI SIM, SK Telecom, South Korea and Dr. Bruno Huttner, ID Quantique, Geneva presented the **Korean National Convergence Network Project** implemented by ID Quantique and SK Telecom building a first nation-wide QKD network in Korea spanning over 2000 Km connecting 48 Government Organisations.

2.35. Dr. Bruno Huttner, ID Quantique talked about OpenQKD Consortium and QKD Testbed as part of Euro-QCI initiative aiming at safeguarding sensitive data and critical infrastructures by integrating quantum-based systems into existing communication infrastructures by 2027.

2.36. Dr. Dong-Hi SIM talked about Quantum-safe Communication Infra Pilot Project, KOREN (Korea Advanced Research Network) to develop a Test network that supports feasibility and verification of Technologies. It includes 490 Km QKD Testbed, 820 Km PQC Testbed for development and demonstration and total 445 Km testbeds with fiber/encryptor to test new protocols.

Standardization in Quantum Technologies

2.37. Sh. K. Rajaraman, Secretary(Telecom), Department of Telecommunications talked about the vulnerability of the communication infrastructure to the threat posed by Quantum computers and emphasized the standardization of the Quantum solutions and devices being developed to ensure that the systems being developed are safe and secure.

2.38. Sh. Ritu Ranjan Mittar, Sr. DDG and Head, TEC highlighted that India will be hosting the upcoming World Telecommunications Standardisation Assembly (WTSA) in 2024 and further, discussed about the role of TEC in formulating the standards. He encouraged all the stakeholders to join National Working Groups (NWGs) led by TEC for submitting the Indian Contribution to the ITU Study Groups where standardization work is being done on Quantum Technologies.

2.39. Sh. Abdul Kayum, DDG(6G), TEC presented the future roadmap of TEC to develop standards on Quantum random Number Generator, Quantum Computing Platforms-Hardware subsystems, Control Software and Quantum Software, Single Photon Source and Single Photon Detectors.

2.40. He also mentioned about various future standardization areas namely Quantum Homomorphic encryption, Quantum Secure Direct Communication, Quantum Secret Sharing, Quantum Repeaters, Quantum Memories, Quantum Router, Switches, Multiplexers, Demultiplexers, Quantum Key Distribution using Satellite, Use of same media (fiber) for data communication and Quantum Key, Transmission and Quantum Direct Messaging, Interfaces among layers and Interoperability.

2.41. Sh. YGSC Kishore Babu, DDG(SRI), DoT gave a brief overview of the different standardization activities being carried out at IEEE, ISO, ETSI and ITU and discussed about the gaps in standardization.

2.42. Sh. Atul Kumar Gupta from C-DOT briefed about the ITU-T Standards for QKD and the items under study in ITU-T Study Group 13 covering different aspects of QKD from the perspective of large scale proliferation in the network.

2.43. Dr. Dustin Moody leading the Post-Quantum Cryptography project at NIST, USA described about the NIST PQC Competition and the details of the algorithms shortlisted by NIST for standardization at the end of the third round and the algorithms being taken to the fourth round.

2.44. Sh. Matthew Campagna from AWS Cryptography, USA and Chairman of ETSI TC CYBER WG QSC presented the post-quantum cryptography work being done within the European Telecommunication Standards Institute (ETSI) Technical Committee CYBER's working group on Quantum Safe Cryptography (QSC) and provided details for participation in the Working Group Activities.

Quantum in Action: Applications of Quantum Technologies in Diverse Sectors

2.45. **Telecommunications Sector:** Dr. Dong-Hi SIM, SK Telecom, South Korea presented on the implementation of quantum-safe communication infrastructure by SK Telecom in South Korea using LTE Backhual Protection with QKD, 5G Subscriber Authentication with QRNG.

2.46. **Defense Sector:** Lt. Gen. M.U. Nair, Signal Officer in Chief, Indian Army mentioned about the potential of Quantum Computer to solve the military problems with huge computing power which cannot be achieved by classical computing system today.

2.47. **Banking Sector:** Prof. P. Syam Kumar from Institute for Development & Research in Banking Technology focused on the use of quantum communication in the fintech sector, particularly in protecting the privacy of customer data stored in the cloud. He presented about, QSafe, a quantum-safe encrypted cloud storage, developed using lattice-based cryptography (LBC).

2.48. **Satellite Communication:** Shri N.M. Desai, Director, SAC, ISRO highlighted the importance of satellite based Quantum Communication with the important works being done at ISRO including demonstration of Satellite based Quantum Communication between LEO spacecraft and Optical Ground Stations. Shri Dilip Singh also presented the implementation of Satellite QKD System in Low Earth orbit being developed by QUNU Labs using high precision Pointing, Acquisition and Tracking (PAT) System and Atmospheric Compensation.

2.49. **Healthcare Sector:** Sh. Animesh Aaryan, CEO, Taqbit Labs talked about the applications of Quantum Sensing and Imaging in diagnosing heart diseases and of Quantum Communication to secure medical records improving patient privacy.

2.50. **Securing of Critical Infrastructure:** Dr. Dong-Hi SIM presented about the use of Quantum Communication to secure critical communication infrastructure, such as power grids and transportation systems.

2.51. **Applications of Quantum Computing:** Various applications of the Quantum Computing were presented by the speakers including Drug discovery, solving optimization problems, Financial Modelling, Supply Chain Management, Climate Modeling, Machine Learning, etc.

Empowering Quantum India: Fostering Research and Development in Quantum Technologies

2.52. Shri Devusinh Chauhan, Hon'ble Minister of State for Communications mentioned about various initiatives launched by the government, such as the National Quantum Mission, Telecom Technology Development Fund, Production Linked Incentive scheme, and Telecom Centre of Excellence, aimed at promoting indigenous design and manufacturing, innovation, entrepreneurship, and start-up ecosystems.

2.53. Prof. Ajay Kumar Sood, Principal Scientific Adviser to Govt. of India highlighted the need of sufficient in-house knowledge base, resources and talent built up in research laboratories and academic institutions across the country and develop a highly skilled human resource. He also emphasized on strategizing our efforts in national Quantum Mission to remain globally competitive with the limited resources and also stressed upon consonance policy measures with efficient and timely funding mechanism to facilitate the development of Quantum Technologies.

2.54. **Technology Roadmap and Policy Recommendations by Inter-Ministerial Committee on Quantum Communication Technologies:** Shri YGSC Kishore Babu, DDG SRI presented the Technology Roadmap for India key recommendations of the Inter-Ministerial Committee on Quantum Communication Technologies which included:

i. Drawing a National Level Program for Quantum Communication (QC) Pilots and Trials with indigenous products

ii. Fund Public access Quantum Communication testbeds and ensuring industry facilitation with access to integrated testbeds at a nominal cost;

iii. Quantum security an integral part of National Security Strategy with specific actions

iv. Setting up of Testing and Certification facility for interoperability, and testing of equipment from multiple vendors

v. Central funding of R&D projects in Quantum Communications to enable synergies - Focused funding for higher R&D goals with and minimizing duplication

vi. Quantum Communication Application Use case labs / Experience Centres in key economic verticals driven and hosted by Industry with funding support

2.55. Dr. Rajkumar Upadhyay, CEO, C-DOT proposed to set up a **Quantum Alliance** comprising all the stakeholders, viz. academia, research institutions, industries, and start-ups working in the development of Quantum Technologies so as to have a cohesive effort towards the development of Quantum Communication Technologies, to avoid any duplication efforts and to enable the use of any sub-systems being developed by others.

2.56. He also talked about development of indigenous QKD protocol and PQC protocol, going forward.

2.57. It was highlighted to develop the framework and align the National Quantum Mission in lines with the US National Quantum Initiative Act.

3. INAUGURAL SESSION

Lighting of Lamp: Inauguration of First International Quantum Communication Conclave

3.1. The young officers of Telecommunication Engineering Centre welcomed the dignitaries with saplings. It was followed by inauguration of the conclave with lighting of the lamp by **Shri Ashwini Vaishnaw**, Hon'ble Minister of Communications, Electronics & IT and Railways in the august presence of **Shri Devusinh Chauhan**, Hon'ble Minister of State for Communications, **Prof. Ajay Kumar Sood**, Principal Scientific Adviser to Government of India, **Shri K. Rajaraman**, Secretary (Telecom), **Shri Sunil Gupta**, CEO, QuNu Labs and **Shri Ritu Ranjan Mittar**, Sr. DDG and Head, TEC.

Welcome Address by Shri R.R. Mittar, Sr. DDG and Head of TEC

3.2. The lighting of the lamp was followed by the welcome address from Shri Ritu Ranjan Mittar, Sr. DDG and Head of Telecommunication Engineering Centre. Shri R.R. Mittar welcomed all the dignitaries, eminent experts, exhibitors, delegates and all stakeholders in the event. He highlighted that this initiative of TEC would provide impetus to R&D in the Quantum Communication area.

Industry Keynote Address by Shri Sunil Gupta, CEO, QuNu Labs

3.3. Shri Sunil Gupta, CEO of QuNu Labs outlined various drivers factoring in commercialization of quantum secure system such as prices of quantum components, testing and certification, and government funding and support for field trials. He further presented the products developed by QuNu Labs: QRNG, Point to Point QKD System, Hub and Spoke QKD Solution and QRNG which are ready for deployment in the Communication infrastructure. He also talked about the Inter-state Hub-N-Spoke QKD Network where Interstate spokes can communicate using the common spoke and the Hub of another configuration as trusted node allowing secure communication between any nodes using secure symmetric keys and the existing data channels.

3.4. He suggested a hybrid approach using both Quantum Key Distribution and Post Quantum Cryptography as the best solution for securing the communication infrastructure. He further talked about it's various applications in Block chain security, Drone security, Tokenization and OTP in banking, Email security, cloud App security, File encryption, Data centre, Disaster recovery centre security, Critical Infrastructure control system, 5G backhaul using QKD network, Quantum communication network, Telecom Network, Defense network etc.

Special Address by Shri K. Rajaraman, Secretary (Telecom), Department of Telecommunications

3.5. Sh. K. Rajaraman, Secretary, Department of Telecommunications (DoT), highlighted the potential security threats that quantum computing could pose to classical communication systems. As an administrator, he emphasized the importance of ensuring the security of critical infrastructures, databases, and the financial sector. He also emphasized the need to standardize the development of quantum solutions and devices to ensure their safety and security. He stressed on the the collaborative efforts of research organisations, government agencies, industries, academia, and other organisations in the development of products and standards in the field of Quantum Technology in India and expressed confidence that the international and national experts participating in the event would bring new ideas to the table, paving the way for India to advance in the field of quantum technologies.

3.6. In addition, he discussed the significance of quantum secure communication in the upcoming 6G standards and highlighted the importance of R&D and security as mentioned by Hon'ble PM during the launch of Bharat 6G vision. He further mentioned about the investments being made in research and development by the Department of Telecommunications through the Telecom Technology Development Fund (TTDF).

