IEEE

IEEE INGR

International Network Generations Roadmap

2022 Edition

Executive Summary

IEEE Future NETWORKS

An IEEE 5G and Beyond Technology Roadmap

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EXECUTIVE SUMMARY

1. THE ROAD FROM 2022 TO 2032

2022 and the next two years will be a time of heavy 5G deployment, transformation at the edge, and increased interworking of network technologies and systems. The 2022 Edition of the IEEE Future Networks International Network Generations Roadmap (INGR) points to trends, challenges, and solutions in the current and near-term mobile network landscape, and the future vision as being cultivated through the activities of Standards Development Organizations (SDOs) and the industry around the globe. This Executive Summary offers brief glimpses into current and forward-looking focal and interworking areas from each of INGR's 14 Working Groups.

Noteworthy areas to watch for rapid development and integration into other technology and network functions in 2022 include satellite communications, artificial intelligence and machine learning, and energy efficiency. As the industry continues to advance, the evolution and deployment of network generations is influenced and impacted not only by emerging, evolving, and potential convergence of technologies, but also by local and world socio-economic and health conditions (and politics). So much can happen in a year, which is why the INGR is a living document that is updated annually.

The inaugural INGR was released in 2020 and its focus was primarily on the evolution of 5G networks. The intention of the 2021 INGR Edition was to take a more end-to-end perspective that included integrating future network technologies and establish a transdisciplinary framework and a predictive model for mobile networks. This 2022 INGR Edition broadens applications of the transdisciplinary framework, progresses each technology and system challenges and opportunities especially while interworking with other areas — while noting lessons learned that can be applied to beyond 5G.

All Working Groups in the INGR have examined the technologies and systems over 3-, 5- and 10-year time periods. It is expected that this approach will better reveal the challenges, possible solutions and opportunities that are likely to exist in network deployments over varying timelines.

CATEGORY	DESCRIPTION	INGR WORKING GROUP CHAPTERS
User Access	This group describes how the users reach the network	• Satellites • Deployment • Connecting the Unconnected (CTU)
Network Components and Performance	This group describes how the networks are interconnected	• Edge Automation Platform • Massive MIMO • System Optimization • Optics • mmWave
Systems and Standards	This group describes system standards and testability	• Standardization Building Blocks • Testbed • Energy Efficiency
Services and Enablers	This group represents all the elements that enable deployment, assure functionality and security and address impact on society and environment	• Security • Applications and Services • Artificial Intelligence and Machine Learning (AI/ML)

Figure 1. The INGR Working Group Categories.

2. WHAT'S IN THE 2022 EDITION

In this, the third publication of the living INGR document, you won't find the "killer app," an expectation created by recent past network generations. Even network industry experts disagree about whether 5G will first take hold across industry or amongst consumers. 5G could be more of a 'build it and they will come' generation, or we could be moving into yet another way to perceive the value of the mobile network, one of possessing characteristics that allows carriers to transform service offerings rather than simply serving as the host of a killer app.

In 2022 the INGR is expanding and establishing frameworks for network functions and systems, broadening and even redefining roles of technologies, pursuing converging points of Working Group areas where results will be greater than the sum of the parts, smoothing pathways for an aggressive period of deployment, and continuing to push out its 3-, 5-, and 10-year scope of view.

There are those who posit that odd-numbered generations serve more as preliminary stage-setting for the more disruptive even-numbered generations. That could be a sign of 5G emerging from the hype cycle. For now, we say stand back 6G, because there is still a lot of work to be done by this "odd" but powerful network generation.

Below are descriptions of the mandates and focal points of each INGR chapter, as reported by the Working Group chairs.

2.1. Applications and Services Working Group

The 2022 Edition of the Applications and Services Chapter extends the transdisciplinary framework with additional details on ecosystems, networks, and governance functions. Intra-ecosystem and inter-ecosystem alignments are identified for eight new industries and public works functions including agriculture, education, electrical power, health care, media and entertainment, public safety, transportation, and water treatment and wastewater treatment. Scenario planning is detailed for smart cities, pandemic response planning and social vulnerabilities, and phased transportation innovations and urban land repurposing.

