2009-12-01

A Bandwidth Aware Modification to the DSR Routing Protocol for Wireless Mesh Networks

Mustafa Ramadhan
Dublin Institute of Technology, mustafa.ramadhan@cnri.dit.ie

Mark Davis
Dublin Institute of Technology, mark.davis@dit.ie

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Mustafa Ramadhan
Communications Network Research Institute, School of Electronic and Communications Engineering
Dublin Institute of Technology
Dublin, Ireland
mustafa.ramadhan@cnri.dit.ie

Mark Davis
Communications Network Research Institute, School of Electronic and Communications Engineering
Dublin Institute of Technology
Dublin, Ireland
mark.davis@dit.ie

***Abstract*—This work proposes a bandwidth aware cross-layer modification to the DSR routing protocol. We include the Access Efficiency Factor (AEF) parameter in addition to the hop-count in the routing discovery mechanism. AEF is a measure to the local availability of bandwidth at a node. Employing the AEF as a metric in the routing discovery mechanism attempts to avoid routing through a congested area in the network. In this modification, we impose a limit on the hop-count in order to control the delay time in the network. The path selection procedure operates by finding a path with the highest minimum AEF value. We have utilized the OPNET modeler simulator to investigate the performance of the modified DSR protocol on a series of randomly generated network topologies of different hop-count limits. 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 global throughput and the average global delay time were recorded for each run. We have calculated the percentage throughput improvement and the percentage delay time increment for each topology. Our results show that using AEF as a routing metric, it is possible to significantly enhance the average global throughput of the network. Furthermore, assigning different values to the hop-count limit allows us to control the network delay time.**

Keywords-component;Hop Count; Routing Protocol; Wireless Mesh Network.

I. INTRODUCTION

Wireless Mesh Network (WMNs) can be viewed as a special case of wireless multi-hop ad-hoc networks and they have the potential to play a critical role as an alternative technology for last-mile broadband Internet access due to their many desirable characteristics such as multi-hop routing, reliable services, self-healing, easy maintenance, self-configuration, self-organization, high scalability, bandwidth fairness, low cost, easy deployment, and they can deliver wireless services for a wide range of applications with various required traffic patterns [1]. The WMN architecture comprises two types of node: mesh routers and mesh clients. Mesh routers are considered to be stationary or at least have very low mobility. They provide integration with other networks such as the Internet, cellular, etc through their functionality as gateway/bridge in addition to the routing functionality to maintain the mesh network. Mesh Clients are either stationary or mobile and can access the Internet through intermediate mesh routers before reaching their corresponding internet gateways. Mesh clients can also work as a router in mesh networking.

Hop-count is the traditional routing metric used in most of the common ad hoc routing protocols like Ad-hoc On Demand Distance Vector (AODV) [2], Dynamic Source Routing (DSR) [3], Destination-Sequenced Distance-Vector (DSDV) [4], etc. It locates paths with the shortest number of hops. This metric reflects the effects of the path length on the performance of an end-to-end flow. Routing algorithms using this metric can be directly applied in WMNs. The relatively stationary topology of WMNs suggests that these ad hoc routing algorithms can be developed to enhance the network performances. However, hop-count metric considers all links in the network to be alike and hence it does not explicitly consider link quality metrics such as bandwidth, packet loss rate, link load, interference, etc. It may sometimes choose paths with low throughput which can result in paths which have high loss ratio and poor performance.

Several routing metrics that consider different link quality have already been proposed for wireless mesh networks such as: the Expected Transmission Count (ETX) [5], Expected Transmission Time (ETT) [6], Weighted Cumulative Expected Transmission Time (WCETT) [7], and Metric of Interference and Channel-switching (MIC) [8]. None of these routing metrics capture interference and congestion area in the network [9]. All of these metrics associated with some drawbacks as explained below [10].

