SAMPLE Written Exam
Radio Systems - ETIN15

Department of Electrical and Information Technology
Lund University

Total 5 hours, max 1.5 hours on Part A

The exam consists of two parts. 15 of 30 points are required to pass (minimum 5 on each part).

- **Part A** (Max 1.5 hours)
  Closed book questions, 1 - 2 points each. (max 15 p)
  Permitted aids: NONE
- **Part B** (Hand in your Part A answers before starting.)
  Open book problems, 5 points each. (max 15 p)
  Permitted aids: Pocket calculator, course textbook (including printed copies of the on-line appendices), lecture slides, and a mathematical handbook (Tefyma, Beta or equivalent).

Print your name on ALL sheets. All assumptions must be motivated.

Note: Read the list of permitted aids carefully. Using anything beyond what is explicitly permitted is considered an act of cheating and will be reported to the Disciplinary Committee of Lund University.

Part A

Closed book questions

1. Wireless communication channels are often characterized as either narrow-band or wide-band. What is the conceptual difference between the two, as seen from a digital-receiver design perspective? (1 p)

2. The inverse power law applied to wireless propagation states that, when transmitting with a power of P_{TX}, the received power at a distance d is proportional to $P_{TX}d^{-\eta}$. Name two types of propagation environments and the (possibly approximate) values on η associated with them. (2 p)

3. One draw-back of a certain class of equalizers in digital receivers is error-propagation. Name an equalizer type suffering from error-propagaion and explain, briefly, why errors do propagate. (1 p)

4. One example of limiting amplitude variations in digital modulation is the rotation of PSK signal constellations between each transmitted symbol. In EDGE this type of modulation is called $3\pi/8$-8PSK. Explain, briefly, why this can reduce amplitude variations and state the motivation for trying to reduce amplitude variations in the first place. (2 p)

5. In OFDM systems, it is quite common to use a guard period between symbols, which is filled with a copy of the last part of the next symbol. What is this special guard period called and how long does it have to be? (2 p)

6. When a wireless standard is developed, one has to decide how much mobility it should be able to handle. Often the amount of mobility measured in terms of maximal terminal velocity v_{max}. When working with the physical layer design (coding, modulation, equalization, etc.) another related number is often required in the calculations, namely the Doppler bandwidth B_d. Express B_d in Hz, when v_{max} is given in km/h. (2 p)

7. Explain, briefly, how multiple antennas on transmitter and receiver can be used to establish several parallel communication links in a “complex enough“ propagation environment. Interpret the ”complex enough“ statement. (2 p)

8. Describe two conceptually different ways of doubling the system capacity (expressed in bits/sec/Hz/km^2) of a cellular system and compare them from a practical point of view. (3 p)

Part B

Open book problems

1. A part of the frequency bands previously used for analog TV broadcasting have been made available for mobile communication systems. We want to make a simple investigation of the required transmit power from a terminal, when a single terminal is being served (no interference). Our scenario is as follows:

   A base station antenna is placed at an elevation of 150 m. It communicates with a mobile terminal located in a large city (metropolitan area), at a 450 MHz carrier frequency. The mobile terminal is 5 km from the base station and at an elevation of 3 m. Both the terminal and the base station are equipped with $\lambda/2$-dipole antennas. The communication is in this case directed from the terminal to the base station. The noise temperature of the receiver antenna is estimated to 1400 K. A low-noise amplifier (LNA) with a noise figure of 4 dB and a 20 dB gain is placed directly at the antenna output. The base-station feeder attenuation, between the LNA and the rest of the receiver system, is 5 dB. The remaining part of the base-station receiver system (i.e., excluding feeder and LNA) has a noise figure of 5 dB. The data rate is 384 kbit/sec and the required ratio E_b/N_0 between bit energy and noise power spectral density is 10 dB (minimum). Due to fading, a 10 dB fading margin has to be added (the given fading margin already includes any corrections for mean/median values). Select a suitable propagation model, draw a link budget diagram, and calculate the required transmit power at the input of the terminal antenna. Motivate your choice of propagation model! (5 p)

2. Assume that we want to design a cellular system that covers a (square) city of size 64 km^2. Since cities often have a quite regular system of streets and city blocks[1], we cannot assume that propagation conditions are the same in all directions. For example, radio waves will experience smaller losses along street canyons than in other directions. This will lead to cell shapes quite different from the hexagonal ones resulting from entirely homogenous and isotropic conditions. For simplicity, assume that this results in a city covered with equal-size square cells. Calculations show that for a certain cell area A_c (in km^2), each cell will be able to handle 20 simultaneous speech channels (active users). Further, assume that this number of simultaneous speech channels does not change with scaling of the cell structure, i.e., when the cell area changes.

