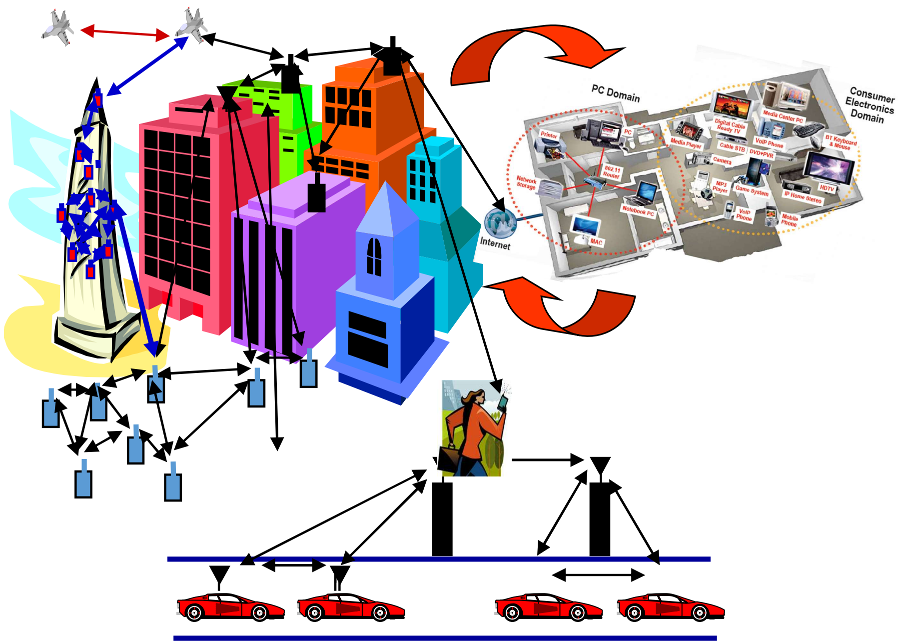
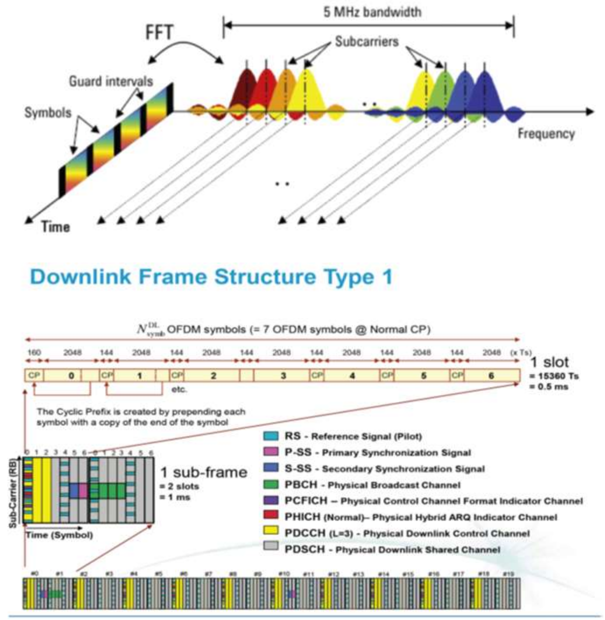
IEE IEE2620: System Aspects in Communications

Muhammad Mahtab Alam, Professor





2024/2025 kevad

Tunniplaan   Tunniplaani kalendrivaade

Muhammad Mahtab Alam (1-16. õppenädal)

Nädala vaade   Kuupäevaline vaade   Kopeeri URL   Ekspordi iCalendar fail

■ Muu ■ Paaris ■ Paaritu ■ 1 - 16   *Rühm kaldkirjas* - aine on rühmale valikuline   Rühm püstkirjas - aine on rühmale kohustuslik

	Aeg	Õppeaine	Keel	Tüüp	Õppejõud	Ruum	Õppenädalad	Rühmad	Ainekava	Kommentaar
Esmaspäev										
■	12:00 - 13:30	IEE2620 - Süsteemiaspektid sides	Eesti keel	loeng	Muhammad Mahtab Alam (täisprofessor tenuuris)	Distantsõpe	1-16	*IAVM21*	Vaata	

2024/2025 Spring

Timetable   Timetable calendar

Muhammad Mahtab Alam (Study week 1-16)

Week view   Dates view   Copy URL   Export iCalendar file

■ Other ■ Even ■ Odd ■ 1 - 16   *Student group italicized* - subject is elective   Student group not italicized - subject is compulsory

	Time	Course	Language	Type	Teacher	Room	Study weeks	Student groups	Syllabus	Comment
Monday										
■	12:00 - 13:30	IEE2620 - System Aspects in Communication	estonian	lecture	Muhammad Mahtab Alam (Tenured Full Professor)	Distance learning	1-16	*IAVM21*	View	

Briefly about me

- Tallinn University of Technology (TTU), Estonia
  - Tenure Track Professor (Communication Technologies) at Thomas Johann Seebeck Department of Electronics. (April’18 – till date)
  - European Research Area-Chair (Holder) of H2020 COgnitive ELectronics (COEL) project. (Sep’16 – till date)
  - **Key Areas:** 5G and IoT -> Massive Machine Type Communication (NB-IoT), Ultra Reliable Low Latency Communication, Critical Communication, Wireless Communication, Body Area Networks.
- Research Scientist at Qatar Mobility Innovation Center, Qatar (2014 –2016)
- Charter Engineer (CEng) Status – Engineering Council United Kingdom (Mar’16)
- Assistant Prof. at University of Engineering and Technology, Pakistan (2013)
  - Lead the team of 20 members in EE Department of Swedish Engineering College
  - Accreditation from the engineering governing body (PEC)
- PhD (Signal Processing and Telecommunication) from Rennes1 University, INRIA/IRISA Lab, France (2009-2012).
  - Visiting PhD researcher – University College Cork, Ireland
- Research Assistant at CSDR-Aalborg University, Denmark (2007-2009)
  - DSP Firmware Engineer at Barco NV, Belgium (Aug’2008- Dec’2008)
- M.Sc Engineering in Applied Signal Processing and Implementation from Aalborg University (2005-2007)
- DSP Design Engineer at And-Or Logic Pvt. Ltd, Pakistan (2005)
- Streaming Networks Pvt Ltd (2004)

Outline

- Course Syllabus
- Course Information
- Wireless History
- The Wireless Basics, Background and Vision
- Technical Challenges
- Current/Next-Gen Wireless Systems
- Spectrum Regulation and Standards
- Summary

Course Materials

- Books:
    - WIRELESS COMMUNICATIONS - Second Edition
        - Andrea Goldsmith (Stanford University)

    - 5G New Radio. Fundamentals, procedures, testing aspects. 2020. Rohde&Schwarz [Online]. Available: https://gloris.rohde-schwarz.com/ebooks/5G
      Create a user to the site (free)

    - Introduction to Wireless and Mobile Systems - Third Edition
        - Dharma Prakash Agrawal (Department of Computer Science University of Cincinnati)
        - Qing-An Zeng (Department of Electronics, Computer and Information Technology North Carolina A&T State University)

    - LTE and the Evolution to 4G Wireless Design and Measurement Challenges, - Second Edition (eBook – Available in Library!!)
        - Moray Rumney (Agilent Technologies, UK Limited)
- Standard Documents
- Tutorials/ Research Papers

Practical Information

- Moodle: (Lectures, Lab and all the information will be uploaded on continuous basis)

Course: IEE2620 System Aspects in Communication (2025 spring) | Moodle

- Course Format:
  - Hybrid (About 15 lectures)
    - it will be via MS-Teams:
    - All practice/labs will be F2F
- Consultation Hours
  - Prior Appointment to be agreed before email: muhammad.alam@taltech.ee
  - Office: U02-224/ MS Teams
- Labs will start from 2nd week – 12th February! Room: U02-209
  - 8 dedicated labs on the 5G
  - 5 labs for the preparation of the subject project

