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Introduction to Cellular/Mobile Systems

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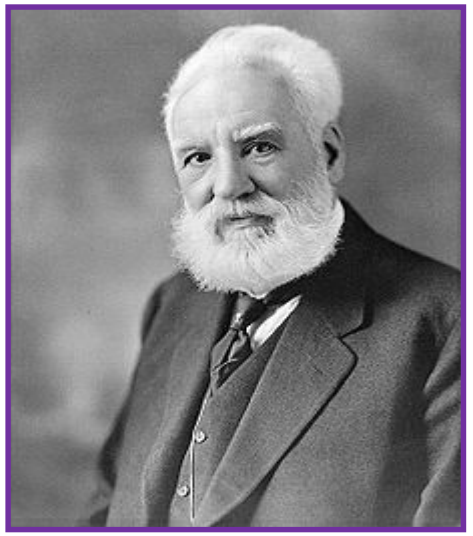
April 2019

Contents

- History
- Basics
- Evolution
- Standardization
- Market share

Important events in radio communications

- ***1855-1870:*** *James Clerk Maxwell*
  - *Developed Maxwell's equations relating electric and magnetic fields*
  - *Was laid off from Aberdeen University before publishing most notable works*



- ***1876:*** *Alexander Graham Bell*
  - *Files the first patent on telephone in the US*
  - *Elisha Gray files his patent for the telephone just a few hours later than Bell*
  - *Later, Gray challenge Bell's patent in court*

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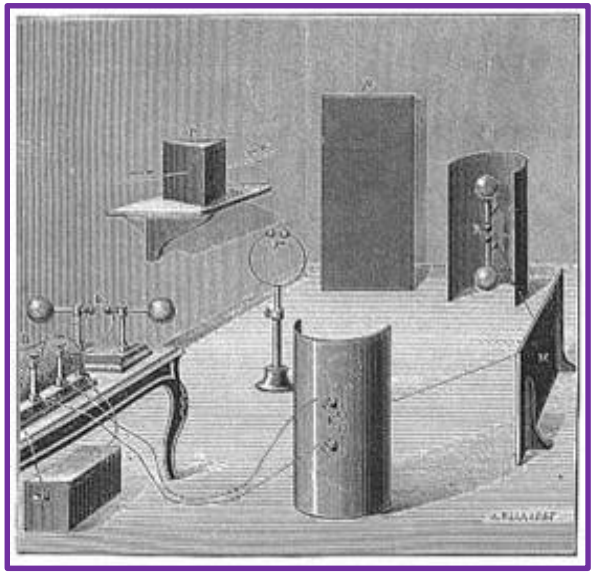
Important events in radio communications

- ***1888:** Heinrich Hertz*
  - *Demonstrate the practical existence of radio communications, by generating and detecting a radio wave*
  - *"It's of no use whatsoever […] this is just an experiment that proves Maestro Maxwell was right"*



- *"we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there"*
- *Asked about the ramifications of his discoveries, Hertz replied,*
  - *"Nothing, I guess."*

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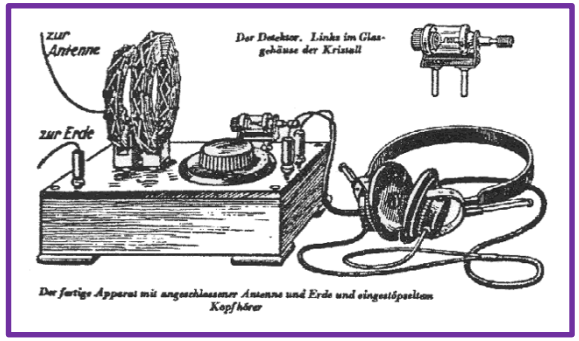
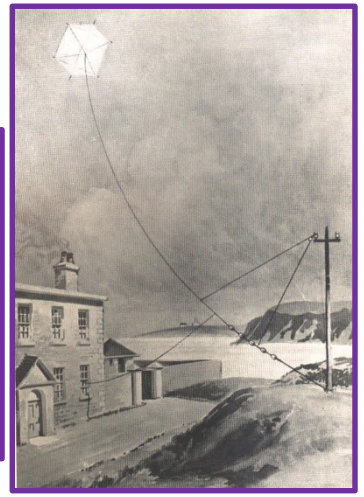
Important events in radio communications

- *Guglielmo Marconi*
  - ***March, 1897:*** *Transmitted Morse code signals over a distance of about 6 km*
  - ***13th May, 1897:*** *Sent the first ever wireless communication over open sea*
  - ***17th December, 1902:*** *A transmission from the Marconi station in Glace Bay, Nova Scotia, Canada, became the first radio message to cross the Atlantic*





- *Marconi was also an effective business person. The last lawsuit regarding Marconi's numerous radio patents was resolved in the US in 1943 (six years after his death)*

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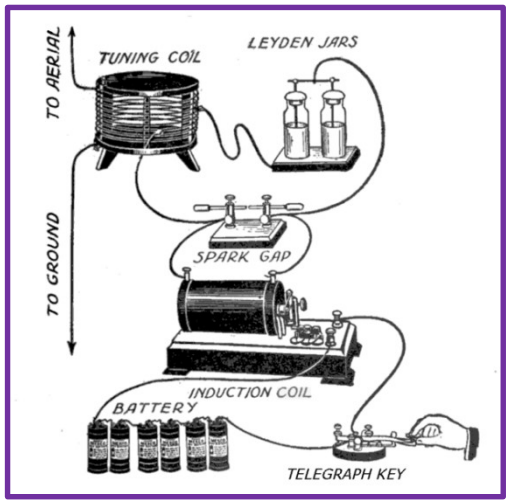
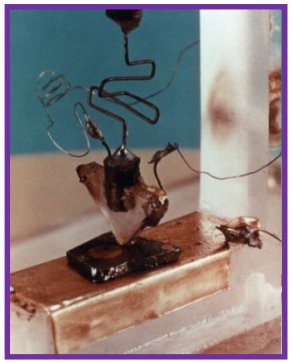
Important events in radio communications



- ***1900s:*** *Reginald Fessendon demonstrates first wireless voice communication*
- ***1907:*** *Commercial transatlantic connections*
- ***1915:*** *Wireless voice transmission NYC – SFO*
- ***1920:*** *Westinghouse company starts the first commercial radio broadcast station*
- ***1936:*** *First commercial television broadcast*

Important events in radio communications

- ***1947:*** *The transistor is invented by J. Bardeen, W. Brattain, and W. Shockley (AT&T Bell Labs)*
- ***1948:*** *Shannon presents the famous channel capacity expression*
- ***1948:*** *Radio relay system between New York and Boston, 4 GHz, 350 km, 7 hops*
- ***1957:*** *Russians launched the first satellite, Sputnik*



- ***1981:*** ***1G cellular:*** *NMT 450 in Scandinavia*
- ***1982:*** *Start of GSM-specification.* ***Aim:*** *Create "pan-European digital mobile phone system with roaming"*
- ***1983:*** *Start of the American AMPS (Advanced Mobile Phone System, analog)*
- ***1983:*** *AT&T introduces analog AMPS in Chicago and Washington D.C. (early cellular system)*

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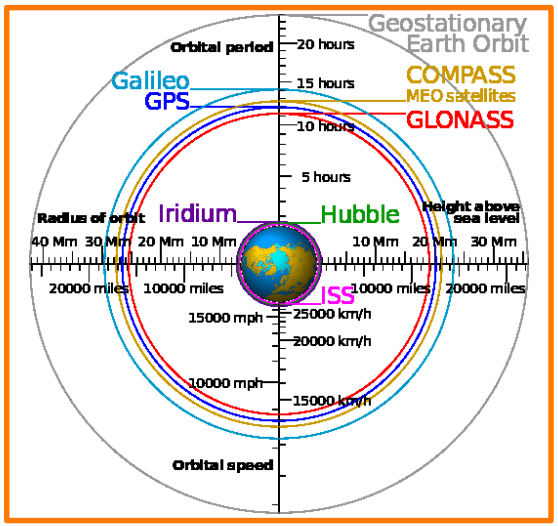
Important events in radio communications

- ***1991:*** *2G cellular: GSM, digital cellular phone*
- ***1993:*** *DECT, digital cordless phone*
- ***1995:*** *First CDMA (code-division multiple-access) based wireless system available in Hong Kong*
- ***1997:*** *Wireless LAN – IEEE 802.11*
- ***1998:*** *Specification of UMTS (Universal Mobile Telecommunication System)*



- ***1998:*** *Iridium: portable satellite telephony (Low Earth Orbit satellite constellation)*
- ***1999:*** *WLAN standard IEEE 802.11b (WiFi). RF band: 2.4 GHz (ISM). Rate: 11 Mbps*
- ***1999:*** *Bluetooth standard version 1.0 (WPAN). RF band: 2.4 GHz (ISM). Rate: 1 Mbps*

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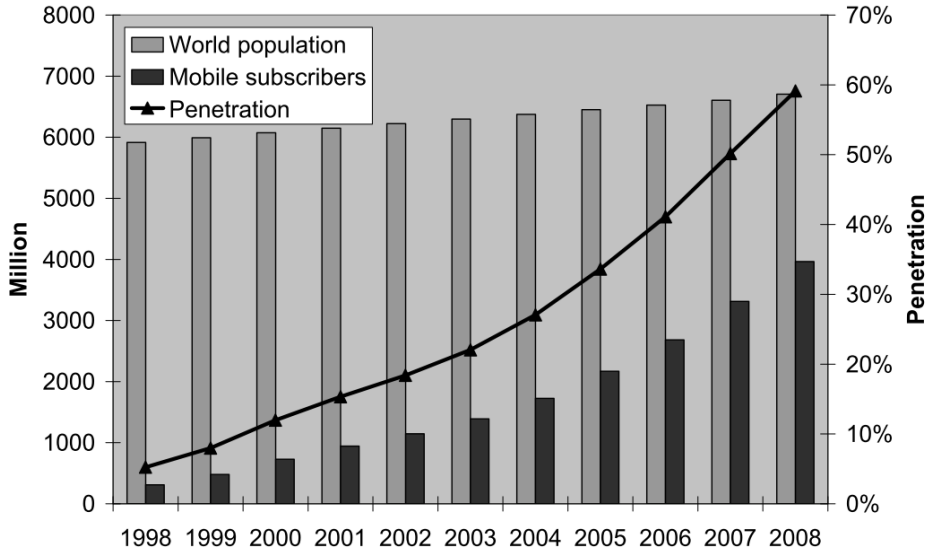
Important events in radio communications