Special Address by Prof. Ajay Kumar Sood, Principal Scientific Adviser to Government of India

3.7. Prof. Ajay Kumar Sood, PSA to Govt. of India appreciated the progress being made by India in the area of Quantum Technologies and highlighted that the Quantum revolution is going to impact various sectors viz. communication, health sector, financial markets, etc. As quantum computing threat to classical network may impend in 3 - 5 year timeline, he highlighted the need of sufficient in-house knowledge base, resources and talent built up in research laboratories and academic institutions across the country and develop a highly skilled human resource. He also emphasized on consonance policy measures with efficient and timely funding mechanism to facilitate the research and development of Quantum Technologies.

3.8. He also mentioned about the Inter-ministerial Committee Report on Quantum Communication Technologies prepared by Department of Telecommunications outlining the roadmap for India and the National Quantum Mission soon to be launched by the Government of India highlighting to strategize and focus the efforts so as to reap maximum benefits from the limited resources and remain globally competitive.

3.9. He emphasized on the use of Post Quantum Cryptography, Quantum Key Distribution and Quantum Random Number Generators to secure the communication infrastructure against the threat of Quantum computing.

Release of standards developed by TEC on Quantum Communication Products:

3.10. Hon'ble Minister of Communications, Electronics & IT and Railways released the following standards developed by TEC on Quantum Communication products:

i. **Test Guide for "Quantum Key Distribution System**" (TEC No. 91001:2023)

ii. **Generic Requirements on "Quantum-safe and Classical Cryptographic Systems"** (TEC No. 91010:2023)

Presentation of "Pandit Deendayal Upadhyaya Telecom Skill Excellence Awards- 2022"

3.11. During the inaugural on 27th March 2023, Hon'ble Minister of Communications, Electronics & IT and Railways presented the "Pandit Deendayal Upadhyaya Telecom Skill Excellence Awards – 2022" for the exemplary and outstanding contributions in the areas of Telecom Skilling, Telecom Services, Telecom Manufacturing, Telecom Applications in deploying telecom dependent sectoral solutions for different fields such as agriculture, commerce, health, education etc. The awards were presented to M/s Sterlite Technologies Ltd, Pune, M/s Vihaan Networks Limited, Gurugram, M/s QuNu Labs Private Limited, Bengaluru, M/s Dhruva Space Private Limited, Hyderabad and M/s Inntot Technologies Pvt Ltd, Ernakulam.

Special Address by Shri Devusinh Chauhan, Hon'ble Minister of State for Communications

3.12. The Hon'ble Minister of State for Communications, Sh. Devusinh Chauhan, paid tribute to Indian scientist S.N. Bose for his contributions to the field of quantum mechanics. He also discussed India's advancements in the telecom sector, including the development of indigenous 4G and 5G technologies, as well as the country's active pursuit of advanced technologies in 6G and Quantum Technologies, in line with the vision of the Hon'ble Prime Minister. He mentioned about the global recognition of India's growing stature in the field of Telecom being acknowledged with the Government Leadership Award at the Mobile World Congress 2023.

3.13. He mentioned about the beginning of 'Amrit Kaal', announced by the Hon'ble Prime Minister, and emphasized the significant role that quantum technologies will play in achieving this vision. He further discussed various initiatives launched by the government, such as the National Quantum Mission, Telecom Technology Development Fund, Production and Design Linked Incentive scheme, and Telecom Centre of Excellence, aimed at promoting indigenous design and manufacturing, innovation, entrepreneurship, and start-up ecosystems.

Inaugural Address by Shri Ashwini Vaishnaw, Hon'ble Minister of Communications, Electronics & IT and Railways

3.14. The Hon'ble Minister of Communications, Electronics & IT and Railways spoke about the remarkable transformation of India's telecom sector over the last eight years, from facing serious challenges to becoming a vibrant, resolute, and forward-looking industry. He shared the vision of the Hon'ble Prime Minister for the sector, which includes developing indigenous technologies to lead as a technology exporter and taking the lead in technology development. He highlighted the successful development of an indigenous 4G and 5G technology stack, tested with 10 million simultaneous connections in less than three years, which has gained popularity in many countries and created trust in India's technology deployment. He emphasized the importance of taking the lead in the development of technologies and becoming a technology exporter rather than just a technology consumer.

3.15. He emphasized the importance of standards and mentioned about the standards developed by TEC on "**Quantum Key Distribution System**" and "**Quantum-safe and Classical Cryptographic Systems**".

3.16. He further mentioned about the pilot **Quantum Secure Communication Link** made operational between the Sanchar Bhawan, Department of Telecommunications and National Informatics Centre (NIC's) CGO Complex in Delhi.

3.17. With an objective to find vulnerabilities in QKD as well as PQC solutions as well as to strengthen the Quantum Ecosystem in India, the Hon'ble Minister of Communications announced the Quantum hackathon with a prize of INR 10 Lakh for each break into the Quantum systems developed by C-DOT.

Inauguration of the Exhibition of Quantum Products

3.18. Hon'ble Minister of Communications, Electronics & IT and Railways along with Hon'ble Minister of State for Communications inaugurated the exhibition of Quantum products at the Exhibition Hall on First Floor of Vigyan Bhawan. The exhibition featured demonstration of Quantum products from the **C-DOT**, **ID Quantique**, **Qu Labs**, **QuNu Labs**, **Scytale Alpha Private Limited** and **Silicofeller Quantum**.

4. TECHNICAL SESSIONS

4.1. The inaugural session was followed by technical sessions and Panel Discussions spread over two days (27th March, 2023 and 28th March, 2023).

4.2. SESSION-I: Trends in Quantum technology

The session was chaired by **Dr. Rajkumar Upadhyay, CEO, C-DOT** and covered the four verticals of Quantum technology, their potential applications in various fields, and the top 10 Quantum Technology trends for 2023. Quantum Computing was discussed, including key concepts and technologies, and the challenges in designing state-of-the-art hardware. Quantum Communication was also highlighted, with a focus on Quantum Key Distribution (QKD) and its various applications. Quantum Materials and Devices were introduced, with an emphasis on topological Quantum matter and its device applications. Finally, Quantum Sensors and devices for navigation, timekeeping, and healthcare were discussed, highlighting their unique features and various applications.

4.3. SESSION-II: Building a Quantum Network

The session was chaired by **Mrs. Suma Varughese, OS & Director General (MED & CoS), DRDO** and highlighted the importance of quantum communication and the role of quantum networks in achieving secure communication and information processing based on quantum mechanics. The speakers discussed the challenges and advancements in quantum memories, quantum technologies in satellite communication, single photon sources and detectors, all-electronic true random number generators, and supporting quantum advantage from the classical side.

4.4. SESSION-III: Challenges and Prospects for Quantum Technology Development

The session was chaired by **Sh. YGSC Kishore Babu, DDG (SRI), DoT** and delivered insights into the initiatives taken by the Department of Telecommunications (DoT) including the recommendations of the Inter-ministerial Committee Report on Quantum Communication Technologies. The session also highlighted the challenges faced during the development of quantum computing hardware and quantum communication, along with the UK National Quantum Technologies Programme and the work of the Quantum Communications Hub. The TEC initiatives for enabling standardization and market access for Quantum communications were also discussed in the session.

4.5. PANEL DISCUSSION-I: Challenges and Prospects for Quantum Technology Development

The panel discussion was chaired by **Dr. Rajkumar Upadhyay, CEO, C-DOT** and moderated by **Sh. Abdul Kayum, DDG(6G), TEC**. The panel discussed on topics such as the need for Quantum Alliance to avoid duplicity of efforts and better collaborative approach, opportunities in the Quantum sector, the state of development of quantum computers in India. The panelists also highlighted the huge potential of quantum technologies in various sectors and emphasized the importance of collaboration between stakeholders and academia to overcome challenges and achieve progress in the field.

4.6. SESSION-IV: Quantum Technologies in Satellite Communication

The session was chaired by **Sh. Sanjeev Agrawal, Member (Technology), DoT** and highlighted the importance of quantum technology in addressing the security challenges in satellite communication. The development of efficient sources of "Single" and "Entangled" photons using photonic technology was emphasized. The speakers also discussed the development of quantum key distribution (QKD) and quantum random number generators (QRNG) for secure communication using satellites. The works being carried out on satellite-based QKD, including the development of a QKD experimenter's

simulation software and a polarization-based compensation method for long-distance QKD implementation in satellite communication were presented. The experts emphasized the need for collaboration and investment in research and development to enable the widespread adoption of quantum technologies in satellite communication.

4.7. SESSION-V: Security in the Quantum-Era

The session was chaired by **Smt. Pamela Kumar, Director General, TSDSI** and discussed about various aspects of security in the quantum era. It highlighted the threat that quantum computers pose to current encryption algorithms and the need for a robust security framework in the quantum era were discussed exploring Quantum key distribution (QKD) and Post-Quantum Cryptography (PQC) as potential solutions for secure communication in a Quantum world. The session had also covered the current state of QKD and PQC research work as well as their practical implementation and integration into existing systems. The session also touched upon the need for cryptographic agility and the importance of migrating legacy systems to secure systems in the post-quantum era.

4.8. SESSION-VI: Standardization efforts on Quantum Technologies

The session was chaired by **Sh. Uma Shanker Pandey, Member (Services), DoT** and focused on the standardization efforts in the field of quantum technologies. The speakers highlighted the importance of standardization in ensuring the security requirements of quantum products. The experts discussed about the works done by TEC, ETSI, ITU, NIST working towards developing standards for quantum key distribution, post-quantum cryptography, and quantum-safe technologies. Additionally, the experts highlighted about the role of TEC in formulating standards, discussed about the implementation of Metro Area Quantum Access Network Testbed as a testbed for evaluating point-to-multipoint QKD and the ongoing PQC competition by NIST aimed at identifying quantum-resistant cryptographic algorithms.

4.9. SESSION-VII: Quantum Communication: Industrial Perspective and Use Cases

The session was chaired by **Lt. Gen. M.U. Nair, SO-IN-C, Indian Army** and highlighted the potential of quantum communication in various sectors, including defense, finance, and telecommunications in building a quantum-safe communication infrastructure. The speakers emphasized the need for quantum-safe cryptography to protect against the threat of quantum computers. The session also covered the potential of quantum communication in building a Quantum Internet and the need for collaborations between various entities to drive quantum technology research and development.

4.10. PANEL DISCUSSION – II: Quantum Communication: Industrial Perspective and Use Cases

The panel discussion was chaired by **Major General Sanjiv Sharma, Indian Army** and moderated by **Sh. Abdul Kayum, DDG(6G), TEC**. The panelists discussed about various topics, including the work done by C-DoT in providing the Quantum safe solutions, QKD and PQC, implementation of 5G end-to-end Quantum solution by S K Telecom in South Korea and the applications of Quantum Technologies across different sectors. The panel discussed about the challenges in encouraging the stakeholders for adoption of the Quantum safe solutions and emphasized on Collaboration with the various stakeholders in steering the development of the Quantum Technologies solutions as per the requirements of the Industry.

