Simulation and Performance Analysis of Wireless Ad-hoc Networks

HOUSSEIN HALLANI and SEYED A. SHAHRESTANI

School of Computing and Information Technology
University of Western Sydney, Locked Bag 1797
Penrith South DC, NSW 1797, Australia

Abstract: - A wireless Ad-hoc network is comprised of wireless nodes, which attempt to communicate with each other in the absence of any fixed communication infrastructure. In this paper we report the experimental results obtained from establishing a small physical network. These include the measurement of network throughput using TCP and UDP, as well as the delay in transmission of packets using TCP. These results are then compared with those obtained from simulations that are carried out using OPtimised NETwork (OPNET) simulator. Correlation between the two sets of results is found to be satisfactory enough to validate the simulation technique and process. Given this validation, based on similar simulation techniques, the investigation of a larger scale Ad-hoc network is then carried out. The simulation results of the larger scale network confirm our previously obtained results.

Key-Words: - Wireless networking, Ad-hoc networks, Delay, Network performance simulation, Throughput, Performance analysis.

1 Introduction

Wireless Local Area Networks (WLANs) have enjoyed widespread acceptance over the past few years as they can provide network connectivity for mobile users. One of the main problems in successful deployment of WLANs relates to the requirement of expansion of its coverage area without investing too much in costly infrastructures. Ad-hoc wireless networks can offer appealing solutions to this problem. A wireless Ad-hoc network consists of wireless nodes communicating without the need for a centralized administration, in which all nodes potentially contribute to the routing process [1].

Wireless Ad-hoc network offers several attracting features. The first of these, relates to ease and simplicity. Adding a node to the network depends only on its capability to reach one or more available neighboring nodes. The second is that wireless Ad-hoc networks allow the users to overcome the geographical and location limitations. This is because all nodes in the network can provide network connectivity for their neighboring nodes as opposed to a single access point in an infrastructure mode wireless network. The independence from centralized administration or fixed network infrastructures provides for the easy deployment of Ad-hoc networks as needed. Another key feature of this type of network is that they do not have a single point of failure. Scalability is also an advantage as Ad-hoc networks are robust and can be easily scaled up. Finally, wireless Ad-hoc networks offer significant cost savings due to omission of large-scale hardware [2]. On the other hand, the technology and implementation of such networks present some serious concerns. They include consideration of the signal strength, the number of hops between the two communicating nodes, and the inherit lack of security [3].

Computer simulation has become one of the primary tools for evaluating the performance of wireless Ad-hoc networks [4]. In this paper we report on simulation results of different scenarios, for which physical experiments have also been carried out [5]. One of our motivations here is to validate the simulation process and results for Ad-hoc networks using OPNET [6].

In this work, we report on collection and comparison of data that include the average throughput between nodes in the network using TCP and UDP transport protocol, and delay in packet transmission using TCP. The validation is based on comparison and analysis of the results of the physical experiments with those obtained from the simulation. Following the validation, the results for simulation of larger networks are reported. The simulation techniques can then be expanded for investigation of other important issues in Ad-hoc networks such as routing and security. To do this, the rest of this paper is organized as follows. In Section 2, a summary of the experimental setup together with

