Faculty of Informatics - Papers (Archive)

Faculty of Engineering and Information Sciences

2008

Development and performance evaluation of a flexible, low cost MANET

Mehran Abolhasan
University of Wollongong, mehran.abolhasan@uts.edu.au

Brett Hagelstein
University of Wollongong, bretth@uow.edu.au

Jerry Chun-Ping Wang
University of Wollongong, jerryw@uow.edu.au

D. Franklin
University of Wollongong, danielf@uow.edu.au

Farzad Safaei
University of Wollongong, farzad@uow.edu.au

See next page for additional authors

Recommended Citation

Abolhasan, Mehran; Hagelstein, Brett; Wang, Jerry Chun-Ping; Franklin, D.; Safaei, Farzad; and Wysocki, Tadeusz A.: Development and performance evaluation of a flexible, low cost MANET 2008, 1-6.
https://ro.uow.edu.au/infopapers/1701

Development and performance evaluation of a flexible, low cost MANET

Abstract

Performance evaluations of multi-hop ad hoc network routing protocols have been primarily conducted through analytic and simulation-based studies, which frequently fail to accurately predict real-world performance and behaviour. One reason for this is the challenge in developing low cost, representative test beds with the degree of flexibility and mobility required. We have developed a Portable Wireless Ad hoc Node (PWAN) device which establishes multi-hop routes using the OLSR routing protocol. The PWAN's performance has been investigated using two test bed configurations to evaluate its capacity under conditions of high node density in a short-range, multi-hop environment. Our results illustrate that such networks are capable of providing high quality connections when traffic density is low. However, the network link quality deteriorates dramatically as the traffic level increases, and the network topology becomes unstable until the traffic level is reduced.

Keywords

Development, performance, evaluation, flexible, low, cost, MANET

Disciplines

Physical Sciences and Mathematics

Publication Details

Abolhasan, M., Hagelstein, B., Wang, J., Franklin, D. R., Safaei, F. & Wysocki, T. A. (2008). Development and performance evaluation of a flexible, low cost MANET. International Conference on Signal Processing and Communication Systems (pp. 1-6). Gold Coast, QLD: IEEE.

Authors

Mehran Abolhasan, Brett Hagelstein, Jerry Chun-Ping Wang, D. Franklin, Farzad Safaei, and Tadeusz A. Wysocki

Published in Signal Processing and Communication Systems, 2008. ICSPCS 2008. 2nd International Conference on
15-17 Dec. 2008 Page(s):1 - 6
Digital Object Identifier 10.1109/ICSPCS.2008.4813669

Development and Performance Evaluation of a Flexible, Low Cost MANET

M. Abolhasan, B. Hagelstein, J.C-P. Wang, D.R. Franklin, F. Safaei
Telecommunications and Information Technology Research Institute
University of Wollongong
Wollongong NSW, 2522, Australia
mehrana@uow.edu.au

T. Wysocki
University of Nebraska - Lincoln
CEEN, Peter Kiewit Institute 200D, 1110 S 67th St
Omaha, NE, USA
twysocki2@unl.edu

Abstract— **Performance evaluations of multi-hop ad hoc network routing protocols have been primarily conducted through analytic and simulation-based studies, which frequently fail to accurately predict real-world performance and behaviour. One reason for this is the challenge in developing low cost, representative test beds with the degree of flexibility and mobility required. We have developed a Portable Wireless Ad hoc Node (PWAN) device which establishes multi-hop routes using the OLSR routing protocol. The PWAN's performance has been investigated using two test bed configurations to evaluate its capacity under conditions of high node density in a short-range, multi-hop environment. Our results illustrate that such networks are capable of providing high quality connections when traffic density is low. However, the network link quality deteriorates dramatically as the traffic level increases, and the network topology becomes unstable until the traffic level is reduced.**

I. INTRODUCTION

A mobile ad hoc network (MANET) is a dynamic, multi-hop wireless network established across a collection of mobile nodes on a common wireless channel. MANETs differ from traditional wireless networks by enabling nodes to communicate without requiring a centralised infrastructure such as a wireless access point. This emerging technology is often proposed as a next-generation communications system to provide robust, flexible and versatile wireless communication in the absence of functional infrastructure.

