A Low-cost Realistic Testbed for Mobile Ad Hoc Networks

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Abstract

Theoretical frameworks and simulation environments are proven to be very useful in evaluating conventional wired settings. However, due to the inclusion of various deficiency parameters which naturally exist in wireless channels modelling the communication behaviour in MANETs become much more complex. To overcome these major problems and create a realistic test platform for MANET research, we propose the use of inexpensive OLPC XO laptops that provide by default a Linux-based open source operating system, multi-hop mesh networking capabilities and a configurable wireless adapter. We believe that a design based on this hardware can substantially reduce the cost and time spent during the implementation and deployment of MANET testbeds and help researchers to focus on the systems to be deployed rather than the testbed itself.

1. Introduction

Within the last decade a substantial need for mobile, wireless and self-organizing networks has emerged. Some major characteristics of these environments such as mobility impose a rather alternative approach to network infrastructure where nodes can spontaneously form arbitrary radio networks. For instance, individual nodes, aside from their application and protocol layer network usage, carry the responsibility of providing routing services through acting as points of relay. Today, these improvised wireless settings–known as mobile ad hoc networks (MANETs)– are either deployed or considered as a future deployment option in a wide range of fields such as aiding emergency response personnel, inter-vehicular communication and free-air community networks.

Accordingly, a vast amount of research has focused on improving MANETs' performance with respect to network density, topology changes caused by node mobility, network traffic and energy consumption. Medium access and routing algorithms are the two general issues specifically addressed in most research regarding the communication, configuration and connection maintenance in MANETs. Due to development time and fiscal constraints of physical testbeds, most of the results were based either on theoretical approaches [12, 4] or simulation results [3, 2, 1].

However, it is known that the theoretical frameworks and discrete event simulation environments alone cannot always produce completely reliable information. In the case of the theoretical frameworks, it is a very difficult challenge to mathematically define the detailed behaviour of complex ad hoc settings while the simplifications at lower layers of the network stack implemented in the discrete event simulation environments may produce results that might not reliably reflect the behaviour of an actual wireless network. As a result, in order to collect factual measurements, it is necessary to have physical testbeds that are equipped with tools to establish accurate assessments. In this paper, we propose a low-cost, easy-to-set-up OLPC XO based MANET testbed that do not impose any hardware configuration or alteration.

The rest of this paper is organized as follows. In Section 2, we provide background information on some of the former research on MANET testbeds, point to the complexities and issues noticed, and underline our motivation and contribution. Section 3 introduces the major requirements of MANET testbeds, outlines our testbed setting and evaluates the suitability of using OLPC XOs to form such a testbed based on the underlined requirements. Finally, in Section 4 we summarize our research and outline our future goals.

2. Background and Motivation

Two of the most well known and widely adopted approaches to observe and evaluate working principals and performance in MANETs are the usage of theoretical frameworks and simulation environments. Although these two methods are proven to be very useful in conventional wired settings, due to the inclusion of deficiency parameters which naturally exist in wireless channels such as fading,

Figure 1. Six of the OLPC XOs that are currently used as MANET nodes at the University of Victoria.

multipath effect, high channel loss and interference, modelling the communication behaviour in MANETs becomes much more complex than the wired settings.

It is an extremely challenging task in theoretical frameworks as the number of parameters and their individual and integrated effects on the network behaviour increase. This also imposes major simplifications, especially at the physical layer implementation of simulation environments which prevents the performance measurement and assessment in a realistic manner. Due to the obvious presence of mobility in MANETs, interference with respect to ever changing topology and its impacts on the quality of channel is also another important ingredient that makes the mathematical model too complex to theoretically assess or implement in a simulation environment. Moreover, the mobility parameter alone introduces complex issues where human movement and its relation to social relations need to be considered in order to create realistic input models. Another important issue that needs to be underlined in theoretical frameworks and simulation environments is that the networks are usually considered to be somewhat stable which prevents the observation and evaluation of true link quality dynamics.

There is also a considerable amount of study that focused on collecting real-time performance measurements using physical settings. While measurements on some of these testbeds have not been reported in detail, there is yet a set of valuable research where performance analysis of specific network layer routing protocols is provided in emulated environments and real-world settings [9, 5, 7, 6, 13, 11].