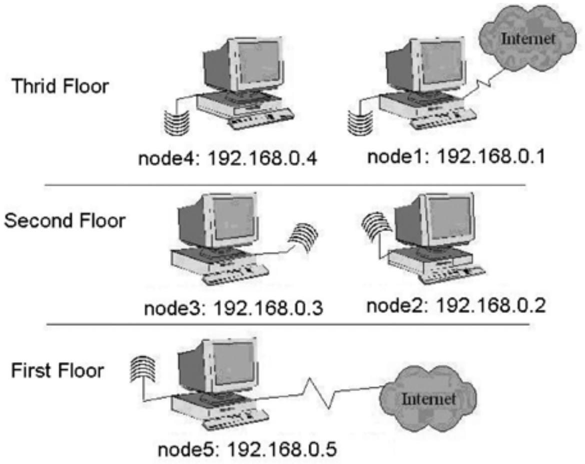

Fig. 1 The physical experiment setup overview

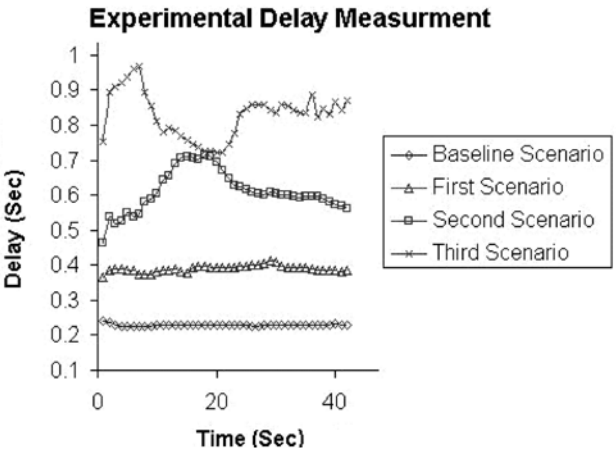

Fig. 2 Experimental TCP delay for four scenarios

experimental data is given. The simulation setup is explained in Section 3. The comparison of the experimental and the simulation results is presented in Section 4. Setup and results from simulating a larger Ad-hoc network are then discussed in Section 5. The concluding remarks are given in the final section.

2 Experimental Setup

For preliminary studies, a physical network has been established previously [5]. The results of that study are used for validation of simulations results reported here. To provide continuity, an overview of the experimental setup and results are also presented here.

The experimental network consists of five desktop PCs, as shown in Fig. 1. These are distributed over three floors of a building. They are all equipped with IEEE 802.11b compatible wireless network cards. Node1 and node5 are also equipped with Ethernet cards and can be connected to the University network. In this manner, the Ethernet cards enable these two nodes to act as a gateway providing Internet access to the other nodes. A detailed description of this network is given in [5].

The routing between the nodes is based on Ad-hoc On Demand Distance Vector Algorithm (AODV) routing protocol [7] using WinAODV software v0.1.14 for Windows XP. This software is developed by researchers from Intel Corporation [8]. Each node has a routing table which lists its neighbouring nodes.

	Average throughput measured at node2 (Mbps)
Baseline Scenario	4.53
First Scenario	2.35
Second Scenario	1.55
Third scenario	1.28

Table 1 Average TCP throughput at node2

The measurement of the throughput is carried out for two cases of transmission based on TCP and UDP transport protocols. The actual measurement of throughput is carried out using Iperf [9]. This software provides a means for measuring TCP and UDP bandwidth performance. It works by sending an array of *length* bytes for *time* seconds. So, to measure the throughput between two nodes, packets are generated from the first node and sent to the second node where an instance of Iperf is running and waiting on a specific port to receive this traffic. The throughput is measured based on the time it takes these packets to reach the second node.

The first step in this investigation is the establishment of some baseline, which forms a basis for comparison with other conditions and scenarios. This is accomplished by measuring the throughput at node2, while it generates traffic and sends it to node4. After establishing the baseline, the changes in throughput under various scenarios are investigated. In the first scenario, three nodes are involved in the throughput measurement. Node2 and node3 generate traffic simultaneously and send it to node4. In the second scenario, four nodes are involved in the data communication. Node4 is now receiving traffic generated and sent simultaneously from node2, node3, and node5. In the third scenario node2 is sending traffic to node5 using either node3 or node4 as a relay node. Table 1 shows the average throughput at node2 for the four scenarios using the TCP protocol.

The throughput results for the four scenarios using UDP as the transport protocol are presented in Table 2. The objective behind the collection of these data is to have more parameters available for the validation process.

The measured throughput is the average amount of data payload transmitted and received between source and destination nodes over a period of time. The UDP payload size used for these measurements is 1470 bytes and the UDP buffer size is 64 K bytes.

Another important parameter considered in this experiment is the delay in transmission of TCP packets between source and destination. The graph is Fig. 2 shows this delay, measured at node2 for the four scenarios.

