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Performance Analysis of Multipath Routing Schemes for MANETS

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Abstract: Ad hoc networks are distinguished by multi-hop wireless connectivity in a bandwidth constrained environment, highly dynamic network topology and the need for efficient dynamic routing protocols. The concept of Multipath routing represents a promising routing method for wireless Mobile Ad Hoc Networks (MANETs). The method achieves efficient load balancing and improved resilience against route failures. Recently, a number of different multipath routing schemes have been proposed for MANETs. Performance evaluations of these schemes showed that they achieve lower end-to-end delay, lower routing overhead and reduced congestion in comparison with single path routing schemes. In this work a detailed simulation study about performance evaluation and comparison of three multipath routing schemes (SMS, AOMDV and M-DART) with the Network Simulator-2 is conducted.

Keywords: MANETs, multipath routing, performance evaluation, performance metrics.

1. INTRODUCTION

A Mobile Ad Hoc Network (MANET) (Giordano, 2002) is a collection of a number of mobile nodes, with no fixed pre-established infrastructure, communicating through relatively bandwidth constrained wireless links. Researchers are designing new MANET routing protocols and comparing and improving existing MANET schemes before any schemes are standardized. The comparison is done mainly using simulations. A variety of routing schemes have been proposed and several of them have been extensively simulated and even implemented.

Some of the routing protocols for MANETs proposed in recent years include Shortest Multipath Source Routing (SMS) (Zafar *et al.,* 2009) which is an extension of the standard Dynamic Source Routing (DSR) protocol (Johnson *et al.,* 2007), and Ad hoc On demand Multipath Distance Vector (AOMDV) routing (Marina et at., 2001) which is an extension of the standard AODV (Perkins *et al.,* 2003) routing protocol. The results from the above protocols are also compared with a proactive protocol Multipath Dynamic Address Routing (M-DART) (Caleffi and Paura, 2010) which is a multipath extension of the Dynamic Address Routing (DART) (Jakob *et al.,* 2007) protocol.

This study provides a comparative evaluation of the above mentioned routing schemes. All the three protocols have been evaluated under situations with varying speed and the number of active sources. The metrics used for evaluation purpose include packet delivery fraction (Goodput), normalized routing load, End-to-End delay and Packet loss. Results of the study highlight the advantages and limitations of the multipath routing schemes.

2. MATERIALS AND METHODS

Wireless ad hoc networks have numerous constraints which make it very difficult to design or select a particular protocol for these networks. Two of the main constraints of wireless networks are limited bandwidth and unreliable wireless medium of transmission which results in an increased probability of packet loss, link breakage and also a higher end-to-end delay. The lately proposed solution to reduce the effect of these constraints, on the network performance, is called multipath routing. Multipath routing protocols propose establishment of multiple routes in a single route discovery process.

The availability of more than one path between a source-destination pair within a wireless network has numerous advantages. Besides the most obvious one, i.e. the rapid availability of an alternate route in case of link breakage or node failure along the route under use, the presence of multiple paths can be used for load balancing as well. This can be achieved by dividing the traffic and sending a portion along each route, hence using all the routes available at a time. The idea of availing all the paths at hand, leads to provision of a high aggregate bandwidth between the source-destination pair which in turn helps in achieving a lower end-to-end delay. Also, since traffic is divided among different paths, no particular node or link is responsible for conveyance of all the traffic from a given source node to a destination, thus allowing the energy resources of the available nodes to be used more evenly as compared to unipath routing where all the traffic is directed through a single route resulting in the rapid depletion of energy recourses of the nodes in the particular path. This decreases the rate of node failure in the overall network, hence increasing the

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reliability of the discovered routes. All these advantages along with some issues and applications of the idea of multipath routing are discussed in detail in (Mueller *et al.,* 2004).

