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5G, 6G, and Beyond

with Artificial Intelligence (AI) & Machine Learning (ML) in 6G and Beyond

Baw Chng
info@bawman.com

IEEE

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Find this presentation at bawman.com/PRESENTATIONS/

Biography

BAW CHNG @ BAWMAN LLC

- **Senior Member of IEEE**, participate in IEEE Standards Association (SA), Future Networks, GHTC
  - Co-Chair, Future Networks Artificial Intelligence & Machine Learning (AIML) Working Group (WG)
  - Vice Chair, P2301 Guide for Cloud Portability and Interoperability Profiles (CPIP) WG; Member, IEEE 802 LAN/MAN, Wi-Fi
  - Treasurer / Finance Chair, Global Humanitarian Technology Conference (GHTC 2023)
- **Founder & President of BAWMAN LLC**, consult in Wireless Networking and Telecommunications
- **Services offered**:
  - **Strategic Consulting** – business strategy, product positioning, technology roadmap development, RFI/RFP
  - **Standards Consulting** – standards development, standards & trade group representation
  - **Technology Consulting** – network system architecture, technology development, evaluation and trial
  - **Patent, Intellectual Property** – patent evaluation, pre-trial consultation, expert witness services
- **Clientele**: communications service providers, technology suppliers, equipment vendors, start-ups, established enterprises, investors, intellectual property firms, the legal community
- **Expertise**: networking systems, wireless communications, standards and protocols
  - cellular, Wi-Fi, IoT, LPWAN, optical, NFV, SDN, cloud, IEEE, IETF, 3GPP, WBA, CableLabs, Broadband Forum
- **Contact**: www.bawman.com ; info@bawman.com

Outline – “5G, 6G, and Beyond”

- Biography
- Background, “5G”
  - Brief history up to “5G”
  - What is “5G”
- “6G” and Beyond
  - What is “6G”
  - Artificial Intelligence (AI) & Machine Learning (ML) in 6G and Beyond
- Discussion, Q&A …

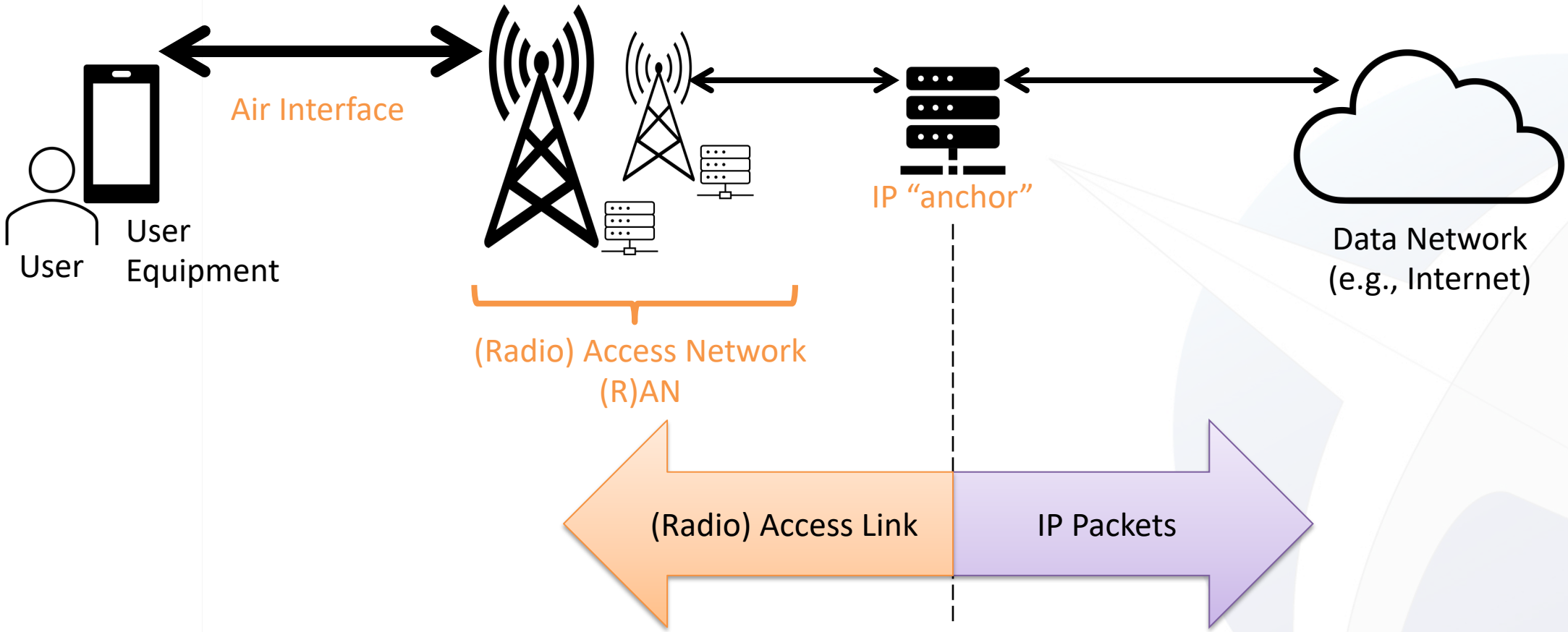
Background, “5G”

Brief history up to “5G”