The ETX routing metric measures the expected number of MAC layer transmissions (including retransmissions) required for successfully delivering a packet to the ultimate destination. The weight of path is defined as a summation of the ETX of all links along the path. In this way, ETX considers both path length and packet loss ratio. However, ETX ignores the interference experienced by the links which has a significant impact on the link quality because of the nature of CSMA/CA mechanism used in MAC layer and also fails to capture the link transmission rate as the fact that different links may have different transmission rates.

To overcome this shortcoming with the ETX the ETT routing metric was introduced. It takes the differences in link transmission rates and bandwidth of a link into consideration. It measures the expected MAC layer duration for a successful transmission of a packet on a given link. The weight of path is a summation of the ETT of all links on this path. Despite the apparent gains achieved by the ETT metric over the ETX, the ETT still fails to capture the interferences among different links as it is not designed for multiradio networks. The ETT also does not consider link load explicitly which leads to the failing of avoiding routing traffic through already heavily loaded links.

The WCETT routing metric introduces an improvement over ETT by taking into account the intra-flow interference. WCETT is designed to combine estimates of transmission time across links with channel information in wireless networks. It reduces the number of links on the same channel within the path of a flow. It captures the intra-flow interference of a path since it essentially gives low weights to paths that have more diverse channel assignments on their links and hence lower intra-flow interference but it does not consider the relative location of these links as it assumes all links of a route operate on the same channel interfere which can lead to non-optimal path selections.

The Metric of interference and channel switching (MIC) routing metric is designed to improve the WCETT by considering both intra-flow and inter-flow interference to support load balanced routing. The drawbacks of this approach are the overhead required to maintain update information of the ETT for each link can significantly affect the network performance depending on traffic loads, the metric assumes that all links located in the collision domain of a particular link contribute to same level of interference and counts the amount of interference on a link only by the position of interfering nodes no matter whether they are involved in any transmission simultaneously with that link or not, and the Channel Switching Cost (CSC) component captures intra-flow interference only in two consecutive links [8].

As the routing metric plays an important role in managing the formation, configuration, and maintenance of the topology of the network, there is a demand on developing a high throughput routing metric. In this work, we have developed an ad hoc routing protocol by introducing a cross-layer modification to the widely used DSR routing protocol. Our routing metric is concerned with finding optimal paths between the source and the destination nodes that can avoid the congested regions in the network. It focuses on multiple objectives to be optimized, such as path capacity (which refers to the number of bits per second (bps) that can be sent along the path between the source and the destination nodes) and end-to-end delay. In this modification, we include the local availability of the bandwidth at a node in addition to the hop-count metric to maximize the end-to-end throughput in WMNs and at the same time to control the end-to-end delay time. In this modification, we introduce the AEF metric which helps the routing protocol to determine the available bandwidth at the node in order to improve the network performance by avoiding routing traffic through the congested areas. Based on simulation tests, setting the hop-count limit to infinity will result in significant enhancement in the average global throughput of the networks. This improvement is associated with increment in the average global delay time of the networks. To overcome the drawback with this approach, the hop-count metric can be included in the routing selection mechanism. In addition to the AEF metric, the hop-count metric will allow the network administrator to control the global delay time of the network by setting the hop-count to an upper limit that satisfies the network requirements. However, adjusting the hop-count metric will affect the average global throughput of the network. In this work, we examine the average global throughput and the average global delay time of the network by including the AEF metric in the routing mechanism in addition to the hop-count metric.

The paper is structured as follows. Section II gives a brief description to the routing metrics in wireless networks. Section III contains an overview of Access Efficiency Factor (AEF). Section IV draws the configuration of the simulation. Section V presents the performance evaluation of our modified protocol. Section VI outlines the conclusion and the future work.

II. Wireless Networks Routing Metrics

Routing protocols provide one or more network paths over which packets can be routed to the destination. The routing protocol computes such paths to meet criteria such as minimum delay, maximum data rate, minimum path length etc. A routing metric that accurately captures quality of network links and thus aids in meeting such criteria is central to computation of good quality paths. One of the challenges in wireless mesh networks is the need for an efficient protocol that determines a path according to a certain performance metrics related to the link quality. Nodes communicate with one another by drawing together information on network topologies through reactive or proactive methods. Where WMNs are highly dynamic reactive methods have demonstrably achieved more in terms of high throughput and low overhead [11]. Two of the most frequently used reactive protocols, utilizing minimal hop-counts, are AODV and DSR.

