DLT Session on
5G/6G Enabled Edge Computing and Edge AI

Fawzi Behmann
President TelNet Management Consulting Inc.
September 20, 2023
Greetings from Austin
IEEE Chapters

2015 Chapter Achievement Award
2015 Chapter-of-the-Year Award
2017 Chapter Achievement Award
2017 Chapter-of-the-Year Award
2020 Chapter Achievement Award
2020 Chapter-of-the-Year Award
2021 Chapter Achievement Award
IEEE Communications Society Chapter Awards Program
2015, 2017, 2020 and 2021 AWARDS TO
IEEE Central Texas (Austin) Chapter

ComSoc Chapter Achievement Award

ComSoc Chapter-of-the-Year Award

IEEE COMSOC
222 Chapters worldwide
Fawzi Behmann Bio

Leadership Experience - “Communications & Networking”
- President TelNet Management Consulting Inc. since 2009
  - Collaborative Technology positioning for smart ecosystem solutions at key markets
  - Distinguished Lecturer and keynote speaker at domestic & international conference
  - Co-author of Collaborative IoT for Future Smart Connected Life and Business
  - Faculty Advisor for Senior Design Program
- Communications & Networking Technology & Applications
  - Director of Strategic Marketing @ Motorola/Freescale/NXP
  - Sr. Product Management Edge/core @ Nortel Networks
  - Telecom Network Management Leader @ Teleglobe
- IEEE
  IEEE: Communications Society Director for NA region & BOG
  - Member, Distinguished Lecturer, Section Chair, R5 Conference
  - Committee Chair, Chapter Chairs (ComSoc/SP, Computer/EMBS)
- MBA, Queen’s University, Canada
- M. Comp. Sc., University of Waterloo, Canada
- B.Sc. Hons. With Distinction in Math, Concordia University
Agenda

• A clear understanding of 5G & 6G positioning, features and roadmap

• Architecture evolution pushing intelligence to the edge

• Provide examples empowered by 5G/6G, IoT and AI

• Provide example of network slicing for bandwidth efficiency, security and QoS.

Takeaways:

• Collaborative technologies and impact on ecosystems and networking smart solutions.

• Opportunity to participate and drive advancement of IEEE transdisciplinary framework and Future Networks Technology Roadmap (INGR) working groups.
5G Vision

Massive Capacity and Connectivity
Efficient Use of Spectrum and Network Utilization
Flexible and Scalable Infrastructure to
Enable value add services affecting the following use cases

- Internet of Things
- Wireless Sensor Networks
- Smart Homes
- Smart Grid
- Intelligent Transport Systems
- Virtual Reality/Online Gaming
- Medical Sensors
Cellular Generations - Roadmap

1G 1980s
2G 1992+
3G 2002+
4G 2012+
5G 2020+
6G? 2030+

traffic dominated by voice
traffic dominated by video
traffic dominated by correlation data?

remote control: Tactile Internet

Source: 5G Lab Germany
5G vs LTE/4G

5G is a quantum leap in speed, density, and latency.
ITU - 5G Use Cases Framework

Enhanced Mobile Broadband

Gigabytes in a second
3D Video, UHD Screens
Work and Play in the Cloud
Augmented Reality
Industry Automation
Mission critical application
Self Driving Car

Smart Home Building
Voice

Future IMT

Smart City

Massive machine type communications
Ultra-reliable and low latency communications
Use Cases / Feature Roadmap
Industry Sectors enabled by evolving 5G/5G Advanced Features
5G/5G Advanced/6G Releases

- **Rel-18**: 5G Advanced - 2nd wave of 5G innovations
- **Rel-19**: 5G Advanced - 2nd wave of 5G innovations
- **Rel-20**: 5G Advanced - 2nd wave of 5G innovations
- **Rel-21**: 3GPP 6G Workshop
- **Rel-22**: Next technology leap for new capabilities and efficiencies

**5G**
- **Rel-15**: A unified platform for innovations
- **Rel-16**: 5G - A unified platform for innovations
- **Rel-17**: 5G - A unified platform for innovations

**6G**
- **WRC-19**
- **WRC-23**
- **WRC-27**
- **WRC-31**
5G Use Cases Market

5G will expand the mobile ecosystem to new industries

$13.1 Trillion
in global sales activities by 2035

Precision agriculture
Construction and mining
Digitized education
Connected healthcare