One of these testbeds was created in Carnegie Mellon University using two stationary and six mobile nodes in a multi-location outdoor setting that used the dynamic source routing (DSR) protocol on top of FreeBSD operating system [9]. The mobility is provided through placing nodes in cars that travel with alternating speeds. Performance of DSR was evaluated through tests where audio packets were used to create a real-time communication. In addition, a number of difficulties in operational outdoor testbeds such as issues with radio propagation, radio range and personnel are described. As a result, need for an indoor setting was clearly underlined in order to eliminate the afore mentioned issues. A similar study was conducted at the University of Colorado using stationary, mobile ground and aerial units [5]. One important deficiency of such testbeds is that the conducted tests can be very expensive in terms of implementation and personnel which in turn makes it very challenging to perform rapid testing cycles. Since there are major difficulties in performing tests under the same conditions, reproducibility is severely compromised. A technique based on choreography scripts is given in Lundgren et. al. to support reproducibility where personnel would carry out the exact same movement trajectories in every test case [8]. However, this can be a high cost solution in the cases where the network size needs to be upscaled.

In order to solve the scalability problem in outdoor settings, Kaba et. al. introduces a platform independent MANET testbed that can be deployed on desktop workstations [7]. Setting the testbed in a relatively small indoor environment is achieved by reducing the transmission range of the workstations through replacement of the existing antenna with an external antenna to attenuate the radio signals. Another important feature of the testbed is the possibility of using a wired adapter in order to completely eliminate the external radio effects that can be encountered during communication. Moreover, mobility is emulated through signal attenuation without physically moving the workstations. Similar emulation techniques are also applied in Jin et. al. [6]. The testbed ensures reproducibility of test scenarious through a traffic generator, while controlled attenuation is also used for emulating mobility without physical movement. However, every node in these two emulation approaches has to be physically prepared through the addition of external antennas and elimination of internal antennas. The same problems encountered in [9, 5] will emerge in the case of upscaling the network size where a considerable amount of time and labor will be necessary to perform the physical configuration and alterations on each of the joining nodes.

In another similar approach outlined in Zhang et. al., the core component is defined as the mobility emulator that is used to inject virtual mobility in the environment without physically displacing the nodes [13]. The test environment is designed to be usable in indoor settings through the same methods used for signal attenuation. The same approach in [7, 6] of emulating a wireless setting through the usage of wired Ethernets, hubs and routers is adopted. Though this approach is both reproducible and affordable, it imposes an artificial substitute for an RF based MAC protocol that does not fully reflect the effects of RF interference. In addition, it is also acknowledged that the emulated environment is not designed for performance evaluation since the first two layers of the network stack is not implemented.

Another MANET testbed is introduced in Sanghani et. al. with the central goal of providing node mobility without the physical displacement of nodes and accurate reflection of RF effects at the same time [11]. The testbed is deployed using Dell CPi laptops with the Cisco Aironet 350 series wireless Ethernet cards. The testbed has been designed to fit in a single room using shielding and signal attenuation. Scalability issues introduced by necessary hardware alterations on each node to support indoor settings is an important deficiency in this testbed as well alongside the possible extra expenses due to the usage of laptop stations.

As summarized in this section, the major problems that exist in the former research is two-fold. In the realistic outdoor settings, the deployment of the test cases is usually expensive due to necessary labor especially when node mobility is considered. In addition, the external effects will prevent the researchers from collecting information about the standard behaviour of the networks deployed on the testbeds. Moreover, experimental reproducibility is extremely hard to achieve due to changing and uncontrolled conditions in the outdoor settings. And finally, upscaling an outdoor MANET testbed is very challenging due to labor and cost. In the emulated indoor settings, the techniques such as signal attenuation and shielding is used in order to be able to fit a large number of nodes in an indoor environment. However, the issues with hardware alteration makes upscaling a challenging problem. Some of the techniques used to fully eliminate radio interference such as usage of wired adapters will result in extra implementation time for mimicking a radio setting and almost eliminating the effects of RF interference.

To overcome these major problems and difficulties observed in the former studies, we propose the usage of cost effective OLPC XO laptops that provide a Linux-based open source operating system, multi-hop mesh networking capabilities and a configurable wireless adapter by default.

3. OLPC XO Testbed

In this section, we detail some requirements that we define as key elements during the process of assessing MANET testbeds in terms of the flaws encountered in/by the related work that was introduced in the previous section. In addition, we are going to outline our OLPC XO based testbed in terms of the aspects and the number of nodes used in the initial setting and the basic properties of our indoor environment that the testbed was deployed in. Finally, we assess our testbed with respect to the outlined key requirements and evaluate what advantages our setting can provide in terms of MANET testbed development.