From Table 2, it is interesting to note that the drop in the throughput, as a function of the number of nodes that simultaneously attempt transmission to a given node, occurs in somehow a linear fashion. The throughput has dropped around 50% for the first scenario, while it has dropped around 66% for the second scenario. The throughput for transmission from node2 to node5 is 1.86 Mbps and that of node2 to node4 is 5.95 Mbps. There are two hops between node2 and node5, and only one hop between node2 and node4. So, by comparing the two mentioned levels of throughput, it can be noted that the addition of one hop has had a dramatic effect on the throughput (i.e. reduction from 5.95Mbps to 1.86 Mbps). This can be attributed to the increased latency as a result of more nodes being involved in the transmission of data packets. This is in line with previously published results [10].

	Average throughput measured at node2 (Mbps)
Baseline Scenario	5.95
First Scenario	2.95
Second Scenario	1.94
Third scenario	1.86

Table 2 Average UDP throughput at node2

3 Simulation Setup and Results

The simulation of the experimental setup described in the previous parts is carried out using OPNET Modeller v11. OPNET Modeller is used to construct models for two different purposes. The first one is to study system behavior and performance. The second main purpose for this software is to deliver a modeling environment to end-users [6]. For validation and comparison purposes, the simulation setup replicates that of the physical setup of the experiments described in the previous parts.

As in the physical experiments, the throughput between two nodes is measured by generating TCP and UDP packets from a node and sending them to a destination node. The simulation studies consist of four scenarios, very similar to the physical experiments. In

	Average throughput measured at node2 (Mbps)
Baseline Scenario	6.12
First Scenario	3.024
Second Scenario	2.124
Third scenario	2.13

Table 3 Average UDP throughput at node2

the baseline scenario only node2 and node4 are involved in the communication. As before, in the first scenario node2 and node3 are set up to send traffic to node4. While in the second scenario node5, node3, and node2 are communicating simultaneously with node4. In the third scenario node2 is sending traffic to node5 to check the effect of having any of the other nodes acting as a relay node between the source and the destination. The throughput is collected at the sending node.

The results of throughput measurements using TCP are presented here. For the baseline scenario the throughput remains constant at around 4.78 Mbps during the whole simulation time. Fig. 3 and Fig. 4 show the throughput variations with the progress of simulation, at node2 for the first and the second scenario respectively. For the third scenario the average value remains rather constant around 1.46 Mbps.

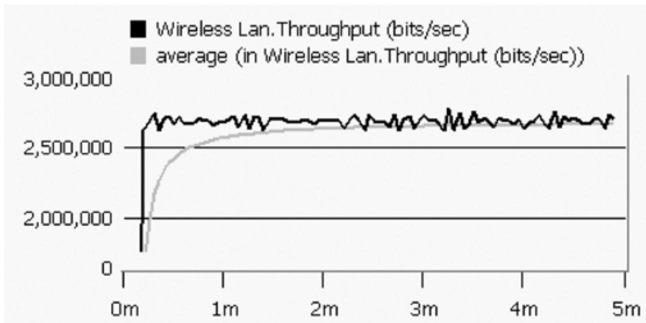

Fig. 3 Throughput at node2 for the first scenario

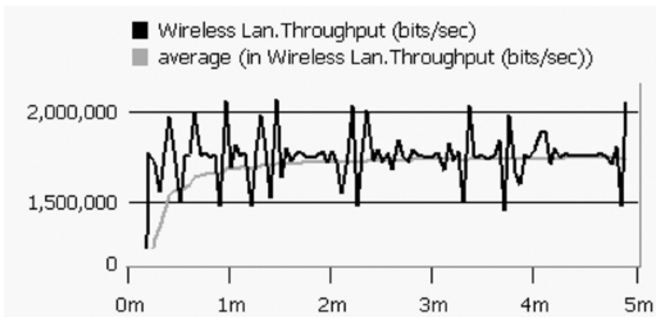

Fig. 4 Throughput at node2 for the second scenario

	Baseline Scenario	First Scenario	Second Scenario	Third Scenario
Physical Experimental (Using TCP)	4.53	2.35	1.55	1.28
Physical Experimental (Using UDP)	5.95	2.95	1.94	1.86
Simulation (Using TCP)	4.78	2.65	1.75	1.46
Simulation (Using UDP)	6.12	3.024	2.124	2.13

Table 4 Physical experiment and simulation results for TCP and UDP throughput

Fig. 3 shows small fluctuations of the throughput within the simulation time. This can be attributed to the nature of the TCP, which ensures that data is delivered in order and error-free. Such characteristics can cause delay at node4, which is trying to respond simultaneously to both node2 and node3. These fluctuations are more noticeable in Fig. 4, as more nodes are involved in the communication. The drop in the throughput between the baseline (4.78 Mbps), first (2.65 Mbps), and second (1.75 Mbps) scenario can be due to the high congestion and the overwhelming of node4.

