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An Inductive Approach to Teaching Wireless Communication Fundamentals

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Abstract

For engineering students, learning wireless communication fundamentals is often faced with the difficulty of relating theory to real-world practice. In this paper, we address the use of inductive teaching methods in wireless communication education for undergrad students in UAE University.

We offer a design of a series of collaborative laboratory and fieldwork tasks that can be integrated with the typical material of a course about wireless communication fundamentals. In addition, the paper outlines some low-cost and ultra-portable wireless communication devices that can be used in performing these tasks. The proposed design of the field and lab tasks follows a discovery-based learning approach that allows the students to learn about the wireless channel effects on transmitted signals before the relevant theory is presented to them in regular lectures. Moreover, the analytical modelling of wireless signal path loss, which is a core topic in a typical wireless communication course curriculum, is introduced to the students following a problem-based learning approach. Based on the outcome of the proposed tasks, the students will be asked to mathematically determine the amount of power lost by a wireless signal in its path to a receiver by using their background in statistics.

Different from the abstract concepts introduced in textbooks, the proposed approach helps the students to touch and feel the nature of wireless channels. Furthermore, it aims at strengthening their ability to form a mathematical model, which is a very important research tool in the wireless communication field.

Key Words: Inductive teaching, wireless communication, engineering, education.

INTRODUCTION

Wireless communication has become one of the most used technologies in the twenty-first century. However, there are difficulties of teaching wireless communication fundamentals to undergraduate students because they often have problems understanding the theoretical abstract concepts. A typical syllabus of an introductory course in wireless communication includes some concepts about wireless signal propagation and empirical modelling of received signal level. These concepts are usually introduced in an abstract way in most of the textbooks. Moreover, empirical (analytical) modelling of practical measurements is not easy to understand without performing real experiments.

In this paper, we address the use of inductive teaching methods in wireless communication education for the undergrad students of the Communication Engineering program in UAE University. Our approach is student-centred. It is hinged on a combination of discovery-based and problem-based learning methods. Usually the effects of the different impairments of a wireless communication channel on signal reception are often hard to imagine or to comprehend by undergrad students. Research shows that inductive teaching methods lead to a deeper student learning experience with longer retention of information than other methods (Prince & Felder, 2006).

The contributions of this paper are three-fold. First, we offer a series of collaborative laboratory and field tasks that can be seamlessly integrated into the design of a typical course about wireless communication fundamentals. The proposed design of the field and lab tasks follows a discovery-based learning approach that allows the students to discover wireless channel effects on transmitted signals before the theory is presented to them in regular lectures. Second, the analytical modelling of a wireless signal path loss is introduced to the students in a problem-based learning approach. Third, the paper presents some low-cost wireless communication devices that can be used in order to accomplish these tasks for classes with moderate or even large number of students.

The rest of this paper is organized as follows. Section 2 introduces a background about inductive teaching technique. It particularly highlights discovery-based and problem-based learning approaches. Section 3 provides the proposed modifications to the design of an introductory course about wireless communication fundamentals. The benefits of the proposed approach are discussed in Section 4. Finally, Section 5 concludes the paper.

INDUCTIVE TEACHING

Prince and Felder in (Prince & Felder, 2007) and (Prince & Felder, 2006) defined inductive teaching as a teaching technique or a strategy that urges students to know on their own what is the required theory, skills and experience in order to learn a certain subject. In inductive teaching, students are given the chance to teach themselves, exert effort to discover problems, and the information they need without instructor intervention. Teachers, who use inductive teaching method, only direct students to the way they should follow in order to discover information and solution to problems (Prince & Felder, 2007) and (Prince & Felder, 2006).

Indeed, it has been found that students may become motivated when they realize that the information they learned is helpful in practice and beneficial to them in their future careers. The authors Prince & Felder, (2006; 2007) indicated that several forms are available for inductive teaching as in the following.

Inquiry-based learning: This is a generic form of inductive teaching. Basically, all other inductive teaching strategies are variants of inquiry-based learning that differ mainly in how much the instructor is engaged with the students.

Discovery-based learning: In this type of inductive teaching, students are given an exercise to be solved. However, students are required to find out how to solve the exercise themselves as no guidance or intervention from the instructor is allowed. According to Prince and Felder (2006), there is a better version of discovery learning called “guided discovery”, where course instructors may give some directions to students.

