Performance Evaluation of Wireless IEEE 802.11b used for E-Learning Classroom Network

Salam A. Najim, Ibrahiem M. M. El Emary, and Samir M. Saied
Faculty of Engineering, Al Ahliyya Amman University
Amman, Jordan

E-mail: drsalamadil@yahoo.com,
doctor_ebrahim@yahoo.com,
samir_m_said@hotmail.com

Abstract: This paper presents an evaluation study of an IEEE 802.11b wireless LAN (WLAN) applied in E-learning classroom. The simulation is conducted using OPNET IT Guru 9.1. Also, this paper presents a simulation study to estimate the appropriate number of E-learning clients that can be supported in the WLAN as well as the user-perceived Web response time as a function of network load. Our simulation results show that an IEEE 802.11b WLAN can support up to 50 clients with modest E-learning and Web browsing activities.

Keywords: Wireless Local Area Network (WLAN), Hyper Text Transfer Protocol (HTTP), E-Learning, OPNET, IEEE 802.11b.

INTRODUCTION

Wireless access points are now commonplace on many areas such as: homes, airports, university campuses [1, 2, 3, 4]. Technologies such as IEEE 802.11b wireless LANs (WLANs) have changed the way people think about networks, by offering users freedom from the constraints of physical wires. Mobile users are interested in exploiting the full functionality of the technology at their fingertips, as wireless networks bring closer the "anything, anytime, anywhere" promise of mobile networking.

A natural step in the wireless Internet evolution is the convergence of technologies to form the "wireless Web": the wireless E-learning classroom, the wireless campus, the wireless office, and the wireless home. Educators can embrace wireless Internet access to enhance the learning experience in the classroom for students with wireless laptops through on-line access to lecture: notes, demos, examples, quizzes, assignments and supplementary reading material.

In this paper, we explore wireless Web performance in the context of E-learning classroom area networks. Our work is based on measurements of a small-scale wireless classroom experiment, where in an Ethernet web server was used in an environment to deliver selected course content to a graduate class with 25 students.

Our paper uses simulation to study a larger-scale classroom area network scenario. We use the OPNET IT Guru 9.1 simulation environment with its detailed models of IEEE 802.11b, TCP/IP, and HTTP. We parameterize the simulation model based on our E-learning classroom measurements and validate the model against empirical measurements using simple E-learning and Web workload models. We then build a model of browsing behavior for an E-learning and Web client and use this model in a simulation study addressing the scalability of the E–learning classroom area network. Our experiments focus on the HTTP transaction rate, wireless delay, end-to-end throughput achievable in the wireless network environment, Wireless Access point delay, and the impacts of factors such as number of clients, and E-learning Web object size.

Corresponding Author: Dr. Salam A. Najim, Faculty of Engineering, Amman Al Ahliyya University, Amman, Jordan, E-mail: drsalamadil@yahoo.com

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Our simulation results of this paper show that an IEEE 802.11b WLAN can easily support up to 50 clients with modest E-leaning and Web browsing behavior. Furthermore, HTTP protocol features such as persistent connections provide a significant performance advantage in a WLAN environment.

The remainder of this paper is organized as follows. Section 2 discusses background information on wireless Internet technologies, including IEEE 802.11b, TCP, and HTTP. Section 3 describes the simulation setup and methodology for our study. Section 4 presents the simulation results and analyses. Finally, Section 5 summarizes the paper and describes ongoing work.

BACKGROUND AND RELATED WORK

The Web and Web Performance: The World Wide Web (WWW) has been the largest source of Internet traffic. The Web has made the Internet available to the masses, by providing location-independent, time-independent, and platform-independent access to information.

