A Testbed for Performance Evaluation of Mobile Ad Hoc Network

Rimantas Plestys, Rokas Zakarevicius
Kaunas University of Technology, Department of Computer Networks, Studentu str. 50-416, Kaunas, Lithuania
rimantas.plestys@ktu.lt, rokas.zakarevicius@ktu.lt

Abstract. A mobile Ad Hoc network (MANET) is made of mobile wireless nodes that can self-organize into a network automatically. Most of MANET research is made by using software simulations. However, experimental evaluations are also necessary, so network testbeds are built. A large-scale testbed is difficult to configure and manage. The design and implementation of the new desktop-size testbed is presented in this paper. RF signals travel through cable connections among Ad Hoc network devices in order to minimize the network medium in the testbed. The network performance is evaluated for different network cases, and results are presented.

Keywords. Mobile Ad Hoc network, wireless network testbed, performance evaluation.

1. Introduction

A mobile Ad Hoc network (MANET) is made of mobile nodes capable to communicate to each other via wireless links. Ad hoc network nodes self-organize into a network without the use of any static infrastructure and communicate over one or multiple hops, functioning simultaneously as routers performing packet routing functions and as hosts sending and receiving data packets. The nodes can move freely or stay fixed in limited area and therefore the network may take different topology.

Mobile Ad Hoc networks are being extensively studied as they enable many interesting future applications. There is a need to evaluate the performance of such networks. Most of MANET research relies on software simulations. However, the simulation results do not always accurately and clearly describe the actual network performance characteristics, because they oversimplify the physical layer [1]. The results can show large differences depending on the simulation software used [2]. Therefore, it is important to validate these results through experiments. Experiments with real, or at least prototype, systems are necessary to evaluate the performance of mobile Ad Hoc networks. Wireless network testbeds are built, which are usually spread over a large physical space because of the wide coverage area of radio signals [3]. Some routing protocols have been implemented on the testbed consisting of mobile nodes, driving around the campus [4]. As MANET is a multi-hop network, wireless nodes have to be distributed several hundred meters apart to form the required topologies. This makes a large-scale testbed difficult and expensive to set up, configure, manage and perform experiments. Even being highly realistic, they do not necessarily enable repeatability of experimental scenarios. Some testbeds have been created that occupy smaller space, because signal attenuators are used [1], [5]. However, it is not easy to ensure clean testing environment due to the shortage of free radio channels, as even relatively weak interfering signals are a problem when using high attenuation [1].

In order to address the issues mentioned, it is necessary to build a testbed, which would enable making mobile Ad Hoc network performance evaluations in a laboratory environment. In this paper the design and implementation of the new desktop-size testbed is presented. It can be used for MANET research and wireless network performance demonstrations.

2. Testbed design and implementation

The testbed is intended to be used for analysing the following characteristics of a mobile Ad Hoc network:

- The performance of routing protocols;
- Control packet streams – the network overhead;
- Network throughput and round-trip-time (RTT).

The network environment can operate under different conditions:
• Nodes do not interfere with each other;
• Nodes in the same communication group interfere with each other;
• Nodes in different communication groups interfere with each other;
• Signal interference is being controlled;
• Nodes are affected by external signal interference.

The testbed is designed by connecting different number of testbed network elements to each other. Each network element (Fig. 1) consists of:

• Network node \( N \) – an embedded network device with wireless interface;
• 4-way signal splitter – \( Sp \);
• Calibrated signal attenuators – \( At \);
• Coaxial cables.

![Figure 1. Testbed network element](image)

### 2.1. Network node

The core part of the testbed is the network node \( N \). The network node architecture is presented in Fig. 2. The node was built using a CPU Board WBD-111 [6]. The system is powered by an ARM920 RISC processor, equipped with 32 Mbytes DDR RAM and 8 Mbytes Flash memory, which is used for non-volatile program and data storage. The CPU board includes an Ethernet interface for wired network access, as well as a serial port for console access, and is equipped with a Mini-PCI socket.

