Aalto University
Comnet

S-72.3216 Radio Communication Systems I (5 cr)

Exam (17th March, 2014)

Exc.	Problem 1	Problem 2	Problem 3	Problem 4	Problem 5	**Sum**
max.	6	6	6	6	6	**30**

Exam rules and regulations: The only materials you are allowed to have at your desk during the exam are writing instruments and calculator with basic scientific features. All electronic devices, including cell phones and laptop computers, are prohibited. Any other personal items must be set-aside (out of view) prior to the exam start.

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Problem 1: *(General concepts within radio communication systems)*

(a) What does the acronym IMT-Advanced mean? Specify the name of the international organization that is behind its development. Define the main goals that were expected to be achieved in IMT-Advanced report. How many proposals (technologies) were presented as response to IMT-Advanced document? Name these proposals (technologies) and mention three characteristics that are shared by them.

(b) List three concepts that differentiate a mobile communication technology (like LTE) from other wireless communication technologies (like Wi-Fi). Explain each of these concepts in a brief but clear way.

(c) What is the difference between licensed and unlicensed spectrum? Who is in charge of regulating the use of them (national or international authorities)? Are both kinds of spectrum used for the same purpose? What are the tools that designers have to control the co-channel interference generated in each case? Name 2 wireless technologies that use each kind of spectrum.

(d) Enumerate the three different phases in which a network planning procedure is usually divided. Explain briefly the main idea behind each of them.

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Problem 2: *(Channel modeling for mobile communication systems)*

(a) In which situation(s) can the theoretical channel modeling be used? What is (are) the key 'theoretical tool(s)' that we have to model the propagation of radio waves using this approach? Mention the advantages and disadvantages of theoretical channel modeling. Does it make more sense to use this approach to model the propagation of electromagnetic waves in the near-field region or far-field region of the antenna of a radio equipment? Why/why not? In any case, justify your answer in a proper way.

(b) Enumerate the three different types of fading that can be usually differentiated, when modeling statistically the instantaneous path loss attenuation

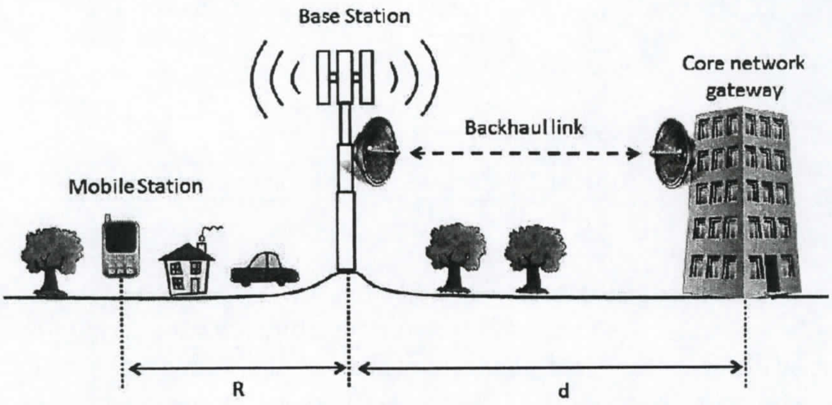

Figure 1: Wireless communication system operating in a sub-urban area. The system consists of a single isolated Base Station (BS) with coverage area R. Backhaul link is implementing using a point-to-point microwave data link with directional antennas, to cover a distance d between the core network gateway and the cell site.

in a wireless link. What originates these three different behaviors? Explain the main characteristic(s) of each of these types of fading.

(c) A single-cell radio communication system operates at $f_c = 900$ MHz to serve an isolated village with environmental conditions similar to a sub-urban area (see Fig. 1 for more details).

The wireless communications system has a single Base Station (BS) located in the center of the village. The height of the BS antenna and the height of the Mobile Station (MS) antenna are $h_b = 30$ m and $h_m = 1.5$ m, respectively. The BS does not apply sectorization: it deploys an omnidirectional antenna with 4.5 dBi gain in all directions. The antenna gain at the MS is 0.8 dBi.

