Written Exam
Radio Systems - ETI051

Department of Electrical and Information Technology
Lund University

2010-05-28
2.00 PM - 7.00 PM

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

- **Part A** (2.00 PM - 3.30 PM)
  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.

Due to scheduling problems in Vic3, Victoriastadion, the exam may start somewhat later than 2.00 PM. Any such delay will shift the above given times by the same amount.

Part A

Closed book questions

1. 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)

2. In CDMA systems, a cluster size of ONE can be used, meaning that all base stations transmit at the same time in the same bandwidth. Describe why this is possible in CDMA, without excessive interference. (2 p)

3. The *generation* terminology used for "mobile telephone systems" have reached generation three, and four is on its way. Each generation has its own properties in terms of the communication technology used and the services offered. The transition from one generation to the next is characterized by a paradigm shift. (2 p)

   (a) Explain briefly the *communication technology* used in each generation from 1G to 3G.

   (b) Descibe the *paradigm shifts* leading from 1G to 2G and from 2G to 3G.

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

5. Cellular systems are often designed so that they are interference limited. Wouldn't it be better to design them so that we don't have to bother about interference? Describe, in a few sentences, the rationale behind interference-limited cellular systems. (2 p)

6. Given that you have a median received power of $C_{med}(d)$ [W] at distance d form a transmitter. This value has been predicted from a given transmit power P_{TX} and some propagation model. In addition to this, there is both large- and small-scale fading. The large-scale fading has a lognormal distribution with standard deviation σ dB and the small-scale fading is Rayleigh-distributed. We know that our receiver will only operate properly if the average power (average over the small-scale fading) is above some specified value. How do you calculate the necessary fading margin to obtain a Y% availability ((100-Y)% outage) at distance d? (2 p)

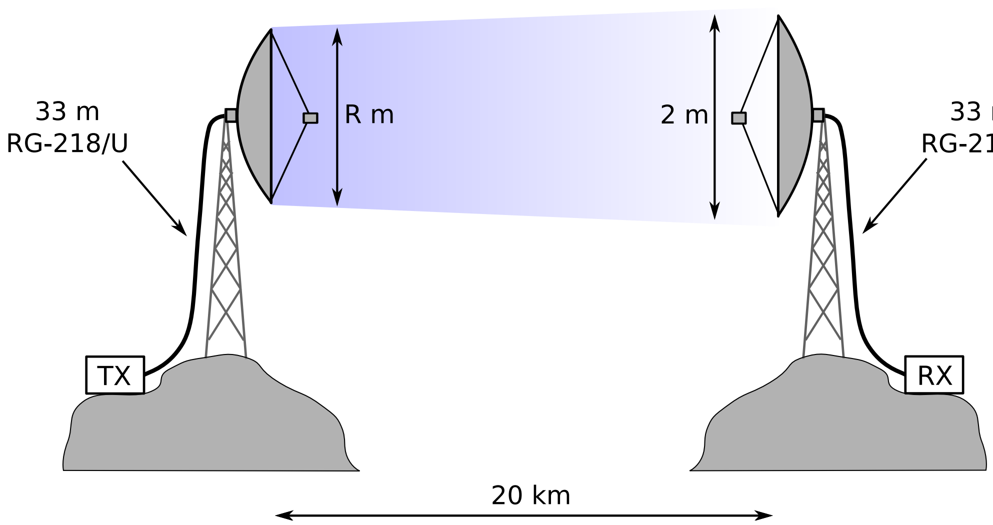
7. GSM uses GMSK modulation with a system data rate of 271 kbit/s and can handle the intersymbol interference (ISI) caused by the channel by applying a Viterbi equalizer capable of taking 4 symbol long ISI into account. Assume that we consider using the same modulation and equalization techniques for a 54 Mbit/s WLAN system. Which (technical) arguments can you find *against* such a WLAN system design? (2 p)

8. In Sweden and several other countries there has been a vivid debate about the possible hazards when people are exposed to electromagnetic radiation from *base stations* in cellular systems. How would you argue that the exposure of electromagnetic radiation from base stations is insignificant, compared to the exposure from terminals (mobiles), even for those who have chosen not to use terminals (mobiles) themselves. (2 p)

Part B

Open book problems

1. A radio link is being established between two mountain tops in Republic of Utopia. Circular parabolic antennas with narrow main lobes are used to avoid multipath propagation caused by ground reflections.