A growing number of routing protocols have been proposed specifically for use in MANETs. According to Kotz et al. [6], most studies in this area focus on using simulation results to evaluate the performance of the proposed algorithms since this provides a low cost method of conducting large scale experiments in a controlled manner. However, simulations inevitably require simplification and approximation of the real-world environment. For example, it is challenging to accurately model the RF channel in complex environments such as three-dimensional spaces within buildings. This may lead to erroneous assumptions that compromise the real-world performance of the protocol. Pawlikowski et al. state that that "one cannot rely on the majority of the published results on performance evaluation studies of telecommunication networks based on stochastic simulation, since they lack credibility" [9]. The existence of these shortcomings highlight the need for proposed MANET protocols and algorithms to be implemented on real-world test beds to prove their worth.

According to recent surveys performed by Kiess et al. [5] and Kropff et al. [7], numerous test beds have been implemented worldwide for evaluating the performance of real-world ad hoc networks. For example, Lundgren et al. provide a Linux distribution which can be installed on portable computers to rapidly provide ad hoc network connectivity [8].

Our contribution to this area has been the development of a wireless ad hoc network test bed that consists of a large number of self-contained and self-configured nodes, called Portable Wireless Ad hoc Nodes (PWANs). These nodes are based around a battery powered, Linux-based embedded system with multiple network radios. They are configured with a variety of ad hoc routing protocols and provide a range of convenient tools for network diagnostics, performance evaluation, data logging and network-wide configuration, as well as a set of test applications to quantitatively evaluate link quality.

In this paper, we describe the PWAN system and present experimental results from a series of indoor multi-hop networking tests. The paper is structured as follows: Section II presents an overview of the Optimised Link State Routing Protocol (OLSR), which is used for establishing multi-hop ad hoc routes; Section III provides a detailed description of the PWAN nodes; Section IV describes the test bed setup and details the scenarios used to investigate the performance of the PWANs; Section V presents test bed results and discusses its performance over each scenario; finally, Section VI presents the conclusions of the paper.

II. OLSR PROTOCOL OVERVIEW

There are four main routing protocols currently being considered for standardization by the IETF MANET group: Ad hoc On Demand Distance Vector (AODV) [2], Dynamic Source Routing (DSR) [4], Optimized Link-State Routing (OLSR) [3], and Topology Broadcast Based on Reverse-Path Forwarding (TBRPF) [1]. We chose OLSR as the routing protocol in our test bed.

In contrast to classic reactive routing protocols such AODV or DSR, OLSR is a proactive routing protocol that

978-1-4244-4242-3/08/$25.00

maintains consistent optimal routes to all nodes in the network. OLSR inherits the stability of the classic link state routing algorithm, and has the advantage of providing immediate route information due to its proactive nature. It is an optimised form of a pure link-state protocol since it effectively minimises the redundant transmission of flooding messages by utilising multipoint relays (MPRs). MPRs are arbitrary subsets of single-hop symmetric neighbours that a node selects for flooding its messages. The MPR is selected as the smallest set of one-hop neighbours that allows all nodes to be covered within two hops.

In the OLSR protocol, two types of control messages are exchanged by the nodes: `Hello` and `Topology Control` (`TC`) messages. The `Hello` messages are used for local topology discovery, and consists of three independent tasks: link sensing, neighbour detection, and MPR selection signaling. A node sends `Hello` messages to advertise itself and provide a list of neighbouring nodes with which it has connectivity through a local broadcast. Upon the reception of `Hello` messages, the mobile node is able to identify both its immediate and two-hop neighbours, and also selects its MPR. A `TC` message is flooded to all MPRs to announce the new node. This enables remote MPRs to maintain network-wide routing information and construct the global routing table using the shortest-path algorithm.