3.1. Testbed Requirements

In order to ensure usability and validity, it is crucial to assess general qualities of a MANET testbed with respect to a certain set of well defined requirements. In the context of our research, also motivated by the outlined properties given in the former studies, we define four key requirements that will later be used to assess our OLPC XO based testbed. These four requirements that will be detailed here are: (1) Predictability, (2) Reproducability, (3) Openness, and (4) Scalability. Although these requirements can be considered separately, it is important to note the strong interrelationship that exists between them.

Predictability is defined as the degree that a certain behaviour can be accurately calculated quantitatively or inferred qualitatively under varying conditions. This imposes that a MANET testbed's state, particularly the nodes' capabilities and behaviour, has to be studied in detail under specific conditions and settings to define a normal behaviour. In order to provide this normal behaviour of the nodes and the overall testbed, the initial setting must take place in a fully controlled environment isolated from random outside effects such as external radio interference and terresterial object movements in the medium. If ensured, this can play an important role in rapidly detecting and precisely explaining most of the unexpected behaviour exhibited by the nodes in the testbed. It is also important to note that the usage of identical nodes at the early deployments of the testbed can work towards enhancing predictability through aiding in definitions of standard performance and behaviour. This can also aid in explaining discrepancies in testbed performance when a heterogeneous set of nodes is used in the later stages.

Reproducibility is a critical principle referring to the ability of accurately replicating the exact conditions of a specific test scenario. In a MANET testbed, it is particularly important to be able to repeat certain scenarios in order to have comprehensive performance measurements in an easy fashion. This requires accurate regeneration of key parameters such as topological modifications, mobility, network and node settings, and traffic patterns. Accordingly, implementation and deployment of an effective central control mechanism that is capable of configuring and feeding the network with certain parameters regardless of the increase in the network size is of utmost necessity to fulfill this requirement in MANET testbeds.

Openness can be defined in the context of this paper as the ability to have unlimited and free access to the different system components of the nodes that form the MANET testbed in order to apply changes to the basic working principals of the overall system. Alongside the possibility to derive the core software on the nodes, an open system also brings along the advantages of deployment and usage of the already provided software utilities for monitoring and measuring system performance. In a fully open MANET testbed, presence of these core utilities eliminates the need to implement extra tool sets to monitor and measure system performance without extra cost which in turn results in an easy and affordable deployment of the MANET testbeds.

We define *scalability* as the ability of a MANET testbed to easily upscale without extensive cost, time and labor. This requirement becomes especially hard to fulfill in the cases where the joining nodes need to go through a set of hardware modifications. Other important parameters that negatively effect scalability are the expenses involved in buying and deploying extra nodes to extend the testbed, and the increasing labor needed to repeatedly carry out per node configuration and general test cases. For a MANET testbed to be fully scalable the cost of the equipment involved in the expansion process needs to be affordable and the labor that is necessary to configure/deploy new equipment and perform test cases need to be minimized.

3.2. OLPC XO Testbed Setting

OLPC is a non-profit initiative that aims to provide low-cost, open-source laptop computers (OLPC XO) to children in developing regions of the world [10]. Besides its application level functionality specifically designed for children, OLPC XO carries built-in mesh networking capabilities that allow multiple users to form multi-hop wireless networks without the need for any predefined infrastructure.

At the University of Victoria, we are working on a low-cost, easy-to-set-up testbed for MANETs on OLPC XOs. Figure 1 shows a portion of the OLPC XOs in our testbed. By default, all of the nodes provide mesh networking that is based on the 802.11s standard and built on top of 802.11b/g standard compliant wireless hardware. The processing of layer-2 frames and layer-3 packets is managed by two different processors. The ARM processor driving the Marvel 8388 SoC Radio is responsible for processing layer-2 frames while the AMD LX700 processor processes layer-3 packets. Marvel SoC Radio is capable of working in different transmission power levels along with different transmission rates. The routing protocol used by OLPC XOs to create the mesh networks is largely based on ad hoc on-demand distance vector routing (AODV). The unicast traffic is routed the same way as AODV while the broadcast traffic relies on limited flooding. Although MANETs have attracted major interest in research, to the best of our knowledge OLPC XO is the first appearance of the multi-hop mesh networking in mass production.

