Aalto University
School of Electrical
Engineering

ELEC-E7120 Wireless Systems (5 cr)

Unit 1: Course Introduction (Lecture 1)

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Department of Information and Communications Engineering (DICE), Aalto-ELEC

Updated 1.9.2025

Lecture #1 (Agenda)

12:10-12:15 Presentation of teaching team

12:15-12:30 Course Content and Practicalities

12:30-12:50 Mobile (4G/5G) vs. Radio Wireless (Wi-Fi)

12:50-13:20 Group activity (Onsite)

13:20-13:40 Mobile generations (4G/5G KPIs)

13:40-13:45 Post-lecture Quiz #1 (Mycourses)

13:45-14:00 Time for open discussion (Onsite/Zoom)

Feedback during session: Write your questions and/or concerns in the following link: https://presemo.aalto.fi/ws2025

Who, Where, When

- **Instructor:**
  - Dr. Alexis Dowhuszko, Kide Building, room 3552 (alexis.dowhuszko@aalto.fi)
- **Teaching Assistants**
  - Ramya Mummadi, TUAS Building, room 3174 (ramya.mummadi@aalto.fi)
  - Deepak Choudhary (deepak.choudhary@aalto.fi)
  - Xinyu Zhang, TUAS Building, room 3174 (xinyu.1.zhang@aalto.fi)
- **Times of lectures (Onsite)**
  - **Lectures, Mon:** 12:15-14:00. Room: T2 – C105 (CS Building, Konemiehentie 2)
  - **Lectures, Wed:** 10:15-12:00. Room: U8-U270 (Undergrad. Center, Otakaari 1)
  - **Exercise sessions, Fri:** 10:15-12:00. Room: U9-U271 (Undergraduate Center)
  - First lecture today, on Mon. 1st Sept. 2025
- **Homepage:** https://mycourses.aalto.fi/course/view.php?id=47756
- All announcements, slides, handouts (if any), homework, *etc.* posted to MyCourses

Grading, Quizzes, Project, Exam, etc.

- **Grading:**
  - **Mandatory requirements:** a) Pass the **exam** by achieving at least 50% of its total points; b) participate actively in the course **project** and the **workshop presentations**
  - Exam registration is mandatory

(1) Exam: 40%

(2) Homework (Fridays): 20%

(3) Group Project (Workshop): 30%

(4) Pre-Lecture Quizzes: 10%

(5) Post-Lecture Quizzes: 10% (bonus points)

Final Grade

≥ 91%	→ 5
81%-90%	→ 4
71%-80%	→ 3
61%-70%	→ 2
50%-60%	→ 1
<50%	→ 0

- Note that the sum is 110%, from which 10% is given as bonus

(*) Exam is on **Mon. 13th Oct. 2025.** Time: 16:30-19:30 (Room: TBD)

(*) If discrepancies, the valid exam date/time/venue is the one that appears in SISU

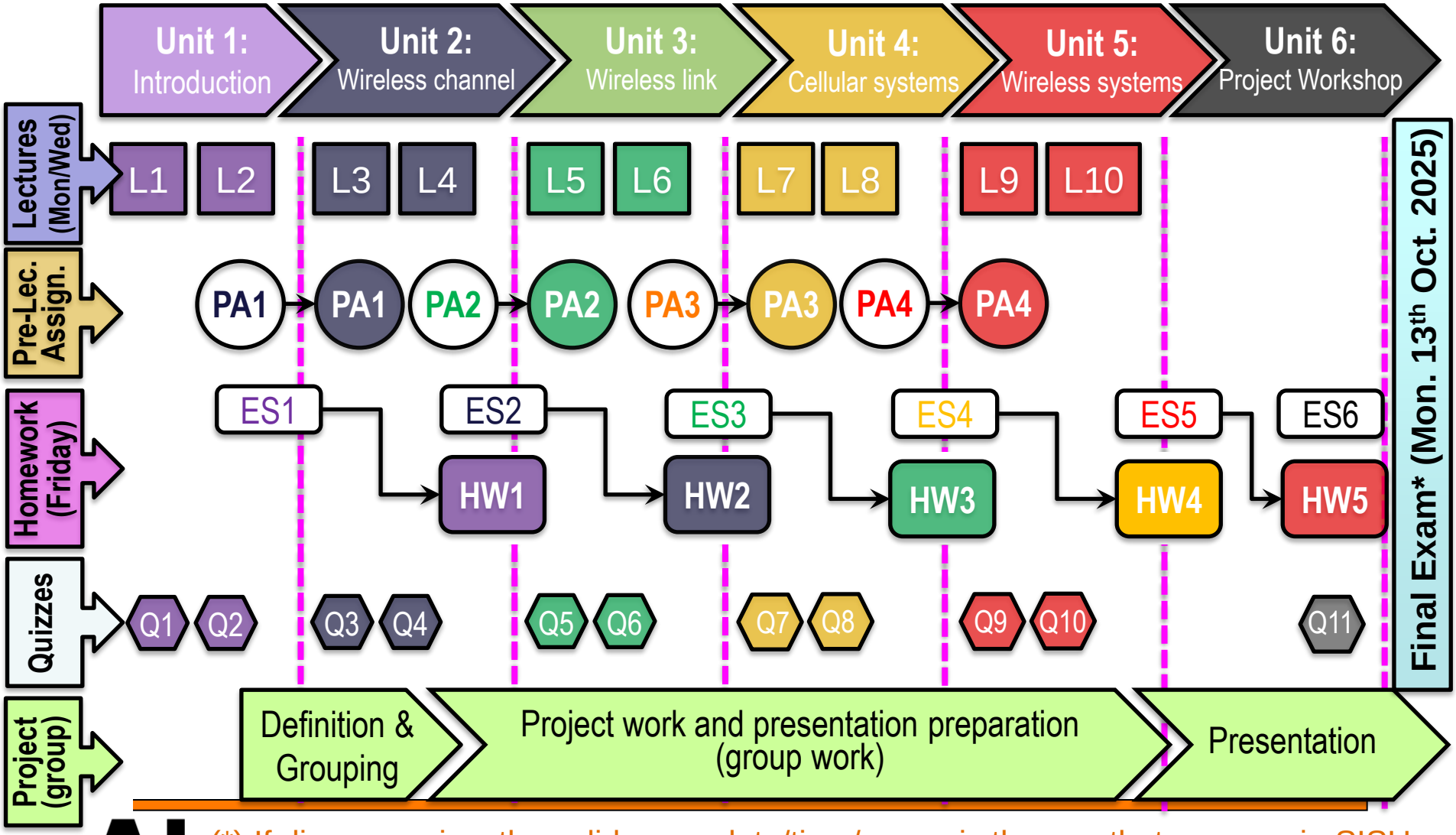
Grading, Quizzes, Project, Exam, etc.

- **Weekly exercise sessions and homework:**
  - **Fridays:** 10:15-12:00 (six sessions)
  - First exercise session on Fri. 5th Sept. 2025
  - 5 weekly exercise sessions (homework) to-be-returned at the beginning of sessions on 12.9., 19.9., 26.9., 3.10., 10.10.
- **Post-lecture quizzes (10 Quizzes):**
  - Duration of about 15 min. Submitted online in *MyCourses*
  - One quiz/lecture (Mon. & Wed.) Deadline: Same day (not negotiable)
- **Pre-lecture activities (4 activities):**
  - Released after Wed. sessions. Pre-lecture Quiz to be submitted in *My Courses* before the following Mon. lecture starts (hard deadline)
- **Group project work:**
  - Mandatory, to-be-done during the lecturing period of the course
  - Precise instructions will be given on Fri. 12th Sept. 2025

Course Syllabus

- **Unit 1: Introduction**
  - General overview of mobile/wireless systems, mobile communications technologies (4G/5G), standardization, licensed vs. unlicensed spectrum
- **Unit 2: Wireless channel characteristics and modeling**
  - RF band for communications (sub-6GHz and mmWave), physical and statistical channel modeling, link budget for different radio systems
- **Unit 3: Overview of wireless link connectivity**
  - Figures of merit in wireless systems, modulation and coding, multiplexing (OFDM), multiple access (OFDMA) and duplexing (FDD/TDD)
- **Unit 4: Cellular systems**
  - Interference in cellular networks, 5G RAN and CN, 4G/5G technology enablers, Low-Power Wide Area Networks (MTC & NB-IoT)
- **Unit 5: Wireless systems**
  - WLAN (Wi-Fi), WPAN (Bluetooth), Satellite communications (LEO/GEO), RFID, Optical Wireless Communications (LiFi & FSO), *etc.*

Course Flow (Teaching & Assessment)



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Learning Outcomes

After the course, the student will be able to:

- **Know** why wireless communication systems are important; General overview of those systems: from very early versions until today.
- **Explain** how to grasp and model the basic physical phenomena that are involved in wireless communication systems.
- **Understand** the function of different blocks in wireless communication systems, as well as its relevant Key Performance Indicators (KPIs).
- **Describe** wide area (long-range) and local area (short-range) radio communication networks, and their main components.
- **Skill** how to do some practical measurements and scientific research on wireless/mobile communication systems (4G/5G and/or Wi-Fi).

Course design: student-centric approach

1. **Goal**: high quality learning (deep-learning)
   - Shared-responsibility.
2. **The role of teacher/instrutor**: facilitate students learning
   - Present the content, provide guidance, feedback, assessment, promote an appropriate context/conditions.
3. **The role of students**:
   - Active participation, enthusiasm, commitment, reflection and critical thinking, build your own-knowledge, independent work.

"I think it's an exaggeration, but that there's a lot of truth in saying that when you go to school, the trauma is that you must stop learning and you must now accept being taught."

— Seymour Papert

Source: *elearningrevolution.bravesites.com*

Teaching and assessment methods

The planned activities for the course include:

1. Lectures (teaching onsite, to be recorded & uploaded in MyCourses)
2. In-class group activities (discussion in small groups)
3. Homework & exercise sessions (independent & onsite group discussion)
4. Course project (teamwork, development of soft-skills)
5. Pre-lecture assignments (readings) and quizzes (independent work)
6. Post-lecture quizzes (continuous assessment, feedback from students)
7. Feedback sessions (teaching assessment, student messengers)
8. Final exam (assessment)

Workload for 5 Credits

- Estimated hours for the course:
  - 12 lectures x 2 h = **24 h**
  - 5(+1) homework sessions x 2 h = **12 h**
  - 5 homework preparations x 5 h = **25 h**
  - 4 pre-lecture activities x 2.5 h = **10 h**
  - Project assignment = **35 h**
  - Preparation for the exam = **25 h**
  - Exam = **3 h**

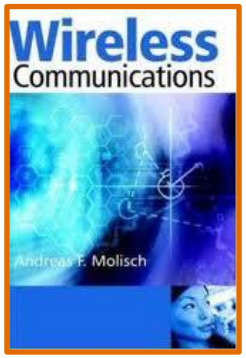
Total hours = 134 hours (4.96 credits)

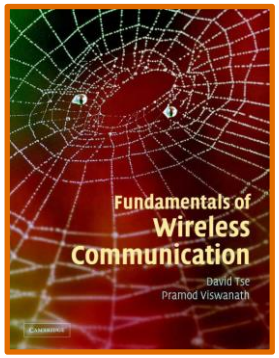
Recommended Reading Material

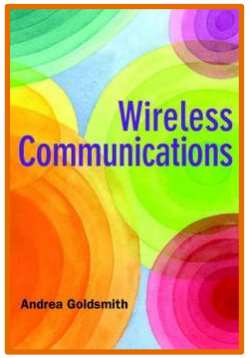
- Course is not based on a single source
- The following books give additional insight into the topics of the course (and represent good sources to consult)

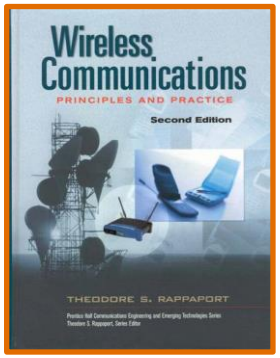
Books dealing with fundamentals of Wireless Communications

1) A. Molisch: *"Wireless Communications"*, Wiley 2005
2) David Tse and Pramod Viswanath: *"Fundamentals of Wireless Communications"*, Cambridge University Press, 2005
3) Andrea Goldsmith, *"Wireless Communications"*, Cambidge University Press, 2005
4) Theodore S. Rappaport, *"Wireless Communications – Principles and Practice"*, Prentice Hall, 2002





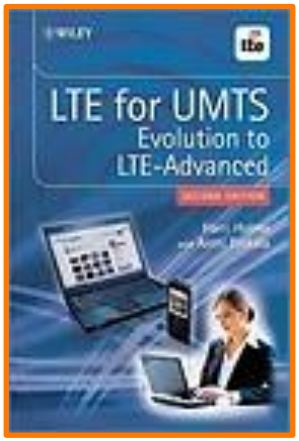


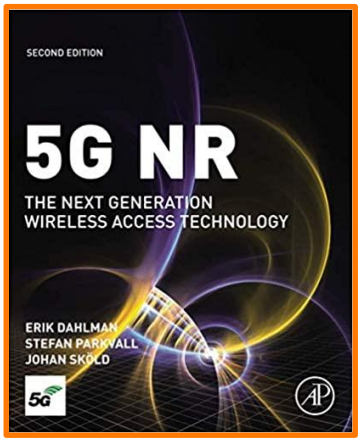


Recommended Reading Material (Cont'd)

Books dealing with 3GPP mobile communication standards (4G/5G)

5) H. Holma and A. Toskala: *"LTE for UMTS – Evolution to LTE-Advanced"*, Wiley, 2009
6) Harri Holma, Antti Toskala, Takehiro Nakmura: *"5G Technology: 3GPP New Radio"*, Wiley, 2020
7) Erik Dahlman, Stefan Parkval, Johan Sköld: *"5G NR – The next generation of wireless access technology"*, 2nd Ed., Elseiver, 2021





IEEE Xplore® Digital Library

Guidelines for using AI in this course

You are allowed to use AI as your *"study buddy"*, with limitations

- You are allowed to ask inspiration from AI, but you must state which tool you used, and how and where you have used AI
- You are still not allowed to *copy-paste* any text or material produced by AI: it is not your work, and you must always state everything with your own words
- You are always responsible for your submitted work
  → it should be your work
- Similarity checking tool Turnitin will be used this year in some assignments

We follow academic writing practices and maintain academic integrity: copy-pasting text produced by someone/thing else and presenting it as yours is cheating.