The CM9 wireless Mini-PCI card, based on Atheros™ chipset, supporting IEEE 802.11a/b/g standards, was used for radio signal transmission. The antenna connector was used to connect the network node to the input of a signal splitter \( Sp \).

The key to miniaturization of the testbed lies in reducing the radio signal strengths to the required level. The simplest technique is to adjust the transmit power on the wireless interface card. Using an Atheros chipset based wireless interface allows setting the transmit power to different values in the range. However, even reducing the transmit power to the smallest is not enough for creating a multi-hop topology for a wireless Ad Hoc network in a laboratory environment.

Coaxial cables are used for RF signal transmission rather than antennas, so the path loss among the Ad Hoc nodes in the network is much lower. Therefore signal attenuators have to be used in every coaxial cable segment to reduce the RF signal levels to proper values.

![Figure 2. Testbed network node architecture](image)
routing protocol LRZR [8] implementation. The operating system console is accessed via the secure shell (SSH) connection either through wired or wireless interfaces. Additional tools for network performance evaluation measurements were also installed into the devices.

2.2. Supplementary equipment

The network operating frequency range is approximately 2.4 GHz. The signal splitters $Sp$ contribute to attenuation in cable connection segments, and the affect to signal strength differs depending on the direction of signal path. The splitter has one input $X1$ and four outputs $Y1$, $Y2$, $Y3$ and $Y4$ (Fig. 1). The attenuation is equal to 8dB in the direction $X1\rightarrow Y1...Y4$, 12dB for $Y1...Y4\rightarrow X1$, and 22dB among the outputs $Y1...Y4/g314Y1...Y4$.

The testbed network topology is built by cabling outputs of every splitter $Sp$, which corresponds to the appropriate testbed node device. $75\Omega$ coaxial cables with F-type connectors and terminators are used. The 16dB, 12dB, 10dB and 8dB attenuators $At$ can be included in every cable connection segment, as well as their serial combinations, depending on the link quality required.

The network nodes are powered by a +12 V DC power supply. The network nodes and signal splitters are shielded to avoid uncontrolled leakage radiation as well as external signal interferences.

2.3. Experiment management system

The network nodes are connected to the Ethernet switch to perform system management and experimentation tasks. The experiment management system consists of two personal computers: $PC1$ – a traffic generator, and $PC2(s)$ – a traffic analyser. $PC1$ is also used for device management and performing experiments. Both computers access network nodes using wired network connections though the Ethernet switch or directly. They can access the network nodes through wireless network interfaces or another network node, which routes data packets. Such highly centralized structure allows to access testbed devices from one point, thus improving manageability.

A standard version of Debian Linux operating system was installed on $PC1$ and $PC2$. The test traffic is generated from $PC1$ by the $netperf$ client-side program, and is received at $PC2$ by a $netperf$ server-side program. As there was a need to generate multiple streams of test packets for some experiments, several $netperf$ instances were run on the receiver test station $PC2$. $Tcpdump$ program is used on $PC1$ for capturing the generated packets and storing them for later analysis. $Tcptrace$ tool was used for the analysis of $tcpdump$ output binary files. The experiment process was automated using the developed bash shell scripts that utilize various pre-existing software tools. The scripts process the packet capture data and output the summarized results (mostly throughput and RTT values) into the comma separated text file format. Such results file can be easily imported into a spreadsheet to make visualizations.

3. Performance evaluation of the experimental Ad Hoc network

The network consisting of six testbed elements was constructed for making performance evaluations of the experimental mobile Ad Hoc network (Fig. 3).

Figure 3. The experimental testbed structure

The network nodes were operating in IEEE 802.11g mode at 54Mbps maximum bit rate.

