Teaching Wireless Communication and Networking Fundamentals Using Wi-Fi Projects

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Abstract – Wireless communication and networking often proves to be a quite challenging subject to teach in a meaningful way, because many students appear to find the subject rather dry and technical, and thus quite boring. The authors have prepared some interesting projects to provide the students of wireless communication and networking with a hands-on learning experience. These projects are designed around low-cost Wi-Fi modules and PC cards that are available from local electronics shops. The projects are suitable for classroom use in introductory level courses about wireless networking. The effectiveness of these projects has been evaluated by both students and teaching team. The feedback from students indicates that both the development and implementation of the projects were successful. This paper describes these projects, their overall effectiveness, and plans for further projects. The impact of Wi-Fi projects on student learning and comprehension is also discussed.

Index Terms - Evaluation, Hands-on experience, IEEE 802.11, Wi-Fi modules, Wireless networking

I. INTRODUCTION

Wireless communication and networking courses are becoming increasingly popular in universities, polytechnical institutions, post-secondary colleges, and private training institutions around the globe. This popularity is partly because of rapid developments in wireless communication and networking technology and the high demand for wireless and mobile networking skills in the industry, both nationally and internationally. Unfortunately, motivating students to learn about wireless communication and networking is often difficult because they find the subject dry, full of technical jargon, and, consequently, rather boring. However, the view is frequently supported in the educational literature [1]-[2] that incorporating practical demonstrations into these courses, thereby illustrating theoretical concepts and providing opportunity for hands-on learning experiences, significantly enhances student learning about wireless communication and networking. Yet, despite the Chinese adage, attributed to Confucius (551-479 BC), 'I hear, I know. I see, I remember. I do, I understand,' only a limited amount of material designed to supplement the teaching of wireless communication and networking fundamentals is publicly available, as searches of the Computer Science Teaching Center [3] and SIGCSE Education Links [4] sites reveal.

The authors strongly believe, as do many others [5]-[10], that students learn more effectively from courses that provide for active involvement in hands-on learning experiences. To that end, some interesting projects have been prepared that facilitate an interactive, hands-on approach to learning wireless communication and networking concepts. The first of these projects used the programmable interface controller (PIC) Sound Generator project described in [11] and the infrared (IR) signals produced by a

pair of TV remote controls. The second project involved setting up a wireless link between two computers. This project used a pair of commercially available receiver and transmitter modules which operate in the 2.4 GHz band and have audio and video inputs and outputs, respectively. The third project involved the students setting up a peer-to-peer wireless link, using a pair of computers fitted with commercially available Wi-Fi PC cards. Finally, several such links were formed into a wireless network. These projects can be used either in the classroom, as a demonstration to enhance the traditional lecture environment, or in the laboratory to provide a practical hands-on learning experience at an introductory level.

Wireless communication and networking is described in many textbooks [12]-[14]. A number of sophisticated network simulators exist for building a variety of network models [15]-[18]. Nevertheless, by setting up and configuring actual wireless communication networks the students gain first hand experience that cannot be gained through computer simulation and modelling.

This hands-on learning approach to teaching and learning wireless communication and networking was trialled for the first time during Semester 2, 2004, in the undergraduate course "e-Business IT Infrastructure" at the Auckland University of Technology (AUT). This course covers various aspects of wireless communication and networking.

The focus of the projects discussed in this paper has been on preparing demonstration projects to support teaching wireless communication and networking. These projects are described in the next section, while in the remainder of the paper, the effectiveness and the main benefits of Wi-Fi projects as a means of enhancing the teaching and learning of wireless networking fundamentals are discussed. A brief

conclusion section ends the paper.

II. PROJECT DETAILS

Table I lists the six projects that have been developed to date. Additional information regarding the Wi-Fi projects, such as the class materials and the equipment list needed for each project, can be found in [19].