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Evaluation

ASSESSMENT METHOD	ASSESSMENT CRITERIA
Individual work (designed telecommunication system), that is related to the study outcomes, where the student: • plans and designs one's own telecommunication system for given conditions as a project task, while • selects suitable technologies when designing one's own telecommunication system.	Assessment preconditions: The project is submitted to the supervisor on time in the way and format the supervisor requests. Deviations need to be agreed with the supervisor before the deadlines. Assessment: The individual work will be assessed by the supervisor if all the learning outcomes are fulfilled. The grade depends on the level, the work was done according to the point of view of the supervisor. The grade can be either „sufficient" (1), „satisfactory" (2), „good" (3), „very good" (4) or „excellent" (5). If some of the learning outcomes are not fulfilled, the grade is „fail" (0).
Presentation that is related to the study outcomes, where the student: • demonstrantes deep knowledge about the selected technologies for the telecommunication system designed.	Assessment preconditions: The presentation is given on time in the way and format the supervisor requests. Deviations need to be agreed with the supervisor before the deadlines. Assessment: The presentation will be assessed by the supervisor if the learning outcome is fulfilled. The grade depends on the level, the work was done according to the point of view of the supervisor. The grade can be either „sufficient" (1), „satisfactory" (2), „good" (3), „very good" (4) or „excellent" (5). If some of the learning outcomes are not fulfilled, the grade is „fail" (0).
Written exam, that is related to the study outcomes, where the student: • classifies and explains novel and existing technologies used for telecommunication systems.	Assessment preconditions: Both, the individual work and presentation is assessed. Assessment: The exam will consist of at least two tasks. The student will have 90 minutes to demonstrante the fulfillment of the relevant learning outcome. According to this the supervisor evaluates if the learning outcome is fulfilled. The grade depends on the level, the work was done according to the point of view of the supervisor. The grade can be either „sufficient" (1), „satisfactory" (2), „good" (3), „very good" (4) or „excellent" (5). If some of the learning outcomes are not fulfilled, the grade is „fail" (0).
PREREQUISITES FOR FINAL ASSESSMENT (EXAMINATION)	Both, the individual work and presentation is assessed.
FINAL GRADE (all learning outcomes)	The finaal grade will be formed as the arithmetic average of the three grades – individual work, presentation and written exam.

- Theorey:
  - Weight - 50%
  - open book exam (40% multiple choise questions and 60% deailed questions)
- Labs:
  - Weight - 50%
    - 25% for the lab reports
    - 25% for the final project

Slide 7

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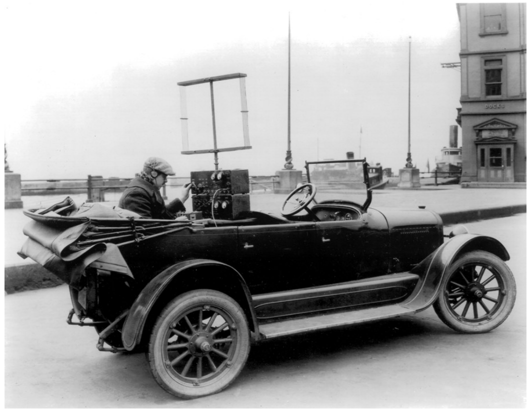
Lecture 1 Introduction: Wireless Evolution and Current State of Play

Wireless History

- **Ancient Systems: Smoke Signals, Carrier Pigeons, …**
- **Radio invented in the 1890s by Marconi**

  1901: First radio reception across the Atlantic Ocean

  1924: First Mobile Radio Telephone

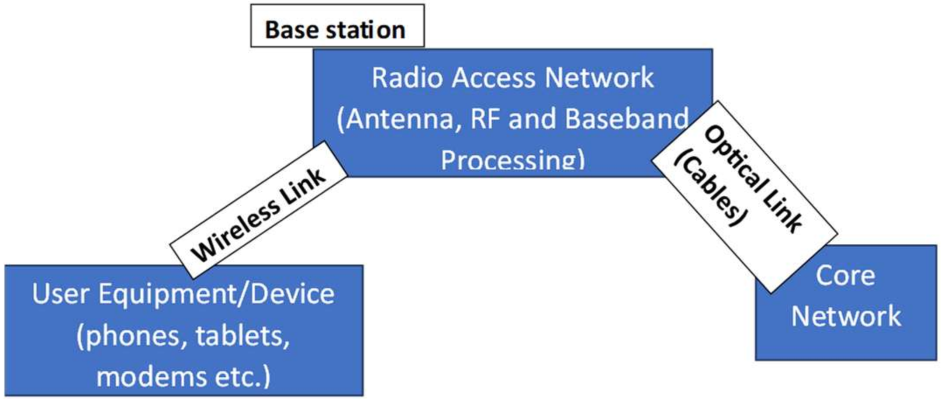


- 1940s-50s: cellular concept discovered (AT&T)
- **1st Generation:** Analog:
  - AMPS: FDMA with 30 KHz FM-modulated voice channels.
  - **1983**: The first analog cellular system deployed in Chicago:
  - FCC increased the cellular spectral allocation from 40 MHz to 50 MHz.
    - Two 25MHz channels: DL and UL
  - AT&T moved on to fiber optics in ‘80s.

- **2nd generation:** digital: **early 90s**
  - higher capacity, improved cost, speed, and power efficiency of digital hardware

Wireless Timeline

- **1991** - Specification of DECT (cordless phone)
  - Digital European Cordless Telephone (today: Digital Enhanced Cordless Telecommunications). Other cordless standards: PHS (Japan), CT-2 (Europe/Asia)
  - 1880-1900MHz, ~100-500m range, 120 duplex channels, 1.2Mbit/s data transmission, voice encryption, authentication, up to several 10000 user/km^2, used in more than 50 countries.
- **1992** - Start of GSM
  - In Germany as D1 and D2, fully digital, 900MHz, 124 channels
  - Automatic location, hand-over, cellular
  - Roaming in Europe - now worldwide in more than 170 countries
  - Services: data with 9.6kbit/s, FAX, voice, ...
- **1996** - HiperLAN (High Performance Radio Local Area Network)
  - ETSI, standardization of type 1: 5.15 - 5.30GHz, 23.5Mbit/s
  - Recommendations for type 2 and 3 (both 5GHz) and 4 (17GHz) as wireless ATM-networks (up to 155Mbit/s)
- **1997** - Wireless LAN – IEEE 802.11
  - IEEE standard, 2.4 - 2.5GHz and infrared, 2Mbit/s
  - Already many (proprietary) products available in the beginning
- **1998** - Specification of GSM successors
  - UMTS (Universal Mobile Telecommunication System) as European proposals for IMT-2000
  - Iridium: 66 satellites (+6 spare), 1.6GHz to the mobile phone



Components of Cellular Communication System

Wireless Timeline

- **1999** - Standardization of additional wireless LANs
  - IEEE standard 802.11b, 2.4-2.5GHz, 11Mbit/s
  - Bluetooth for piconets, 2.4Ghz, <1Mbit/s
  - Decision about International Mobile Telecommunication (IMT-2000)
    - ITU globally coordinated definition of 3G covering key issues such as frequency spectrum use etc.
    - Several “members” of a “family”: UMTS, cdma2000, DECT, …
  - Start of WAP (Wireless Application Protocol)
  - Access to many (Internet) services via the mobile phone

- **2000** - GSM with higher data rates
  - HSCSD offers up to 57,6kbit/s
  - First **GPRS** trials with up to 50 kbit/s (packet oriented!)
  - GSM Enhancements for data transmission pick up (EDGE, GPRS, HSCSD)
  - UMTS auctions/beauty contests
  - Hype followed by disillusionment (approx. 50 B$ payed in Germany for 6 UMTS licenses!)
- **2001** - Start of 3G systems
  - Cdma2000 in Korea, UMTS in Europe, Foma (almost UMTS) in Japan
- **2002** – Standardization of high-capacity wireless networks
  - IEEE 802.16 as Wireless MAN

4G/LTE Cellular

- Much higher data rates than 3G (50-100 Mbps)
  - 3G systems has 384 Kbps <u>peak rates</u>
- Greater spectral efficiency (bits/s/Hz)
  - More bandwidth, adaptive OFDM-MIMO, reduced interference
- Flexible use of up to 100 MHz of spectrum
  - 10-20 MHz spectrum allocation common
- Low packet latency (<5ms).
- Reduced cost-per-bit (not always clear to customers!)
- *All IP network*

Background

- LTE stands for *Long Term Evolution* and it was started as a project in 2004 by telecommunication body known as the Third Generation Partnership Project (3GPP).
  - SAE (System Architecture Evolution) is the corresponding evolution of the GPRS/3G packet core network evolution.
  - The term LTE is typically used to represent both LTE and SAE.
- LTE evolved from an earlier 3GPP system known as the Universal Mobile Telecommunication System (UMTS), which in turn evolved from the Global System for Mobile Communications (GSM). – Tutorial (Moodle)
- Even related specifications were formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN).

