ELG 4179 Wireless Communications Fundamentals

Laboratory Guidelines

Instructor: Dr. S. Loyka

The laboratory component of ELG 4179 is to be done in a form of computational mini-projects and one measurement-based project (termed "Labs"). Students are expected to perform analysis, numerical simulations and measurements of various wireless communication systems following the guidelines provided and to submit a formal report for each Lab, for which the guidelines are also provided below.

Each Lab consists of two parts:

- Part 1: Preparation.
- Part 2: Matlab programming, experimentation and measurements.

Part 1 has to be done ***beforehand*** so that you can promptly proceed with Part 2 during the lab time slot (session). Part 1 will be submitted to the TA supervising the Lab at the beginning.

Numerical simulation part is performed on the workstations available in the lab rooms using the Matlab/Simulink software, during the time slots allocated by the schedule. Students can also perform simulations outside the scheduled time using workstations equipped with Matlab/Simulink software in the other computer facilities rooms with open student access (e.g. STE 0110). You need to have an account for access to workstations.

The attendance during the scheduled laboratory sessions is **mandatory**. These sessions will be supervised by a teaching assistant.

Due to the time and space limitations, the mini-projects are performed in groups of two students each, with each group submitting a single report for Lab.

It is expected that each Lab will take 1-2 sessions to complete and the report submission deadline will be one week after completion of a Lab. The reports will be submitted to the TA directly.

Students who are unfamiliar with Simulink and/or Matlab are advised to familiarize themselves with these important tools beforehand; extensive help is available for both of them.

Engineering Report Guidelines

The reports must be prepared according to the standard format generally used for the preparation of an engineering technical report. It must contain the following parts in order:

- **Title Page**. It gives the title of the report and identifies its authors. It is clear that if an author's name appears on the title page then she/he has participated actively in the work and agrees with the contents of the report.

- **Abstract.** One paragraph that summarizes the topic, methodology and main results presented in the report.
- **Body.** The body is the main part of a technical report. It must contain the following:
  - Introduction: the introduction addresses the objectives of the project, describes the system to be analyzed and simulated, discusses possible applications of such a system.
  - Mathematical model of the system, its block diagram(s), analysis.
  - Simulations: a Simulink block diagram and its description or, equivalently, a Matlab simulation code with detailed comments (i.e. 1 line of code – 1 comment), complete set of simulation results for the system.
  - Insightful and intelligent discussion of the results. Key observations.
- **Conclusion**

Presentation guidelines are as follows:

Concise writing style

- typed or clear legible handwriting
- a 12pt font double-spaced (except for Matlab code: 10pt, single-spaced)
- 0.75 inch margins all round; use double-sided printing
- stapled

- **Participation**

Please indicate percentage of the project done by each group member, the total being 100%, as well as the particular tasks performed by each group member.

Marking Scheme

- 80% of the mark goes to the body of the report and your participation in the project.
- 20% of the mark goes to the preparation part.

Plagiarism (i.e. "cut-and-paste" from a group to a group, other forms of "borrowing" the material for the report) is absolutely unacceptable and will be penalized. Each group is expected to submit their own report. If two (or more) identical or almost identical reports are found, each group involved receives 0 (zero) for that particular report. If this happens twice, the groups involved receive 0 (zero) for the entire lab component of the course in the marking scheme and the case will be send to the Dean's office for further investigation.

Lab # 1

Preparation

1. Read Ch. 4 of Rappaport's textbook.
2. Consider a line-of-sight (LOS) wireless communication link in free space with the Tx-Rx distance $R = 1$ km, the Tx and Rx antenna heights $h_t = 10m$, $h_r = 1m$; Tx and Rx antenna gains $G_t = G_r = 1$, and the frequency $f = 1$ GHz. Find the propagation path loss and the received power if the Tx power is $P_t = 20$ dBm.
3. Do #2 for the two-ray (ground reflection) model. Hint: verify the far-field approximation condition ($R > 20h_t h_r / \lambda$ or more relaxed $R > 4h_t h_r / \lambda$) and use it. Compare to #2 and explain the difference, if any.
4. How would #2 and 3 change if the frequency changes to 2 GHz?
5. Show that constant A in (2.18) of Lecture 2 can be expressed as $A = \sqrt{30 P_t G_t}$.

