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Investigation of Across-layer Modification to the DSR Routing Protocol in Wireless Mesh Networks

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Abstract

This work introduces a cross-layer modification to the DSR protocol that increases the global throughput in wireless mesh networks. In our modified DSR protocol we have introduced the Access Efficiency metric as an alternative to the hop-count metric in order to improve the route selection mechanism. The selected path in the route selection mechanism is identified by choosing the path with the highest minimum Access Efficiency value. We have employed the OPNET modeller as a simulator to examine two different patterns of traffic for a series of randomly generated network topologies. Each topology was simulated twice. One simulation used the original DSR algorithm while the other utilised the modified DSR algorithm. The average throughput was recorded for each run and the percentage improvement for the particular topology was calculated. Our results demonstrate that a significant increase in the global throughput of the networks can be achieved by implementing our modified DSR protocol.

Keywords: Access Efficiency, WMN, MAC mechanism.

1 Introduction

Wireless Mesh Networks (WMN) have attracted much interest as they appear to be a promising technology to offer low cost broadband wireless access to the Internet, but also to realise self-organizing networks in areas where a wired infrastructure is not available or not viable to deploy. A WMN consists of two major components, the mesh router and the mesh client [De Couto et al 2002]. Mesh routers are static devices that are capable of self-configuring themselves as an access or a backbone network, offering connectivity to end-users by means of standard radio interfaces. Mesh clients are generally single radio communication devices that can either be mobile or stationary. Figure 1 shows a union of static WMN routers and mobile WMN clients. Routing in these types of networks is challenging, since the radio environment is hostile, unstable, and limited by interference.

