Experimental Study of Data Dissemination in Wireless Ad Hoc Networks

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Abstract[1]

An ad hoc network is decentralized collection of multiple nodes connected with wireless links instead of using special devices for routing or switching like in a wired network. The communication ability between nodes is degraded by the distance and the environmental factors. So, each node in the network uses the service of other nodes in order to transmit packets to the destination node that is out of the range of the source node. In this paper, we present the performance of wireless ad hoc networks under different system configurations with some important performance metrics which are obtained by transmission of different sized application data and varied number of nodes in the network. All network configurations are conducted in an outdoor land and carried out by laptop computers running Windows Vista operating system. An application layer multithreaded program is used to investigate network performance.

1. Introduction

Unlike wired networks, ad hoc networks can be settled up in a various different environments without any specific equipment [1]. Therefore, there are many different application areas of wireless ad hoc networks. Nodes in an ad hoc network are free to move and organize themselves in an arbitrary fashion [2]. As far as ad hoc networks are formed without any established infrastructure, the performance of network may vary in terms of throughput, which depends on IP routing protocols, number of hops, distance between source and destination, data size, application area, number of hops in the network, etc. All nodes in an ad hoc network are connected via wireless links [3]. The main benefit of ad hoc networks is that, in the case where the source node and the destination node are out of the range of each others wireless radio signal, it is possible to use other nodes as a router to perform connection. So, it is easy to say that, wireless ad hoc networks are flexible and adaptive way of communication where it is not easy to conduct a wired network.

Efficient routing protocol is one of the most important problems faced in dynamic wireless ad hoc networks since the speed and security of data transmission is directly related with routing protocol [2, 3]. For wireless ad hoc networks, there are many routing protocols which were tested and evaluated among many studies. Most of these studies were carried out by simulation models [4, 5, 6] rather than taking place on real life within real environmental factors [7, 8, 9]. Although simulation experiments are less time consuming type of experimentation and easier to modify [3, 4, 6], their results are not efficient when compared with real-world experimental results. On the other hand, real-world experimentations are very hard to achieve and need lots of resources (time and human).

The purpose of this paper is to present new features of the application layer program described in [10] and demonstrate the new real-world experimental results. The experiments were carried out by laptop computers which were placed as a node in a wireless ad hoc network and ran the developed multithread program under Windows OS.

The rest of the paper is organized as follows. Section 2 describes the architecture of the application layer

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program. Section 3 presents the real-world network configuration of the experiments and performance metrics. In Section 4, results of experiments collected from different network configurations were illustrated and analyzed. Finally, Section 5 concludes the paper.

2. Architecture of the program

This section overviews the structure of the application-layer program used in the experimental investigation of wireless ad hoc networks. The program was developed based on the simulation model and the prototype program presented in [1] and [2] respectively. In the program, flooding scheme is used for data distribution in the network [11]. In this scheme, a node transmits each message to all its neighbors. The neighbors, in their turn, rely each received data packet to their neighbors, and so on until the message reaches to the destination node in the entire network.

In the implementation of the flooding mechanism, area-restricted multicast mode of transmission mechanism, which represents a limited broadcast form, is used to send each packet to the destination node. Each multicast packet is received by a group of nodes whose network interfaces have been configured to receive multicast packets, as shown in Fig.1. To multicast packets, the socket mechanism was used with the UDP transport protocol. IP and CSMA/CA protocols were considered at the network layer and MAC layer, respectively. The MAC layer performs the collusion detection by expecting the reception of an acknowledgment to any transmitted frame except multicast frames [12]. According to [10, 13], multicast packets are not acknowledged.

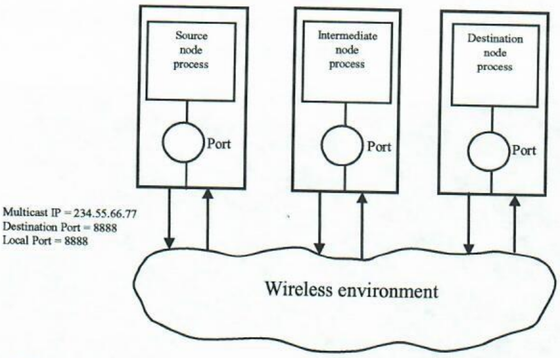


Fig. 1. Multicast mode for wireless network architecture

The program under study was implemented as a multithreaded C program to be run on all laptop computers in the wireless ad hoc network configuration. There are two threads in the implemented program – the originating thread and the relaying thread.