In addition to what is shown in the figure, the system has the following parameters:

Carrier frequency	$f_c = 1$ GHz
Total receiver noise, at antenna output	$N_0 = -124$ dBm/Hz
RX bandwidth	$B = 20$ MHz
Carrier to noise requirement	$C/N = 30$ dB
Effective area of parabolic antennas	55% of opening area
RG-218/U feeder attenuation at 1 GHz	12 dB/100m

(a) Express the transmitter EIRP as a function of TX power P_{TX} (input power to the feeder at the TX) and the transmitter parabolic antenna diameter R. (1 p)

(b) Given that we have a limited transmit power $P_{\mathrm{TX}} = 10$ W, how large a diameter R do we need on the transmitter parabolic antenna to fulfill the C/N requirement above? (1 p)

(c) The simple formulas we use for antenna gain (effective area 55% of opening area) are only good approximations under certain conditions. For instance, if the antennas are "too close" the results become trivially unrealistic. Assuming that the RX and TX parabolic antennas have diameters R_1 m and R_2 m, respectively, and are pointed towards eachother in free space. Determine an antenna-to-antenna distance below which the antenna gain formulas are trivially unrealistic. *Hint: Assuming that we do not beleive in the existence of a perpetuum mobile, a comparison of power-in/power-out can give such a distance.* (2 p)

(d) With the result from (c) in mind, do you think that your result in (b) is correct? Explain why! (1 p)

2. Calculate the traffic capacity, expressed in terms of terminals/km^2, for a cellular mobile telephony system with prerequisites and requirements as stated below. (5 p)

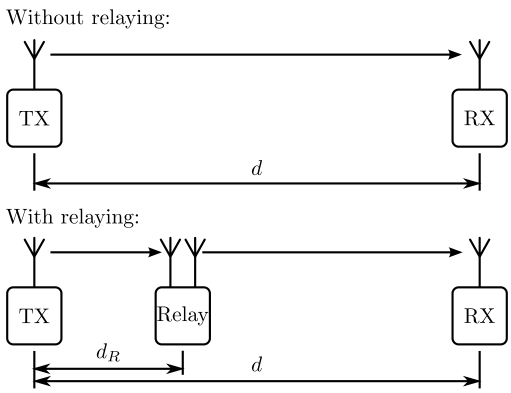
   Prerequisites:

   - Only downlink (base station to mobile) is studied.
   - The cell structure contains hexagonal cells with area 1 km^2 and the terminal distribution is assumed homogenous over the covered area.
   - Co-channel interference is assumed to be the only disturbance affecting the overall quality. This interference originates from the first-tier (closest) co-channel cells, where all six are active at any moment in time.
   - The system has a bandwidth of 15 MHz available for the downlink.
   - FDMA is used and each channel occupies a bandwidth of 30 kHz.
   - The sharing of channels is done according to the Erlang-B model.
   - Each terminal is assumed to generate 0.1 Erlang during a busy hour.
   - Base stations have omni-directional antennas and are placed in the center of each cell.
   - Large scale fading of the desired signal has a log-normal distribution with $\sigma = 6$ dB.
   - The interference level is calculated as the sum of the global averages in the center of the studied cell and no large scale is assumed fading for the interfering signals.
   - The global average of the desired signal and the co-channel interference (same transmit powers) are determined by a propagation exponent $\eta = 4$.