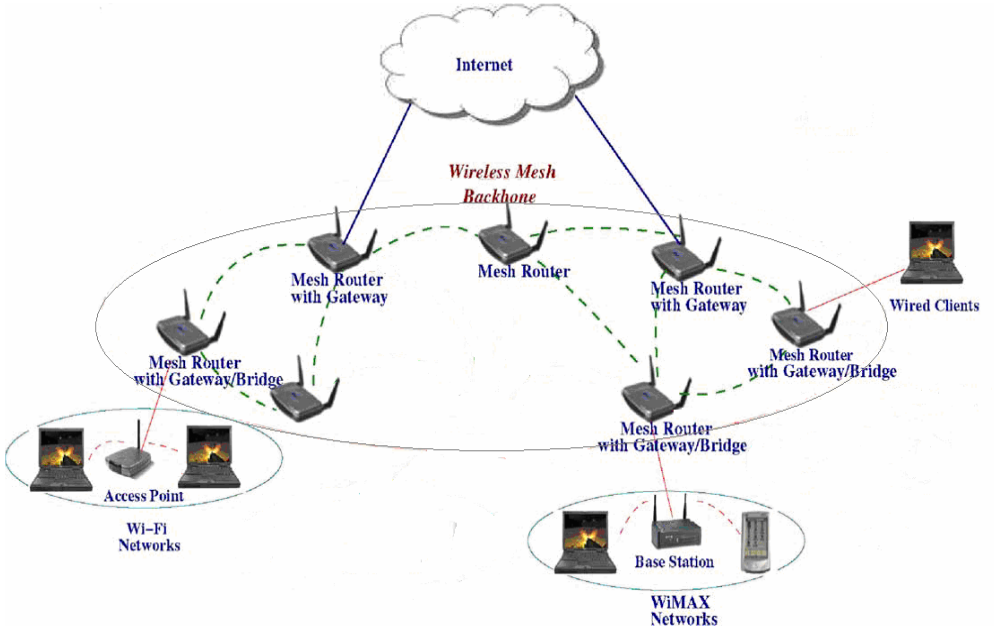

Figure 1: Typical WMN

Many studies have been carried out concerning routing in WMNs. For example, De Couto et al declared that using the traditional shortest path metric is not sufficient to build good paths in order to efficiently transport data with acceptable throughput, delay, and reliability [De Couto et al 2002]. Lundgren et al have claimed that the multi-rate feature may lead to unreliable gray-zone communications [Lundgren et al 2002]. Typically, different data rates have different transmission ranges where the lower the rate, the larger the range. Paths are usually established in reactive protocols by using broadcast messages sent at the minimum rate, which may create routes formed by links that do not support higher rates. Gupta et al have shown the global throughput capacity of the network is reduced as consequence of 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 [Gupta et al 2000]. Iannone et al explored three basic physical layer (PHY) parameters: Interference, Packet Success Rate, and Data Rate. They defined the metrics so that the routing level can correctly find paths that offer low levels of generated interference, reliability in terms of Packet Success Rate, and highest available transmission rate [Iannone et al 2004].

As the router nodes in wireless mesh networks tend to be static, the dynamic variations are much less than in mobile ad hoc networks (MANETs). Hence, the main design goal for routing protocols has shifted from maintaining connectivity between source and destination nodes to finding stable high-throughput paths between the nodes. Based on this goal, more complicated routing protocols than the shortest path protocol have been proposed such as Cruz et al who have studied the problem of joint routing, link scheduling and power control to support high data rates for broadband wireless multi-hop networks [Cruz et al 2003]. Couto et al introduced the expected transmission count metric (ETX) which finds high-throughput paths on multi-hop wireless networks [De Couto et al 2003]. Draves et al have developed a metric that chooses a high-throughput path between a source and a destination. The metric assigns weights to individual links based on the Expected Transmission Time (ETT) of a packet over the link [Draves et al 2004]. All these metrics have been proposed and evaluated for unicast routing protocols such as the Highly Dynamic Destination-Sequenced Distance Vector Routing (DSDV) [Perkins 1994], the Dynamic Source Routing protocol for mobile ad hoc networks (DSR) [Johnson et al 2001], and the Ad-hoc On-demand Distance Vector Routing (AODV) [C. E. Perkins et al 1999].

Classical wireless network architectures follow the principle of a separation of functionality between layers. However, neglecting certain features and characteristics of the other layers can have unexpected side effects on the network performance. Addressing these side effects is still an open research area. A cross-layer approach which breaks the separation between layers might turn any disadvantage of the MAC or PHY layer into an advantage, thereby enhancing the operation of the network.

Since the shortest-path metric does not take into account the variability of the wireless medium, other metrics which are aware the nature of wireless nature must be explored. The objective of our work is to make use of MAC layer information at the routing layer to enhance the global performance of the network. Adopting a cross-layer approach for routing should help in finding paths that are reliable and efficient, as well as optimized in their performance.

A wide range of applications with varying network performance requirements can be deployed on WMNs. For example, multimedia applications such as audio-video conferencing require minimal jitter and finite delay bounds. These applications are predominantly Internet oriented and thus the traffic is either from the end users towards the Internet gateway or in the reverse direction. This is different to MANETs, where traffic tends to be distributed more evenly across the network.

The contribution of this work is the modification of DSR protocol to include a new link metric that explicitly consider the local availability of bandwidth at a node. Through computer simulation using the OPNET modeller we show that significant increases in throughput can be achieved through the use of the modified DSR routing protocol.

The rest of this paper is organized as follows. Section 2 gives an overview of the IEEE 802.11 MAC mechanism. Section 3 presents the definition of link capacity. Section 4 gives a brief view of the Route Discovery mechanism of the DSR protocol as it operates as a route finding process between the source node and the destination node. Section 5 describes the modification to the DSR Packet Format that incorporates the new metric. Section 6 details the Performance Evaluation of our modified protocol. Finally, in section 7 we present the conclusion of our work.

2 IEEE 802.11 MAC Mechanism

The Distribution Coordination Function (DCF) is defined in the IEEE 802.11 standard as the basic MAC mechanism. DCF can be described as a listen-before-talk mechanism where all stations must contend with each other to access the medium in order to transmit their data. Any station wishing to transmit first listens to the medium during a DCF interframe space (DIFS). If the medium is busy, the station defers its transmission until the medium becomes idle. When the station senses the medium idle, it additionally waits for a random backoff interval as a part of the collision avoidance mechanism. The random backoff interval is randomly chosen according to the following formula: Backoff Interval = BC × Slot_Time, where BC is a pseudorandom integer drawn from a uniform distribution over the interval [0, CW - 1] and where CW is the size of Contention Window.