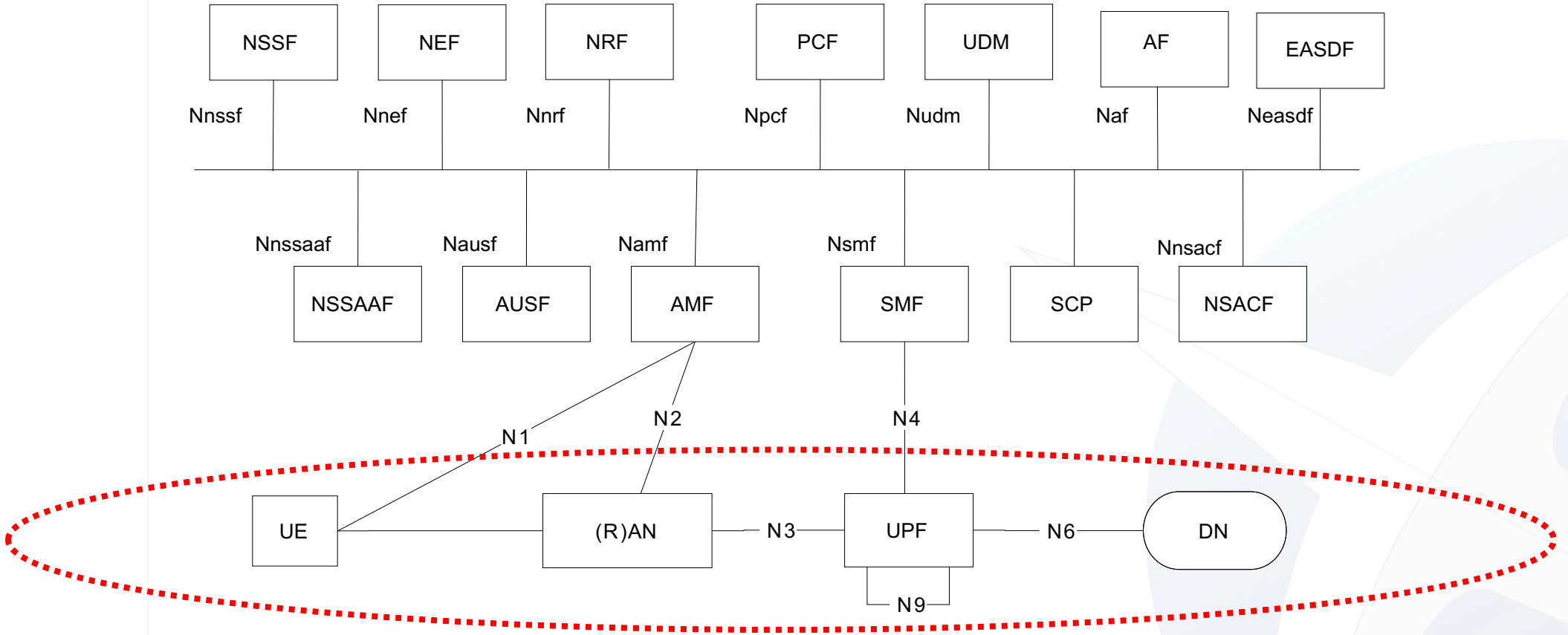
What is “5G”

Sidebar

Different Parts of Cellular Data Network (Architecture)



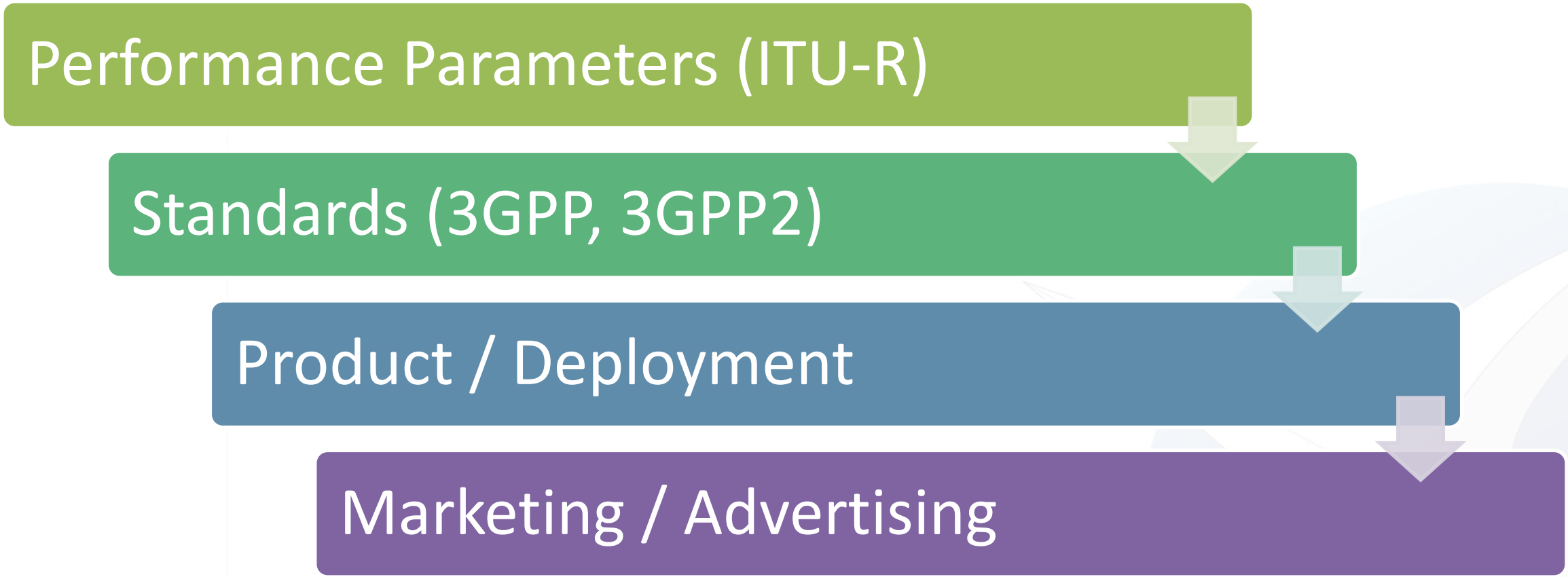
3GPP 5G System Architecture (Release 18)



Source: 3GPP TS 23.501 V18.0.0 Figure 4.2.3-1 “Non-Roaming 5G System Architecture”

Sidebar

3G, 4G, 5G … what do they mean, who defines them?



