S-26.3142 Radiowave propagation in mobile communications
End-Term Exam

13.12.2010

9:00am-12:00am

This is a closed-book exam, but you can use a calculator (no laptop allowed).
This exam consists of 7 problems and 6 pages.

1. Figure 1 shows a trend in the development of mobile communication systems in terms of data rate and mobility/range.
   A) What in radio wave propagation makes it very challenging to reach the area A? Identify 3 aspects. (3 points)
   B) For each aspect identified in A), explain why (12 points).

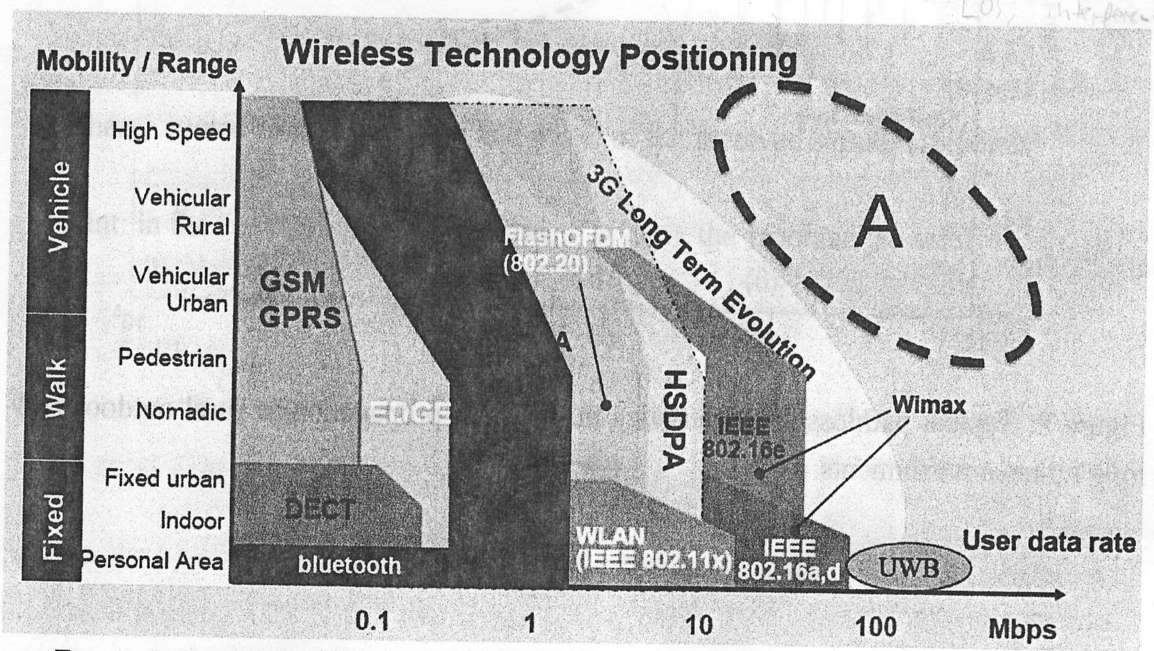

Figure 1: Evolution of data transmission technology in mobile communications.

2. Among several field prediction methods for radio wave propagation, there is a method called an image method.
   A) What is the image method? (10 points)
   B) What are the advantages and disadvantages of the method? (5 points)

3. A) Define the Fresnel zone. (10 points)

   B) In rural outdoor and confined environment such as long tunnels, we often see the pathloss curve similar to Figure 2. The pathloss curve has different slopes before and after the point A. What is this point called? (3 points)

   C) How can we explain the pathloss curve in Figure 2 using the concept of Fresnel zone? (7 points)