Motivation Behind LTE

- A rapid increase of mobile data usage and emergence of new applications such as MBMS (multimedia broadcast and multicast service), MMOG (Multimedia Online Gaming), mobile TV, Web 2.0, streaming contents have motivated the 3rd Generation Partnership Project (3GPP) to work on the Long-Term Evolution (LTE) on the way towards fourth-generation mobile.
- LTE improves up to 50 times performance and much better spectral efficiency to cellular networks.
  - LTE introduced to get higher data rates, 300Mbps peak downlink and 75 Mbps peak uplink.
  - In a 20MHz carrier, data rates beyond 300Mbps can be achieved under very good signal conditions.

FDD downlink peak data rates (64QAM)

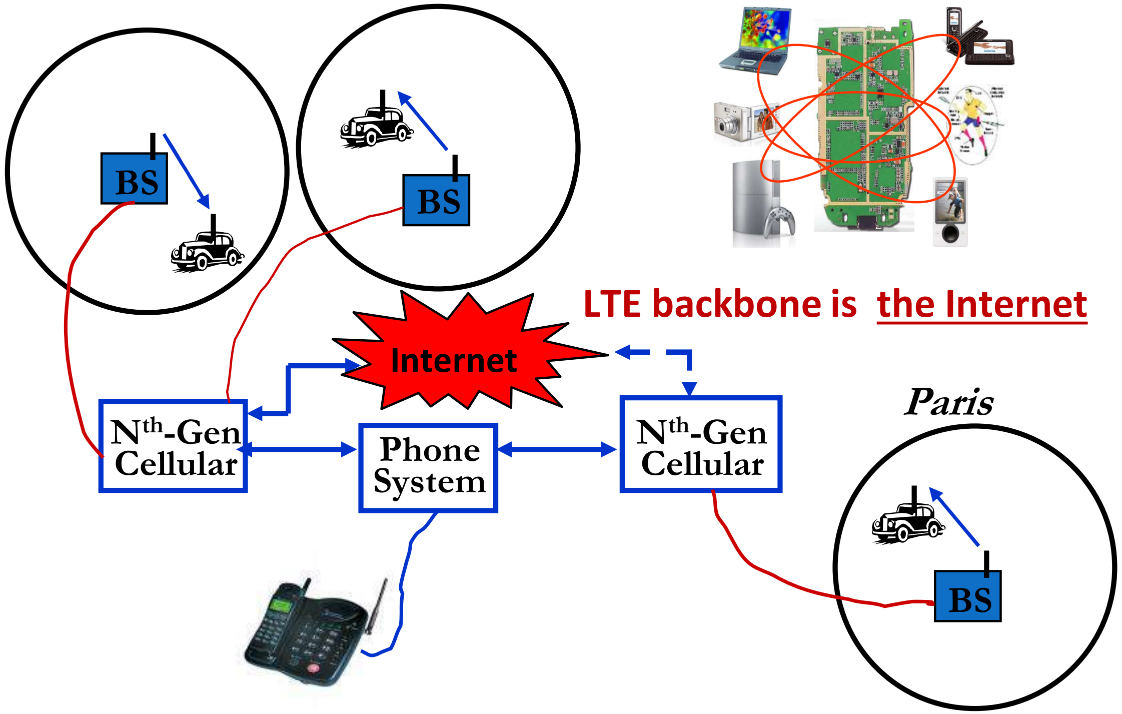
Antenna configuration	SISO	2x2 MIMO	4x4 MIMO
Peak data rate Mbps	100	172.8	326.4

FDD uplink peak data rates (single antenna)