- They do not line up neatly
- Marketing / advertising may not align with technical requirements / standards

ITU-R, IMT Standards (1)

- International Telecommunication Union – Radiocommunmication Secector (ITU-R)
  - Explicitly disclaims responsibility for defining “3G,” “4G,” “5G”
  - Takes inputs from governments, regulators, industry, academia
  - Published three sets of standards
    - **IMT-2000** – roughly corresponds to “3G”
    - **IMT-Advanced** – roughly corresponds to “4G”
    - **IMT-2020** – roughly corresponds to “5G”
  - IMT stands for “International Mobile Telecommunications”
  - IMT standards are not technology-specific
    - Define requirements (e.g., peak data rate, latency, spectrum efficiency) without specifying the technology to meet them

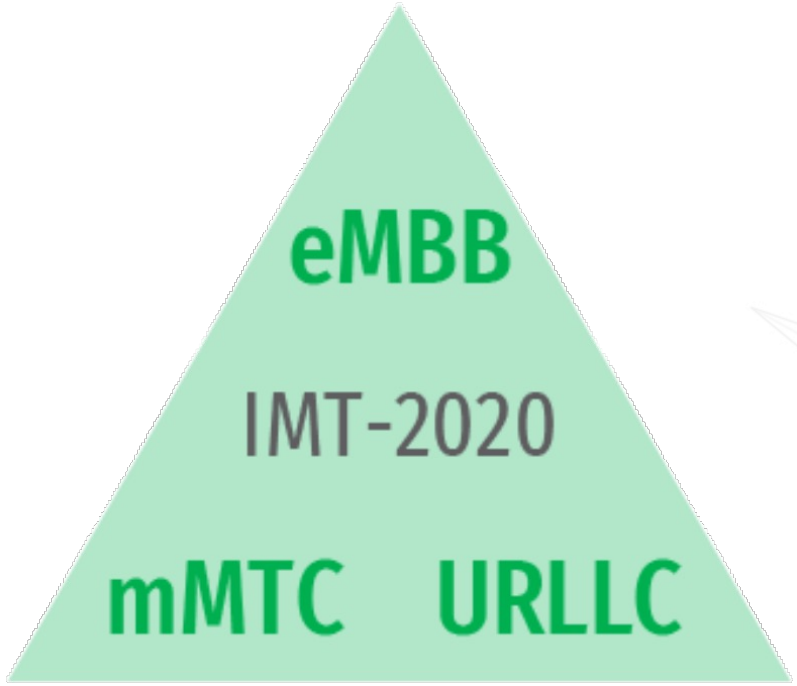
ITU-R, IMT Standards (2)

- **IMT-2020** key technical performance parameters:
  - **Peak data rates**: 20 Gbps downlink, 10 Gbps uplink
  - **User experienced data rates**: 100 Mbps downlink, 50 Mbps uplink
  - **Latency**: 4 ms for eMBB, 1 ms for URLLC
  - **Connection density**: 1 million devices per km^2
  - **Spectrum efficiency**: 30 bit/s/Hz downlink, 15 bit/s/Hz uplink
  - **Area traffic capacity**: 10 $Mbit/s/m^2$
  - **Mobility**:
    - **Pedestrian**: 0 km/h to 10 km/h
    - **Vehicular**: 10 km/h to 120 km/h
    - **High speed vehicular**: 120 km/h to 500 km/h

Reference: Report ITU-R M.2410

IMT-2020 – Triangle of Usage Scenarios

capacity
enhanced mobile broadband



IoT (Internet-of-Things)
massive machine type communication

latency
ultra reliable low latency communication

Source: [R1]

Background: Brief History Up To “5G” (1)

"1G" 1980s

- Analog, voice/telephony only, circuit switched
- TACS, NMT, AMPS

Licensed Frequencies

"2G" 1990s

- Digital, voice/telephony centric, slow data, packet domain added later
- GSM (TDMA), cdmaOne, Digital AMPS, PDC, PHS
- GSM → GPRS, EDGE (384 kb/s); cdmaOne → cdma2000 1xRTT (153 kb/s)

Licensed Frequencies

"3G" 2000s

- Digital, data centric, fast data (megabit/s), packet switched
- **3GPP**: GSM → UMTS, HSPA+; **3GPP2**: cdma2000 → 1xEV-DO, Rev. A/B/C
- Practical deployment: “2G” for voice/telephony, “3G” for data

Licensed Frequencies

Femtocell & “small cells” popularized in the later part of the “3G” era.
See “Re-Architecting the Wireless Telecom System” at https://www.bawman.com/PRESENTATIONS/

Background: Brief History Up To “5G” (2)

"4G" 2010s

- Data centric, faster data, voice/telephony carried as data
- LTE (OFDMA), Voice over LTE (VoLTE), mobile WiMAX
- (Later) LTE in unlicensed spectrum, LTE-U, LAA
- Software Defined Radio (SDR), Open Wireless Architecture (OWA)

Licensed & Unlicensed

"5G" 2020s

- 3GPP Service Based Architecture (SBA) for the Core
- 3GPP Release 15 (2018) – initial release for “5G”
- 3GPP Releases 16 (2020), 17 (2022) – “5G Evolution”
- 3GPP Release 18 (2023?) – “5G Advanced”

Licensed & Unlicensed

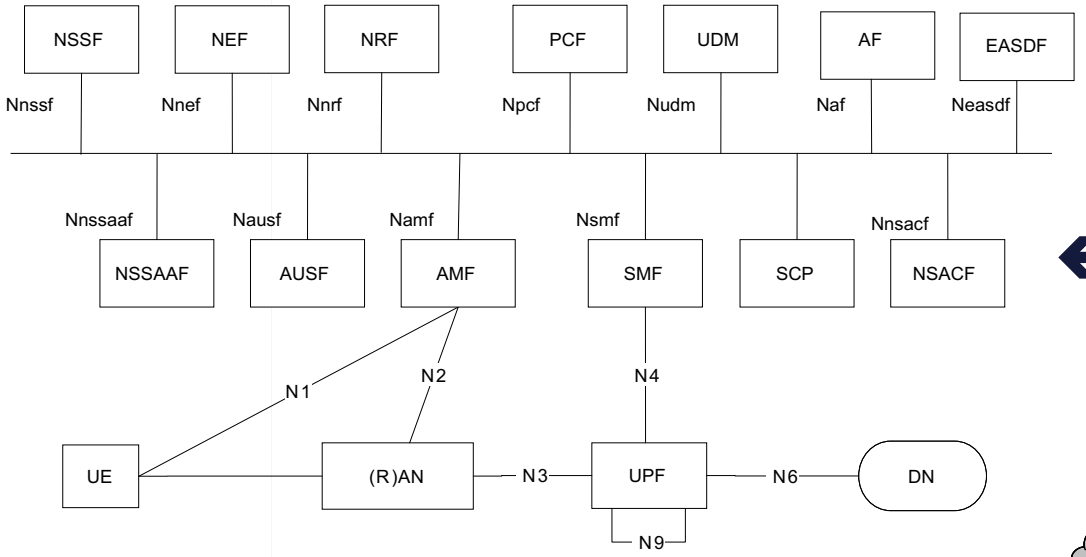
3GPP Service Based Architecture (SBA) for “5G”

