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ELEC-E7120 Wireless Systems

Homework for Unit 1

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Problem 1.1 (1.5 point). *Mobile Generations*

- 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?

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- Table

Item		GSM	UMTS/WCDMA	LET	NR
Name		Global System for Mobile Communications	Universal Mobile Telecommunications System / Wideband Code Division Multiple Access	Long-Term Evolution	New Radio
Mobile generation		2G	3G	4G	5G
Year of introduction	Who	Radiolinja (now part of Elisa Corporation)	NTT DoCoMo	TeliaSonera (now part of Telia Company)	SK Telecom
	Where	Tampere, Finland	The Tokyo and Yokohama areas of Japan.	Stockholm and Oslo	Seoul, South Korea
	When	July 1, 1991	October 1, 2001	December 14, 2009	April 3, 2019

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Key technology enablers	Multiple access	Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA)	Code Division Multiple Access (CDMA)	Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink Single Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink	Orthogonal Frequency Division Multiple Access (OFDMA)
	Duplexing method	Frequency Division Duplex (FDD)	Frequency Division Duplex (FDD) and Time Division Duplex (TDD)	Frequency Division Duplex (FDD) and Time Division Duplex (TDD)	Frequency Division Duplex (FDD), Time Division Duplex (TDD) and dynamic TDD (D-TDD)

	Channel coding	Convolutional code	Turbo code	Turbo code	LDPC (Low-Density Parity-Check) codes and polar codes
	MIMO	Single-antenna transceivers for both the base station and the mobile device	Diversity rather than MIMO	MIMO	massive MIMO
Peak data rate	Downlink	9.6 Kbps	7.2 Mbps	100 Mbps	20 Gbps
	Uplink	2.7 Kbps	5.76 Mbps	50 Mbps	10 Gbps
Radiofrequency band		900 MHz, 1800 MHz and 850 MHz Band	2100MHz, 850MHz and 1900 MHz Band	700 MHz, 1800 MHz, 2600 MHz and AWS (Advanced Wireless Services) Band	Sub-6 GHz (600 MHz, 2.5 GHz, 3.5 GHz and 4.9 GHz) and mmWave Bands
Communication channel bandwidth		200 kHz	5 MHz and 10 MHz	1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz	5 MHz, 10 MHz, 20 MHz, 40 MHz, 50 MHz, 100 MHz

Typical use cases	Voice Calls, Short Message Service (SMS) and Low-Speed Data	Voice and Video Calls, Mobile Broadband and GPS and Location-Based Services	High-Speed Mobile Broadband, Voice over LTE (VoLTE) and IoT Connectivity	Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC). and Massive Machine Type Communication (mMTC)

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- Conclusion:

From GSM to NR, the multiple access method upgraded from FDMA and TDMA to CDMA, then OFDMA in NR. So, the trend in multiple access methods is to increase flexibility and efficiency, and the aim is to accommodate the increasing diversity of services and applications in communication.

Also, the peak data rate increases significantly with each generation of communication technology. From 9.6 Kbps in GSM to 10 Gbps in NR, the peak data rate has grown by almost a million times.

Over the past few decades, a new generation has been introduced nearly every ten years. The radio frequency channel bandwidth has grown many times over, and the evolution of radio frequency channel bandwidths reflects the use cases. For example, the usage transfers from traditional voice calls to high-speed data services, IoT connectivity, and latency-critical applications. This development in channel bandwidth plays an important role in adapting to the diverse needs of users and industries.

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Problem 1.2 (1.5 point). *Mobile vs Wireless technologies*

- 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.
- 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.
- 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.

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WLAN (Wireless Local Area Network) - IEEE 802.11:

- Example Standard: IEEE 802.11ac (Wi-Fi 5)
- Coverages: 30 to 45 meters (indoor); 45 meters (outdoor)
- Use Cases: IEEE 802.11ac is usually used in indoor wireless networking, mobile device connectivity, video streaming, online gaming, and more.
- Purpose: WLAN technology is designed for providing wireless connectivity and local network access within a relatively small area, typically within a building.

WMAN (Wireless Metropolitan Area Network) - IEEE 802.16:

- Example Standard: IEEE 802.16e (WiMAX)
- Coverages: several miles, around 30 miles (typical)
- Use Cases: WiMAX is developed to provide broadband wireless access to underserved or remote areas and it can also perform as a last-mile solution for internet service providers (ISPs). In addition, WiMAX can be used for mobile

broadband services and wireless backhaul for cellular networks.

- Purpose: WMAN is designed to provide wireless connectivity over larger geographical areas, typically covering a city or metropolitan region. It is used to extend network coverage beyond the reach of WLANs.

WPAN (Wireless Personal Area Network) - IEEE 802.15:

- Example Standard: IEEE 802.15.4
- Coverages: 10 meters
- Use Cases: WPAN is used in home and industrial automation, healthcare devices, and other applications where low-power and short-range wireless communication is required.
- Purpose: WPAN is designed for short-range wireless communication within a very limited area such as a few meters and low-power and low-data-rate applications.