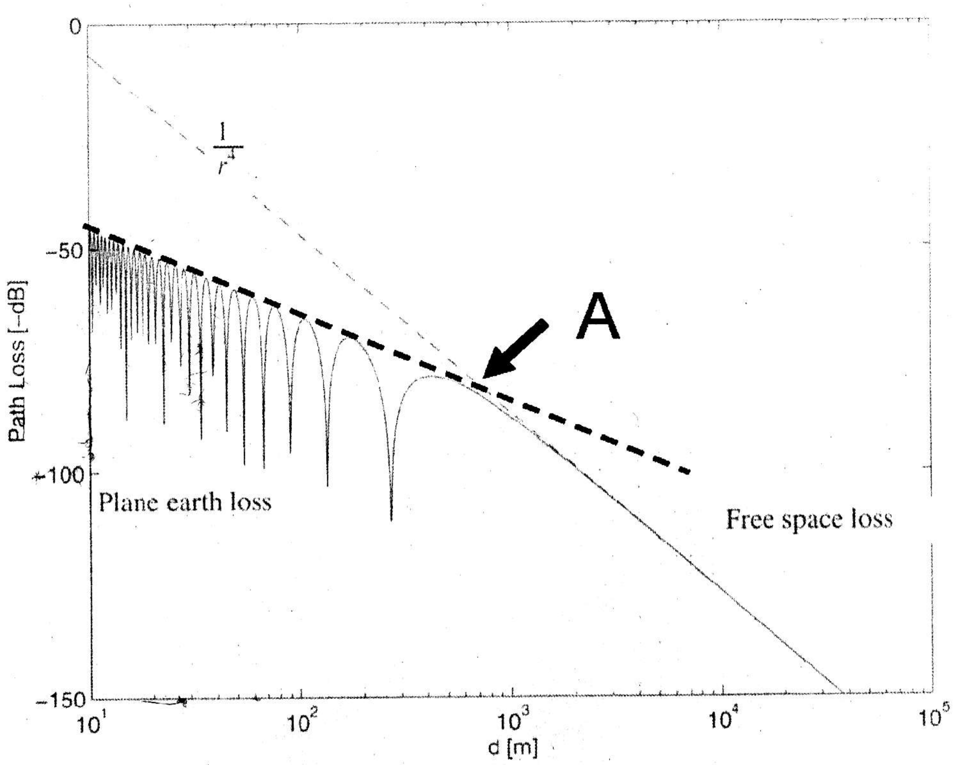

Figure 2: Typical pathloss characteristics in two-path propagation in rural outdoor and long tunnel environments.

4. When there are many multipath components arriving at the receiver, the combined received signal usually follows the complex Gaussian distribution as denoted by

$$f(x,y) = f(x) \cdot f(y)\,, \qquad (1)$$

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{x^2}{2\sigma^2}\right), \qquad (2)$$

$$f(y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{y^2}{2\sigma^2}\right), \qquad (3)$$

where $f(x,y)$ is a probability distribution function of the complex amplitude of the received signal, $x + jy$. Verify that the envelope and phase of the complex Gaussian signal follow the Rayleigh and uniform distribution,

$$f(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right), \qquad (4)$$

$$f(\theta) = \frac{1}{2\pi} \quad (0 \le \theta < 2\pi)\,, \qquad (5)$$

where r and θ are envelope and phase of the received signal. (15 points)

Hint: in the conversion of the coordinate system, the Jacobian is useful:

$$\mathrm{d}x\mathrm{d}y = J \cdot \mathrm{d}r\mathrm{d}\theta \qquad (6)$$

$$J = \det\begin{pmatrix} \dfrac{\partial x}{\partial r} & \dfrac{\partial y}{\partial r} \\ \dfrac{\partial x}{\partial \theta} & \dfrac{\partial y}{\partial \theta} \end{pmatrix} \qquad (7)$$

5. I (Katsu) measured fading statistics using isotropic antennas in a city centre at 2.4GHz frequency. The map of the measurement environment is shown in Figure 3. In order to obtain small-scale amplitude statistics, I moved the Rx antenna along a line at each location as shown in Figure 3. As a result, I got the following K-factor estimates:

A) 10 dB
B) 5 dB
C) -5 dB
D) Could not get trustable value

Point out in which location in Figure 3 I got the estimates A), B), C, and D). Also explain why you thought so. (15 points)

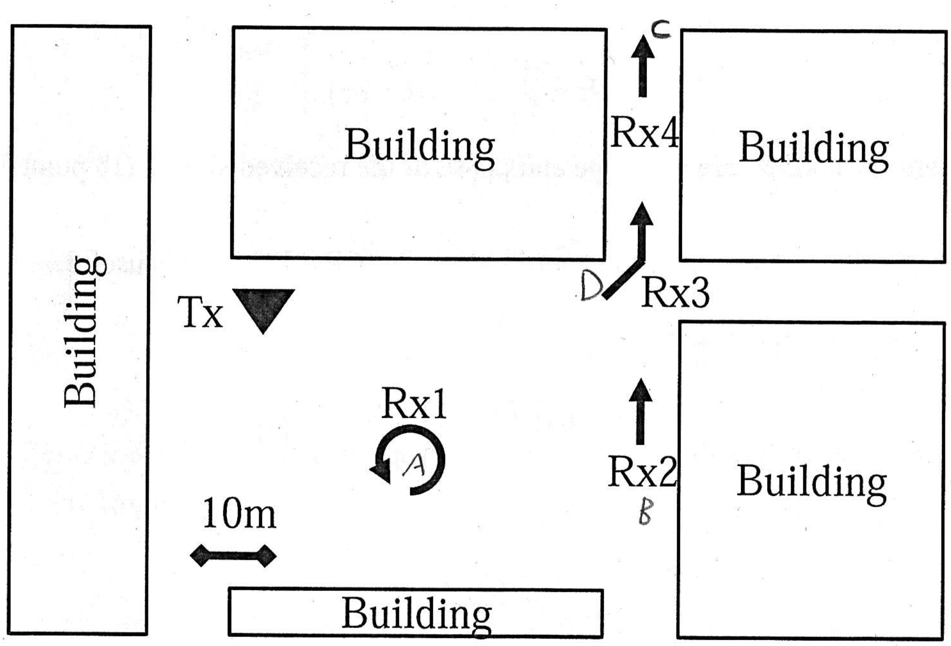

Figure 3: Map of an outdoor fading statistics measurement.