Frame transmission is initiated when a backoff interval reaches zero value. If the medium becomes busy while a station is decreasing the backoff timer, the backoff procedure is paused and is resumed after the medium is sensed to be idle for an interval of DIFS. Upon a successful transmission, a new backoff value is selected and the contention window is set to minimum, otherwise the CW value is doubled up to the maximum value. A collision may occur since more than one station may be concurrently attempting to gain access to the medium. When a transmission fails to be positively acknowledged, the size of the contention window CW is doubled, i.e. a new BC value is chosen.

The main problem with the DCF mechanism when it operates in a WMN environment is the shared medium among the contending nodes where all stations in the network must contend with each other to win access to the medium. In order to deal with this problem, the MAC bandwidth components framework [Mark Davis 2004] can be used to describe how the distributed MAC mechanism allocates the bandwidth of the medium among the contending stations. Under the MAC bandwidth components framework, three parameters are defined which describe how a station utilizes the bandwidth of the medium. These parameters are the load bandwidth BW_{load} which corresponds to that portion of the transmission rate of a station used in transporting its load, the access bandwidth BW_{access} which associated with the contention mechanism (whereby a station wins access to the wireless medium), and the free bandwidth BW_{free} which is associated with the Quality of service. Two of these parameters are used to define the Access Efficiency η_a which is used a basis of our modification to the DSR protocol.

3 Access Efficiency

The access efficiency η_a is a measure of how efficiently a station contends for access to the wireless medium. The access efficiency at a node can be obtained by measuring BW_{access} (which is related to the average time required to get the backoff counter to zero) and BWl_{oad} (which is related to the average time required to transmit a frame). The access efficiency η_a is defined as [Mark Davis 2005]:

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

4 Route Discovery

Route Discovery is one of the DSR protocol mechanisms that is used to find routes between the nodes in a network. In the DSR protocol, when a node needs to send a packet to a destination, it initially searches its cache for suitable routes. If no routes are contained in its cache, the Route Discovery operation is performed by broadcasting a Route Request in order to find routes between the source node and the destination node. Any intermediate node that receives a non-duplicate Route Request appends its address to the source route list in the Route Request packet and rebroadcasts it. This process continues until either the destination is reached or maximum hop counter is exceeded. If the destination is successfully reached, the destination receives the Route Request, appends its address and transmits a Route Reply packet back towards the source using the reverse of the accumulated route. If any intermediate nodes contain cache routing information obtained from Route Discovery. Moreover, if an intermediate node has some requested information, it may send a Route Reply back to the source. In this way, a source node obtains several routes to reach the desired destination. For further details regarding the DSR protocol, we refer readers to [Johnson et al 2001].

The rationale for modifying the DSR protocol is to make it better suited to the WMN environment. The WLAN medium is a shared medium where nodes must contend for accessing the medium using 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. This in turn limits the maximum throughput that can be achieved. Unfortunately, the DSR protocol fails to explicitly consider the availability of bandwidth locally at a node which is an important omission in WMNs based upon the IEEE 802.11 standard. In this case, the access efficiency measured locally at a node is used as a measure of the local availability of bandwidth at that node. By incorporating bandwidth availability information into the DSR protocol the cost of Route Discoveries can be reduced and the overall performance of the network can be significantly improved. The performance of modified DSR is investigated through a series of simulations performed on the OPNET modeler package.

5 DSR packet format Modification

In this work a new metric to support the DSR node cache mechanism has been developed. The modification to the DSR protocol is intended to incorporate knowledge of the path capacity into the route discovery mechanism. Specifically, the DSR protocol was modified by replacing hop count field in the cache route table with an access efficiency field. The optimal route is determined by selecting the path with the highest minimum access efficiency value.