3.1. TCP throughput performance of the chain topology Ad Hoc network

In a large-scale wireless Ad Hoc network the nodes are spread away from one another, and signal strength (i.e. radio link quality) depends on the distance between them. The goal of this
experiment is to measure the TCP throughput in two chain topology networks without mobility, when imitating distance by setting different attenuation in coaxial cable connections.

In the first case of the experiment, two network nodes \( N1 \) and \( N2 \) are used to create a single-hop Ad Hoc network. They are connected directly through one coaxial cable segment with appropriate attenuation \(-\text{X} \text{dB}\). \( PC1 \) is connected to node \( N1 \), and \( PC2 \) to \( N2 \) (Fig. 3).

In the second case of the experiment, three network nodes \( N1, N2, \) and \( N3 \) are used to create a multi-hop Ad Hoc network. Two coaxial cable segments with appropriate attenuation \(-\text{X} \text{dB}\) are used for connecting them into a chain. \( PC1 \) is connected to node \( N1 \), and \( PC2 \) to \( N3 \) (Fig. 3).

For both cases static routes are set in network nodes in order to route data packets hop-by-hop along the chain and TCP throughput and RTT are measured. \( PC1 \) generates traffic, which is inserted into the Ethernet interface of the first network node in the chain, and \( PC2 \) receives the generated packets from the Ethernet interface of the last node in the chain.

Traffic is generated by \texttt{netperf}, such that a traffic source always has data to send and tries to transmit data as quickly as possible. \texttt{Tcpdump} and \texttt{tcptrace} tools are used to measure the average throughput and RTT.

Results show the impact on the TCP throughput and RTT by the attenuation in the signal path among the network nodes. Attenuation \(-\text{X} \text{dB}\) was always equal for all network segments (Fig. 3). The splitters attenuate the signal by \(20\)dB along the one-hop path between the neighbour network nodes. It is a constant attenuation value, which was added to every segment.

The TCP throughput and RTT results for the single hop \((N1-N2)\) experiment indicate that the change in throughput and RTT is very small with different attenuation values. Two network nodes do not interfere with each other in a single-hop Ad Hoc network. The maximum throughput is approximately \(27\)Mbps, when the attenuation between the nearby network nodes is around \(48\)dB. The minimum average RTT is approximately \(12.1\)ms.

The TCP throughput and RTT results for the multi-hop \((N1-N2-N3)\) experiment are presented in Fig. 4 and Fig. 5.

As seen in Fig. 4, the polynomial trendline indicates, that the maximum throughput is approximately \(11\)Mbps, when the attenuation between the nearby network nodes is around \(46\)dB. When the attenuation is increased, the throughput decreases. As there are three nodes in the network chain, they form a group, where only one of them can transmit at a time, ex. when the first node transmits to the second node, the third node cannot transmit without interfering with the second node [5].

As seen in Fig. 5, the minimum average RTT is approximately \(45\)ms. The RTT increases as the attenuation is reduced. The signal attenuation in the coaxial cable system among the network nodes corresponds to the distance among the network nodes in an open space; therefore decreasing the attenuation corresponds to moving the network nodes closer to each other. The collision avoidance is the dominant source of RTT in the network, in which most of the nodes are within the carrier sense range of each other [5]. Therefore, RTT increases mostly because of the collision avoidance at the MAC layer or the retransmission due to collision. The TCP throughput parameter is related to TCP RTT, so the throughput decreases significantly as RTT is increased when signal strength levels are high.
As the attenuation is increased, the TCP throughput decreases due to the degradation of link quality. When the signal levels are low, a bigger amount of corrupted MAC frames have to be resent. As TCP is a reliable protocol, the corrupted information is being resent, so the TCP throughput decreases. The increase in RTT is not significant, as an amount of collisions is low.

The major result of this experiment is the optimal attenuation value X=50dB in the testbed network coaxial cable segments, where TCP throughput reaches the maximum value.

3.2. Inter-node interference on TCP throughput performance

The goal of this experiment is to measure the impact of the TCP throughput by inter-node interference between two Ad Hoc network communication groups.