- Think in terms of “functions” rather than “nodes”
- Better suited for virtualization, deployment in the cloud
- Prizes automation and programmability, orchestration

- Network Slicing, network slice
  - Logical network including (radio) access and core
    - Not limited to airtime and capacity reservations (differentiated services)
    - May also include computing resources (e.g., vCPU, memory, storage)

5G SBA vs. 4G/LTE Architecture

Sidebar

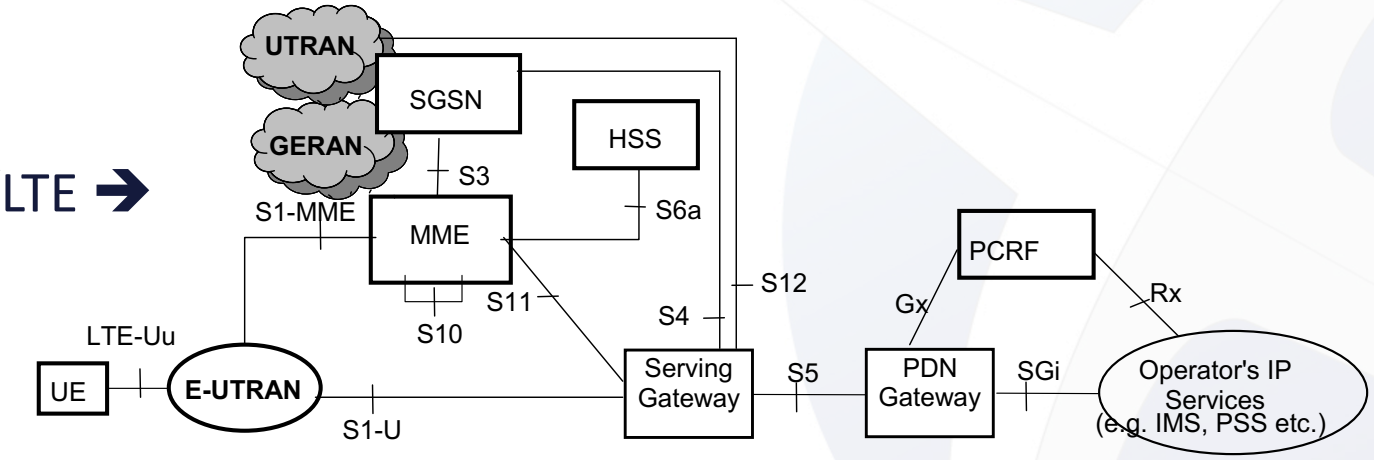


5G ←

- NSSF = network slice selection function
- NEF = network exposure function
- NRF = network repository function
- PCF = policy control function
- UDM = unified data management (“HSS”)
- AF = application function
- EASDF = edge application server discovery function
- NSSAAF = network slice-specific authentication and authorization function
- AUSF = authentication server function
- AMF = access & mobility management function
- SMF = session management function
- SCP = service communication proxy
- NSACF = network slice access control function
- UPF = user plane function
- DN = data network

- UTRAN = UMTS terrestrial RAN
- GERAN = GSM edge RAN
- SGSN = serving GPRS support node
- MME = mobility management entity
- HSS = home subscriber server
- E-UTRAN = evolved UTRAN
- PCRF = policy & charging rule function
- PDN = packet data network
- IMS = IP multimedia subsystem
- PSS = packet-switched streaming service

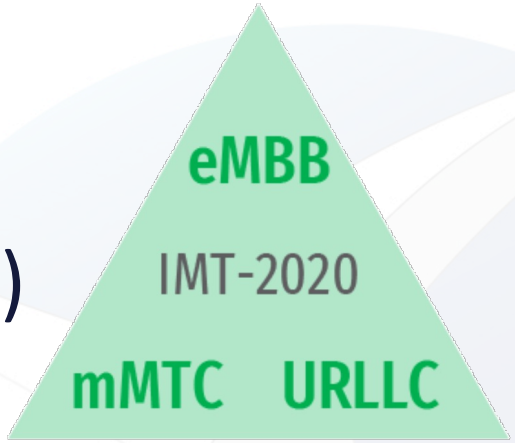
4G/LTE →



Source: 3GPP TS 23.401 V18.1.0 Figure 4.2.1-1: Non-roaming architecture for 3GPP accesses

3GPP Release 15 – “5G”

- New Radio “NR” (new air interface)
  - OFDMA with variable subcarrier spacings, larger channel BWs
  - more dynamic, more configurable
- Enhanced Mobile Broadband (eMBB)
- Ultra Reliable Low Latency Communications (URLLC)
- Massive Machine Type Communications (mMTC)



- **Non-Standalone**
  - 4G control plane, core
  - NR to boost capacity
- **Standalone**
  - Use without 4G/LTE
  - 5G control plane, core

3GPP Release 16 – “5G Evolution”

- Improvements & enhancements
  - Massive MU-MIMO, multi-TRP (transmission & reception point), multi-beam management, cell edge uplink coverage, peak-to-average power ratio (PARR), enhanced URLLC (eURLLC), improved HARQ, coordinated multi-point (CoMP), power saving, wakeup signal (WUS)
- Integrated Access and Backhaul (IAB) (for mmWave)
- Unlicensed Spectrum Support – “NR-U”
  - “Standalone” vs. “Anchored” (anchored to licensed spectrum)
- Cellular Vehicle to Everything (C-V2X)
- Non-Public Network (NPN)

3GPP Release 17 – “5G Evolution”

- Improvements & enhancements
- Operations beyond 52 GHz
- Multicast & Broadcast Services (MBS)
- Reduced Capability (“RedCap”, “NR-Light”) devices (IoT)
- Non-terrestrial Network (NTN) (satellite communications)
- Positioning: more precise, faster, more efficient positioning
- Further expansion of C-V2X (e.g., public safety, relay)
- (Study) Characterizing traffic of XR, AR, VR, cloud gaming, etc.