TABLE I
WI-FI PROJECTS AND RELATED WIRELESS NETWORKING CONCEPTS

Projects	Wireless networking concepts
1. Infrared (IR)	IR transmission link; signal interference; modulation and demodulation
2. 2.4 GHz wireless link	Wireless FM transmission; encoding and decoding; modulation and demodulation
3. Wi-Fi antenna	External Wi-Fi antenna; signal strength; response time and throughput
4. Ad hoc network	Peer-to-peer networking; file sharing; security
5. Infrastructure network	Infrastructure-based network; centralized network control; wireless access point; basic service set; extended service set
6. Network security	Access control; firewalls; encryption; service set identifier (SSID)

Project 1: Infrared remote controls

Attention is drawn in [20] to the similarities between communication links that utilize IR and wireless links that utilize radio transmission in the 2.4 GHz band. The first project exploits these similarities as a means of introducing Wi-Fi to students via a technology with which they are already familiar – IR remote control units. Project 1 uses an IR-detector module from a dismantled computer to detect the IR pulse-modulated signals produced by a pair of TV remote controls. The IR detector and power supply were

assembled on a breadboard, and the output from the IR detector was captured on a Tektronix 2230 storage oscilloscope.
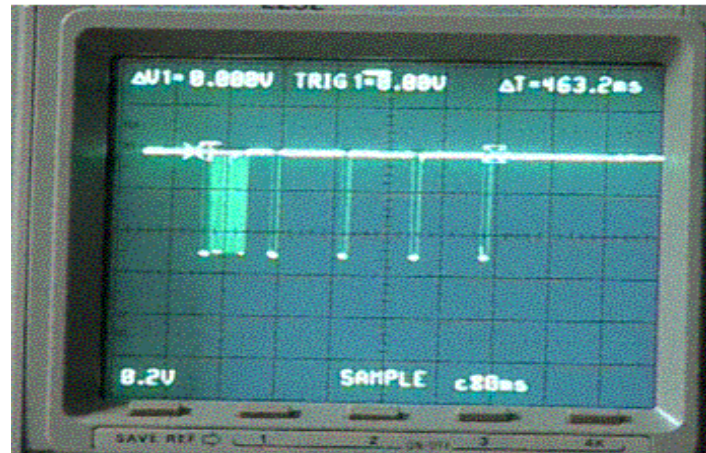

Fig.1. The signal produced by a single remote control unit.

The same signals were also fed to the PIC Sound Generator project described in [11], where they were filtered and then passed to the audio amplifier built into that project. As a result, students could both see and hear representations of the IR signals being produced by the two remote control units. Fig. 1 shows the signal train produced by a single remote control. In Fig. 2, the overlapping of the IR signals produced by a pair of TV remote controls when one controller is operated slightly later than the other can be seen. The importance of the receiver being able to distinguish between overlapping signals can be well demonstrated by the refusal of devices (such as a TV set) to react as expected when both remote control units are used simultaneously. The storage oscilloscope can be used to capture also a display of the serial signal used to control the LCD display described in [11] and the RS232C signals produced by the project described in [21]. Many students have indicated that they found being able to experience in new ways something as familiar to them as a TV remote control unit was

both enlightening and intriguing, and they were thus better able to appreciate the behavior of a wireless communication link.
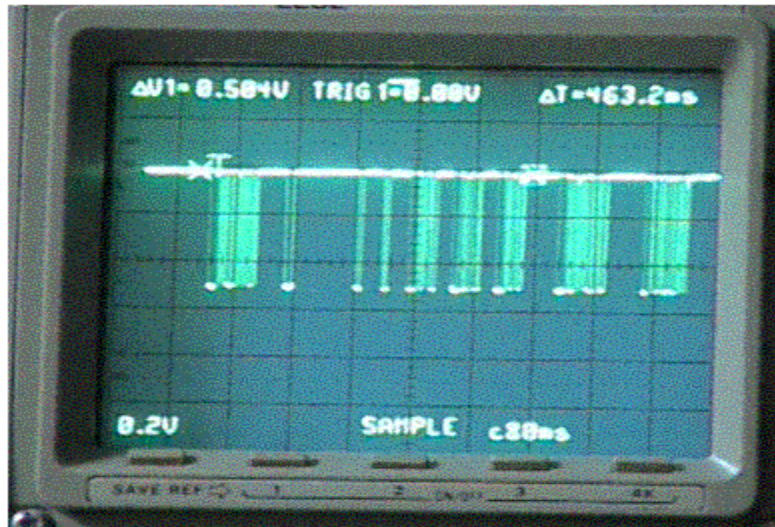

Fig.2. The signal trains from the two remote control units.