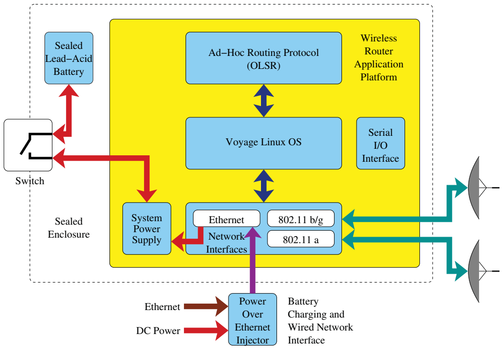

Fig. 1. Portable Wireless Ad hoc Node (PWAN) Architecture

Fig. 2. Portable Wireless Ad hoc Node (PWAN) prototype

III. SYSTEM DESIGN

The aim of our experimental study was to investigate the performance of multi-hop ad hoc networks in indoor scenarios. A number of Portable Wireless Ad hoc Nodes (PWANs) were developed to facilitate this test.

The PWAN architecture is based on the Wireless Router Application Platform (WRAP) from PCEngines as shown in Figure 1. The WRAP used provides a highly flexible node base that includes two Ethernet interfaces, two mini-PCI slots, a compact flash memory socket and a serial port. The AMD Geode CPU is appropriate for portable, battery powered applications and the entire WRAP consumes approximately 5W under load.

The PWAN operates using SAND OS, our custom Linux installation based on Debian Linux, which runs from the Compact Flash memory. SAND OS provides the flexibility to install Linux drivers and applications into the Linux kernel version 2.6.23. The multi-hop ad hoc networking capability was provided by OLSR version 0.5.5.

A variety of wireless network interfaces are available for the mini-PCI platform. The PWAN has been tested using WiFi IEEE 802.11a/b/g network interfaces available from Ubiquiti, EnGenius and Wistron Neweb. Each of these interfaces uses an Atheros chipset and can be used in conjunction with the MadWiFi Linux driver. Interfaces were configured to operate in IEEE 802.11g mode for these experiments.

A custom weather-proof enclosure was developed to house the PWAN. Each PWAN contains a 12V 7.2Ah sealed lead-acid battery that enables it to be used without mains power for up to ten hours and allows the node to be deployed in locations without access to a mains power supply. This battery may be charged by connecting an external 12V DC power supply to the PWAN. The node has also been configured to be powered or recharged using a Power Over Ethernet (PoE) supply to minimise the number of external connections required. Figure 2 illustrates the PWAN prototype device.

We also developed a modified PWAN prototype that could be used to investigate the performance of Voice over Internet Protocol (VoIP) over a multi-hop ad hoc network. Two options were considered when designing this system: firstly, a purely software-based VoIP implementation known as a softphone; and secondly, a dedicated VoIP hardware platform. Employing a softphone would require each device to carry a display or to be operated using a laptop and this would significantly reduce the flexibility and convenience of the PWAN. The second option of incorporating a VoIP board into the existing PWAN architecture would allow voice calls to be made via the interface of an analogue handset telephone. The latter was

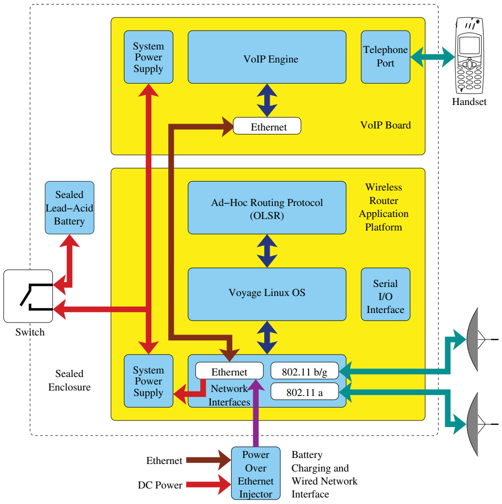

Fig. 3. VoIP-enabled PWAN architecture

Fig. 4. VoIP-enabled PWAN prototype

a simpler, more cost-effective and more elegant solution. A VoIP board was integrated into a number of PWAN devices as shown in Figure 3.