Rich mobile experiences
Smart manufacturing
Intelligent retail
Smart city
Path to 6G – enabling a connected intelligent future
6G’s Disruptive revolution with novel technologies

6G will bring new and enhanced user experiences across the connected intelligent edge
6G’s Evolutionary Challenges “Stretching 5G”

6Genesis 2030 6G Vision: 1 Tbps speeds, microsecond latency and AI optimization

- Increase data rate: beyond 10Gb/s (e.g. for VR)
- Address latency: Comms. Control Codesign (e.g. for robotics)
- Expand coverage: connect 4B people missed-out
- Scalable HW/SW: enable cost-efficient applications (e.g. verticals)
- Tactile Internet - AI: transport correlation results, weights,…

“faster, higher, stronger…” 😊😊

Source: 6Gensis

Source: 5G Lab Germany
6G’s Disruptive revolution with novel technologies

- **Integrated communication, sensing, compute**
  Enhanced immersive XR, collaborative positioning, RF sensing for the merging of physical, digital, and virtual worlds, ...

- **Cloud-native network convergence**
  Merging of core and RAN as well as application services with distributed service model, ...

- **Wireless machine learning**
  Cross-node (i.e., network and device) AI/ML air interface design, and intelligent network operations, ...

- **Full-duplex communication**
  Single-frequency and subband full duplex, device-side full duplex, for communication, sensing and beyond, ...

- **New device types and service models**
  Ultra-low power and passive devices, hologram AI, cooperative devices, ...

Source: Qualcomm
6G’s Disruptive revolution with novel technologies

Extrem evolution of the wireless foundation

- Air interface innovations for enhanced spectral efficiency and new spectrum
  Giga-MIMO unlocking upper mid-band (7-24 GHz), sub-THz, visible light, distributed massive MIMO, RIS, 5G/6G DSS, ...

- New channel coding, modulation scheme, and waveform design
  Enhanced LDPC, polar codes vs. new techniques such as spinal, PAC, staircase codes, constellation shaping, ...

- Expanded network topology and enhanced device mobility management
  Disaggregated network architecture, multi-access interworking with Wi-Fi/BT/UWB, public/private network interoperability, ...

- Strengthened end-to-end system security building on 5G and LTE
  Post quantum security, data management and identity privacy, full encryption down to PHY/MAC, integrity protection, ...

Disruptive revolution with novel technologies

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6G will bring together

Evolutionary and revolutionary wireless advances
Across radio and baseband, machine learning and AI, cloud — network, and the merging of the worlds
6G Support enhanced services and new use cases
5G - 5G Advanced - 6G Use cases

Ericsson’s View on 3GPP’s 6G Roadmap

5G

- eMBB
- URLLC
- mMTC

5G Advanced

- eMBB+
- XR
- NTN
- TSN
- RedCap

6G

- Global broadband
- Compute-AI services
- Immersive communication
- Spatio-temporal services
- Critical services
- Omnispread IoT
- Institutional coverage
- Earth monitor
- Personal Concierge
- E-health for all
- Robot navigation
- Robot twins
- Smart agriculture
- Digital twins
- Institutional health
- Institutional coverage

enhance
expand
5G/6G – Edge Computing/Edge AI
High Level Model

**Center/Apps (Insightful Intelligence)**
This layer provides insight to the data collected from all layers and offers the information as a service to individuals, industries or infrastructures.

**Edge Computing -> Edge AI (Gateway/Aggregation)**
This layer enables the stream of data to move from one level to the next for additional processing.

**Sensing**
This layer enables interface to objects that are currently passive, where tapping into these objects will generate a stream of pertinent data and information.

Source: Collaborative IoT book, Wiley
5G – Application Drivers

Video streaming is exploding, and buffering is a deal breaker

Billions of devices will become connected, driving the need for network capacity to scale

Machine to machine communications will create opportunities, requiring ultra-low latency
5G Technical Drivers

5G’s promise of greater speed and overall network performance brings huge opportunities not only for the Internet of Things, 4K video, augmented and virtual reality, autonomous driving, mission critical and much more.
Drivers for the need of 5G - IoT

IoT Global Market

2019: US$ 212 billion

2025: US$ 1.6 trillion

Across multiple of vertical markets
Global AI revenue
2017: US$ 7.1 billion
2023: US$ 98.4 billion

Growing adoption: Smart Cities initiatives
Highest CAGR in APAC followed by Latin America

Source: IDC, Bloomberg NEF, Ericsson, Strategy Analytics

Artificial Intelligence (AI)
A process where a computer solves a task in a way that mimics human behavior. Today, narrow AI—when a machine is trained to do one particular task—is becoming more widely used, from virtual assistants to self-driving cars to automatic tagging your friends in your photos on Facebook.