The originating thread is active only on the source node and is used to generate data packets to the destination node. Since the data packets are sent in multicast mode, they received by all the neighbors of the source node. If the destination node is in the transmission range of the source node, the packet will be delivered directly. Otherwise, it will be sent through one or more intermediate nodes. After sending all data packets, the originating thread waits for the termination of the relaying thread, collects statistics and terminates.

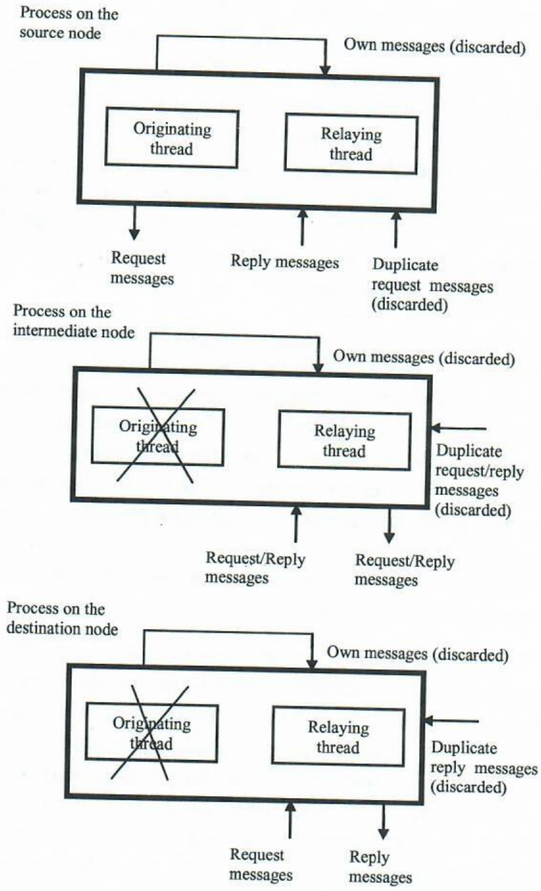


Fig. 2. Structure of the the program.

The relaying thread is active on all nodes in the network. It is used to receive multicast data packets from the network and then analyzing the received packets. The received packets can be request or reply messages for all nodes in the network. All nodes discard duplicate request/reply messages (e.g. messages that are coming from the neighbors to the original sender) and their own transmitted messages.

Each node (a node can be source, intermediate or destination), performs different actions in the relaying thread. The source node calculates the round trip time of each acknowledged message, finds the number hops from the destination node and determines the lost reply messages. The intermediate node forwards each received request and reply message to the network, if the message is not in the array of the latest received messages. It counts forwarded request and reply messages as well. The destination node sends a reply message to the source node after receiving a request message and determines lost request messages. This node also computes number of hops for each received message from the source node.

3. Environment of the experiments and performance metrics

Researchers who aim to experiment the performance of wireless ad hoc networks in an efficient manner mostly prefer real-world environments rather than simulation models for their investigations. Real-world experiments may take place in indoor or outdoor environments [14]. In this paper, all of the experiments were held in outdoor environment and the positions of the source node, the destination node and all other nodes were kept fixed. In other words, the distance between the nodes was stable during the experiments in order to gain opportunity for repetition of the experiments.

Two groups of experiments were conducted with different network configurations in outdoor environment. First group of experiments are the extension of the experiments which were done in [15] with one source node and three destination nodes. In that work, the experiments were deployed in the campus area of EMU. In this recent paper, we have described the experiments which were done in an open field. In the second group of experiments routing and data dissemination were considered in different network configurations with fixed nodes.