The VoIP board chosen for our experiments was the ZyXEL Prestige 2002. This allows VoIP connections to be established in either a peer-to-peer manner or connected to a server over the Internet, and also provides an analogue telephone interface to greatly increase the PWANs flexibility as a VoIP device. The VoIP cards were configured to make peer-to-peer calls and were interfaced with the WRAP board using an Ethernet connection as shown in Figure 4. The WRAP boards then acted as a gateway for the VoIP platform and routed data using the OLSR protocol to establish voice calls over a multi-hop ad hoc network.

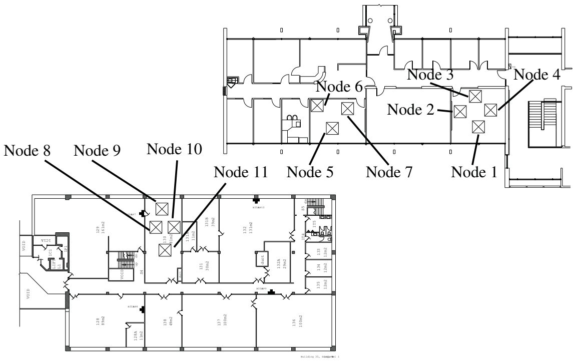

Fig. 5. Node layout of multi-hop ad hoc test bed

IV. TEST BED MODEL AND SCENARIOS

Two different test bed configurations were employed to investigate the performance of the PWANs. In the first configuration, eleven PWANs were located in one room and all external antennas were removed to simulate the effects of a longer propagation path between the PWANs while minimising the amount of interference from outside networks. The objective of this test bed topology was to investigate the capacity of the nodes under high node densities and we refer to this topology as the “Node Capacity” configuration. In the second scenario, an omni-directional antenna was connected to each node and nodes were distributed between three rooms in two separate buildings as shown in Figure 5. This topology is referred to as the “Multi-hop Ad hoc” configuration. All nodes were set to operate in ad hoc mode and the OLSR protocol was enabled in both scenarios. This enabled the characteristics of a multi-hop ad hoc network to be monitored even though the actual data tansmission may have only been over a single-hop communication.

Testing scripts were written that simultaneously introduced ICMP (ping) traffic between pairs of nodes in the network. The test started with two nodes transmitting to two arbitrary nodes, possibly other transmitting nodes. This created four data flows when the return data path is accounted for. Each ping session was set to transmit using a packet size of 576 bits. This effectively simulated a bi-directional constant bit rate traffic flow between the specified end-points. The number of ping flows in the network was progressively increased for each test run to evaluate the performance of the network under increasing load. This began by configuring two additional nodes to transmit data that produced a total of eight flows. This was repeated until 24 simultaneous data flows were attained. Three different tests were performed with different packet transmission rates for each set of flows. Data was transmitted at intervals of 0.2, 0.02 and 0.004s, which corresponds to a packet rate of 5, 50 and 250 packets per second (pkt/s) respectively. Each test was run for a period of five minutes.

The average throughput, packet delivery ratio (PDR) and average round trip delay (ARTD) were measured for each network configuration to evaluate its performance. The throughput measures the average data transmission rate achieved per flow. The PDR is the rate of successful packet delivery, that is, the ratio of the number of packets received at the destination to the data packets sent by the source. The ARTD metric measures the length of time it takes for a packet to complete a round trip between the source and destination, or two complete flows. ARTD was used instead of the end-to-end delay (EED) metric, since EED requires accurate clock synchronisation at all nodes. Better synchronisation techniques to allow accurate EED may be investigated in the future.

A real voice call was established through the network using two VoIP-enabled PWANs in addition to the quantitative data transmission test. The VoIP test involved observing the voice quality and the stability of the voice connection during each of the network loading tests.

V. RESULTS

The following sections present the results for the "Node Capacity" and "Multi-hop Ad hoc" test beds respectively.

A. Node Capacity Test Bed

Our initial run of this experiment used the default OLSR parameters. This test showed that the network became highly unstable as the number of data flows increased. This was due to the loss of vital `TC` packets reaching the MPRs. We tuned the OLSR parameters to produce fewer `Hello` and `TC` packets and re-ran the experiment. We found that the overall network stability was dramatically improved for routes between static nodes. This also meant that the network topology had more inertia and took longer to update routes. This was ideal for our static node experiments and all ensuing tests used the tuned OLSR parameters.