Table 3 shows the throughput results for the four simulation scenarios using UDP as the transport protocol.

4 Comparison of the Experimental and Simulation Results

As mentioned before, validation is an essential process to check the accuracy of the simulation outcome. Table 4 summarizes the average throughput values at node2 for the physical experiment and for the simulation using TCP and UDP.

The comparison of the first and the third row as well as the comparison of the second and the last row shows good similarity. Figures 5 to 8 show the TCP delay comparison between simulation and physical experiment at node2 for baseline, first, second, and third scenarios respectively. The graphs in Figures 5 to 8 show noticeable differences between the results of simulation and physical experiment when it comes to delay in transmission of TCP packets. This can be attributed to the difficulty in accurate simulation of temporal and environmental factors, such as walls, interference, signal strength and so forth. For Ad-hoc networks in particular, to achieve reasonably accurate results, this aspect of the

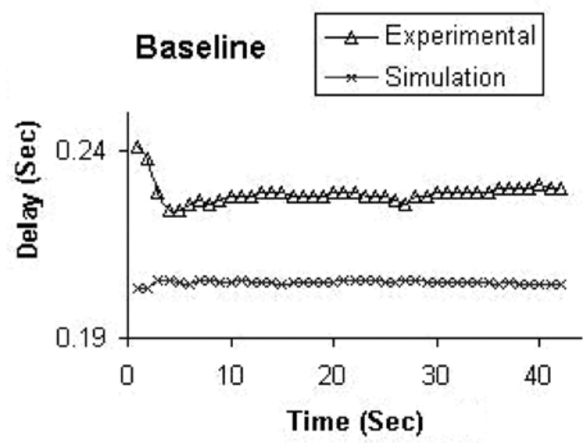

Fig. 5 Delay comparison for baseline scenario, node2 transmitting to node4

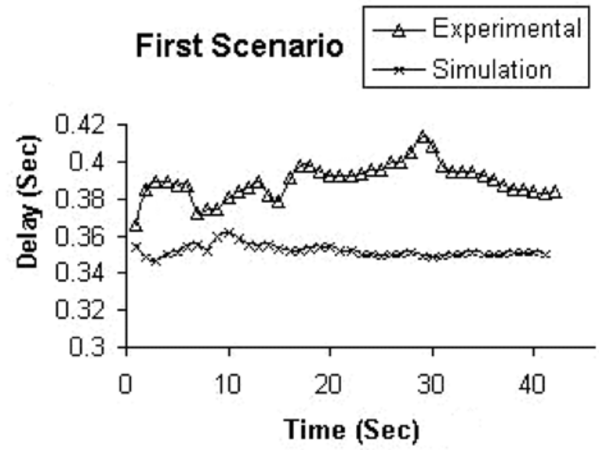

Fig. 6 Delay comparison for first scenario, node2 and node3 transmitting to node4

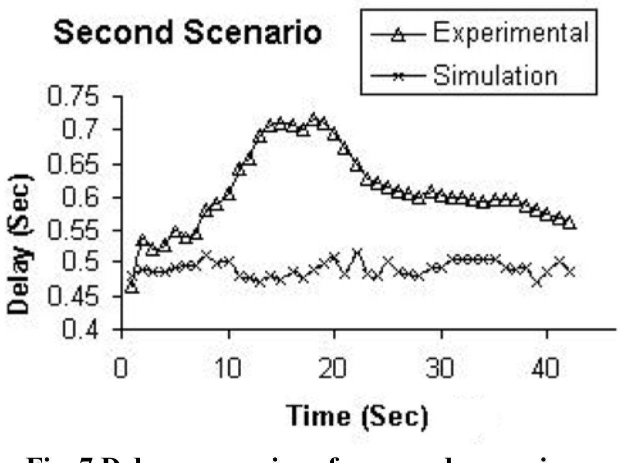

Fig. 7 Delay comparison for second scenario, node2, node3, and node5 transmitting to node4

simulation seems to be a much more difficult task. While this deserves more extensive investigation, our preliminary conclusion is that validation of delay and jitter simulations for Ad-hoc networks probably need to be done on a case-by-case basis.