Radio communication systems:

Mobile systems vs. Wireless systems

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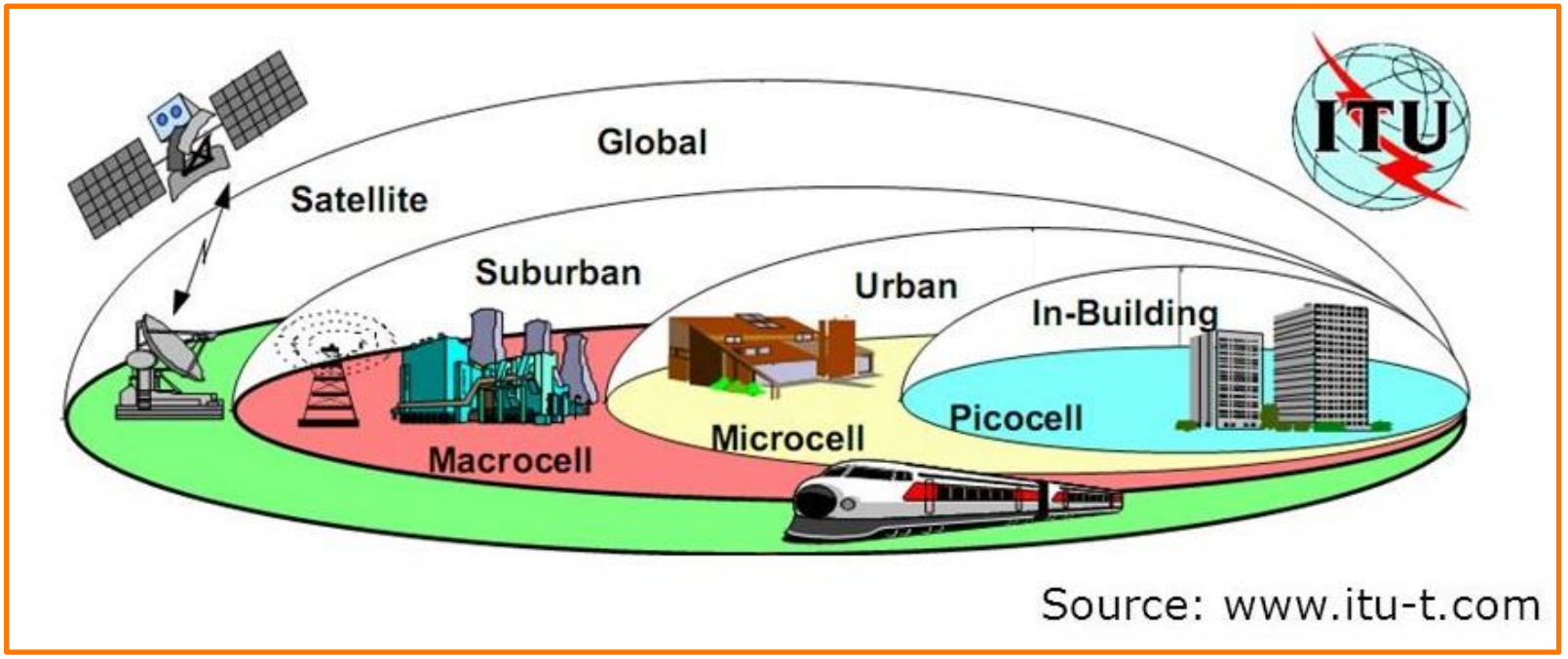
Examples: Mobile communication system (1)

Mobile communication systems

- **2G: GSM/GPRS/EDGE** = Global System for Mobile Communications / General Packet Radio Service / Enhanced Data rates for GSM Evolution
- **3G: W-CDMA/HSPA** = Wideband Code Division Multiple Access / High Speed Packet Access
- **4G: LTE/LTE-A (Pro)** = Long Term Evolution/ LTE Advanced (Pro)
- **5G: NR** = Fifth Generation New Radio
- **(4G): Mobile WiMAX (IEEE802.16e)** = Worldwide interoperability for Microwave Access
- **(5G): DECT NR+** = Digital Enhanced Cordless Telecommunications New Radio Plus

The underlined systems are the most popular ones found by mobile operators around the globe in these days

Examples: Mobile communication system (2)

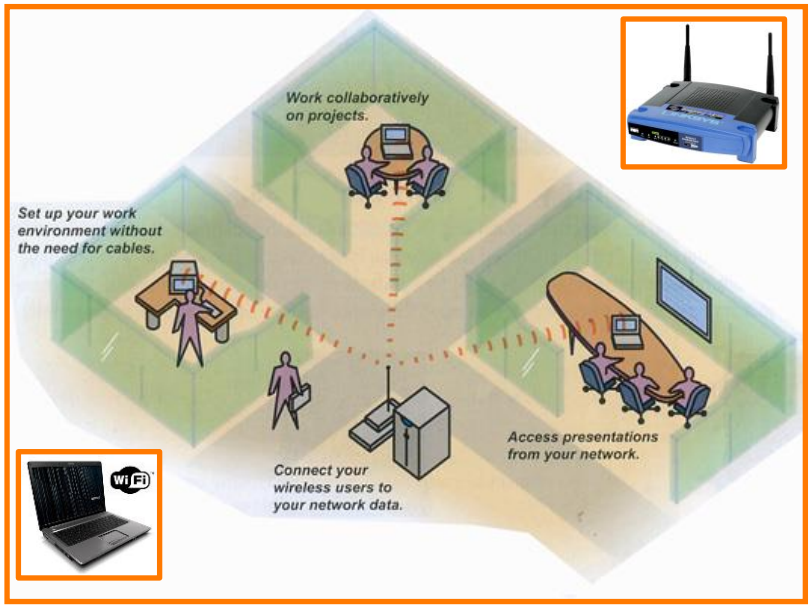


Mobile (cellular) networks are composed by cells of different sizes to provide seamless wireless connectivity from a wide area perspective

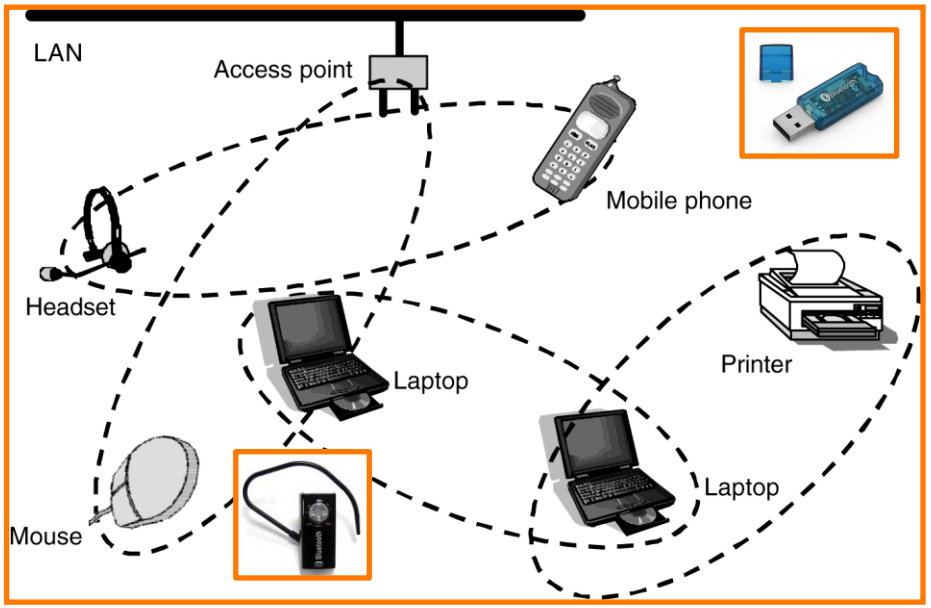
Examples: Local / Personal / Metropolitan area communication systems

- **Wireless Local Area Networks (WLAN)**
  - IEEE 802.11 standards family
  - Examples: 802.11g, 802.11ac, 802.11n, 802.11ad; 802.11bb
- **Wireless Personal Area Networks (WPAN)**
  - Bluetooth (IEEE 802.15.1 standard); Bluetooth Low Energy (BLE)
  - ZigBee (IEEE 802.15.4 standard)
  - Ultra WideBand (UWB) (IEEE 802.15.3 standard)
- **Wireless Metropolitan Area Networks (WMAN)**
  - IEEE 802.16 Fixed wireless (most popular IEEE 802.16d)
  - WiBro (Wireless Broadband, Korean version of IEEE802.16 standards)
  - IEEE 802.16e (Mobile WiMAX), IEEE 802.16m (WiMAX 2)