- ***2001:*** ***3G cellular:*** *First WCDMA system available in Japan*
- ***2002:*** *1 billion mobile subscribers*
- ***2005:*** ***3.5G cellular:*** *HSDPA specifications*
- ***2007:*** *3 billion mobile subscribers*
- ***2008:*** *LTE Release 8 specifications*
- ***2009:*** ***4G cellular:*** *First LTE networks deployed*
- ***2010:*** *5 billion mobile subscribers*
- ***2011:*** *LTE-Advanced Release 10 is frozen*
- ***2012:*** *6 billion mobile subscribers*
- ***2014:*** *7 billion mobile subscribers*
- ***2015:*** *3GPP Release 12 frozen*
- ***2016:*** *LTE-Advanced Pro Release 13 frozen*
- ***2018:*** *8 billion mobile subscribers*
- ***2019:*** ***5G Phase 1*** *Release 15 frozen*

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Characteristics of mobile systems

- *From the perspective of a mobile user, the cellular systems are characterized by:*
  - ***Two-way communication** between users and the network*
  - ***Wide area coverage**, where users can connect to the network anywhere at any time*
  - ***Ubiquitous mobility**: User services continue smoothly when users move from one cell to another*
- *Thus, cellular systems are by nature wireless Wide Area Networks (WANs), while wireless Local Area Networks (LANs) provide connectivity in a limited geographical area*
- *Note that in recent terminology, "cellular system" has been replaced by terms like **"mobile networks"** or "mobile systems"*

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Reasoning of mobile system

- *From the perspective of a mobile user, the cellular systems are characterized by:*
  - ***Two-way communication** between users and the network*
  - ***Wide area coverage**, where users can connect to the network anywhere at any time*
  - ***Ubiquitous mobility**: User services continue smoothly when users move from one cell to another*
- ***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 4G coverage area to a 3G coverage area)*
- ***Global roaming***
  - *User expect to have mobile connectivity (almost) anywhere in world*
  - *Obstacles for global roaming: lack of a roaming agreement between operators (usually not an issue) and costs (this is an issue)*

Reasoning of mobile systems

- ***Trustworthy authentication and secure connection***
  - *Nowadays, WLANs may also provide secure connectivity but manual authentication is usually needed.*
  - *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 lead to global markets for both terminals and networks*
  - *Large production volumes and tight competition have lead to low equipment prices*

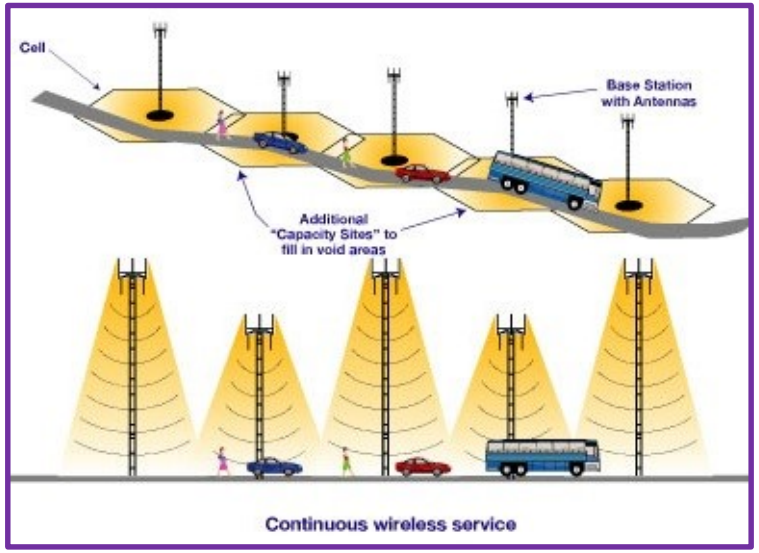
Reasoning of mobile systems

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

  are the main differences between mobile systems and other communication technologies
- *Although WLANs standards are also global in nature, security and connectivity are usually handled locally by network administrator.*

Wide area connectivity

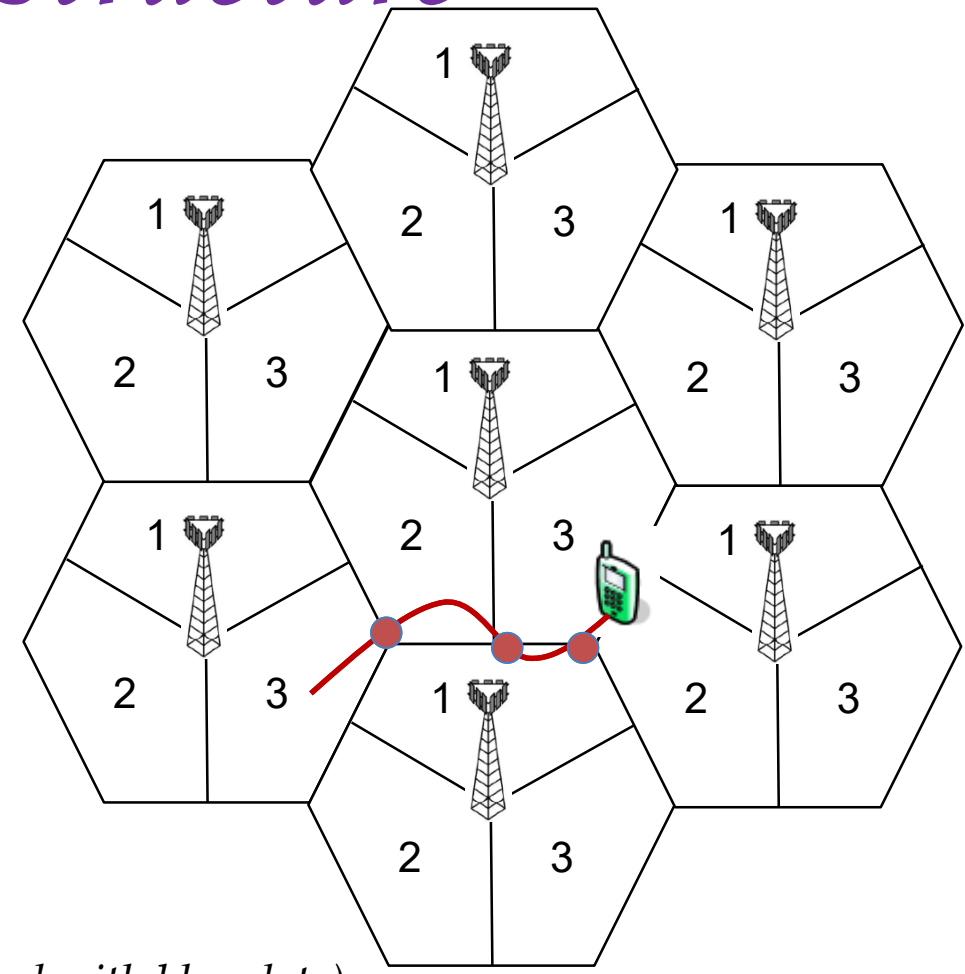
- *Wide area connectivity basically means that all areas where users may move needs to be covered by the system*
  - *Thus, numerous equipment providing connectivity (in practice, a lot of base stations) are needed*
- *Wide area connectivity requirement leads to the so-called **cellular structure** of 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*

Cellular network 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)*

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Network architecture

- *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 system architecture

Radio interface ***RAN-CN interface*** ***CN-External Network interface***

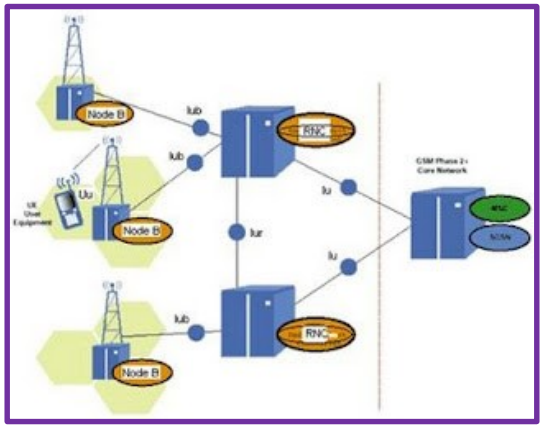
User Terminal

RAN
Handles all radio related functions. May also handle some mobility issues. Include at least base stations

CN
Switching, routing, security and mobility related functions. Includes switches, gateways, registers, and other controlling elements