Figure 2 illustrates the operation of the path selection mechanism for the DSR protocol and our modified DSR protocol. From this figure, the original DSR protocol selects path B as the hop count of this path is smaller than the hop count of the other paths (path A and path C). While our modified DSR protocol chooses path A over paths B and C as it selects the path with the highest minimum link capacity.

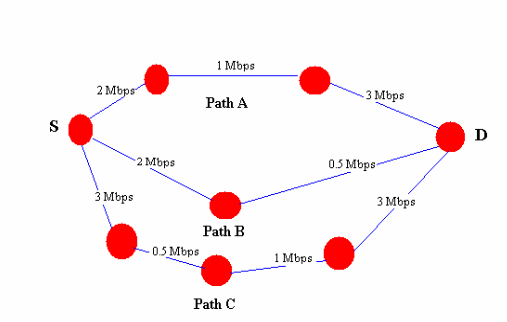

Figure 2: Example of Route Discovery mechanism

6 Performance Evaluation

6.1 Simulation Setup and procedure

The aim is to investigate the performance of the network with the modified DSR for different topologies and traffic patterns using video conferencing as an application. The OPNET modeller is used to simulate the IEEE 802.11b radio interface at the MAC layer, with the implementation of the distributed coordination function (DCF) and also to study the performance of the modified DSR protocol. Packets are sent at exponentially distributed sending times with a uniformly chosen average rate of 5 and 10 packets per second. Packet lengths are set to 1000 bytes. Packet transmission in the simulator is based on a network using link level acknowledgments at each hop. In this work we generate random topologies of 100 nodes scattered across a 200m x 200m area. Two different traffic patterns were examined on the networks: the Pattern 1 networks consist of a single sender and a single receiver (gateway) with the remaining nodes relaying traffic; the Pattern 2 networks comprise 99 senders and one receiver (gateway).

6.2 Procedure and Results

A number of different simulation studies were performed within this environment, analyzing the behaviour and performance of the modified DSR and comparing it to the original DSR routing protocol. A modification of link cache data structures and new path selection criterion are incorporated in this work to achieve better results. The link cache uses only the highest minimum of the AE to find the best route.

In this work we have generated 2500 random topologies for the Pattern 1 where we have one sender and one receiver using DSR and modified DSR algorithms. For each topology, the simulation run was performed twice, once with the original 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 this pattern, we have calculated the probability distribution function (PDF), see Figure 2, and the complementary cumulative distribution function (CCDF), see Figure 3, of the throughput improvement for all network topologies examined with this pattern. Figures 2 and 3 verify that the minimum improvement in the throughput for all topologies is about 3%, the maximum improvement about 27%, and the average improvement 15% when the modified DSR algorithm is implemented.

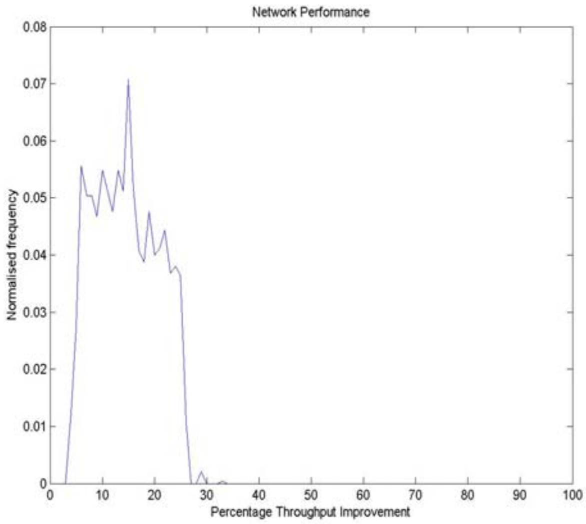

Figure (3): Probability Distribution Function (PDF) of Pattern 1.

