Performance Evaluation of Multi-path and Single-path Routing Protocols for Mobile Ad-Hoc Networks

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Keywords: Multi-path Routing, Single-path Routing, Dynamic Source Routing, Node Disjoint, MANETs

Abstract
There is an ambiguous opinion in the literature on whether multi-path routing offers significant merit in terms of a network’s performance. The one camp supports the belief that multi-path routing is indeed advantageous compared to single-path counterparts and the other contends that the improvement is not significant, if at all. For the performance evaluation of the two counterparts, Dynamic Source Routing (DSR) protocol, is compared against a modified version of DSR which exploits multiple node disjoint routes. The comparison of the two routing schemes, is carried out using the Network Simulator ns-2, and the comparison is performed for static and mobile scenarios. The performance is quantified and it is shown that the proposed routing scheme outperforms the unipath counterpart.

1. INTRODUCTION
Mobile ad-hoc networks (MANETs) are characterised by the lack of infrastructure and frequent topological changes. In such networks, when two peers seek to communicate with each other and are not within communication range, they enlist the aid of other hosts in forwarding packets to their destination. Routing protocols operating in an on-demand manner (reactive) are preferred over table driven (proactive) ones due to the increased overhead generated as the result of frequent topological changes. Various reactive routing protocols have been proposed in the research community such as Ad-Hoc on Demand Distance Vector (AODV) and Dynamic Source Routing (DSR). In such routing protocols, the nodes of the network cache routes and, when a node does not find a route to the desired destination, it initiates the route discovery mechanism to find paths to that destination.

The discovery can be logically separated into two main phases. In the first phase, flooding techniques propagate packets throughout the network and the destination node is reached. Once the destination receives the flooded packets, the second phase of the discovery starts. In this phase, the destination replies back to the initiator of the discovery, using the reverse path found in the received (flooded) request.

The most expensive part of the discovery procedure is the flooding of the network, whereas the second leg of the discovery is comparatively cheaper.

Single path routing protocols do not fully utilise the fact that the first phase of the discovery has already been performed and potentially more than one path can be discovered. The additional discovered paths can be used to distribute the load in the network and reduce congestion and the additional overhead introduced by the multipath routing protocol operation is compensated.

Previously, the authors have shown that a clear benefit exists in using multi-path routing schemes by contrast to single-path schemes; particularly when considering the network lifetime extension.

This paper proposes a modification to the DSR protocol called Multi-path Dynamic Source Routing with Node Disjoint Routes (MDSR-NDR) which exploits the node disjoint routes to reduced network congestion, end-to-end delay, routing overhead, despite the fact that traffic is routed to sub-optimal/longer paths.

The paper is organised as follows. Section 2 discusses existing work in the research community. Section 3 describes the proposed scheme in terms of the route discovery mechanism. Section 4 discusses how the routes are cached and how a path is selected for each packet. Section 5 presents the parameters used in the simulation model. Section 5.1 and 5.2 present and discuss the results for static and mobile scenarios respectively. More specifically, Section 5.2.1 presents the results for mobile scenarios with the mobile intensity varied by changing the maximum nodal speed, while in Section 5.2.2 the mobile intensity is varied by changing the percentage of mobile hosts. Finally, Sections 6 and 7 present future work and conclusions.

2. RELATED WORK
Nasipuri and Das propose and evaluate two DSR extensions which enable DSR to discover multiple routes and show the merits of multi-path routing in terms of the route discovery procedures initiated. No modification was made to the route request propagation, only to the route reply process. The destination node is reached by multiple route requests transversing through different sets of links. The destination

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node responds to multiple route requests which contain link disjoint routes. In such a way, the instigator of the route discovery is informed about the existence of multiple alternative routes. However, the additional routes are not exploited until a failure occurs, in which case the instigator switches all the traffic to the alternative backup path.

Lee and Gerla [6] proposed a protocol called Split Multi-path Routing which discovers maximally disjoint routes by modifying the route discovery procedure of DSR and the scheme uses per-packet allocation to distribute the load to the paths. The scheme incurs lower overheads than its unipath counterpart, but still there are higher than other multi-path schemes. Additionally, the per-packet allocation distributes the load to the multiple paths with equal probability which results in the shortest path and the sub-optimal maximally disjoint paths to be used equally.

Wang et al. propose the Multi-path Source Routing (MSR) [7, 8]. The protocol discovers multiple paths based on the Round-Trip-Time which is measured periodically using the SRPing [7] tool. Too frequent pings impose additional overhead, while infrequent pings may result in outdated route cost information.