External networks

RAN = Radio Access Network; CN = Core Network



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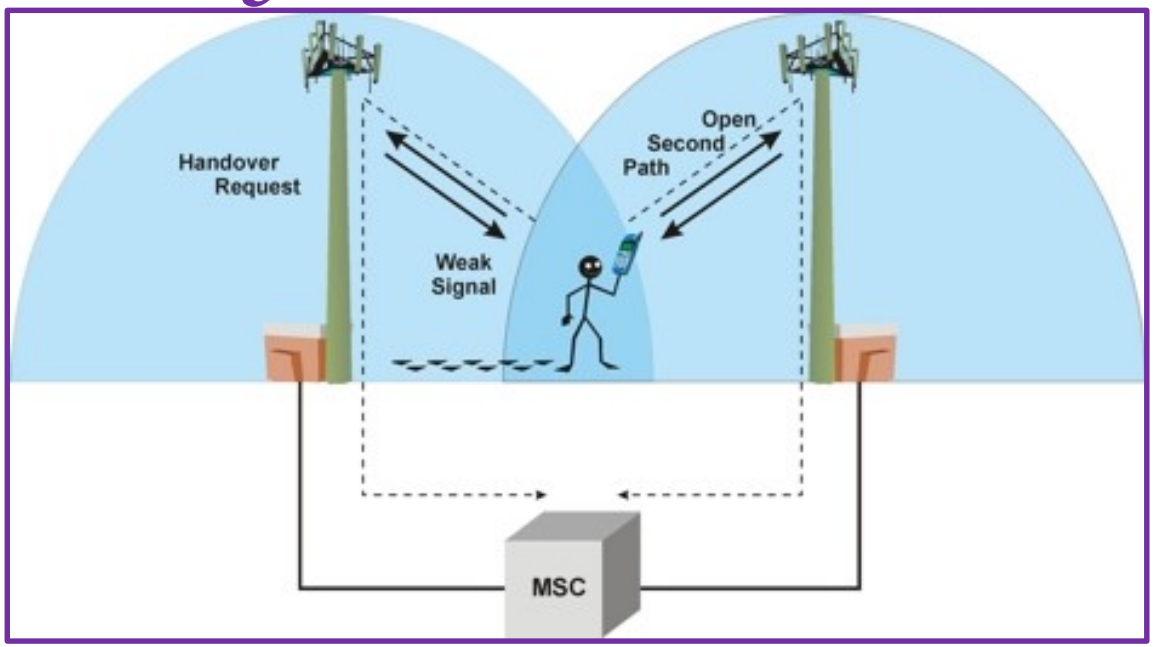
Radio spectrum

- *Conventionally two types of radio frequency bands have been available for commercial radio systems:*
  - ***Licensed** and **unlicensed** frequency bands*
- *License for certain frequency band can be granted by national regulator, which administrates the usage of radio frequencies*
  - *E.g., FCC in the US*
- *In case of mobile communication systems, license is usually granted for a certain operator*
  - *Operator then owns the right for exclusive use of the freq. band*
- *There are also global agreements and guidelines, regarding to the use of the applied frequencies*
  - *National regulators usually follow these guidelines quite well, to make radio devices **compatible** in different countries*

Mobility

- *As discussed earlier, the user mobility is one of the basic characteristics of a mobile network*
  - *To ensure a smooth switch of a user connection between neighboring base stations, a **handover operation** is needed*
  - *Handover operation is also called **hand-off***
- *The main phases of the handover include:*
  1) *Signal quality measurements by mobile station,*
  2) *Handover decision, usually made at the base station (i.e., from the network side), and*
  3) *Exchange of signaling required to inform to the target base station the control information regarding the new mobile user*
- *Handover protocol details are system specific*

Mobility



Three phases for mobile assisted handover:

1) *Signal quality measurements (@ MS),*
2) *Handover decision (@ BS/NTW)*
3) *Exchange of control information (@ NTW)*

MS = Mobile Station, BS = Base Station, NTW = Network

Radio Resource Management (RRM)

- *The **radio resource management** (RRM) functions are responsible for efficient usage of the air interface (physical layer) resources*
- *In general, RRM is needed to:*
  - *Guarantee QoS for users,*
  - *Maintain the coverage according to network plan, and*
  - *Provide as high system efficiency as possible*
- *The RRM concept covers usually the following functions:*
  - *Handover control*
  - *Power control*
  - *Admission control, load control, and congestion control*
  - *Packet scheduling*

Procedures

- *In connection with e.g.* ***3GPP technologies****, an important part of the system is formed by the so-called* ***Procedures*** *that may cover*
  - *System specific power control,*
  - *Paging procedure,*
  - *Random access procedure,*
  - *Cell search procedure, and other*
  - *Measurement and multi-antenna algorithms*
- *Procedures are system specific*

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1st generation (1G)

- ✓ *AMPS (Advanced Mobile Phone System), in the Americas*
- ✓ *NMT (Nordic Mobile Telephone), in the Nordic countries*
  - *variants for 450 MHz and 900 Mhz bands*
- ✓ *TACS (Total Access Communication System), in Europe*

- ❖ *Analog modulation & voice processing*
- ❖ *Almost voice only application*
- ❖ *Systems are incompatible each other*
- ❖ *Roaming inexistent*
- ❖ *Handset were so expensive (more than $1000)*
- ❖ *Low penetration*

Why Digital Cellular?

- *Digitalization:*
  - *Digital source code*
  - *Digital air interface*
- *Digital source coding allows compression*
  - *Narrowing the bandwidth by removing redundancy of speech*
  - *Nyqvist sampled, almost distortion free: ISDN 64 kbps Î GSM voice 13 kbps*
  - *Spectrum efficiency: less resources used per call*
- *Digital air interface allows*
  - *Error detection and error correction*
    - ✓ *Robustness against noise and interference*
    - ✓ *QoS can be guaranteed independently of location*
  - *TDMA & CDMA possible*
    - ✓ *More flexibility in resource usage, multiplexing of different kinds of data*
  - *Half duplex implementation possible (no duplex filter)*
  - *Adaptation to radio conditions*
  - *Security (digital encryption)*
- *Drawbacks of digital:*
  - *Processing & delays*
  - *Application specific (voice) codecs*

2nd generation (2G)

- ✓ ***GSM (Global System for Mobile Communications / Groupe Special Mobile), almost worldwide***
  - ➢ ***Variants for 900 MHz, 1800 MHz, 1900 MHz bands***
- ✓ *PDC (Personal Digital Cellular), in Japan*
  - ➢ *a.k.a. JDC (Japanese Digital Cellular)*
- ✓ *DAMPS (Digital AMPS), in Americas*
  - ➢ *a.k.a. IS-54 (Interim Standard 54), IS-136*
  - ➢ *a.k.a. TDMA in the US*
- ✓ *IS-95 (Interim Standard 95), in Americas, South Korea, India, China*
  - ➢ *a.k.a. cdmaOne*

- ❖ *Digital modulation and voice processing*
- ❖ *Voice and some data*
- ❖ *SMS was a phenomenal success*

2G evolution (2.5G)

- *Higher data rates, packet switched data*
- *GSM evolution*
  - *HSCSD (High Speed Circuit-Switched Data), extension of GSM*
  - ***GPRS (General Packet Radio Services), extension of GSM***
  - ***EDGE (Enhanced Data rates for GSM Evolution), extension of GSM***
- *IS-95 evolution*
  - *cdma2000 1x uses one 1.25 MHz band, in Americas*

Why 3G?

- *The success of 2G digital cellular (GSM) lead to capacity exhaustion → need for systems with higher spectral efficiency*
- *2G radio interfaces optimized for voice*
  - *only low-rate data services*
  - *Need system supporting high-speed multirate data services with asymmetric radio links*
- *The majority of users are pedestrians or indoor nomadic users with handheld terminals*
- *3G cellular standard to merge most mobile communications into a single system*
  - *Cellular, cordless, paging, satellite, private mobile radio*
  - *ITU IMT-2000 recommendations define a common, worldwide framework for future mobile commun. at 2 GHz*
  - *ITU approved IMT-2000 radio interfaces in 1999 and 2007*

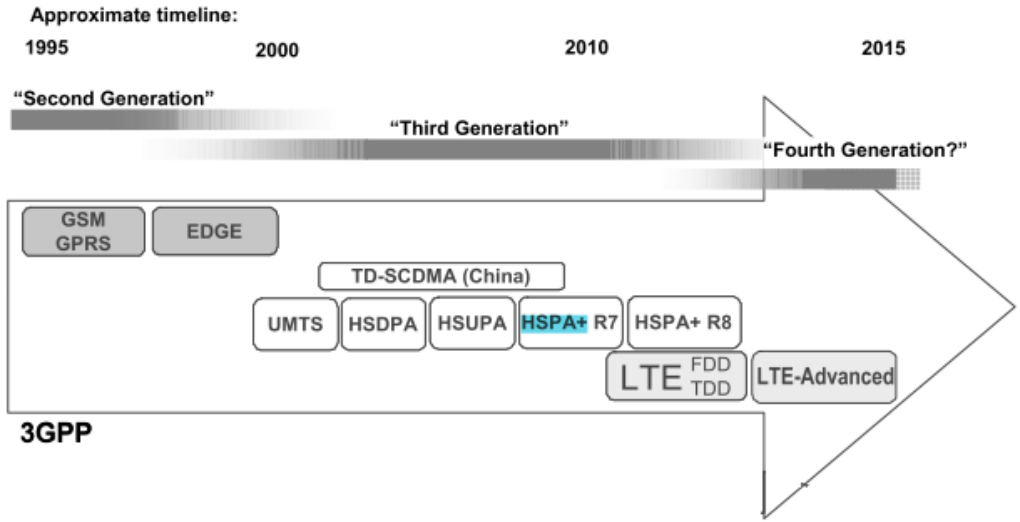
3rd generation (3G)

- ✓ *CDMA2000 family*
  - ➢ *CDMA2000 1xEV-DO (Evolution-Data Optimized), in Americas, Japan, South Korea*
- ✓ ***WCDMA release 99***
  - ➢ ***UMTS (Universal Mobile Telecommunication System), almost worldwide***
- ✓ *TD-SCDMA (Time Division Synchronous CDMA), in China*

- ❖ *Circuit switched voice and packet switched data*
- ❖ *Increased data rate and network capacity*

3G evolution (3.5G/3.75G)

- ***HSDPA*** = *High Speed Downlink Packet Access. Release 5 was the first HSDPA release (2005)*
- ***HSUPA*** = *High Speed Uplink Packet Access. Release 6 was the first HSUPA release (2007)*
- ***HSPA*** = *High Speed Packet Access = HSDPA + HSUPA*
- ***HSPA Evolution (HSPA+)***=*Since Release 7*