Below section briefly explains the protocols that are the subject of the current study. A total of three routing protocols namely AOMDV, SMS and M-DART are selected for the purpose of evaluation. All of these are multipath extensions of some of the basic and most commonly used unipath ad hoc routing protocols. AOMDV and SMS are reactive multipath protocols. For the purpose of highlighting the advantages of reactive protocols for ad hoc network over their proactive counterparts, a proactive multipath protocol known as M-DART is also included in the comparison. A brief discussion about the operation of the selected protocols and how they vary from their origins now follows.

Ad hoc On Demand Multipath Distance Vector (AOMDV)

Ad hoc on demand multipath distance vector routing protocol (AOMDV) is a multipath extension of the well-known unipath routing protocol, AODV. As the name indicates, AOMDV is a reactive and multipath routing protocol, which means that a single route discovery process discovers multiple paths and is repeated only when required. AOMDV guarantees disjointedness and loop-freedom in the multiple paths calculated by it. The paths discovered by AOMDV are both node disjoint and link disjoint, but this applies only to the paths between a pair of nodes and not all the paths in the network.

According to (Perkins *et al.,* 2003) AOMDV has several characteristics that make it different than the other multipath routing protocol. First, it guarantees all the computed paths to be disjoint and this is established through distributed routing rather than source routing. The idea of including information about the last hop, on the path, in the control packets is employed to achieve disjointedness among the computed paths. Secondly, AOMDV does not use any special control packets like most of other ad hoc routing protocols and the multiple paths are computed through minimum additional overhead. This particular characteristic is established through the thorough use of the routing information that is already available to the nodes. AOMDV, like AODV, ensures loop-freedom in all the computed paths through the use of concept of advertised hop-count.

Shortest Multipath Source Routing (SMS)

As the name indicates, shortest multipath source routing protocol (SMS) is a source routing protocol. It is based on DSR protocol. SMS aims to discover multiple partially-disjoint paths between source destination pairs on demand.

Being a multipath routing protocol, SMS inherits the main advantages of multipath routing, i.e. reduced routing overhead and availability of alternate routes in case of link failures. The basic idea of SMS routing is to discover a number of partially disjoint paths, each with at least one node different from the others (Jayalakshmi and Rameshkumar, 2012). Specifications of the protocol are presented in (Zafar *et al.,* 2009) along with some performance evaluation results. According to the work done in the document, SMS achieves improved performance in terms of end-to-end delay, routing overhead and Fraction of delivered packets.

Multipath Dynamic Address Routing (M-DART)

Multipath Dynamic Address Routing (M-DART) protocol is a multipath extension of the Dynamic Address Routing protocol (DART) which by nature is a DHT (Distributed Hash Table) based proactive protocol. M-DART uses the idea of dynamic addressing. In dynamic addressing, the address of the node change with its changing position and hence every time a node changes its position, the whole network needs to be updated on the information about the topology change. A node in the network may be known by its location, but due to obvious reasons, the location of a node alone is not enough to identify it in a network, therefore the identity of the node is also used for this purpose. This gives rise to a need for mapping between the node identity and its location. For this purpose, the DHT is used. In addition to keeping the mapping details, the main feature of DHT is the hash function which serves the purpose of spreading the information about topology changes throughout the network.

As stated previously, M-DART is a multipath extension of DART. It follows the hop-by-hop routing method and is based on the distance vector routing concept. It has all the features of DART. The additional features of M-DART protocol include availability of multiple paths with a guarantee of considerably less or no increase in the routing overhead as compared with DART. It has two features that distinguish it from the rest of the multipath protocols. First, the M-DART protocol discovers all the possible paths between any source and destination pairs. Secondly, the multiple routes discovered by the protocol does not require any additional communication or coordination overhead (Caleffi and Paura, 2010).

3. RESULTS AND DISCUSSION

The performance evaluations of the selected protocols are performed on NS2 (NS-2, 2016). The simulations are carried out by varying mobility and network load, one at a time, and monitoring the model for packet delivery fraction, normalized routing load, average end-to-end delay and packet loss.