6. There are two multipath channels, i.e., A) and B) as defined in Tables 1 and 2.

A) The root-mean-square delay spread of the channel is given by

$$\tau_{\mathrm{rms}} = \sqrt{\frac{\int_{-\infty}^{\infty} P(\tau)\tau^2 \mathrm{d}\tau}{P_0} - \tau_{\mathrm{m}}^{\ 2}} \qquad (8)$$

where τ and $P(\tau)$ are delay and power of a multipath; τ_{m} and P_0 are the mean delay and total power of the channel. Derive the delay spread of channels A) and B). Furthermore, estimate the coherence bandwidth for each channel by

$$B_{\mathrm{coh}} \simeq \frac{1}{2\pi\tau_{\mathrm{rms}}}. \qquad (9)$$

(8 points)

B) I (Katsu) sent data over the channels A) and B) using radio frequency signals having 5 MHz bandwidth. The data transmission revealed bit error probability shown in Figure 4. It was found that the error goes to 0 as the receiving signal-to-noise ratio increases in the curve “a”, whereas the error occurs even if the receiving signal-to-noise ratio goes infinity in the curve “b”. The curves “a” and “b” correspond to which channel? Give reasons why you thought so. (8 points)

Table 1: Multipath channel A.

Excess delay [ns]	Power [dB]
0	0
50	-10
100	-20

Table 2: Multipath channel B.

Excess delay [ns]	Power [dB]
0	0
50	-3
100	-6
150	-9
200	-12

Figure 4 is in the next page. There is the last problem in the next page.

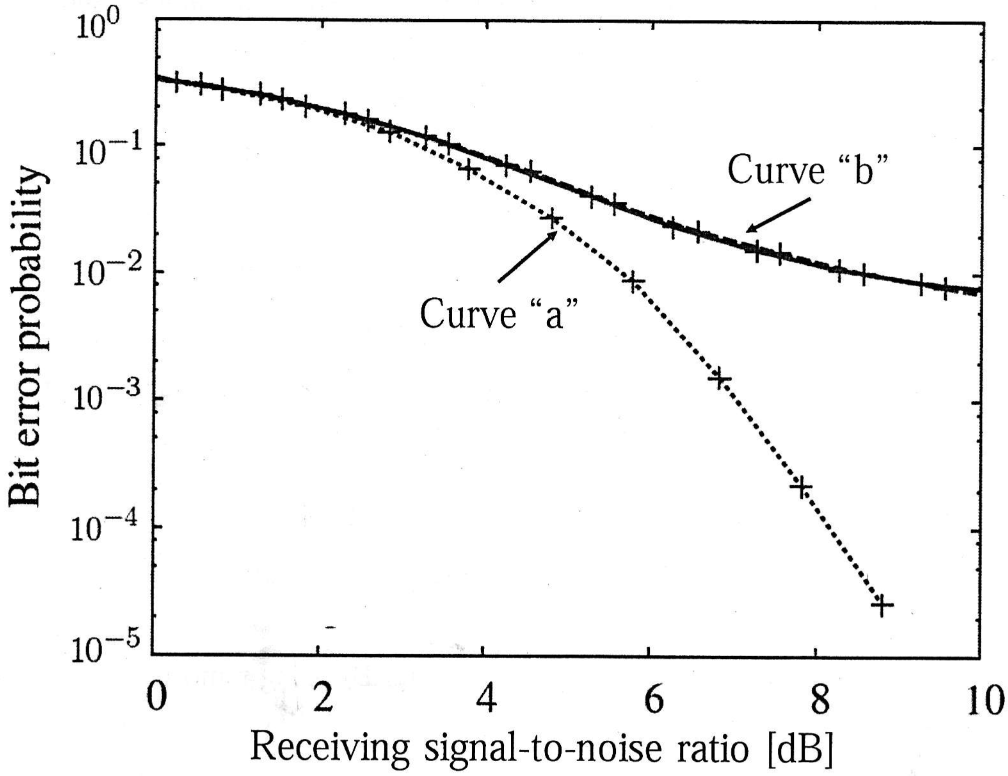

Figure 4: Bit error rate characteristics of data transmission over channels A) and B).

7. What did you like most and least in this course? You will not get points if you make a comment "the amount of exercises was too much" or something like that since I have heard it so many times already. (4 points)

[Problems end]