Figure 6 plots the data throughput results versus the number of simultaneous data flows. It was found that when the data packet dissemination rate was set to 5pkt/s and 50pkt/s the throughput graph stays fairly flat as the number of flows in increased. A slight drop in throughput was experienced when the data rate was increased to 250 packets per second. This drop in throughput in this case was caused by high levels of contention, which meant fewer control packets were able to travel through the network to maintain an up-to-date network topology. This was evident by monitoring the route table, which became highly unstable and loops began to occur even with the tuned OLSR parameters.

We also observed that VoIP call at this rate was not stable and often resulted in a break in connection. However, this total single-hop bandwidth equates to more than 70 simultaneous, bi-directional VoIP calls using a 24kb/s sampling quality. This is significantly greater than the expected end-use and is satisfactory for the purpose of this test.

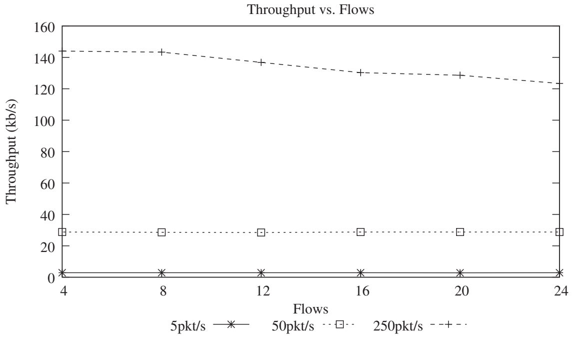

Fig. 6. Throughput vs. Flows in capacity test bed

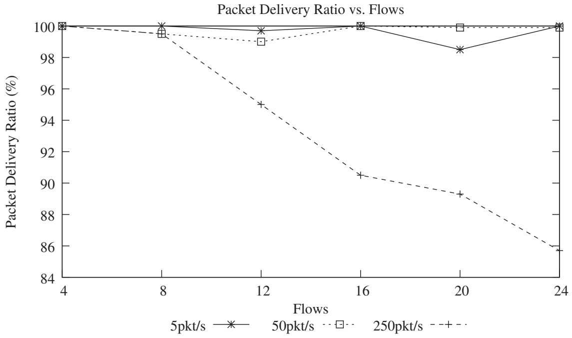

Fig. 7. Packet Delivery Ratio vs. Flows in capacity test bed

Figure 7 illustrates the packet delivery ratio (PDR) versus flows. These results show that the network achieved over 98% delivery for both 5pkt/s and 50pkt/s transmission rates. The delivery ratio for the 250pkt/s began to drop when 12 or more flows were used. Again, this was caused by the network becoming unstable as a result of control packet loss and interference.

Figure 8 illustrates the route trip delay (RTD) as the number of flows was increased. It can be seen that the network maintained a RTD of less than 3ms for both the 5pkt/s and 50pkt/s scenarios. This represents an approximate average end-to-end delay of 1.5ms assuming similar forward- and reverse-path delays. The delay began to significantly increase in the 250pkt/s test when the number of concurrent flows were increased to 16 or more.

The `TC` packet loss due to network contention was the limiting factor in the single-hop network capacity test. The network performance may be significantly improved if the routing tables were able to be accurately maintained. This performance was significantly improved by tuning the OLSR `TC` parameters to decrease the frequency of the routing table updates. This also had the effect of taking