Example: WLAN vs. WPAN

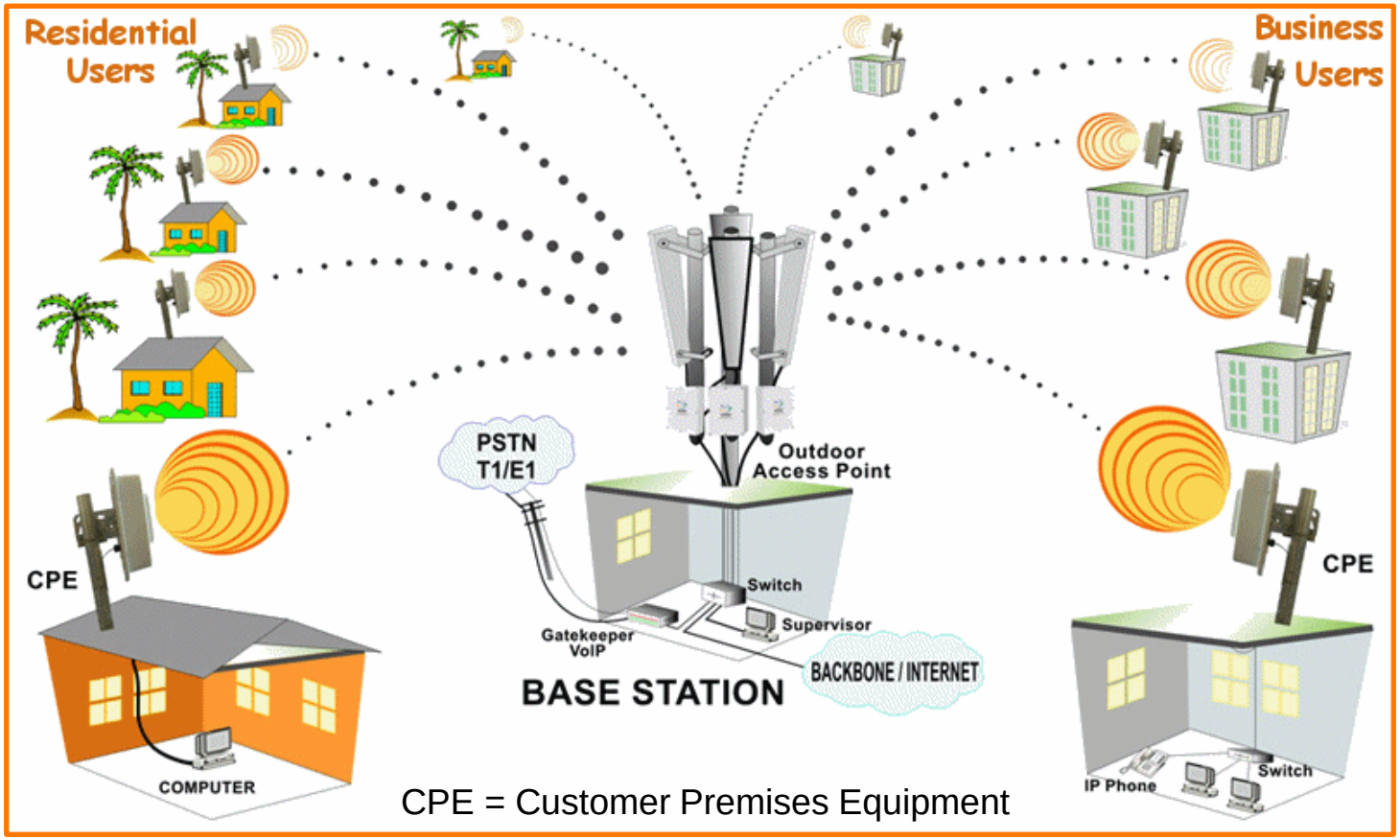


Example of a WLAN as provided by Wi-Fi Standard



Example of a WPAN as provided by the Bluetooth standard

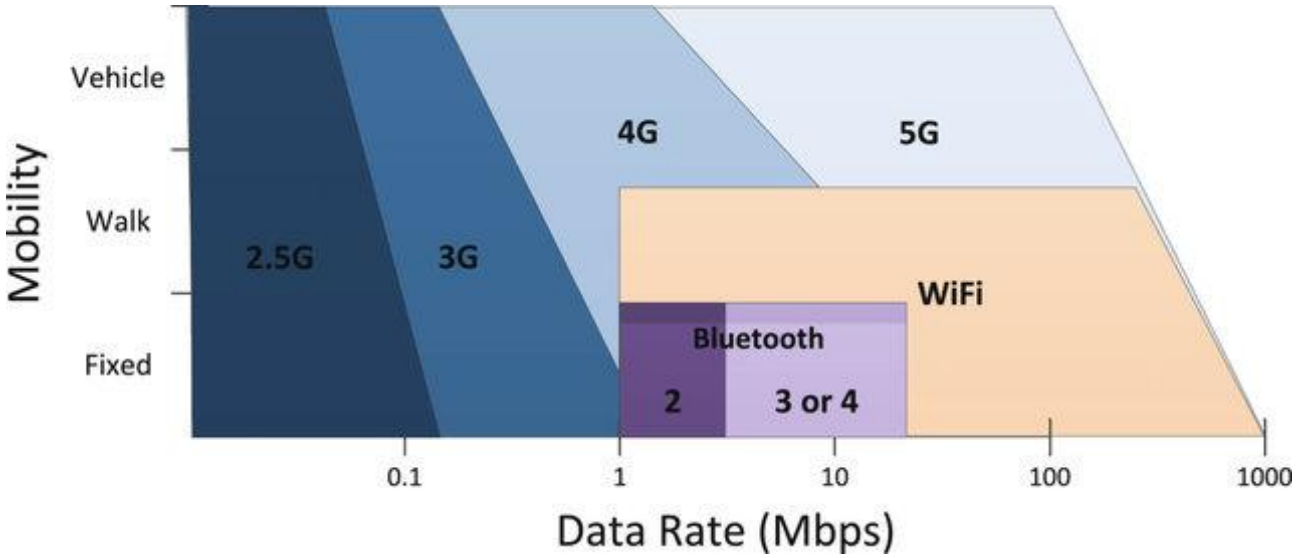
Example: Wireless metropolitan area network

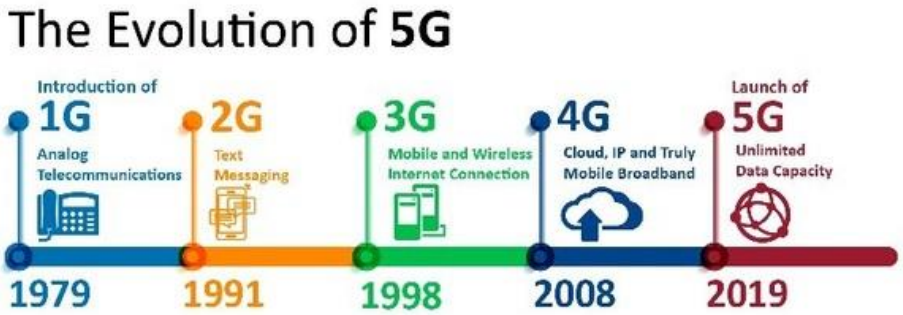


Example of a WMAN to provide broadband internet access in a metropolitan area

Mobile vs. Wireless:
Competitive or complementary?

Mobility vs data rate figure of merits provided by most popular Radio Communications Standards nowadays

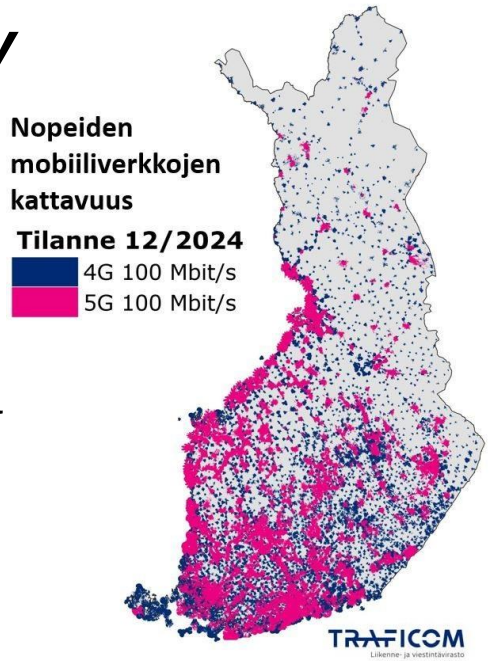




Evolution paths of mobile communication standards (from 1G to 5G). Key performance indicators are aligned with target use case

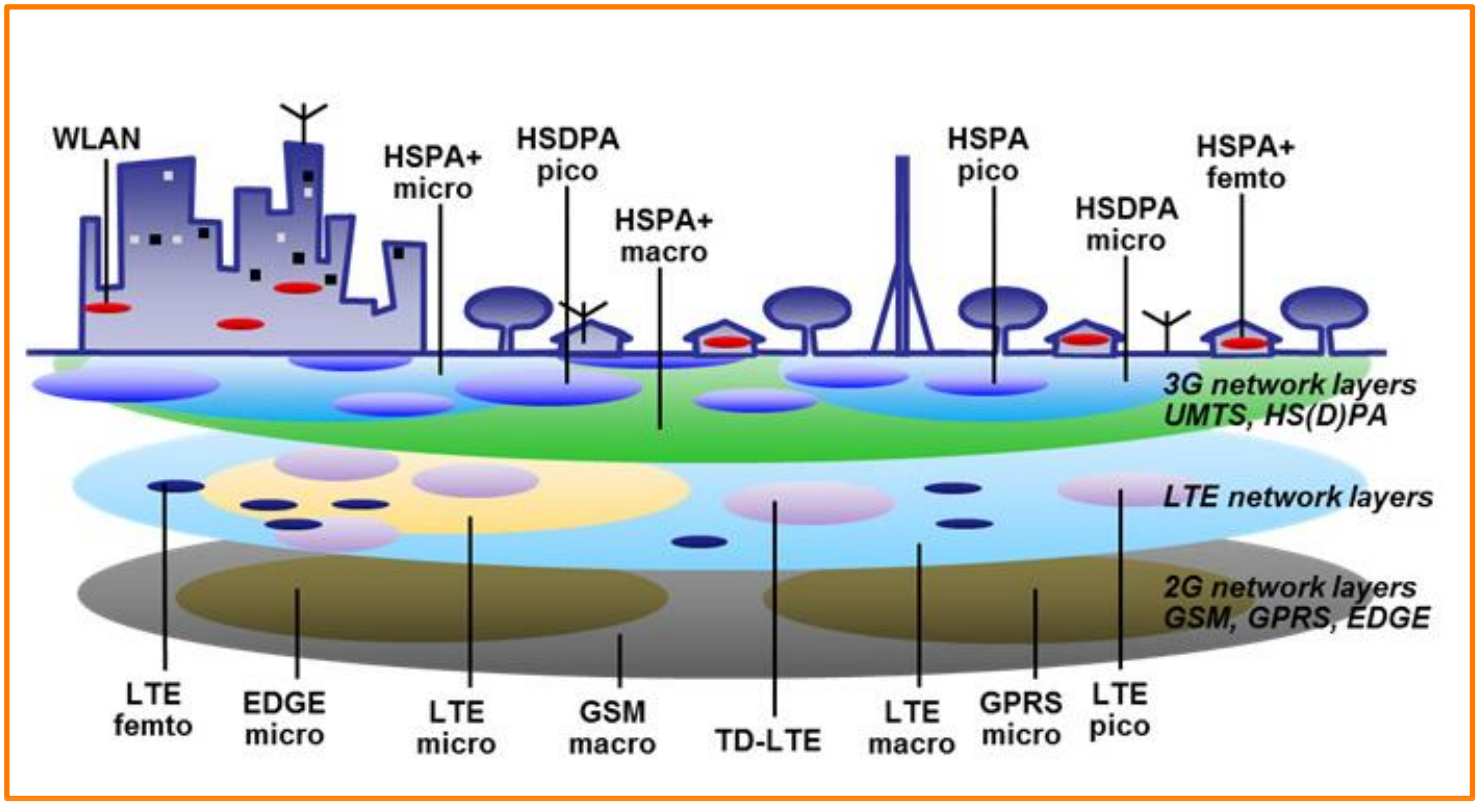
The user's reason behind current mobile communication systems (1)

- ***Global connectivity and seamless mobility***
  - User should be able to connect to the network everywhere (*i.e.*, the user should have service continuity)
  - This aspect is very well handled for speech connection, but may sometimes fail in case of data services (e.g., when user is moving from a 5G/4G coverage area to another one served by 3G/2G)



- ***Global roaming***
  - User expect to have mobile connectivity (almost) anywhere in world
  - Recent technologies like 5G (or 4G) may provide coverage in major cities, but GSM (2G) could be considered as truly global system
  - Only obstacle is lack of a roaming agreement between operators

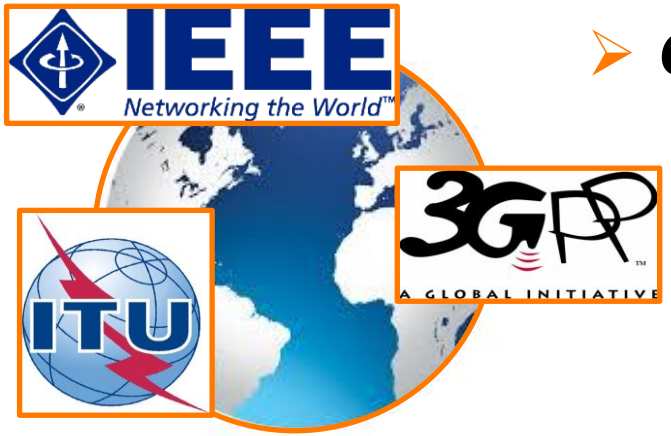
The user's reason behind current mobile communication systems (2)



Example of a heterogeneous mobile network composed by different radio access technologies, where seamless mobility needs to be guaranteed

The user's reason behind current mobile communication systems (3)

- ***Trustworthy authentication and secure connection***
  - WLANs usually provide secure connectivity
  - However, *centralized authentication* is employed in mobile networks
  - Thus, secure connection and authentication service is available basically everywhere, without additional manual actions



- ***Global standards***
  - Open global standards, designed *jointly by industry community,* have led to global markets for both terminals and networks
  - Large production volumes and tight competition have led to low equipment prices