5 Simulation of a Larger Network

Based on the findings and validation procedure discussed in the previous parts, in this section the simulation studies of the throughput performance of a larger network is reported. This network consists of twenty nodes distributed randomly in an area of 100 square meters in an Ad-hoc manner. A number of cases that deal with the effects of having a larger Ad-hoc network are then investigated.

The first case is an attempt to investigate the effect of having a number of relay nodes between the source and the destination of traffic. Fig. 9 shows a comparison of the average throughput in transmission of TCP packets with the progress of the simulation time for four different situations. The curves in Fig. 9 correspond to transmission of TCP packets between node1 and a destination node, with different number of hops in the middle. From top to bottom, these show average throughput in transmission to nodes 8, 10, 19 and 20 with three, five, six, and seven hops in between. Fig. 10 shows throughput values under similar conditions but using UDP as the transport protocol.

The second case deals with studying the effects of increasing the number of nodes that simultaneously try to communicate with a destination node. The graphs in Fig. 11 show the average throughput at node14 for four different situations. The curves correspond to one, four, five, or seven nodes attempting simultaneous transmission to node12. The average values for throughput are seen to be around 5.85, 1.45, 1.2, and 0.78 Mbps, respectively. The linear nature of drop in throughput as a function of the number of the nodes that are trying to communicate simultaneously with a destination node is again noticeable.

6 Conclusions

In this paper, the results of an investigation on implementation of small wireless Ad-hoc networks are presented. The performance of such networks has also been studied through physical experimentation, simulation, and analysis. The throughput simulation results show good agreements with those obtained through the physical experiment. There is somehow noticeable difference between the results of simulation and physical experiments for delay values in transmission of TCP packets. These differences can be attributed to the difficulty in reasonably accurate

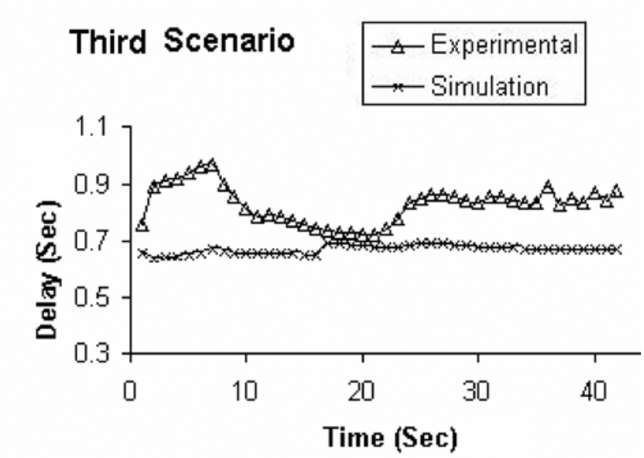

Fig. 8 Delay comparison for third scenario, node2 transmitting to node4

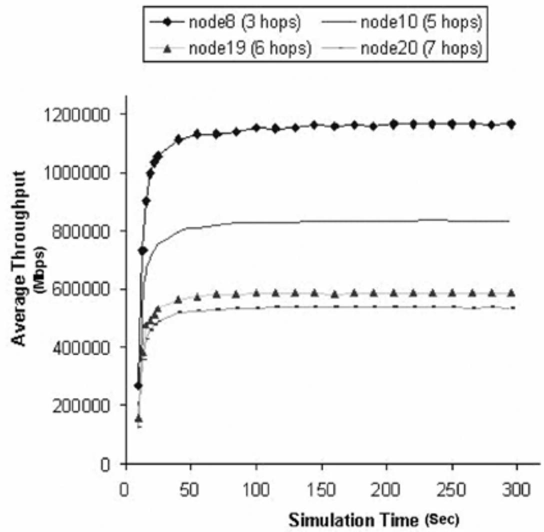

Fig. 9 Average TCP throughput for the four situations, showing the effect of having more hops between the source and the destination