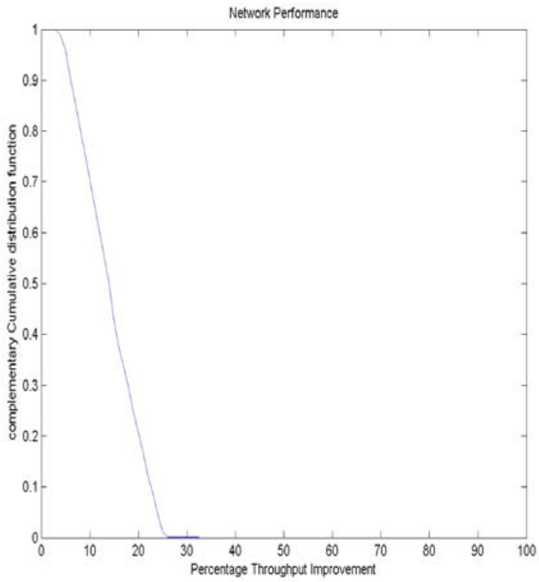

Figure (4): Complementary Cumulative Distribution Function (CCDF) of Pattern 1.

We also, generated a pattern of 1000 random topologies for the Pattern 2 (confusing use of the word pattern here) where there is one receiver and 99 senders implementing both the modified DSR protocol and the original DSR protocol. In this pattern, each topology was also run twice using the original DSR protocol and the modified DSR protocol. The resulting average throughput was recorded for each run over 10 minute intervals and the percentage improvement was calculated. The probability distribution Function (PDF) and complementary cumulative distribution function (CCDF) of the throughput improvement, see Figures 5 and 6, for all network topologies examined with this pattern. We can see from Figures 5 and 6 that the minimum throughput improvement for all topologies is about 10%, the maximum improvement in the throughput about 32%, and the average improvement 20%.

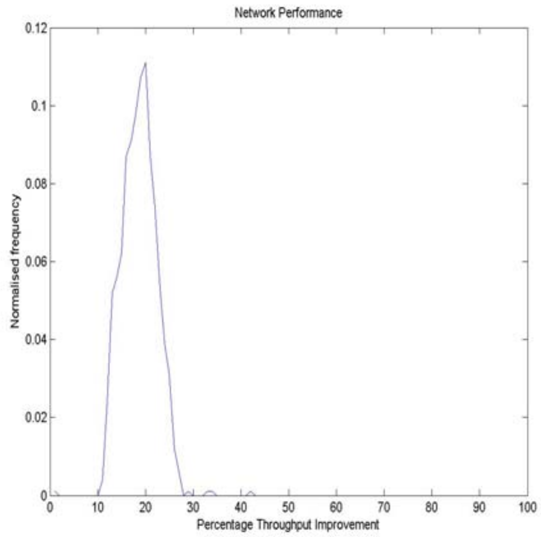

Figure (5): Probability Distribution Function (PDF) of Pattern 2.

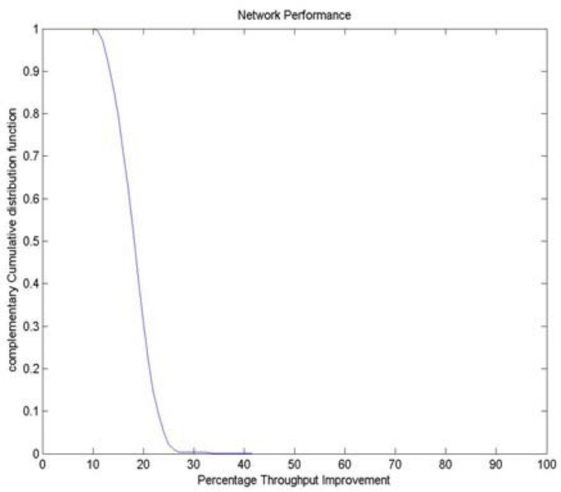

Figure (6): Complementary Cumulative Distribution Function (CCDF) of Pattern 2.

7 Conclusions and future work

In this work we have modified the DSR protocol for mesh networks using a new metric called access efficiency that takes into account the availability of the bandwidth locally at a node. Simulations performed on OPNET modeler show that our modified DSR protocol significantly increases the global throughput of the networks by finding the routes with high throughput than a minimum hop-count metric, particularly with paths two or more hops.

The potential of our future work is to investigate the topology effect on the global throughput measurements of mesh networks using our modified DSR protocol. 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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