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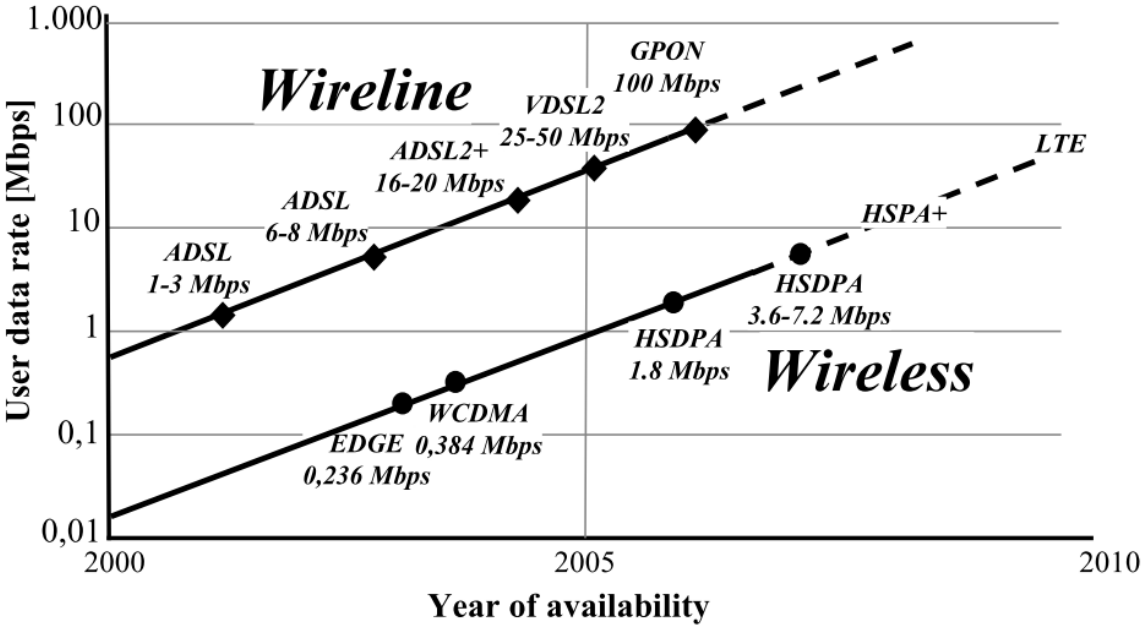
Driving forces for 4G

- Wireline capability evolution
- Need for additional wireless capacity
- Need for lower cost wireless data delivery
- Competition of other wireless technologies (WiMax)



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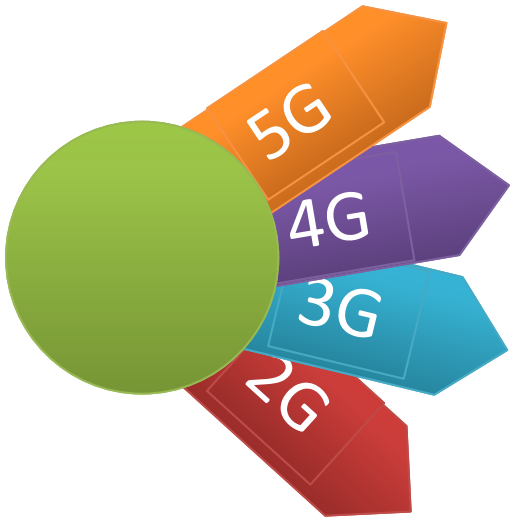
4th generation

- *Long term evolution (LTE), first version in Release 8, enhancement in Release 9*
  - *Approaching 4G*
  - *Packet switched only*
  - *Increased network capacity, data rate*
  - *Decreased latency*
  - *Different access principle for DL and UL*
- *LTE-Advanced, first version in Release 10*
  - *Real 4G*
  - *Backward compatible with LTE Release 8*
  - *Efficient utilization of spectrum*
  - *Homogeneous distribution of capacity provisioning and user experience*
- *LTE-Advanced pro, further enhancement since Release 12*
  - *D2D, M2M, …*

5th generation

Key drivers:

1. *Massive growth in traffic volume*
2. *Massive growth in connected devices/things*
3. *Wide range of requirements and characteristics*



5G phase 1 is ready!

- *2G: Voice: Analog to digital*
  - *New radio*
- *3G: Voice + Broadband data*
  - *New radio*
- *4G: Broadband data*
  - *New radio*
- ***5G: All data – lots of it***
  - ***3G+4G+new technology components***
  - ***New radio***

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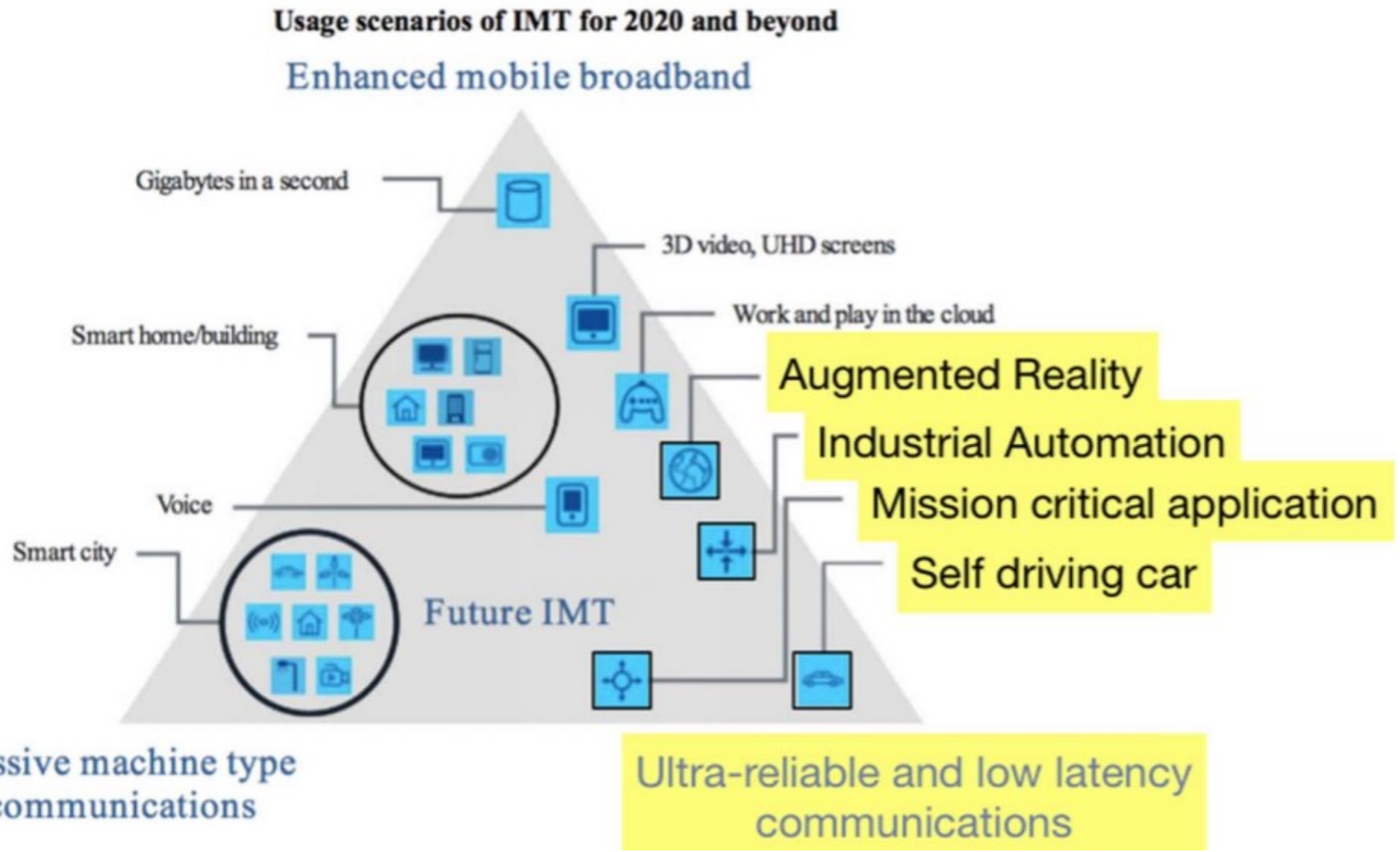
Future of mobile communication



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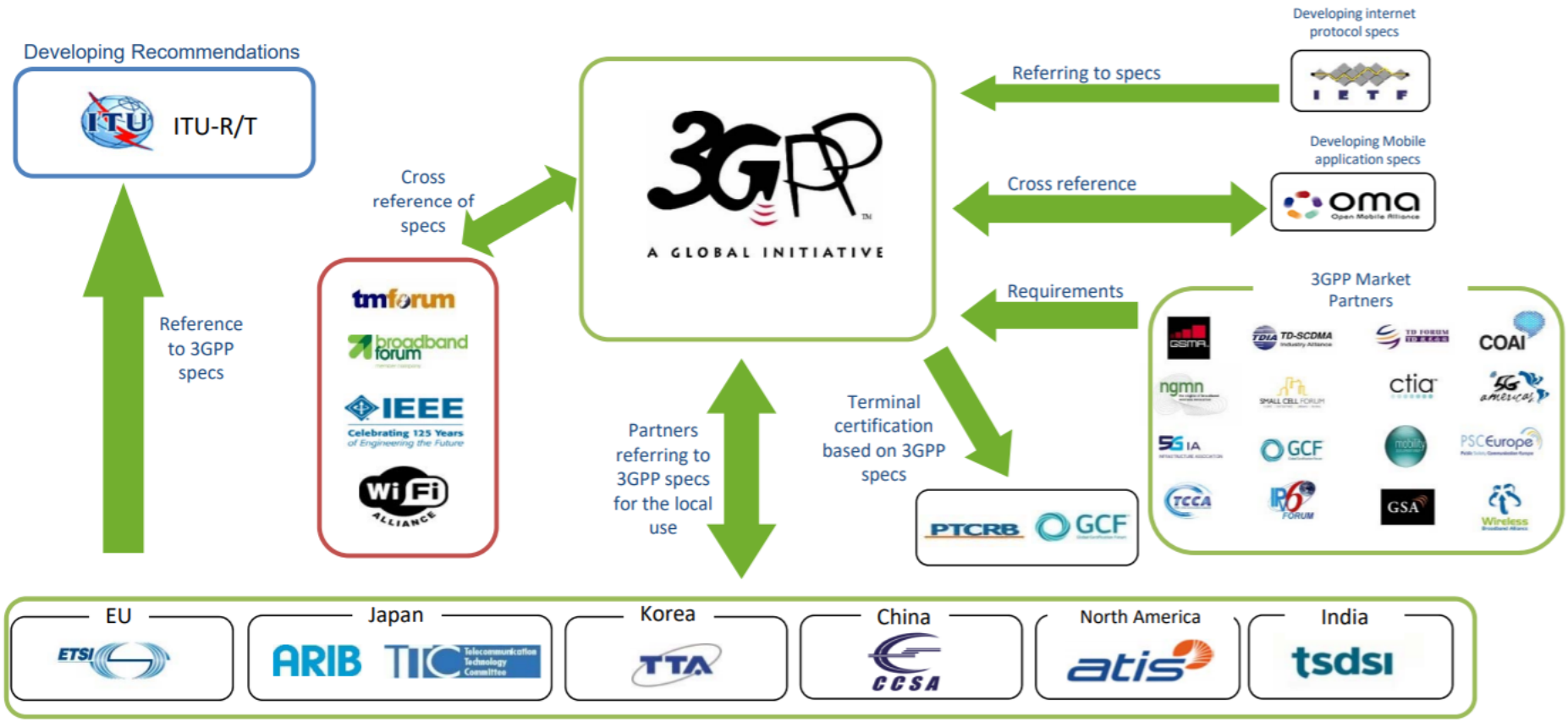
3GPP: leading standardization body