Laboratory

1. Write a Matlab program to compute a propagation path loss. The input variables are:

- frequency
- Tx-Rx distance
- Tx and Rx antenna heights
- type of the link: LOS (free space) or two-ray model; for two-ray model, use the complete model without the far-field approximation, and, as an option, add the far-field approximation as well.
- relative permittivity of the ground,
- field polarization (horizontal or vertical).

The output is the path loss. To validate the program, reproduce the path loss graph from the lecture notes (Lecture 2).

Hint: to find the 2-ray path loss, use the analysis of the 2-ray model in Lecture 2 and your notes of what was discussed in the class (in addition to Chapter 4 of the textbook) to show that the 2-ray Rx power P_r can be expressed as

$$P_r = P_{r0} \left| 1 + \Gamma \frac{d_D}{d_1 + d_2} e^{j\Delta\varphi} \right|^2$$

where P_{r0} is the free-space or direct path Rx power, and use it to express the 2-ray path loss via the free-space one and accounting for the reflected path as well.

Note: the formula for the reflection coefficient of vertically- polarized wave in the course textbook is incorrect. Find the correct one and use it. Hint: you may use the following formula found in ref. 5 (chapter 2):

$$\Gamma = \frac{\sin\theta - z}{\sin\theta + z}$$

where $z = \varepsilon^{-1}\sqrt{\varepsilon - \cos^2\theta}$ for vertical polarization and $z = \sqrt{\varepsilon - \cos^2\theta}$ for horizontal, and where ε is the relative dielectric constant. Compare this expression to that in the textbook and comment on any difference (if any). To get some insight, consider the case of $\theta = 0$ ("grazing angle", this represents the case of $R \gg (h_t + h_r)$ as far as Γ is concerned).

2. Consider now the scenario where $N = 100$ users (receivers) are uniformly distributed over the distance from 0.1 to 1 km to the basestation (BS), which is a transmitter (Tx). The Tx power is 100 W, the ground relative permittivity $\varepsilon_r = 15$, the field polarization is vertical, $f = 1$ GHz and the rest of the parameters as in the preparation part. Find the empirical PDF (histogram) and CDF of the received power. Plot each one on the same graph for both types of the link (LOS and two-ray). Explain the difference. Use dBm for the X-axis.

3. Now increase N to 1000, 10000. What is the difference? Explain.

4. Now increase the frequency to $f = 2$ GHz, 10 GHz. What is the impact? Explain.

5. Change the field polarization to horizontal and do # 2, 3. Comment on the difference.

6. In this part, we assume that the users are uniformly distributed over the distance in the interval $[R_{\min}, 1 \text{ km}]$ and investigate the impact of $R_{\min}$. Do #2 for $R_{\min}$ =1, 10, and 100 m and compare the results on the same graph, separately for the free-space and two-ray models. What is the observed impact of $R_{\min}$? Can you explain it?

7. Now assume that the users are uniformly distributed over the square area of 2 x 2 km, except for the 0.1 x 0.1 km central square where there are no users, and the transmitter is at the center. Repeat parts 2 and 3: are the results the same as before? Why?

Hint: to generate uniformly-distributed users over the square, generate uniformly-distributed x and y coordinates for each user.

8. How would your results change if the users become transmitters and the BS becomes a receiver instead?

9. Optional (for analytically-minded students): derive analytically the received power PDF and CDF under the LOS and approximated two-ray models, when the users are uniformly-distributed on the line and square.

References:

1. T.S. Rappaport, Wireless Communications: Principles and Practice, Prentice Hall, New Jersey, 2002. (2nd Edition)
2. J.G. Proakis et al, Contemporary Communication Systems Using MATLAB and Simulink, Thomson & Books/Cole, 2004.
3. W.H. Tranter et al., Principles of Communication Systems Simulation, Prentice Hall, 2004.
4. M.C. Jeruchim et al, Simulation of Communication Systems: Modeling, Methodology, and Techniques, Kluwer, New York, 2000.
5. W.C. Jakes, Microwave Mobile Communications. New York: IEEE Press, 1974.