SESSION – I

TRENDS IN QUANTUM TECHNOLOGY

Quantum Communication

Dr. Rajkumar Upadhyay, CEO, C-DOT chaired the session where he discussed the significance of Quantum Technology and its various applications, including Stimulated Emission, Photovoltaic Effect, and Magnetic Resonance, which were significant developments during the first Quantum revolution. He introduced the four verticals of Quantum technology, namely Quantum Computing, Quantum Communication, Quantum Sensing/Metrology, & Quantum Material.

The talk also explored the potential applications of Quantum technology in various fields such as Defence and Security, Drug Discovery, Healthcare, Manufacturing and Supply Chain among others. The talk highlighted the significant investments being made globally, the maturing of technology, and the exponential growth of the market in relation to the second Quantum revolution. Moreover, it was highlighted that a group of scientists, academia, and scientific bodies are working with UNESCO and the United Nations to declare the year 2025 as the International Year of Quantum Science and Technology during the 2023 General Assembly of the UN.

He also mentioned the top 10 Quantum Technology trends for 2023 and focused on Quantum Key Distribution (QKD) as a significant technology candidate for Quantum communication. He informed the audience about CDOT's development of a Quantum system between Sanchar Bhawan and NIC, which has been commissioned and is now open for ethical hackers, with an award of 10 Lakh Rupees per event for anyone who can break it. He also discussed various applications of Quantum communication, such as Quantum Random Number Generator (QRNG), Secure Communication, Distributed Quantum Processing, and Blind Quantum Computing. Finally, he mentioned the products developed by CDOT, including QKD/PQC and invited researchers to work in collaboration with C-DOT.

Quantum Computing: Realization of Quantum Hardware

Prof. Mustafijur Rahman, IIT Delhi discussed Key Quantum Concepts such as Superposition, Entanglement and Fragility, which enable quantum computers to perform complex computations in a single shot and outpace even the mostadvanced supercomputers. He also explained the DiVincenzo criteria for building a Quantum Computer and compared different Quantum technologies like Superconducting qubits, Trapped Ions and Silicon Quantum Dots. He mentioned the challenges in designing state-of-the-art Quantum Computing hardware & Cryogenic Controller IC and discussed qubit states & control, single & two qubit operations and spin qubit control signals. Finally, he mentioned the ARIL chip being designed by IIT Delhi for both superconducting and spin qubits.

Quantum Materials and Devices

Prof. Bhaskaran Muralidharan, IIT Bombay discussed Quantum Materials and Devices, which are essential for the development of Quantum technologies. He provided a general overview of the topic and then focused on topological Quantum matter, which is technologically relevant. He explained how topological Quantum materials, such as topological insulators, feature dissipation-less edge states with lane discipline, unlike conventional materials. He discussed the low-level Quantum mechanics involved in these materials and their device applications. He explained the building blocks of Quantum devices for various verticals of Quantum technology and showed their anatomy. Towards the end of his talk, he described graphene-based qubits and Single photon emitters-TMDC. He also mentioned how IIT Bombay is involved in the development of Quantum technologies.

Quantum Sensors and devices for navigation, timekeeping and healthcare

Professor Umakant D Rapol, IISER Pune provided a comprehensive overview of Quantum Sensors, including Atomic Sensors, Squeezed Light, Spin Qubit Sensors, Quantum Clocks and Quantum Imaging among others. He highlighted the various applications of Quantum sensors in rotations, accelerations, gravity, magnetic and electric fields and time measurement. He also discussed the unique features of Quantum sensors, including Standard Quantum Limit (SQL), Squeezing, wave-particle duality, use of Entangled Quantum States and Quantum Tunneling. He elaborated on the magnetic sensors used in Healthcare, differentiated Atomic Sensors and Atomic Clocks, such as the Cs fountain clock. Additionally, He provided insights into the international status of optical atomic clocks.

SESSION – II

BUILDING A QUANTUM NETWORK

Building a Quantum Network

Mrs. Suma Varughese, OS & Director General (MED & CoS), DRDO briefly described the Quantum Efforts worldwide with Europe launching a $1 billion quantum computing research project, Quantum Flagship; China prioritizing the development of quantum computing and communications by 2030 in its 14th Five Year Plan (2021-2025). She then presented about the components to build a Quantum network (Quantum Source, Quantum Detector, Quantum memory, Quantum Repeeaters, etc) and the challenges ahead of Quantum Networks like:

- Compatible co-existence requiring the compatibility with existing Telecom infrastructure for scaling up the network. Quantum frequency conversion modules can be used to convert the emitted light into the telecom band.
- Maintaining synchronization between the nodes.
- Development of a Quantum repeater

The Quantum Random Number Generator prototype in-house developed by DRDO and it's Transfer of Technology (ToT) to Industry along with the field testing of the Fiber based QKD by DRDO and IIT-Delhi at Praygraj – Vindhyachal over a distance of 100 Km with a secure key rate of ~5 Kbps and QBER of 6% were also presented in the session.

Quantum Memories and Repeaters: Challenges

Dr. Nixon Patel, CEO, Qu Labs talked about the challenges and advantages of various types of Quantum memories which included Atomic Vapor Quantum Memory, Cold Atom Quantum Memory, Atomic Frequency Comb based Quantum Memory and Gradient Echo Memory.

He highlighted the activities carried out at QuLabs for the development of Quantum Memory and Quantum Repeaters including the Table-top Proof of Concept of Rb-based EIT Quantum Memory carried out in collaboration with IIT Roorkee. He highlighted that Warm Rb vapor-based Quantum memories can provide a field deployable solution towards building a scalable quantum repeater network.

He further talked about mitigating the challenges to pave the way for practical quantum networks in near future:

- Memory efficiency & storage time: It is needed to support robust communication.
- Frequency Conversion: Frequency conversion is required to interchange frequency of qubits to enable storage in Quantum Memory as well as transmission at telecom wavelengths.
- Entangled Photon Source/Single Photon Source Efficiencies: Need for highly efficient, preferably deterministic single photon sources to increase probability of entanglement generation/swapping.
- Clock Synchronization and Time Stamping: Need time tagging modules with picosecond precision and highly accurate clocks.
- Photon Detector Efficiencies: Need for high efficiency at 1330/1550 nm with low dark count and low dead time.

He also mentioned about the Tucson Test Bed and Boston Test Bed Centre for Quantum Communication USA for the Quantum Network and emphasized on the Quantum Network Test-bed in India.

Quantum Technologies in Satellite Communication

Sh. Nilesh M. Desai, Director, SAC, ISRO emphasized the importance of Quantum Communication Technologies mentioning about Nobel Prize in Physics 2022 awarded for conducting experiments using entangled quantum states, establishing the violation of Bell inequalities. He further talked about the applications of quantum communication in different areas, the need for satellite-based quantum communication (SBQC) and the worldwide developments related to SBQC in China, Spain, Japan, Germany, Singapore mentioning about the successful demo missions/programs related to QKD:

i. **MICIUS** by Chinese Academy of Sciences, University of Vienna, Austrian Academy of sciences: Decoy state BB84 and Entanglement distribution over 1200 Km using Micius Satellite

ii. **SOCRATES** by NICT, Japan: Satellite-to-ground quantum-limited communication using a 50 Kg microsatellite

iii. **SpooQY-1** by The CQT (Center for Quantum Technologies) at NUS (National University of Singapore): Demonstrated the operation of a compact, low-power, lightweight, and robust source of entangled photon pairs into low Earth orbit. (Loop-back mode)

He further talked about the **Baseline Technologies**: Quantum Transmitter and Receiver, Time tagging and synchronization, QKD protocols, Telescope with PAT system, Atmospheric Channel Modelling and Microwave Quantum Source and **System-Level Technologies:** Single photon based QKD system, Entangled photon based QKD System, QKD over moving platform, QuantESS payload, TDS payload, Optical Ground Station, Opto-Quantum Communication Payload for Satellite Based Quantum Communication. He then mentioned about the works being done at ISRO:

- Inter-building Free Space **Single-Photon based** Quantum Key Distribution inside SAC Campus over a distance of 300m with NavIC enabled synchronization, 300 kbps key rate and with indigenously designed and developed weak coherent pulse source.
- Inter-building Free Space **Entanglement based** Quantum Key Distribution inside SAC Campus over a distance of 300m.
- **QuantESS Payload (Quantum Entanglement studies in Space) onboard POEM-2 on PSLV-C55** for Carrying out Entanglement study and Hong-Ou-Mandel (HOM) Experiments for development of space worthy entangled photon source and demonstration of entangled photon source application in space by generating quantum keys using end-to-end entanglement based QKD protocol implementation with limited hardware.
- **Space Segment: QuTDS Payload (Quantum Technology Demonstration in Space)** proposed for TDS-01 Satellite with Quantum Random Generator, Quantum Cryptography, QKD.
- Development of Quantum-Dot Single/ Entangled Photon Source and Single Photon Avalanche Detector (SPAD)
- Photonic Integrated Circuit Development eg. QKD Transmitter Chip
- **Opto-Quantum Communication (OQC) Program** to demonstrate Satellite based Optical and Quantum Communication between LEO spacecraft and Optical Ground Stations.

Single Photon Source and Detector

Professor Bijoy Krishna Das, IIT Madras talked about the Silicon Photonics research being carried out at IIT Madras under Centre for Programable Photonic Integrated Circuits and Systems (CoE-CPPICS) funded by MeiTY and the collaborations with SilTerra Silicon Photonics Foundry Malaysia and Si2 Microsystems Bangalore. He explained Photon Source integrated with Pump Rejection Filter as the approach to generate efficient photon source and discussed about quantum photonics applications in quantum key distribution, quantum metrology, quantum imaging, quantum simulation, quantum sensing and quantum computation. He also briefed about the processing and test facility of silicon photonics technology available at IIT Madras which includes

- **Design & Simulation Tools:** Ansys Lumerical, Cadence Photonics, COMSOL Multiphysics, Synopsys Sentaurus;
- **Process Tools:** Upgraded E-Beam Lithography, DUV Lithography Mask Aligner, ICP RIE Systems, E-beam Deposition Systems, LPCVD and PECVD Systems, Oxidation & Diffusion Furnace, Chemical Mechanical Polishing
- **Characterization Tools:** Indigenous chip-scale silicon photonics probe station, Silicon photonics probe station for die-level testing, RF Phase Noise Analyzer, Fully automated wafer-scale silicon photonics probe station, 8 Channel SNSPD for testing Quantum Photonics Chips, Light Component Analyzer for e/o and o/e device characterization, High Resolution Source Optical Spectrum Analyzer and Fiber Pigtailing and Packaging Setup.

An all-electronic true random number generator

Prof. Kausik Majumdar, IISc Bengaluru talked about the need of random numbers for increasing demand for hardware security in secure communication, digital money, cryptocurrency, quantum communication. He presented his work on all-electronic van der Waals heterostructure-based device generating a random sequence with record-high value (>0.98 bits/bit) of min-entropy through the detection of discrete charge fluctuation in a quantum dot embedded in a tunnel junction. The generated high quality random sequence passes tests such as NIST SP 800-90B and NIST SP 800-22. In addition to chip-scale solution of Quantum Random number Generator, he also briefed upon the works being carried out by Quantum Electronics Laboratory at IISc Bengaluru on chip-scale solution of Single Photon Source and Single Photon Detector.