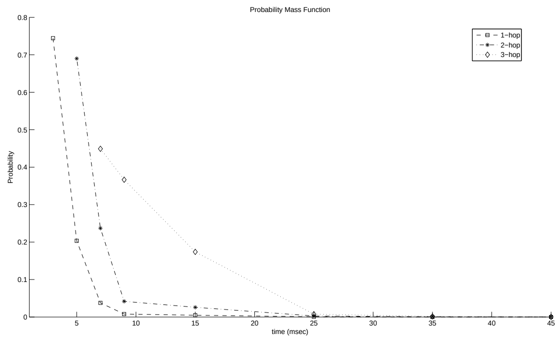

Figure 3. Probability mass function of RTTs in one hop, two hop and three hop scenarios.

In our initial setting, nine OLPC XO nodes are set up in an isolated medium that is free of any random effects that can be caused by uncontrolled events such as foreign object movements and external radio interference. We perform network initialization through a central command unit that broadcasts setup and modification commands to the existing nodes in the testbed. This functionality is achieved through simple scripts that we have implemented and deployed on the central control unit in order to manipulate the testbed in an easy fashion. Some of the major setup actions performed by the central control unit are configuring the virtual mesh interfaces, assigning unique network addresses for each node in the testbed and instrumenting test cases.

3.3. OLPC XO Testbed Assessment

The qualities of our OLPC XO based testbed will be assessed here with respect to the key requirements that are defined as predictability, reproducibility, openness and scalability. We believe that achieving fulfillment of these four key requirements is crucial to deploying low-cost and adaptive MANET testbeds that consumes neither extra time nor labor.

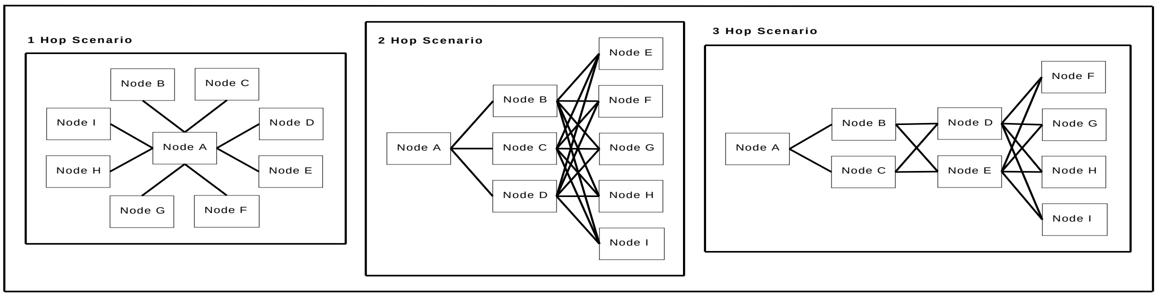

Figure 2. Topological view and connectivity of one hop, two hop and three hop scenarios.

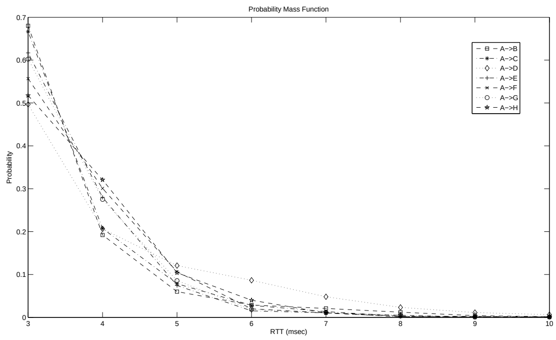

Figure 4. Probability mass function of RTTs in the one hop scenario. Each function represents the distribution of RTTs between a pair of nodes.

In order to ensure the predictability, we first checked for the stability and normal behaviour of the nodes in our testbed through a set of tests cases where we observed the round-trip-times (RTT) of a number of ICMP echo requests. The topological view and connectivity of nodes for each of the test scenarios is given in Figure 2. In each of the cases the sender generated 10000 ICMP echo requests to the specified receiver nodes in a pseudo random and equally distributed fashion with 100msec inter-arrival time. The overhead of packet processing is considered insignificant since the action is carried out by the ARM processor on the radio without moving further up in the network stack. Figure 3 shows the probability mass function of collected RTTs in the three scenarios respectively. The reasonable ratio of increase in RTT in Figure 3 due to the number of hops and the proximity of RTT distributions per node pair depicted in Figure 4 imply that there is no instability or unexpected behaviour among the testbed units in terms of network performance. This standard behaviour of the nodes observed in an isolated environment will work in favor of predictability in the cases where we need to explain the reasons behind any random behaviour in the future outdoor deployments.

