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Performance Study of a Cross-layer Optimization to the DSR Routing Protocol in Wireless Mesh Networks

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Performance Study of a Cross-layer Optimization to the DSR Routing Protocol in Wireless Mesh Networks

Mustafa Ramadhan and Mark Davis

Abstract—**A cross-layer modification to the DSR protocol is presented in this work which is intended to enhance the global throughput performance of wireless mesh networks. This modification involves the use of an access efficiency factor (which is a measure of the local availability of bandwidth at a node) as an alternative metric to the hop-count metric in order to allow for improved routing selection. The key feature of this modified route selection procedure is that it attempts to discover paths that have a large availability of bandwidth which can support high throughputs. In this work we have employed the OPNET modeler simulator to investigate the performance of the modified DSR protocol on a series of randomly generated network topologies of different node densities. The simulator was run twice for each network topology. The first run implemented the standard DSR algorithm while the second implemented the modified DSR protocol. The average throughput was recorded for each run and the percentage improvement for the particular topology was calculated. Our results demonstrate that a significant enhancement in the global throughput of the networks can be achieved by implementing our modified DSR protocol.**

***Index Terms*—Mesh Networks, DSR Routing Protocol, IEEE 802.11, Access Efficiency Factor.**

I. Introduction

THE IEEE 802.11 technology is the most widely used wireless LAN technology that provides for infrastructure and infrastructureless networks. In the infrastructureless network, which is also called ad hoc, there are no centralizing elements; nodes are typically mobile and operate in a collaborative way to route packets across multiple hops to the destination. However, other issues such as the mobility of the nodes, wireless medium instabilities, and the absence of an infrastructure often result in low connectivity [1]. Consequently, Wireless Mesh Networks (WMNs) were proposed as a solution to the often poor availability of ad hoc network connectivity. WMNs extend the coverage area of access points by using multihop communications [2]. One of the main differences between WMNs and ad hoc networks is the traffic pattern, i.e. in WMNs practically all the traffic flows either to or from a gateway; while in ad hoc networks, the traffic flows between arbitrary pairs of nodes. In a WMN, node devices can be classified into two groups: mesh routers and mesh clients. Mesh routers have superior capacities (in terms of memory, multiple interfaces, computing power etc.) and have limited or no mobility compared to mesh clients, allowing them to form a network backbone and serve as powerful dedicated packet routers. Mesh clients connect to these routers in order to form a network and can enjoy additional services provided by routers with gateway functionalities, such as a connection to the Internet.

The growth of WMNs has resulted in a demand for the development of high throughput routing metrics. Several routing metrics have already been proposed such as the Expected Transmission Count (ETX) which is the first metric specifically suggested for WMNs [3]. The ETX metric estimates the expected number of attempts required to successfully transmit a frame on a link. The ETX finds the route with the highest probability of packet delivery, instead of the shortest path. They are some drawbacks associated with this metric: ETX does not differentiate between links with different capacities as IEEE 802.11 broadcast frames are sent at the network basic physical rate and probes are usually smaller than data packets. Also the loss probability of small probes differs from the loss probability of data packets. To overcome these problems, the Expected Transmission Time (ETT) metric was proposed [4]. The ETT metric predicts the amount of time required for a data packet to successfully traverse a route. The ETT also considers the highest usable bit rate of each link and the probability of successful delivery at that rate. This protocol does not take into account that the individual link with high loss rate along a path causes more interference and may further cause decreases in the performance of the path and it also does not consider the MAC overhead delay.

Since the shortest-path metric does not take into account the variability of the wireless medium. A cross-layer approach has emerged which takes into account the nature of wireless medium. There have been a large number of cross-layer design proposals in the literature recently. The cross-layer approach can be referred to as a protocol design based on actively utilizing the dependence between protocol layers to enhance the network performance. This differs from the traditional layered approach where the protocols at the different layers are designed independently [3]. As an example, cross-layer multi-channel selection algorithms have

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been developed which can be used with any routing protocol, even when the protocol was developed for use with a single network interface [5].

The objective of our work is to utilize MAC layer information at the routing layer to improve the global performance of the network. The goal of implementing a cross-layer technique for routing mechanism is to find good paths that are reliable and efficient, as well as optimized in their performance. The contribution of this work is in utilizing the Access Efficiency Factor (AEF) as a new metric that explicitly considers the local availability of bandwidth at a node. The AEF has been integrated into route discovery mechanism of the DSR protocol. Through computer simulation using the OPNET modeler we demonstrate that significant enhancement in throughput can be achieved through the use of this modified DSR routing protocol.