Supporting Quantum Advantage from the Classical Side

Dr. Sadik Hafizovic, CEO, Zurich Instruments AG reported on the latest developments of quantum computing control systems at Zurich Instruments. It included the qubit state discrimination, feedback architectures for quantum error correction, speed-up of the practical operation of quantum computers and an outlook on control systems that will go towards 1,000 qubits. He further talked about the various collaboration projects of Zurich Instruments with different entities working on Building a stabilized qubit, Quantum error correction, Control 100 qubits, Quantum Computer on Web, Scaling of Superconducting QCs and Entanglement of 2 fridges over 30m.

SESSION – III

CHALLENGES AND PROSPECTS FOR QUANTUM TECHNOLOGY DEVELOPMENT

DoT Initiatives on Quantum Technologies

Sh. YGSC Kishore Babu, DDG (SRI), DoT presented the initiatives taken by DOT for Quantum communications. He mentioned about the constitution of Inter-Ministerial Committee (IMC) on Quantum Communication Technologies by DoT with members from various stakeholders like ISRO, PRL, O/o PSA, DOT, Academia, Industry, RRI, NSCS, C-DoT, CDAC etc. The various Task Forces were created to give recommendations on Build Synergies across institutions, Identify use case and enable pilot trials, standards development and representation in global standards bodies, Policy measures to promote Quantum Communication products, production and deployment, facilitate IPR creation In India and Roadmap and Action plan for the development of Quantum Communication Technologies. He presented the key recommendations of the committee as below:-

- Drawing a National Level Program for Quantum Communication (QC) Pilots and Trials with indigenous products.
- Fund Public access Quantum Communication testbeds and ensuring industry facilitation with access to integrated testbeds at a nominal cost.
- Quantum security an integral part of National Security Strategy with specific actions.
- Setting up of Testing and Certification facility for interoperability, and testing of equipment from multiple vendors.
- Make available public R&D infrastructure created with government funding for collaborative and federated use.
- Central funding of R&D projects in Quantum Communications to enable synergies - Focused funding for higher R&D goals with and minimizing duplication.
- Quantum Communications facilitation centre by TEC to galvanize government, industry and academia in taking actions on Quantum Communications.
- Quantum Communication Application Use case labs / Experience Centres in key economic verticals driven and hosted by Industry with funding support.

He also gave a brief overview of the different standardization activities being carried out at IEEE, ISO, ETSI and ITU on various domains viz. SDN, QKD APIs, Channel, Network, Protocols, Terminologies, Interfaces, Characterization, Use cases, Test and Evaluation, benchmarking and QoS.

Challenges and Prospects for Quantum Technology Development

Sh. Nagendra Nagaraja, CEO, QpiAI talked about Quantum and AI being vertically integrated. He talked about the quantum computer developed by QpiAI for Quantum communication harnessing 25 Qubits and scalable upto 300 Qubits with hardware, temperature controlled controller and complete software stack developed by QpiAI only.

He presented the various solutions developed by QpiAI for various industry problems like drug discovery, banking services, financial services, Automotive services etc.

- QpiAI Explorer for classical circuit simulation
- QpiAI ML for Machine learning

- QpiAI Opt for optimization problem solver
- QpiAI Sim with 20 Qubit quantum enhanced simulation.

He further talked about practical challenges faced during development of Quantum Computing hardware i.e. while deploying Managed Jobs to run on Quantum computer and workload distribution between GPUs, CPUs and Quantum Computers due to very less coherence time of Qubits. He also talked about challenges faced during development of Hardware aware optimized quantum circuit compiler with Qubit Mapping and routing for quantum software and framework for Hybrid Quantum Classical Compilation. He mentioned efficient design of EMI and radiation shields is required to mitigate the noise and interference for operation of the qubits and at Cryogenic environments, the qubit generate heat, that needs to be managed to maintain stability and high fidelity operation. He also talked about the challenges faced during Quantum communication i.e. Noise and signal loss in transmission, Limited distance of transmission and Limited Detector Efficiency.

The UK National Quantum Technologies Programme

Sh. Timothy P. Spiller, Director, Quantum Communications Hub, United Kingdom gave overview about the UK National Quantum Technologies Programme (UKNQTP) set up by the UK Government to translate academic research into products and services. The phase-I of the project supported four Quantum Technology Hubs, Centres for Doctoral Trainings, Innovate UK funding programme (industry-led), a new Metrology Centre at the National Physical Laboratory (NPL) and New QT Training and Skills Hubs linked to the existing CDTs. The four Quantum Technology Hubs include:

i. Quantum Hub for sensors and metrology, led by the University of Birmingham

ii. Quantum Communications Hub, led by the University of York with focus on QKD applications

iii. NQIT: Quantum hub for Networked Quantum Information Technologies, led by the University of Oxford

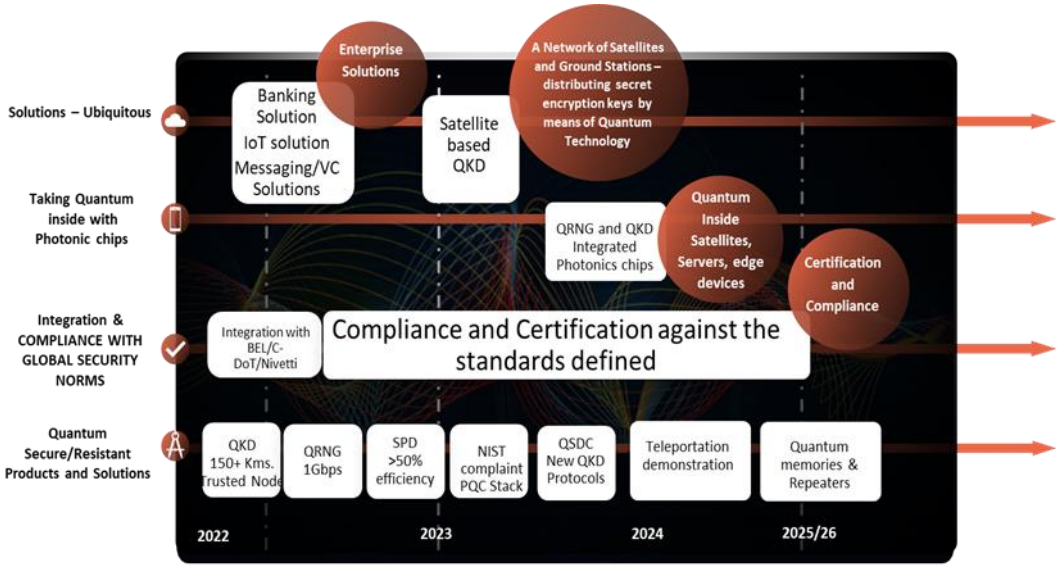
iv. QuantIC: Quantum hub for quantum enhanced imaging, with a central team at the University of Glasgow

The Hub established the UK's first quantum network (UKQN) and is now moving to entanglement-based networks preparing for a Quantum Internet. The Hub also established the first fibre network link to industry (Cambridge to BT Adastral Park). Their work facilitated technology transfer into industry-led development. UNQTP is continuing it's Phase-II in 2019-2024 with a total budget of ~ £1billion. Their current work includes:

- collaboration with Network Rail using trackside fibre for QKD, via Hub Partnership Resource Funding (PRF) project QTRAX.
- in-orbit demonstration (launch 2024) of QKD from a CubeSat (supplier ISISPACE) to an optical ground station (Errol Airfield, Scotland).
- Canadian QEYSSat mission: UK-Canada QT programme downlink source; Hub PRF project uplink entangled source.

TEC Initiatives in enabling standardization and market access

Sh. Abdul Kayum, DDG (6G), TEC presented about the TEC initiatives in enabling standardization and market access for Quantum communication products developed in India. He mentioned about Focus Areas of R&D in India such as Quantum Key Distribution Solution, Quantum Enabled NextGen Enterprise Messaging Platform, Post Quantum Cryptography Encryptor, Quantum Random Number Generator – Hardware and Cloud based, Trusted Relay Node, Hub & Spoke QKD, Quantum Network Simulator, Quantum secure Video Conferencing, Single photon detector, Room Temperature Telecom wavelength Quantum memory. Quantum chipset. He presented the Quantum Communications roadmap and mentioned about the 'anchoring role' of TEC in synergizing the efforts of universities, research institutions, Industry, Start-ups and Government organisations for development of products. He also mentioned about the participation of TEC in the standards development activities at IEEE, ITU, ISO, NIST, ETSI etc.



He mentioned about the standards developed by TEC:

- Generic Requirements and Test Guide for validation of Quantum Key Distribution Systems
- Generic Requirements for Quantum Safe and Classical Cryptographic Systems.

He also presented the future roadmap of TEC to develop standards on Quantum random Number Generator, Quantum Computing Platforms- Hardware subsystems, Control Software and Quantum Software, Single Photon Source and Single Photon Detectors and also mentioned about various future standardization areas namely Quantum Homomorphic encryption, Quantum Secure Direct Communication, Quantum Secret Sharing, Quantum Repeaters, Quantum Memories, Quantum Router, Switches, Multiplexers, Demultiplexers, Quantum Key Distribution using Satellite, Use of same media (fiber) for data communication and Quantum Key, Transmission and Quantum Direct Messaging, Interfaces among layers and Interoperability.

He thereafter discussed about the successful POC field trials done by TEC for the Quantum key Distribution System developed by C-DOT between the Sanchar Bhawan, Department of Telecommunications and National Informatics Centre (NIC's) CGO Complex in Delhi and the

trial of secure VC solution with the Post-Quantum Cryptography based system developed by C-DOT between TEC, C-DOT and DoT HQ, Sanchar Bhawan.

The future of Quantum Communications, from QKD to the Quantum Internet

Dr. Bruno Huttner, Director, ID Quantique, Geneva, Switzerland described the Quantum as a new Paradigm for Information Processing with Qubits providing randomness (QRNG), secure communications (QKD and Quantum Network) and enhance computing power (Quantum Computer). Based on Entanglement i.e. coherent superposition of multiple qubits, Quantum Computer can process an exponential number of input states in one step.

He presented the various Quantum Key Distribution (QKD) solutions provided by ID Quantique and explained about the integration of QKD with existing encryption solutions. The secured key can be delivered using QKD which can then be used by intended transmitter and receiver to encrypt data using any encryption algorithms like AES 256, AES 512 or Post Quantum Computation (PQC) algorithms. He further talked about limitation of current QKD infrastructure i.e. dedicated Point to point physical link required, distance limitations, costs involved, no standards etc. He talked about the building blocks of the Quantum Network and emphasized on the Key Management System (KMS) layer as the glue of the QKD network to ensure QKD keys are synchronized through QKD network.