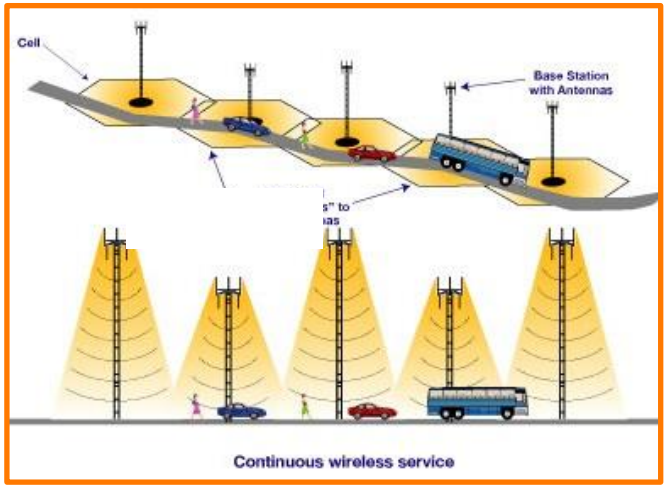
The user's reason behind current mobile communication systems (4)

- To sum up,
  - Wide area connectivity,
  - Mobility,
  - Roaming,
  - Centralized authentication

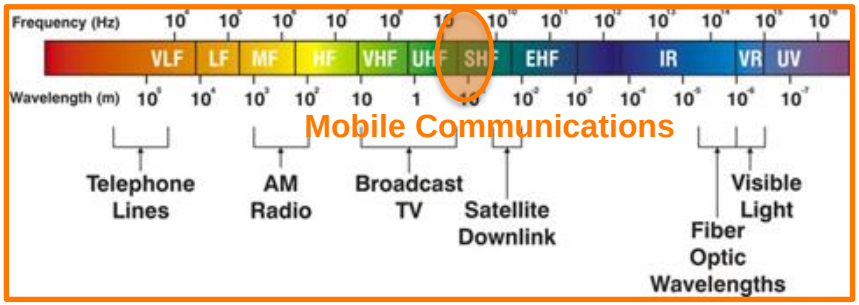
  are the main differences between mobile systems and other radio communication technologies (so-called *Wireless* systems)
- Although WLANs standards are also global in nature, security is usually handled locally by network administrator (using suitable authentication and encryption methods)

Some implications of the user's aspects (1)

- Wide area connectivity means that all areas where users may move needs to be covered by the system
  - Thus, numerous equipment providing connectivity (base stations) are needed



- Wide area connectivity requirement leads to the **cellular structure** of the network, where geographical area is divided into cells served by different base stations
- **Limitation:** Radio spectrum availability is limited

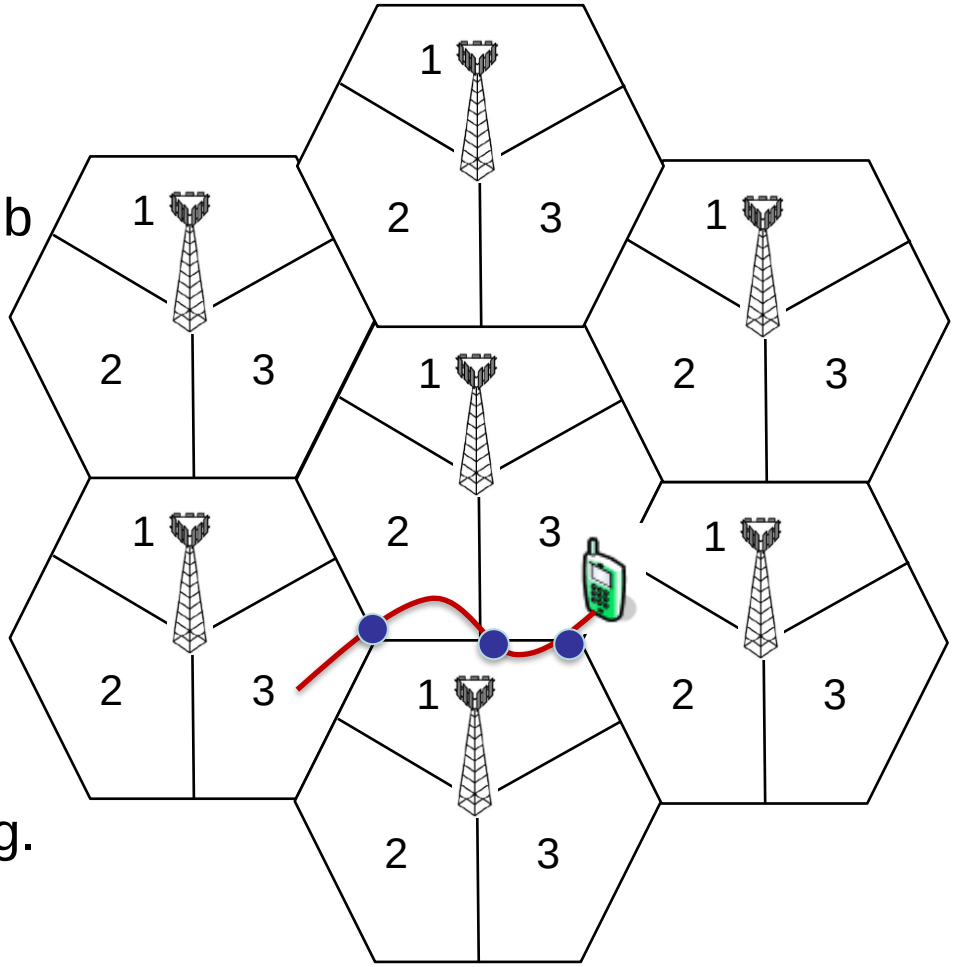


  - All users in the network should share the same set of channels
  - So, radio **resource reuse principle** between cells needs to be applied

Illustration of cellular structure

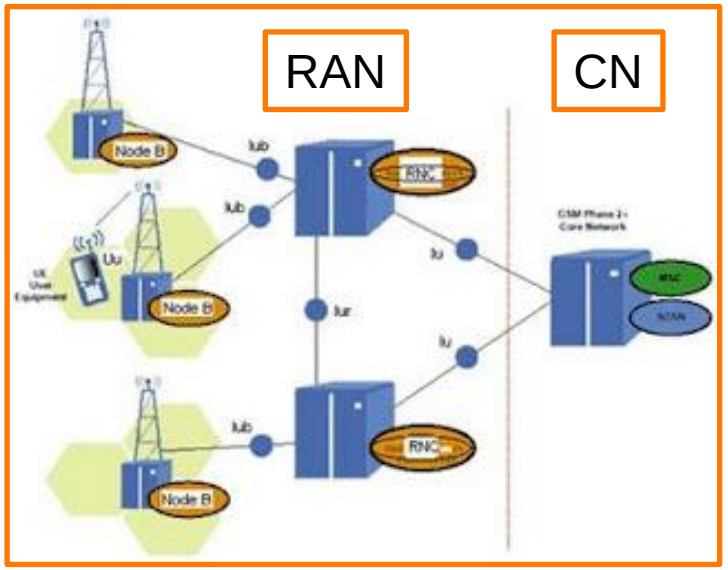
- Wide area coverage
  (connectivity everywhere)
- **Cellular structure** like honeycomb

- **Radio resource reuse**
  - Reuse = 1/3 in the figure
- Cells can be split into sectors
  - Three sectors per site in the fig.
- Wide area mobility (**handover** points marked with blue dots)

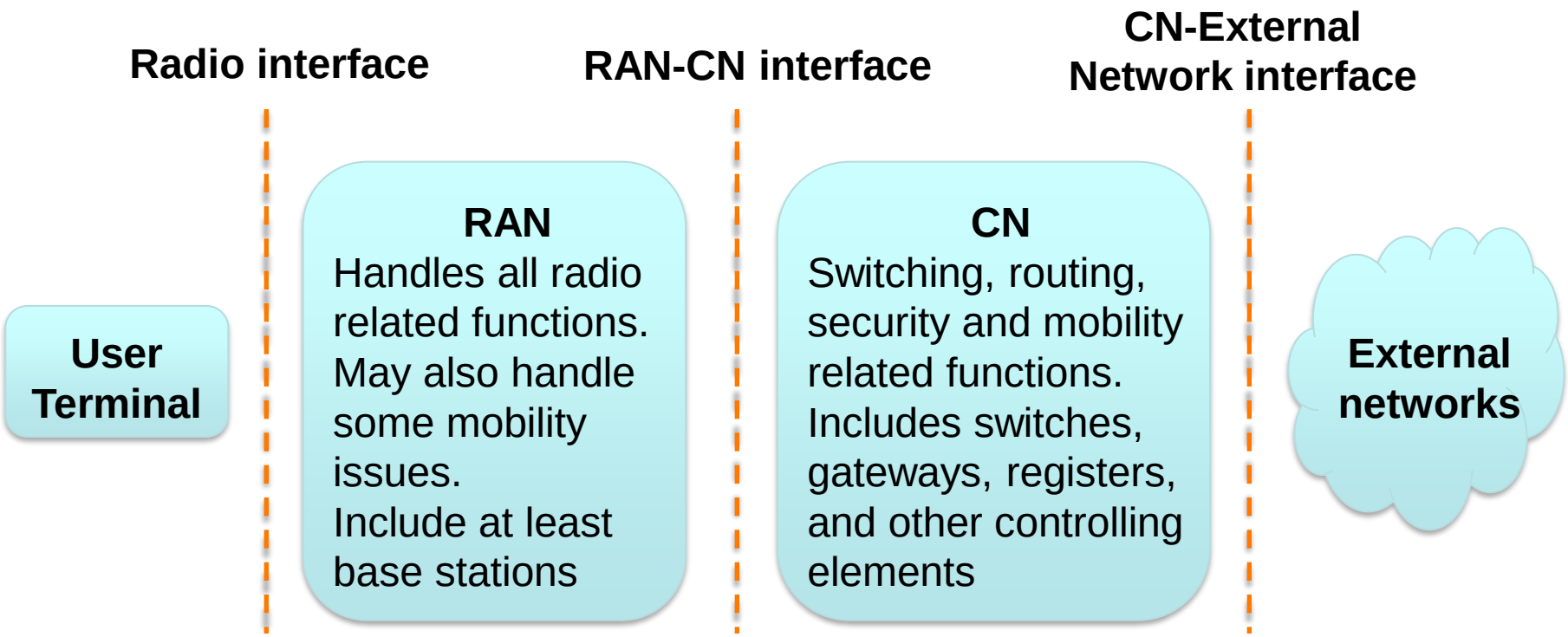


Some implications of the user aspects (2)

- Mobility and global authentication require the presence of centralized network elements, connected to other network elements that provide wireless connectivity (i.e., BSs)
  - Those centralized elements form the **Core Network** (CN), while
  - Elements handling wireless connectivity form the **Radio Access Network** (RAN)
- Global standards ensure compatibility of radio devices produced by different manufacturers
- However, a legal contract called *"roaming agreement"* is needed to ensure reliable authentication & billing



General high level system architecture of mobile networks



RAN = Radio Access Network; CN = Core Network

Group Activity # 1

- Whole classroom is divided into groups (4-5 students)
- Each group will nominate a **representative**, who will coordinate discussion, take notes and represent group in the wrap-up activity

Answer the following questions (10 minutes)

1. What are the main changes that you have noticed in mobile networks in the last 10 years? (4G: 2010; 5G: 2020)
2. Apart from surfing the Internet at a higher speed or watching high-quality videos, do you foresee any use case in 5G that cannot be supported with current 4G networks?

Mobile generations: 4G/5G Key Performance Indicators (KPIs)

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How did it start?