Problem-based learning: Students are requested to solve a relatively large, but practical problem in groups, which they should solve themselves by going through all the required phases such as problem formulation, exploring solution techniques, and identifying solution limitations. They should also figure out the background knowledge required to solve the problem themselves. In a lecture context, instructors can explain the required background information if it is complex for students to understand on their own. Alternatively, instructors can give students some hints and directions on where they can find the required information (Prince & Felder, 2007; Smith, Sheppard, Johnson, & Johnson, 2005).

Project-based learning: This kind of inductive teaching has mixed features of both inquiry-based learning and problem-based learning. Students are asked to work on a design project, which is an application to parts of the course material they have already studied. Students try to apply their practical and theoretical knowledge in order to come up with a reasonable solution to the project problem. It involves some instructor guidance since students will have already studied the necessary background information during the course lectures (Prince & Felder, 2007) (Prince & Felder, 2006).

Just-in-time teaching*:* This implies challenging students with a pre-lecture question that may be emailed to them. Students then send their answers to the course instructor prior to the lecture. After that, the course instructor collects students’ answers, tries to identify any lack of background or the pieces of lecture material that may cause confusion to students, and then prepare for the lecture based on students’ response (Prince & Felder, 2007) (Prince & Felder, 2006).

PROPOSED MODIFICATIONS TO COURSE DESIGN

This section addresses the proposed modifications to the design of a typical introductory course about wireless communications. The modifications include the introduction of guided discovery-based learning as an inductive teaching tool represented by a series of collaborative lab/field tasks. Moreover, we exploit another inductive teaching tool (problem-based learning) for introducing the Path Loss Modelling topic, which is usually offered by textbooks in an abstract manner. The section also provides some hardware equipment that can be purchased with an affordable budget to fit a class with a reasonable number of students.

Collaborative Lab/Field Tasks

The proposed tasks require collaborative effort from the students in the class. The students should be divided into groups with a maximum of 3 students in each group. Each task (experiment) should start with preparing a given setup.

Each group of students will be given a router, a WiFi adapter, a measuring tape, and a Linux Ubuntu (Ubuntu, 2015) installed as a Live CD option. A smartphone with a global positioning system (GPS) should be available with at least one student in each group. The router is considered to be the sender. The WiFi adapter is the receiver that measures the received power, i.e., the received signal strength indicator (RSSI) value. Each group of students should use their own laptop.

Students should be informed about the indoor and outdoor areas where the measurements are to be taken. There are some common steps of the setup that should be followed and documented before the measurements can be taken as in the sequel. First, students should measure the received power at least 10 times for some distance between the sender and the receiver. The students should also be instructed to take the measurements at different locations inside a room (or outdoors) in order to take shadowing effects into account. Second, the power should be measured over a distance range of 1 to 10 meters with a step of 1 m for indoor measurements. For the outdoor measurements, the distance range should be chosen differently in order to reach greater distances.

Lab tasks should be done to cover both line-of-sight LOS and non-LOS cases. LOS means there is a virtual straight line connecting the sender and the receiver without any obstacles intersecting it. On the other hand, non-LOS implies that the line passes through one or more obstacles such as computers, monitors, tables, and chairs in an indoor environment. One of the lab tasks is dedicated to address mobility effects on power measurements. The LOS field tasks, Non-LOS field tasks, outdoor field tasks, and mobility tasks are listed in the following experiments. The steps for each task are grouped into three main phases, namely, Setup, Measurements, and Observations.

Task 1: LOS Scenario Investigation

The main objective of this task is to measure the received signal power at different locations of the transmitters and receivers and different transmitter-receiver distances in an LOS setting. The experiment also aims at getting the students acquainted with the setup and the measurement procedure. In addition, they are expected to observe the effect of shadowing on the RSSI values for different locations. Students should provide their results in a table documenting the outcome of each time the experiment is performed, which includes the power received at each transmitter-receiver distance (from 1 to 10 meters).

Setup:

- Run Ubuntu Linux as a Live CD on your laptop.
- Connect the WiFi adapter to the pre-configured access point name broadcasted by the router

Measurements:

- Select two locations for the receiver and the transmitter. Make sure there are no obstacles in between.
- By using the measuring tape, determine the distance separating the router and the laptop then record it in a table.
- Measure and record the received power after staying stationary for few seconds to avoid fast fading effects.