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WLAN (Wireless Local Area Network) - IEEE 802.11:

- Pros of Using 4G/5G:
  1. High data rates: 4G/5G can offer high data rates, which are suitable for users and applications.
  2. Wide coverage: 4G/5G can offer wide coverage in both urban and rural areas.
  3. Flexibility: Users can transfer between 4G/5G and WLAN, so the flexibility is much better.
- Cons of Using 4G/5G:
  1. High power consumption: Mobile networks consume much more power compared to Wi-Fi.
  2. High cost: Usually Wi-Fi costs less than mobile network.

WMAN (Wireless Metropolitan Area Network) - IEEE 802.16:

- Pros of Using 4G/5G:
  1. High data rates: 4G/5G can offer high data rates.
  2. Mobility: 4G/5G can support mobile connections, so users can keep connecting while moving.
  3. Capacity: 4G/5G can accommodate a huge number of devices and applications.
- Cons of Using 4G/5G:
  1. Small range: In remote areas, 4G/5G signals become weak because of the small number of base stations.
  2. Spectrum and Interference: In densely populated areas, spectrum resource is not enough, and interference between users can be severe.

WPAN (Wireless Personal Area Network) - IEEE 802.15:

- Pros of Using 4G/5G:
  1. Security: 4G/5G can offer robust security features.
  2. Standardization: 4G/5G is well-standardized, making it easy to develop IoT using 4G/5G.
  3. Scalability: 4G and 5G technologies can extend coverage for WPAN applications
- Cons of Using 4G/5G:
  1. High power consumption: Mobile networks consume much more power compared to WPAN.
  2. High cost: Usually mobile network costs more than WPAN.
  3. Complexity: Mobile networks and devices need more complex network architectures and protocols.

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I think that Wi-Fi could not be supplanted and disappear in the future by 5G and its evolutions for the following reasons:

1. Power consumption:
   Devices connected to Wi-Fi consume less power than those to mobile networks. Wi-Fi is important in sustainable development.
2. Cost:
   Using mobile networks, especially with high-speed 5G and its evolutions (5G+, 6G, …), can be more expensive than using Wi-Fi.
3. Use cases:
   Wi-Fi is suitable for local area network (LAN) applications in indoor areas and public spaces. Wi-Fi is widely used for indoor connectivity due to its ease of use, low cost, and compatibility with a wide range of devices.
4. Spectrum Availability:
   Wi-Fi operates in unlicensed spectrum bands and are available for free use by the public. Mobile networks rely on licensed spectrum which is managed strictly by telecommunications companies

In conclusion, I don't think Wi-Fi will disappear in the future. Instead, Wi-Fi will continue to develop to adapt to future market changes. Both Wi-Fi and mobile networks (5G, 6G, …) will play significant roles in communications.

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Problem 1.3 (1.5 points). *Licensed vs unlicensed wireless system*

- 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.

- Table:

	mobile networks (LTE and NR)	Bluetooth	GPS/Galileo	Wi-Fi (802.11ac)	Globalstar/Iridium/Starlink	RFID	Li-Fi/IEEE 802.11.bb
Frequency band of operation	600 MHz to 100 GHz	2.4 GHz	1.57542 GHz	2.4 GHz and 5 GHz	L-band(1-2 GHz))/ Ku-band (12-18 GHz) and Ka-band (26.5-40 GHz)	LF (Low Frequency, 125-134 kHz), HF (High Frequency, 13.56 MHz), and UHF (Ultra-High Frequency, 860-960 MHz)	400 THz to 800 THz
Transmission power	23 dBm to 33 dBm	0 dBm to 20 dBm	less than 0 dBm	13 dBm to 30 dBm	45 dBm	less than 0 dBm (passive) 10 dBm to 30 dBm (active)	0 dBm to 30 dBm

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Transmission method	OFDMA, SC-FDMA, QAM	FHSS, AFH	CDMA	OFDM	PSK, QAM	ASK, QAM	OOK
Estimated range of operation	a few hundred meters to a few kilometers	a few meters	the entire Earth's surface	30 to 45 meters (indoors)	global coverage	a few meters	the area illuminated by the light source
Frequency band licensed or unlicensed	licensed	unlicensed	licensed	unlicensed	licensed and unlicensed	unlicensed	unlicensed

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Main differences:

1. Bands:
   Licensed wireless systems operate in frequency bands that are controlled by the government and access to these bands needs licenses. Unlicensed wireless systems operate in frequency bands for shared use by users without the need for specific licenses. These bands are open for anyone to use, but devices must follow rules to avoid interference.
2. Quality:
   Licensed systems usually offer higher quality and reliability, and interference and congestion are less than unlicensed systems.
3. Coverage:
   Licensed systems can provide broader coverage and longer-range communication while unlicensed systems have shorter communication ranges and are more susceptible to interference.

Are there any visible patterns among systems that use the same kind of spectrum?

- Yes. For example, both Wi-Fi and Bluetooth operate in the unlicensed 2.4 GHz and 5 GHz bands.

Why do you think these patterns exist or not?

- Physics law
  Propagation and signal behavior are similar at specific frequencies, which are related to specific functions. Technologies with similar functionality use similar frequency bands
- Methods and technologies
  Signal processing methods in some frequency bands are relatively mature and can be exploited by other technologies.
- Supervision
  The use of specific frequency bands is convenient for supervision by the relevant authorities.