Machine Learning (ML)
Algorithms that allow computers to learn from examples without being explicitly programmed.

Deep Learning (DL)
A subset of ML which uses deep artificial neural networks as models and does not require feature engineering.
The FCC defines 5G spectrum in four primary bands,
1. Low-band between 600–900MHz,
2. Mid-band between 2.5–4.2GHz also known as Sub-6,
3. Frequencies above 24GHz, otherwise known as mmWave,
4. Unlicensed spectrum, that can be accessed for a variety of dedicated uses including 5G.
5G commercialization at a glance: network investment and an expanding device ecosystem are helping to drive adoption globally.

Note: Data correct to June 2021
5G is now available in every region, making it a truly global technology

Note: Data correct to June 2021
5G – Deployment (Sub-6, Sub-6 + mmWave)

5G global rollout

30+ launched in 6 months
Faster than 4G

Source: Qualcomm
5G is expected to benefit all economic sectors; some industries will benefit more than others due to their ability to incorporate 5G use cases.
Almost half of the world remains unconnected; Asia Pacific and Sub-Saharan Africa account for the largest unconnected populations.
4G now accounts for half of total connections; 5G will start moving the needle in 2020
5G Use Cases Categories

- Enhanced mobile broadband
- Mission-critical services
- Massive Internet of Things
Mobile Communications Roadmap

Every 10 years a new generation of mobile communication

- 1G: Voice Analogue
  - 1980s
  - Mobile Voice Messaging ~28.8 kbps
- 2G: Start of mobile broadband
  - Information in hand ~14 Mbps
  - 1990s
- 3G: Smartphone Apps/video
  - ~225 Mbps
  - 2000s
- 4G: Mobile broadband
  - ~10 Gbps
  - Divergence
  - Internet-of-things
  - Rise of M2M Traffic
  - 2010s
- 5G: eMBB
  - Peak data rate >100 Gbps
  - Extreme coverage
  - Pervasive connectivity
  - Holographic telepresence
  - 2020s
- 6G: URLLC
  - 2030s
- MM2M

Nadine Collaert, imec, Emerging device and heterogenous integration technologies for sub-THz Applications, ISSCC 2022, 6G Forum.
5G Applications – Enhanced Mobile Broadband

Video Demand for Faster Network:
• **Video applications examples**: Streaming video, video conferencing, and virtual reality demands higher data speeds.

• **Video** is projected to be 82 percent of all IP traffic by 2022 (video traffic 2017: 56 exabytes, 2022: 240 Exabytes)

5G Faster download of 2hr HD video
Merging of the physical, digital, and virtual worlds

XR will become a mass-market compute platform
5G Applications – Drone

Potential Use Cases
• Delivery of emergency kit or rescue equipment to a disaster area using drones
• Search missions with HD imaging in disaster recovery zones, specifically areas of difficult access
• Coordinated missions where multi drone fleets from multiple countries could be used to inspect an emergency area or perform specific tasks (e.g. load handling)
• Rapid deployment of a temporary cellular network using drones, enabling vital communications for disaster recovery
IoT Innovative Approaches
Drone and Future Healthcare

• Most clinics are primarily collection sites.
• Blood samples are loaded on the drone and flown around for varying time periods between 6-38 minutes.
• The blood samples are completely unaffected by turbulence or changes in air pressure.
• The samples are packed in a special foam with a sponge that would fully absorb the specimens in the case of a crash.
• The regulations for drones differ in every country.