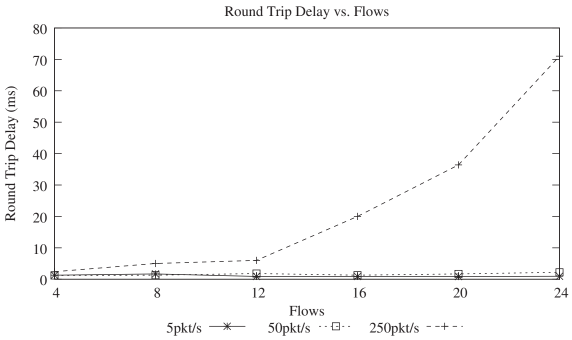

Fig. 8. Round Trip Delay vs. Flows in capacity test bed

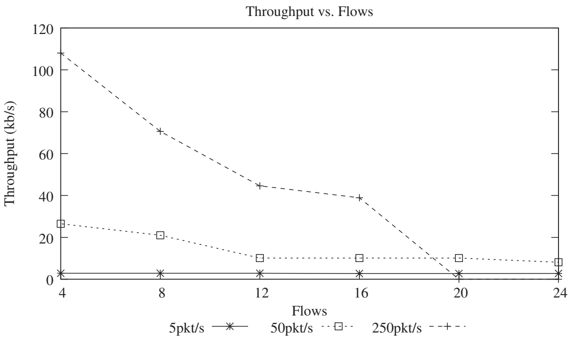

Fig. 9. Throughput vs. Flows in multi-hop test bed

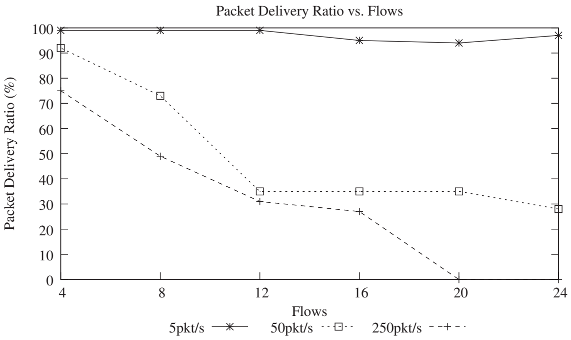

Fig. 10. Packet Delivery Ratio vs. Flows in multi-hop test bed

a longer time to recover network stability after the data throughput was decreased at the end of a test.

However, the results suggest that the network is capable of supporting many simultaneous, bi-directional, single-hop VoIP calls. This was confirmed by making an active VoIP call with what we consider a reasonable call clarity in conjunction while maintaining a mid-range network traffic test. Actual voice quality testing is beyond the scope of this paper although we hope to examine this further in a future study.

B. Multi-hop Ad hoc Test Bed

We measured the performance of the flows that travelled over two or more hops to investigate the network's multi-hop performance. The four flow base test consisted of two data flows over a two-hop connection and another two flows over a three-hop connection. Four single-hop flows were then added to increase the network congestion. The network loading was then increased until there were 24 simultaneous data flows. The two-hop data flow performance was used in preparing the following results.

Figure 9 presents the throughput of a multi-hop route as the number of concurrent flows was increased. The throughput stayed consistent for the 5pkt/s test as the number of flows was increased. However, the throughput began to drop significantly when the number of flows was increased using a dissemination rate of 50pkt/s. This trend was more evident in the 250pkt/s test where multi-hop communications could not be established when more than 16 flows were present.

The packet delivery ratio results versus the number of flows is presented in Figure 10. A PDR of over 94% was achieved for all flow levels in the 5pkt/s scenario. However, the PDR levels begins to fall significantly after four flows in the 50pkt/s test. Network congestion had an even greater effect on PDR at 250pkt/s which saw PDR drop to less than 50% when the number of flows were increased to eight and become unusable at 20 flows.

Figure 11 illustrates the average round trip delay versus the number of flows. Again, the 5pkt/s scenario has the best performance where an average RTD of less than 3.5ms was maintained irrespective of the number of flows. Using 50pkt/s, the average delay slowly increased toward 20ms as the number of flows was increased to 24. When the dissemination rate was increased to 250pkt/s, the RTD increased dramatically when the number of flows was increased to eight and continued to increase until multi-hop connections were unable to be established at 16 flows.