Project 2: A 2.4 GHz wireless link

Leading on from the first project, this project endeavors to provide students with an appreciation of the characteristics of another part of the electromagnetic spectrum, viz. microwave radiation as an information carrier. The project is based around two commercially available kits [22], which comprise an FM transmitter and a matched receiver. These modules are pre-tuned to one of four frequencies within the 2.4 GHz band. Again, students will be familiar with the some aspects of the technology involved through their experience with FM broadcasting and television broadcasts, although these services operate at lower frequencies than Wi-Fi. The kits were installed in plastic project boxes, and the transmitter was fitted with a socket so that it could be fitted with an external antenna (Figs. 3 and 4). The transmitter module has inputs for both audio and video. In this project, only the audio inputs were utilized, these being connected to the speaker jack on the sound card of a PC (computer A). Similarly, the receiver has

audio and video outputs, but only the audio outputs were utilized, these being connected to the line in socket on the sound card of a second PC (computer B). Students could then arrange to play a music CD on computer A and listen to the contents of the CD on computer B via the radio link. The influence of the distance between the transmitter and the receiver, the polarization of the respective antennas, the presence of obstacles between the transmitter and the receiver, as well as interference by out of phase reflected signals, and the polarization of the signal were all easily observable via the changing quality of the music produced by computer B. The ability to switch between the four different channels within the 2.4 GHz band that are built into the modules would enable channel-hopping to be explored as a future project using a PIC microcontroller. The currently active channel is indicated by one of the LEDs seen in Fig. 4.

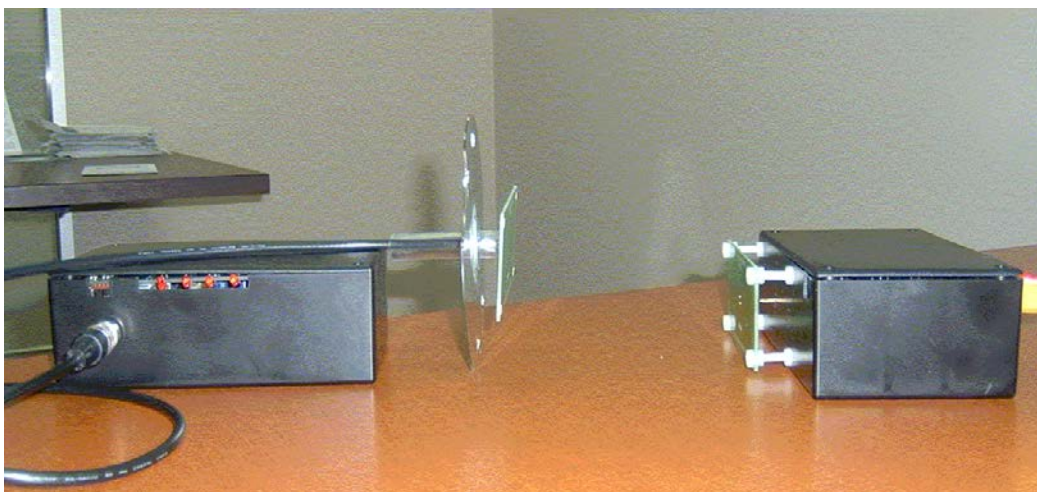Fig.3. Linking two computers via a wireless link.

Fig.4. Close-up view of the transmitter and receiver modules.