He then presented the **Korean National Convergence Network Project** implemented by ID Quantique and SK Telecom building a first nation-wide QKD network in Korea spanning over 2000 Km connecting 48 Government Organisations and the **Euro-QCI initiative** aiming at safeguarding sensitive data and critical infrastructures by integrating quantum-based systems into existing communication infrastructures by 2027. He also briefed about QKD Testbeds and OpenQKD Consortium as a part of Euro-QCI initiative.

Building an ecosystem for Quantum Technologies

Sh. Pradeep Kumar, Director, Qbit Labs briefed upon the major players in the Global Landscape of the Quantum ecosystem which includes Specialists, Software and service players, Hardware and systems players and end-to-end providers. He further talked about the challenges in India including lack of research environment, lack of hardware systems, limited funds in R&D and lower priority in technology and suggested the following way forward:

- Preparing Quantum engineering workforce
- Technological alliance with global players
- Building indigenous Quantum computer targeting end-to-end development
- Priority investment in Quantum Technologies

Prosperity and Resilience in the Quantum era

Prof. Michele Mosca, Institute for Quantum Computing, University of Waterloo, Canada mentioned about the threats to security posed by the Quantum Computer and the World Economic Forum report citing cybercrime and cyber insecurity as one of the top 10 global risks in both the short and long-term. He mentioned about taking into account the security shelf-life (x years), migration time (y years) and collapse time (z years) in planning to migrate to Quantum-safe protocols and emphasized on acting immediately if x+y approaches z.

To maximize India's ROI in Quantum innovation, he emphasized on establishing quantum readiness requirements for key economic sectors, leveraging available best practices and contributing new findings back to the community. He further proposed to engage with broader ecosystem (supply chain, third parties, standards, etc.) to identify key challenges that need to be tackled together and support the vendor system by deploying the solutions and testing them in real world scenarios.

PANEL DISCUSSION – I

CHALLENGES AND PROSPECTS FOR QUANTUM TECHNOLOGY DEVELOPMENT

The panel discussed about the various aspects in the development of Quantum Technologies viz.

a. **Technological Challenges**: requirement of low temperature, highly prone to noise

b. **Ecosystem Challenges**: Being an interdisciplinary field with mix of Electronics, Physics, Mathematics it requires a multidisciplinary approach in developing the Quantum systems.

c. **Regulatory Challenges:** Development of standards and ensuring inter-operability among the systems

d. **Funding Support:** Required by institutions to carry out research and development

The salient key points discussed during the panel discussion are enumerated below:

- Creation of a **Quantum Alliance** with research institutions, academic institutions and industry/start-ups, which are working towards the development of Quantum technologies to collaborate and carry out cohesive research in India. The Quantum Alliance would also help in channelization of fund to the right partners to develop indigenous solutions and would also avoid duplication of any efforts.
- Organisation of **Quantum Hackathon** announced by the Hon'ble Minister to find vulnerabilities in the QKD and PQC systems developed by different Indian entities.
- Emphasis on development of indigenous QKD protocols and PQC algorithms.
- **Quantum Economic Development Consortium (QED-C)** in USA with support from multiple agencies and a diverse set of industry, academic, and other stakeholders working together to identify gaps in technology, standards, and workforce and to address those gaps through collaboration.
- Diverse job opportunities in the area of Quantum Technologies but unavailability of the required skill set and training in academia. Dr. Nixon Patel, Qu Labs mentioned about the Centre for Quantum Communication (CQC) partnership with IIT Hyderabad which include building a course for Quantum certification focusing on the skills required by the industry.
- Collaboration among different stakeholders with the basic research done by the academic institutions to be worked upon by applied R&D institutions (C-DOT, C-DAC, CSIR Labs, ISRO, DRDO etc.) to take it to higher TRL Levels (upto 7-8) and then the transfer of technology to industry for development of commercial applications.
- Four qubit quantum computer built at Centre of Excellence in Quantum Technology (CEQT) at IISc, Benglauru and 25 qubit Quantum computer being developed by QpiAI along with a roadmap to build a Quantum Computer upto 300 qubits under National Quantum Mission in 1 – 1-5 years and working towards error-corrected qubits.
- Need for adoption of the developed Quantum solutions by the industries across different sectors such as Telecom sector for securing the communication infrastructure using QKD, Pharma sector for discovering new molecules, Logistics companies for supply chain management and Defense sector. For instance, Prof. Urbasi Sinha mentioned about MoU between RRI and WESEE (Weapons And Electronics Systems Engineering Establishment), Indian Navy to promote research in Quantum for maritime use cases in line with Atmanirbhar Bharat and is also working on projects with ISRO, MeitY, DRDO, etc.

CONCLUDING REMARKS: DAY 1

Dr. Manjunath Ramachandra, Wipro and Champion for Quantum communication TRIP forum, TSDSI, spoke about the potential for India to become the quantum capital of the world within the next few decades. He emphasized that the government is supportive and liberal in funding for quantum technologies, as they have a lot of dreams and aspirations for India's future in this field. He drew parallels to India's success in becoming the IT and software capital of the world by making the right decisions three decades ago and believes that India has a similar opportunity with quantum technologies.

However, one of the major challenges with quantum communications is the need for very low temperatures to operate. Unlike mobile phones that can be kept in pockets, quantum communication devices cannot be operated at room temperature yet. This limits mass adoption until these devices or advanced technologies, such as quantum teleportation, can operate at room temperature. Additionally, noise is another issue that must be addressed in the quantum channel. He emphasized that advancements in quantum teleportation will be crucial for communication, particularly when humans set foot on Mars, as it can solve the problem of round-trip delays in communication. Quantum sensors and metrology are also important for quantum communication, but putting these technologies into usable forms will take time and research efforts.

He encouraged the audience to network, socialize, and collaborate to leverage each other's capabilities and expertise in advancing quantum technologies in India.

SESSION – IV

QUANTUM TECHNOLOGIES IN SATELLITE COMMUNICATION

Quantum Technologies in Satellite Communication

Sh. Sanjeev Agrawal, Member (Technology), Department of Telecommunications highlighted that Satellite communication has become very important but it also some vulnerabilities. The quantum technology offers solution to these challenges and enables secure satellite communication. We need to invest in R&D as well as development of robust and reliable infrastructure that can support quantum communication in satellite systems. There is a need to work towards Standardization also to ensure interoperability and widespread adoption of technology. He emphasized on collaboration and collective efforts to work towards quantum communication in satellite quantum technologies.

Entangled photon source for free space and fiber based QKD – Highlights from Lab at IIT Delhi

Prof. Joyee Ghosh, IIT Delhi discussed about the research works being carried out by Quantum photonics Group on Fiber-based Quantum Communication, Free-Space Quantum Communication, Twin Photons for QI Applications, Coherent Light-Matter Interaction in Atomic media, Quantum Detection and Correlated Photons in SOI Nano-waveguides.

She talked about the challenges in the Prepare and Measure Protocols (single-photon based) with possible attacks such as PNS Attack, Intercept-resend attack and emphasized on Entanglement based protocols.

She presented about the projects "**Quantum Technologies using Hybrid Photons for Secure Communication & Quantum Information**" funded by DRDO and "**Integrated sources of entangled photons for quantum communication and quantum information applications**" funded by DST-QUEST. She also briefly talked about the integrated architectures in ppLN and ppKTP for generating entangled and hyperentangled photons and Telecom-Band Quantum Light Sources Using Dispersion-Engineered SOI Waveguides.

QKD in Satellite Communication

Prof. R.P. Singh, Physical Research Laboratory, Ahmedabad explained about the Discrete Variable and Continuous variable QKD and the related Prepare & Measure protocols and Entanglement based protocols. He presented the various works being done and the future plan of work at PRL, Ahmedabad:

- Implementation of BB84 QKD protocol in free space for 200 meters with weak coherent laser pulses, Sift key rate (~200 kbps) and Secure key rate (~150 kbps), QBER < 3%
- Development of bright entangled photon source at 810 nm (105 photon pairs per second)
- Implementation of BBM92 QKD protocol in free space for 200 meters with entangled photons, Sift Key rate (~4.5 kbps) and Secure Key rate (~2 kbps), QBER < 5% and effect of aerosols on the key rate
- End to end encryption for audio and video with Space Application Centre (ISRO), Ahmedabad for free-space channel of 300 meters using BB84 as well as BBM92 protocol

- New QKD protocol – Gaussian Modulated CV-QKD Protocol – using weak coherent pulses that gives higher key rate compared to BB84/Decoy state protocol for same mean photon number per pulse
- Side channel attack analysis for BB84 source using a new technique based on cross-correlation.
- Working towards development of Optical Ground Stations (OGS) for satellite-based QKD

Future Plan of Work at QST Program at PRL Ahmedabad:

- Effect of turbulence and for terrestrial communication.
- Simulating conditions for uplink and downlink to check the key rate for satellite based quantum communication.
- Development of Device Independent QKD protocol.
- Entanglement swapping and quantum teleportation in free space for 200 meters towards setting QC network
- Using structured light such as - Vortex beam, Pencil beam, Gaussian Schell Model beam and Twisted Gaussian Schell Model beam - for robust and secure key distribution
- Development of Photonic Quantum Computing since it is the best bet for quantum internet, World Wide Quantum Web (WWQB), the ultimate stage of quantum communication (China, Xanadu in Canada and Psi Quantum in USA, ORCA Computing in UK are making good progress)

Space-Qualified Quantum Random Number Generator

Dr. Bruno Huttner, Director, ID Quantique, Geneva, Switzerland mentioned about the aspects of randomness in the cryptography and presented the applications of QRNG in space, gaming, cryptography, IOT, Datacenter Telco/MSP, Critical infrastructure, etc.

He explained the challenges with Many Physical-RNG's or True-RNG's (TRNG's) which are based on classical chaotic systems with extreme sensitivity to initial conditions, which prevents any long-term prediction of the behavior of the system. However, chaotic systems have challenges and therefore using chaotic system may be possible idea but not the best one. He mentioned Quantum Technology as the safest way to generate randomness and explained about the QRNG products developed by ID Quantique and their QRNG chip solution providing a new level of Quantum enhanced phone security allowing differentiated security solutions for ICT services.

He thereafter presented the main requirements for QRNG in space, which include SWAP (Size, Weight and Power), Radiation hardening and operation in harsh environment. He presented the First IDQ QRNG space project with European Space Agency and mentioned about different environmental qualifications that have been performed to ensure robustness in space environment which include Radiation, Thermal Vacuum, Shocks and Vibration Tests.

Satellite-based Quantum Communication

Prof. Urbasi Sinha, Raman Research Institute, Bengaluru citing some fundamental physical constraints related to losses in optical fibres, emphasized on satellites in Earth orbit as the way to provide global-distance QKD services, for example, between cities or continents. She talked about the China, Europe, the United States, Japan, Canada, Singapore and other nations currently engaged in a “Quantum Space Race”, vying to be the forerunners in satellite based QKD. With China having demonstrated the feasibility of satellite based QKD through the successful “Micius” quantum communication satellite, space based QKD has become a more important research direction globally than ever before.

