Aalto University
School of Electrical
Engineering

ELEC-E7120 Wireless Systems

Final Exam (Max. points: 40) Duration: 3 hours.

Date: Mon. 16.10.2023 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)

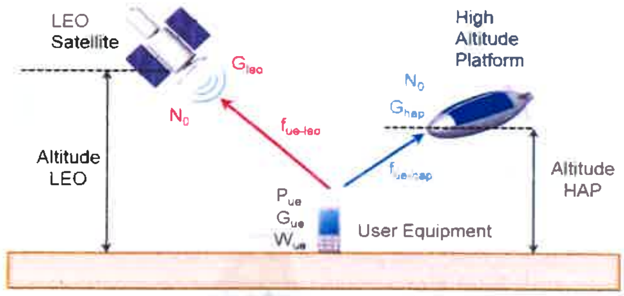
1.a. What is the difference between licensed and unlicensed spectrum? Which are the authorities in charge of regulating the use of both kinds of spectrum at the national and/or international level? Are both kinds of spectrum used for the same purpose? What are the tools that designers can use control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

1.b. What does 3GPP mean? What is the main goal of this organization? What kind of international organizations are members of this partnership? What kind of structure does 3GPP has? How is the collaborative carried out at 3GPP? Name three standards that have been developed by 3GPP.

Part 2: Wireless Channel Modeling (8 points)

2.a. A terrestrial user equipment (UE) has a communication link in uplink with a High-Altitude Platform (HAP) placed at a height of 25 km on a carrier frequency $f_{UE\text{-}HAP}$ = 30 GHz. The same UE has another communication link in uplink with a Low Earth Orbit (LEO) satellite placed at a height of 2000 km on a RF carrier $f_{UE\text{-}LEO}$ = 3 GHz. Both links use the same RF channel bandwidth (W_{UE}). See figure below for a schematic diagram, in which distances are just illustrative and are not in scale.

The antenna gains of HAP (@ 30 GHz) and LEO satellite (@ 3 GHz) are G_{HAP} = 7 dBi and G_{LEO} = 23 dBi, respectively. The gain of the antenna in the UE (G_{UE}) is fixed but unknown (same value for both 3 and 30 GHz). Let us assume that the UE uses the same transmit power (P_{UE}) 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

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

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. Determine the SNR that should be observed at the LEO satellite given the assumptions listed above.

2.b. What are the situations in which Okumura-Hata model should be applied? What are the basic propagation mechanisms, borrowed from the theory of Physics, that Okumura-Hata model takes into account in its formulas. Which component of the statistical channel modelling of a wireless channel does it model (i.e., mean path loss, shadowing, or fast fading)? Can Okumuara-Hata model be directly applied for studying the coverage range a Wi-Fi network? Justify your answer propoerly.

Part 3: Wireless link connectivity (8 points)

3.a. Explain the functionality of the channel encoder and source encoder blocks in the context of a wireless communication system. What is the main difference that exists between them? In which order should these encoders be placed in the transmitter chain (*i.e.*, which one should come first)? Why? What is the purpose of combining an interleaving block with a channel encoder block? How should the size of the interleaving block be selected? Justify your answer properly.

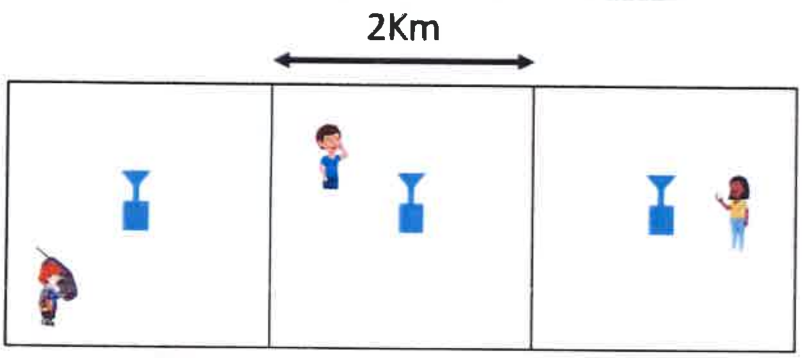
3.b. What is the difference between Frequency Domain Duplexing (FDD) and Time Domain Duplexing (TDD)? Describe at last two advantages and two disadvantages when comparing them.

Part 4: Cellular Networks (8 points)

4.a. Present at least two strong reasons why cellular concepts evolved from the conventional *single-cell* radio system approach (before 1970s) to the multi-cell system approach (after 1980s). Define cell clusters and frequency reuse concepts. How can co-channel interference (CCI) be controlled in cellular systems? Explain at least two methods to control CCI in the different mobile generations.

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 the *'piconet'* and *'scatternet'* concepts within Bluetooth standard? How many master and slave devices can a Bluetooth piconet and scatternet have? How is co-channel interference controlled in each case (*i.e.*, intra-piconet and intra-scatternet interference)? What happens with the aggregate throughput of a Bluetooth piconet as the number of devices grows? Does the same effect take place when the number of devices in a Bluetooth scatternet increases? Explain all these concepts in a simple but clear way.

5.b. Compare radio wireless communication technologies and optical wireless communication technologies. Identify two features that should favour the use of optical wireless technologies (VLC or FSO) over radio wireless ones, and two features that should favour the use of radio wireless technologies over optical wireless ones. Please, give a short a short but clear explanation of each of them. Propose two use cases (application scenario) in which optical wireless would have notable advantages with respect to State-of-the-Art solutions based on radio communications.