The rest of this paper is organized as follows: Section II considers some of the features of suitable routing metrics. Section III presents the definition of the Access Efficiency Factor which is used as a metric for the DSR route discovery mechanism. Section IV describes the OPNET simulation model. Section V details the performance evaluation of our modified protocol based upon OPNET simulations. Finally, in section VI we present our conclusions and future work.

II. Wireless Networks Routing Metrics

One of the important issues for wireless networks is the choice of the routing protocol as it plays an important role in managing the formation, configuration, and maintenance of the topology of the network. In order for nodes to successfully communicate with each other they must gather information regarding the network topology. This is generally achieved either reactively or proactively. Reactive methods have proven to be more successful in terms of high throughput and low overhead for WMNs if such networks are highly dynamic and nodes are allowed to roam. Among the most commonly used reactive protocols are AODV [6] and DSR [7] both of which employ a minimum hop count.

Hop count is the most convenient routing metric for ad hoc networks because of node mobility which leads to frequent link breakages. It reflects the effects of the path length on the performance of an end-to-end flow. The path weight equals the total number of links through the path. However, hop count does not take into account the interference in the network nor the differences of link quality between different wireless links, including the local availability of the bandwidth, transmission rates. The most popular and widely used hop count protocol is the Dynamic Source Routing (DSR) protocol. DSR protocol operates on-demand in order to minimize the overhead by reacting only when route discovery is necessary. The main feature of the DSR routing protocol is the use of source routing where the sender learns the complete hop-by-hop route to the destination. These routes are stored in a route cache. The data packets carry the source route in the packet header.

Many studies have been concerned about routing in WMNs. For example, De Couto et al stated that using the hop count metric is not sufficient to build good paths in order to efficiently transport data with acceptable throughput, delay, and reliability [8]. Gupta et al declared that using a routing algorithm that does not take into account the interference produced in regions of the network when they select paths through the region leads to the reduction in the global throughput capacity of the network [9]. Iannone et al acknowledged that employing different physical layer parameters as a definition to the metrics help the routing algorithm to correctly find paths with low level of interference, reliability in terms of Packet Success Rate, and highest available transmission rate [10]. From the work noted above, the employment of certain features and characteristics of network layers can provide a sufficient routing algorithm that finds routes with satisfactory throughput and delay.

III. Access Efficiency Factor (AEF)

The AEF η_f is an indicator of the station's efficiency in accessing the wireless medium. The AEF can be computed from the access efficiency parameter η_a. By finding the BW_{access} (which is related to the average time required to get the backoff counter to zero) and the BW_{load} (which is related to the average time required to transmit a frame) we can measure the η_a which is defined as:

$$\eta_a = \frac{BW_{load}}{BW_{access}} \qquad (1)$$

In calculating the capacity. All the idle time is used to support the station's load:

$$BW_{load} + BW_{access} = 1 \qquad (2)$$

Substituting (1) in (2):

$$BW_{load} + \frac{BW_{load}}{\eta_a} = 1 \qquad (3)$$

Equation (3) can be rewritten as follows:

$$BW_{load}\left(\frac{\eta_a + 1}{\eta_a}\right) = 1 \qquad (4)$$

Letting:

$$\eta_f = \frac{\eta_a}{1+\eta_a} \qquad (5)$$

Equation (4) can be written as follows:

$$\eta_f = BW_{load} \qquad (6)$$

In the equation (6), η_f corresponds to the maximum load for a station under ideal network conditions, i.e. when no other stations are present. For the general case where there is more than one station present in the network, the η_f depends on the η_a and thus can be used as a measure of how efficiently a station contends for access to the wireless medium.

IV. SIMULATION MODEL

For the purpose of investigating the performance of our modification to the DSR protocol, we have examined the performance of the network with the modified DSR for different topologies.

We have employed the OPNET modeler using the default setting to simulate the IEEE 802.11b radio interface at the MAC layer, with the implementation of the distributed coordination function (DCF) and also to exam the performance of the modified DSR protocol. We have used a Constant Bit Rate (CBR) traffic source at each node to generate the network traffic where each source has an average rate of 5 packets per second with a packet size set to 512 bytes. Packet transmission in the simulator is based on a network using link level acknowledgments at each hop.