Two observations can be made from these results. Firstly, the introduction of single-hop traffic has a significant effect on the multi-hop flows. This is because contention increases at each node, which creates further

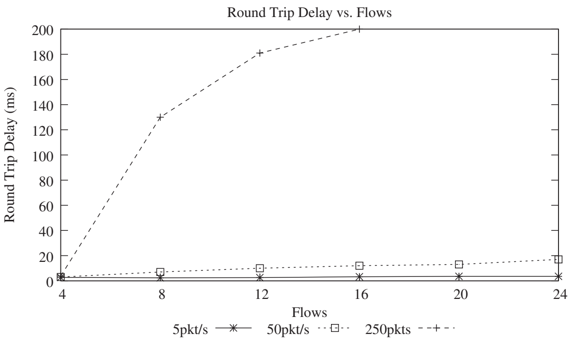

Fig. 11. Round Trip Delay vs. Flows in multi-hop test bed

delays. Secondly, the loss of `TC` packets reduces the accuracy of the routing table at each forwarding node, which adds further delay to the delivery of each packet as it travels towards the destination. These are the same symptoms founds in the single-hop experiment. However, the effects were amplified in a multi-hop environment where data packets must contend with other packets at every node in the path to its destination.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we have investigated the performance of a multi-hop ad hoc network in an indoor environment using a real test bed. Our test bed consisted of a number of custom developed Portable Wireless Ad hoc Nodes (PWANs) which used the OLSR routing protocol to establish multi-hop routes. It was found that the PWANs provide a suitable platform for both network testing and also for a low cost general-purpose ad hoc network including VoIP communication.

Two different scenarios were created to investigate both the effect of high node density and the behaviour of multi-hop routes as the level of traffic was increased. Our studies showed that a multi-hop network becomes highly unstable at high data traffic levels. This was primarily due to high levels of contention, which increased the amount of control packet loss and caused routing errors in the OLSR protocol. This not only decreased the data throughput for each route, but required several seconds for the network to reach stability after the traffic levels were reduced.

The `TC` packet loss due to network contention was the limiting factor in the single-hop network capacity test. The network performance may be significantly improved if the routing tables were able to be accurately maintained. A possible solution for this could include making the routes effectively static by further tuning the OLSR topology parameters, although this would make the network less able to handle dynamic nodes. We are also investigating a more radical solution that places control and data packets on different radio channels that will effectively eliminate contention on control packets.

In summary, the PWANs that we have created provide a good test bed for examining the performance of multi-hop ad hoc routing protocols in a real-world test. We hope to continue using the PWAN platform to perform head-to-head comparisons of different routing protocols in a real test bed in the near future and to compare these results against those obtained by simulation.

REFERENCES

[1] B. Bellur, R.G. OGIER, and F.L Templin. Topology broadcast based on reverse-path forwarding routing protocol(tbrpf). In *Internet Draft, draft-ietf-manet-tbrpf-06.txt, work in progress*, 2003.

[2] S. Das, C. Perkins, and E. Royer. Ad Hoc On Demand Distance Vector (AODV) Routing. In *Internet Draft, draft-ietf-manet-aodv-11.txt*, work in progress, 2002.

[3] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, and L. Viennot. Optimized Link State Routing Protocol for Ad Hoc Networks, IEEE INMIC Pakistan. 2001.

[4] D. Johnson, D. Maltz, and J. Jetcheva. The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks. In *Internet Draft, draft-ietf-manet-dsr-07.txt*, work in progress, 2002.

[5] Wolfgang Kiess and Martin Mauve. A survey on real-world implementations of mobile ad-hoc networks. *Ad Hoc Netw.*, 5(3):324–339, 2007.

[6] David Kotz, Calvin C. Newport, Robert S. Gray, Jason Liu, Yougu Yuan, and Chip Elliott. Experimental evaluation of wireless simulation assumptions. In *MSWiM*, pages 78–82, 2004.

[7] Matthias Kropff, Tronje Krop, Matthias Hollick, Parag S. Mogre, and Ralf Steinmetz. A survey on real world and emulation testbeds for mobile ad hoc networks. In *Proceedings of 2nd International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TRIDENTCOM)*, March 2006.

[8] H. Lundgren, D. Lundberg, J. Nielsen, E. Nordstrm, and C. Tschudin. A large-scale testbed for reproducible ad hoc protocol evaluations. In *IEEE Wireless Communications and Networking Conference (WCNC)*, March 2002.

[9] K. Pawlikowski, H. D. J. Jeong, and J. S. R. Lee. On credibility of simulation studies of telecommunication networks. *Communications Magazine, IEEE*, 40(1):132–139, 2002.