The other camp in the research community contends that multi-path routing does not offer significant merit. Ganjali and Keshavarzian [9] suggest that, in order for multi-path routing to offer advantages over unipath counterparts, a huge number of paths must be discovered to improve load balancing. The following is claimed: if a small number of paths is considered, then the alternative paths tend to be physically close to the shortest path and since devices use a shared medium, congestion is not reduced. In order to make improvements routing paths must be such that they push the traffic further from the centre of the network. In addition, Pham and Perreau [10] support that multi-path routing incurs high overheads and careful consideration must be paid when designing multi-path routing protocols. When the protocol attempts to find more than three paths then the overhead is increased significantly. Additionally, these authors calculate the upper bound of the path length in order for multi-path routing to offer merit; such a bound depends upon traffic intensity.

3. ROUTE DISCOVERY PROCESS

3.1. Route Request Propagation

When any node in the ad-hoc network seeks to communicate with another, it searches its cache to find any known routes to the destination. In the event of finding no such routes, the node initiates a route discovery. The route discovery process involves the source node broadcasting a Route REQuEst (RREQ) packet, containing an ID which along with the source address uniquely identifies the current discovery. Upon the reception of a RREQ, each node inspects the packet and forwards it to its neighbours, as well as recording the ID of the RREQ in its database. The RREQ is suppressed if it has been processed previously in the same node [8]; this can be identified by the route request ID. The route propagation mechanism of the DSR protocol remains intact.

As illustrated in Figure 1, node M suppresses the RREQ packet received from node P because it has already processed an RREQ from node L containing the same request ID. Therefore, a RREQ containing node P in its path will never reach the destination node D.

![Figure 1. Route discovery mechanism of MDSR-NDR.](image)

3.2. Route Requests Reply

The proposed routing scheme, MDSR-NDR, modifies the route reply procedure of DSR in the following way. When the node receives the first RREQ, it generates a Route REPLY (RREPLY) which is destined to the initiator of the discovery using the reverse path found with in RREQ. In addition, the node records the reverse path within its internal cache. Upon receiving subsequent RREQs, the node only replies in the event of the reverse path of the request packet being node disjoint, the new path is also appended to the internal cache.

Figure 1 illustrates node D responding to the RREQ of the path A → B → C → D (path 1) immediately. The node also replies to subsequent RREQs which are node disjoint, i.e. A → E → F → G → H → I → D (path 2) and A → J → K → L → M → N → O → D (path 3). However, the RREQ received through the path A → J → K → L → M → N → O → Q → D is suppressed because it has not travelled through a node disjoint path compared with the routes already in the internal cache; it has a common node with path 3.

Finally, the above procedure is followed as long as the request ID remains less or equal to the one stored in the internal cache. If the request ID is increased, this indicates that a new discovery process has started and the information in the cache is outdated; then the node clears its cache.
4. ROUTE CACHE MAINTENANCE

Upon receiving the RREPLY the initiator caches up to 3 routes[10] pertaining to the same destination. In the event of the cache already containing 3 routes, the longest route is overwritten. When all the routes in the cache are marked as invalid, a new route discovery is performed with an increased request ID. Therefore, the number of route discoveries initiated by the traditional DSR protocol will be higher due to route discoveries being performed when the one and only path is marked invalid. On the other hand, MDSR-NDR maintains more than one path to each destination (if more exist) leading to less frequent initiation of route discoveries.

In this paper, a simple cost function is adopted whereby route cost is proportional to length.

\[ C_k = \text{length} \]

When a node seeks to send a packet across the network, the cache is searched and candidate paths are selected. A random selection is performed among the candidate paths according to the probabilities attached to them and the packet is sent through the selected path. The probability of a candidate route \( i \) is given by

\[ P_i = \frac{1}{n} \cdot \frac{1}{\sum_{k=1}^{n} C_k} \]

where \( n \) is the number of candidates.

This results in the longer paths being selected less frequently than shorter ones. However, the load is distributed over more than one path (see Figure 2).

5. EVALUATION PLATFORM

\( \text{Ns-2} \)[11] is used to model the proposed protocol which is compared to the traditional DSR implementation of CMU Monarch[12]. The experiments are conducted for 100 static nodes uniformly distributed in an area of 500x200 square metres; each node has range of 75 metres. The Lucent WaveLAN DSSS radio interface is used and the propagation model selected is the Two-Ray Ground with each node being at height of 1.5 metres. The mean duration of each connection is selected from a uniform distribution of 0-10 seconds. Each individual connection is represented by a Constant Bit Rate (CBR) source transmitting packets of 512 bytes each, at an appropriate rate with fixed inter-packet gaps. The simulation duration is set to 2000 seconds and the number of connections initiated within the simulated period is varied. The prefix \( \text{NCON} \) is used to indicate the number of connections in the graphs. The experiments are repeat for 10 different traffic patterns and topologies (or mobility scenarios). The first 200 seconds are excluded from the calculations of the performance metrics to allow the system to reach stability in terms of traffic load and average nodal speed[13][14]. The performance metrics displayed in the graphs are the mean values after 10 repetitions accompanied by the 95% confidence intervals. The confidence intervals are eliminated in graphs with multiple lines due to the limited space and in the interest of clarity and visibility.