The backhaul link to the core network is composed by a Line-of-Sight (LoS) connection in the 40 GHz band (microwave data link), with powerful direction antenna at both extremes of the link (the gain of each antenna is 18 dBi).

(c.1) What is the minimum transmit power that is required in the backhaul link to cover a distance $d = 20$ km, if the threshold power that is required in reception for a proper quality of communication is -85 dBm (do not consider any losses originated in cables, connectors, weather conditions, or due to any other phenomena).

(c.2) Assume that BS transmit power is 30 dBm. Calculate the cell range R if shadow fading is not considered. Use receiver sensitivity -104 dBm.

(c.3) Calculate the new range that the cell should have when shadow fading is taken into account for an outage probability of 10 %. Use shadow fading standard deviation $\sigma_s = 8$ dB (valid for sub-urban areas).

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Problem 3: *(Functional blocks of a radio link and channel capacity concepts)*

(a) Explain the functionality of the transmit filter and the receive filter in the context of a wireless communication system. What it the main difference between these two filtering blocks?

(b) What is the purpose of combining an interleaving block with a channel encoder block? What would happen if the interleaving block is taken out from the transmitting chain? Justify your answer in a proper way.

(c) Define the concepts of throughput, channel capacity, and goodput. What is the relationship that exists between each of these concepts?

(d) Explain the concept of Inter-Symbol Interference (ISI). What is the physical phenomenon that generates this impairment in a wireless communication system? How is this impairment tackled in 3G systems (i.e., CDMA newtorks) and 4G systems (i.e., OFDMA networks)?

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Problem 4: *(Multiple access techniques and duplexing methods)*

(a) Name at least two mobile communication technologies that are considered 'narrowband technologies', and two that are considered 'broadband technologies'. What are the main characteristics that make them fall in each of these categories? To answer this question, you may focus on the target goals during their design (e.g., target applications, frequency reuse factor, SINR working regime, among others).

(b) Explain in a simple but clear way the following concepts related to TDMA networks: (1) Discontinuous Transmission and Reception (DTX/DRX), and (2) Timing in Advance (TA) control.

(c) Describe at least two advantages and two disadvantages of the following multiple access techniques: (1) CDMA and (2) OFDMA.

(d) What is the difference between Frequency Domain Duplexing (FDD) and Time Domain Duplexing (TDD)? Describe at least two advantages and two disadvantages of each of these duplexing methods.

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Problem 5: *(Co-channel interference in mobile systems)*

(a) Define Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI). Give a brief explanation of their nature and characteristic(s). Describe briefly the tools that hardware/network designers have to keep these impairments under control.

(b) What is the purpose of using cell clusters of different sizes in a mobile (cellular) network? In which part of a network planning procedure is the

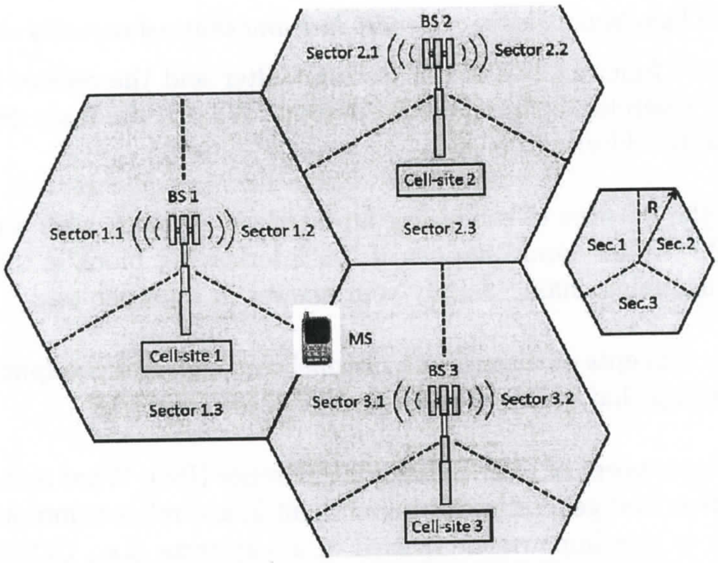

Figure 2: Wireless communication system composed by 3 cell sites with 120° sectors.

size of the cell cluster *usually* defined? Should the size of the cell cluster follow some rule from a 'theoretical' perspective? And from a 'practical' perspective? What are the pros and cons of increasing/decreasing the size of the cluster? In all cases, justify your answer properly.