Modulation depth	QPSK	16QAM	64QAM
Peak data rate Mbps	50	57.6	86.4

Future Cellular Phones

Burden for this performance is on the backbone network

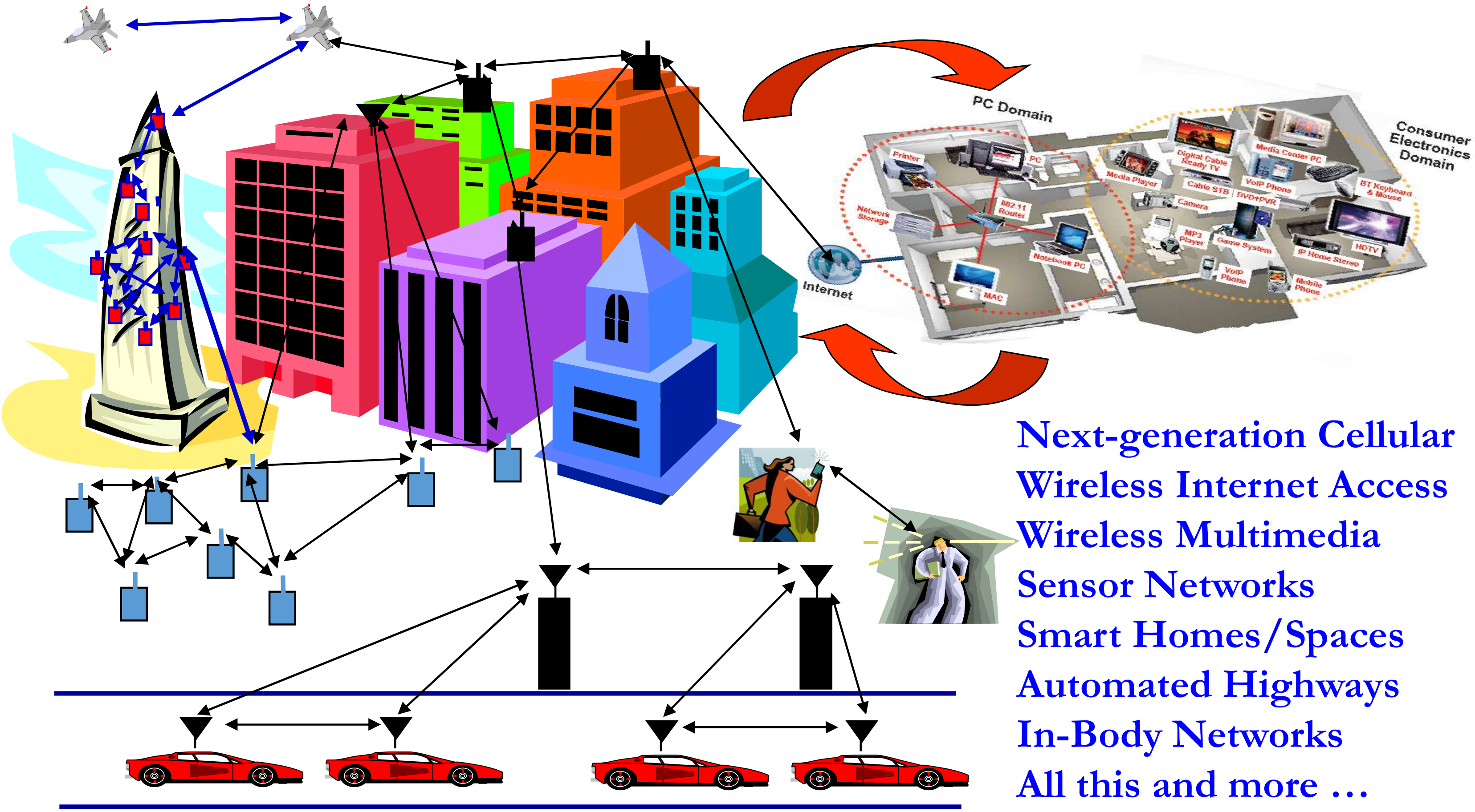


Much better performance and reliability than today

- Gbps rates, low latency, 99% coverage indoors and out

Future Wireless Networks

Ubiquitous Communication Among People and Devices



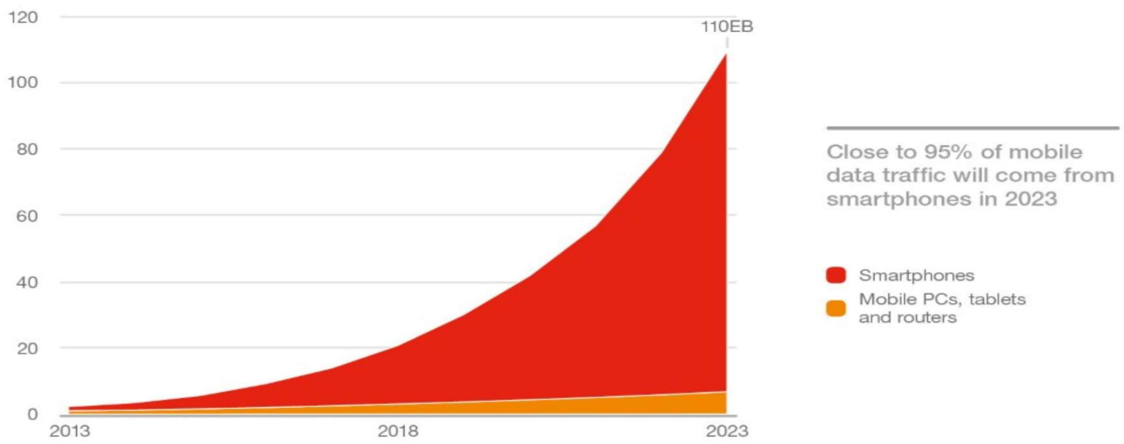
Next-generation Cellular
Wireless Internet Access
Wireless Multimedia
Sensor Networks
Smart Homes/Spaces
Automated Highways
In-Body Networks
All this and more …

Ericsson’s Mobility Stats

- Mobile subscriptions worldwide Q3 2017
  - In Q3, 95 million new mobile subscriptions were added
  - resulting in a total of 7.8 billion.
  - LTE becomes the dominant mobile access technology in 2017
- In 2023, there will be 9.1 billion mobile subscriptions
  - 8.5 billion mobile broadband subscriptions
  - 1 billion 5G subscriptions for enhanced mobile broadband

Mobile subscriptions by technology (billion)

Global mobile data traffic (ExaBytes per month)



[Source] ERICSSON Mobility-report November-2017

Figure 9: Global mobile network data traffic (EB per month)

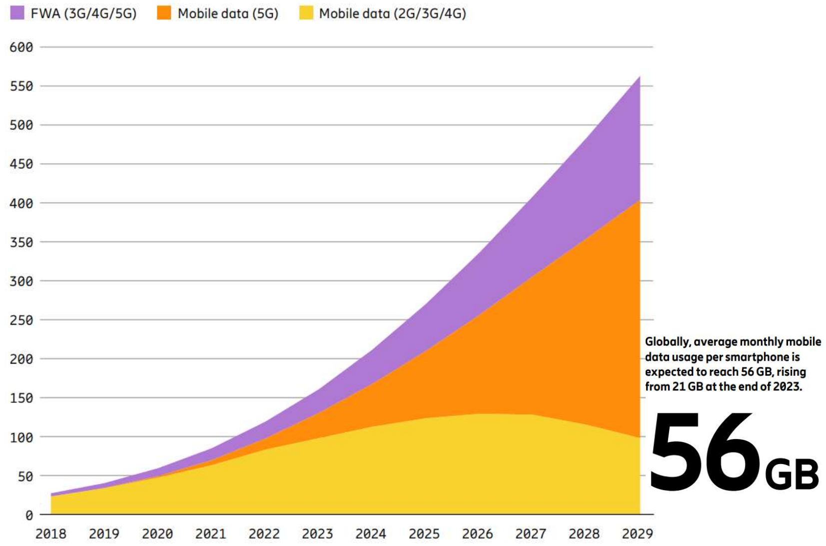
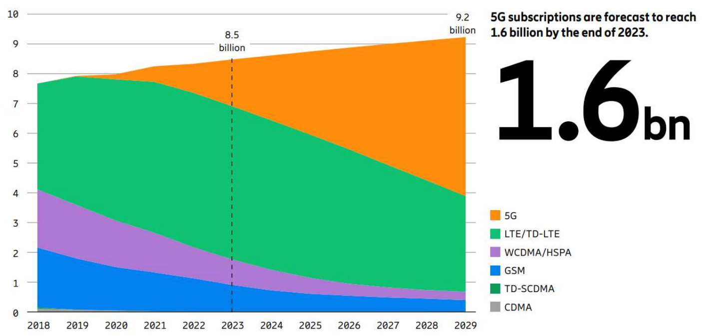
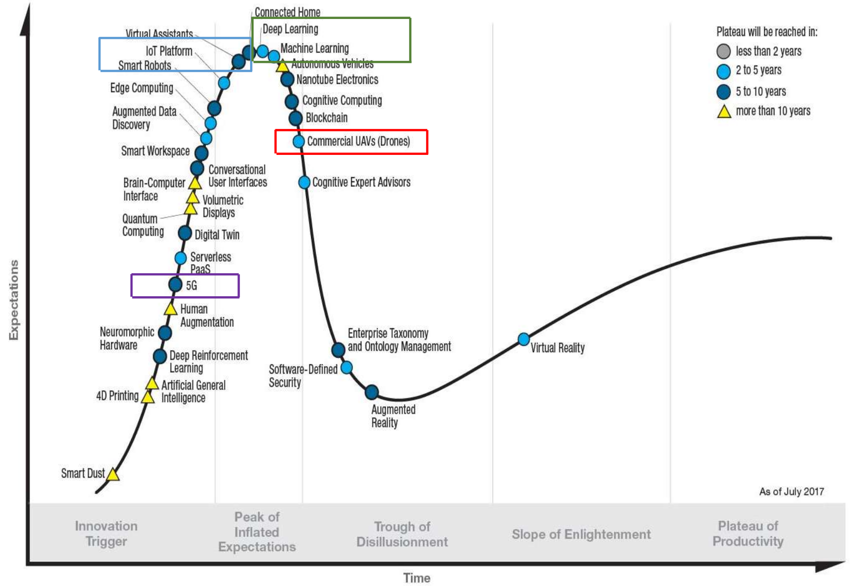


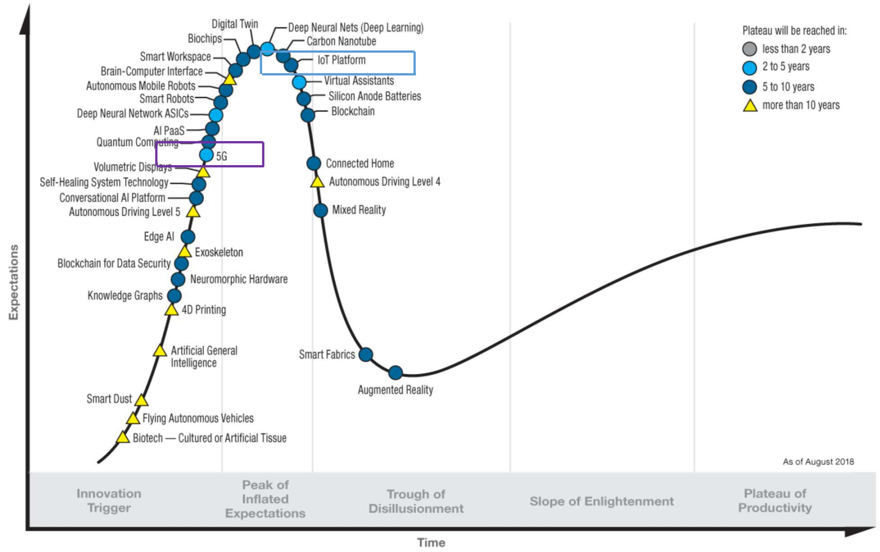
Figure 1: Mobile subscriptions by technology (billion)



[1] 1 GSA and Ericsson (November 2023).
[2] A 5G subscription is counted as such when associated with a device that supports New Radio (NR), as specified in 3GPP Release 15, and is connected to a 5G-enabled network.
[3] Mainly CDMA2000 EVDO, TD-SCDMA and Mobile WiMAX.

