ELEC-E7120 - Wireless Systems (Fall 2023)

Weekly Exercise Session #2

Unit I. Introduction

Dr. Alexis Dowhuszko and Prof. Jyri Hämäläinen

Teaching Assistants:

- Cesar Olvera Espinosa (cesar.olveraespinosa@aalto.fi)
- Nida Arshad (nida.arshad@aalto.fi)
- Xinyu Zhang (xinyu.1.zhang@aalto.fi)

Aalto University

Solutions for Homework 1

Unit I. Introduction

Homework 1

1.1. Mobile Generation

- Purpose is to perform a comparison between different cellular technologies (i.e., GSM, UMTS/WCDMA, LTE, and NR). Study of the main characteristics that these technologies have. For this purpose, build a table including the following information

  1. **Name** of 3GPP mobile generation of cellular technologies (with **enhancements**)
  2. Year of introduction (first commercial deployments: **Who**? **Where**? **When**?)
  3. Key technology enablers that were implemented (**Multiple Access & Duplexing method, Channel coding, MIMO, etc.**) and **peak data rate** (downlink and uplink)
  4. **Radiofrequency band** and **communication channel bandwidth** (give some examples, it does not need to be an exhaustive list)
  5. Most typical use case(s)

- Based on the table and your own knowledge, draw conclusions about the **trends** observed in this mobile generation **evolution**. For example, what is the trend observed in the **multiple access method**? What is the trend observed in the **peak data rate**? How often is a new generation introduced? What about the radio frequency channel bandwidth and the evolution of use cases?

Problem 1.1

Cellular technologies	GSM	UMTS	LTE	NR
Mobile generation of cellular technologies	2G	3G	4G	5G
Enhancements	GSM -> GPRS -> EDGE	W-CDMA-> HSPA -> HSPA+	LTE -> LTE-A -> LTE-A pro	NR->5G-Advanced
Year of introduction	1991 (Finland)	2001 (Japan)	2009 (Sweden & Norway)	2019 (South Korea)
Multiple access method	TDMA/FDMA (DL & UL)	CDMA(DL & UL)	SC-FDMA (UL), OFDMA (DL)	OFDMA (DL & UL)
Duplexing	FDD	FDD, TDD	FDD, TDD	TDD, but also FDD, SDL (supplementary downlink), SUL (Supplementary Uplink)
Channel Coding for Transport channel(TrCH)	Block code	Convolutional coding Turbo coding Service-specific coding	Turbo coding Tail biting convolutional coding	LDPC code Polar code
MIMO			2x2 MIMO 4x4 MIMO	Massive MIMO (16x16; 64x64)

Problem 1.1

Cellular technologies	GSM	UMTS	LTE	NR
Peak data rate (Mbps)	GSM: 0.0096 GPRS: 0.171 EDGE: 0.384	UMTS: 2 HSPA+: 28 (DL) 11 (UL)	LTE: 300 (DL) 75 (UL) LTE-A: 1000 (DL) 500 (UL)	NR: 20 000 (DL) 10 000 (UL)
Radio frequency band	850, 900, 1800, 1900 (MHz)	700, 800, 850, 900, 1500, 1700, 1900, **2100**, 2600, 3500 (MHz)	450, 600, 700, 800, 850, 900, 1500, 1700, 1800, 1900, 2000, 2100, 2300, 2500, 2600, **3500**, 3700, 5200 (MHz)	FR1: 410 - 7125(MHz) FR2-1: 24250-52600(MHz) FR2-2: 52600-71000(MHz)
Communication channel bandwidth	200 kHz	5 MHz	1.4, 3, 5, 10, 15, **20 MHz**	FR1: 5, 10, 15, 20, 30, 35, 40, 45, 50, 60, 70, 80, 90, **100 (MHz)** FR2: 20, 50, 100, 200, **400 (MHz)**
Typical use cases	Mobile phone calls, SMS	Mobile web surfing	Mobile multi-media Machine type communication Device-to-device communication	Enhanced mobile broadband (eMBB), Massive machine type communications (mMTC), Ultra-reliable and low latency communications (URLLC)

Problem 1.1

- Conclusions
  - **Every 10 years** -> A **next mobile generation** can be introduced
  - Efficiency of using **frequency bandwidth** resources is **increasing**
  - **Peak data rate grows has been growing 100-1000 times** every new generation
  - Radio **frequency band** is becoming **higher** from 2-3 GHz to below 6 GHz (low frequency). 5G also uses high-band frequency (millimetre wave, beyond 20 GHz)
  - Radio **channel bandwidth** has a significant **increase** (about 10 times) from 0.2 MHz in 2G to 100 MHz (low frequency) in 5G
  - Trend of use cases is **from the case that people can communicate** with each other **to the case that everything can be connected**

Problem 1.2

Aalto University

I. Compare the "nominal" coverages of wireless network technologies (WLAN/IEEE 802.11, WMAN/IEEE 802.16, WPAN/IEEE 802.15). Choose one example of technology/standard for each category, describing its purposes through its characteristics such as target service range, use cases, and so on.

Wireless Network	Technology	Coverage	Purpose	Use Cases
WLAN	Wi-Fi	45 meters(indoors) 90 meters (outdoors)	Allows users to move around the coverage area, often a home or small office, while maintaining a network connection	Possible use in warehouses, factories, retail stores, homes
WMAN	WiMAX	15 km	Wireless broadband to more remote places with no wired infrastructure	Educational institutes/campus, Transportation and Logistics
WPAN	Bluetooth	1-10 m	Allows transmission of data between Bluetooth-compatible devices	Cellular phones, computers, portable data terminals, and bar code printers or scanners.