3GPP Release 18 – “5G Advanced”

- Support for AI/ML Services
- XR, Media Services
- Satellite Backhaul
- VN Group Management
- Personal IoT Network
- Vehicle Mounted Relays
- Ranging Based Services & Sidelink Positioning (C-V2X)
- Timing Resiliency (URLLC)
- Real-Time Communications
- Deterministic Networking
- UPF enhancement for SBA
- 5G Access and Mobility Policy
- 5G UE Policy (route selection)
- Service Function Chaining
- UE Context Recovery
- (Release 17 carryovers)

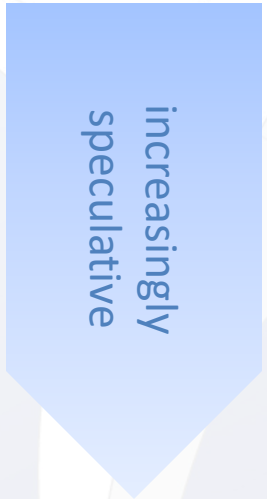
6G and Beyond

What is “6G”

Artificial Intelligence (AI) and Machine Learning (ML) in 6G and Beyond

6G and Beyond

- 3GPP Standardization Perspective
  - Release 15 “5G”
  - Release 16 “5G Evolution”
  - Release 17 “5G Evolution”
  - Release 18 “5G Advanced”
  - Release 19 “5G Advanced”
    - content yet to be decided (may start near the end of 2023)
  - Release 20 “5G Advanced”
  - Release 21 “6G” ???
    - maybe 2028



6G and Beyond

- ITU IMT Perspective
  - **IMT-2000** – roughly corresponds to “3G”
  - **IMT-Advanced** – roughly corresponds to “4G”
  - **IMT-2020** – roughly corresponds to “5G”
- What about “6G” ?
  - **IMT-2030** (not specified yet)
    - “The ITU-R Framework for IMT-2030”, July 2023
      - Reference: [R1] https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Documents/IMT-2030%20Framework_WP%205D%20Management%20Team.pdf

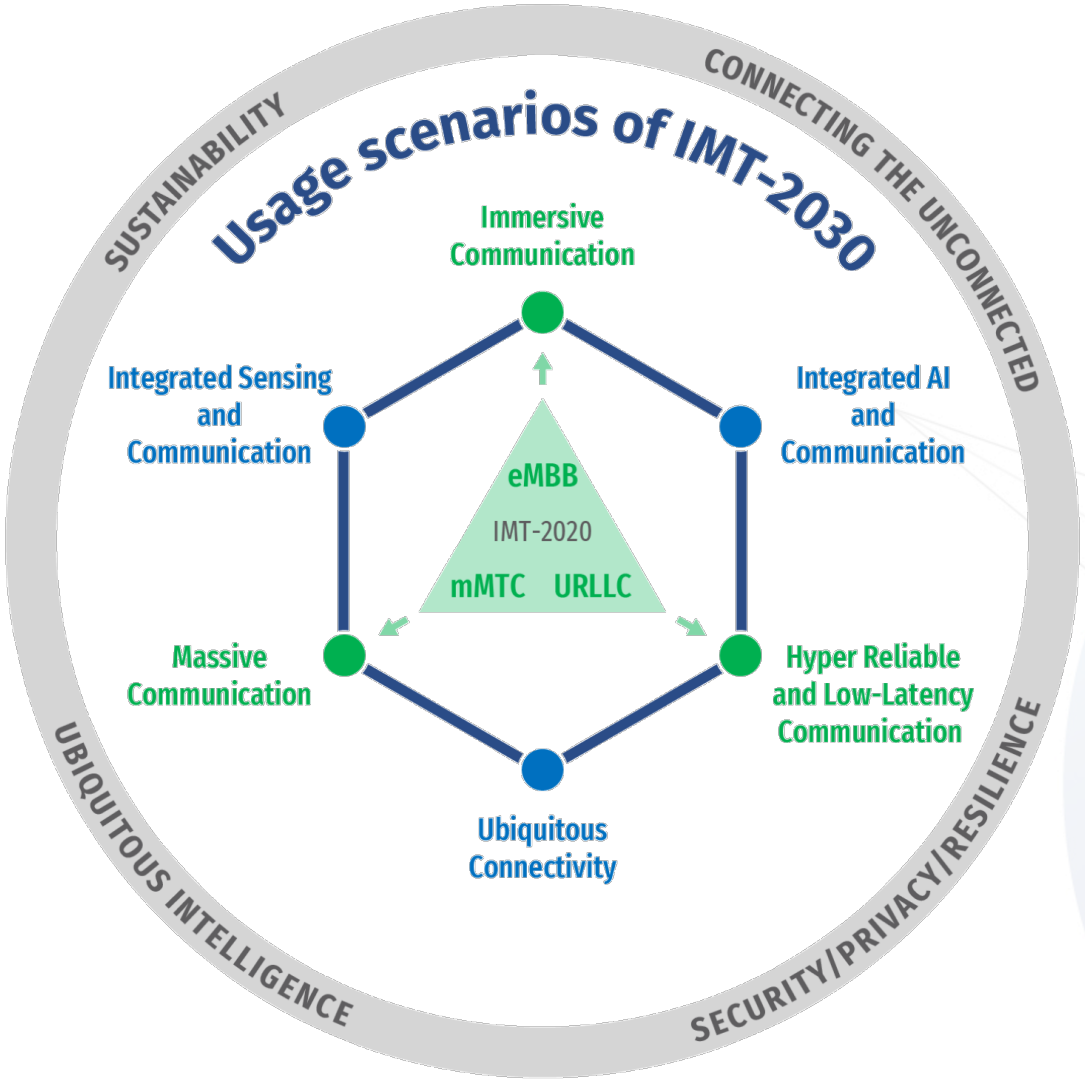
6G and Beyond – ITU-R Framework for IMT-2030 (1)