A number of simulations were carried out for each of the three protocols i.e. AOMDV, SMS and M-DART. For the varying-speed simulations, the number of sources were kept constant as 25. On the other hand, for the varying-load (number of sources) simulations, the speed of mobile nodes was kept constant at 20 m/s. **(Table 1)** summarizes the above mentioned as well other significant characteristics of the mobile model used in the simulations.

Table 1: Specifications of the network model.

Simulator used	Network Simulator 2(Version 2.34)
Studied protocols	SMS, AOMDV and M-DART
Node movement model	TwoRayGround
Simulation Area	700m x 500m
Simulation time	900 seconds
Node Speed	0,2,4,6,8,12,16,20 (m/s)
Pause time	30 sec
Packet sending rate	4 packets / sec
Traffic type	CBR
No. of Nodes	50
No. of Sources	15,20,25,30,35,40

Additional particulars include the transmission range of the nodes which was set as 250m and the nominal channel bandwidth, 2Mbps. It is important to mention here that all the specifications used for the simulations in this study are in conformation with (Broch *et al.,* 1998).

Varying maximum Speed

The three protocols (SMS, AOMDV and M-DART) were analyzed by comparing them in scenarios with different speed of mobile nodes i.e. 0, 2, 4, 8, 12, 16 and 20 m/s. For these simulations the number of active sources was kept constant at 25. The rest of the parameters were also kept constant with values shown in **(Table 1).** Each simulation was run at least 6 times (using a different seed), the average values being used for plotting the graphs.

Average Packet Delivery Fraction

(Fig. 1) shows the comparison of Packet delivery fraction for SMS, AOMDV and M-DART for different mobility speeds of the network nodes. According to the results, the average packet delivery fraction decrease with increase in the speed of mobile nodes for all the three protocols. This is true in general for most of the protocols used for wireless networks because an increase in the speed of nodes means rapid changes in topology, and hence increased number of route failures resulting in a decrease in the number of successfully delivered packets.

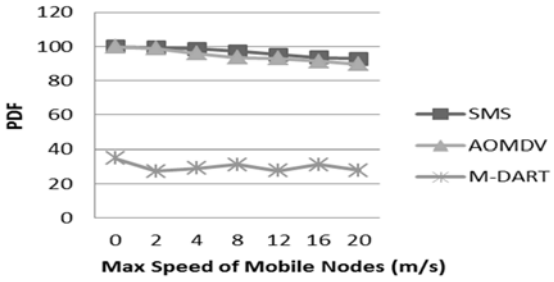


Fig. 1: Packet Delivery Fraction versus Max. Speed of Mobile Nodes

Normalized Routing Load

(Fig. 2) shows how normalized routing load varies with an increase in the speed of mobile nodes. According to the results, the normalized routing load increase with increasing speed of mobile nodes for all the three protocols that are studied. This behavior can be explained with the fact that higher speed of nodes in a network leads to rapid changes in topology. And rapidly changing topology leads to increased rate of link failures and higher rate of link failures lead to a higher rate of route maintenance and new route discovery processes initiated. Thus, increasing the overall routing load of the network.

The graph shows that routing load under M-DART is quite high as compared with those of SMS and AOMDV. It further shows that in case of SMS and AOMDV the routing load increase relatively smoothly

against the increasing node speeds as compared to M-DART where the routing load is highly non-uniform and also very high compared to the rest of the protocols. One reason for this behavior could be the proactive nature of M-DART protocol. Since in proactive routing protocols, the routing overhead is generally high as compared with reactive routing protocols. In addition to that, the performance of proactive routing protocols decline rapidly with increase in the topology changing rate of the network.