- ARIB (Japan)
- ATIS (USA)
- CCSA (China)
- ETSI (Europe)
- TTA (Korea)
- TTC (Japan)
- TSDSI (India)

3GPP ecosystem



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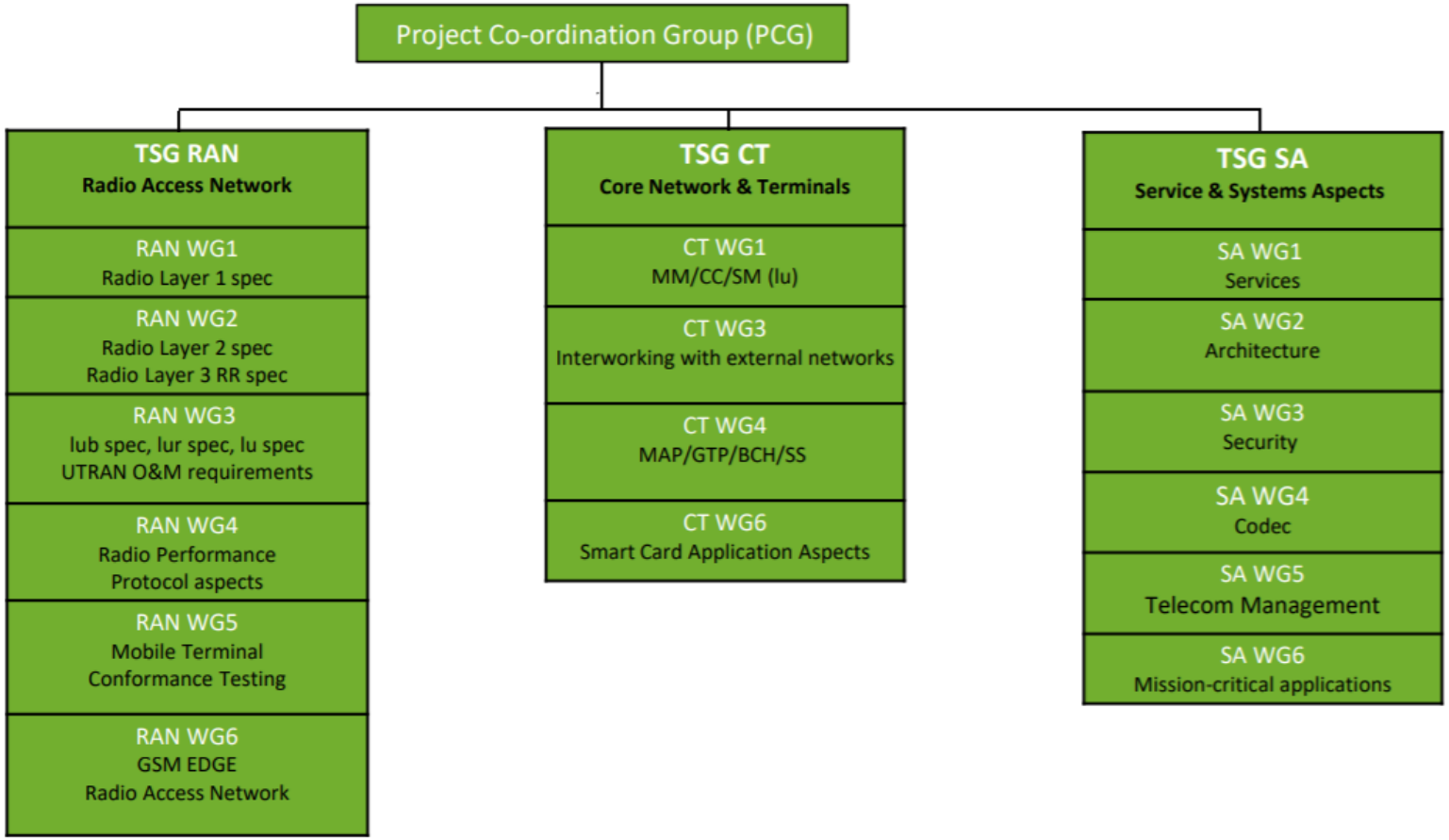
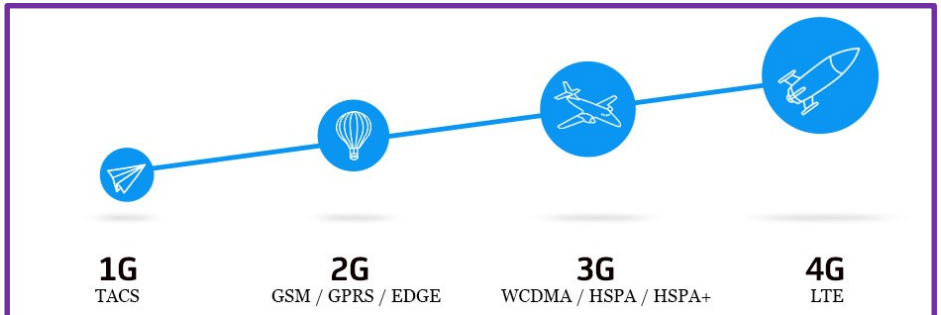
3GPP organizational structure

- *3GPP has three Technical Specification Groups (TSG)*
- *Each TSG has a set of Working Groups (WG) which*
  - *Meet regularly few times a year (from four to six times), and*
  - *Are responsible for development of Reports and Specifications that belong to their area of competence*



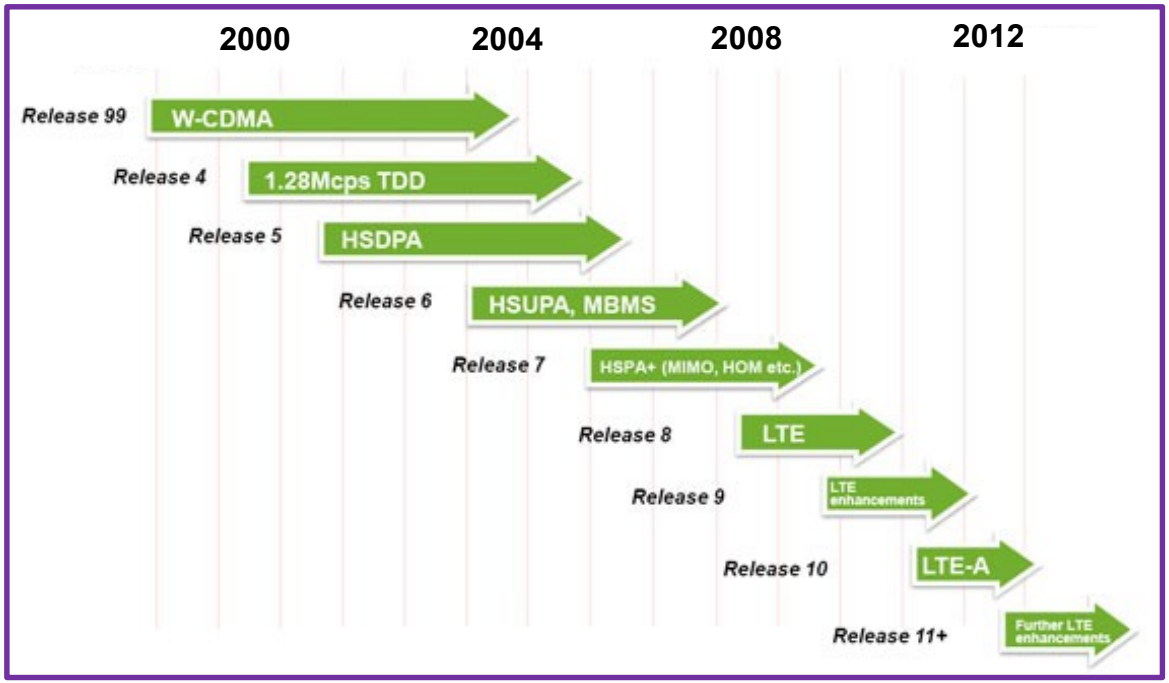
3GPP family of technologies

- *The 3GPP technologies from these groups **are constantly evolving** through Generations of commercial cellular/mobile systems*
- *Although these **Generations** have become an adequate descriptor for the type of network under discussion, real progress on 3GPP standards is measured by the milestones achieved in particular **Releases***
- *New features are 'functionality frozen' and are ready for implementation when a Release is completed*
- *Although this adds some complexity to the work of WGs, such a way of working ensures that progress is continuous and stable*



3GPP family of technologies

3GPP works on a number of Releases in parallel, starting future work well in advance of the completion of the current Release