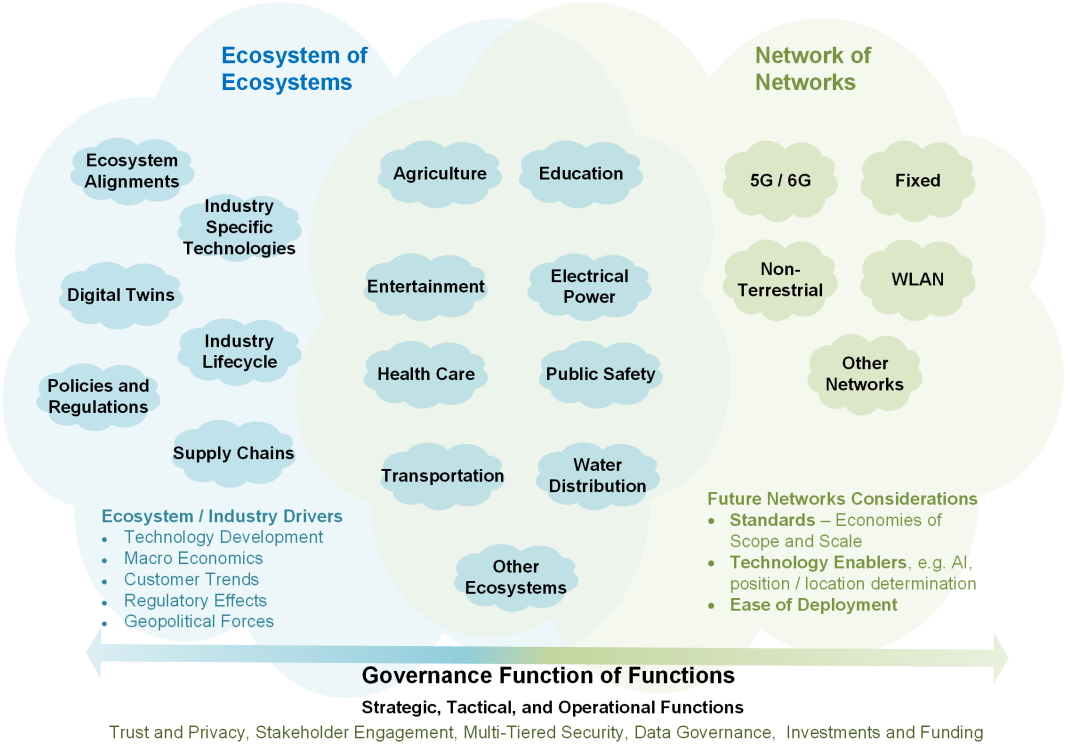

Figure 2. Transdisciplinary Framework drivers for applications and services

The transdisciplinary framework described in this chapter is the basis for several IEEE initiatives that include standards development for smart cities architecture, telehealth industry connections and the transdisciplinary framework with an initial focus on agriculture.

2.2. Artificial Intelligence & Machine Learning Working Group

This Working Group's chapter demonstrates how AI/ML can be smoothly migrated to support current and future 5G systems, such as in Cloud Computing (CC) and virtualization. Virtualization, a key element of Network Function Virtualization (NFV) for cybersecurity needs, and CC are growing rapidly in today's technological ecosystem, and the objectives here are both to include and optimize these technologies for future networks.

The goal of the AI/ML working group is to define a framework that uses open-source technology and commercial architecture to run AI/ML workloads. Enabling technologies in AI/ML/DL are expected to work with: Security, Applications and Services, and Deployments. Therefore, the AI/ML WG will work with other WGs to identify and collaborate on opportunities to implement and enhance the AI/ML architecture. As well, the Edge Services, Security, and Satellite WGs may bring critical data to edge and IoT analytics and processing and will need advanced AI/ML algorithms and technologies to process and optimize their systems. Identifying these specifics will be an important part of this collaboration.

The INGR AI/ML chapter's 2022 Edition contains the following updates:

- New section on AI/ML standards development.

- New topical sections on AI/ML for optical networks.
- New topical section on AI/ML for systems analytics.
- Additional considerations for the Network Slicing topic with regards to 'net neutrality.
- Revisions to the Dynamic Spectrum Access topic.