The Web relies primarily on three communication protocols: IP, TCP, and HTTP. The Internet Protocol (IP) is a connection-less network-layer protocol that provides global addressing and routing for datagram delivery on the Internet. The Transmission Control Protocol (TCP) is a connection-oriented transport-layer protocol that provides end-to-end data delivery across the Internet [5]. Among its various functions, TCP is responsible for flow control, congestion control, and error recovery mechanisms to provide reliable data transmission between sources and destinations. The robustness of TCP allows it to operate in many network environments. Finally, the Hyper-Text Transfer Protocol (HTTP) is a request-response application-layer protocol layered on top of TCP. HTTP is used to transfer Web documents between Web servers and Web clients. Currently, HTTP/1.0 [6] and HTTP/1.1 [7] are widely used on the Internet.

Wireless Internet and IEEE 802.11b WLANs: Wireless technologies are playing an increasingly prominent role in the global Internet infrastructure. One of the popular technologies in the wireless LAN market is the IEEE 802.11b standard. This popular "WiFi" (Wireless Fidelity) technology provides low-cost wireless Internet capability for end users, with up to 11 Mbps data transmission rate at the physical layer. The IEEE 802.11b standard defines the channel access protocol used at the MAC layer, namely Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). It also defines the frame formats used at the data link layer: 128-bit preamble, 16-bit Start-of-Frame delimiter, 48-bit PLCP (Physical Layer Convergence Protocol) header, followed by a 24-byte MAC-layer header and variable size pay load which can be used for carrying IP packets. Frames that are correctly received over the shared wireless channel are acknowledged (almost immediately) by the receiver. Unacknowledged frames are retransmitted by the sender after a short timeout (typically a few milliseconds) using the same MAC protocol.

Wireless E-learning Web Performance: The overall performance of the E-learning Web depends on the behaviors of E-learning Web clients, the E-learning Web server, and the network in between. The primary challenge in the wireless Internet context is the characteristics of the wireless channel. Communication over wireless links often suffers from limited bandwidth, high error rates, and interference from other users on the shared channel. The obvious concern is that TCP and HTTP performance may degrade over wireless networks.

The focus of this paper is on the performance of wireless E-learning Web access and in an E-learning classroom area network. Our primary emphasis is on performance problems due to the wireless network bottleneck, and understanding how these problems affect user-perceived performance.

Related Work: There is a growing literature on wireless traffic measurement and Internet protocol performance over wireless networks [8, 1, 2, 9, 11, and 4]. For example, Tang and Baker [11, 4] discuss wireless network measurements from two different environments: a metropolitan area network and a local area network. More recently, Balachan-dran et al. [8] report on network performance and user behavior for general Internet access by several hundred wireless LAN users. They find that for this set of technology-literate users a wide range of Internet applications are used, user behaviors are diverse, and overall bandwidth demands are moderate. Kotz and Essein [3] characterize campus-wide wireless network usage at Dartmouth College focusing on infrastructure mode using access points.

THE PROPOSED SIMULATION METHODOLOGY

Simulation Environment: In this work, we use OPNET IT Guru 9.1 for our network simulations. OPNET IT Guru is a powerful communication system simulator developed by OPNET Technologies [10]. OPNET IT Guru 9.1 assists with the testing and design of communications protocols and networks by simulating network performance for wired and/or wireless environments.

The OPNET tool provides a hierarchical graphical user interface for the definition of network models. A network is constructed by graphically connecting network nodes via communications links. OPNET IT Guru comes with an extensive model library, including application traffic models (e.g., HTTP, FTP, E-mail, Database), protocol models (e.g., TCP/IP, IEEE 802.11b, Ethernet), and a broad set of distributions for random variant generation. There are also adequate facilities for simulation instrumentation, report generation, and statistical analysis of results.

The IEEE 802.11 standard defines a set of wireless LAN protocols that deliver services similar to those found in wired Ethernet LAN environments. The IEEE 802.11 WLAN architecture is built around a Basic Service Set (BSS). A BSS is a set of stations that communicate with one another. When all the stations in the BSS can communicate directly with each other (without a connection to a wired network), the BSS is known as an ad hoc WLAN. When a BSS includes a wireless access point (AP) connected to a wired network, the BSS is called an infrastructure network. In this mode, all mobile stations in the WLAN communicate via the AP providing access to stations on wired LANs and the world-wide Internet.