Project 3: Wi-Fi Antenna

The transmitter module in Project 2 was fitted with a BNC socket so that an external antenna could be attached. Numerous antenna designs have been published [23]-[24], and students were encouraged to consult these sources to build an antenna of their own design. One such endeavor, consisting of the bow-tie PCB antenna supplied by the module manufacturer [22] coupled with a CD disc used as a reflector, can be seen in Fig. 4. The student's work does not need to be an elaborate design for it to be an effective means of engendering student interest and confidence. In fact, the wireless link can be established with a 50-ohm terminator (as used in Ethernet networks) connected to the transmitter antenna socket, provided the receiver and transmitter modules are located within a few meters of each other. This link however is easily broken if the separation between the modules is increased to about five meters. The influence of objects in or near the signal path is more apparent when the signal strength is restricted in this way; one indicator of the link quality is the quality of the sound produced by the receiving computer (B). A second way of determining the strength of the signal being

received by the receiving computer is to use either a proprietary software program, such as Netstumbler [25], or the program that is provided within Windows XP. Projects 1 and 2 appear to provide students with a qualitative grasp of the behavior of IR and Wi-Fi links, preparing them to set up a peer-to-peer link between two computers using commercially available Wi-Fi computer cards, as described next.

Project 4: Ad hoc Network

The basic concept of wireless ad hoc networks and their potential application areas are discussed during lectures. This project showed students how to set up a wireless ad hoc network. In addition, students were able to investigate the effect of transmitter-receiver separation, floors, line-of-sight blockage on the file transmission time, and link throughput of a typical IEEE 802.11b wireless local area network (WLAN) in peer-to-peer mode. The project involved the installation in a pair of PCs two IEEE 802.11b Wi-Fi PC computer cards purchased from an electronics store. This procedure is well documented in texts, such as [26], and most of the students found little difficulty in completing this step. Of greater interest to them was the question of how to achieve the transmission of the same music that they had become acquainted with via the 2.4 GHz FM wireless link. Should the file on the CD be sent as a compact disc audio track file (cda file) or should it be sent as a bit stream? By completing these activities, students gained a sound knowledge and understanding about ad hoc networks.

Project 5: Infrastructure Network

When more than two computers are to be connected, a means of controlling the communication between each computer is necessary. In an infrastructure network this task is allocated to a wireless access point (AP). The APs are more expensive than computer Wi-Fi cards, but only one is needed for a small network. The basic concepts of

wireless access points, infrastructure-based wireless LANs, basic service set (BSS), and extended service set (ESS) are introduced during lectures. This project shows students how to set up an infrastructure-based network. As in Project 4, the procedure for setting up an infrastructure network is well documented [26], and most students are able to complete this extension of their network with little supervision.

Project 6: Network Security

This project demonstrates to students the basic concept of wireless network security [27]-[28]. In lectures, the basic concept of wireless LAN security and related issues and challenges were introduced. These concepts were reinforced when the students were setting up Project 4 and Project 5, in accordance with the procedures described in [26], because the information required when setting up the network software requires a good knowledge of both network operation and terminology, e.g., terms such as SSID (Service Set IDentifier), access control, MAC (Media Access Control) address.

Additional Projects

The following projects are being considered:

- **Integrating Wi-Fi with PIC projects**: The hands-on learning activities include using a Wi-Fi radio link to control a PIC microcontroller.

- **IEEE 802.11a/g**: The learning activities include experiment with OFDM (Orthogonal Frequency Division Multiplexing) technology and the 5 GHz radio spectrum.

- **Open -** A category for student-suggested projects.

III. BENEFITS OF WI-FI PROJECTS

The Wi-Fi projects discussed in this paper provide the following benefits:

- **Hands-on:** Wi-Fi projects facilitate an interactive, hands-on learning experience in wireless communication and networking.

- **Easy to use:** Wi-Fi projects are easy to use and set up for demonstrations.

- **Low cost**: Wi-Fi projects can be built with limited resources and budget (e.g., within a few hundred dollars).

- **Reusability:** Some hardware components of Wi-Fi projects can be reused in developing a variety of other projects.

- **Usefulness:** The Wi-Fi projects reported in this paper can be used either in the classroom or in the laboratory to provide hands-on learning experience in wireless communication and networking.

- **Challenging:** Wi-Fi projects provide an opportunity for students to test their knowledge about wireless networking and communication.