2.3. Connecting the Unconnected Working Group

The Connecting the Unconnected (CTU) chapter highlights the need to develop unique requirements in 5G and 5GB networks in the standardization process, the development of use cases, and affordable solutions. It is the goal of the CTU WG to create an open platform where experts can bring their ideas and solutions and collaborate to create large global projects and influence network service providers, manufacturers and governments.

Technologies available today need to be customized and optimized at the systems level to bring down the cost of the network in order to be affordable. Content needs to be relevant and in local languages to be useful and offered in human computer interaction (HCI) solutions that are not text based so that people who are not literate or are digitally disadvantaged can easily use the devices and consume services. Another important area is that of flexible spectrum allocation regime at the lower range of the spectrum to increase reach and coverage. Use of renewable energy sources will enable deployment in remote areas where there is lack of a power grid, or it is intermittent. Thus, this WG identifies technology gaps to be filled in by 5G and 5GB networks, such that access is affordable and content relevant.

Technology aside, the need to develop innovative business models is a must to be commercially sustainable in the long-term. Models especially designed for the rural population are proposed, such as Village Level Entrepreneur, Freemium (Free + Premium), revenue sharing among the chain of service providers, and subsidized billing by Universal Service Obligation Funds.

2.4. Deployment Working Group

The Deployment Working Group (WG) overviews stakeholder perspectives — both public and private — and seeks to examine the challenges both face and sets forth suggestions for ways to ensure that all perspectives in the wireless network deployment ecosystem are communicated and understood.

The success of any wireless network is predicated on successful deployment of equipment and systems. As the number of users grows, and the amount of data transferred increases, the laws of physics and information theory require placement of wireless sites closer to populated areas – creating new challenges for both carriers, site developers, and local governments. Wireless communications facilities cannot be deployed in a vacuum — communication across the product development chain, and between private and public entities, is critical to enabling practical solutions.

To address these and other deployment challenges, this WG works to ensure that practical aspects of deployment are kept in mind across the wireless technology ecosystem ranging from academia, research and development, semiconductors, product definition and management, and marketing.

2022 is the year 5G deployment will shift into high gear. The focus of wireless cellular deployment is on deployment in new spectrum bands; T-Mobile in the 600 MHz "low-band" reclaimed from broadcast

television service and the 2.5 GHz bands they acquired from Sprint, and Verizon/AT&T in 3.7 GHz "mid-band" reclaimed from TV receive-only service. Low-band deployments will extend basic coverage across wide areas, and mid-band deployments will add high-performance coverage to suburban and urban areas.

2.5. Edge Services and Automation Working Group*

Worldwide 5G standardization efforts propelled by 3GPP, 5GPP and others are rapidly unleashing a plethora of technologies and services propelling edge services toward becoming an inherently essential fabric of information ecosystems.

The 2022 Edge Services chapter elucidates compelling use cases for edge technologies leveraged through 5GB evolution. Included among these are IIOT (Industry 4.0), V2X usage, applications and services provided as almost local at remote or distant locations, content and entertainment delivery, on-demand emergency and ad hoc services safeguarded by AI/ML-powered security measures.

The Edge Services chapter also recognizes several key ingredients to fuel the momentum for years to come. These include rapid and significant AI/ML success in automation operation efficacy, adaptive, predictive and cognitive security, resource virtualization in massive scale, distributed scalable microservices with orchestration, highly secured management plane for infrastructure/domain slicing and customization, along with the reliability and availability, and a fabric with ultra-high bandwidth through 5G and other terrestrial and non-terrestrial wireless networks.

**In recognition of the remarkable advancements taking place at the Edge, this Working Group was renamed in 2022 to Edge Services and Automation, from Edge Automation Platform.*

2.6. Energy Efficiency Working Group

Energy efficiency is the fundamental enabler to deliver on the technology capabilities and social impact that 5G and 5GB networks promise. Only a comprehensive approach, which addresses the complete ecosystem, can deliver on the required targets to achieve economic viability.

The effort of the Energy Efficiency Working Group (EE WG) aims at addressing all critical aspects of the network, from cloud to edge, and the energy supply infrastructure that can support its efficient operation, with the ultimate goal of creating a heterogeneous systems-of-systems framework that can be used to describe, analyze, and optimize each element that has an impact on its energy footprint. The EE WG has examined energy efficiency through the lens of the universal currency of energy. This perspective has helped to form a Systems-of-Systems framework that will integrate technical and business drivers in such a way as to position EE optimization at the forefront of considerations for future networks. The group's methodologies employ new, proposed metrics/terminology and overall modeling/simulation approaches to solving global EE optimization challenges.