In our work, we use OPNET IT Guru to model a simple infrastructure WLAN as shown in Fig.1. The network consists of a mobile client, a wireless Access Point (AP), an Ethernet-based E-learning Web server, and an Ethernet Switch. The Web server is located on a 100 Mbps Ethernet LAN segment. The mobile client accesses content from the E-learning and Web server via the AP1, using the IEEE 802.11b protocol. (Additional clients are considered in later experiments.)

The mobile client node represents a laptop with client-server applications running over TCP/IP. These applications make use of the WLAN connection, which can operate at 1 Mbps, 2 Mbps, 5.5 Mbps, or 11 Mbps, as defined in IEEE 802.11b. We use only the 11 Mbps setting in our work. The Ethernet-based E-Learning Web server node represents an E-Learning and HTTP server running over TCP/IP. The operational speed is determined by the wired link's data rate. In our configuration, the WLAN is the bottleneck.

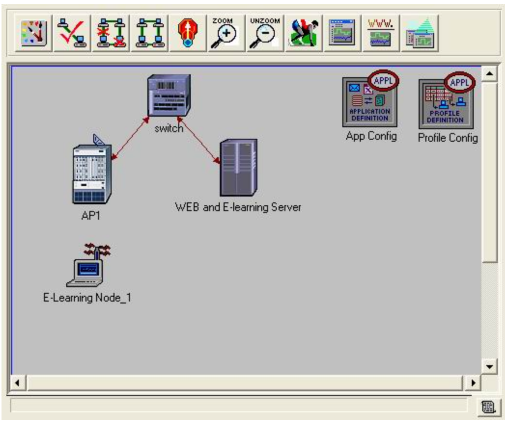


Fig.1. Single Client simulation scenario

Simulation Design: A one-factor-at-a-time simulation design is used to study the impacts of many factors on wireless LAN performance and user-level Web performance. These factors include number of clients, Web object size, and HTTP/TCP protocol features. The simulation factors are summarized in Table 1. The values in bold font show the default levels used.

Table 1. Simulation factors and levels for wireless E-Learning Classroom area network study

Factor	Levels
Number of Clients	1, 25, 50,
E-Learning and HTTP Transfer Size (KB)	1, 8, 32, 64
HTTP protocol	/1.0, /1.1

SIMULATION RESULTS

This section presents selected results from our OPNET simulations of the network shown in Fig.1.

Experiment 1: 25 Clients: The first experiment studies 25-client scenario, to see if there are fairness problems between 25 clients on a shared WLAN. We consider different loads in experiment; Figure 2 shows the results from the 25-client scenario using HTTP/1.0. In the high load case with E-learning and HTTP transfer size are (8, 32, 64 KB), the 25-clients share the channel fairly, and experience similar user-level Web performance, and similar numbers of TCP resets.

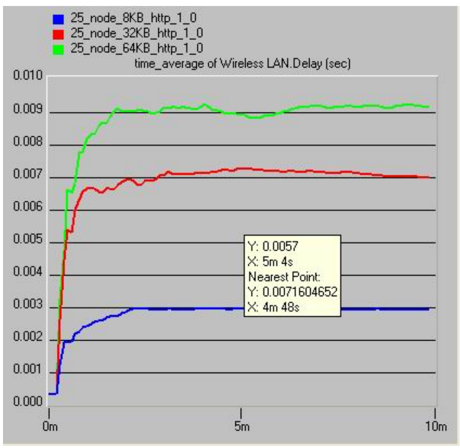


Fig.2 (a) Average of wireless Delay (sec)