Emerging Trends of Innovation





IoT Platforms

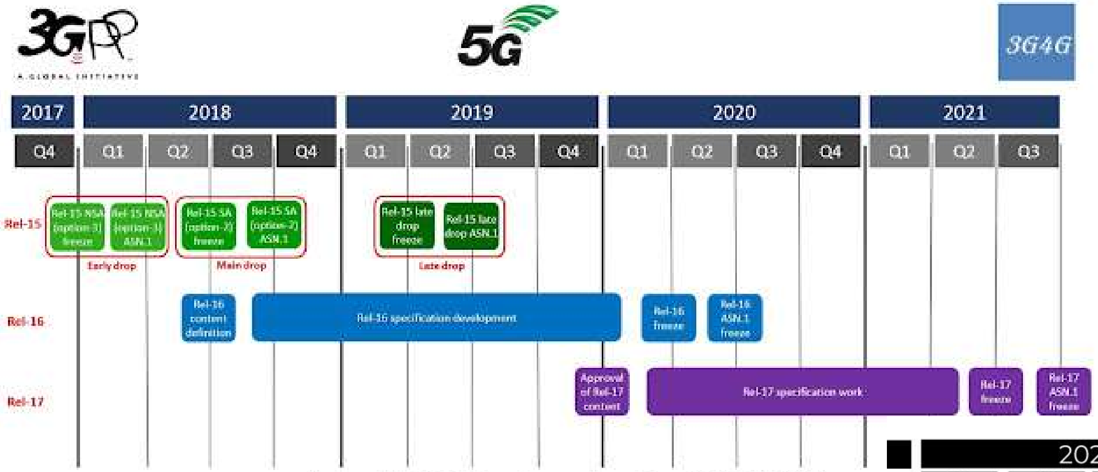
Machine Learning

5G

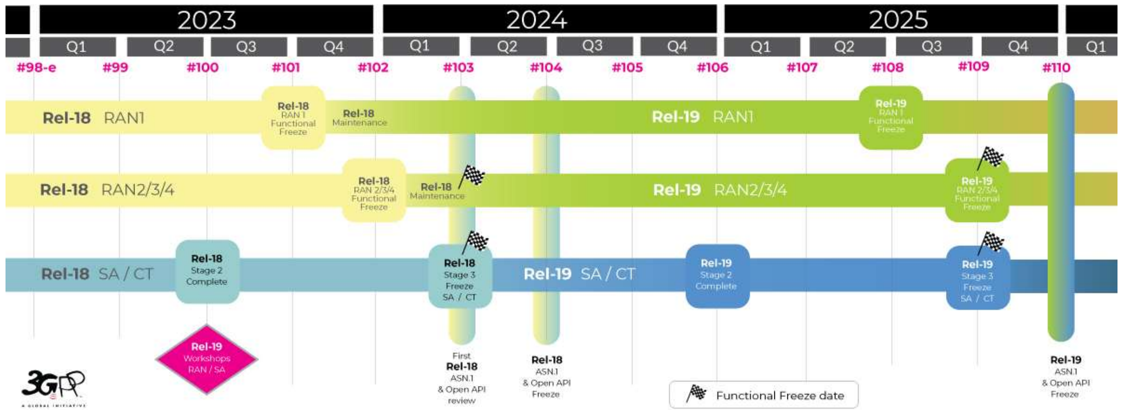
Commercial UAVs (Drones)

"1,2 trillion dollar market in next 10 years!". Borje Ekholm (CEO-ERICSSON)

Standardization Activities and Timelines



Designed by 3G4G, based on roadmap from 3GPP, July 2019



Source: https://www.3gpp.org/specifications-technologies/releases

What is 5G?

❑ 5G is a 5th generation network:

- that connects new industries
- enable new services
- empower new user experiences
- set new levels of cost and energy efficiency.

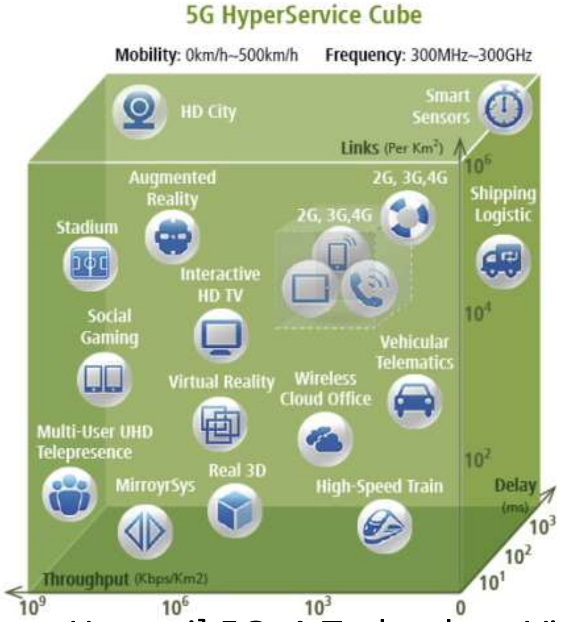
"Developing vertical applications for the future requires re-imagining of how we create and deliver data and services".

[Source]: Qualcomm Technologies, Inc.

Overview of 5G: Architectures – Services

The “5G HyperService Cube” a multi-dimensional overview

- throughput,
- latency
- number of connections



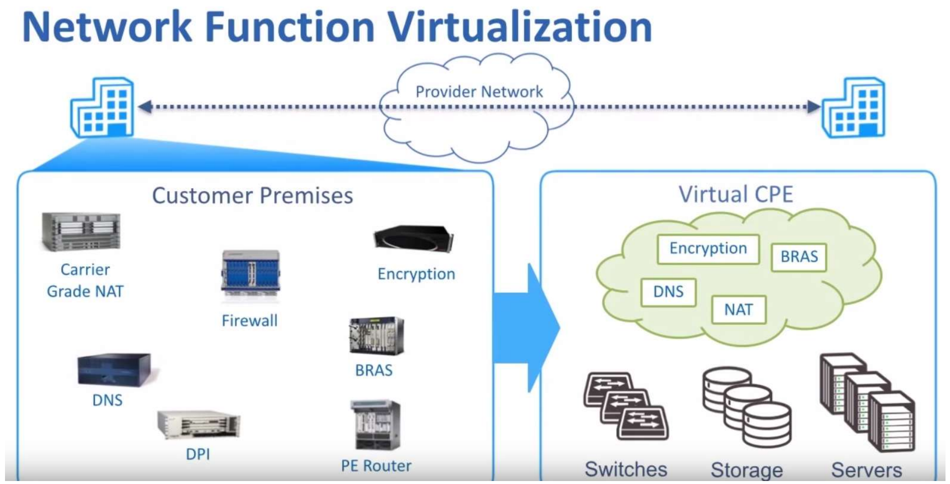
[Source - Huawei] 5G: A Technology Vision

Architecture elements are defined as virtualized network functions (NFV) that offer operators to provide services:

- Reduced hardware cost
- Flexible orchestration services

SDN is a solution for

- High demand on resources
- Unpredictable traffic patterns
- Rapid network reconfiguration
- Incorporating business rules