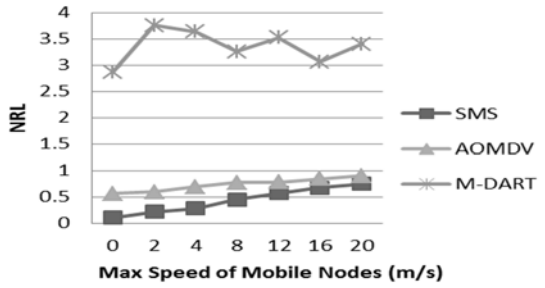


Fig. 2: Normalized Routing Load versus Max. Speed of Mobile Nodes

Overall result shows that SMS outperforms both AOMDV and M-DART in the given scenario with respect to normalized routing load at all the node speeds between 0 m/s and 20 m/s. It ensures lowest routing overheads at all the given speeds.

Average End- to- End Delay

(Fig. 3) shows the variation in the average end-to-end delay with changing speed of mobile nodes. As the graph shows, SMS and AOMDV shows an increase in the delay with the increasing speed while M-DART is exhibiting a considerable decrease for the same scenario. The behavior of SMS and AOMDV is expected because reactive routing protocols act on demand i.e. routes are discovered only when required and hence an increase in route failure rate due to increasing speed in case of such protocols leads to increased delay in the transmissions simply because of the additional time taken by the route discovery processes.

On the other hand, in case of M-DART the average end-to-end delay decreases as the speed of the nodes increase from zero to 20m/s. This shows that in proactive routing protocols the increase in the routing overhead for the same scenario pays off in the form of a decrease in the average delay in the network.

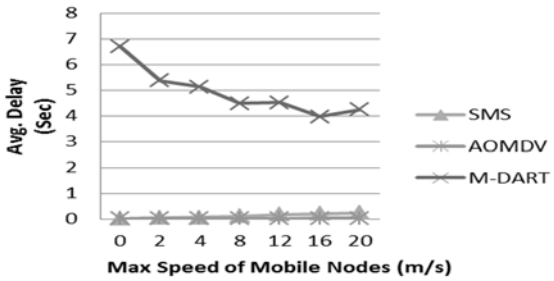


Fig. 3: Average End-to-End Delay versus Max. Speed of Mobile Nodes

The negative slope of M-DART might look preferable to those of SMS and AOMDV but as evident from the graph, the actual delay in case of M-DART is very high as compared to the rest of the protocols. Among the two reactive protocols, the performance of AOMDV is slightly better than that of SMS.

Average Packet Loss

Packet loss in a wireless network depends on a number of factors. Two of the most relevant reasons here are packets being dropped at the source due to unavailability of a route to the destination or if the buffer that holds pending packets is full. Packets may also be dropped at any intermediate host in case the link to the next hop has broken. As stated previously, high speed of nodes means high rate of link failures and hence a possibility of all of the above reasons of packet loss. **(Fig. 4)** shows an expected increase in the percentage of packet loss against increasing node speed for all the three protocols in question. It can be seen clearly in the graph that curves for all of the three protocols exhibit same behavior i.e. increasing packet loss with increasing speed of mobility. However looking at the actual values, one can conveniently say that SMS outperforms both AOMDV and M-DART in this case with a relatively smooth curve and very small percentage of packet loss.

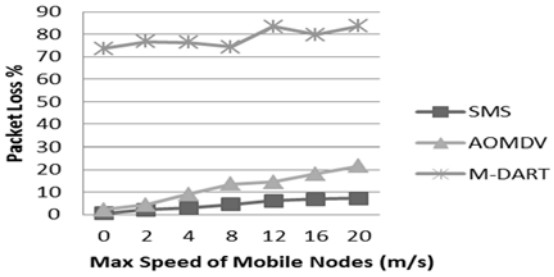


Fig. 4: Packet Loss versus Max. Speed of Mobile Nodes

Varying Number of Sources

The three multipath routing protocols (SMS, AOMDV and M-DART) were analyzed by comparing them in scenarios with different number of active mobile nodes (sources). For these simulations the maximum speed of the mobile nodes was kept constant at 20 m/s.