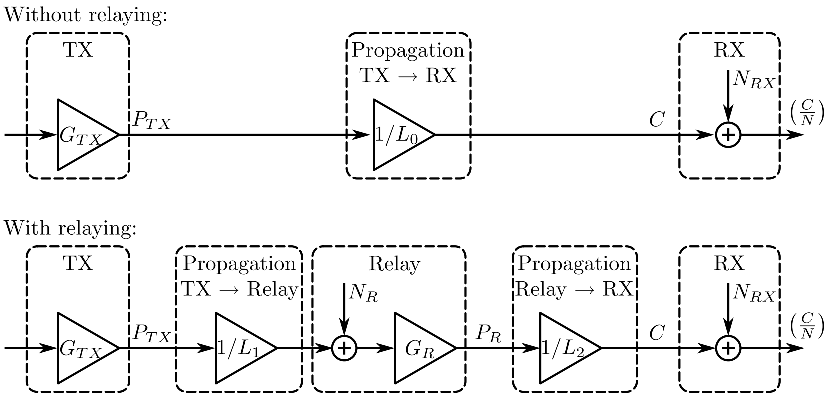
   Requirements:

   - Acceptable link quality is quantified as a C/I not falling short of 12 dB.
   - We only accept 1% blocking during a busy hour.
   - Only 3% outage is accepted at the cell boundary.

3. One of the trends in wireless communications today is using relays to improve the performance. In this problem we will study a simplified case, and draw some conclusions about the properties of communication over wireless channels with and without relays. The general situation is shown below, where the distance between transmitter (TX) and receiver (RX) is d m. In the case where we use a relay, the relay is placed at a distance d_R m from the TX.



The TX antenna is placed at a height of $h_{TX} = 30$ m, the relay antenna at $h_R = 10$ m, and the RX antenna at $h_{RX} = 2$ m. All antennas have antenna gains equal to 3 dBi, except for the relay receive antenna which is more directive and has a gain of 13 dBi. We assume that the theoretical "propagation over a ground plane" model is applicable for all links, within the normal limits of validity (approximation error if distances are too short). The propagation models are further assumed to give the average received powers. This allows us to perform calculations based entirely on average powers (average over the fading). The TX transmits a signal with power P_{TX}, which is received by the relay. The relay amplifies the signal (and some noise) by a factor G_R and re-transmits this signal on a nearby frequency to which the RX is tuned. As shown in the block diagram below, both the relay and the RX introduce noise with powers N_R and N_{RX} at their respective receive antenna outputs.



(a) Given the block diagrams above, attenuations L_0, L_1 and L_2 each include **both** propagation losses and the antenna gains for the respective links. Express these three attenuations in terms of antenna heights as well as distances d and d_R. (1 p)

(b) Assume that the requirement on average $(C/N) \geq (C/N)_{req}$ at the RX is the same in both cases, *i.e.*, when a relay is used and when a relay is not used. Express, for both cases, the required transmit powers P_{TX} and P_R in terms of $(C/N)_{req}$, G_R, N_R, N_{RX}, d and d_R. *Note: The powers P_R and C ONLY include the wanted signal. The contribution to N in (C/N) from the relay noise N_R has to be added separately.* (2 p)

(c) Assume that the power consumption of the transmitter and the relay are 200% of their respective transmit powers (50% efficiency) plus power consumption due to other functions given by the constants K_{TX} W and K_R W, respectively. This implies that the total power consumption of the TX is $2P_{TX} + K_{TX}$ W and the total power consumption of the relay is $2P_R + K_R$ W. (The power consumption in the relay due to amplification and transmission of the noise N_R is included in K_R.) The RX, which does not transmit anything, has a constant power consumption of K_{RX} W.

Given that the relay amplifies the signal by $G_R = 50$ dB before re-transmitting, both noise powers are $N_R = N_{RX} = -134$ dB[W], the required reception quality is $(C/N)_{req} = 10$ dB, the communication (for both links) is taking place at carrier frequencies of about 500 MHz and that the distance between TX and RX is $d = 10$ km:

- What is the optimal distance d_R between TX and relay, to minimize total power consumption of the two transmitters? *Hint: A rough numerical solution of the minimum is accepted and it is wise to search for the optimum where the relay is not very far from the RX.*
- How much lower is the total transmitted power (from TX and relay), when we compare with the case without relaying?

(2 p)