Hop-count is the widely used routing metric for ad hoc networks. It reflects the effects of the path length on the performance of an end-to-end flow. The routing mechanism based on path weight equals to the total number of links through the path. The chief disadvantage of this routing protocol is that it does concede some important issues such as the interference in the network or the variations in link quality amongst different wireless links. However, a widely used hop-count protocol is the Dynamic Source Routing (DSR) protocol. DSR protocol operates on on-demand in order to minimise the overhead by reacting only when route discovery is necessary. The main feature of DSR routing protocol is the use of source routing. That is, the sender learns the complete hop-by-hop route to the destination. These routes are cached in a route cache. Routed packets contain the address of each node it will traverse in order to get its destination.

Routing over wireless mesh networks is a complicated problem due to the variations in the link qualities, even when nodes are static [12]. Many studies have been concerned about it. For example, Gupta et al announced that by not taking into account the interference produced in regions of the network when the routing algorithm selects paths leads to the noticeable reduction in the global throughput of the network [13]. 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 [12]. 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 [14]. A key challenge for mesh networks is the need for efficient routing protocol in order to meet the requirements of applications, especially when network density increases over time, and newer applications require higher throughputs. Employing certain features and characteristics of MAC and network layers can provide an efficient routing algorithm that finds routes with satisfactory throughput and delay.

In this work, we address the issue of cross-layer networking, where the MAC layer knowledge of the wireless medium is shared with higher layers in order to provide an efficient approach of allocating network resources. We propose a cross-layer modification to DSR which can select routes based on two criteria. First criteria is, find a path with the highest minimum Access Efficiency Factor in order to maximize the end-to-end throughput. Second criteria, limit the hop count to some maximum value that overcomes the shortcoming associated with AEF metric. The simulation experiments demonstrate the affectivity of our proposal.

III. ACCESS EFFICIENCY FACTOR

The AEF (η_f) is a measure of how efficiently a station contends for access to the wireless medium. It is based on the BW_{access} and BW_{load} parameters. BW_{load} represents the portion of the transmission rate required by the station for transmitting its load and can be defined as follows [15]:

$$BW_{load} = \frac{T_{load}}{T_{busy} + T_{idle}} \quad (1)$$

While BW_{access} represents the portion of the transmission rate required by the station to win access opportunities for its load and can be shown as follows:

$$BW_{access} = 1 - BW_{busy} \quad (2)$$

T_{busy} and T_{idle} are expressed as follows [15]:

$$T_{busy} = \sum_i T_{busy}^{(i)} \quad (3)$$

And

$$T_{idle} = \sum_i T_{idle}^{(i)} = 1 - T_{busy} \quad (4)$$

Where T_{busy}^{i} and T_{idle}^{i} are the durations of the i^{th} busy and idle intervals respectively within the measurement interval of interest. BW_{busy} can be defined as follows:

$$BW_{busy} = \frac{T_{busy}}{T_{busy} + T_{idle}} \quad (5)$$

The AEF is based on the Access Efficiency (η_a) parameter and is defined as [15]:

$$\eta_a = \frac{BW_{load}}{BW_{access}} \quad (6)$$

In calculating the capacity, at the saturation condition when all the free time is used to support the station's load:

$$BW_{load}^{(sat)} + BW_{access} = 1 \quad (7)$$

Substituting (6) in (7):

$$BW_{load}^{(sat)} + \frac{BW_{load}^{(sat)}}{\eta_a} = 1 \quad (8)$$

Equation (8) can be rewritten as follows:

$$BW_{load}^{(sat)}\left(\frac{\eta_a + 1}{\eta_a}\right) = 1 \quad (9)$$

By defining the AEF as:

$$\eta_f = \frac{\eta_a}{1 + \eta_a} \quad (10)$$

Equation (9) can be written as follows:

$$\eta_f = BW_{load}^{(sat)} \quad (11)$$

In the equation (11), η_f corresponds to the maximum load achieved by 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:

$$T_p \propto BW_{load}^{(sat)} \propto \eta_f \quad (12)$$

Where T_p is the station's throughput and $BW_{load}^{(sat)}$ is the saturated load of the station. Equation (12) states that the bigger η_f is the bigger saturated BW_{load} and hence the bigger the T_p.