- **Motivation & societal trends**
  - Inclusivity
  - Ubiquitous connectivity
  - Sustainability
  - Innovation
  - Enhanced security, privacy, and resilience
  - Standardization and interoperability
  - Interworking
- **User & application trends**
  - Ubiquitous intelligence
  - Ubiquitous computing
  - Immersive multi-media & multi-sensory interactions
  - Digital twins & virtual world
  - Smart industrial applications
  - Digital health & well-being
  - Ubiquitous connectivity
  - Integrating sensing & communications
  - Sustainability

6G and Beyond – ITU-R Framework for IMT-2030 (2)

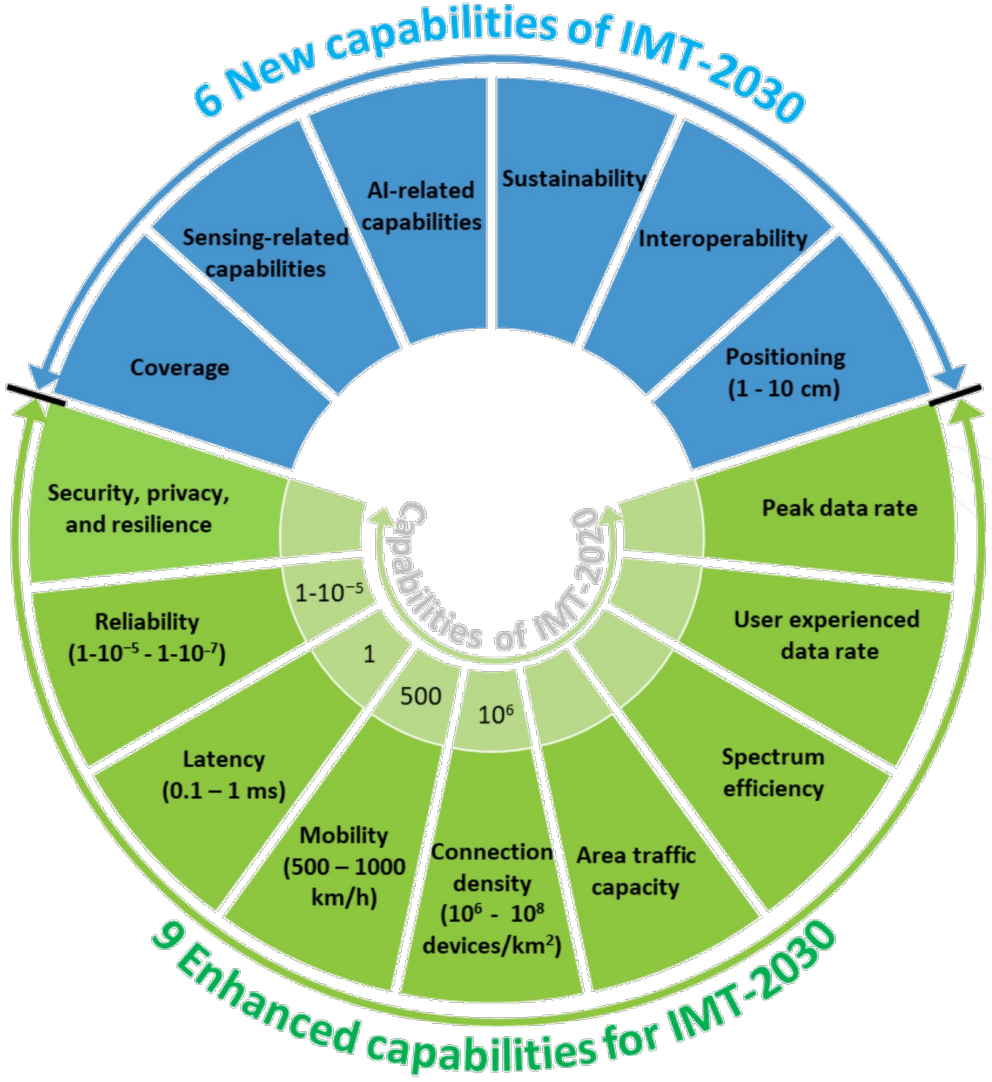
- Spectrum implications
  - Multiple frequency ranges to meet capacity & coverage requirements
  - Contiguous & wider spectrum bandwidth
    - From sub-1 GHz to sub-THz bands
      - low bands
      - mid bands
      - mmWave bands
      - sub-THz bands
        - » going over 100 GHz

6G and Beyond – ITU-R Framework for IMT-2030 (3)



