Aalto University
School of Electrical
Engineering

ELEC-E7120 Wireless Systems
Final Exam

Date: Mon. 17.10.2022 Name: _____ Student No.: _____
Duration: 3 hours
Max. points: 40

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. List three key concepts that differentiate a mobile/cellular communication system (like LTE or NR) from other wireless communication technologies (like IEEE 802.11 or Bluetooth). Explain each of these concepts in a brief but clear way.

1.b. What is the goal of IEEE standard association? What kind of standards does IEEE SA develop in the field of wireless communications? Name key standards that this association has developed for WLANs, WPANs and WMANs. List at least two characteristics that differentiate each of them.

Part 2: Wireless Channel Modeling (8 points)

2.a. The free-space path-loss (FSPL) attenuation that a radio signal experience is given by

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

where *'λ'* is the wavelength of the radio signal and *'d'* is the distance between transmitter and receiver. Let us also assume that propagation measurements in a city kind of environments suggests a terrestrial path-loss (TPL) attenuation model that attains the form

$$\text{TPL} = \left(\frac{4\pi}{\lambda}\right)^2 d^{3.6}.$$

Consider that the separation distance between transmitter and receiver are 1.5 km. How many "less" dBs of received signal power do we have when the propagation takes place in a city kind of environment, when compared to the free-space case? Assume a carrier frequency of 700 MHz (speed of light $3\text{x}10^8$ m/sec.) Repeat the evaluation when the carrier frequency increases to 3.5 GHz.

2.b. What causes *'small-scale fading'* in a radio channel and how does it affect digital transmissions? Some wireless channels exhibit frequency-selective fading: Give a brief explanation of what is the effect of frequency-selective fading in a received radio signal. Finally, explain the connection that exists between frequency-selective fading and small-scale fading concepts. Provide a concise answer to each of these sub-questions.

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 it is possible, try to use pictures to explain the different concepts.

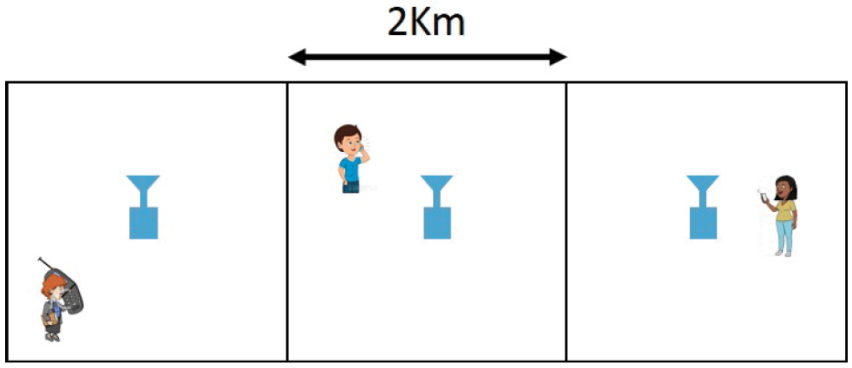
3.b. What generates the so-called *"cross-link"* (also known as *"cross-slot"*) interference problem in flexible TDD wireless networks? Does it represent a serious challenge for mobile operators? Is this problem more serious in the downlink or in the uplink direction of communication? How can this impairment be kept under control? Justify your response in a simple but clear way.

Part 4: Cellular Networks (8 points)

4.a. What is the concept of "carrier aggregation"? Present and explain in a brief but clear way the main advantage of using carrier aggregation in 5G. What are the challenges of carrier aggregation in 5G, when compared to 4G? For this, consider the dynamic mechanisms that are used to control the allocated resources in uplink/downlink in presence of a TDD air interface.

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 (equal gain in all directions). Assume that signal propagation follows the free space path loss formula, that the same FDD paired channels are in the cell for both uplink and downlink. Consider as well that transmit power of mobiles is 'P_m' [watt] and transmit power of base stations is 'P_b' [watt]. Neglecting the effect of noise 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 and right 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 observes 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 Synchronous Connection-Oriented (SCO) links and Asynchronous Connection-Less (ACL) links within Bluetooth technology? What kind of communication services must have designers had in their mind when designing each of these link types? What is the link-layer mechanism that can be used to protect the payload of the user (i.e., useful information) in case of a collision over the air interface? Indicate clearly if these link-layer mechanisms are present in SCO links, ACL links, or both.

5.b. What do the acronyms "VLC" and "FSO" mean? What portion of the electromagnetic spectrum is used to enable wireless connectivity in each of these cases? What kind of "light sources" are used in transmission both VLC and FSO? Which of both technologies is more suitable for *"wireless access"* and for *"wireless point-to-point"* connectivity? Why? Propose two use-cases (application scenarios) in which VLC has notable advantages with respect to FSO, and two use cases in which FSO has notable advantages with respect to VLC. Give a short justification of your choice.