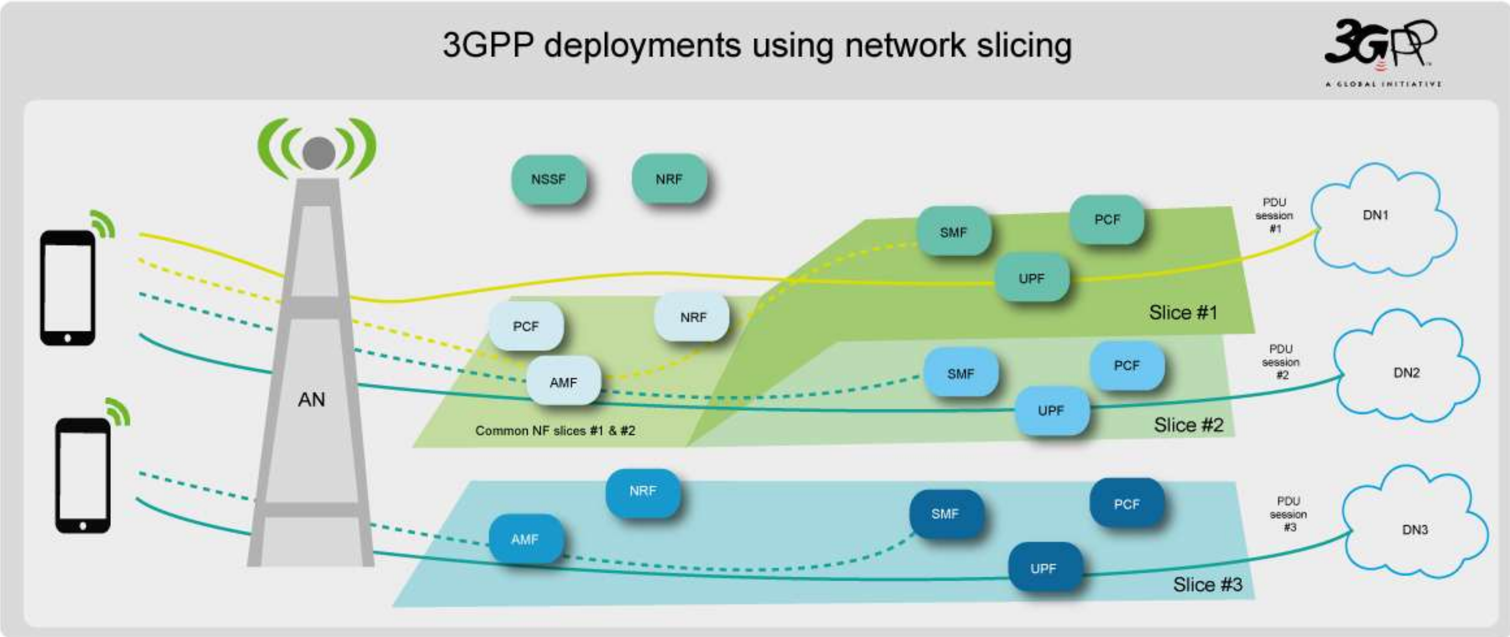


5G Service-based Architecture

Virtual network architecture – Network Slicing!

- multiple logical networks from common shared physical infrastructure
- to meet the specific needs:
  - applications, services, devices, customers or operators

Dynamic end-to-end network slicing for 5G



Courtesy 3GPP

5G Radio Access Methods and Technologies

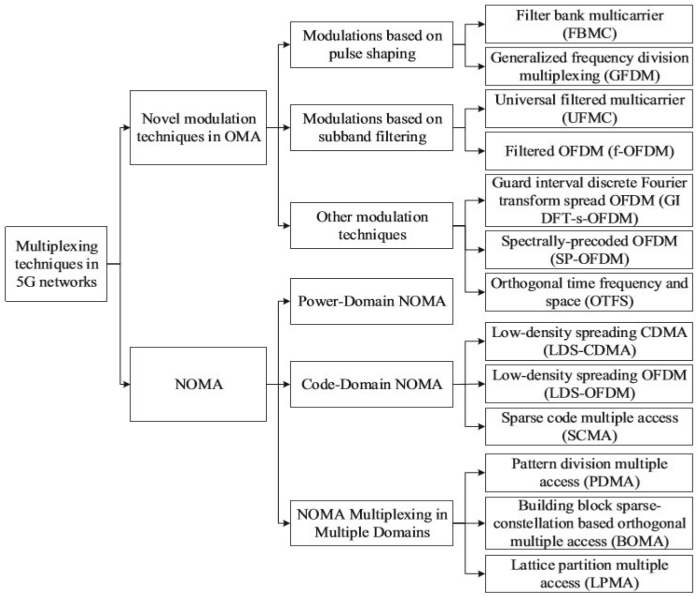
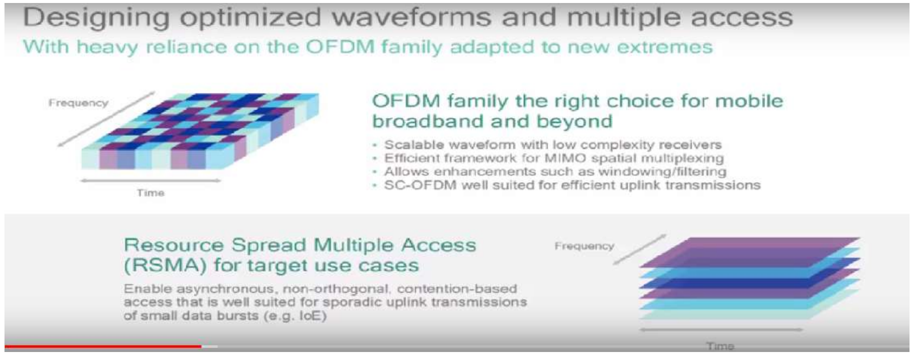
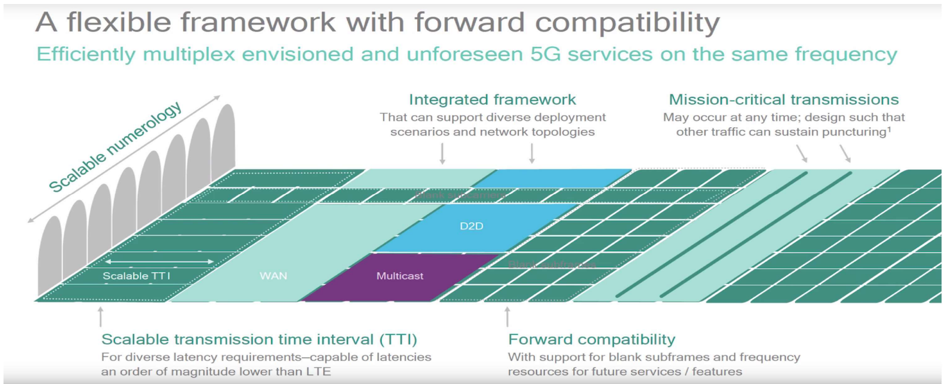
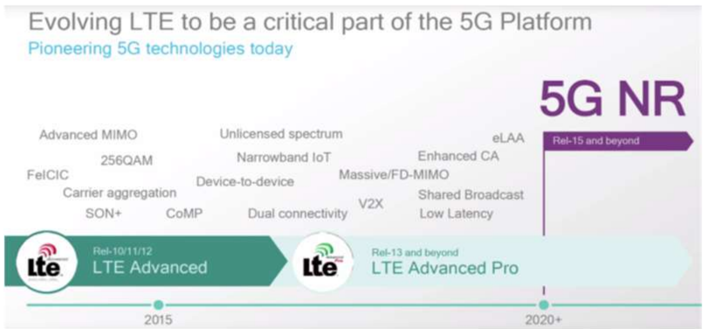


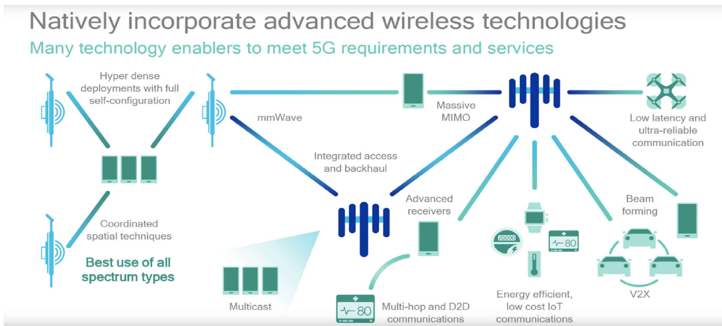
Fig. 1: A classification of the novel multiplexing techniques in 5G networks.