In this work we explore the performance of network topologies of different densities of the modified DSR protocol against the standard DSR. We generated 1000 random topologies comprising 100 nodes distributed across four area scenarios: 100m x 100m, 200m x 200m, 500m x 500m, and 1000m x 1000m. All topologies comprise 99 sender nodes and one receiver (gateway) node.

V. PERFORMANCE EVALUATION

OPNET simulation studies were used to analyze the performance improvement of our modified DSR protocol compared to the standard DSR protocol. The analysis focused on the improvement in the average global throughput rather than that of the individual links. The modification to the DSR protocol involves a modification to the route discovery mechanism where the strategy behind this modification is to find the optimum path by selecting the path with the highest minimum AEF value. An advantage of this technique is that it employs passive monitoring of the wireless medium and therefore it does not incur the overhead usually associated with active probing.

In this simulation study, we have generated 1000 random topologies for each scenario with 99 senders and one receiver. We ran the simulation twice for each topology, once with the standard DSR followed by the modified DSR. For each run we recorded the average throughput over 10 minute intervals in order to calculate the percentage improvement for the particular topology. For each scenario, we have calculated the probability distribution function (PDF), see Figures (1, 3, 5, 7) and the complementary cumulative distribution function (CCDF), see Figures (2, 4, 6, 8), of the throughput improvement for all network topologies examined with these scenarios. Figures 1 and 2 indicate that the minimum improvement in the throughput for 100m x 100m scenario examined for the modified DSR protocol against the standard DSR is 14%, the maximum improvement is 46%, and the average improvement 32%.

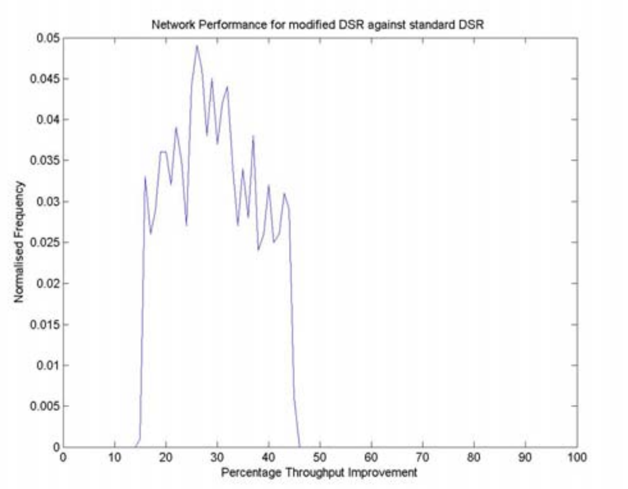

Fig. 1: Probability Distribution Function (PDF) for 100m x 100m scenario.

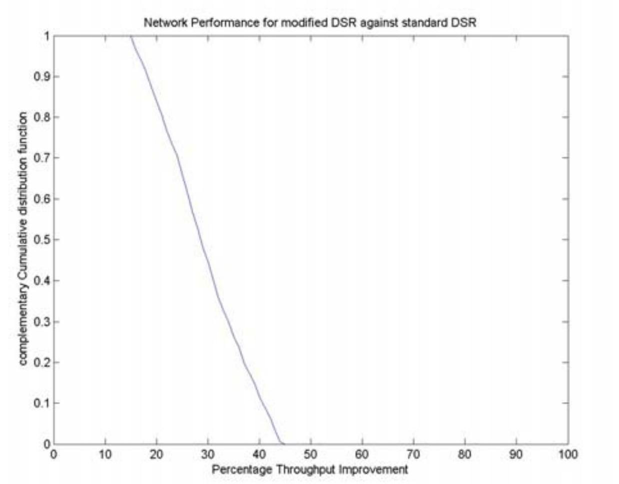

Fig. 2: Complementary Cumulative Distribution Function (CCDF) for 100m x100m scenario.

While the 200m x 200m scenario exhibits a minimum improvement in the throughput of about 15%, the maximum improvement is 58%, the average improvement is 35%, see Figures 3 and 4.