Air delivery of blood samples could save lives.
5G will expand the mobile ecosystem to new industries

- $389B: Precision agriculture
- $1,061B: Construction and mining
- $258B: Digitized education
- $1,056B: Connected healthcare
- $2,291B: Richer mobile experiences
- $4,687B: Smart manufacturing
- $1,198B: Intelligent retail
- $2,242B: Connected smart cities
Accelerated Tele-Service

- Scaled Technology
- Remote Monitoring
- Health Monitoring Device
- Patient Vitals
- Data stored on Cloud
- Triggers Alarm on a GP's Dashboard
- Reports available to Users
- Ongoing Monitoring
- Big Data
Smart Hospital

Patient – Nurses care

- Patient Integrated access to services & Environment
- Integrated devices and healthcare records
5G Applications – Healthcare
Potential Use Cases
Tele Health, Remote Diagnostics, Surgery

Requirements for 5G eHealth systems
- Quality of Service of 99.999%
- End-to-end latency reaching 5 ms
- Security (End2End Encryption)
- Upload is as important as Download
- Safety in hospital environment 5G
- Seamless Wireline + Wireless
Examples of IoT-enabled healthcare solutions utilized to support patients during the pandemic

<table>
<thead>
<tr>
<th><strong>Remote patient monitoring</strong></th>
<th>Healthcare professionals use IoT devices to track heart rate, blood pressure and blood glucose levels of patients remotely, particularly the elderly and other vulnerable patients that have had to shield during the pandemic.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contact tracing</strong></td>
<td>A number of contract tracing systems implemented around the world rely on IoT-based solutions to track the movement of patients and enforce social distancing in public areas.</td>
</tr>
<tr>
<td><strong>Vaccine cold chain monitoring</strong></td>
<td>IoT platforms have been used to develop cold chain monitoring systems that track the temperature and location of vaccine carriers. For example, the Electronic Vaccine Intelligence Network, developed by the United Nations Development Programme (UNDP) and the Indian government, has reduced vaccine stock-outs by 80%.</td>
</tr>
<tr>
<td><strong>Hospital sanitisation</strong></td>
<td>Non-surgical robots connected to IoT systems have been used to clean patient rooms and to disinfect and sterilise surfaces from Covid-19 contamination with a special UV light and chemicals.</td>
</tr>
<tr>
<td><strong>Automated temperature screening</strong></td>
<td>IoT-enabled thermal imaging systems have been used to identify people with elevated body temperatures before they enter buildings, such as airports, office spaces, schools, shopping centres and hospitals, for further screening.</td>
</tr>
<tr>
<td><strong>Facilities and PPE stock management</strong></td>
<td>IoT system have been used to provide supply-chain planners and policymakers with actionable information on the availability of hospital beds and personal protective equipment (PPE) for medical staff for the efficient allocation of resources.</td>
</tr>
<tr>
<td><strong>Healthcare delivery drones</strong></td>
<td>IoT-enabled drones have been utilised to deliver test kits and results, PPE, medicines and other vital medical supplies, especially in developing regions with poor logistics infrastructure. For example, in Ghana, connected-drone company Zipline is supporting the delivery of vaccines to remote parts of the country.</td>
</tr>
</tbody>
</table>
Foundation of Covid-19 IoT Healthy Home/Building

- Ventilation
- Thermal Health
- Indoor Air Quality (IAQ)
- Moisture
- Dust & Pets
- Lighting & Views
- Safety & Security
- Acoustics
- Water Quality

Foundations of a Healthy Building

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Lighting & Control
- AI-based lighting control
- Voice enabled Lighting Control
- Human-centric Lighting

Automation & Energy Optimization
- Building energy performance optimization (BEPO)
- Cloud-based remote services
- Predictive maintenance
- Digital twin
- Workplace analytics

HVAC & IAQ
- HVAC optimization
- Indoor air quality (IAQ)-based ventilation
- Ultraviolet germicidal irradiation (UVGI)
- High efficiency particulate air (HEPA) filters

Post-COVID Applications
- Occupancy detection (OD) based social distancing
- Indoor positioning (IP) based contact tracing
- AI-based face and mask detection
- Antimicrobial paints in wash rooms
- Foot operated elevator
- Touch-free bathroom fixtures
- Thermal imaging
- AI-based access control
- Building health performance benchmarking (BHPB)
- Pathogen scanner
- Nano technology (NT)-based self cleaning surfaces
- Touch-free toilet seat cover cleaning

Communication
- Power over Ethernet (PoE)
- Narrowband communication
- Bluetooth Low Energy (BLE)

5G Applications – Smart Energy

Cloud

Power Grid

Utility

Homes
Must ensure that public safety vehicles receive the proper prioritization in terms of ultra-high-speed data access for building schematics, local maps, communications, etc.
5G – Enable Smart Transportation and EV/Autonomous driving
IoT Smart Connected Cars
In The Plan – Capabilities/Features Roll-out

- Active Safety, Accident avoidance V2X (V2V, V2I)
  > Wifi Peer-to-Peer (P2P) Mesh Networking
    802.11p for V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-Infrastructure)

- Car Tracking (Location, Speed etc); Logistics: Taxi, Truck etc

- Autonomous Car (Google Car)
IoT and Sensing for Autonomous car

Under the bonnet
How a self-driving car works

Signals from GPS (global positioning system) satellites are combined with readings from tachometers, altimeters and gyroscopes to provide more accurate positioning than is possible with GPS alone.