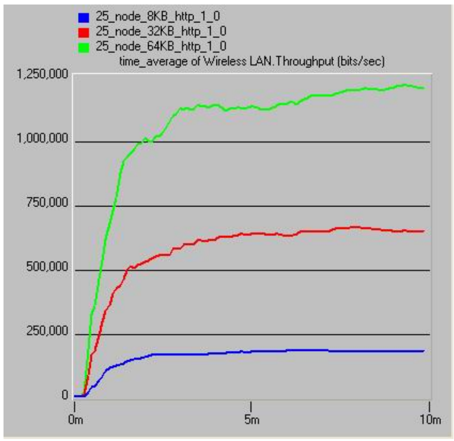
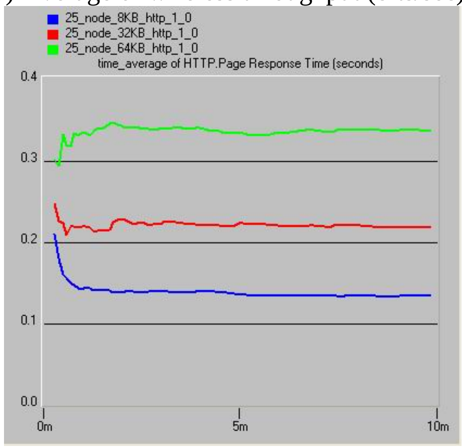
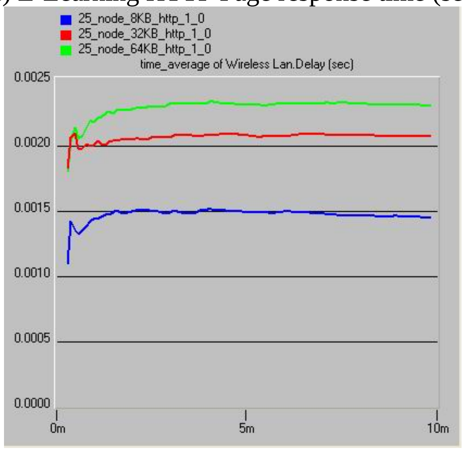


Fig.2 (b) Average of wireless throughput (bits/sec)



(c) E-Learning HTTP Page response time (sec)



(d) Wireless Access Point (AP1) Delay (sec)

Fig. 2. Results of 25-clients using HTTP/1.0 protocol.

Experiment 2: Persistent Connections: TCP connection handshaking adds a lot of overhead (and latency) to an HTTP transaction when using non-persistent connections in HTTP/1.0. For example, only two of the packets in Fig. 2 carry "useful" data; the others are control packets to establish, update, and release TCP connection state information. The overhead is particularly painful in a WLAN environment where each TCP packet must contend for access to the shared WLAN using the MAC channel access protocol.

The overhead of TCP was one of the motivations for persistent-connection HTTP [12, 7, 13]. In a persistent connection, multiple HTTP transactions can be sent (sequentially, synchronously) on the same TCP connection, amortizing the overhead of the TCP SYN and FIN handshakes over multiple HTTP transfers. The purpose of the next experiment is to demonstrate the performance advantages of persistent connections in a WLAN environment, as shown in figure 3. In the OPNET simulation model, we changed HTTP/1.0 to HTTP/1.1, and set a 10-second persistent connection timeout. With these settings, we simulated three different HTTP/1.1 transactions take place using the same (single) TCP connection. Each of the individual HTTP transactions takes about 3-4 milliseconds to complete, using only 4 network packets rather than 10. These transactions are about 3 times faster than with HTTP/1.0.

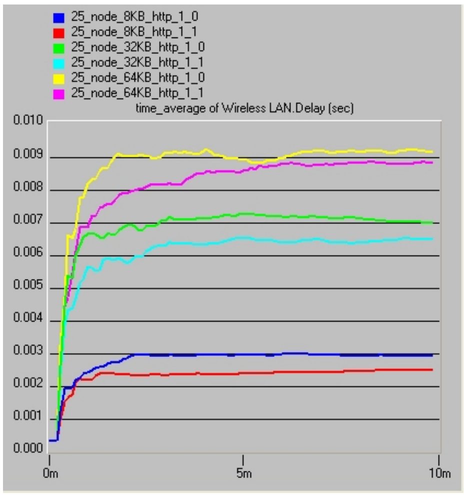


Fig. 3 (a) Average of wireless Delay (sec)