IV. THE WI-FI PROJECTS IN PRACTICE

The authors' experiences with the Wi-Fi projects have been favorable overall. The Wi-Fi projects were easy to use and set up for demonstrations, and by participating in the Wi-Fi projects and demonstration activities, students became increasingly motivated to learn more about wireless communication networks. They enjoyed this course more than previous courses that consisted of lectures only. The authors seek feedback regularly both from students and staff for further improvement of the demonstration materials.

A   ***Evaluation***

The Wi-Fi projects were offered as a capstone project to two undergraduate diploma students who carried out the project in the final semester towards the Diploma in Information Technology (DipIT) qualification. The students had completed most of the courses required for a DipIT qualification, including data communications and computer networking, before taking up the Wi-Fi projects. The students achieved the following learning outcomes: (1) setting up a wireless link using IR technology; (2) setting up both ad hoc and infrastructure based wireless LANs; (3) designing a Wi-Fi booster antenna; (4) setting up Wi-Fi projects for class demonstration and evaluating the effectiveness of the projects by means of staff and student feedback; (5) writing a report containing requirements analysis, a project plan, minutes of the meetings, summary of findings and reflective statements; (6) giving an oral presentation to an audience of staff and students.

The Wi-Fi projects were completed successfully, and the students indicated that they had learned considerable about wireless communication and networking through the hands-on experience that the Wi-Fi projects provided. This learning is evident in the students' reflective statements, which follow:

"I learnt quite a lot about Wi-Fi technology and networking by doing hands-on projects."

"Even though we had passed the "Data communication and networking" courses before taking up the Wi-Fi projects, we did not learn much about the practical aspects of wireless communication and networking until we carried out the Wi-Fi projects.

"Wireless communication and networking should be taught using hands-on learning activities as we did with the Wi-Fi projects."

B   Impact of Wi-Fi Projects on Student Performance

The Wi-Fi projects were trialed, as a class demonstration, in the undergraduate course, "E-business IT Infrastructure (EBITI)" in Semester 2 of 2004. The EBITI [29] course is at level 6 or first-year degree level and constitutes 15 credit points (52 contact hours) at AUT. Until this trial, the wireless communication and networking course was conducted through of a series of lectures and tutorials only.

To estimate (quantitatively) the impact of the Wi-Fi projects and demonstrations on student learning and comprehension, the class was given an assessment test (multiple-choice questions) on wireless communication networks before the projects were introduced. Then, after the entire class had an opportunity to gain hands-on experience with the Wi-Fi projects, the same test was given again to measure any change in student learning and comprehension.

The class consisted of 11 students, five female and six male. While not a particularly large group, it was at least a diverse mix. The exam consisted of 19 multiple-choice questions covering various aspects of wireless and mobile networking technology, including ad hoc and infrastructure wireless LANs, Bluetooth, and wireless security (see Appendix for a listing of the test questions).

Table II shows results of these tests. The question numbers of the 19 multiple-choice questions are indicated in the first column. The fraction of the students in the class who answered correctly (expressed as a percentage) in each of the 19 questions in the class test before and after they had experience with the Wi-Fi projects are shown in column 2 and 3, respectively.

TABLE II
IMPACT OF WI-FI PROJECTS ON STUDENT LEARNING AND COMPREHENSION

Question	Percentage of class answering correctly		Improvement (%)
	Before	After	
1	33	100	67
2	67	91	24
3	11	73	62
4	56	91	35
5	44	100	56
6	33	64	30
7	0	100	100
8	67	91	24
9	56	64	8
10	22	36	14
11	22	82	60
12	22	36	14
13	56	64	8
14	44	91	46
15	56	64	8
16	22	55	32
17	56	64	8
18	22	45	23
19	33	45	12
Overall	38	71	33

As seen in Table II, on each of the 19 questions the class as a whole showed an improvement ranging from 8 to 100%, and the overall improvement for the test is 33%. This improvement can be accounted for by the practical experience that the students gained from the Wi-Fi projects between the two tests since no other forms of instruction were given to the students before the second test. The tests (before and after) were

conducted among students having the same background and who had been exposed to the same theoretical material.