The main mechanism provided to achieve reproducibility is the central control unit we implemented in order to support remote access to the configuration tools on individual nodes. Regardless of the scale of the testbed, we can easily configure our testbed by only defining the nodes that will be used for specific test cases or instrument test cases through the central control unit and without the need to physically interacting with each of the individual nodes.

Openness is automatically achieved on an OLPC XO testbed due to the open source Linux distribution deployed on the nodes by default. In addition, in terms of the core utility tools such as *tcpdump*, *iptables*, *snmp* and *nmap*, and external monitoring and reporting tools such as *ethereal*, *mrtg*, *openNMS* and *BigBrother* OLPC XOs are very easy to observe and analyze. The existance of these tools is a property that provides us with major help during the process of monitoring and performance evaluation of our testbed without implementing any extra tools. Furthermore, this minimizes the time spent on testbed deployment and configuration, and helps researchers to rather focus on implementation of the network systems to be tested on the testbed.

Scalability is also a strong aspect of the OLPC XO based MANET testbed. First of all, the equipment cost is minimal. Secondly, through the usage of a central control unit we have eliminated most of the problems regarding initiation and reproduction of test scenarios regardless of the the testbed size. Furthermore, there is no need to perform any physical configuration on the network equipment of the nodes to provide controlled attenuation. And finally, as described previously, the openness aspect of our testbed automatically eliminates the need for the implementation of monitoring and reporting tools which in turn reduces the time spent while upscaling the testbed.

Aside from the assessments made based on the key requirements that we have detailed in this section, it is also important to underline a few important additions that need to be made to the testbed environment. One of these two crucial additions is the mobility aspect which is obviously of central concern in MANET testbeds. The solution that we provide for this addition is two-fold. One way to in-

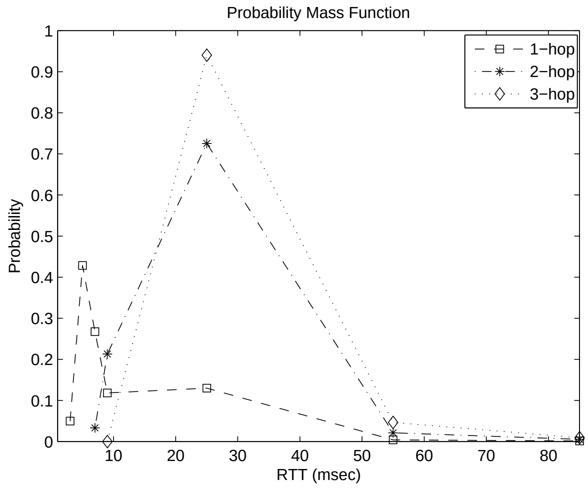

Figure 5. Probability mass function of RTTs in one hop, two hop and three hop scenarios under controlled radio interference.

clude mobility in such an environment is through the usage of extra equipment that can provide physical mobility while another is to use controlled signal attenuation through the usage of standard wireless tools to emulate mobility without physically moving the nodes. In order to support physical movement, we have been working on a set of robots that can be preprogrammed or remotely controlled via a Bluetooth interface to support mobility. On the other hand, while physical mobility provides more realistic observations with respects to parameters such as link quality, fading and changing radio interference at a cost of extra equipment, the emulation method provides a free solution at a cost of extra implementation on the central control unit.

Another component that an indoor MANET testbed needs is an artificial interference generator in order to be able to inject external radio effect to the system in a fully controlled manner and observe performance under such events. We have injected controlled interference during a re-run of the test cases given in Figure 3 through transmitting a large binary file between two external wireless nodes that communicate on the same channel as our OLPC XO testbed. Figure 5 provides the probability mass function of the RTTs in the three settings under this controlled effect.

4. Conclusion and Future Work

In this paper, we have introduced an easy-to-setup and low-cost OLPC XO based MANET testbed. The platform is assessed with respect to four key requirements; predictability, reproducibility, openness and scalability. We have performed a series of tests, in order to ensure the stability and define the standard behaviour of the nodes in the testbed. The results show that the testbed units do not exhibit any instability in terms of network performance which in turn is going to help us define unexpected behaviour especially in the cases where external effects are present. The most important factors supporting the scalability of our testbed are the low-cost of equipment and network hardware that do not impose altering. We believe that this testbed will help researchers focus only on improvements to the MANETs' core mechanisms. Our utmost goal is to provide a large-scale, highly deployable platform based on OLPC XOs to assist researchers in this process.

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