She presented the work being done by Quantum Information and Computing lab at RRI on a mega project called **Quantum Experiments with Satellite Technology (QuEST) in** collaboration with the Indian Space Research Organisation. This is India’s first satellite based QKD project which aims to develop indigenous technologies for satellite based QKD towards a quantum secure future for India. She reported the various milestones achieved by the QuEST project which includes the development of a novel, indigenous QKD simulation toolkit as well as the establishment of a prepare and measure based QKD experiment ensuring that resources are invested only after prior performance analysis, and is faithful to experimental capacities and limitations. The QKD simulation toolkit qkdSim is aimed at being developed into such a software package that can precisely model and analyse any generic QKD protocol. The simulation results match well with experiment done for the B92 protocol.

The demonstration of free space entanglement based quantum communication between two buildings at RRI through an atmospheric channel was presented. Furthermore, she highlighted the major challenges in long distance quantum communications due to the polarization degree of freedom of single-photons getting affected while transmission through optical fibres, or atmospheric turbulence and discussed about the recent work at RRI on passive feedback based polarisation scrambling mitigation, a crucial requirement for long haul quantum communications.

SESSION – V

SECURITY IN THE QUANTUM ERA

Security in the Quantum Era

Smt. Pamela Kumar, Director General, TSDSI stated that India is actually participating in growth of quantum era. She mentioned that India should participate in NIST standardization efforts of PQC algorithm and enhancing leadership position in advanced technology by safeguarding National Security and taking the Next Jump.

Imminent Quantum Threat

Sh. Tommi Lampila, Director of Business Development, Xiphera, Finland discussed brief on how Shor's algorithm can affect and break the RSA and other encryption algorithm. He also briefed about NIST PQC activities and list of shortlisted algorithms. He recommended instead of going on full PQC algorithms, hybrid approach systems may be used as fixed solutions lack crypto agility and thus, we cannot fully trust that the new PQC schemes are secure as it was observed during lab testing that NIST Round 3 finalist Rainbow and Round 4 candidate SIKE were broken. Therefore, using Hybrid system by combing PQC with ECC is a better solution.

Security in the Quantum-Era

Sh. G Narendra Nath, Joint Secretary, National Security Council Secretariat discussed about the implication of these technologies, especially w.r.t. National Security of the country. Countries which have leadership positions in Advance technologies are actually ruling the world today. Hence, keeping that in mind, Quantum Technology is one key area where India should have a leadership position.

He highlighted a few important aspects of Technology Supply Chains. Firstly, Transfer of Technology with likeminded countries, Secondly, Export controls and Access to Materials involved for technology transfer such as raw material, equipment etc. Lastly, he also emphasized on development of skilled Manpower especially under Critical Emerging Technological Programme. He also briefed about the Quantum Communication Ministerial Report covering current scenarios, products, companies involved, thereby increasing the visibility in these areas and proposing targeted interventions.

He also mentioned about the "Harvest today & decrypt later" strategy and raised the importance of Access & Authorization mechanism intact. He also raised the need of security of the Quantum product and deployment by implementing End-system key generation mechanism, secure Key generation life cycle, monitoring & configuration systems. Lastly, to integrate with the legacy systems, he also raised the importance of an active Testing, Certification & Standardization Mechanisms.

Quantum Key Distribution System

Sh. Atul Kumar Gupta, Group Leader, C-DOT briefly discussed about the challenges with the present public key cryptography solutions and presented the Quantum Key Distribution System as a solution. He talked in brief about the different QKD protocols, Continuous Variable (CV), Discrete Variable (DV) and Distributed Phase Reference (DPR) along with the different architecture of protocols: Prepare & Measure, Measurement Assisted and Entanglement based.

He further discussed about current projects under C-DOT which include Measurement Device Independent QKD, which eliminates the chance of side channel attacks and Quantum hacking (i.e. Detector-Blinding Attack and Time-shifting Attacks) and CV-QKD which is more compatible with existing telecom technologies, more resilient to noise when quantum channel is multiplexed with classical channel on same fiber and Detection is way more efficient (~90%) as compared to single-photon detector (~30%). He also mentioned about the applications being invited by C-DOT from Indian entities for collaborative development of CV-QKD.

Subsequently, he briefed about the various ITU-T Standards for QKD Y.3800 – Y.3806 along with the items under study in ITU-T Study Group 13: Y.QKDN.BM, Y.QKDN_frint, Y.QKDN-qos-gen, Y.QKDN-qos-mlreq and Y.QKDN-qos-fa, which covers all the aspects of QKD from the perspective of large scale proliferation in the network, reducing dependencies on individual vendors and ensuring Interoperability to the extent possible. He mentioned about the QKD solutions mostly vendor proprietary with limited scope of interoperability and projected the requirement of open and standard interfaces among different layers of the Quantum Communication network stack. For the future scope of development, he suggested Twin-Field (TF) QKD that overcomes the PLOB bound on rate-distance limit could be explored for long-distance QKD and Chip-based miniaturized QKD for rapid adoption and cheaper deployment.

Post Quantum Cryptography Systems

Sh. Prashant Chugh, Group Leader, C-DOT emphasized "QUANTUM THREAT IS REAL!". Quantum computers are becoming an ever-increasing potential threat to security and can lead to Crypto-apocalypse, if mitigation actions are not planned and executed. Symmetric key cryptography will become half, so if we double the key size it might address the issue to some extent. However, Asymmetric key cryptography will be completely broken, so a new solution/ algorithm will be required. The other secure communication protocols that are under threat include IPsec, SSH and TLS, VPN, HTTPS.

He elaborated on Post Quantum cryptography as a solution that uses a new class of cryptography algorithm solution based on hard-to-compute problems and that can be implemented using today's classical computers which will be resistant to attack from tomorrow's quantum computers. He also briefed about shortlisted NIST PQC algorithms such as Crystals Kyber for KEM (Key Encapsulation Mechanism) algorithms and Crystals Dilithium, Falcon & SPHINCS+ for Signature algorithms chosen for standardization at the end of 3rd round and BIKE, Classic McEliece and HQC Key Encapsulation Mechanism algorithms selected for 4th round at NIST.

He talked about C-DOT's PQC-based IP layer Encryptors with NIST PQC key exchange algorithms, Encryption/ Decryption of Ethernet (L2) and IP (L3) packet payload at 1Gbps, scalable to 10Gbps, with Platform related Security as per FIPS140-3 standards & supporting

cryptoagility and both Classical and PQC Algorithms in hybrid mode. He also talked about PQC-enabled Quantum Secure Smart Video IP Phone developed by C-DOT.

Post-Quantum Cryptographic Migration and Cryptographic Agility

Prof. Prabhakar Krishnan, Scientist, Amrita Center for Cybersecurity discussed about how to migrate and transit from our legacy systems to secure systems. PQC transition is an unprecedented move, thus Post-Quantum Crypto literature may not offer drop-in replacements for all features.

Simple & well understood is better than complex & less understood. Quoting PQC migration Handbook (ETSI), he talked about the level of urgency required to migrate RSA algorithm, Elliptic-curve algorithm, etc. For transition to PQC Algorithms, we need to consider Performance parameters (such as Algorithm, Hardware & Network), specific Security levels, and then Implementation factors whether in Software or Hardware. Furthermore, he elaborated Migration Frameworks using Hybrid Scheme, Formal Modeling, Automated tools, Complex infrastructure and also highlighted key findings for PQC migration such as Size Constraints, memory constraints, API problems, Versioning difficulties etc. and talked about a New Science of Crypto-Agility & its need along with architecture and key finding.

Lastly, he pointed out New Frontiers of Cryptography such as Secure Multi-Party Computation (MPC), Identity-based Encryption/Attribute-based Encryption, Fully Homomorphic Encryption, Blockchain, Password -authenticated key Agreement, etc.

Post-Quantum Cryptography in HSMs

Sh. Swami Saran, Thales described about the applications of Quantum Computers in Molecular Discovery, Drug Discovery, optimization problems ,and also the threats posed by them to the cryptographic systems or the security infrastructure emphasizing on Quantum-safe data security in Banking & Finance, Defense, Telecommunication, Data center etc. He briefly discussed about the different types of Quantum resistant Algorithms being developed viz. Lattice based, Code based and Multivariate cryptography.

Furthermore, he talked about the Hardware Security Modules developed by Thales providing Quantum safe crypto agility and Quantum Randomness using QRNG from ID Quantique for high assurance key protection. These Hardware security modules are used to provide encryption services to many applications across different sectors viz. Database encryption, Transaction processing, Blockchain, IOT, etc. He further emphasized on migration to Quantum-safe infrastructure maintaining backward compatibility between Classical and Quantum safe Public Key Infrastructure.

SESSION – VI

STANDARDIZATION EFFORTS ON QUANTUM TECHNOLOGIES

Standardization efforts on Quantum Technologies

Sh. Uma Shanker Pandey, Member (Services), Department of Telecommunications highlighted the potential of QKD and PQC as remedies for the vulnerability of communication infrastructure caused by the emergence of quantum computers. He emphasized the importance of standardization in ensuring the security requirements of products and maintaining a consistent level of protection against quantum computers. He mentioned several organisations that are currently working on developing standards for QKD and PQC. TEC has already formulated a set of standards and test procedures for QKD systems. He also encouraged start-ups to take part in the development of quantum technologies and offered support to facilitate their involvement.

Role of TEC in standardization of Quantum Technologies

Sh. Ritu Ranjan Mittar, Sr. DDG and Head, Telecommunication Engineering Centre discussed the role of TEC in formulating the Standards including the use of National Working Groups (NWGs) to submit the Indian Contribution to various ITU-T Study Groups (SGs). He encouraged participants to become members of NWGs and submit contributions through the Standards Coordination Portal (https://tec.gov.in/scp) of TEC. He also mentioned that India will be hosting the upcoming World Telecommunications Standardisation Assembly (WTSA) in 2024. He explained various Standards/ Specifications formulated by TEC such as Generic Requirement (GR), Interface Requirement (IR) and Essential Requirements (ER) as well as different types of certifications including Certificate of Approval (CoA), Technology Approval Certificate, Type Approval Certificate and Mandatory Testing & Certification of Telecom Equipment (MTCTE)

ETSI standardization work on Quantum-Safe Technologies

Sh. Matthew Campagna, AWS Cryptography, USA presented the post-quantum cryptography work being done within the ETSI Technical Committee CYBER's working group on Quantum Safe Cryptography (QSC). He gave a description of the working group, its published recommendations and specifications including Quantum Safe Key Exchanges, Quantum Safe Public Key Encryption & Key Encapsulation, and Migration strategies for Quantum Safe schemes. He highlighted the current work items and priorities of the working group (WG) and discussed upon how to participate and become a member of ETSI WGs.