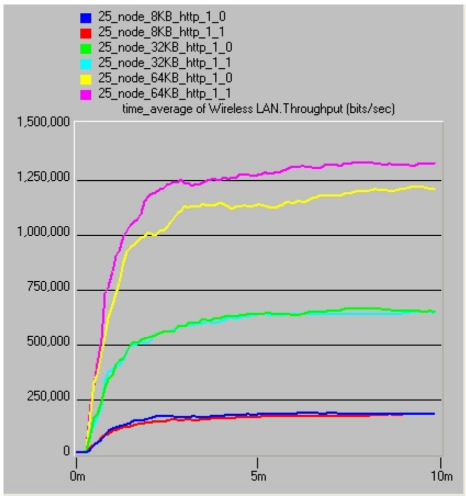


Fig.3 (b) Average of wireless throughput (bits/sec)

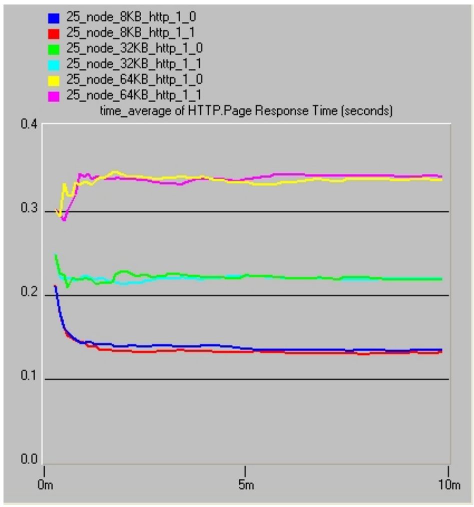


Fig. 3 (c) E-Learning HTTP Page response time (sec)

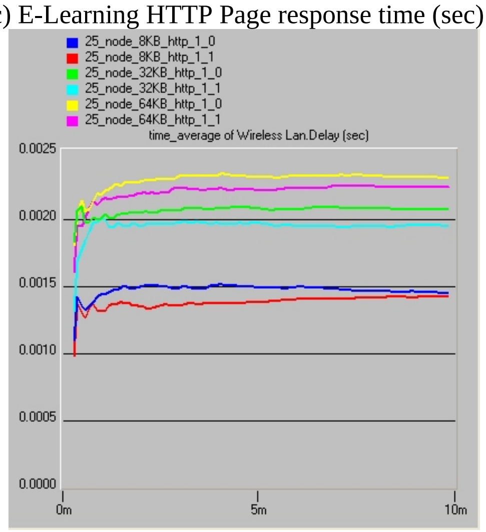


Fig. 3 (d) Wireless Access Point (AP1) Delay (sec)

Figure 3. Comparison Results of 25-clients using HTTP/1.0 and HTTP/1.1 protocols.

Experiment 3: Large Classroom Network: Our main interest is in the scalability of classroom area networks (i.e., how many clients can be supported in the WLAN, and how does user-perceived browsing performance degrade with network load). Figure 4 shows the simulation results from these experiments. Figure 4(a) shows the wireless delay for the Web clients, averaged over the simulated 10 minutes period. This delay is primarily a function of the number of clients, reaching almost 0.0125 (sec.) with 50 clients. HTTP/1.1 has a small advantage over HTTP/1.0; this advantage would increase significantly with more efficient TCP DATA/ACK packetization. Figure 4(b) shows the network-level throughput results. The network throughput is higher than the application-layer throughput because of protocol overhead (e.g., TCP, IP, headers, retransmissions). Again, this load is a direct function of the number of clients. Figure 4(c) shows the mean HTTP transfer time, averaged across all transfers by all clients. The mean HTTP transfer time increases slightly with the number of simulated clients, because of contention for use of the shared WLAN, and perhaps queueing delay at the server. Finally, Figure 4(d) plots the mean channel access delay for the shared WLAN channel. This graph shows an increase in channel access delay with the number of competing clients, as expected.