Fig. 3 presents settings of the source node and three destination nodes at different directions for the network configuration deployed in an open field for the first group of experiments. The laptop computer, which was used as the source node, was placed at the center and three destination nodes were positioned on a circle with equal distances from the source node and from the neighbor destination nodes. In the experiments, the place of the source node was fixed and the place of the destination nodes was varied in the range from 30 m up to 150 m, to investigate the effect of the inter-node distance to the performance metrics that is going to be described at the end of this section. In these settings, all destination nodes were within the coverage area of the source node.

Fig.4. illustrates the environment which all of the second group of experiments were took place that is located side of the Famagusta city. Two sets of experiments were conducted in this environment with two network configurations. One network configuration was with five nodes and another one was with ten nodes. Fig.4 also shows the settings of the source node, destination node and eight intermediate nodes for the ad hoc network configuration with ten nodes deployed in the open field.

In this group of experiments the source node and the destination node were positioned in such a way that the destination node is not in the coverage area of the source node while intermediate nodes were positioned in the field randomly. Due to the long distance between the source node and the destination node packets from the source node are transmitted through the intermediate nodes to the destination node. Flow of packets through intermediate nodes again follows an arbitrary fashion.

From our experiments it is observed that, it is nearly impossible to achieve same results from two experiments with the same network configuration and parameters due to the real-world environmental factors such as fading, attenuation, and presence of other interfering factors are not stable [6]. Therefore, in order to get more statistical and realistic data, all of the experiments with 5 different packet sizes are iterated 3 times and only the average of these 3 trials were taken into the consideration.

In real-world wireless ad hoc networks experiments, it is clear that there could be many different performance metrics that gives us rights to talk about the performance

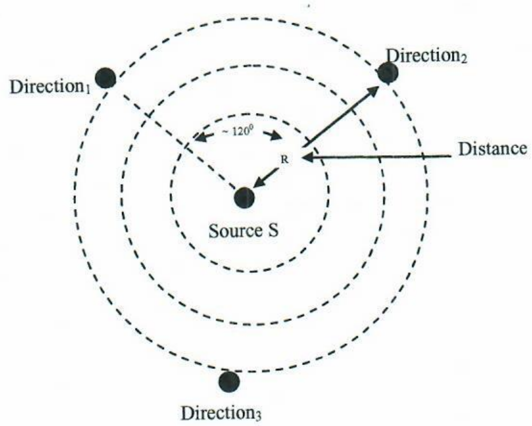


Fig. 3. A configuration of a wireless ad hoc network consisting of a source node and 3 destination nodes forming a circle

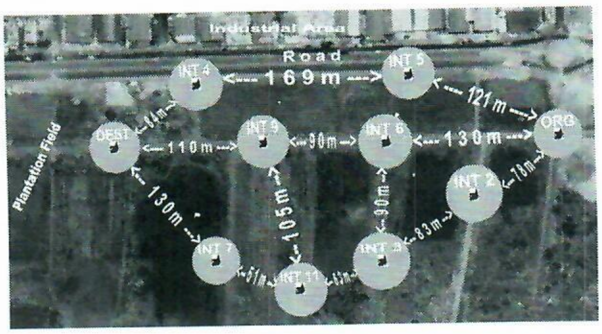


Fig. 4. A configuration of a wireless ad hoc network consisting of one source node (ORG), one destination node (DEST) and eight intermediate nodes

of the network. The round trip time (RTT) and the delivery ratio of packets are the most common performance metrics that could be used for this purpose. The round trip time is measured at the source node and presents the amount of round trip delay which underlying network produces till receiving a reply for a request message. The delivery ratio specifies the effectiveness of the network in delivering packets from the source node to the destination node. The efficiency of forwarding of packets from a source to the destination node through intermediate nodes acting as routers is represented by the average number of hops. It is observed that, delivery ratio and number of hops highly depend on the node density of the network area, routing scheme and node mobility. These performance metrics could be used in experimental studies with different parameters such as; distance, packet inter-arrival time, data size and number of hops between source and destination nodes. In this study, we considered the delivery ratio and the number of hops at the destination node and average round trip time at the source node.