(c) Consider the system presented in Fig. 2, composed by three cell sites of radius $R = 800$ m. We are interested in determining the signal strength that the Mobile Station (MS) experiences from each of the Base Stations (BSs) under different system configurations.

Assume that the path loss attenuation (in dB scale) is given by

$$L(d) = 137,4 + 35,2\ \log_{10}(d) \qquad d > 0, \tag{1}$$

where d is the distance between transmitter and receiver in kilometers. Shadow fading and fast fading are not taken into account.

For sake of simplicity we consider that all BSs apply the same transmit power, and that each cell site uses a 3 sector configuration with identical antenna gain patterns:

$$G(\theta) = G_{\max} + \max\left\{ -12 \left(\frac{\theta - \theta_0}{\theta_{3\,\text{dB}}} \right)^2, -G_{\text{fb}} \right\}, \tag{2}$$

where θ is the angle of arrival/departure in degrees, $G_{\max} = 18\,\text{dBi}$ is the maximum antenna gain, θ_0 is the main direction of the irradiated power in degrees, $\theta_{3\,\text{dB}} = 60°$ is the beam width at 3 dB, and $G_{\text{fb}} = 25\,\text{dB}$ is the front-to-back ratio for the antenna.

Assume that the MS is always connected to the BS from which it receives the best Signal-to-Interference power Ratio (SIR).

(c.1) Determine the SIR at MS when the cluster size is 3 (i.e., each sector of the cell uses a different set of frequencies). Provide the result in dB.

(c.2) Find the new SIR at MS when the cluster size is reduced to 1 (i.e., all sectors use the same set of frequencies). Provide the result in dB.

Assume that the throughput can be approximated using the formula

$$R = N_{\mathrm{RB}}\, W_{\mathrm{RB}}\, A\, \log_2\left(1 + B\, \mathrm{SIR}\right), \tag{3}$$

where N_{RB} is the number of assigned Resource Blocks (RBs), $W = 180\,\mathrm{kHz}$ is the bandwidth of a single RB, and $A = 0.88$ and $B = 0.8$ are parameters that take into account the bandwidth and SINR efficiencies of LTE, respectively.

(c.3) Estimate the throughput that the terminal is able to support in both cases when the total bandwidth of the communication system is 10 MHz (use the SIR values calculated in the first part of the problem).

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Appendix Information: *(Formulas and Curves that MAY be required)*

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$$f(L_s) = \frac{1}{\sqrt{2\pi}\sigma_s} e^{-\frac{{L_s}^2}{2{\sigma_s}^2}} \tag{4}$$

$$\Pr\left\{L_s < L_0\right\} = \int_0^{L_0} f(t)\, dt = 1 - Q\left(\frac{L_0}{\sigma_s}\right) \tag{5}$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{+\infty} e^{-\frac{t^2}{2}}\, dt = \frac{1}{2}\,\mathrm{erfc}\left(\frac{x}{\sqrt{2}}\right) \tag{6}$$

$$\left(1 - \frac{1}{z^2}\right) \frac{1}{z\sqrt{2\pi}} e^{-\frac{z^2}{2}} \leq Q(z) \leq \frac{1}{z\sqrt{2\pi}} e^{-\frac{z^2}{2}} \tag{7}$$