IV. SIMULATION CONFIGURATION

We have investigated the performance of randomly generated WMN topologies using AEF in addition to the hop-count as routing metrics. The OPNET modeler is employed to simulate the performance of the modified DSR protocol for different network topologies. The node traffic was generated using a Poisson traffic source with rate of 5 packets per second. Packet lengths are set to 512 bytes.

In this work, the examination of the performance of the modified DSR applied for different network scenarios of different hop-count limit (hop-count = ∞, 7, 6, 5, and 4). Each scenario consists of 1000 randomly generated topologies comprising one gateway and 99 nodes scattered randomly across a 500m x 500m area. The transmission range of all nodes set to 50m. The simulator was run twice for each topology, once with the standard DSR followed by the modified DSR in order to compare the computed average global throughput and the average global delay time for the standard DSR and the modified DSR algorithms. The average throughput and the average delay time were recorded for each run over 10 minute intervals in order to calculate the percentage improvement for the particular topology. For each scenario the complementary cumulative distribution function (CCDF) of the throughput improvement and the delay increase for all network topologies examined have been calculated. The CCDF provides for a statistical characterisation of the improvement in the throughput and the increment in the delay produced by the modified DSR algorithm.

V. Performance Evaluation

We have modified the routing discovery mechanism of the DSR protocol by incorporating the local availability of the bandwidth, by finding the AEF, at the node in addition to the hop-count metric to achieve better results. Link cache data structures and new path selection are included in this modification to achieve better results. The link cache uses the highest minimum of the AEF in addition to the hop-count to find the best route in terms of end-to-end throughput and delay time.

The goal of this work is to analyze the performance of the modified DSR protocol against the standard DSR protocol for all examined scenarios. The hop-count limit is set to different value for each scenario. The idea behind using the hop-count metric in the routing discovery of the modified DSR protocol and setting it to different limit is to control the average global delay time of the network. The analysis focuses on the improvement in the average global throughput and concomitant increase in the average global delay was also analyzed.

Figures 1 and 2 are the CCDFs of the four scenarios, which represent the average global throughput improvement and the average global delay time increment of the modified DSR protocol against the standard DSR protocol with different hop-count limits.

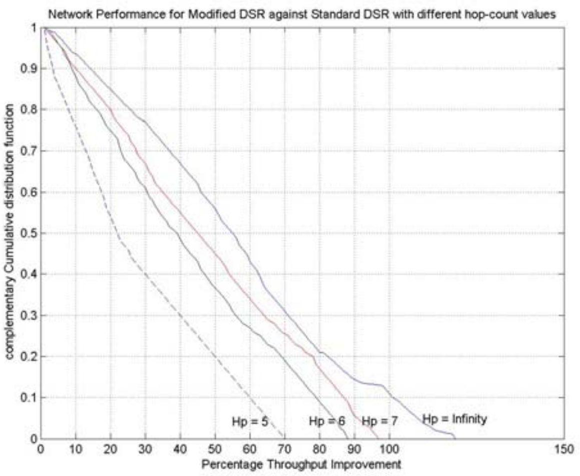

Figure 1. CCDF of the percentage throughput improvement for all examined scenarios of different Hc limits.