Portable phone → Mobile/Cell phone → Smart phone → Tablets

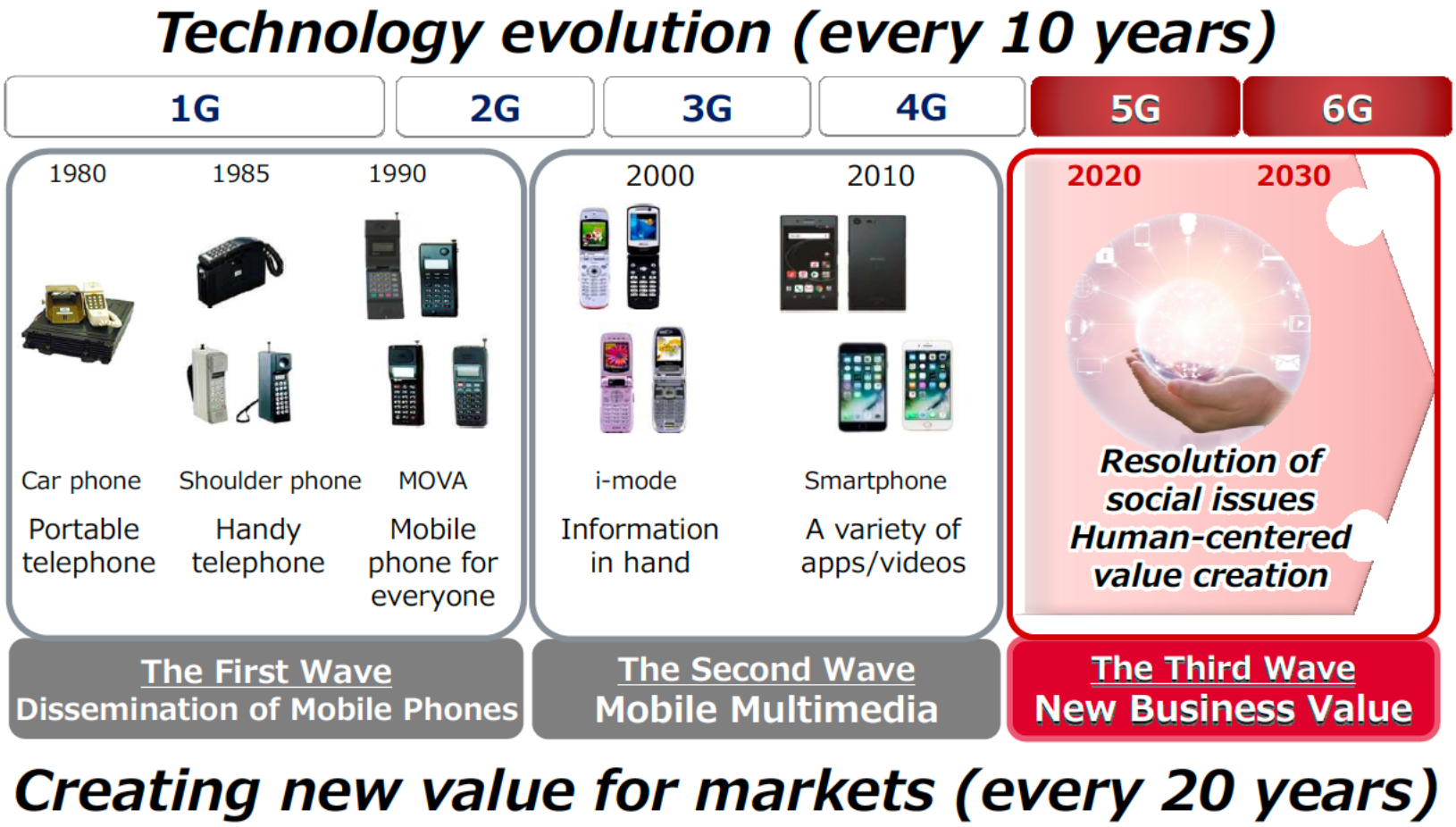
voice → video

text, email, browsing

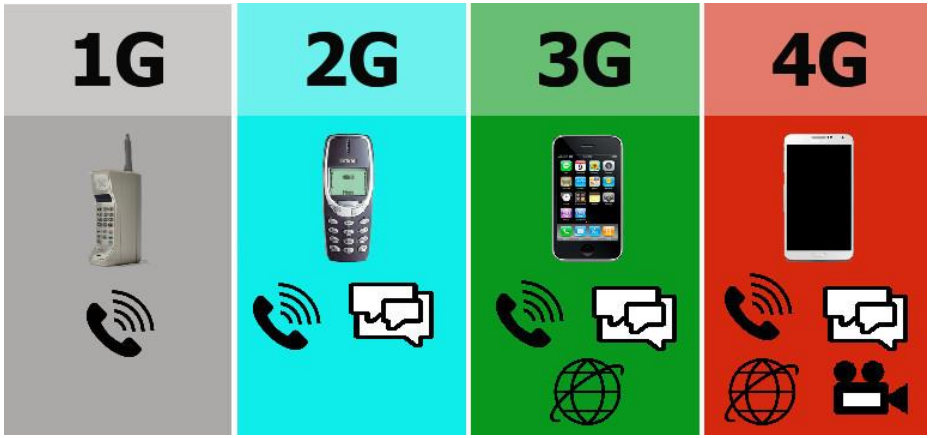
Increasing Demand for Wireless Connectivity

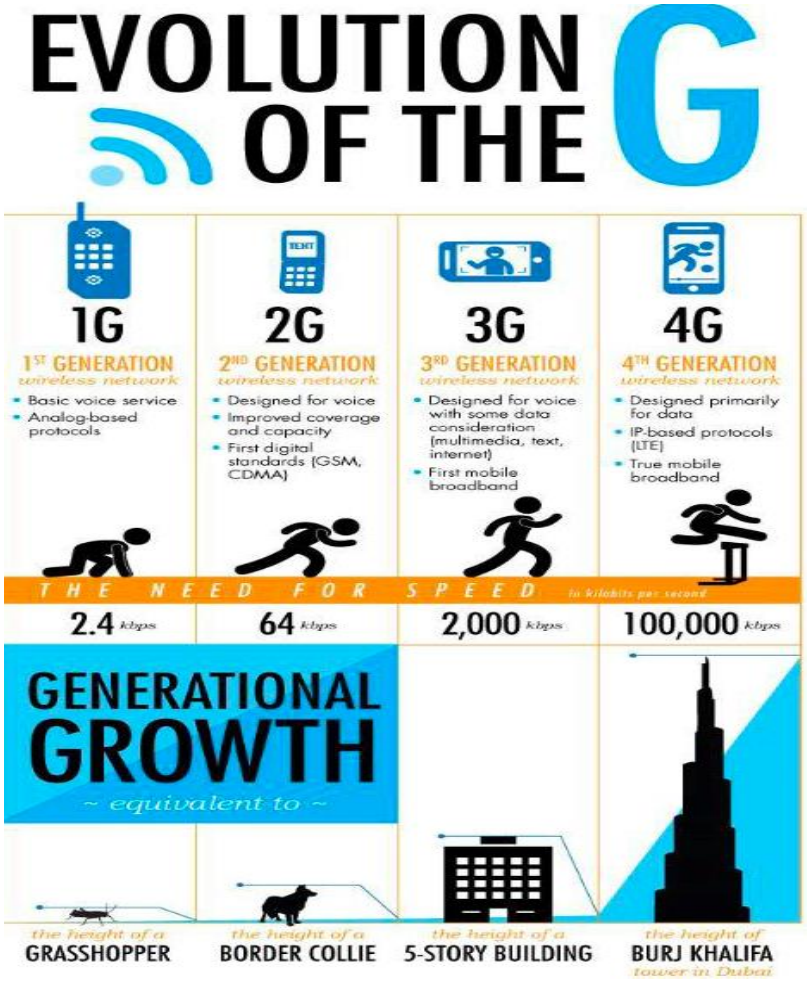
Connecting People

Mobile generations and value markets

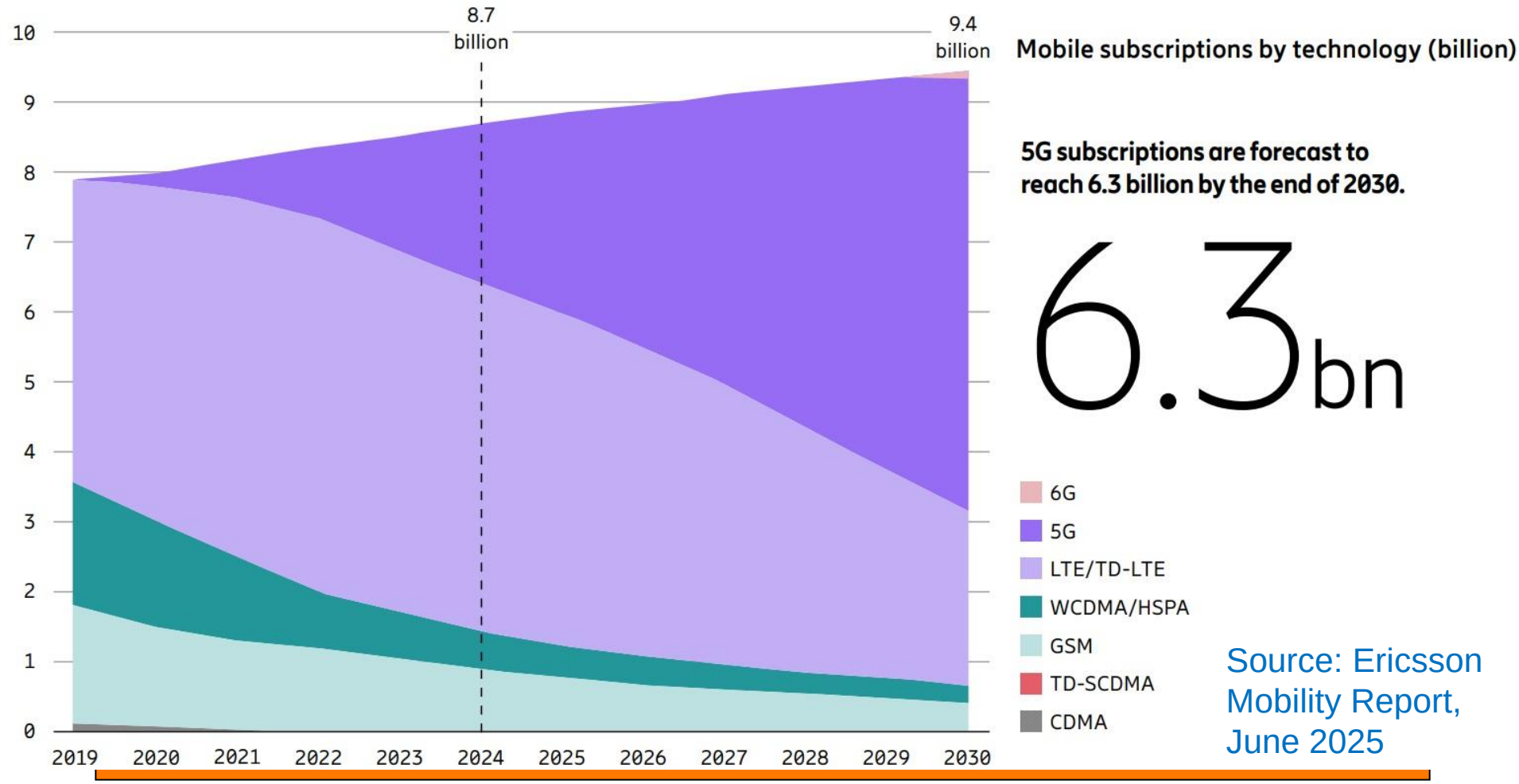


Technology drivers from 1G to 4G



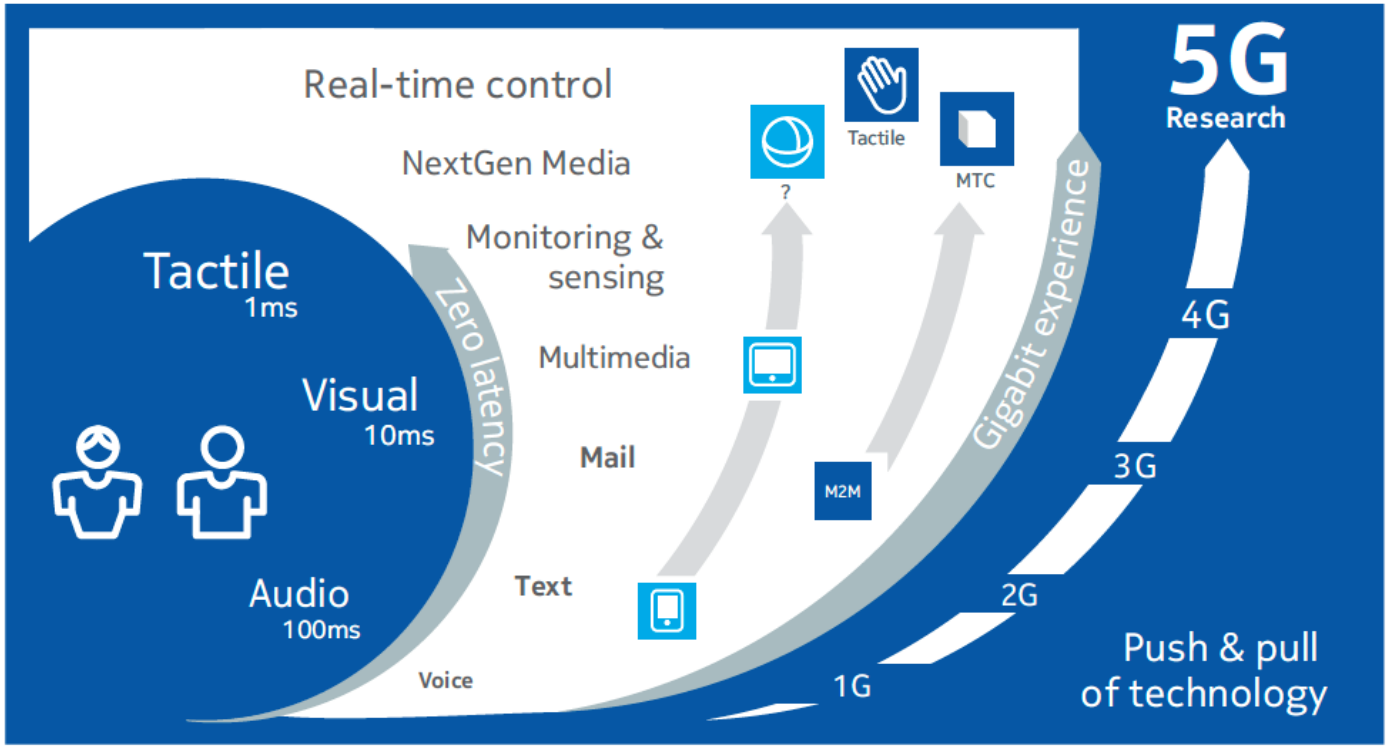


Which is the most popular mobile technology?