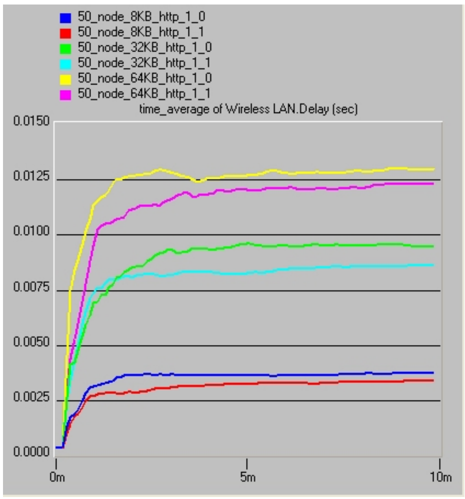


Fig. 4 (a) Average of wireless Delay (sec)

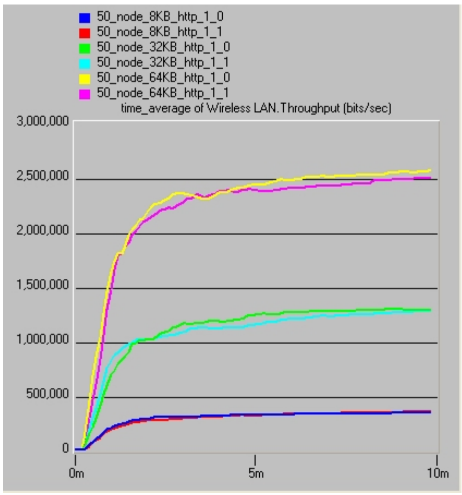


Fig. 4 (b) Average of wireless throughput (bits/sec)

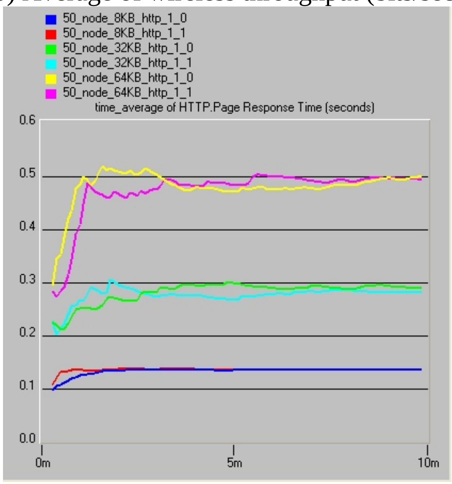


Fig.4 (c) E-Learning HTTP Page response time (sec)

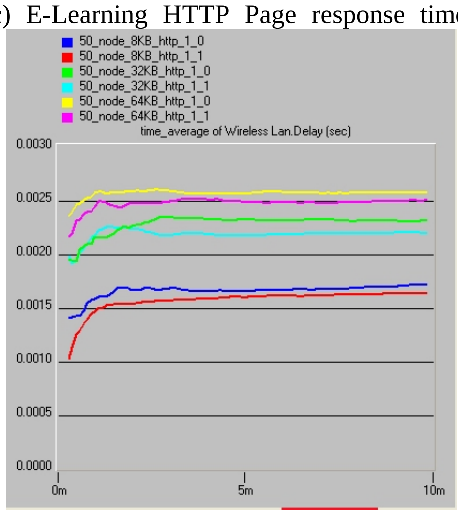


Fig.4 (d) Wireless Access Point (AP1) Delay (sec)

Figure 4. Comparison Results of 50-clients using HTTP/1.0 and HTTP/1.1 protocols.

SUMMARY AND CONCLUSIONS

This paper presented a simulation study of an IEEE 802.11b wireless LAN in an E-Learning classroom network scenario. The simulations, conducted using OPNET IT Guru 9.1. The simulation results show that an IEEE 802.11b WLAN can easily support up to 50 clients doing modest E-learning and Web browsing. The results also show that persistent HTTP connections can provide a significant performance advantage in a WLAN environment. Ongoing work focuses on extending our E-Learning and Web browsing model to represent more realistic Web workloads [4], and simulating larger network models.

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