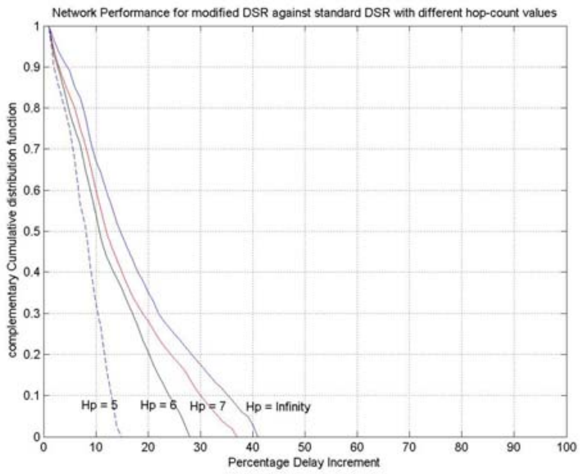

Figure 2. CCDF of the percentage delay increnent for all examined scenarios of different Hc limits.

Scenario 1 in Figure 1 represents the throughput improvement for the modified DSR protocol against the standard DSR when the hop-count limit is set to ∞. For this case, the routing mechanism determines the optimal path based on finding the path with the highest minimum AEF value which attempts to avoid routing through congested areas in the network. Avoiding a congested area will result in a significant improvement in the network performance. A major advantage of this approach 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 scenario, the fraction of stations that exhibit a percentage throughput improvement (P_T) greater than or equal to 30% and 50% are 77% and 56% respectively, see Table 1. The CCDF of the average global delay time for this scenario is showing in figure 2. We can see in this figure, the fraction of stations that exhibits a percentage delay increment (P_D) greater than 20%, 30%, and 40% are 35%, 18%, and 3% respectively, see Table 2. Examination of scenario 1 proved that there is a significant improvement in the global throughput of the network but that improvement in the throughput is associated with increasing in the global delay time.

Table 1. Percentage throughput improvement for all examined scenarios of different Hc limits.

Hop-Count (Hc)	*Improvement (P_T) ≥ 30%]*	*Improvement (P_T) ≥ 50%*
∞	77%	56%
7	67%	45%
6	61%	37%
5	40%	20%

Table 2. Percentage delay increment for all examined scenarios of different Hc limits.

Hop- Count (Hc)	***Increment (P_D) ≥ 20%***	***Increment (P_D) ≥ 30%***	***Increment (P_D) ≥ 40%***
∞	35%	18%	3%
7	28%	10%	0%
6	20%	0%	0%
5	0%	0%	0%

To control the increasing in the delay time we examine the modified DSR protocol with different hop-count limit (hop-count = 7, 6, 5). Scenario 2 in Figure 1 shows the throughput improvement and the delay increment of the modified DSR protocol against the standard DSR protocol when the hop-count limit set to 7. The strategy of the algorithm for this case is finding the optimal path with which the highest minimum access efficiency with the maximum hop-count limit is set to 7. In this scenario, a clear reduction in the global delay time of the network can be seen but that is associated with reduction in the global throughput, see Table 1. As we reduce the value of the hop-count limit to 6 and 5 and apply the same algorithm of the previous cases when the hop-count limit is set to ∞ or to 7, the global throughput improvement is reduced and the global delay time is also reduced, see scenarios 2, 3, and 4 in Figures 1 and 2 respectively.

Based on the above investigation, our modified DSR protocol allows the network administrator to tune the hop-count limit to a value that can satisfy the specific requirements of the network.

Limiting the hop-count metric to a specific value in our approach affects the percentage of the throughput and the delay time. As we can see, improving the global throughput of the network always associated with increasing in the global delay time and vise versa. Hence, when designing routing metrics, a trade-off must be found between these two trends.

VI. CONCLUSIONS AND FUTURE WORK

The DSR routing protocol has been modified in this work by incorporating the AEF metric in addition to the hop-count in the routing selection. The routing mechanism of our modified protocol operates by setting the hop-count limit to a value, which can be chosen according to the specific requirements of the network, and finds the route with the highest minimum AEF value. Experiments performed on OPNET modeler for different network scenarios show that setting the hop-count limit to infinity significantly improves the global throughput of the networks by determining the routes with high throughput. This is improvement is associated with an increase in the delay time of the network. Setting the hop-count to a limit such as 7, 6, and 5 reduces this increase in the delay time. This limitation performed on the hop-count significantly affects the throughput of the network. Using our modified DSR protocol will allow the network administrator to tune the hop-count limit to a value in order to meet the network requirements.