Formally, the delivery ratio measured at the destination is calculated by the expression

$$n_d = \frac{N_d}{N_s}, \tag{1}$$

where N_s is the number of data packets transmitted by the source node and N_d is the number of data packets received by the destination node.

The average round trip time, measured at the source node is calculated by the following expression

$$R = \frac{1}{N_r} \sum_{i=1}^{N_r} R_i, \tag{2}$$

where N_r is the number of replies at the source node and R_i is the round trip time for reply i, $i = 1, 2, \ldots, N_r$.

The number of hops that a packet takes to reach from its source to the destination node is the hop count. This quantity helps us to determine the path optimality of a given routing protocol over another.

The third performance metric, average number of hops, measured at the destination node, expressed with the expression

$$h_d = \frac{1}{N_d} \sum_{i=1}^{N_d} N_i \tag{3}$$

where N_i is the number of hops for request i i=1,2,3,…,N_d.

In the first group experiments, the expressions given in [14] were used.

4. Results of Experiments and Discussions

The laptop computers used in the experiments as a network node have similar specifications with Intel core 2 duo 2.2 GHz processor and they are joining to the network by 802.11 b/g Wi Fi wireless interface adapter. During the experiments laptops are powered by 9-cell batteries and they are positioned nearly 50cm higher than ground level in the experiment area. Experiments were carried out during daytime with the temperature varying from 20°C to 30°C.

In each experiment, the number of requests, which were sent from the source node to the destination node, was 2000 and the inter-packet transmission time (delay between transmissions of each packet) at the source node was set at 100 ms. A number of experiments were carried out with the same configuration except the size of packets was changing on each run such as 100, 400, 800, 2000 and 4000 bytes as a parameter. Because of the maximum data size of IEEE 802.11 standard is 2312 bytes in a packet including all headers of the upper layers [16], large application data sizes such as 4000 bytes transmitted as two packets from the source node to the destination node.

The results of experiments that were performed with the network configuration shown in Fig. 3 (for the first group of experiments) and with the network configuration shown in Fig. 4 (for the second group of experiments) are shown in Figs. 5–12 and Fig. 13–15 respectively.

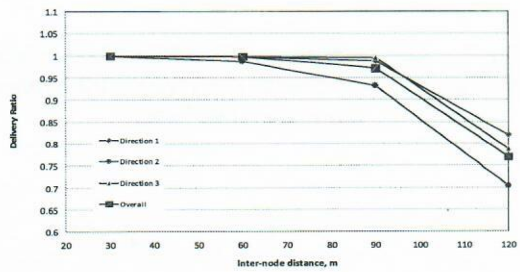


Fig. 5. The The delivery ratio versus inter-node distance, for different directions with application data size = 50 bytes

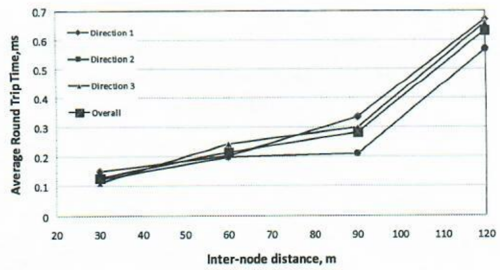
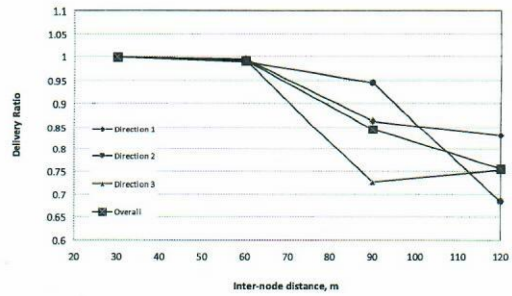


Fig. 6. The average round trip time versus inter-node distance, for different directions with application data size = 50 bytes



The delivery ratio versus inter-node distance, for different directions with application data size = 800 bytes