The rest of the parameters were also kept constant with values shown in **(Table 1)**. Each simulation was run at least 6 times (using a different seed), the average values being used for plotting the graphs.

Average Packet Delivery Fraction

(Ng and Liew, 2007) Provides a detail of the factors on which the throughput of wireless ad hoc networks depends. According to the study, generally the throughput of a wireless network decrease as the number of sources in the network increase. According to **(Fig. 5)**, the network in the current study performs likewise under all three of the routing protocols. An increase in the rate of packet delivery is experienced with an increase in the number of active sessions.

As the number of active sessions increase, the rate of route failure increase as a result of congestion caused by the increased traffic flow. This leads to a drop in the rate of successful delivery of packets to the destinations. **(Fig. 5)** shows that SMS performs best in the current scenario with the number of active sources increasing from 15 to 40. For the active sessions ranging between 15 and 30, SMS performs considerably better than AOMDV but as the number of active sources increase further, the performance of SMS and AOMDV becomes almost same.

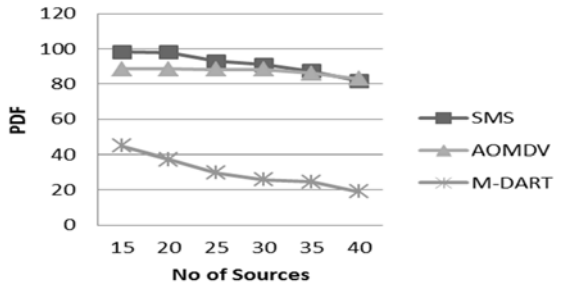


Fig. 5: Packet Delivery Fraction versus Number of Active nodes

M-DART also exhibits a negative slope like the reactive routing protocols but with comparatively very low values of PDF**.** One reason for this behavior could be the higher rate of congestion due to very high routing overhead in case of M-DART as compared to SMS and AOMDV.

Normalized Routing Load

Increased number of sources increases the probability of packet collisions and packet congestion increases, leading to an increase in normalized routing load **(Fig. 6).**

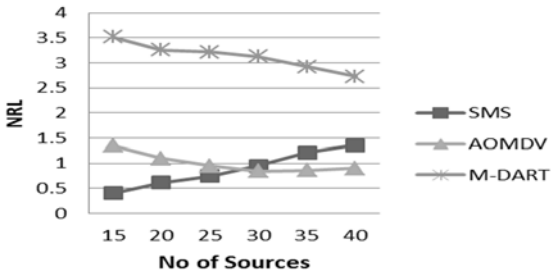


Fig. 6: Normalized Routing Load versus Number of Active nodes

Average End-to-End Delay

(Fig. 7) shows a plot of average end-to-end delay against increasing number of sources for the given protocols. The graph depicts an increase in the delay for all the three protocols as the number of active sources in the network is increased.

This behavior can be explained with the fact that as the number of packets for delivery increase, the average end to end delay increase due to increase in congestion and the data packets are queued in the buffers until they get served. Another reason could be the increase in the rate of route failure due to congestion. As an increase of the numbers of sources leads to higher network load traffic and consequently more routes will become invalid, further necessitating new requests. While these new requests propagate through the network in search for a new route, buffers become full and packets are then dropped.

The results in **(Fig. 7)** show that SMS and AOMDV performs equally well for number up to 20 active sources in the network. When the number of active traffic sessions becomes more than 20, AOMDV performs slightly better than SMS. On the other hand M-DART suffers a very high end to end delay in packet transmission, increasing further as the number of active sessions increase. The reason for this could be the proactive nature of M-DART. Proactive protocols suffer high routing overheads at high speed of mobile nodes and large number of transmissions. In the current scenario, besides the increasing number of active transmissions, the speed of mobile nodes is kept to be 20m/s which are quite high for an ad hoc network. Hence a highly congested network condition can be expected, leading to increased delay in transmission.