Our future work is to investigate the affect of the packet size on the performance of our modified DSR protocol. We also are planning to examine our modified DSR protocol with networks of different traffic rates.

REFERENCES

[1] [1] J. Jun and M. L. Sichitiu, “The nominal capacity of wireless mesh networks,” IEEE Wireless Commun- ications, Vol. 10, No. 5. (2003), pp. 8-14.

[2] [2] C. Perkins and E. Royer, “Ad Hoc On-Demand Distance Vector Routing,” in The 2nd IEEE Workshop on Mobile Computing Systems and Applications, Feb. 1999.

[3] [3] D. Johnson, D. Maltz, and J. Broch, “DSR: The Dynamic Source Routing Protocol for Multihop Wireless Ad Hoc Networks,” in Adhoc Networking, Charles E. Perkins, Ed. 2001, pp. 139–172, Addison-Wesley.

[4] [4] C. Perkins and P. Bhagwat, “Highly dynamic destination sequenced distance-vector routing (DSDV) for mobile computers”, in ACM SIGCOMM, 1994.

[5] [5] D.S.J. De Couto, D. Aguayo, J. Bicket, R. Morris, “A high-throughput path metric for multi-hop wireless routing,” in: ACM Annual International Conference on Mobile Computing and Networking (MOBICOM), 2003, pp. 134–146.

[6] [6] Y. Yang, J. Wang, and R. Kravets, “Interference-aware load balancing for multihop wireless networks” Technical Report UIUCDCS-R-2005-2526, 2005

[7] [7] R. Draves, J. Padhye, and B. Zill, “Routing in multi-radio, multi-hop wireless mesh networks,” in MobiCom ’04: Proceedings of the 10th annual international conference on Mobile computing and networking. New York, NY, USA: ACM Press, 2004, pp. 114–128.

[8] [8] Y. Yang, J. Wang, and R. Kravets, Designing routing metrics for mesh networks, in: IEEE Workshop on Wireless Mesh Networks, WiMesh, 2005.

[9] [9] L. T. Nguyen, R. Beuran†, Y. Shinoda, “A Load-aware Routing Metric for Wireless Mesh Networks,” IEEE Symposium on Computers and Communications, July, 2008 (ISCC 2008).

[10] [10] Hung Quoc Vo Young Yig Yoon Choong Seon Hong, “Multi-path routing protocol using cross-layer congestion-awareness in wireless mesh network,” Proceedings of the 2nd international conference on Ubiquitous information management and communication, Suwon, Korea Jan 31 - Feb 01, 2008

[11] B. Keegan, K. Kowalik, and M. Davis “Experimental measurement of overhead associated with active probing of wireless mesh networks” IEEE International Conference on Signal Processing and Communications (ICSPC 2007), Dubai, November 2007.

[12] D. De Couto, D. Aguayo, B. Chambers, and R. Morris, “Performance of multihop wireless networks: Shortest path is not enough,. Proc. ACM First Workshop on Hot Topics in Networks (HotNets-I), Princeton, New Jersey, USA, pp. 83.88, Oct. 2002.

[13] P. Gupta, P.R. Kumar, “The capacity of wireless networks,” IEEE Transactions on Information Theory 46 (2), 2000, pp. 388–404.

[14] L. Iannone, K. Kabassanow, S. Fdida, “Evaluation of cross-layer rateaware routing in a wireless mesh network test bed,” Eurasip journal on wireless communications and networking, vol 2007, Article Id 86510.

[15] M. Davis, “A Wireless Traffic Probe for Radio Resource Management and QoS Provisioning in IEEE 802.11 WLANs,” ACM Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM’04), Oct. 2004.