Reducing the network node density by increasing the area of the topology scenario to 500m x 500m verifies that the minimum improvement in the throughput is 17%, the maximum improvement is 60%, and the average improvement is 38%, see Figures 5 and 6.

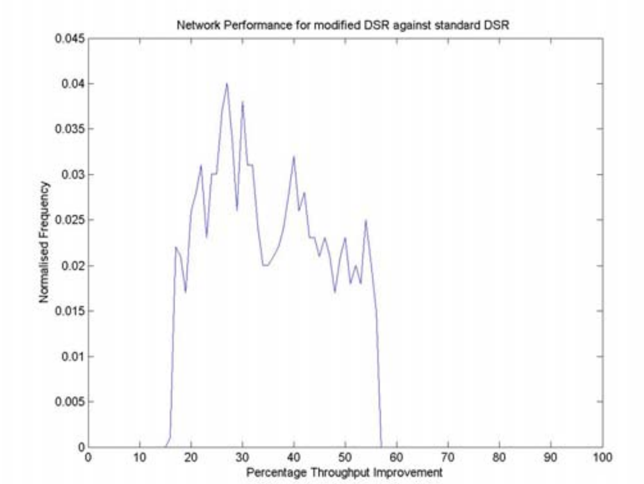

Fig. 3: Probability Distribution Function (PDF) for 200m x 200m scenario

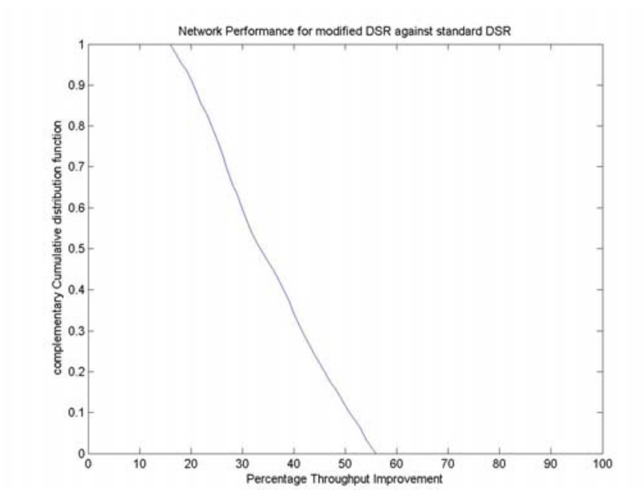

Fig. 4: Complementary Cumulative Distribution Function (CCDF) for 200m x 200m scenario.

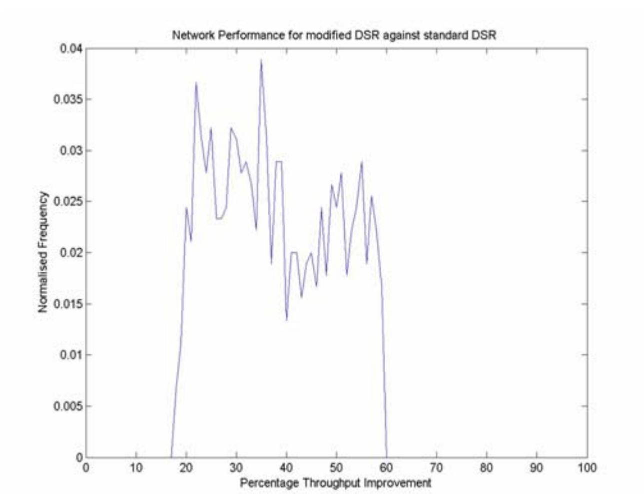

Fig. 5: Probability Distribution Function (PDF) for 500m x 500m scenario.

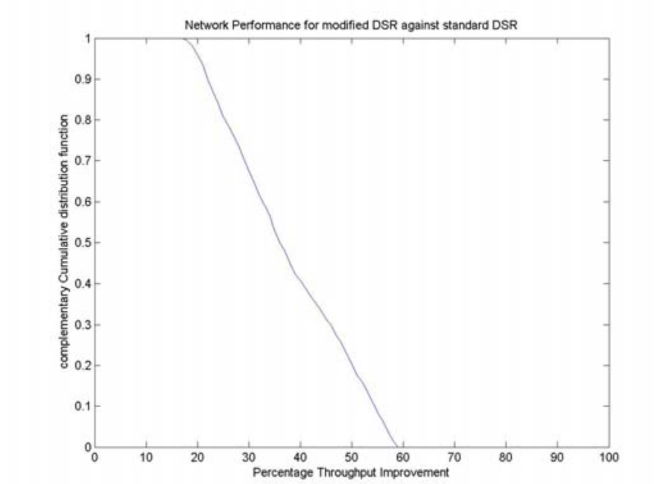

Fig. 6: Complementary Cumulative Distribution Function (CCDF) for 500m x 500m scenario.