Source: Ericsson Mobility Report, June 2025

What has been promised for the 5G-era?

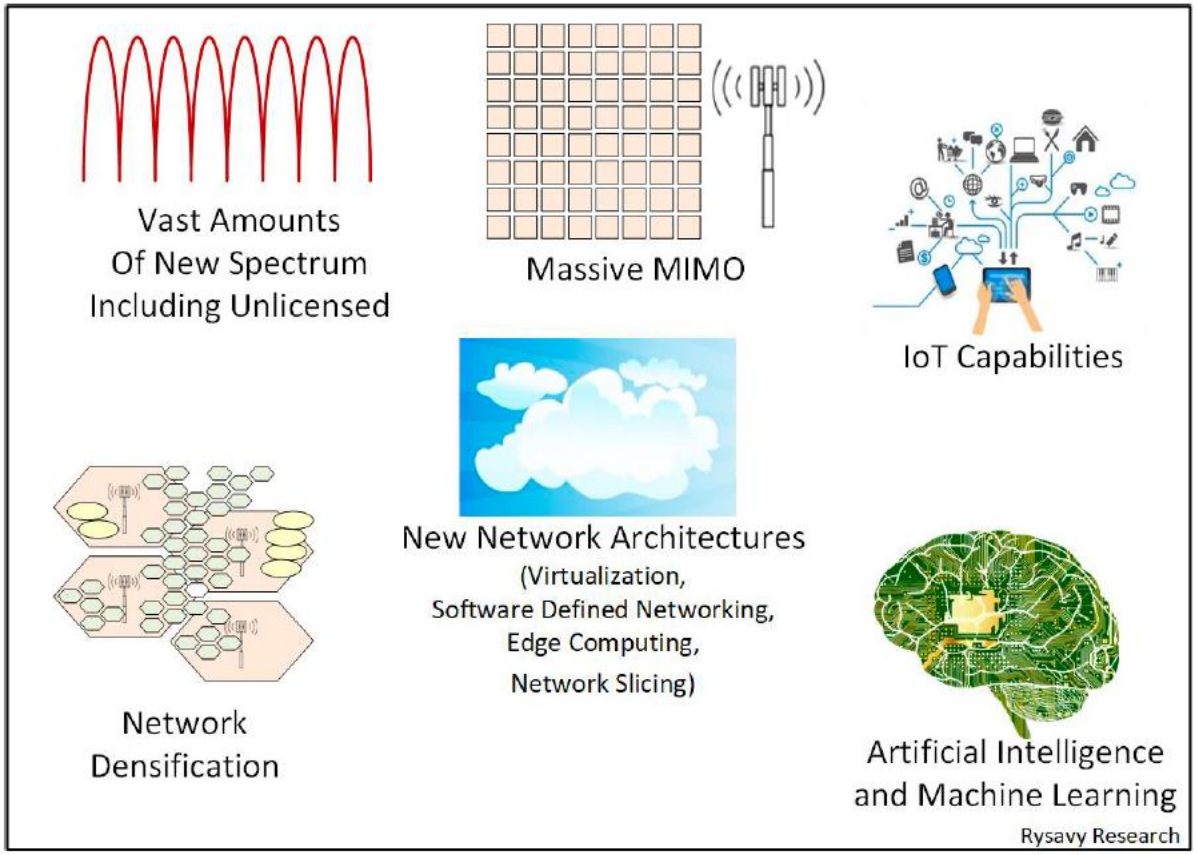


What is 5G?

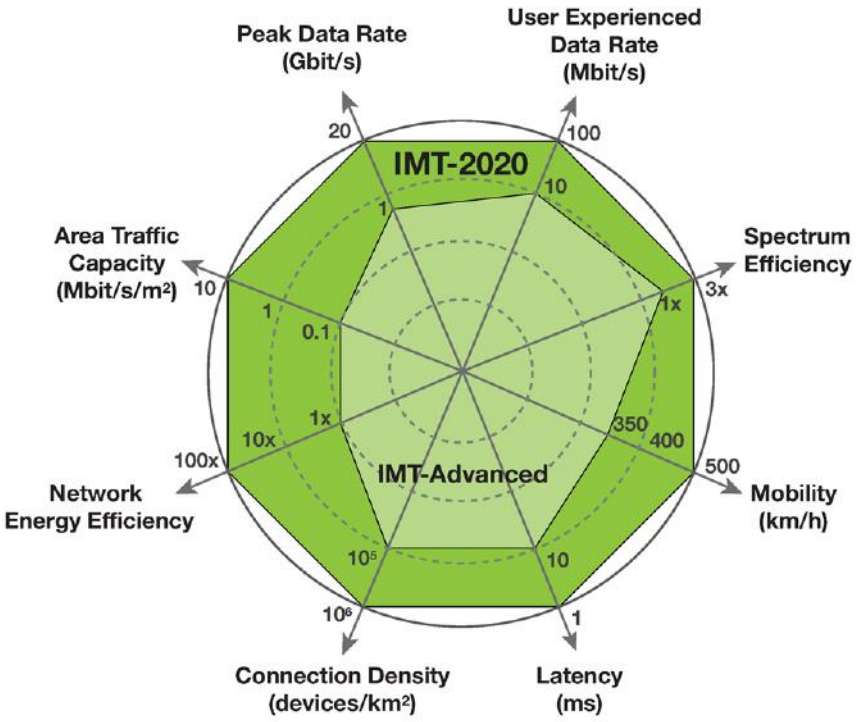
5G is not <u>only</u> about only smart phones

5G is about novel use cases

What are the 5G technology enablers?



5G (IMT-2020) vs. 4G (IMT-Advanced)



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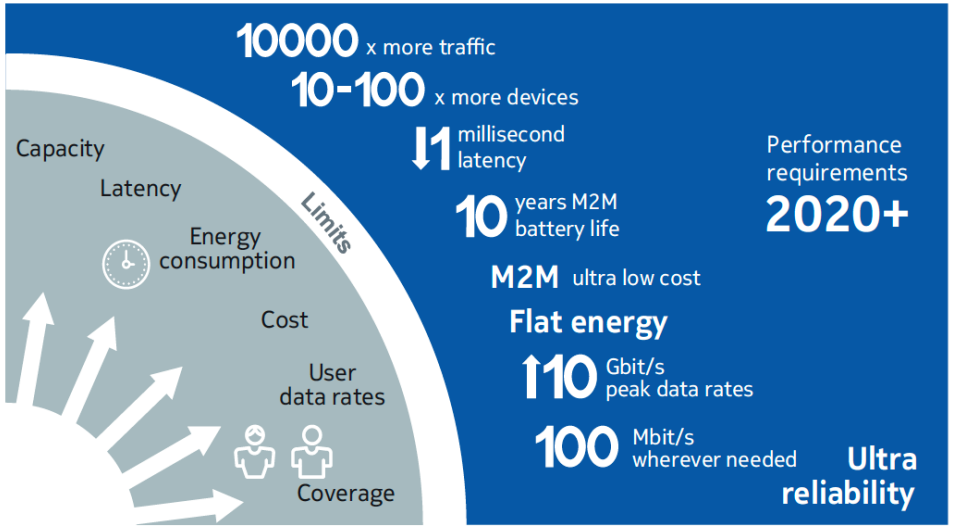
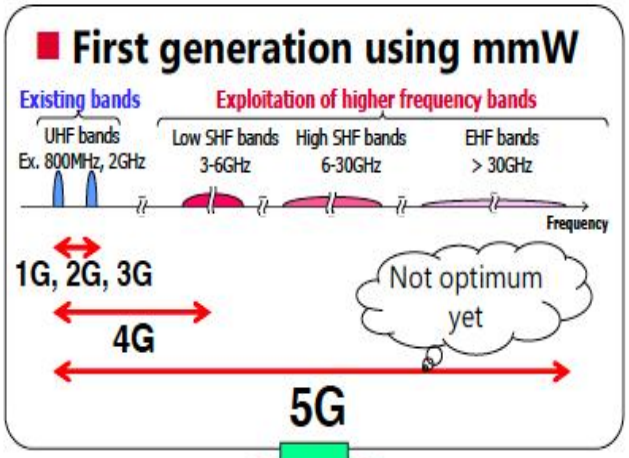
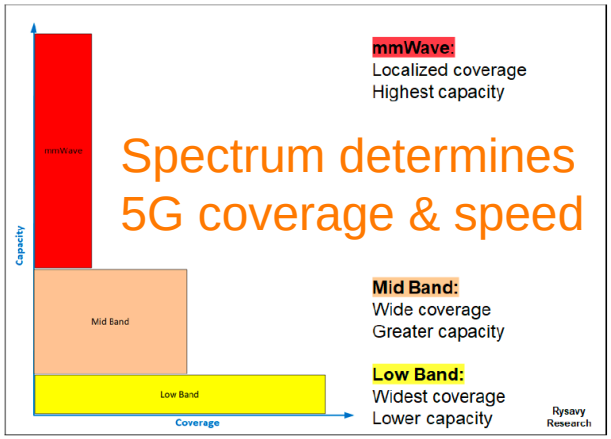
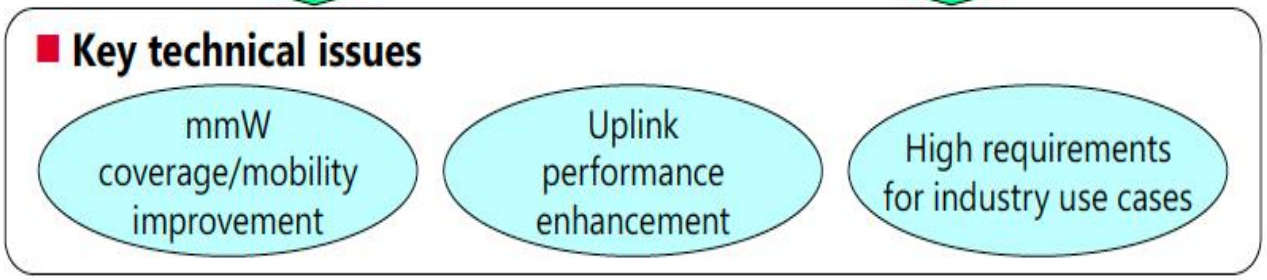


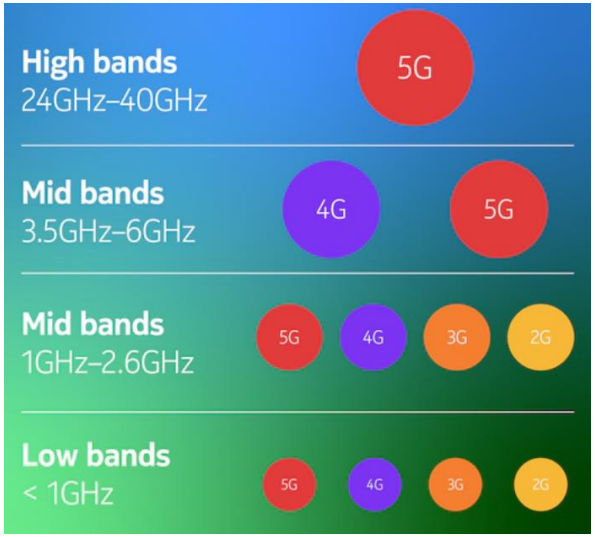
- 5G **Key Performance Indicators (KPIs)** are grouped into three major categories:
  - **eMBB** (Enhanced Mobile Broadband)
  - **URLLC** (Ultra-Reliable Low Latency Communications)
  - **mMTC** (massive Machine Type Communications)..