Metro Area Quantum Access Network Testbed

Prof. Anil Prabhakar, IIT Madras provided an overview of the Centre for Quantum Information, Communication and Computing (CQuICC) at IIT Madras and discussed the implementation of the Metro Area Quantum Access Network (MAQAN) as a testbed for evaluating point-to-multipoint QKD. He also talked about collaborations between MAQAN and various entities such as IIT Madras, SETS, CDAC-Bengaluru, CDAC-Trivandrum, and ERNET.

MAQAN connects laboratories at IIT Madras, ERNET and SETS in a star topology, and also demonstrates QKD using WDM techniques. He further informed about DARPAN, a geographical user interface developed by CDAC to manage the Quantum Software Defined Network (QSDN). Finally, he discussed the expansion of MAQAN's role in building a Quantum Internet with Local Access (QILA) and to enable standardization and interoperability of quantum secure hardware, even as we continue to develop indigenous equipment, and newer modalities for quantum key distribution and quantum secret sharing.

Quantum Simulators for research and development of standards, Benchmarking & validation

Prof. C. M. Chandrashekar, IISc Bengaluru discussed various Quantum Simulators for research and development of Standards, Benchmarking and Validation. He provided a timeline from Quantum Mechanics to Quantum Technology and highlighted the importance of Quantum Supremacy, using an example of a 53 qubit Superconducting Processor. He categorized simulators and explained how they can be used for validating algorithms, benchmarking performance of quantum gates and protocols. He differentiated between Digital and Analog Quantum Simulations and discussed the computational power of Qubits with different numbers of particles in the quantum system. He also classified categories of Quantum Processors and highlighted the problems with Noisy Intermediate Scale Quantum (NISQ) computers, while informing about the Variational Eigenvalue Solver.

Standardization developments at NIST in Post Quantum Cryptography

Dr. Dustin Moody, NIST, USA explained the NIST Public Key Cryptography Standards and their vulnerability to attacks from Quantum Computer. He talked about the PQC Competition, which was aimed at identifying quantum-resistant cryptographic algorithms for new public key cryptography standards. He also discussed about the selection criteria and briefed about shortlisted PQC algorithms: Crystals Kyber for KEM (Key Encapsulation Mechanism) algorithms and Crystals Dilithium, Falcon & SPHINCS+ for Signature algorithms chosen for standardization at the end of 3rd round. He also touched upon the 4th round candidates; BIKE, Classic McEliece and HQC Key Encapsulation Mechanism algorithms and NIST new call for additional signature algorithms.

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SESSION – VII

QUANTUM COMMUNICATION: INDUSTRIAL PERSPECTIVE AND USE CASES

Quantum Communication: Use Cases in Defense

Lt. Gen. M.U. Nair, SO-IN-C, Indian Army emphasized on advancement of technology in warfare with application of quantum communication Technologies in Indian Army and defense sector. The use of information theory and quantum mechanics in new application of computing and communication technologies. Quantum domain has imminence potential in the field of defense technology and quantum ware fare. It could be used and assist in the protection of military asset of nation. Computer based on the principal of quantum physics have potential to solve the military problems with huge computing power. Which classical computing system could not compete at this pace. He also emphasized on QKD based on quantum physics and post quantum cryptology based on classical physics. These have large number of used cases in defense domain.

Quantum Communication: Use Cases in the FinTech Sector

Prof. P. Syam Kumar, Institute for Development & Research in Banking Technology focused on the use of quantum communication in the fintech sector, particularly in protecting the privacy of customer data stored in the cloud. While encrypting data is a common practice, searching for specific information becomes a challenging task. Public key searchable encryption (PKSE) is a solution, but existing schemes based on traditional public key cryptography are vulnerable to quantum attacks. To address this, QSafe, a quantum-safe encrypted cloud storage, has been developed by IDRBT using lattice-based cryptography (LBC), which is post-quantum secure. QSafe uses attribute-based searchable encryption to provide both data privacy and access control for bank customer data stored in the cloud. Its security is based on the learning with errors (LWE) problem and is resistant to quantum attacks. QSafe is also efficient, requiring only simple addition and multiplication operations instead of heavy pairing operations.

Quantum-safe communication infra in SK Telecom, South Korea

Dr. Dong-Hi SIM, SK Telecom, South Korea presented on the implementation of quantum-safe communication infrastructure by SK Telecom in South Korea. SK Telecom has over 2000km of Quantum Key Distribution (QKD) links with 330 Km providing LTE/5G backbone in major metropolitan areas, 1000 Km QKD links deployed since 2020 through the Quantum New Deal project funded by the Korean government and QKD overlay spanning 800 Km for integrated government networks.

He mentioned that since 2019, SK Telecom has been using QKD to protect their 5G backbone and has developed end-to-end Quantum solution with subscriber authentication using Quantum Random Number Generators (QRNG) and has collaborated with Samsung to build a Quantum a built-in QRNG.

He further talked about Quantum-safe Communication Infra Pilot Project, KOREN (Korea Advanced Research Network) to develop a Test network that supports feasibility and verification of Technologies. It includes 490 Km QKD Testbed, 820 Km PQC Testbed for

development and demonstration and total 445 Km testbeds with fiber/encryptor to test new protocols.

Applications of Quantum Technologies

Sh. Animesh Aaryan, CEO, Taqbit Labs talked about the applications of Quantum Technologies across various sectors viz. Govt. & Defense, healthcare, Space, Finance, Telecom and Industry 4.0 as mentioned below:

- **Quantum Computing:** solving optimization problems, data analysis simulations, etc.
- **Quantum Secure Communication:** Key Distribution, High security access network, securing assets
- **Quantum Imaging and Quantum Sensing:** Diagnosing heart diseases, Imaging through fog, snow and heavy rain.

QKD & PQC: approaching security as an onion

Dr. Bruno Huttner, Director, ID Quantique, Geneva, Switzerland emphasized on the risks posed by the Quantum computers to the encryption systems making • Data encrypted with current public Key protocols already vulnerable to “harvest now, decrypt later” attacks. He suggested Post Quantum Cryptography as a possible solution integrated with QRNG and QKD adding a further level of security.

Free Space QKD – Creating practical QKD networks

Sh. Dilip Singh, Chief Product Officer, QuNu Labs presented the latest developments across the countries like China, UK, USA, etc. and the works being done by QuNu Labs in the development of Free Space QKD Systems. He highlighted the various parameters like Atmospheric Turbulence, low working power levels of QKD system, unreliable Key Rate affecting the performance of the Free Space QKD system.

He further talked about the various challenges in the development of free space QKD Systems: Free space channel losses, Ground Station Challenges, Alignment and pointing, Transmitter/ Receiver challenges and Space segment challenges. He then presented the implementation of Drone based Free Space QKD system and Satellite QKD System in Low Earth orbit being developed by QuNu Labs using high precision Pointing, Acquisition and Tracking (PAT) System and Atmospheric Compensation.

Quantum and the Cybersecurity Imperative

Sh. Vikram Sharma, CEO, Quintessence Labs, Australia emphasized on Quantum and the cyber security imperative and highlighted that quantum revolution will transform our world in generating, processing and communicating information in a fundamentally different way. The quantum computers will break

current encryption in minutes. Nearly, 30B Euro has been invested in quantum across the world

He said in the coming times, Communication would not be trusted to be authentic and transactions could be repudiated. He emphasized on:

- Identifying and mapping the sensitive information in the organisation.
- Understanding the consequences of compromise of each data category
- Evaluating quantum-safe solutions through trials and pilot program
- Developing & implementing a quantum-safe transition roadmap operating with hybrid infrastructure integrating quantum-safe products such as Post Quantum Crypto Algorithms, High entropy symmetric key cryptography and Quantum Key Distribution.

PANEL DISCUSSION – II

QUANTUM COMMUNICATION: INDUSTRIAL PERSPECTIVE AND USE CASES

The panel discussed upon the applications of Quantum Technologies across different sectors. Some of the key points discussed are enumerated below:

- Challenges posed by the Quantum computer to the current encryption algorithms e.g. RSA 2048, IPsec, HTTPS, etc. and the need to move towards Quantum solutions.
- Quantum Key Distribution and Post Quantum Cryptography solutions for securing the communication infrastructure against the threat of Quantum computers and the works being done for increase in capacity or scaling of the solution to handle more traffic for different applications.
- Development of Quantum Smartphone by SK Telecom in collaboration with Samsung equipped with Quantum Random Number Generator (QRNG) developed by ID Quantique to generate unpredictable random OTP numbers. It helps customers use services that require security, such as authentication, finance, and messengers, more safely.
- Deployment of QKD solutions securing LTE/5G Backbone in the Telecommunication Infrastructure by SK Telecom in South Korea and interconnection of Government Departments on QKD Network.
- Standardization aspects of the Quantum Key Distribution Protocols and Post Quantum Cryptography Algorithms.
- Applications of Quantum solutions in the Defense sector, Banking sector, OTT Applications, Security of IoT Devices, etc.
- The use of Quantum sensors to detect any underground movement in the sea, detection of submarines, etc.
- Challenges in making the stakeholders aware about the Quantum Threat to the secured communication and encouraging them for adoption of the Quantum safe solutions.
- Collaboration with the various stakeholders and steer the development of the Quantum Technologies solutions as per the requirements of the industry.

CONCLUDING REMARKS: DAY 2

Dr. Manjunath Ramachandra, Wipro and Champion for Quantum communication TRIP forum, TSDSI, appreciated the well-structured technical talks, enthusiasm and knowledge of the audience and the opportunity provided by the conclave for the participants to interact and collaborate with each other.

He emphasized that temperature and channel modeling are the major factors hindering the large-scale deployment of quantum communication systems. One of the challenges in satellite-based QKD systems is modeling the open space channel and locating the satellite. However, when teleportation is possible over a large distance, it can resolve the channel issues naturally, but it still has a long way to go. He also mentioned that Quantum Teleportation could open up several applications when it is available for use.

On the security aspects, he highlighted that although we may think we have immunity to Shor's algorithm, new versions of the same can emerge, which could pose security issues in the Post

Quantum era and therefore, emphasized to work on such algorithms to ensure that the systems are immune to them.

He also highlighted the importance of adhering to standards while developing new products. and the need to secure the IPs. At the last, he expressed hope to meet the audience in the next conclave and thanked everyone for their participation in the event.

5. KEY RECOMMENDATIONS & TAKE AWAYS

The face-to-face interaction among the delegates both on the podium and during the networking brought out several useful recommendations and take-aways:

5.1. There is a need to strengthen the collaborations and partnerships between academic institutions, research organisations, and industry to accelerate the research, development, and adoption of quantum communication technologies. Mechanisms should be established to facilitate the transfer of quantum communication technologies from academic and research institutions to industry and the wider community.

5.2. C-DOT has proposed to set up a **Quantum Alliance** comprising all the stakeholders, viz. academia, research institutions, industries, and start-ups working in the development of Quantum Technologies so as to have a unified effort towards the development of Quantum Communication Technologies, to avoid any duplication efforts and to enable the use of any sub-systems being developed by others. During the conclave, C-DOT showed interest in the works being carried out at Raman Research Institute, PRL Ahmedabad, IITM and IISc Bengaluru, etc.