$$P_{e,\mathrm{awgn}}(\mathrm{SNR}) = Q(\sqrt{2\,\mathrm{SNR}}) \tag{8}$$

$$\begin{aligned} P_{e,\mathrm{fading}}(\mathrm{SNR}) &= \mathbb{E}\{Q(\sqrt{2\,\gamma\,\mathrm{SNR}})\} = \int_0^{\infty} Q(\sqrt{2\,\gamma\,\mathrm{SNR}})\, f_\gamma(\gamma)\, d\gamma \\ &= \frac{1}{2}\left(1 - \sqrt{\frac{\mathrm{SNR}}{1+\mathrm{SNR}}}\right) \end{aligned} \tag{9}$$

$$L_{\text{free space}}\,[\mathrm{dB}] = 32,44 + 20\log_{10}(f\,[\mathrm{MHz}]) + 20\log_{10}(r\,[\mathrm{km}]). \tag{10}$$

$$\begin{aligned} L_{\mathrm{Hata}}\,[\mathrm{dB}] &= 69,55 + 26,16\log_{10}(f\,[\mathrm{MHz}]) - 13,82\log_{10}(h_b\,[\mathrm{m}]) \\ &- a_i(h_m\,[\mathrm{m}]) + [44,9 - 6,55\log_{10}(h_b\,[\mathrm{m}])]\log_{10}(r\,[\mathrm{km}]) \end{aligned} \tag{11}$$

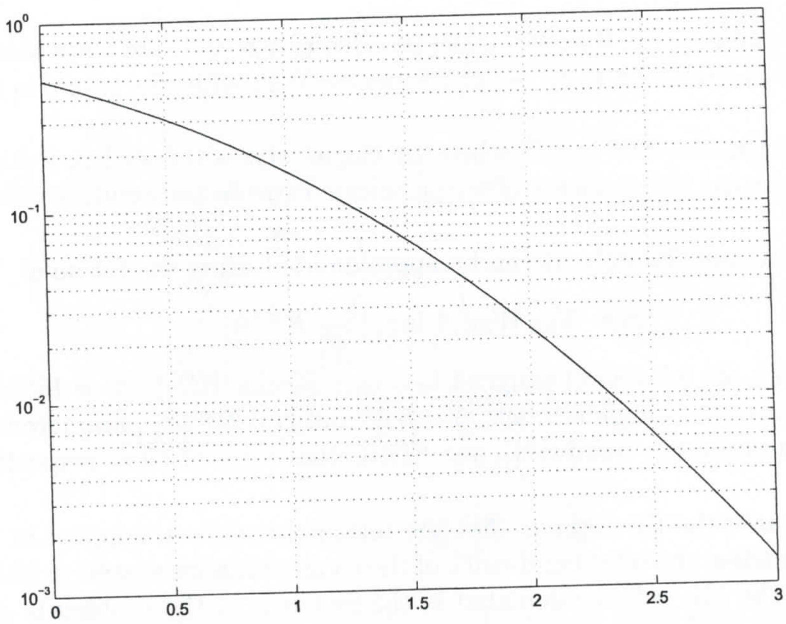

Figure 3: Plot for the Marcum Q-function.

Large sized city (i.e., $i = 1$):

$$a_1(h_m) = 3,2\,[\log_{10}(11,75\,h_m)]^2 - 5,0 \qquad 200\,\text{MHz} \leq f \leq 1500\,\text{MHz} \quad (12)$$

Medium/small city (i.e., $i = 2$):

$$a_2(h_m) = 0,8 + \left[1,1\ \log_{10}(f\,[\text{MHz}]) - 0,7\right] h_m - 1,56\log_{10}(f\,[\text{MHz}]) \quad (13)$$

Sub-urban area (i.e., $i = 3$):

$$a_3(h_m) = a_2(h_m) + 2\left[\log_{10}\left(\frac{f\,[\text{MHz}]}{28}\right)\right]^2 + 5,4 \quad (14)$$

Rural/open area (i.e., $i = 4$):

$$a_4(h_m) = a_2(h_m) + 4,78\ [\log_{10}(f\,[\text{MHz}])]^2 - 18,3\log_{10}(f\,[\text{MHz}]) + 40,9 \quad (15)$$