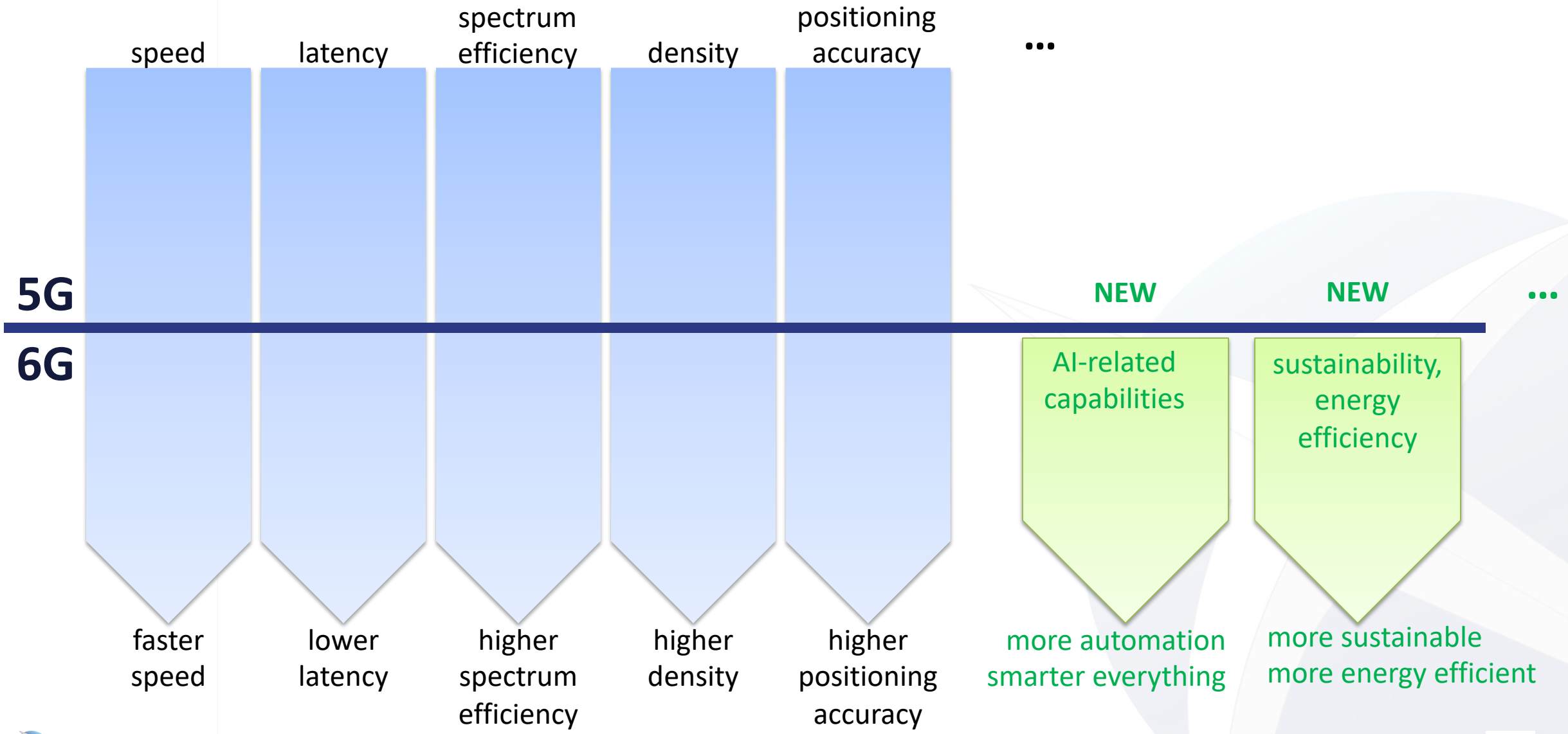
Source: [R1]

6G and Beyond – ITU-R Framework for IMT-2030 (4)



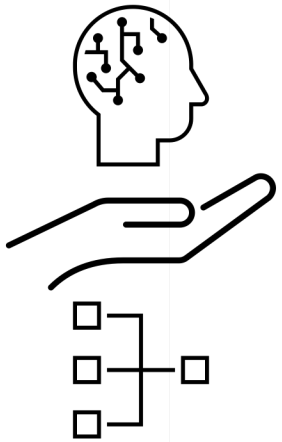
Source: [R1]

6G and Beyond – New Dimensions of Improvements

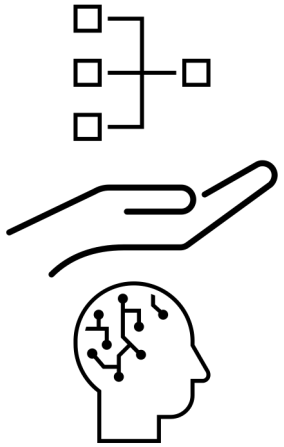


6G and Beyond
Artificial Intelligence (AI) & Machine Learning (ML) – (1)

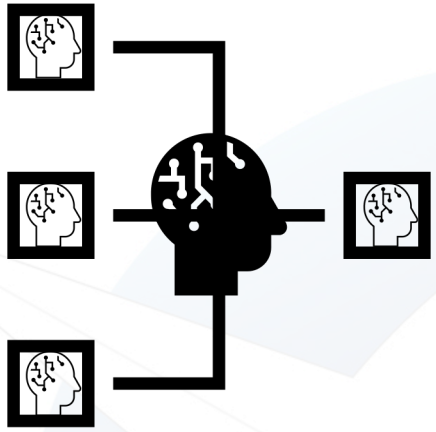
- Broad approaches to AI/ML in communications networking



① Build networks that better support AI/ML applications

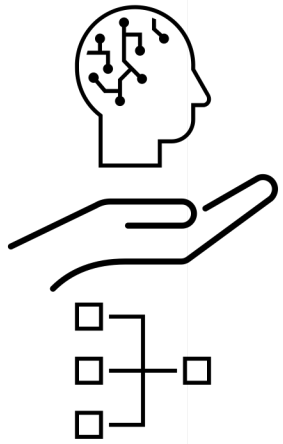


② Use AI/ML to build better networks



③ Integrate AI/ML and the network; make the network itself intelligent

6G and Beyond
Artificial Intelligence (AI) & Machine Learning (ML) – (2)



① Build networks that better support AI/ML applications

General methodology:

- Identify AI/ML applications
- Characterize usage patterns & traffic profiles
- Design or fine-tune networks accordingly

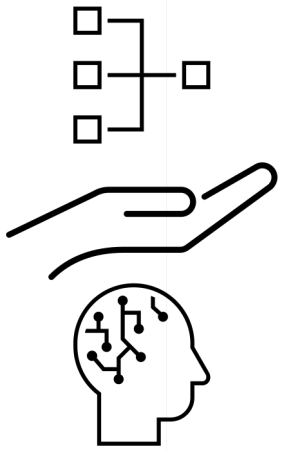
Examples:

- VR, AR, XR, autonomous driving/flying, generative AI, industry-specific verticals

New considerations:

- Large scale data collection, ML model training/learning, distribution of models
- "Federated learning"

6G and Beyond
Artificial Intelligence (AI) & Machine Learning (ML) – (3)



② Use AI/ML to build better networks

General approach:

- Take a specific network function (R&D or operational)
- Try to improve/scale/automate with AI/ML

Examples:

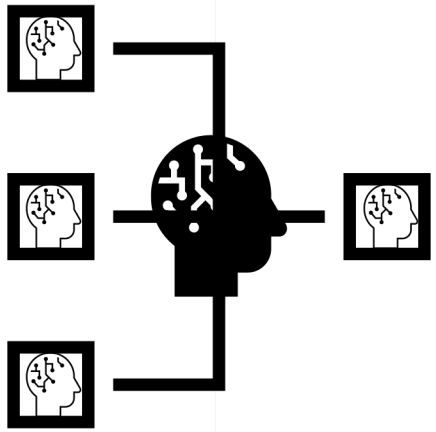
- Antenna design
- Beamforming
- Cell selection
- Routing
- Load balancing
- Security
- Orchestration
- SON
- Radio resource management
- Network management

- Generally respect existing functional boundaries
  - Little to no impact on existing standards

New/recent concept: “Intent driven automation”

Reference: TM Forum IG1253

6G and Beyond
Artificial Intelligence (AI) & Machine Learning (ML) – (4)



③ Integrate AI/ML and the network; make the network itself intelligent

New/Recent Concepts:

- "Intent driven automation"
  - Deduce/adapt operational specs from "intent"
- "Semantic communication"
  - Instead of transmitting "information," transmit the "meaning" behind the information
    - Discern "meaning" from "information"
- "Task-oriented communication"
  - Transmit data relevant to specific tasks
    - Recognize "tasks," discern what is "relevant"

Conclusion?

Just getting started with “6G” and AI/ML

Too early for “conclusion”

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Sidebar

Future Networks Technical Community

- Organized under IEEE Communications Society (ComSoc)

International Network Generations Roadmap (INGR) – 14 Topical Chapters, 10 Year Horizon

- https://futurenetworks.ieee.org/roadmap

AI & ML §Δ
Apps & Services
Connecting the Unconnected
Deployment
Edge Services
Energy Efficiency
Massive MIMO
mmWave
Optics
Satellite
Security & Privacy Δ
Standardization Δ
System Optimization Δ
Testbed

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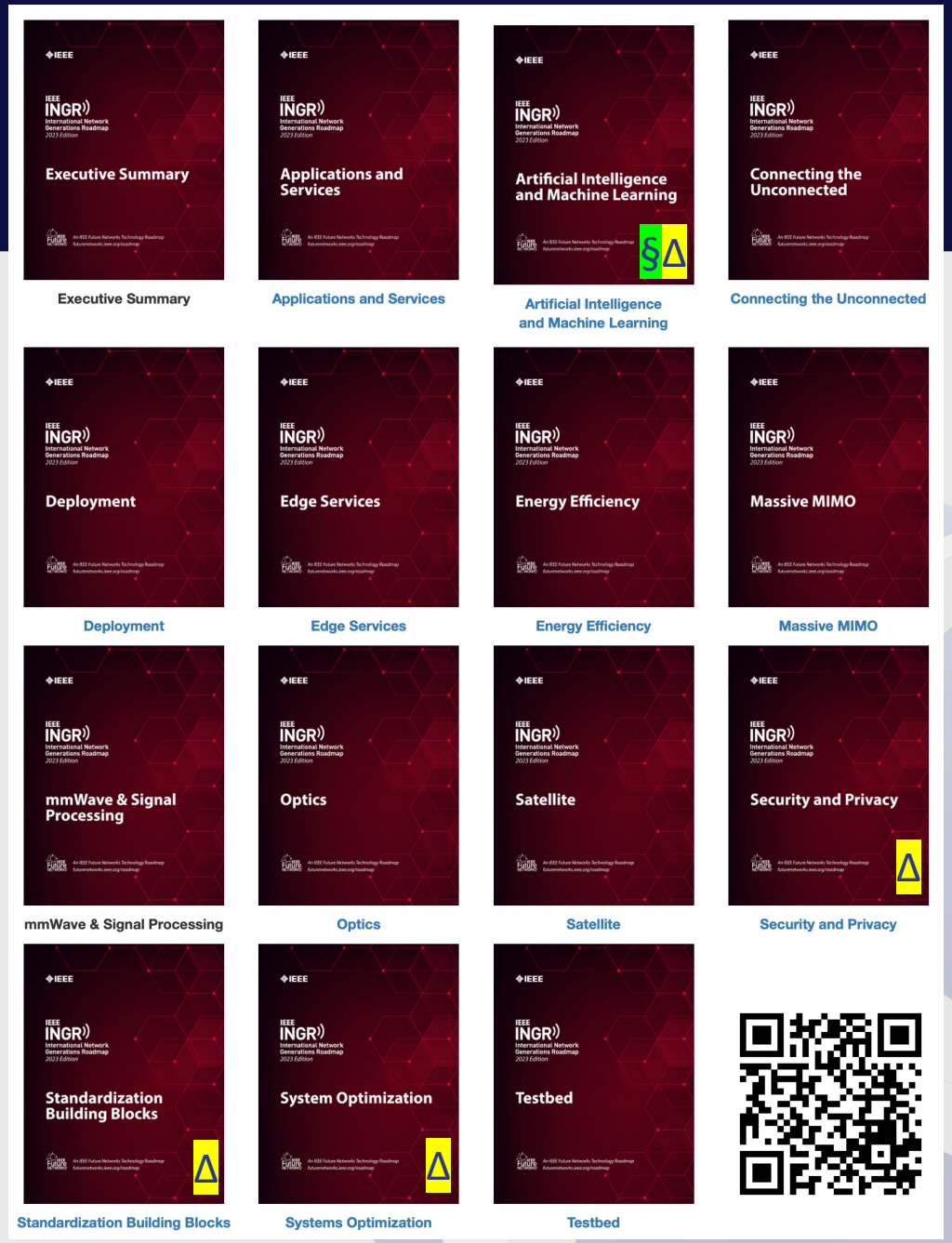

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5G, 6G, and Beyond

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Thank you!

Questions and Answers, Discussion …