In 2022, the EE WG examines:

- Renewable enabled cellular networks
- Challenges and solutions for the optimization of energy use and environmental/financial impact of 5G and 5GB network infrastructure
- Collaborative opportunities with ICT standards

2.7. mmWave and Signal Processing Working Group

The mmWave and Signal Processing (MMW-SP) Working Group (WG) examines improvements in current millimeter-wave architectures, hardware capabilities and signal-processing techniques to enable 5G systems to achieve the 3GPP Release 17 requirements for massive mobile broadband (eMBB), and for Release 16 requirements for ultra-reliable low-latency communication and massive machine-to-machine use cases. 3GPP Release 17 was scheduled to be frozen by Q1 2022. The WG will translate the requirements for these drivers and describe technical challenges that should be addressed to support the growth of 5G applications within the 3-, 5-, and 10-year timeframes.

The 2022 edition provides a high-level perspective and projection of how these topics will evolve to address the 5G and beyond ecosystem needs that are identified in 3GPP Release 17. The top-level challenges to achieving these goals and the potential solutions to those challenges are highlighted.

2.8. Massive MIMO Working Group

Massive MIMO has played a major role in the development of the 5G wireless networks, and it is the physical interface between User Equipment and Base Station (BS). As user applications place more demand on next-generation wireless networks, 6G and beyond, higher data rate, and Internet of Everything, more innovations are needed to provide breakthrough solutions. Among the technologies being developed is Ultra-Massive MIMO (UM-MIMO), which requires a significant increase in the number of antenna elements at the BS. UM-MIMO is what the Massive MIMO WG is working on in 2022.With that comes more challenges in beamforming, channel estimation, computational complexity, and system architecture. The INGR Massive MIMO Working Group stays at the forefront of these developments and provides the interface that facilitates seamless interactions between researchers and developers.

2.9. Optics Working Group

The Optics Working Group is structured to create the space for key stakeholders to discuss the optical technologies being developed to meet the needs and goals of future networks—identifying and bringing focus to roadblocks, challenges, and opportunities. In 2022, the Optics WG identifies eight optical networking areas:

- Optical Xhaul (front/mid/backhaul) networks.
- High-speed optical access networks.
- Co-packaged optics / data center networks.
- Machine learning in optical networks.
- In-building optical networks.
- Optical wireless technologies for space communications using satellites or high-flying platforms.
- Optical fibers and spatial division multiplexed networks.
- Quantum communications.

For each of these areas, a description of the current state of the art is clearly presented, along with the challenges and their potential solutions in addressing the future needs and scalability of the technologies.

2.10. Satellite Working Group

In 2022, the Satellite Working Group is focused on satellite 6G. The chapter contains an enriched description of use cases combining direct satellite access and satellite backhaul, satellite IoT, mmWave for satellite networks, network management aspects, QoS/QoE, security, and recent standardization activities by 3GPP, ETSI, ITU, and IEEE. Satellite 6G is expected to provide KPIs and QoS at an unprecedented level for Non-Terrestrial Networks (NTNs). This chapter describes future technological challenges and solutions to achieve such ambitious goals.

This chapter also highlights the importance of AI/ML schemes that provide a powerful tool for real-time optimizations for many satellite system problems like routing and path selection, handover scheme, PHY adaptation, security, etc. A significant emphasis is given to network management, encompassing mobility management, radio resource management, support of IoT applications, routing, and softwarization and virtualization of the satellite network. Security aspects are also addressed including NTN in the framework of terrestrial 5G/6G system security. Finally, recent standardization progress is surveyed with the role of GNSS for satellite communications and the current work for 3GPP Release 18 dealing with new radio, network continuity, and satellite IoT.

2.11. Security and Privacy Working Group

The digital transformation brought on by 5G is redefining current models of end-to-end (E2E) connectivity and service reliability to include security-by-design principles necessary to enable 5G to achieve its promise. 5G trustworthiness highlights the importance of embedding security capabilities from the very beginning while the 5G architecture is being defined and standardized. Security requirements need to overlay and permeate through the different layers of 5G systems (physical, network, and application) as well as different parts of an E2E 5G architecture within a risk-management framework that considers the evolving security-threats landscape.