Lidar (light detection and ranging) sensors bounce pulses of light off the surroundings. These are analysed to identify lane markings and the edges of roads.

Video cameras detect traffic lights, read road signs, keep track of the position of other vehicles and look out for pedestrians and obstacles on the road.

Capable of sensing the environment and navigate without human input.

Ultrasonic sensors may be used to measure the position of objects very close to the vehicle, such as curbs and other vehicles when parking.

The information from all of the sensors is analysed by a central computer that manipulates the steering, accelerator and brakes. Its software must understand the rules of the road, both formal and informal.

Radar sensors monitor the position of other vehicles nearby. Such sensors are already used in adaptive cruise-control systems.

Source: The Economist
IoT Smart Connected Cars
Self-Driving Cars challenge at Intersection
Bigger issues regarding IoT Smart Transportation (V2V & V2I)
IoT Smart Connected Cars
DSRC and C–V2X

**DSRC Technology**
Dedicated Short-Range Communication
- Ad hoc networking technology that allows vehicles to communicate with each other, roadside devices, pedestrians, bicycles, trains, ....
- IEEE portions also called WAVE (Wireless Access in Vehicular Environments)

**V2X Communications**
- Long range sensing
- Non line-of-sight capability
- Collaborated driving

**V2I**
- Red Light Violation Warning
- Curve Speed Warning
- Stop Signal Gap Assist
- Reduced Speed/Work Zone Warning
- Pedestrian in Signalized crosswalk Warning

**V2V**
- Emergency Electronic Brake Lights
- Forward Collision Warning
- Intersection Management Asist
- Left Turn Assist
- Blind Spot/lane change warning
- Do not pass warning
Disruptive Technologies for 5G New Radio (NR)

High reliability, low latency and high data rates are required

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Latency</th>
<th>Reliability</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle platooning</td>
<td>&lt;25 ms</td>
<td>&gt;90%</td>
<td>Low</td>
</tr>
<tr>
<td>Remote Driving</td>
<td>&lt;5 ms</td>
<td>&gt;99.99%</td>
<td>&gt;10 Mbps DL, &gt;20 Mbps UL</td>
</tr>
<tr>
<td>Collective perception of environment</td>
<td>&lt;3 ms</td>
<td>&gt;99%</td>
<td>1 Gbps for a single UE</td>
</tr>
<tr>
<td>Cooperative collision avoidance</td>
<td>&lt;10 ms</td>
<td>&gt;99.99%</td>
<td>&gt;10Mbps</td>
</tr>
<tr>
<td>Info sharing for level 2/3</td>
<td>&lt;100 ms</td>
<td>&gt;90%</td>
<td>&gt; 50 Mbps</td>
</tr>
<tr>
<td>Info sharing for level 4/5</td>
<td>&lt;100 ms</td>
<td>&gt;99.99%</td>
<td>100-700 Mbps</td>
</tr>
</tbody>
</table>
Integration of **smart vehicles** which can act as storage devices to reduce transmission losses and promote **cleaner transport** and the introduction of **smart infrastructure, and intelligent** demand response systems.
Telecom: ITU TMN versus IoT Functional Models

ITU TMN

Edge Computing (Gateway/Aggregation)

Big Data/DL/Services

3G/4G/5G Data/ML/Control

ZigBee, NFC, WiFi

Sensing

Wearables, Sensors, RFID, ....
Telecom Functional Network Management Systems

**Supervisory**
- Facility & Traffic Management

**Control**
- Performance Measurement
- Configuration Provisioning/Control
- Fault Analysis Reporting

**Monitoring**
- Systems/Equipment
- Data Acquisition System
- Digital/Analog sensing points
- 70 vendors

**Monitors/Projection Screens**
- Graphical views
- Service Performance

**Smart Work Stations**
- TMN Functions (Multiple views)
- ACK/Control

**Work Stations**
- Elements of TMN
- Sensing (analog, digital)
- RS-xxx

**Network Control/Analysis Center**
- Int’l Gateways
- Switching & Transmission
- Stations
  - Cable Stations
  - Satellite Base Stations