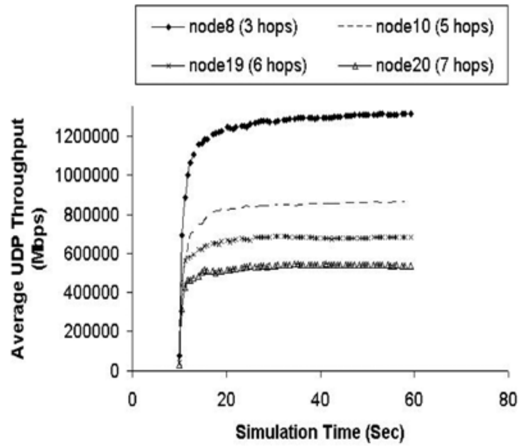

Fig. 10 Average UDP throughput comparison between the four situations

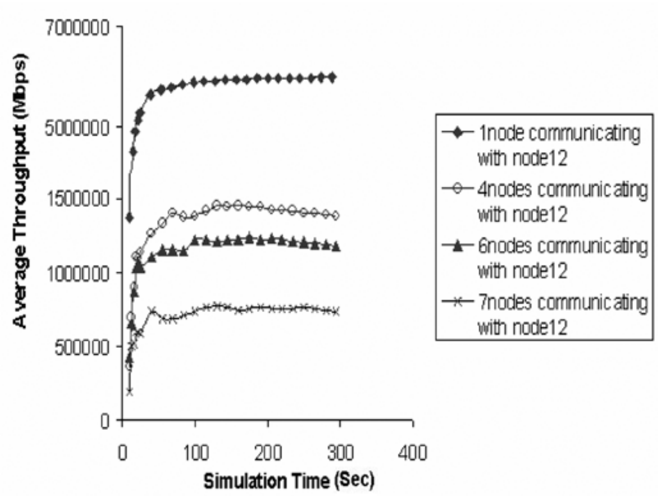

Fig. 11 Average throughput comparison at node14 for the four different situations

simulation of temporal and environmental factors, particularly for Ad-hoc networks. This study has also shown that with regard to the number of nodes that are trying to simultaneously connect to the same destination, a linear drop in the throughput can be expected.

References:

[1] V. Srinivasan, P. Nuggehalli, C.F. Chiasserini, and R.R. Rao, "Cooperation in wireless ad hoc networks", *Proc. 22nd Annual Joint Conference of the IEEE Computer and Communications Societies. IEEE, INFOCOM 2003* April. 2003, pp. 808-817.

[2] J. Centi, "Wireless mesh: The evolution of the wireless network", *Bechtel Telecommunications Technical Journal*, January 2004.

[3] R. Ramanathan, and J. Redi, "A brief overview of Ad-hoc networks: challenges and directions", IEEE Communications Magazine, Volume 40, Issue 5, May 2002, pp.20 - 22.

[4] Liu, J., Y. Yuan et al, "Simulation validation using direct execution of wireless Ad-hoc routing protocols", *Proc. 18th Workshop on Parallel and Distributed Simulation (PADS 2004),* May. 2004, pp. 7 – 16.

[5] H. Hallani and S. Shahrestani, "Wireless mesh networking: Implementation issues and analysis", *Proc. 3rd International Business Information Management Conference*, Dec. 2004, pp. 200-205

[6] OPNET Modeler, http://www.opnet.com

[7] C. E. Perkins and E. M. Royer, "An implementation study of the AODV routing protocol", *Wireless Communication and Networking Conference*, Sept. 2000, pp. 1003-1008.

[8] P. Barron, J. Dowling, and S. Weber, "WinAODV", University of Dublin, http://www.dsg.cs.tcd.ie/

[9] M. Gates, A. Tirumala, J. Furgeson, J. Dugan, F. Qin, K. Gibbs, National Center for Supercomputing Applications, University of Illionis at Urbana-Champaign, http://www.ncsa.uiuc.edu

[10] D. De Couto, D. Aguayo, J. Bicket, and R. Morris, "A High Throughput Path Metric for Multi-hop Wireless Routing", *Proc. 9th ACM Int. Conf. Mobile Computing and Networking,* Sept. 2003, pp. 134-146.