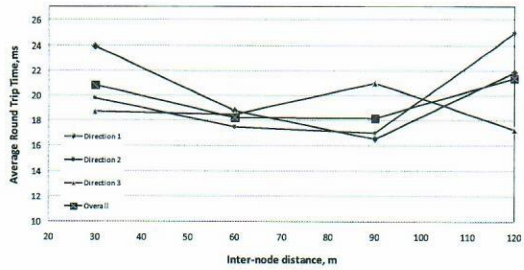


Fig. 7. The average round trip time versus inter-node distance, for different directions with application data size = 800 bytes

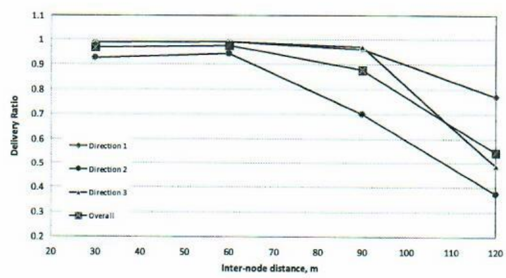


Fig. 8. The delivery ratio versus inter-node distance, for different directions with application data size = 4000 bytes

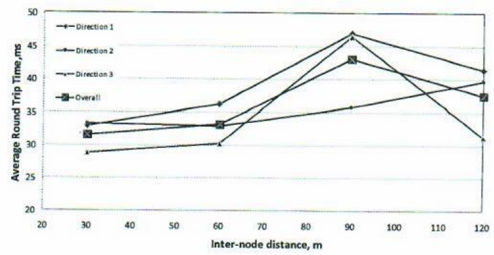


Fig. 9. The average round trip time versus inter-node distance, for different directions with application data size = 4000 bytes

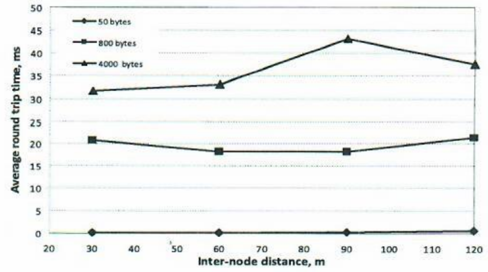


Fig. 10. The average round trip time (overall) versus inter-node distance for different application data sizes

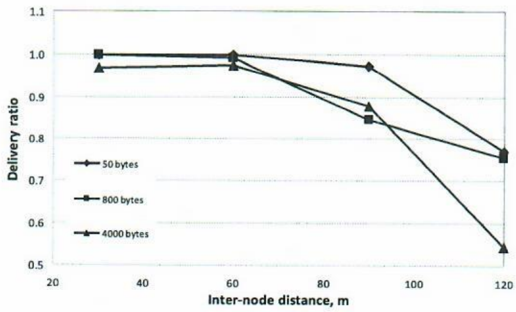


Fig. 11. The delivery ratio (overall) versus inter-node distance, for different aplication data sizes

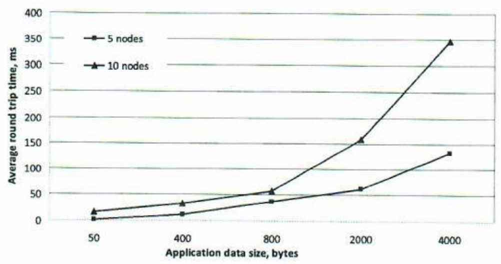


Fig. 12. The average round trip time versus aplication data sizes with 5 and 10 nodes

Fig. 13.

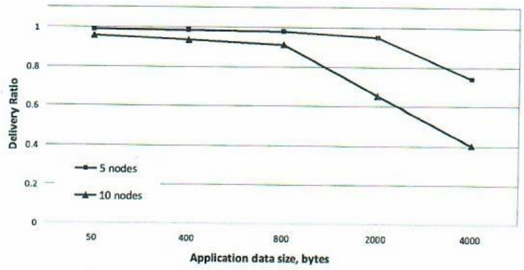


Fig. 14. The delivery ratio versus aplication data sizes with 5 and 10 nodes

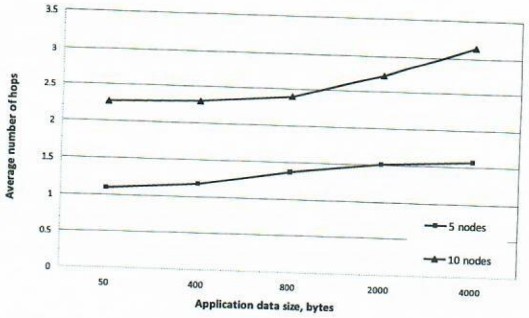


Fig. 15. Average number of hops versus application data sizes with 5 and 10 nodes