Problem 1.2

Aalto University

II. Compare the pros and cons of using mobile standards networks (4G/5G) in the relevant applications for wireless networks mentioned in the previous bullet point.

		Pros	Cons
Mobile networks (4G/5G)		Large network coverage Increased privacy and security Continuous coverage (high mobility)	May have lower data rates (depending on cellular network) Costly infrastructure(licensed bands, cellular towers, etc) Less cost-effective
Wireless networks	**WPAN**	Low cost- little or no infrastructure required Unlicensed spectrum Low energy consumption	Limited range Interferes with radio signals (unlicensed spectrum) Low data rate
	WLAN	Low cost for operators (unlicensed spectrum) High data rate due to small area of coverage	Communication may not be very secure Increase in connecting devices would reduce data rate (collision, hidden-node problem) More energy consumption than PAN Possible health related problems when used in handheld devices (e.g., headset)
	WMAN	Wider coverage than LAN Lower implementation cost compared to WAN	Communication may not be very secure Data rate is slower compared to LAN Possible need of an external antenna

Problem 1.2

III. Do you think that Wi-Fi could be supplanted and disappear in the future by 5G and its evolutions (5G+, 6G, …), based on the prospect that in 5G (and beyond) standards data rate are expected to be much higher and latencies much lower than with Wi-Fi? Justify your answer in a proper way.

- *Higher data rates but Less mobility*
- *Best suited for indoor use cases; further support for IoT-connected devices in larger public spaces*
- *Cost-effective option*
- *Device Penetration (Billions of Wi-Fi-enabled devices already in use worldwide)*
- *Unlicensed Spectrum (Easily Accessible)*

- *Comparable data rates to Wi-Fi (if properly deployed)*
- *Higher mobility (long-range use cases)*
- *More costly to deploy (especially rural areas)*
- *Security and privacy*
- *Licensed spectrum (less interference)*
- *Due to License Spectrum, it limit the widespread deployment of 5G*

Problem 1.2

Aalto University

Conclusions

- Wi-Fi and 5G will coexist and complement each other most probably rather than being in competition.
- The choice between Wi-Fi and 5G will depend on many factors such as use case, deployment cost, spectrum availability, and the need for control and security.
- At the moment, Wi-Fi is more popular for indoor *"nomadic"* users, whereas 4G/5G seems to be a better option for outdoor "moving" users.
- **Example:** A connected car may offer in-Vehicle Wi-Fi for users' devices, while the car itself connects to a 5G cellular network

Homework 1

1.3 Licensed vs Unlicensed (1.5 pts)

- Study if these following wireless communication systems use licensed or unlicensed electromagnetic spectrum: mobile networks (LTE and NR), Bluetooth, GPS/Galileo, Wi-Fi (802.11ac), Globalstar/Iridium/Starlink, RFID, Li-Fi/IEEE 802.11.bb. For this purpose, you can construct **a table that includes the following information**:
  1. Frequency band of operation (does not need to be an exhaustive list)
  2. Transmission power (in Watts/dBm) (focus on the order of magnitude)
  3. Transmission method (modulation)
  4. Estimated range of operation
  5. Is frequency band for licensed or unlicensed use?

- Based on the table and your own knowledge, draw conclusions about the main **differences between licensed and unlicensed wireless systems**. Are there any **visible patterns among systems that use the same kind of spectrum**? Why do you think these patterns exist or not? Justify your answer in a simple but clear way.

Problem 1.3

Aalto University

Wireless system	Licensed / Unlicensed	Frequency band of operation	Transmission Power	Transmission method (modulation)	Estimated range of operation
LTE	**Licensed**	700 - 2600 MHz	200 mW (UE) 10 W (BS)	OFDMA/SC-FDMA	**2-10 km**
NR	**Licensed**	450 - 6000 MHz (Sub-6G), 24-52 GHz (mmWave)	200mW (UE) 250 mW (BS for a Small Cell) 120 W (BS for the largest 5G MIMO arrays)	OFDMA	**50m-1 km**
GPS/Galileo	**Licensed**	1.6 GHz	50 W	BPSK	**5000 -12000Km (MEO)**
Globalstar/Iridium	**Licensed**	1616~1626.5 MHz	7 W	DE-QPSK	**500-1500Km (LEO)**
Wi-Fi (802.11ac)	**Unlicensed**	2.4 / 5 GHz	100 / 200 mW	OFDM	**170 m**
Bluetooth (BLE power)	**Unlicensed**	2.4 GHz	10~500mW	GFSK	**1-10 m**
RFID	**Unlicensed**	**LF:** 125~134.2 KHz, 40~148.5 KHz **HF**:13.56MHz **UHF**:433MHz, 865-868MHz(EUR), 902~928MHz(US)	10mW~1W	ASK	**1-10m**
Li-Fi	**Unlicensed**	Ultraviolet: 750 THz-30 PHz Visible light: 430-750 THz Infrared light: 300GHz-430THz	1~100W	OFDMA	**10m**

Problem 1.3

Aalto University

🤔 **Main Differences:**

- For **most licensed** wireless systems have **a higher range of operation** than unlicensed wireless systems.
- **Unlicensed** wireless systems tend to be more in a **shorter range of operation** (Wi-Fi, Bluetooth)
- The frequency band is **licensed** are for **a large-scale deployment to provide a quality service** to **a large number of people** (LTE, NR or satellite communications)