[Source]: Yunlong Cai et. al., "Modulation and Multiple Access for 5G Networks" , IEEE Communications Surveys & Tutorials, 2017.









[Source]: Qualcomm Technologies, Inc.

mmWave Channel Measurement Campaign by NYW

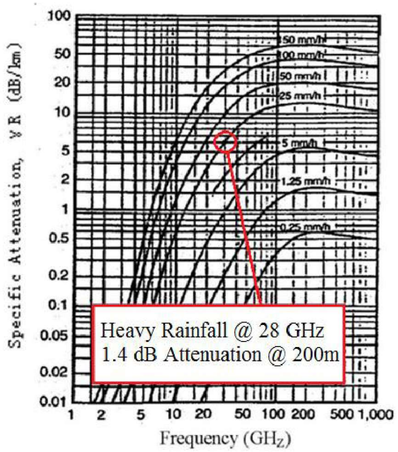


FIGURE 1. Rain attenuation in dB/km across frequency at various rainfall rates [26]. The rain attenuation at 28 GHz has an attenuation of 7 dB/km for a very heavy rainfall of 25 mm/hr (about 1 inch per hour). If cell coverage regions are 200 m in radius, the rain attenuation will reduce to 1.4 dB.

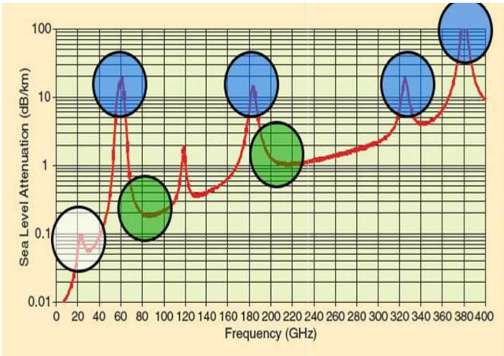
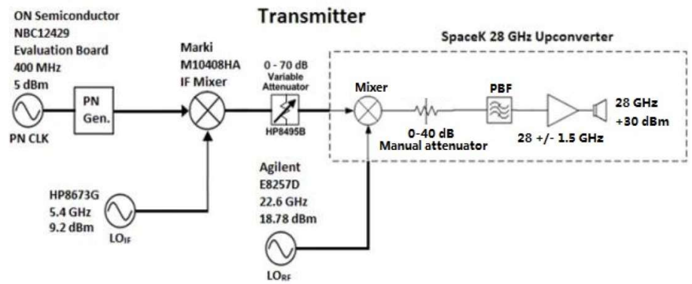


FIGURE 2. Atmospheric absorption across mm-wave frequencies in dB/km [1]. The attenuation caused by atmospheric absorption is 0.012 dB over 200 m at 28 GHz and 0.016 dB over 200 m at 38 GHz. Frequencies from 70 to 100 GHz and 125 to 160 GHz also have small loss.



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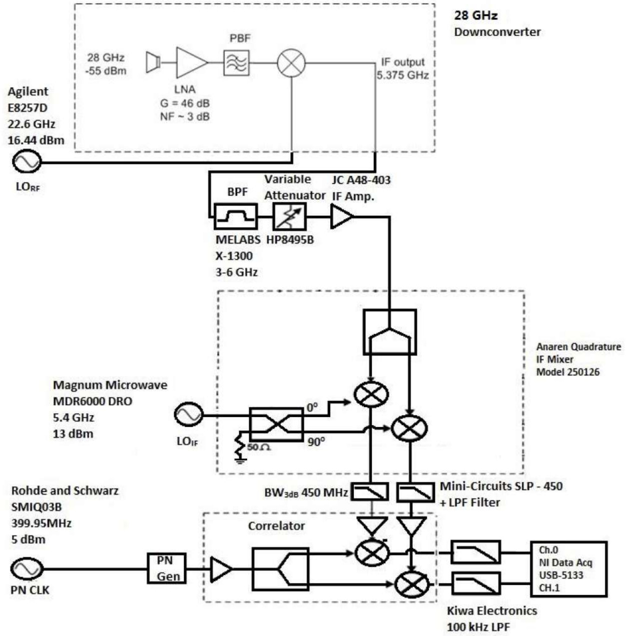
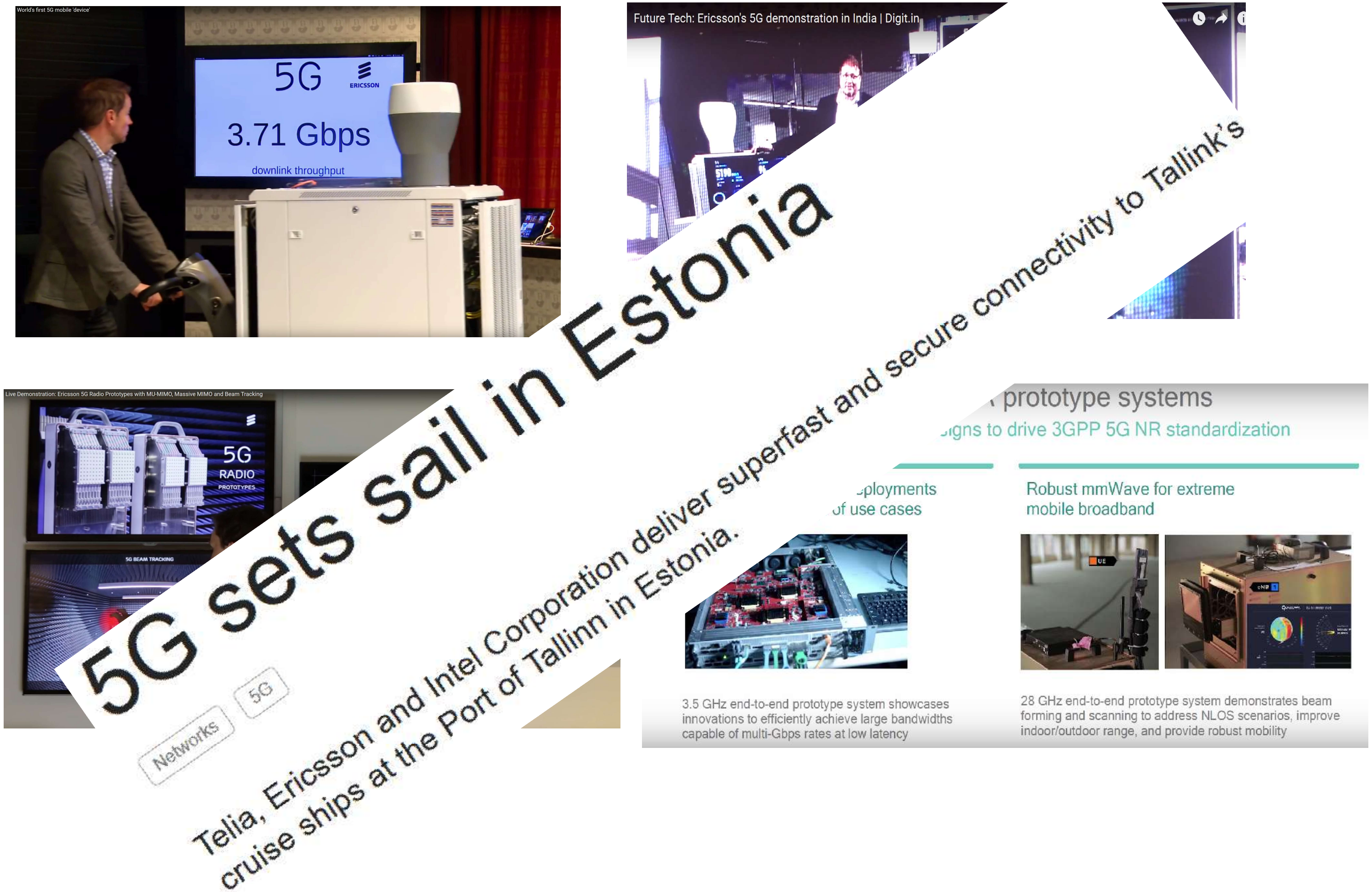