During the performance of the first group of experiments with the network configuration given in Fig. 3, the source node was placed at the center and three destination nodes were positioned on a circle with equal distances from the source node and from the neighbor destination nodes as was explained in the previous section of the paper. The inter-node distance between the source node and the destination nodes was varied from 30 m to 120 m. At all these distances, the three destination node was in the coverage area of the source node. After 120 m the source node transmissions could not reach to the destination node under the given conditions.

Graphs in Figs. 5–10 demonstrate the dependence of the delivery ratio and average round trip time on inter-node distance with different application data sizes for the first group of experiments. In the graphs corresponding performance metric values are given for three different directions with the overall value of three destinations.

Graphs in Figs. 11 and 12 present the dependence of the overall delivery ratio and overall average round trip time on inter-node distance with different application data sizes.

The results of the experiments that was performed with the network configuration shown in Fig. 4 is presented in Figs. 13–15. In the graphs corresponding performance metric values are given for 5 and 10 nodes in the network configurations based on the obtained experimental results, one can make the following inferences.

1. The average round trip time depends on the application data size and the delivery ratio depends on the inter-node distance between the source node and the destination node and the application data size.

2. As it was expected, the average round trip time increases with the increase of the application data size (Fig 6, 8, 10, and 11). Especially it is quite high for a large application data size, since in this case, there is more than one packet transmission. For small application data size it remains quite low. From the same graph, it is also clear that, the average round trip time does not depend on the distance between two nodes, if the destination node is in the coverage area of the source node.

3. Figs. 5, 7, 9, and 12 show that the packet delivery ratio considerably decreases with the increase in the inter-node distance between the source node and the destination node. This performance metric is quite low for large number of inter-nodes distances, since large number of packets are lost on the way from the source node to the destination node.

4. From the graph of Fig. 12 one can also see that, there is a large decrement in the packet delivery ratio when application packet size increases (especially for 4000 bytes). In wireless ad hoc networks Bit Error Rate of a radio link is high, therefore, the probability of a packet to get corrupted or lost increases with the increasing packet size. For a large application data size, more than one packet is transmitted since there is a limitation on the frame size in IEEE 802.11 MAC layer [14].

5. The average round trip time increases with the increase of the application data size (Fig. 13). Especially it is quite high for a large application data size, since in this case, there is more than one packet transmission. For small application data size it remains quite low. From the same graph, it is also clear that, the average round trip time with 10 nodes is higher than with the 5 nodes in the network.

6. In the network configuration with 10 nodes the distance between the source and the destination in too much comparing with 5 nodes configuration. As a result the delivery ratio is low with 10 nodes comparing with 5 nodes (see Fig. 14).

7. Graph in Fig.15 illustrates the average number of hops from the source node to the destination node. Number of hops taken by each packet is increasing due to increase in packet size. Additionally, it is clear that number of hops taken by packets whose sizes are greater than 2000 bytes is at higher level when compared to smaller sized packets. In the 10 nodes case the distance between the source node and the destination node was increased and more intermediate nodes inserted in between. As a result there is an increase in the average number of hops with 10 nodes.

5. Conclusion

A multithreaded program for experimental investigation of data transmission in a wireless ad hoc network has been developed. Through the paper, series of experiments have been carried out in outdoor real-world network environment with the use of program running on Microsoft Windows Vista. The performance of wireless ad hoc network was investigated by some important performance metrics which are obtained by the transmission of different sized packets. The program and the results of the experiments can be used for investigation of different schemes of routing and data transmission in real-world wireless ad hoc networks and as data for sensible simulations.

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