In the first case of the experiment, each communication group contains two network nodes that are used to create their own single-hop Ad Hoc network (N1-N2) and (N4-N5) (Fig. 3).

In the second case of the experiment, each communication group contains three network nodes (N1-N2-N3) and (N4-N5-N6). As a result of the experiment, described in section 3.1, the fixed X=50dB attenuation is used in order to ensure the maximum throughput within the communication group. Coaxial cable segments with attenuation -YdB connect the communication groups in order to create the inter-node interference (Fig. 3).

For each communication group a source node transmits TCP data stream that is generated by netperf. The groups try to communicate simultaneously, and contend for medium when they are close to each other. The average throughput is measured for both communication groups at different attenuation values.

The first case (group1: N1-N2, group2: N4-N5) TCP throughput results are presented in Fig. 6. The first communication group has higher TCP throughput during the experiment. Both traffic streams are being simultaneously generated from PCI and the second netperf client process is started only after the first one has been put to run as a background process. As the network nodes interfere with each other, the first stream occupies more medium access time, and it is hard for the second stream to achieve as much TCP throughput due to the unfair nature of the IEEE 802.11g collision avoidance mechanism. Therefore, the total TCP throughput calculated by summing both streams is also presented.

Figure 6. The impact on the TCP throughput by the inter-node interference in the network (N1-N2, N4-N5)

As observed in Fig. 6, the attenuation Y=85dB is the critical point, where the TCP throughput is still high, but it starts decreasing when attenuation is being decreased. The change in the inter-node interference is really sharp, as throughput decreases by half when attenuation is reduced to 76dB. As attenuation is being reduced down to the minimal value (about 5Mbps), throughput decreases exponentially. The TCP throughput of different single-hop Ad Hoc network communication groups was also evaluated in [5], but, instead of attenuation, the distance was varied in order to change the inter-node interference between the communication groups. The results presented in Fig. 6 and in [5] correlate; therefore setting different attenuation values in the testbed really corresponds to changing the distance among the network nodes.

The second experiment (group1: N1-N2-N3, group2: N4-N5-N6) TCP throughput results are presented in Fig. 7. The critical point is the same Y=85dB attenuation, but the change in TCP throughput is not as sharp as in the previous case of this experiment. The extreme level of unfairness between the communication groups has been noticed during this experiment. With low attenuation the first stream occupies most of medium access time, and the TCP throughput of the second stream drops to the minimum (even less than 50Kbits).

The results validate the statements, presented in [9], that TCP throughput unfairness is very high in a multi-hop Ad hoc network, when data
streams go from wired to wireless links and then vice versa.

Unfairness reflects in the results as damaged or timed-out segments are not counted into the throughput parameter. Netperf sends data as quickly as possible for the time specified. The number of packets or bytes is not specified, so communication groups can transfer different amount of data during the same time. The tcptrace calculates throughput at the source by counting only the number of acknowledged segments among all the segments transmitted. Netperf uses default 1448 bytes packet size. As presented in [10], the throughput unfairness is significantly higher for large packet sizes.

4. Conclusions and future work

In this paper, the details of the testbed design and implementation are described. The testbed with required network topology is built by combining different number of simple network elements, thus ensuring unlimited scalability. It enables making mobile Ad Hoc network performance evaluations in a laboratory environment. RF signals travel through cable connections among Ad Hoc network devices in order to minimize the network. The capability to emulate different Ad Hoc network topologies in the testbed environment is demonstrated. The experiments have been made showing the network performance dependences on the signal attenuation in the testbed cable segments.

The testbed can be used for Ad Hoc network research and wireless network performance demonstrations. Further research is going to be made with UDP data streams for similar experimental setups as well as deeper analysis of TCP RTT. The routing protocol evaluations are going to be performed to observe their impact on the network performance, taking network mobility into consideration.

5. References