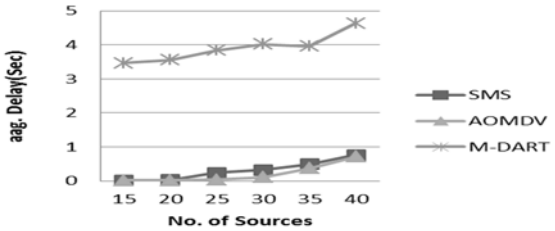


Fig.7: Average End-to-End Delay versus Number of Active nodes

Average Packet Loss

As stated previously, an increase of the numbers of sources leads to higher network load traffic and consequently more routes becoming invalid, further necessitating new requests. While these new requests propagate through the network in search for a new route, buffers become full and packets are then dropped, hence an increased packet loss rate. Hence it can be safely stated that **(Fig. 8)** depicts some expected curves for the given scenario.

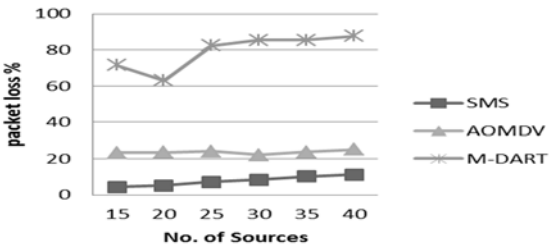


Fig. 8: Packet Loss versus Number of Active nodes

It is evident from the graph that SMS outperforms both AOMDV and M-DART in terms of packet loss when it comes to increasing number of active transmissions in a network. SMS exhibits very low values of packet loss and a smooth curve with small slope. The delay in case of AOMDV is slightly higher as compared to SMS but it is almost uniform throughout the range considered in the current study. Based on the plot, AOMDV can be expected to perform better than SMS if the number of active sessions is increased further. The curve in case of M-DART is comparatively non-uniform as compared to those from SMS and AOMDV. In addition M-DART suffers very high values of packet loss.

4. CONCLUSIONS

The paper evaluated some of the latest multipath routing protocols meant for use in MANETs. Each of the protocols was evaluated for four different performance metrics i.e. Packet delivery Fraction, Normalized Routing Load, Average End-to-End Delay and Packet Loss. All of the above mentioned parameters were evaluated under two different scenarios i.e. under increasing speed of mobile nodes in the network and increasing number of maximum connections in the network.

Result from the first scenario show that SMS performs better as compared to AOMDV and M-DART in terms of packet delivery fraction, normalized routing load and packet loss under the scenario with varying speeds of mobility. It delivers the highest packet delivery fraction, lowest normalized routing load and lowest percentage of packet loss in comparison with the other two protocols under the same scenario. However the average end-to-end delay of SMS is slightly higher in comparison with AOMDV. Hence AOMDV outperforms SMS and M-DART in terms of end-to- end delay in packet delivery and it keeps up with the performance as the mobility speed increase from 0 to 20 m/s.

The second scenario presents an increasing number of active mobile node transmissions in the network with the number increasing from 15 active transmissions to 40 transmissions throughout the simulation time of 900 sec. The results from this scenario show that SMS outperforms both AOMDV and M-DART in terms of packet delivery fraction and packet loss through the complete scenario while AOMDV exhibits lowest end-to-end delay, throughout the increase in the number of sources, outperforming both SMS and M-DART. The results further show that for the given scenario, SMS performs better than the other two protocols when the number of sources is less than 30, but as the number of sources goes above 30, SMS suffers a considerable increase in the normalized routing load. For number of active sources above 30, AOMDV provides the best performance in terms of NRL. The performance of M-DART was found unsatisfactory under both the considered scenarios.

As a direction for future work, the same routing schemes can be evaluated under different and more diverse scenarios. Also the same study can be extended to include other more recent multipath as well as unipath hybrid routing schemes for Ad hoc networks.

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