Time schedule of 3GPP standards

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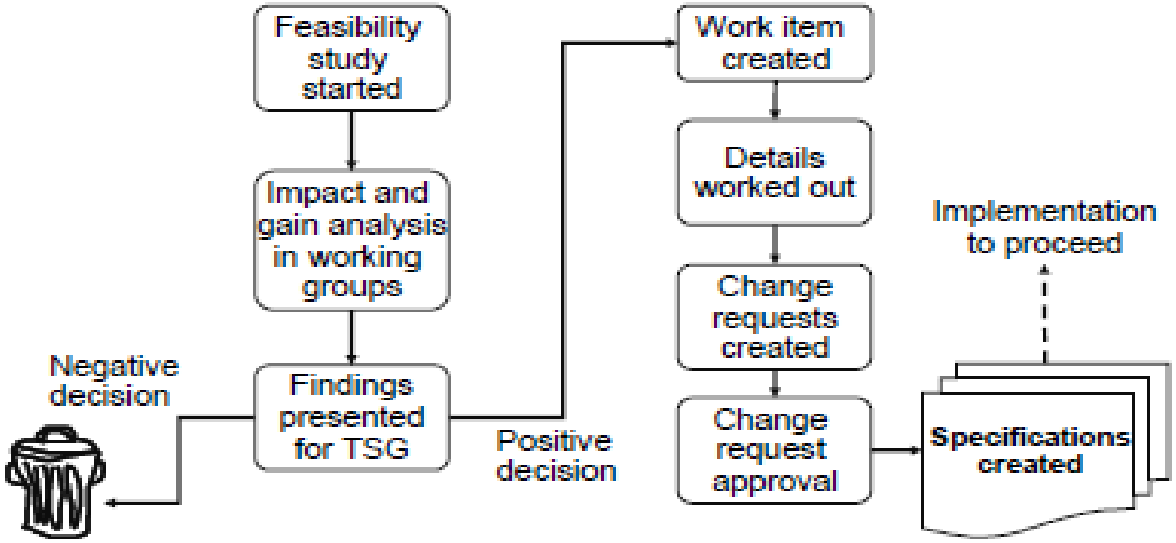
3GPP Standardization process

- *The 3GPP process is such that more topics are started than eventually end up in the specifications.*
- *Within the study, only a small set of features is usually entering to specification.*
- *Sometimes a study is closed after it is found that there is not enough gain to justify the added complexity. A change requested in the work item phase could also be rejected for this same reason.*



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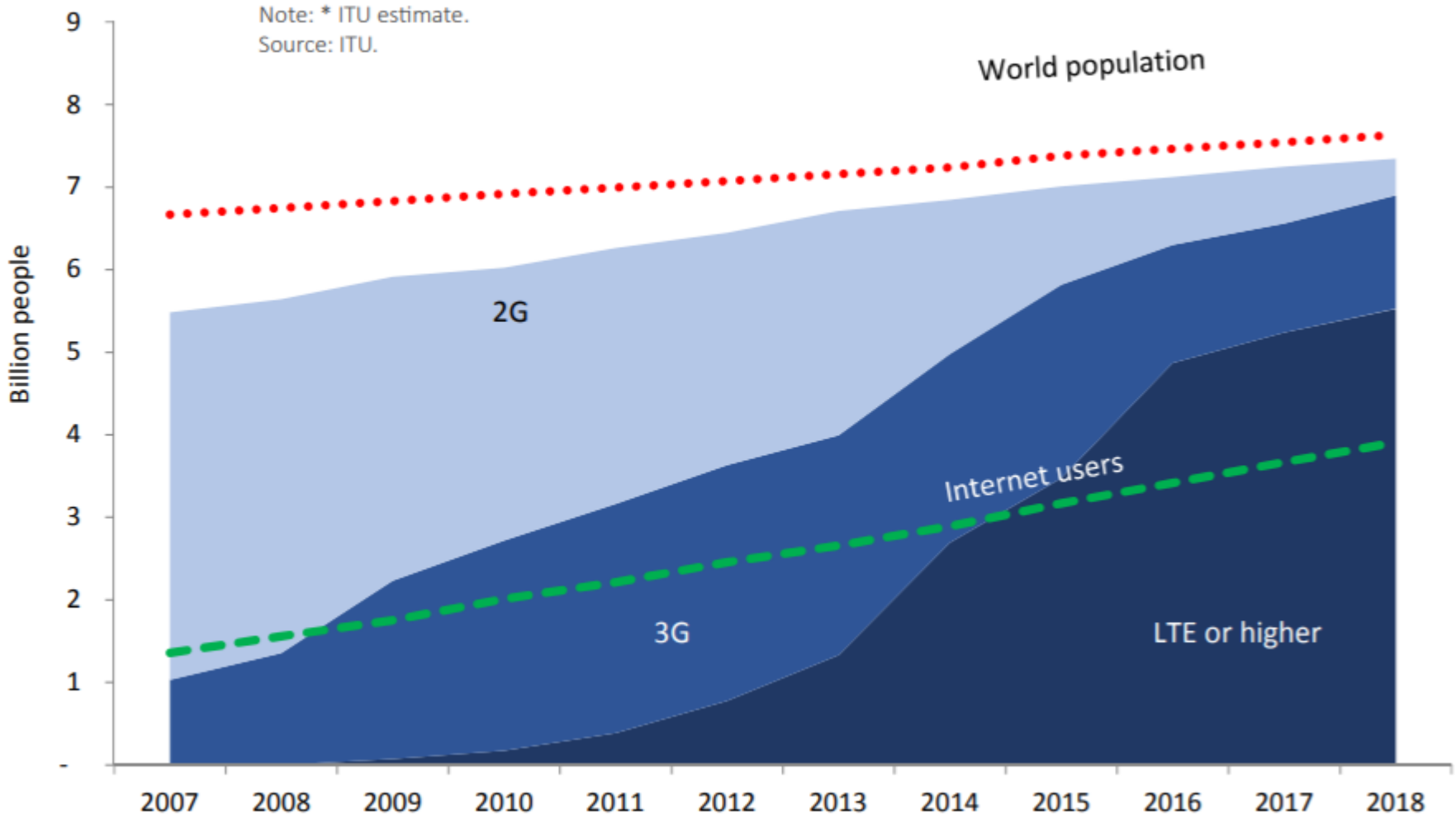
Mobile network population coverage share



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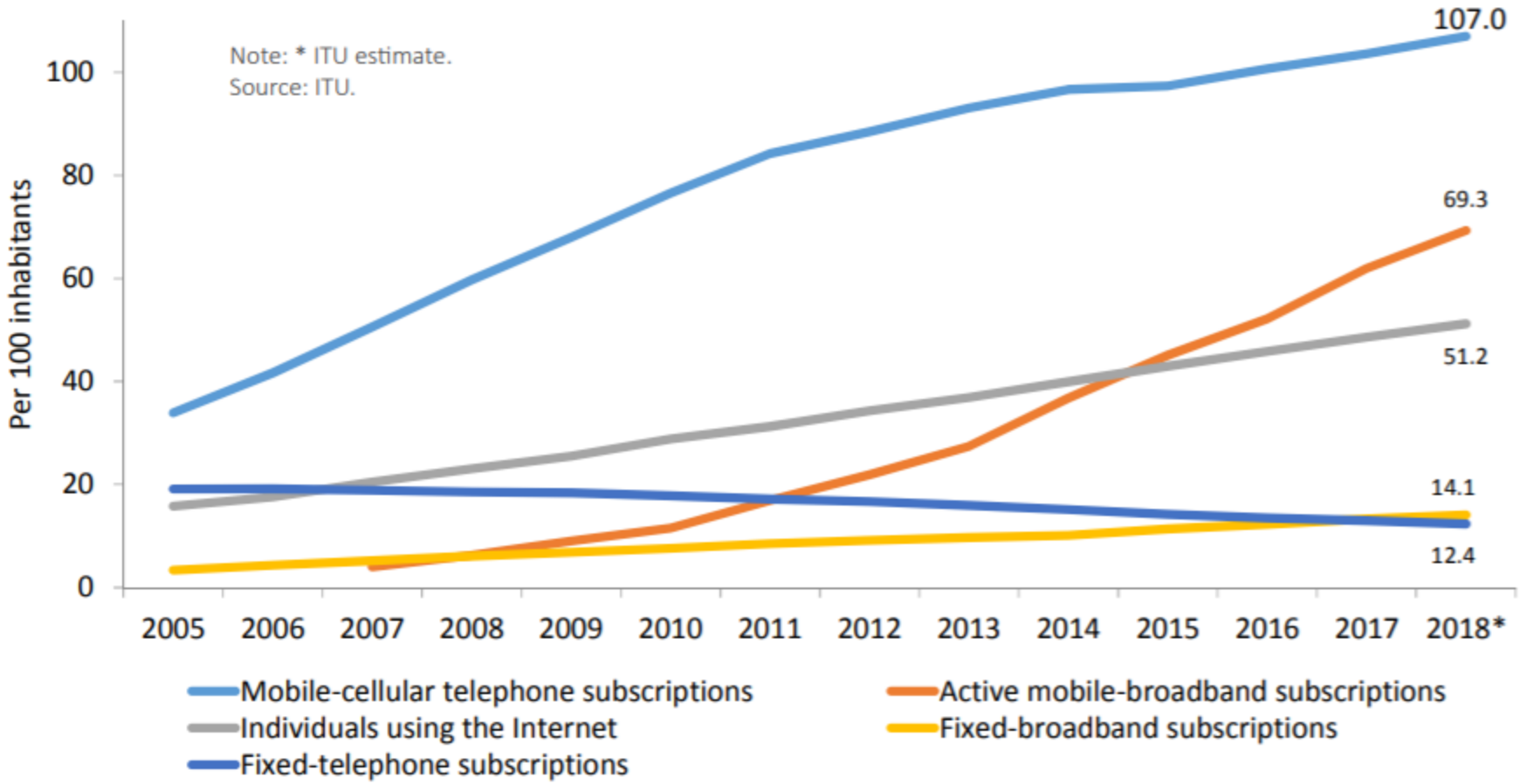
Mobile subscriptions compared to fixed networks