Further increasing the area to 1000m x 1000m shows the minimum improvement in the throughput is 7%, maximum improvement is 84%, and average improvement is 40%, see Figures 7 and 8.

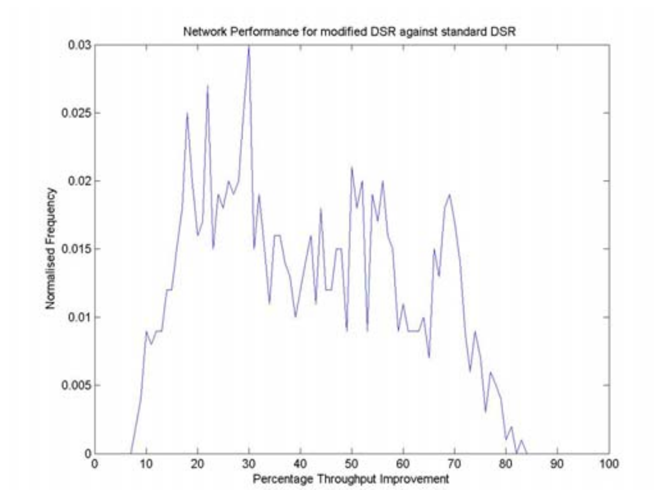

Fig. 7: Probability Distribution Function (PDF) for 1000m x 1000m scenario.

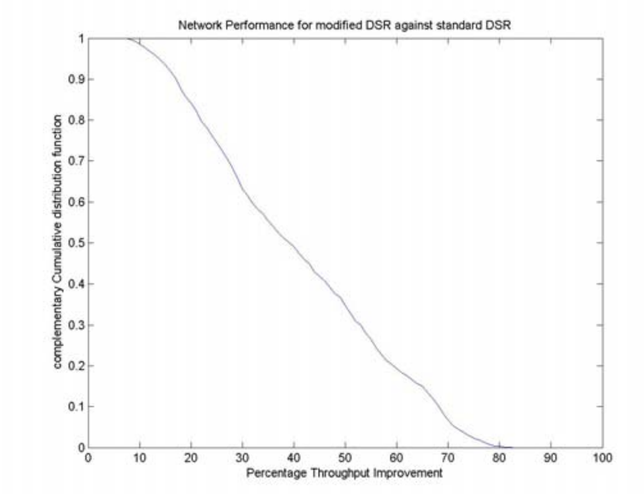

Fig. 8: Complementary Cumulative Distribution Function (CCDF) for 1000m x 1000m scenario.

The above figures show as the network density is reduced the PDF plots become broader which indicates that our modified protocol functions better in high density networks compared to sparser networks.

VI. CONCLUSIONS AND FUTURE WORK

The wireless medium is a shared resource and the capacity of a multi-hop network rapidly degrades as the node density increases due to increased interference. As a result, we have modified the DSR protocol to make it better suited to the WMN environment. The objective of this modification is to incorporate knowledge of the path capacity into the route discovery mechanism. The strategy of this modification is to find the optimum path by selecting the path with the highest minimum AEF value. Considering the availability of bandwidth locally at a node is important in wireless medium as nodes contend for accessing it using the DCF MAC mechanism. Since the DCF is a “listen before talk mechanism”, a high level of contention for access to the medium will result in a low availability of bandwidth at a node. Incorporating this information into the DSR protocol serves to reduce the cost of Route Discovery and the overall performance of the network can be significantly improved. Using OPNET modeler as a network simulator showed that significant improvement in the global throughput of the network can be achieved through our modified DSR algorithm by discovering routes with a high throughput rather than a minimum hop-count.

Our future work will attempt to experimentally validate the improved performance of our modified DSR algorithm. We also planning to modify the DSR protocol by including hop-count metric in addition to access efficiency metric and compare the percentage through improvement of this protocol with currently modified DSR protocol.

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