   (a) How many simultaneous phone calls can be made in the entire city, given that the cell area of our deployment is $A_c = 0.25$ km^2? (1 p)

   (b) Assuming that we have 100,000 subscribers in the city and we want to design a system where 100,000 phone calls can be made at the same time. What is the largest value on the cell area A_c that can support this? (1 p)

   (c) In reality, the probability is very small that all users in a cell want to make phone calls at the same time. Assume that we use the Erlang-B blocking model and tolerate a 2% blocking probability during a busy hour. Studies of the subscribers have led us to the conclusion that on Friday, late afternoon, we have the busiest period. In a Friday busy hour, each subscriber on average makes four phone calls lasting one minute each. How many base stations (cells) do we need to support 100,000 subscribers with the given requirements? (2 p)

[1] Lund not included in this category.

(d) Assume that the cost for installing the base stations, at 300,000 SEK/base station, have to be shared among the subscribers (indirectly through the charges for their phone calls over some period of time). How much would each of the 100,000 subscribers have to pay in total under the conditions given in (b) and (c), respectively? Comment the result. (1 p)

3. Assume that we are designing a wireless surveillance system (home alarm) for outdoor monitoring, where communicating sensors will be placed at a height $h = 0.5$ m above ground, at a maximum distance of $d_{max} = 30$ m from each other. The sensors are equipped with motion detectors and will forward any alarms to the other sensors using the IEEE 802.15.4 (ZigBee) standard. The communication is based on direct-sequence spread-spectrum (DS-SS), using offset quadrature phase shift keying (O-QPSK) with half-sine chip shaping and chip time $T_c = 0.5$ μs, in the 2.4 GHz band with a maximum data rate specified to $r_{d,max} = 250$ kbit/sec. A transceiver circuit from Texas Instruments (TI CC2520) is used, which has a programmable transmit power up to $P_{TX,max} = 5$ dBm. When it operates as a receiver, the sensitivity is given as $C_{min} = -98$ dBm. The sensor nodes are equipped with antennas that have gain $G_a = 3$ dBi.

   (a) Draw a link budget for the above described system, from a transmitting node to a receiving node, assuming that it operates at its maximum transmit power and at the maximum distance. Two unknown parameters at this stage, which should be included in the link budget, are the path loss L_p and the fading margin M (both in dB). (1 p)

   (b) How large is the resulting propagation loss L_p and how much fading margin M do we have if we use an empirical model for a typical garden, where the propagation loss is given as $L_{1m} = 40$ dB at 1 m distance and beyond that the propagation exponent is $\eta = 3.8$. (1 p)

   (c) Assume that we have two sensor nodes and an intruder moving around in the garden, between the transmitter and receiver, who will cause log-normal fading with standard deviation $\sigma_F = 7.8$ dB. Calculate the probability of outage, which is defined as failure to forward the alarm message to the other sensor node on the first communication attempt. (Assume that communication above the receiver sensitivity level is 100% successful and below the sensitiv level 100% non-successful.) (1 p)

   (d) Now, assume that our sensor has two neighbor nodes at the max distance and that the fading on the two communication links have the same general properties as above. When the node detects an intruder it will immediately try to transmit the alarm message to both its neighbors. Outage is defined as none of them detecting the alarm message on the first communication attempt. Let us study two different setups:

      i. An initial placement of the nodes was done and tests showed that an intruder causes fading on both links at the same time (fully correlated fading) with $\sigma_F = 7.8$ dB.

      ii. In an attempt to improve the situation, the nodes are moved so that shadowing on the two links become independent. They are still at the max distance from each other. Unfortunately, this also makes the fading worse (higher standard deviation). The new fading is now $\sigma_{F,1} = 10.1$ dB on one link and $\sigma_{F,2}$ dB on the other.

   How large can $\sigma_{F,2}$ be in (ii) without resulting in worse performance than in (i), in terms of outage probability? Comment on the result! (2 p)