- Repeat the measurements 10 times with the same separation distance but in different locations and record the results each time.

Observations:

After finishing the experiment, observe the variation in the RSSI values at one distance and explain what could be the reason behind it.

Task 2: Non-LOS Scenario Investigation

The same setup steps in Task 1 should be followed. The main differences lie mainly in the Measurements and Observations phases as indicated below. The objective of this task is to let students observe the effect of shadowing in non-LOS communication.

Measurements:

- Use the measuring tape and/or the Pythagorean theorem to measure/calculate the distance between a router and a laptop then record the measured distance.
- Make sure that there are some obstacles in between the router and the laptop. The variation of obstacles results in more accurate path loss measurements.
- Measure and record the received power after staying stationary for a few seconds to avoid the fast fading effects.
- Repeat the measurements 10 times, with the same router-laptop separation distance, but in different locations, and record the results.

Observations:

- Observe the variation in the RSSI values at one distance and try to explain the reason behind it.
- Observe the difference between the LOS and the non-LOS RSSI values and try to explain the reason behind it.

Task 3: Outdoor Scenario Examination

The same setup steps, which are mentioned in Task 1 and 2, should be followed.

Measurements:

- Use GPS coordinates obtained from a GPS-enabled smart phone to measure/calculate the distance between a router and a laptop then record the measured distance.
- First make sure there is an LOS between the transmitter and the receiver. Do the measurements the same way as in Task 1.
- Repeat the measurements with some obstacles in between the router and the laptop as in Task 2. The type of obstacles should cover both metal and non-metal objects.
- Measure and record the received power the same way as in Task 2.

Observations:

- Observe the variation in the RSSI values and the difference between the LOS and the non-LOS RSSI values. Explain the reason for this difference.

Task 4: Mobility Scenario Exploration

The objective of this experiment is to let the students experience the effect of mobility on received signal power. This setup requires one extra piece of equipment (robot) to hold one of the transceivers and move it around the area where the task is performed. A configured moderate speed robot should be available to each group of students.

Setup:

- Make sure that the robot is programmed to move correctly over a predetermined path. The path should make the distance between the laptop and the robot fixed.
- Run Ubuntu Linux as a Live CD on the laptop.
- Fix the wireless router over the robot firmly.
- Connect the laptop to the access point broadcasted by the router.

Measurements:

- Make sure the robots do not stay in the same place while measuring the power.
- Make sure there are no obstacles between the wireless router and the laptop for LOS measurements.
- Leave the robots running long enough to take about 10 RSSI measurements.
- Change the distance between the router and the laptop, record the new distance in a table until the whole range of distances is covered.

Observations:

- Observe the variation in the RSSI values at one distance and try to explain the reason behind it.
- Observe the difference between the results of Task 1 and Task 4 results then write down your observations.

Problem-based Teaching Approach for Path Loss Modelling

After finishing all the lab/field tasks, the students are expected to find the solution of a given problem. The problem asks the students to express mathematically the amount of power that a wireless signal loses in its path to a receiver (path loss) based on their lab/field measurements and by using their background in statistics.

Consequently, the students should be introduced to the theoretical background that is required to solve the problem. The theoretical background includes the following path loss equation (Rappaport, 2002)

$$PL(d)(dB) = \overline{PL}(d_\emptyset) + 10 * n * log\left(\frac{d}{d_\emptyset}\right) + X_\sigma$$

The terms of the above equations are commonly described in most of the textbooks as in the following. The path loss exponent *n* describes how quickly the path loss increases, d_ϕ is the close-in reference distance, *d* is the separation between transceivers, X_σ is the standard deviation for a zero mean Gaussian random variable with a standard deviation of **σ**, and *PL(d)* is the path loss at distance *d* in decibels (Rappaport, 2002).