**70 vendors**

- Technical details and network infrastructure components.
Use of the Drone in Public Safety

- Search and rescue
- Situational awareness
- Safety – Egress
- Medical delivery
**IoT Smart Streetlight**

**Sensing**
- Smart Grid lighting
- Image sensors
- Environmental/Water

**Gateway/Control**
- Notification light
- Audio
- Signage
- Push to talk
- App based wireless control

**Services/Data Analytics**
- First Responders
- Interact with traffic light control
- Stat/Planning for safety

---

**IoT Smart Streetlight**

- **Wireless Dual Band Mesh Transceiver**
- **App Based Wireless Control**
- **Notification**
- **Digital Street Sign**
  - EVENT
  - <- Parking
- **Facade Lighting**
  - (Color change)
- **Environmental Sensor**
- **Water Detection**

---

**"Smart Grid" Street Light**
- Photocell control
- Dimming control

**Concealed Placement Speaker**
- Music
- Announcement
- Alerts

**Image Sensor**
- Proximity sensors
- Pedestrian

**Digital Signage**
- Way finding
- Traffic direction
- Alert notification
- Civic information
- Revenue Gen. via ADV

**Push to Talk System**
- "Blue Emergency light"

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**Different Styles**
FACILITY MANAGER – NEW JOB DESCRIPTION!

- Building health assessment
- Indoor air quality (IAQ) solutions
- Data driven services
- Health and wellness standards

Source: CABA Intelligent Buildings and COVID-19 Report
Smart Connected Building
AI-driven building solutions and cloud-based remote services

5G/IoT/AI Use Cases: Smart City

Economic Growth
Quality of Life
Ecological Footprint, Sustainability

Across multiple Sectors
Technology Roadmap 2020-2025

**Lighting & Control**
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Source: Collaborative IoT book, Wiley
5G Network Slicing (NS) Difference from 4G

- Each slice is optimized to meet different KPIs: wide coverage, massive connection, low latency and high reliability, high data rate, etc.
- However, not all network slices are created equal
Network Slicing (NS) partitions common network infrastructure into multiple, logical, end-to-end, virtual network instances to provide customized virtual private services.
5G Network Slicing

Orchestration deliver cost effective, timely and efficient NS governed by a service level agreement
Network Slicing and Multi-access Edge Computing (MEC) are two key enablers for 5G QoS service differentiation optimizing use of resources in the network and use of network slicing.

Flexible orchestration of network slices is realized using software defined functions and programmable infrastructures. RAN’s backhaul are governed by the NFV infrastructure, the control of which relies on the MEC.

The intelligence data comes in streams: from multiple sites; in multiple forms that include videos from surveillance systems, images from cameras, verbal reports in many languages and dialects, and responses from databases to queries.

Actionable information must be extracted continuously from this streaming data and delivered in customized form to appropriate addresses.
5G/6G and Edge Computing Takeaways

• 5G Commercial trials/deployment are progressing (eMBB, mMTC, URLLC)

• Collaborative 5G & IoT transform from identifying symptoms to identifying root cause leveraging mass connectivity, low latency and higher speed.

• IoT, 5G/6G and AI usher a beginning of collaborative, end-to-end, scalable services aimed at improving business process, quality of life and personalization of services.

• Multi-access Edge Computing (MEC) and Edge Intelligence allows for faster processing closer to the equipment at lower latency.

• Network Slicing enable QoS service differentiation, optimizing use of resources in the network and revenue generation.
5G Network Slicing - Examples

eMBB:
• Video applications for faster download or streaming, video conferencing and virtual reality demanding higher data speeds.
• The network will likely need a lot of small cell coverage and will take advantage of higher bandwidth spectrum.

Automotive
Network slices may be needed for high throughput needs for in-vehicle entertainment, and ultra-reliable and low latency (URLLC) needs for assisted/autonomous driving, data gathering and analysis from telemetry sensors, device to device communication, etc.

