Aalto University
School of Electrical
Engineering

ELEC-E7120 Wireless Systems

Re-take exam

Date: 27.3.2023
Duration: 3 hours
Max. points: 40

Name: _____ Student No.: _____

General guidelines:

- The exam consists of five parts and two pages
- Individual questions per topic are guidelines to elaborate the answer as a single statement
- The only materials that you are allowed to have on your desk are writing instruments and calculator with basic scientific functionalities. All electronic devices, including cell phones and laptops, are prohibited. Any other personal items must be set aside before exam starts.

Part 1: General Concepts in Wireless Communications (8 points)

1.a. What is the main goal of the ITU? What kind of members does this international organization has? What kind of *"documents"* does this organization issue? What kind of target goals do these *"ITU documents"* specify? What is the connection that exist between the work done by the ITU and by 3GPP? Can you give a concrete example under the scope of contemporary 5G technologies?

1.b. What is the difference between licensed and unlicensed spectrum? Which are the authorities in in charge of regulating the use of both kinds of spectrum at the national and/or international level? Are both kinds of spectrum used for the same purpose? What are the tools that designers have to control the co-channel interference that is generated in each case? Name two representative wireless technologies that use each of these kinds of spectrum.

Part 2: Wireless Channel Characteristics and Modeling (8 points)

2.a. Consider an outdoor cellular system with cells that covered a quite large part of a city, generating Inter-Symbol Interference (ISI) in the received signal samples. Which ISI mitigation technique can a mobile cellular standard based on CDMA (3G) or OFDMA (4G/5G) use? Explain each of them in a simple but clear way.

2.b. A terrestrial user equipment (UE) has a communication link with a High-Altitude Platform (HAP) placed at 20 km on a carrier frequency $f_{UE\text{-}HAP}$ = 30 GHz. The UE has also a communication link with a Low Earth Orbit (LEO) satellite placed at 2000 km on a RF carrier $f_{UE\text{-}LEO}$ = 3 GHz. Both links use the same RF channel bandwidth. The antenna gains of HAP and LEO satellite are G_{HAP} = 7 dBi and G_{LEO} = 23 dBi, respectively (antenna gain has the same gain for both frequency bands). The gain of the antenna in the UE in dBi is fixed but unknown (same value for both RF bands). Let us assume that the UE uses the same transmit power in both UE-HAP and UE-LEO links. Consider that only free-space path loss (FSPL) is present in both ground-to-air uplinks, with attenuation modelled as

$$\text{FSPL} = \left(\frac{4\pi}{\lambda}\right)^2 d^2,$$

where 'λ' is the wavelength of the radio signal and 'd' is the distance between transmitter and receiver. Consider that the spectral power density of noise 'N_0' is the same for both HAP and LEO receivers. Let us assume that receive SNR in that HAP is 11 dB. What is the SNR that should be observed at the LEO satellite given the assumptions listed above?

Part 3: Wireless link connectivity (8 points)

3.a. Difference between multiplexing and multiple access concepts. What is the purpose of each of them? In which dimensions (degrees-of-freedom) can each of these methods be applied? Can you illustrate a practical communication system example in which the difference between both concepts is clearly identified? Whenever is possible, try to use pictures to explain the difference between them.

3.b. Describe at least two advantages and two disadvantages of the following multiple access techniques: (1) CDMA and (2) OFDMA. Give a brief but clear justification of each of them.

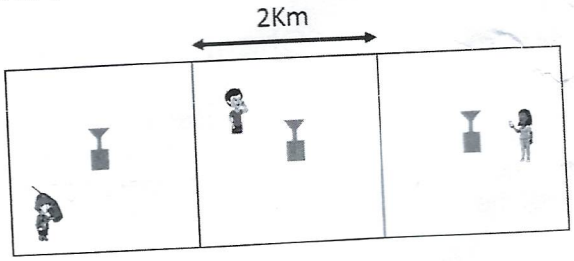
Part 4: Cellular Systems (8 points)

4.a. How does machine-type communication differ from human-type communications? Let us assume that you are responsible of designing a Low-Power Wide Area Network (LPAN) system. Which key performance indications will be your priorities? Justify your answer properly. Give two examples of IoT use-cases. How does NB-IoT tackle Maximum Coupling Loss (MCL) requirement?

4.b. Consider the one-dimensional linear cellular system shown below, with three square cells of length 2km and a base station in the middle. All base stations and mobiles use omni-directional antennas (same gain in all directions). Assume that signal propagation follows the free space path loss formula and that the same FDD paired channels are in the three cells for both uplink and downlink (frequency-reuse factor = 1). Consider as well that transmit power of mobiles is 'P_m' and transmit power of base stations is 'P_b' [watt]. Neglecting the effect of noise with respect to interference (i.e., SINR ≈ SIR), and considering that each cell has exactly one mobile station, find:

- For the uplink direction of communication, the worst-case locations that the interfering users (in the left-hand and right-hand cells) and the target user in the middle cell must jointly take have the worst possible received SIR in the middle base station
- Using the location of the three mobiles identified in the previous point, find the SIR that the mobile user in the middle cell would observe in downlink.

Note that the square-shapes in the figure below show the *"imaginary"* border of the square cells.



Part 5: Wireless Systems (8 points)

5.a. What is the difference between Direct Sequence Spread Spectrum (DSSS) and Frequency-Hopping Spread Spectrum (FHSS)? What are the names of the most popular IEEE wireless standards that use each of these Spread Spectrum schemes to communicate on the 2.4 GHz ISM band? How is co-channel interference controlled in each case (both intra- and inter-system interference)? Justify your answer in a simple but clear way.

5.b. Why are Non-Terrestrial Networks (NTN) important in the context of 5G and beyond? What kinds of nodes are expected to be deployed in NTNs? Are all of them placed at the same altitude? Why? What are the challenges that non-terrestrial network designers should face? List three representative use cases/application in which using NTN connectivity is a much more (economically) viable solution for mobile connectivity when compared to network that only use terrestrial nodes (base station) on the ground level.