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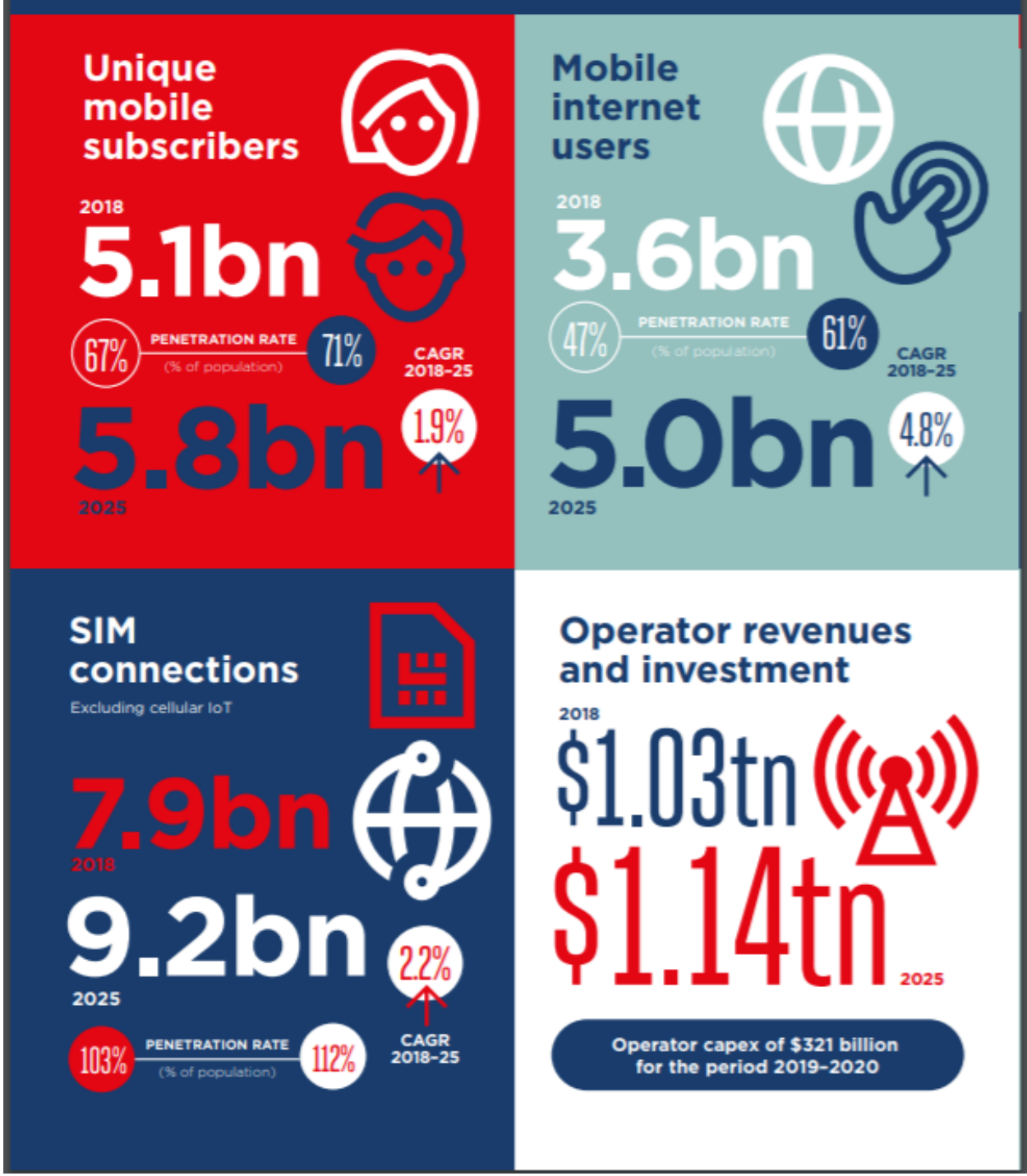
Mobile market according to GSMA



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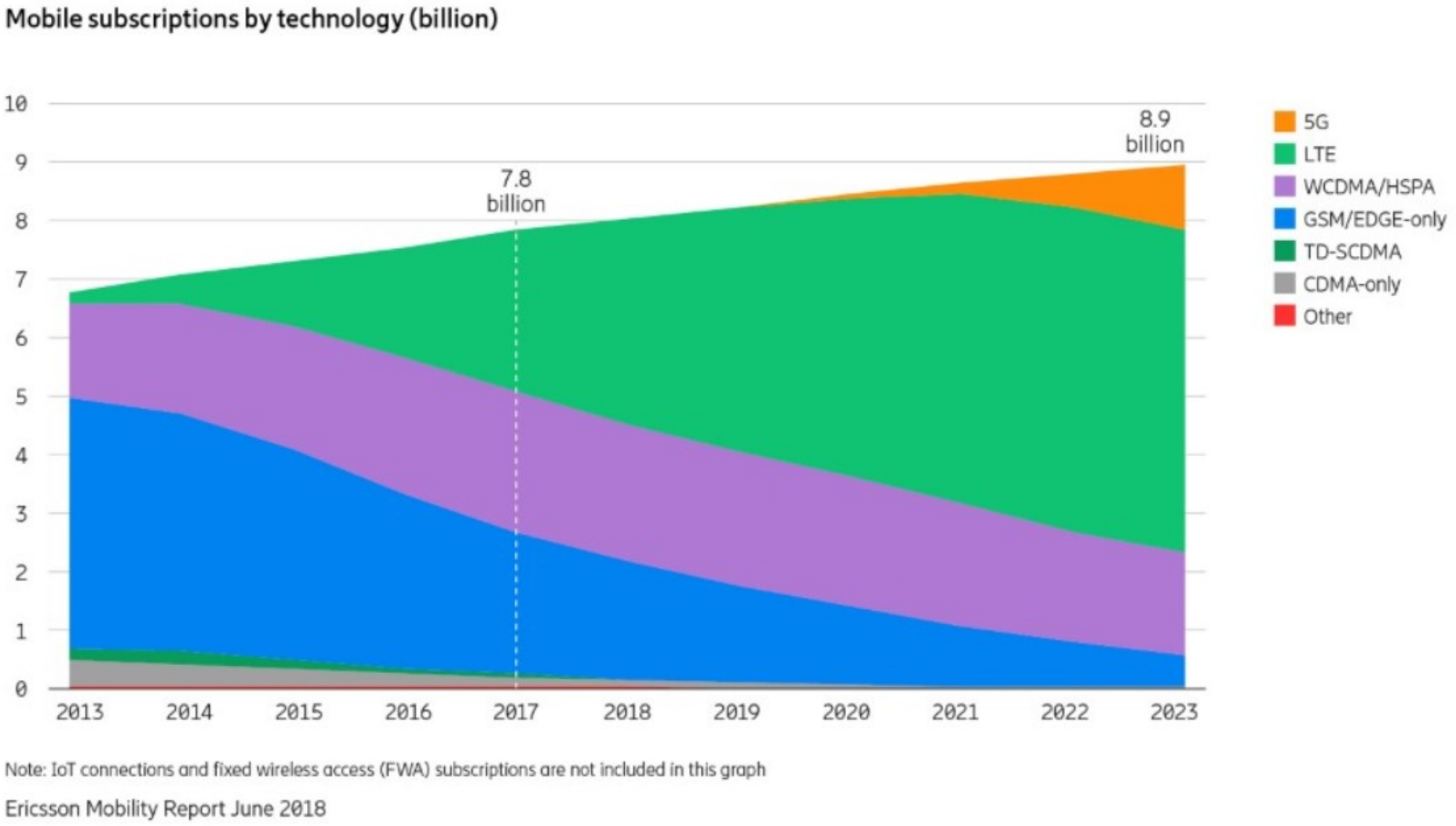
Share as of Q1 2016 according to GSA

- *Mobile subscriptions worldwide - all technologies* → ***7.416 billion*** → ≥ ***100%*** *of the global population*

- *3GPP-family mobile system technologies* → ***6.946 billion*** → ***93.66%*** *market share*
  - *GSM/EDGE* →*3.451 billion subscriptions* →***46.5%*** *market share*
  - *WCDMA/ HSPA/HSPA+* → ***2.202*** *billion subscriptions* → ***29.7%*** *market share*
  - *LTE/LTE-Advanced/LTE-Advanced Pro* → ***1.292*** *billion subscriptions* → ***17.4%*** *market share*

Mobile connections share



Note: IoT connections and fixed wireless access (FWA) subscriptions are not included in this graph

