Written Exam
Radio Systems - ETIN15

Department of Electrical and Information Technology
Lund University

2013-05-27
8.00 AM - 1.00 PM

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

- **Part A** (8.00 AM - 9.30 AM)
  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).

base-station
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. Explain, briefly, why we often have to rely on different diversity schemes in wireless communications. (1 p)

2. In what *unit* do we measure *spectral efficiency* of a certain modulation type, and how does it depend on our requirement on *out-of-band power*? (2 p)

3. Give a short description of *effective antenna area*, including its relation to *antenna gain*. (2 p)

4. Write down *Friis' law* for calculating received power and *define* the variables you use in the expression. (2 p)

5. Describe the relation between *system bandwidth* and a receiver's capability to resolve signals that arrive with different *time delays*. (1 p)

6. Assume that we have a received desired signal with power C and an interfering signal with power I, where both are subject to independent log-normal large-scale fading with standard deviations σ_C dB and σ_I dB, respectively. Characterize the resulting fading on the carrier-to-interference ratio (C/I). (2 p)

7. Decreasing the bandwidth of the Gaussian filter used on the phase of GMSK signals will decrease the power in the side-lobes of the modulation spectrum, thus reducing adjacent-channel interference and allowing a smaller channel frequency separation. What is the penalty? (1 p)

8. Assume that we use an error correcting code of rate R in combination with M-ary modulation to transmit information over a channel. What is the relation between:

   (a) information-bit rate (d_b bit/sec), code-bit rate (d_c bit/sec), and channel-symbol rate (d_s symb/sec)? (1 p)

   (b) received power (C Watt), symbol energy (E_s Joule), and information-bit energy (E_b Joule)? (1 p)

9. When analyzing cellular systems for homogeneous propagation conditions and user distributions, we often use hexagonal cell structures where the cluster size N_{cl} is related to the reuse ratio D/R as $D/R = \sqrt{3N_{cl}}$. Explain, in words,

   (a) why only certain values on N_{cl} are allowed (*e.g.*, 12 is ok but not 10), and (1 p)

   (b) how increased tolerance to interference can influence our selected value on N_{cl} (if we want an efficient system). (1 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 between bit energy and noise power density ($\frac{E_b}{N_0}$) 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 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 range 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. (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. (Communication above the receiver sensitivity is assumed to be 100% successful.) (1 p)

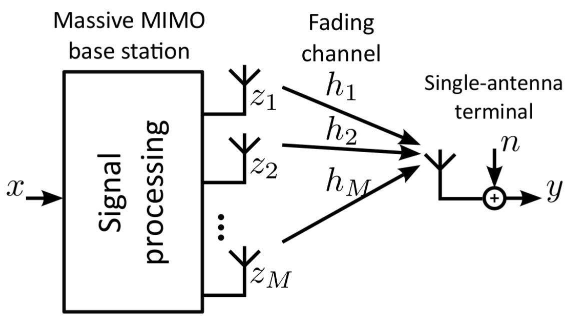
(d) Now, assume that each node has two neighbor sensor nodes at the max distance and that the fading on the two communication links has the same general properties as above. The fading on different links is also considered independent. A node that detects an intruder will, in this case, try to transmit the alarm message to both its neighbors. What is the outage probability if success means that at least one of them detects the alarm message on the first communication attempt? Calculate the outage probability for the two cases:

i. The nodes are placed so that the intruder causes equal fading on the two links, with $\sigma_F = 7.8$ dB. (1 p)

ii. The nodes are placed so that an intruder will shadow one of the links more than the other. This is modeled by having $\sigma_F = 7.8$ dB fading on one link and $\sigma_F = 10.1$ dB fading on the other. Depending on the direction from which the intruder comes, it is either the first or the second link that has the "stronger" fading. We do not know which. (1 p)

3. One of the "hot" new technologies, promising high spectral efficiencies and power efficiency several orders of magnitude better than today's systems, is called Massive MIMO (MaMi). In this problem we are going to use the knowledge we have about analyzing radio systems to investigate the increase in power efficiency we can obtain when the number of base-station antennas grow large, under some quite simplified conditions.

A very simple MaMi system is shown in the figure below, where the base station is equipped with M antennas and the terminal has only a single antenna. We model the system in the base band, with x being an information carrying complex-valued signal constellation point of unit magnitude $|x| = 1$ to be transmitted to the terminal, z_m the complex amplitude (envelope) of the signal transmitted from antenna m, h_m the complex (fading) channel coefficient from antenna m to the terminal, n the receiver noise with variance/power $\mathbb{E}|n|^2 = \sigma_n^2$, and y the received signal.



(a) Write down an expression for the received signal y as a function of the transmitted signals z_m, the channel coefficients h_m, and the receiver noise n. (1 p)

(b) Now, assume that the base station knows the channel coefficients h_m, which it has obtained by performing a (perfect) channel estimation. The signal processing in the base station is done in a very simple way, assigning $z_m = \sqrt{\alpha} h_m^* x$ to antenna m, where $*$ denotes complex conjugation and α is a variable allowing us to scale the total transmit power. Include this in the expression derived in (a) to show that the received signal can be written in the form $y = \sqrt{\alpha} f(h_1, h_2, \ldots, h_M) x + n$, *i.e.*, find $f(h_1, h_2, \ldots, h_M)$. (1 p)

(c) Let us assume that the fading has a simplified form. The channel coefficients are given as $h_m = \sqrt{\beta} e^{j\phi_m}$, where they all have the same constant magnitude $\sqrt{\beta}$, but their phases ϕ_m are independent and uniformly distributed in the interval $[0, 2\pi)$ radians.

Given this, determine how the value on the "power control" variable α depends on the number of antennas M when

i. we choose to keep the *total transmit power* (across all antennas) at some fixed level P_{tot}, and when (1 p)

ii. we instead choose to keep the *received signal quality* (at the terminal) at some fixed signal to noise ratio (SNR). (1 p)

(d) Compare the two choices in (c) and comment on the differences, in terms of what happens to total transmitted power and signal quality when the number of antennas M grow very large as compared to today's MIMO systems. (Possibly finding some "unexpected" behavior as $M \to \infty$.) (1 p)