5G (IMT-2020) vs. 4G (IMT-Advanced)









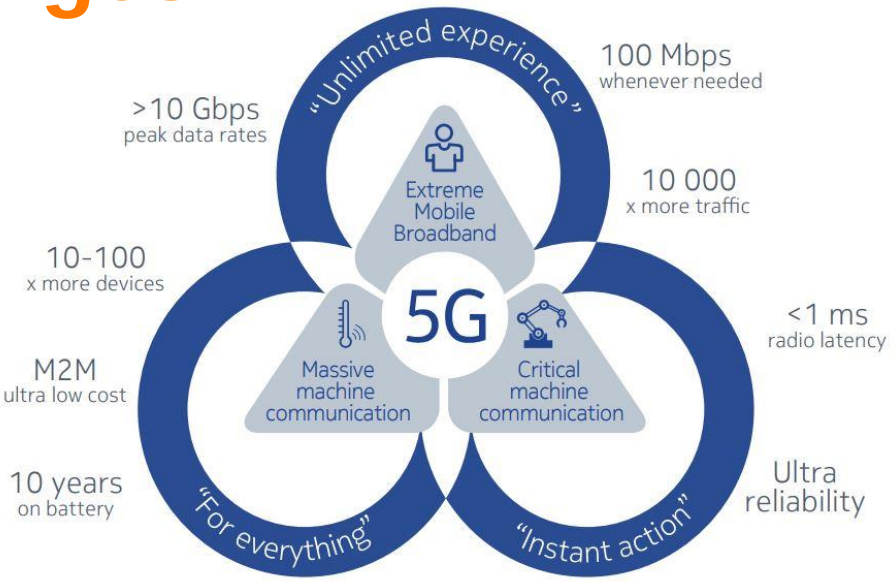
- The 5G technology use cases include broadband access in dense areas, high user mobility, massive IoT, tactile internet, natural disaster, e-health services, broadcast services, *etc.*

What are the challenges?

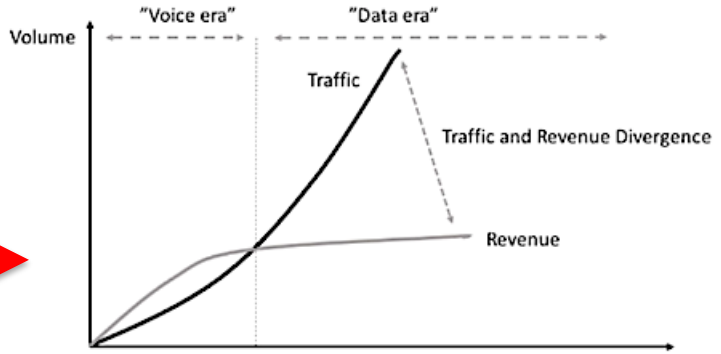
Example for 5G requirements:

Some of the challenges:

- Increasing throughput (or payload data transmitted without errors)
- Spectrum scarcity
- Energy efficiency
- Reliability and coverage
- Heterogeneity of wireless systems
- Seamless handover (or handoff)
- Devices' performance, cost, power, integration, complexity, etc. issues
- Security and privacy
- Data traffic grows much faster than the revenues from mobile subscriptions, creating a "revenue gap". Economic (or business) sustainability of next G



https://gsacom.com/paper/5g-mission-critical-communication-nokia-white-paper/

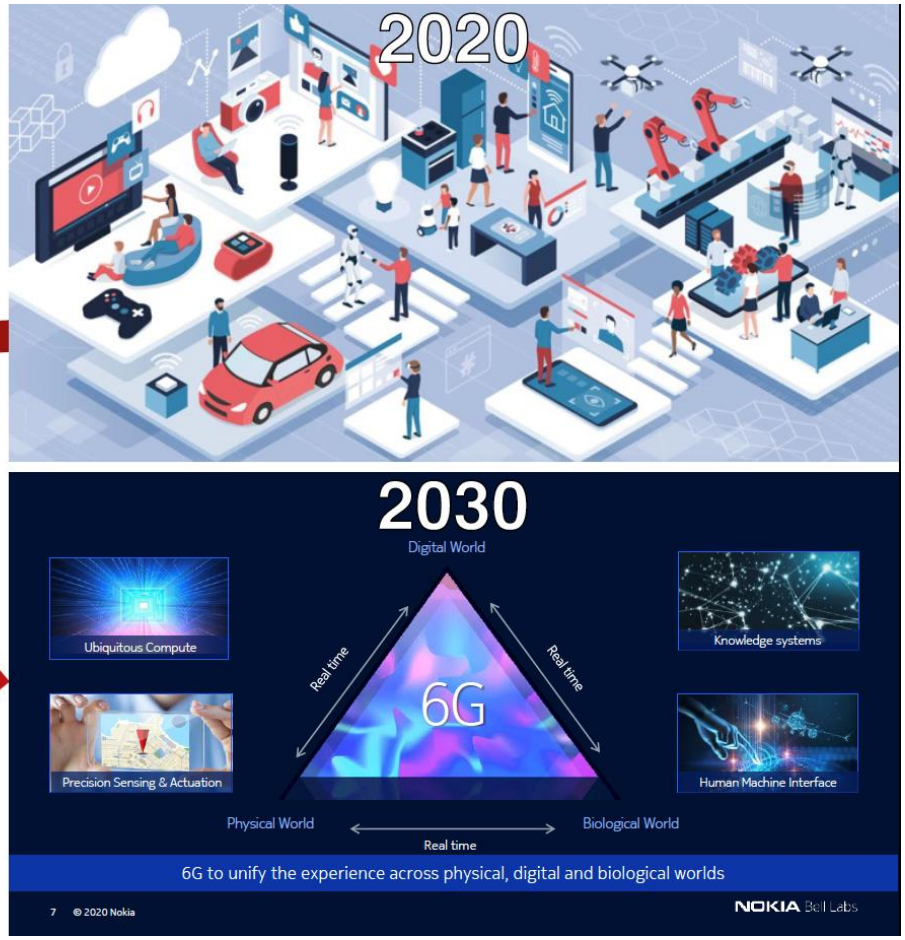


Source: https://www.electronic.nu/2015/12/01/the-networked-society-a-vision-that-requires-strategic-choices/

How will be the near future? (current vision for 2030)

Increasing Demand for Wireless Connectivity

Connecting + Sensing Everything



How will be the near future? (current vision for 2030)

6G (IMT-2030) vs. 5G (IMT-2020)

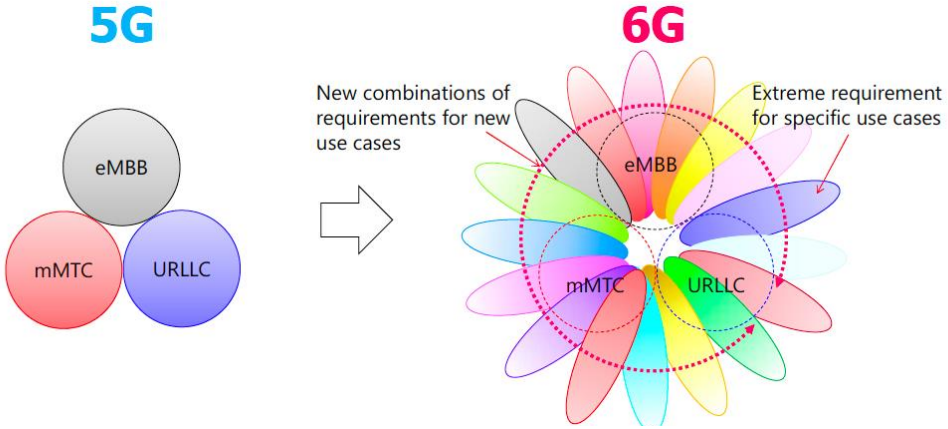


Figure 3-3. Extreme coverage extension

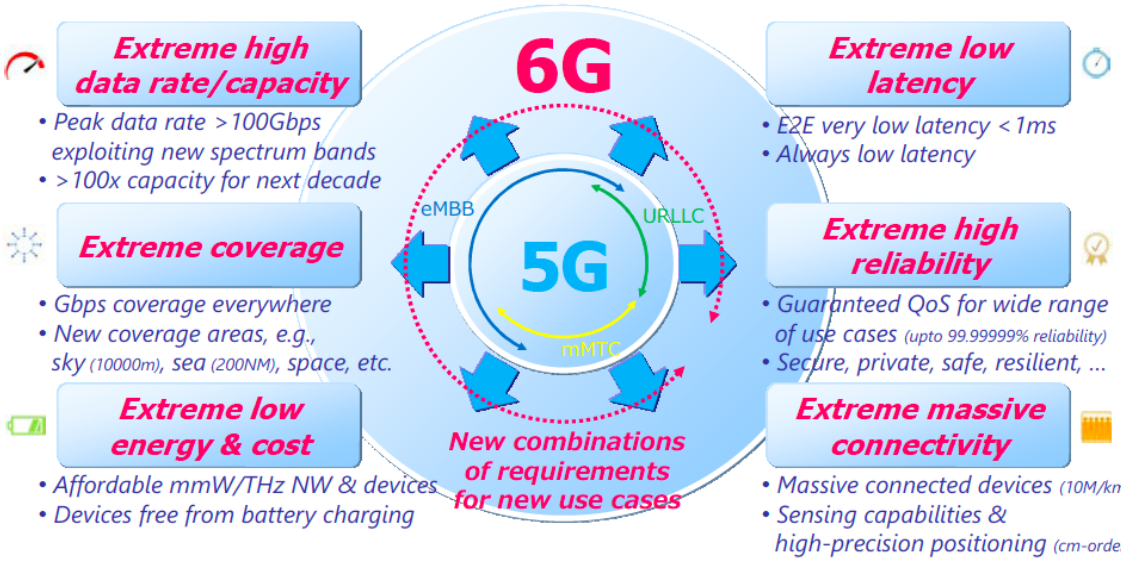
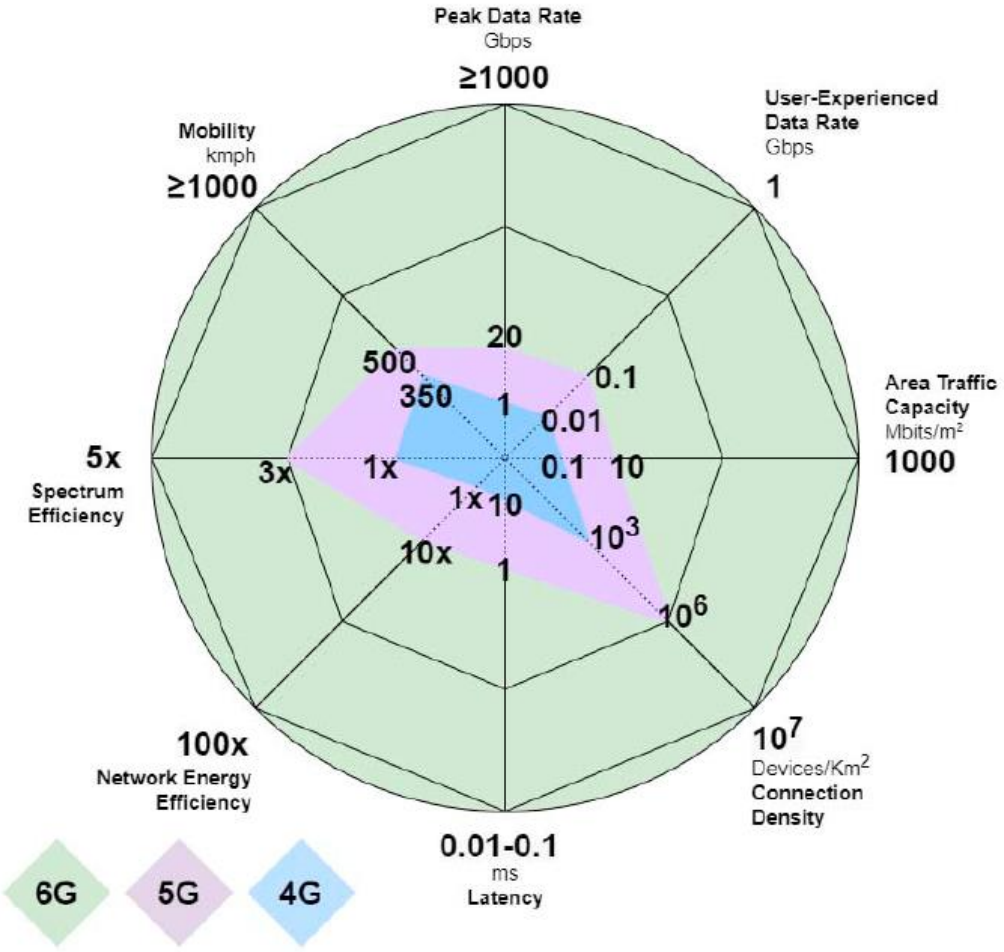
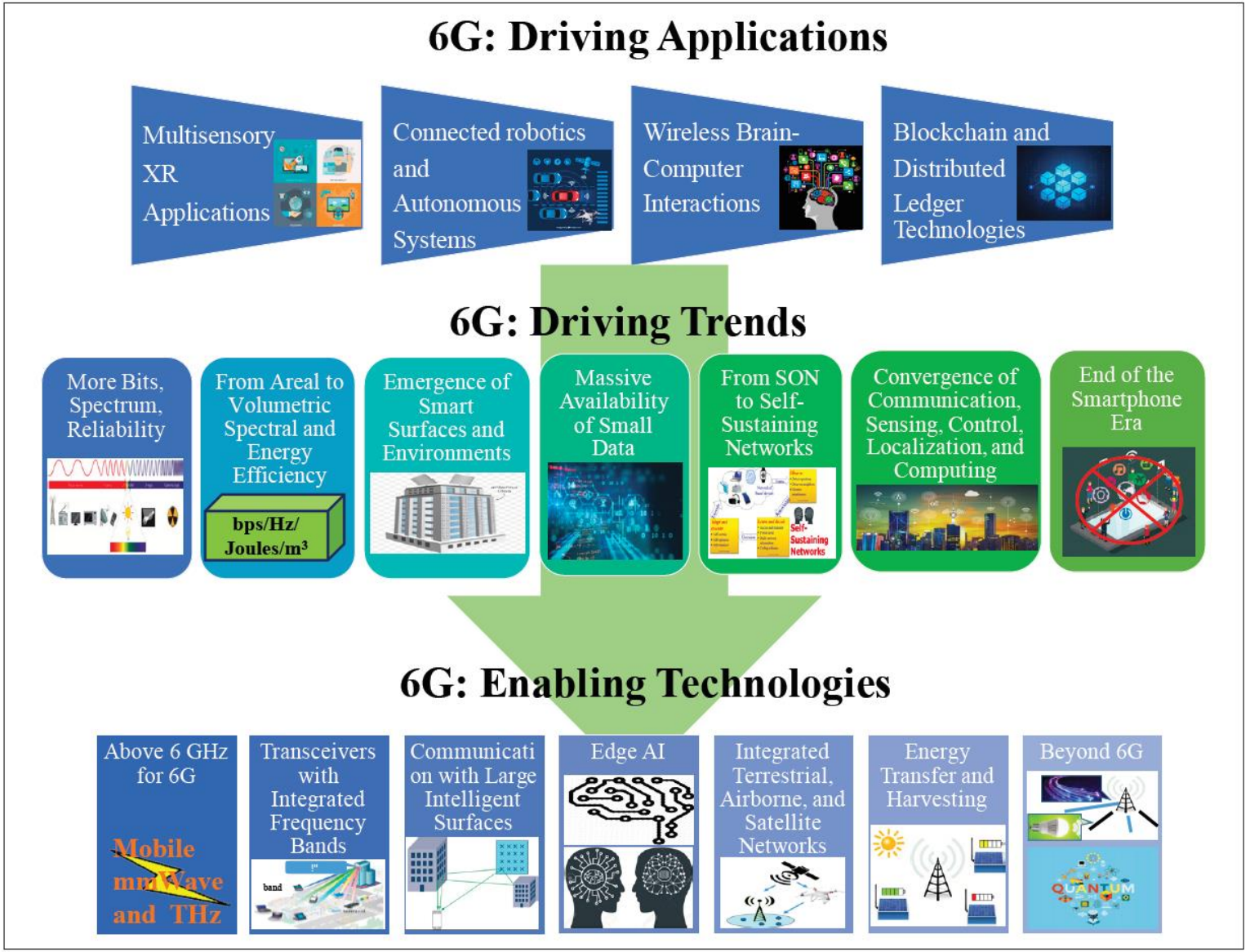