5.3. There are many indigenous products being developed, viz. Single Photon Source, Single-Photon Detector, Quantum Random Number Generators, WDM QKD, and quantum sensors where the standardization work is required. Along the lines with the USA "National Quantum Initiative Act" led by NIST, a **Quantum Consortium led by TEC** comprising members of academia, research institutions, industries, etc., may be set up to identify the areas where *accelerated standardization* is required.

5.4. The matured technologies developed by India, such as WDM QKD may be positioned in the appropriate global standardization bodies, including ITU, ETSI, etc. Participation of Indian academia, R&D institutions and industries in the global standardization must be encouraged and enhanced. This can be achieved by creating awareness among stakeholders about the importance of standards and providing them with the necessary resources and infrastructure to participate effectively in the standardization process.

5.5. **Bilateral cooperation between countries** should be encouraged to promote the research, development and adoption of quantum technologies. This can include establishing joint research and development initiatives, sharing expertise and resources, and joint investments in quantum communication infrastructure and facilities. Additionally, efforts should be made to promote international collaboration and knowledge-sharing through initiatives such as joint workshops and conferences. The conclave featured talks from international experts from USA, Canada, Australia, Switzerland, South Korea, United Kingdom, Finland, which can pave the way for the creation of a global network of knowledge sharing and collaboration.

5.6. There is a need to have "**Quantum Testbeds**" equipped with state-of-the art equipment. Industry and academic researchers should have access to these testbeds to develop and test quantum communication technologies in a controlled and secure environment. Implementation of the Metro Area Quantum Access Network (MAQAN) developed by IIT Madras as a testbed for evaluating point-to-multipoint QKD was discussed in the conclave.

5.7. The **pilots and trials for the indigenous products** being developed may be facilitated in the telecom network, defense projects, government organisations, etc., to facilitate their adoption. The users of Quantum Technologies viz. Armed forces, Telecom Service Providers, ISRO, DRDO, Banking sector, shall also be involved in the various projects being undertaken in the Quantum Communication Domain. In this regard,

a. SO-IN-C, Indian Army has expressed that the trials and evaluations can be conducted on operational networks at their training facilities and in the field.

b. Hon'ble Minister of Communications also asked M/s QuNu Labs for **the deployment of their QKD system in the Railway network.**

5.8. There is a **requirement for highly skilled human resources** to support the research, development, and implementation of quantum communication technologies. This can be achieved through the establishment of specialized training programs, courses, and workshops, as well as the development of partnerships between academic institutions and the industry to provide hands-on training and experience. NTIPRIT may take the lead.

5.9. Advancements in quantum computing have led to grave security challenge for the data communication and becoming a serious threat day by day. All digital applications involving the data networks get affected. It includes all major sectors such as finance, healthcare, defence, insurance, infrastructure, enterprise, administration, manufacturing, Telecom, energy, utility etc. There is a need to prepare **a transition roadmap** from classical cryptographic systems to Quantum-safe cryptographic systems, including the application of Quantum Key Distribution at a scale in the TSP network covering all the critical public and private infrastructure. SK Telecom, South Korea, presented their **implementation of the World's First LTE Backhaul protection with QKD, 5G Subscriber Authentication with QRNG, a national backbone network of 800km interconnecting individual networks run by 48 government organisations**. A study of the implementation of Quantum security in the SK Telecom network can be carried out for trials in the Indian Telecom Network.

5.10. To encourage the startups and other organisations in the development of standards and contributing to the global standardization activities, a couple of measures were suggested:

(i) **Open-source implementation of the standards**: It helps the startups and organisations to focus on the R & D of the differentiating features rather than reinventing the wheel. It ensures the products adhere to the standards.

(ii) **Protection of the IPs**: It is important to take the implementations (and work arounds for the standards) of the startups and R&D institutions to standardisation bodies. Before that, IPs are to be protected as patents, copy rights etc. A comprehensive policy to support the different players involved is required, specifically for the quantum technologies. A database of existing patents & IPs is required to position them accordingly in various standardization bodies. The patents and IPs are to be mapped to the work in SDOs accordingly. It will boost the participation in the international bodies, would help to fund the individuals, organisations and startups who need financial support to develop IPs and patents.

(iii) **Development of simulators:** It is required for experimentation before taking the R & D to expensive hardware. It reduces the time and investments.

(iv) **Testbeds**: Testbeds are required for providing equipment's for the researchers and startups to test their algorithms and features. In addition, it would help in the validation of the new proposals before taking them for standardisation. Testing of standards on the products is not widely available. Testbeds fill-in this crucial gap. The same testbeds can assist for certification. The testbeds are to be reused across the country rather than duplicating the resources. It is required to identify the disjoint testbed requirements considering the available standards and categorise them.

5.11. Organising a **Quantum hackathon** challenge to probe the vulnerability in the Quantum safe security systems (e.g., QKD and PQC) developed by C-DOT and other start-ups. M/s QuNu Labs has also proposed to offer its products for hackathons.

5.12. Organisation of more interactive sessions and hands-on workshops involving the policy makers, Domain experts, Implementers, academia, startups, etc. will be helpful to leverage the expertise and resources optimally.

5.13. The expensive measuring equipment's are not accessible to many organisations even on shared basis. A Centre of Excellence (CoE) is required to incubate startups in collaboration with academia to develop these precision devices indigenously. The equipment's and components after each project may be reused or absorbed in to testbed. A MoU with research labs and industries outside India to share such instruments and train the workforce on their simulators and equipment's will be helpful.

6. ANNEXURE – A: PRESENTATION OF PANDIT DEENDAYAL UPADHAYAYA TELECOM SKILL EXCELLENCE AWARDS – 2022

6.1. Pandit Deendayal Upadhyaya Telecom Skill Excellence Awards have been instituted by Department of Telecommunications, Ministry of Communications, Government of India to encourage and stimulate/ inspire Telecom Skill ecosystem by rewarding the successful telecom skilled people and institution of India annually for their exemplary and outstanding contributions in the areas of Telecom Skilling, Telecom Services, Telecom Manufacturing, Telecom Applications in deploying telecom dependent sectoral solutions for different field such as agriculture, commerce, health, education etc.

6.2. The selection process for Pandit Deendayal Upadhyaya Telecom Skill Excellence Awards includes nomination by all Indian citizens as well as institutions registered in India through Rashtriya Puraskar Portal (https://awards.gov.in) managed by Director General, Awards at the Ministry of Home Affairs. This is followed by selection of awardees by an award Committee constituted under the chairmanship of Secretary, Telecom with representation from government, industry and academia.

6.3. Hon'ble Minister of Communications, Electronics & IT and Railways presented the "Pandit Deendayal Upadhyaya Telecom Skill Excellence Awards – 2022" to the following awardees:

Sl. No.	Name of Awardee	Work/ Contribution
1	M/s Sterlite Technologies Ltd, Pune	Skill development works in telecom sector
2	M/s Vihaan Networks Limited, Gurugram	Technology development and manufacturing of solar powered 4G RAN in India for remote and rural area
3	M/s QuNu Labs Private Limited, Bengaluru	Quantum Communication and security solution
4	M/s Dhruva Space Private Limited, Hyderabad	Satellite communication field
5	M/s Inntot Technologies Pvt Ltd, Ernakulam	Software Defined Radio based Digital Radio Mondiale Receiver solutions

M/s Sterlite Technologies Ltd, Pune

M/s Dhruva Space Private Limited

M/s Vihaan Networks Limited, Gurugram

M/s Inntot Technologies Pvt Ltd, Ernakulam

M/s QuNu Labs Private Limited, Bengaluru

7. ANNEXURE-B: PHOTO GALLERY


IRS ANJALI BYCE


FIRST INTERNATIONAL
QUANTUM
COMMUNICATION
CONCLAVE
Sh. Ashwini Vaishnaw
Sh. Devusinh Chauhan


GUESTS


FIRST INTERNATIONAL
QUANTUM
COMMUNICATION
CONCLAVE
RESERVED
SPEAKER

8. ANNEXURE-C: Conclave Presentations and Videos

Presentations of the Speakers:

The presentations delivered during the conclave can be accessed at the link given below or by scanning the QR Code.

https://tec.gov.in/first-international-quantum-communication-conclave/

Live Streaming of the Event:

The event was streamed on the YouTube Channel of Department of Telecommunications and could be accessed at the link given below or by scanning the QR Code.

https://www.youtube.com/@departmentoftelecommunicat2207/streams

Session-wise Videos

S.No.	Details of the Session	Scan QR Code to watch the session
1.	Inaugural Session	
2.	Session-I: Trends in Quantum Technology	
3.	Session-II: Building a Quantum Network	
4.	Session-III: Challenges and Prospects for Quantum Technology Development	

5.	Panel Discussion-I	
6.	Session-IV: Quantum Technologies in Satellite Communication	
7.	Session-V: Security in the Quantum era	
8.	Session-VI: Standardization efforts on Quantum Technologies	
9.	Session-VII: Quantum Communication: Industrial Perspective and Use Cases	
10.	Panel Discussion-II	
11.	Concluding Remarks	

ORGANIZING COMMITTEE

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Telecommunication Engineering Centre is a technical arm of Department of Telecommunications and responsible for formulation of standards, specifications, test procedures, service specifications and technical regulations for communication sector. TEC seeks to promote and ensure standardization in the telecom sector to ensure development of world class telecom network and smooth interconnection of individual networks. TEC actively participates in the meetings of standards development organizations, viz., ITU, ETSI, APT, WRC, etc. and also interacts with other international forums, viz., 3GPP, ETSI, IETF, oneM2M, etc.

Centre for Development of Telematics (C-DOT) is an autonomous Telecom R&D Centre of Department of Telecommunications, Govt of India. Established in 1984, C-DOT has contributed significantly in indigenous design, development and production of telecom technologies especially suited to Indian conditions. In its initial years, C-DOT triggered a telecom revolution in rural India that was responsible for all-round socio-economic development. Over the years, C-DOT has developed a large number of products of national and strategic importance in various Telecom areas such as Optical, Switching, Wireless, Security and Network Management. C-DOT is also contributing significantly in development of products in technologies such as M2M/IoT, 5G, AI and Quantum Security. In Quantum Security Vertical, C-DOT has developed Quantum Security products in the areas of Quantum Key Distribution (QKD) as well as Post-Quantum-Cryptography (PQC). C-DOT also has plans to increase its Quantum Communication Security products' portfolio in the upcoming years.

Telecommunications Standards Development Society, India (TSDSI), https://tsdsi.in is an autonomous, membership-based, standards development organization (SDO) for Telecom/ICT products and services in India. We develop standards for access, back-haul, and infrastructure systems, solutions, and services that best meet India-specific Telecom/ICT needs, based on research and innovation in India. We work closely with global standards bodies to reflect Indian requirements into international telecom/ICT standards. TSDSI is carrying out a Study on Post-Quantum-Cryptography for 5G Networks [SI 78]. TSDSI has also initiated a Technology Roadmap Item Proposal (TRIP) Forum on Quantum Communications to identify opportunities for standardization.