In a regular deductive teaching approach, the majority of the students are usually not able to follow why the above equation is represented with the variables *n* and X_σ, which is different from the fairly simple free space equation. In our proposed teaching approach, students have to compare the path loss measurements they have done in Section 3.1 with the above equation. It should be emphasized that the calculated $PL(d)$ at distance d does not always equal the measured one. Based on the collected measurements, students should be able to discover for themselves the reason behind having a random component in the above equation. The solution to the problem requires finding the variables *n* and the standard deviation σ. The students should use the background that they acquired from previous statistics courses to be able to estimate the values of the two variables, and hence estimate analytically the path loss model. After that, the students should compare their findings for *n* and σ with the corresponding values in their textbooks and other sources from the literature. They should also comment on any discrepancy that may be found.

As a supplementary assignment, the students will be asked to investigate the current techniques that are used in the literature to mitigate wireless channel impairments. They should also mention some practical examples for commercial products that use these techniques.

Low-Cost Hardware for Lab/Field Tasks

Figure 1 A spectrum analyzer and a vector generator

Many transceivers can be used in our proposed lab/field tasks. Some of these transceivers provide a high degree of accuracy, whereas others are more affordable in terms of their cost. For instance, a vector signal generator and a portable spectrum analyser as depicted in Figure 1, can be used to perform all the proposed lab/field tasks. They provide highly accurate results. However, the configuration of a setup that includes this equipment is not straightforward. Moreover, it is very expensive to purchase more than one unit of each one of them. For educational purposes, high accuracy may not be required since the results, which are obtained with moderate accuracy, are sufficient to correctly represent the concepts under consideration.

Figure 2 A WiFi adapter and a wireless router

Given the relatively large number of students who usually register in wireless communication courses, we propose using a wireless router and a WiFi (IEEE802.11, 2012) adapter for educational purposes due to their availability, easy setup, and configuration.

Figure 3 A Zigbee gateway and a TelosB mote.

In fact, ZigBee (IEEE802.15.4, 2003) transceivers and gateways, as shown in Figure 3, can also be used. They measure the RSSI directly and easily. They are normally inexpensive with a price range that is between 25 and 50 US Dollars per unit. Figure 3 also shows a TelsoB mote (TelosB, 2015). TelosB motes represent a viable option as they are able to measure RSSI values directly, however, they are a bit more expensive. Their price range is from 100 to 150 US Dollars each.

BENEFITS OF THE PROPOSED APPROACH

One of the main objectives of the introduction of the proposed inductive teaching approach is to help the students to touch and feel the nature of wireless communication channels and the impairments they may have. Field experiments often surprise the students with some results that need unintuitive explanation. Moreover, the students can be exposed to the physics of wireless signal propagation and the effect of different types of obstacles on the received signal level in a practical way. In addition, it helps students to understand typical empirical channel models that are usually introduced as an abstract theoretical part in most of wireless communication textbooks.

Furthermore, the proposed inductive teaching approach allows the students to engage in practical exercise of concepts they learn in statistics courses. This leads to the strengthening of their ability to form a mathematical model describing some random phenomena, which is a very important research tool in the wireless communication field. Thus, the proposed approach provides a smooth transition between the stages of acquiring basic knowledge, during the undergraduate education, to the next stage of seeking deeper knowledge through scientific research.

In addition to the technical learning benefits, the proposed teaching approach has also some non-technical positive impacts. First, it helps to develop the teamwork spirit among the students since they have to conduct the lab/field tasks together in groups and also to collaborate in order to solve the path loss modelling problem. Second, it promotes information sharing, in addition to knowledge and findings exchange among students. Third, it helps to enhance time management skills of the students as they are required to take a sufficient number of measurements within the allotted time of each lab\field task.

CONCLUSION

In this paper, we introduce an inductive approach to teaching wireless communication fundamentals to undergraduate students. We exploit inductive teaching methods in order to transfer the usually hard-to-comprehend abstract wireless communication concepts into an exciting practical experience. We offer a series of lab/field tasks that can be easily integrated into the design of a basic course about wireless communication fundamentals. The design of the lab/field tasks follow a discovery-based learning approach that encourages the students to discover by themselves the phenomena accompanying wireless signal propagation. Moreover, we propose using a problem-based learning approach to introduce one of the core topics in wireless communication courses, namely, path loss modelling. The proposed problem-based learning aims at strengthening the mathematical modeling skill for the undergraduate students, which is an essential skill for scientific research in the wireless communication field and electrical engineering in general. Furthermore, we present some inexpensive lab equipment that can be used in the proposed lab/field tasks for classes with moderate or even large number of students.

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