Massive IoT:
• Support a huge number of devices, many of which require longer battery life, the 5G network will be building off of the LTE Advanced Pro platform.
• 5G will use the platform’s two narrowband technologies, enhanced machine-type communication (eMTC) and narrowband IoT (NB-IoT).
Examples: Transport traffic management department may use a massive IoT network slice to monitor and manage the real-time status of their systems.
Future Networks Technical Community

- Collaboration
  - + other IEEE and non-IEEE collaborators

- Content
  - IEEE Future Networks Tech Focus Issue 14, April 2022
  - technical newsletter, podcasts, videos, articles

- Events
  - IEEE Future Networks World Forum 2022
  - + workshops and more

- Research & Education
  - IEEE INGR International Network Generations Roadmap
  - + eLearning courses, webinar series, tutorials
INGR Strategic Objectives

Address diverse areas of interest through targeted working groups that benefit humanity through technology

14 Working Groups focused on technology and society

Provide a suite of technology roadmaps to identify risks and opportunities within 3, 5, and 10 year periods

2022 INGR Edition released

2023 INGR Edition coming soon

Engage stakeholder groups within and across IEEE initiatives and external entities for added value

Internal INGR community

IEEE and IEEE SA entities

External entities

https://futurenetworks.ieee.org/roadmap
• Annual technical document highlighting network technology evolutions over 3-, 5- and 10-year horizons
• Created by 100+ international experts across 14 working groups
• 2022 Edition (3rd) was 14 chapters, 1000+ pages
• Available exclusively to Future Networks participants
• 14,500+ total INGR downloads

Events and outreach:
• Presentations and readouts at conferences
• Technical workshops
• 2021-22 webinar series
• Paid advertising campaigns
• In 2021, FNI’s INGR events compiled 6,200 registrants
INGR Editions

Scope.
- High-level perspective and projection of how the industry could evolve
- Highlights of common needs
- Challenges to achieving those needs
- Potential solutions to those challenges

Projections
- INGR projections for the next 10 years:
  - Key Timeframe points at 3, 5, and 10 years.

Foundation for future editions
- This INGR 1st edition was released in 2020 and was followed by 2021 and 2022 Editions. They laid the foundation for subsequent editions that will include a description and evaluation of 6G and other future network enhancements.

2023 Edition
- Extend the range and depth of the 2022 Edition
# IEEE INGR Structure and Working Groups

<table>
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<tr>
<th>CATEGORY</th>
<th>DESCRIPTION</th>
<th>INGR WORKING GROUP CHAPTERS</th>
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| 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  
                                          • Systems 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)             |
Applications and Services WG

INGR Applications and Services WG Focus
- Provides a sustainable transdisciplinary framework across end-to-end ecosystems in urban and non-urban areas, and caters to different stages of priorities, resources, and technologies.

INGR Applications and Services Chapter Highlights include
- Applications and Services Framework
- Ecosystem of Ecosystems: intra-ecosystem and inter-ecosystem alignments. Eight ecosystems are addressed – Agriculture, Education, Electrical Power, Health Care, Media and Entertainment, Public Safety, Transportation, and Water Distribution & Wastewater Treatment.
- Network of Networks: Future networks components (access, service delivery, operations and service management, and network extensions), use case categories and deployment drivers, and network operations enhancements.
- Function of Functions: strategic, tactical and operational governance functions.
- Scenarios: Smart Cities, Smart Regions, and Pandemic Response Scenarios

WG Recommendations / Highlights of 2022 Edition Topics
- Framework Enhancements – Additional details on ecosystem enhancements, cross-ecosystem touchpoints, and KPIs
- Inter-INGR WG Collaboration, e.g., AI/ML use cases, Comprehensive Plans, Rural Development, Trust, Multi-tiered security, etc

IEEE INGR Applications and Services WG
- Roadmap Details – Refer to INGR WG chapter
- WG Participation – 5GRM-appssvcs@ieee.org
Security WG

INGR Security WG Focus

• 5G security considerations for different layers (physical, network, and application).
• Security challenges and opportunities.

INGR Security Chapter Highlights include

• Foundational Concepts: NIST CyberSecurity Framework and SecurityThreat Models
• Security Use-Cases for various Verticals: Security focus on Applications, Critical Infrastructure Systems, AI/ML, Interoperability, Industrial Control Systems (ISC), Safety & Security, etc.