Ericsson Mobility Report June 2018

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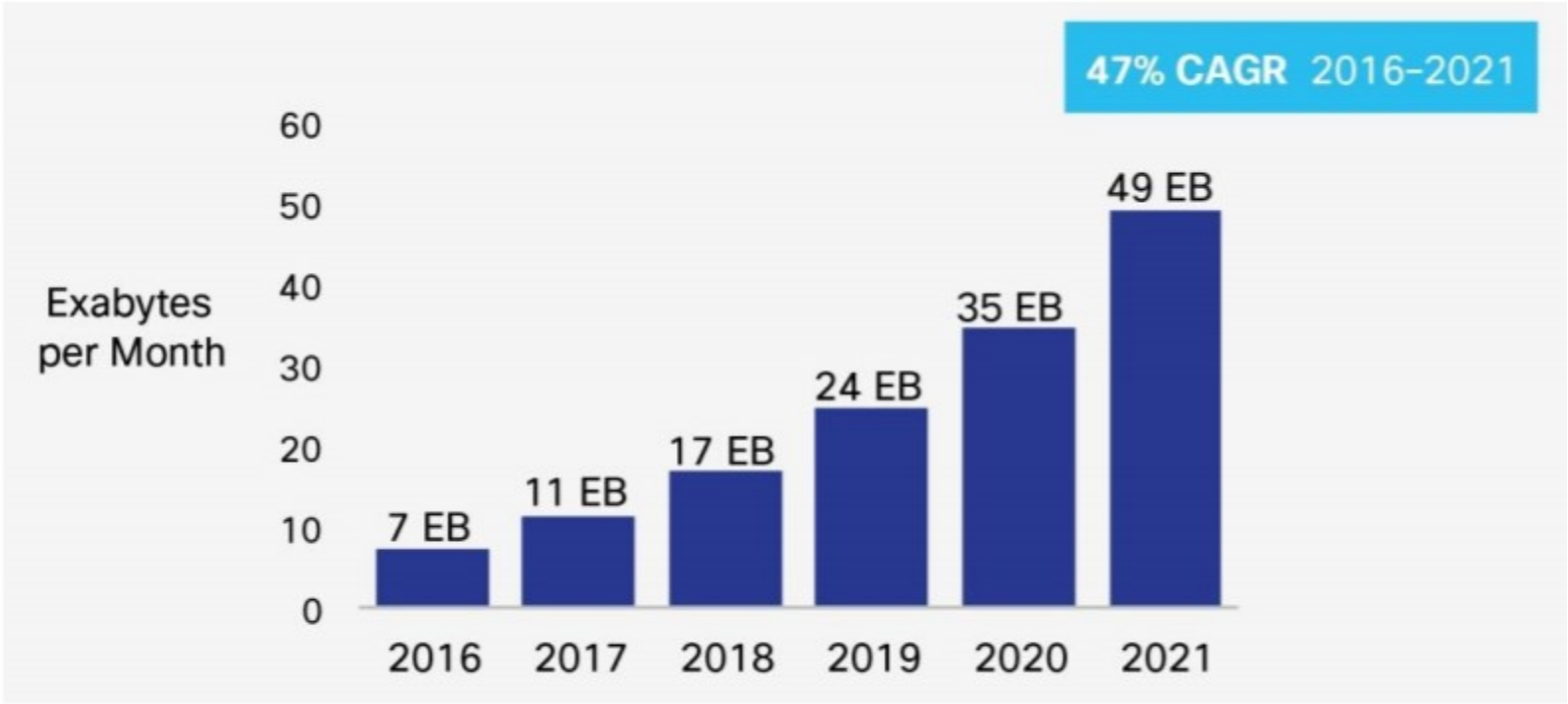
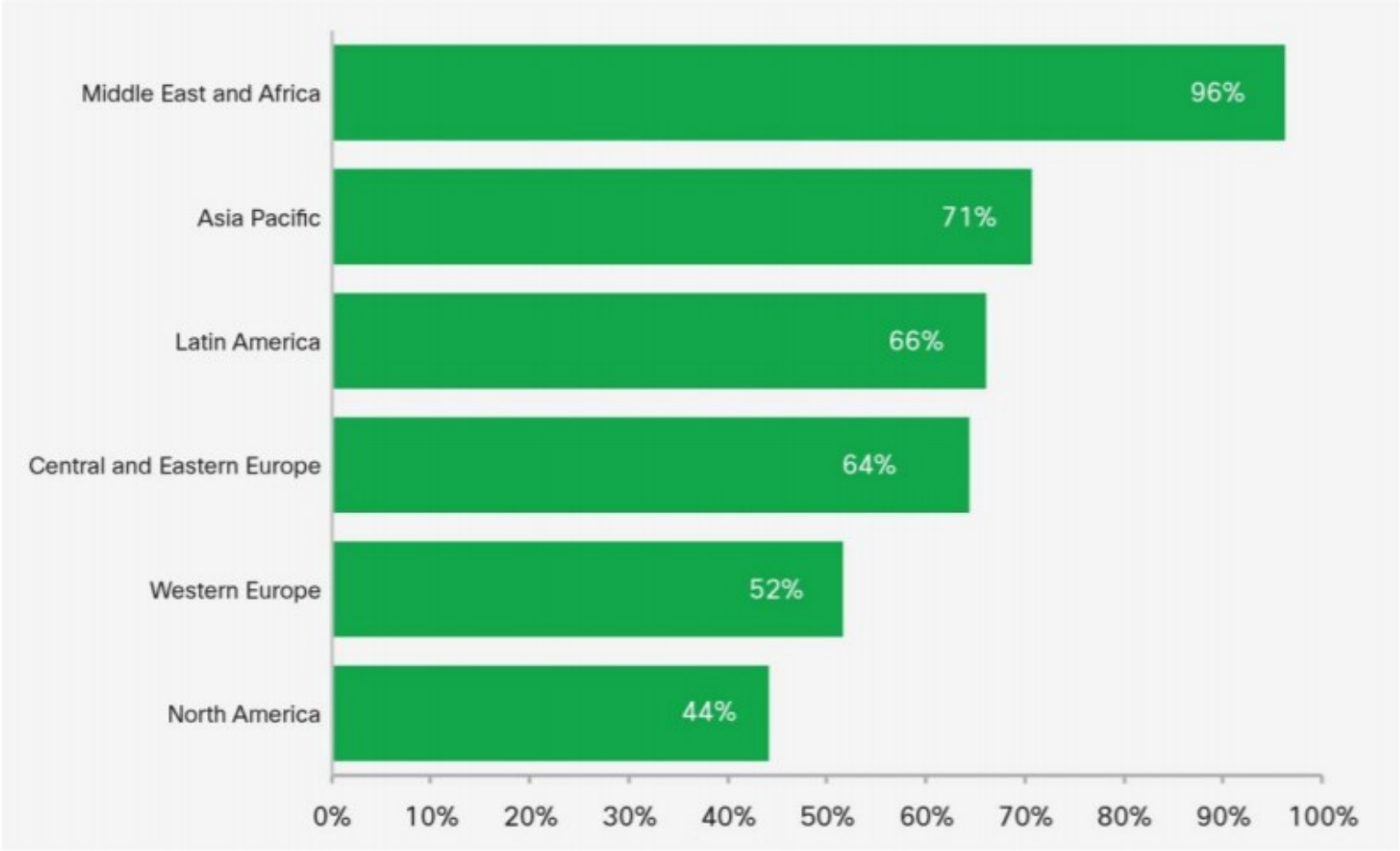
Mobile data traffic growth



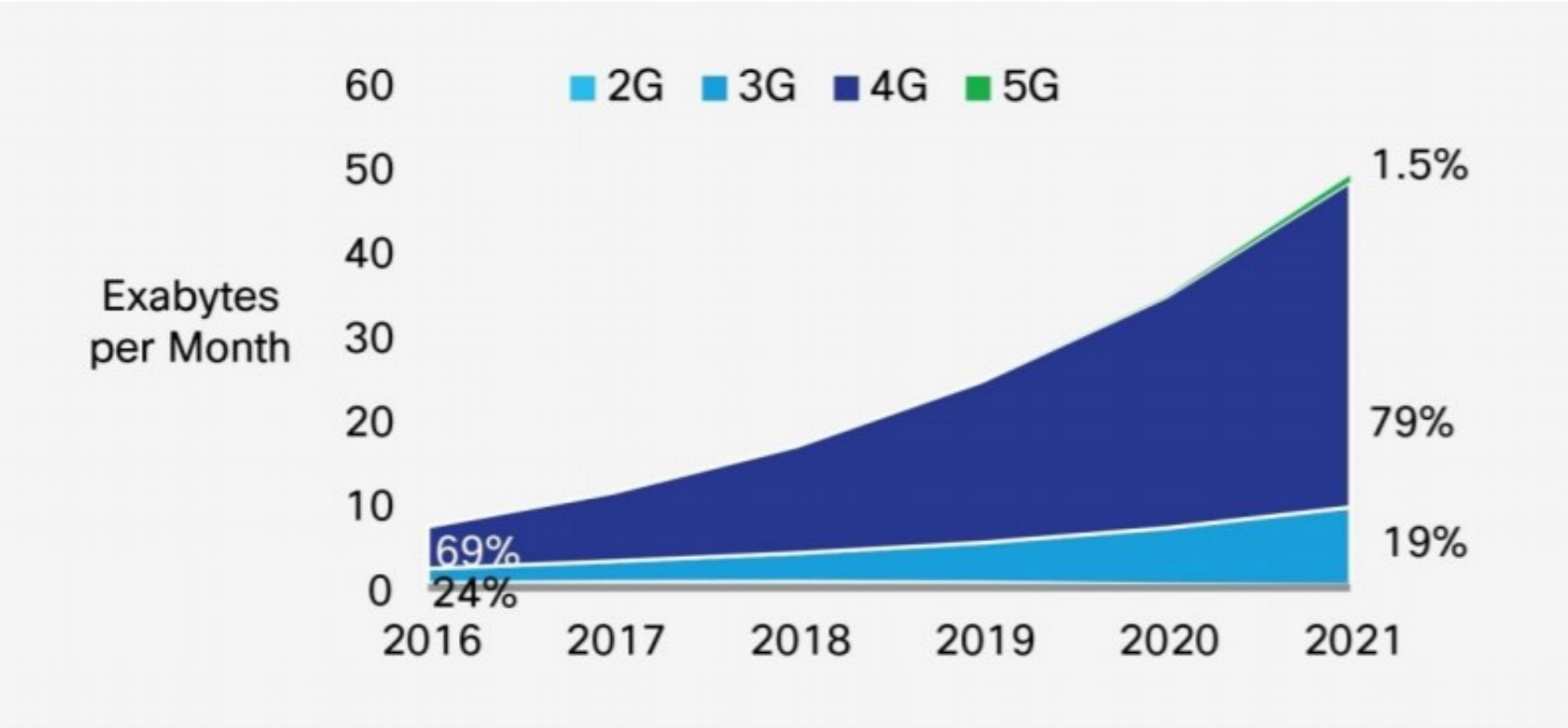
Source: Cisco VNI Mobile, 2017

Mobile data traffic growth in 2016 by region



Source: Cisco VNI Mobile, 2017

Mobile traffic share



Source: Cisco VNI Mobile, 2017

Survey Assignment

History, evolution and future outlook of the following aspects of mobile communication in the Ethiopian market (Addis Ababa and regional):
Group1: All Services (text, voice, video, data, multimedia and other VAS)
Group2: Subscriptions, User Side Device Models & Vendors
Group3: Network Technology & Vendor
Groups are formed by equally segmenting alphabetically ordered list.

Expected output: Brief slides articulated using years and penetration numbers/figures.
Evaluation: Presentation of slides to be take place on April 19. Each group members will be evaluated based on their performance during presentation.

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