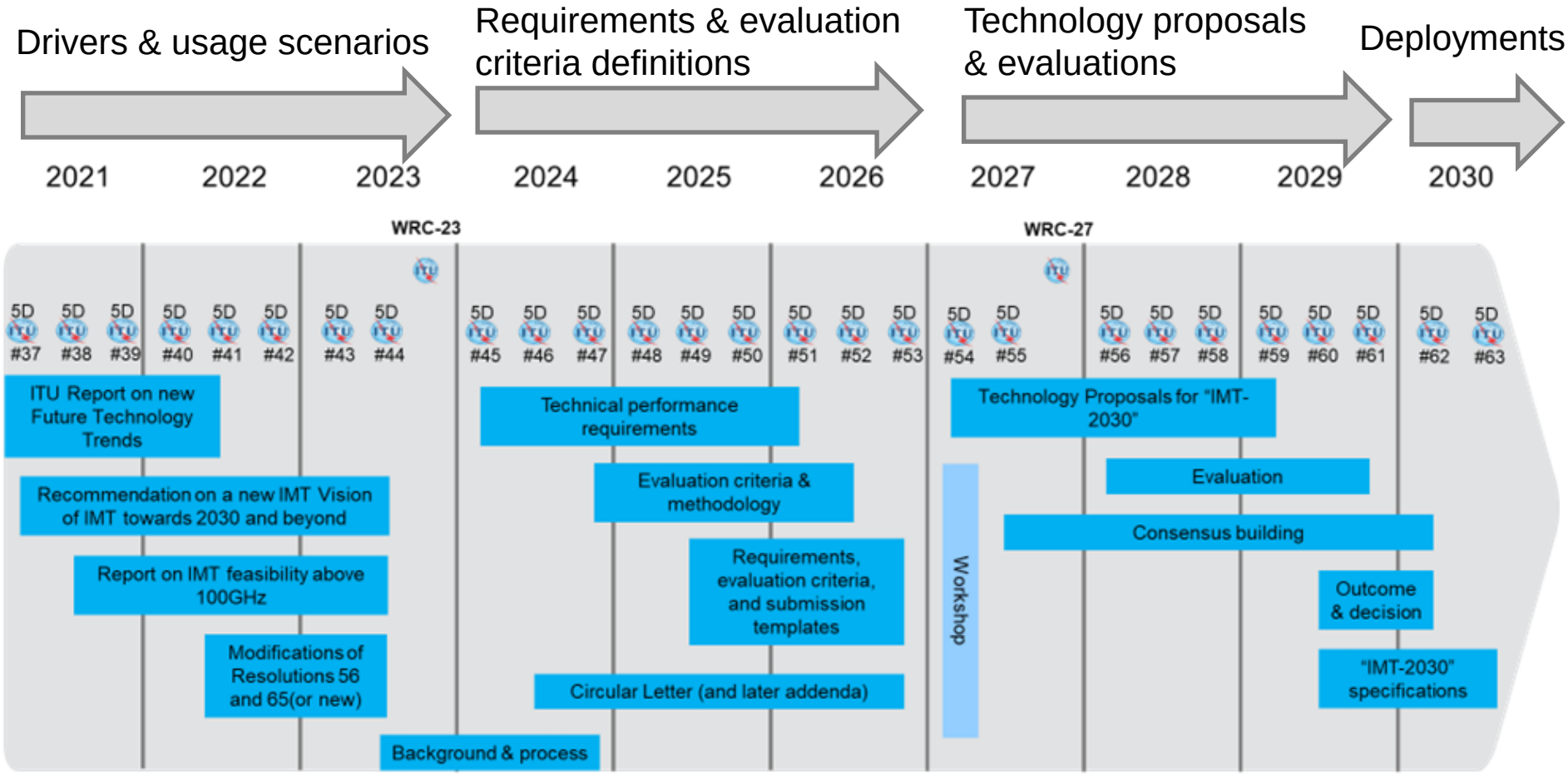
Figure 3-7. Extreme-massive connectivity & sensing

6G (IMT-2030) vs. 5G (IMT-2020)




6G: Driving Applications
Multisensory XR Applications
Connected robotics and Autonomous Systems
Wireless Brain-Computer Interactions
Blockchain and Distributed Ledger Technologies
6G: Driving Trends
More Bits, Spectrum, Reliability
From Areal to Volumetric Spectral and Energy Efficiency
bps/Hz/ Joules/m3
Emergence of Smart Surfaces and Environments
Massive Availability of Small Data
From SON to Self-Sustaining Networks
Self-Sustaining Networks
Convergence of Communication, Sensing, Control, Localization, and Computing
End of the Smartphone Era
6G: Enabling Technologies
Above 6 GHz for 6G
Mobile mmWave and THz
Transceivers with Integrated Frequency Bands
band
Communicati on with Large Intelligent Surfaces
Edge AI
Integrated Terrestrial, Airborne, and Satellite Networks
Energy Transfer and Harvesting
Beyond 6G
QUANTUM

6G (IMT-2030) vs. 5G (IMT-2020)



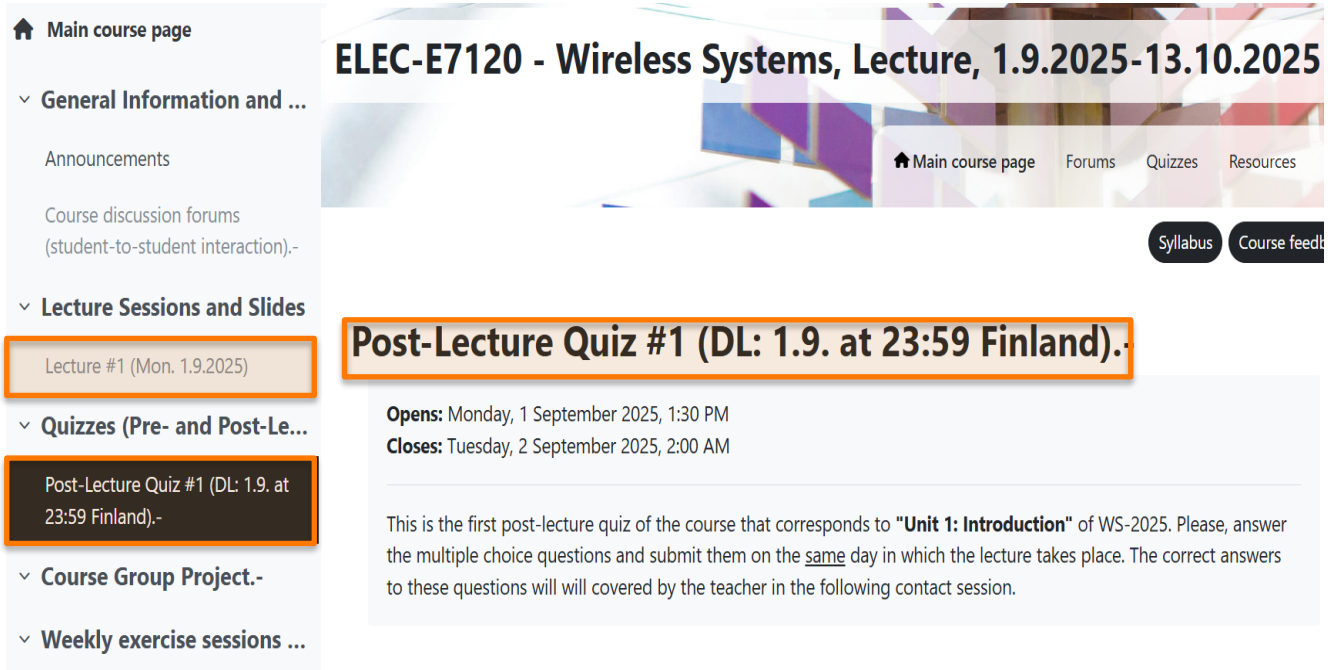
Note 1: Meeting 5D#59 will additionally organize a workshop involving the Proponents and registered IEGs to support the evaluation process
Note 2: While not expected to change, details may be adjusted if warranted. Content of deliverables to be defined by responsible WP 5D groups

Source: Doc. 5D/1361 Chapter 2 - ITU-R Working Party 5D structure and work plan. June 2022.

Summary

- Course information and practicalities
- Mobile (4G/5G) versus Wireless (Wi-Fi)
- Mobile technologies and their Key Performance Indicators (KPIs)

- **Post-lecture quiz #1** should be now available in *My Courses*
  - At the end of quiz, do not forget to click on **Submit all and finish**



ELEC-E7120 Wireless Systems (5 cr)

End of Slide Set for Lecture 1