WG Recommendations / Highlights 2022 Edition Topics

• 2022 Edition to include additional coverage of data sharing and privacy, satellite communication, physical layer security, identity and access management, application security KPI/SLA, etc.
• Perform an in-depth security gap analysis with current industry standards
• Enable studies (research, verification) via established 5G test-beds
• Publications to inform/guide/socialize 5G security directions/focus areas.
• Collaborations with ONF, ORAN, Linux Foundation to develop an open source security framework
• Engagement, education and socialization, e.g. conferences, webinars, world forum

IEEE INGR Security WG
• Roadmap Details – Refer to INGR WG chapter
• WG Participation – 5GRM-security@ieee.org
Artificial Intelligence / Machine Learning (AI/ML) WG

INGR Artificial Intelligence / Machine Learning (AI/ML) WG Focus

- Provide the Roadmap based on research and industry advancement to deliver the AI/ML vision beyond 5G.
- Identify and define the taxonomy and state of AI (sense, think, and act like a human) and ML (detection, classification, segmentation, predictions, and recommendations).
- Survey existing frameworks that support AI/ML workloads for different domains and identify a reference architecture to compare emerging protocol stacks and infrastructure elements.

INGR AI/ML WG Areas of Interest include:

- Network Automation
- Network Slicing
- Network Digital Twins
- Security
- Dynamic Spectrum Access
- Cloud Computing
- Multi-access Edge Computing

Highlights of AI/ML Topics for INGR 2022 Edition include

- Cross-team collaboration with other FNI WGs for AI/ML augmentation.
- Investigate additional 5G and Future Networks areas where technology gaps can be closed using AI/ML, e.g., Quantum Computing and Security.
- Set priorities for future development to include both technological advances and AI/ML developments that are being undertaken by other organizations, e.g., ETSI, 3GPP, etc.
- Develop an AI/ML based management and orchestration framework.
- Define how open source and open architectures can be used and adopted, e.g., a joint effort for Open RAN technologies may be adopted by industry via the O-RAN Alliance and Telecom Infra Project (TIP).
- Develop and demonstrate AI/ML 5G and Future Networks use cases

IEEE INGR Artificial Intelligence / Machine Learning (AI/ML) WG

- Roadmap Details – Refer to INGR WG chapter
- WG Participation – 5GRM-AIIML@ieee.org

INGR AI/ML WG

• Network Automation
• Network Slicing
• Network Digital Twins
• Security
• Dynamic Spectrum Access
• Cloud Computing
• Multi-access Edge Computing
The 5G & Beyond Testbed

- A virtual end-to-end network testing and innovation platform
- Reduced-cost innovation across interdependent industry players
- Win-win collaboration opportunities across the broad range of 5G/6G technologies
- Academic/education opportunities
The 5G & Beyond Testbed Project will bring together industry participants across the broad range of 5G/6G technologies to enable win-win collaboration opportunities and contribute to the roadmap for future technological direction.

The academic institutes will have access to the testbed grand branch in later stages.
End-to-End Overview of 5G System

5G & Beyond Testbed Enables New Use Cases for Industry

Embedding cloud technologies into the mobile network

AI – Orchestrator

Robust networks that can support drone operations, medical monitoring and surgeries, autonomous cars, etc.

Opportunity for startups to develop new products and applications

Enhance knowledge and skills for students and faculty staff
INGR 2nd Edition Release

• Access the documents online at futurenetworks.ieee.org/roadmap
• The roadmap documents will also be available at IEEE Xplore
• INGR is a program of the IEEE Future Networks Initiative
Reduce technical and engineering risks associated with the migration to 5G and beyond

IEEE INGR
International Network Generations Roadmap

The purpose of the International Network Generations Roadmap (INGR) is to stimulate an industry-wide dialogue to address the many facets and challenges of the development and deployment of 5G in a well-coordinated and comprehensive manner.

The First Edition is accessible via the IEEE Future Networks Initiative website: https://futurenetworks.ieee.org/roadmap

Applications & Services
  - Edge Automation
  - Platform
  - Hardware
  - Massive MIMO
  - Millimeter Wave

Optics
Satellite
Security
Standardization
Building Blocks

The INGR authors believe that, with widespread participation, the roadmap process can reduce some of the technical and engineering risks associated with the migration beyond 4G and related technologies. As work continues with the Second Edition, new experts are encouraged to participate, to evolve and strengthen this crucial set of documents. Join us!

futurenetworks.ieee.org/roadmap
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THANK YOU!

Questions?

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