At the same time, 5G networks offer security improvement opportunities that should be considered so that 5G architectural flexibility, programmability and complexity can be harnessed to improve resilience and reliability.

The INGR Security Working Group chapter expands on an updated system view of main 5G security domains. Further, the chapter discusses 5G security requirements through use cases and applications such as critical infrastructures, smart grid, emergency and first-responder networks security, and autonomous vehicles, v2x security.

2.12. Standardization Building Blocks Working Group

The Standardization Building Blocks Working Group (SBB WG) reviews the current landscape of relevant to future networks SDOs and industry alliances, open-source organizations and their relations with SDOs. Challenges of cross-SDO collaborations in selected areas are also addressed. The chapter describes the global challenges and the IEEE approach to standardization of emerging technologies

leveraging the IEEE Future Directions initiatives, and the IEEE Standards Activities ecosystem compatible with engagement of industrial and academic researchers in standards development.

This 2022 edition of the SBB chapter contains new and updated standardization status and plans in the area of 5G and beyond:

- Relevant industry alliances and open-source organizations reflecting the dynamics of the global industry, as well as an example on inter-SDO cooperation.
- Future landscape related to SDOs, industry alliances, and open-source anticipated activities.
- The latest developments on the Open RAN community.
- Standardization of inter-system coordination for exchanging network service level assurance information.
- Federated testbeds example of SDO/Fora collaboration.

2.13. Systems Optimization Working Group

New architectures for 5G and beyond such as Open RAN will lead to increasing complexity and use of distributed control intelligence in the network to cope with greater traffic variance and service variance. This results in a need for novel design, planning and operations paradigms utilizing self-organizing systems. Technologies such as AI/ML are available to support self-adaptive optimization of resources, however, there remains a need to assess the new AI solutions versus legacy tools for systems optimization. The Systems Optimization chapter will discuss the current state of systems optimization work, use cases such as Open RAN that are driving the need for new approaches, and future needs in modeling, optimization methods and standards to support peering and federation of intelligent network control systems.

The Systems Optimization chapter for 2022 adds updates on developments of the hybrid SON concept for loose coupling of systems, further developments in Open RAN requirements, discussion of Trust concepts for AI/ML systems and tooling for systems optimization, and finally the evolution of standards efforts in the area, including a recent multi-SDO initiative to develop Common Operational Principles for Autonomic/Autonomous Networks specifications.

2.14. Testbed Working Group

The Testbed Working Group (WG) helps collaborate with existing 5G testbeds to make those available to industry & academia to ease deployment of 5G and accelerate development of next-generation networks (e.g., 6G). Collaboration with the vendor and research communities will result in expansion upon existing testbeds towards federated development of testbeds for next-generation networks. The working group has established stronger relationships with IEEE & ITU's standardization study group.

In addition to informing the community on the capabilities and usage modalities of existing testbeds, the WG also aims to solicit contributions and promote discussion on co-development and co-deployment of future experimental platforms for 5G and beyond.

Considering recent developments around the world, the WG has identified priorities on next-generation networks' testbed requirements. End-use devices for both human and machine users are anticipated to see dramatic changes with emergence of next-generation wireless networks. In addition to the previous

requirements, the WG has highlighted requirements and a roadmap for end-use (user equipment) hardware and compatible software as well as candidate spectrum bands for future networks.

3. A Final Note

This Executive Summary merely touches upon the high points of work underway in the IEEE INGR overall and each Working Group. Delve into complete chapters to see the full substance and scope of work. Although this Executive Summary is free, access to individual chapters requires the simple and affordable step of IEEE Future Networks membership, which ranges from free to a maximum of $15 USD per person. You can join IEEE Future Networks at https://bit.ly/fni-join

We also encourage and welcome new working group members to bring their enthusiasm, expertise and insights to the INGR. Select a Working Group where you can help envision the future of networks and plan a path that helps avert and overcome challenges, while helping to realize the full potential of the current and future telecommunications network generations.

Email contacts for each INGR Working Group:

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