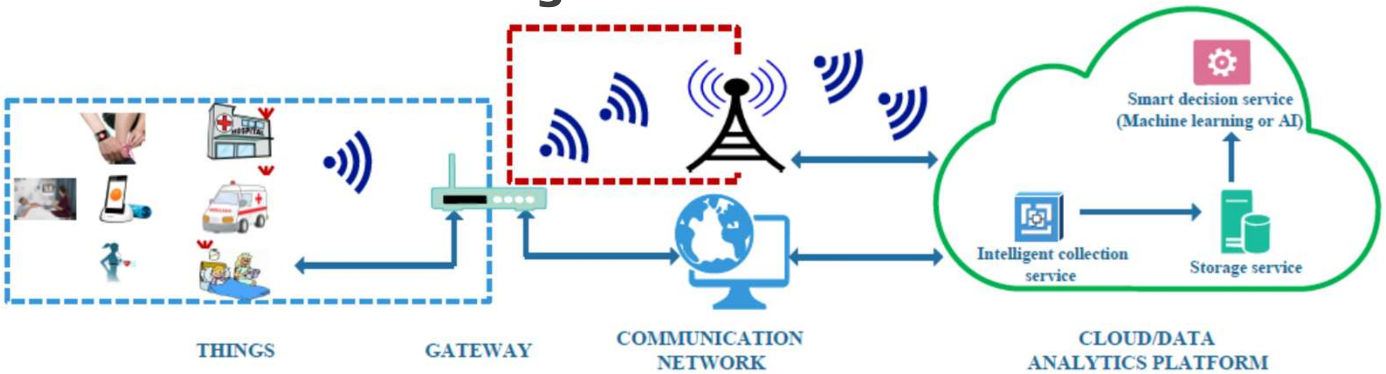
(b)

T. Rappport et al., *"Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!",* IEEE Access,

5G Demos, prototypes and Trials



Massive Internet of Things



Low Power Wide Area Technologies (unlicensed)

COMPARISON OF LPWA TECHNOLOGIES

Parameters	SIGFOX	LORA ALLIANCE	INGENU	WEIGHLESS-P	WEIGHTLESS-N	WEIGHTLESS-W
Modulation	UNB/ GFSK/DBPSK	CSS	RPMA-DSSS, CDMA	GMSK, offset-QPSK	GFSK	16-QAM, BPSK, QPSK, DBPSK
Band	SUB-GHz ISM	SUB-GHz ISM	ISM 2.4 GHz	SUB-GHz ISM or licensed	SUB-GHz ISM	TV White Space (470-790 MHz)
Data Rate	10-100bps	0.3-50 kbps	8bps-8kbps	200 bps-100kpbs	30kbps-100kbps	1 kbps-10 Mbps
Range	10 km (URBAN), 50 km (RURAL)	5 km (URBAN), 15 km (RURAL)	3 km (URBAN), 10 km (RURAL)	2 km (URBAN)	3 km (URBAN)	5 km (URBAN)
Topology	Star	Star on Star	Star, tree	Star	Star	Star
Link Symmetry	No	Yes	No	NA	Uplink only	NA
Devices per access point	1 Million	1 Million	$\leq$ 500,000	Unlimited	Unlimited	Unlimited
MAC	Unslotted Aloha	Unslotted Aloha	CDMA	TDMA/FDMA	Slotted Aloha	TDMA/FDMA
Power Consumption	Tx: $\leq$ 50 mA, Rx: $\leq$ 10-40 mA, Sleep: $\leq$ 0.01 mA	Tx: $\leq$ 50 mA, Rx: $\leq$ 10-40 mA, Sleep: $\leq$ 0.01 mA	Tx: $\leq$ 750 mA, Rx: $\leq$ 300 mA, Sleep: $\leq$ 0.072 mA	NA	NA	NA
Encryption	No Support	AES 128b	16B hash, AES 256b	AES 128/256b	AES 128b	AES 128b
Mobility Support	NO	Yes	Yes	Yes	Yes	Yes
Location Support	NO	Yes	Need GPS	NO	NA	NA
Over the air update	NO	Yes	Yes	Yes	NO	NA

Deployed well for a specific area (i.e., home, hospital)

Limited global coverage, for smart city, logistics and personal healthcare.

Low Power Wide Area Technologies (licensed)

Traditional cellular networks:

- global footprint (better coverage).
- Higher rates, reliable and secure
- Low energy efficiency to support ten years of battery lifetime for the end devices.

3GPP IoT STANDARDS SPECIFICATIONS

	LTE-M1	NB-IoT	EC-GSM-IoT
Deployment	In-band LTE	In-band, Guard-band LTE, Standalone	In-band GSM
Coverage (dB)	155.7	164	164 (with 33 dBm power class), 154 (with 23 dBm power class)
Downlink	OFDMA - 15KHz tone spacing, Turbo Code, 16 QAM, 1Rx	OFDMA, 15KHz sub-carrier spacing, tail-biting convolutional code (TBCC), 1Rx	TDMA/FDMA. GMSK, 8PSK (optional), 1 Rx
Uplink	SC-FDMA, 15KHz tone spacing, Turbo code, 16 QAM	Single tone, 15 KHz and 3.75 KHz spacing, SC-FDMA, 15Khz tone spacing, Turbo codes	TDMA/FDMA. GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 KHz	200 KHz
Data Rates UL/DL	1 Mbps - both for UL and DL	DL: 250 Kbps UL: 250 Kbps (Multi-tone), 20 Kbps (Single-tone)	
Duplexing	FD, HD, FDD and TDD	HD, FDD	HD, FDD
Power Saving	PSM, ext. DRX	PSM, ext. eDRX	PSM, ext. DRX

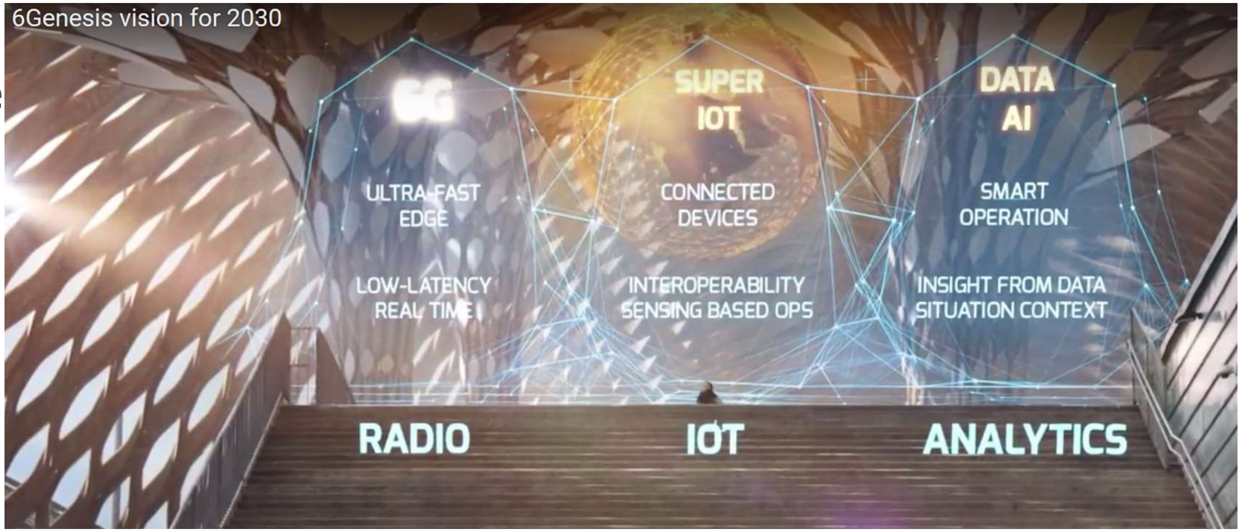
FUTURE – 6G?

6G-Enabled Wireless Smart Society & Ecosystem (6Genesis) - http://www.oulu.fi/university/6gflagship

Centre for Wireless Communications (CWC) – University of Oulu

Key Components:

Mobility as a service



The goals:

Support industry in finalization of 5G

Develop the fundamental technology needed to enable 6G

Speed up digitalization in society

To place Finland at the leading edge of 6G

"Developing vertical applications for the future requires re-imagining of how we create and deliver data and services."