V. CONCLUDING REMARKS

A series of interesting projects has been developed, which can be used either in the classroom for class demonstrations, in enhancement of the traditional lecture environment, or in the computer laboratory for hands-on practical work in introductory wireless communication and networking course. The Wi-Fi projects described in this paper are easy to use and set up for class demonstrations. The projects consist of inexpensive and widely available modules and kits, and are thus likely to be within reach of even already extended budgets. Student responses to the project demonstrations were mostly favorable. The students indicated that they had found the Wi-Fi projects easy to use and helpful in gaining an understanding of wireless communication and networking fundamentals. The Wi-Fi projects demonstration has had a positive impact on student learning and comprehension.

More projects, such as IEEE 802.11a, IEEE 802.11g, and integrating Wi-Fi and PIC projects, are being prepared. These materials are available to faculty interested in using the Wi-Fi projects to supplement their wireless communication and networking courses or as the basis for more complex projects. More information about the Wi-Fi projects and demonstration materials can be obtained by contacting the first author.

APPENDIX: Assessment Test

Maximum time allowed: 20 minutes

Please answer as many questions as you can. Thank you for your participation.

1. What is the maximum distance an IEEE 802.11b network can cover?

    a) 100 meters
    b) 10 meters
    c) 1000 meters
    d) 20 meters

2. What is the maximum theoretical speed of IEEE 802.11b and IEEE 802.11g?

IEEE 802.11b	IEEE 802.11g
a) 12 Mbps	a) 12 Mbps
b) 54 Mbps	b) 54 Mbps
c) 22 Mbps	c) 22 Mbps
d) 11 Mbps	d) 11 Mbps

3. What security protocols are commonly used in Wi-Fi?

    a) MAC address restrictions
    b) WEP Key 64/128 bit
    c) BLT on rye
    d) USB access key

4. What does SSID stand for?

    a) Super Security Implementation Device
    b) Seismic Standard Identification Deployment
    c) Service Set IDentifier
    d) Slow Service IDentifier

5. What is the difference between WEP and MAC filtering?

    a) One's hardware and one's software
    b) They're the same thing
    c) One is a pie protocol
    d) WEP has a greater maximum distance

6. What is a MAC address?

    a) Location of the closet Mac Donald's
    b) Management Address Character for Wi-Fi
    c) The Numeral ID of your network card
    d) Closet reseller of Mac Trucks

7. What is the difference between an Ad-hoc and an Infrastructure network?

8. What are hotspots?
    a) Something you should avoid standing on
    b) Areas that you can get open assess to a Wi-Fi Network
    c) Areas on the sun that are brighter
9. Which of the following characteristics differ between Bluetooth and Wi-Fi?
    a) Speed
    b) Frequency
    c) Distance
    d) Cost
10. List three advantages of wireless LANs over wired networks
11. List three disadvantages of wireless LANs over wired networks
12. What is DHCP?
    a) A protocol that assign your computer an IP address?
    b) A devise that lets Wi-Fi dial up ADSL
    c) Decipher Help Character Protocol
    d) Transdimensional Gateway to Pluto
13. What other common household items use the same frequency as Wi-Fi?
    a) Cell Phone
    b) Microwave
    c) Cordless Phone
    d) Sky Box
14. What does Wi-Fi stand for?
    a) Wired-Fiction
    b) Wireless-Fitting
    c) Wireless-Fidelity
    d) Wired-Fix
15. Can a Wi-Fi network replace a wired network in every case?
    a) No
    b) Yes
    c) No clue
16. Is all Wi-Fi equipment compatible?
    a) No
    b) Yes
17. Is each Wi-Fi a secure network?
    a) Yes, better than wired networks
    b) No, worse than wired networks
    c) Yes, equal to wired networks
18. Does it cost more to set a Wi-Fi network than a wired network?
    a) Yes, a lot more than a wired network
    b) Yes, but not much more than a wired network
    c) No, the same
    d) No, a lot cheaper than a wired network
19. An access point is required to set up a wireless LAN.
    a) False
    b) True

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