5.1. Static Scenarios

In the first set of experiments the number of connections is set to 5000, giving an average of 26 active connections and the goodput (the ratio of packets received over total packets transmitted, also referred as packet delivery ratio) is shown in Figure 3. Initially, the goodput of DSR and MDSR-NDR is almost identical. As the rate of the connections increase to intermediate loads, the unipath counterpart suffers from congestion and, as a result, the successfully delivered traffic drops resulting in a drop in goodput. On the other hand, MDSR-NDR suffers lower congestion as a consequence of the distributed load. As the rate increases further, the performance improvement reduces because the overall network is saturated.

Figure 2. Typical load distribution for 3 cached paths of lengths 4, 8 and 10 respectively.

Figure 3. Goodput versus Packet Rate for 5000 connections.
The average end-to-end delay comparison (Figure 4), agrees with the goodput observations. Initially, the two contenders experience almost identical delay. However, as the load increases unopath protocol suffers from higher delay until it saturates. Any further increases in load contribute to network saturation and packets are simply discarded and delay remains constant. It should be noted that saturation in MDSR-NDR incurs lower absolute delay because MDSR-NDR distributes the load to multiple paths, while DSR uses a single path and increases the delay by unevenly loading the network.

This observation is verified by the normalised routing load. The normalised routing load is the ratio of routing packets injected to the network compared to the number of packets delivered successfully. Figure 5 shows the normalised routing load versus the rate. Initially, the routing load is high for both contenders, because the packets/second for each connection is low and both protocols go through the route discovery procedure to send only a few packets and then a new connection is initiated, resulting in low efficiency. However, MDSR-NDR imposes lower routing load because the multiple route reply packets send by the destination of the route discoveries are overheard by intermediate nodes which cache the paths. The cached paths are subsequently used and route discoveries are avoided. As the packet rate increases, both protocols improve in routing efficiency because the increase in load can be met with no increase in the route discovery overhead. Further increases in the network load result in an increase in routing overhead because the network enters saturation and the number of packets dropped increase, reducing the successfully delivered packets and consequently the ratio of routing packets over successfully delivered packets decreases (normalised routing load).

The final performance metric measured is the mean path length (Figure 6). MDSR-NDR has the higher mean path length as expected. Initially, the mean path length of MDSR-NDR is slightly higher than that of DSR; at low rates only a small number of packets are sent per connection and MDSR-NDR selects the shortest path with higher probability, resulting in almost identical behaviour to DSR. As the rate increases, more packets are routed per connection, and MDSR-NDR has a chance to exploit the additional available paths. Further increases in load reduce goodput (as previously explained) and packet drops are more likely to occur in longer
paths forcing the mean path length to drop.

The previous simulation experiments were repeated for a variable number of connections (2500, 3000, 4000) with the same simulation duration. The conclusions drawn from the effect of changing connections rather than just packet load are broadly as expected. Figures 7, 8, 9 and 10 show the goodput, average end-to-end delay, normalised routing load and mean path length versus rate respectively for MDSR-NDR only. For the same packet load it can be seen that, the goodput reduces as the number of connections increase while the reverse is the case for delay; the delay increases as the number of connections increase. The normalised routing load decreases because the number of route discoveries performed are reduced due to the reduced number of connections and the mean path length increases because network saturation occurs at higher rates.

5.2. Mobile Scenarios

Clearly, modelling mobile ad-hoc networks routing schemes in a static environment has limited value. The second part of the experimental work considers the case when nodes are now able to move. To maintain consistency, the number of nodes, transmission range and simulated area re-
main the same as in the static case (100 nodes, 75 metres and 500×200m²). However, nodes now have mobility capabilities following the modified random waypoint mobility model [15] with zero pause time. The experiments were performed for 2500, 3000, 4000 and 5000 connections and the duration of each connection is still selected from a uniform distribution of 0-10 seconds. Due to space limitations, only the results for 2500 connections are shown, but the results for the other values mirror the general behaviour. Finally, the experiments are conducted for 10 random mobile scenarios and traffic connection patterns. The confidence intervals are not shown in the graphs to increase clarity and visibility; the intervals are relatively small.

5.2.1. All hosts mobile with variable maximum speed
In the first experiment of this set, all the nodes of the network are mobile (RWP100). Nodes select their speed from a uniform distribution between \([1, V_s]\), where \(V_s\) is 5, 10 and 15 m/s (18, 36 and 54 km/h respectively). The resultant goodput versus load for MDSR-NDR and traditional DSR is presented in Figure 11. The prefix \(U\) (unipath) is used in the labels to signify DSR and \(M\) for MDSR-NDR. It is clear that MDSR-NDR performs better than its traditional counterpart for all speeds. It is also clear that, as the speed increases, the improvement is reduced. However, MDSR-NDR still outperforms DSR at low loads, while at high loads the two protocols converge due to network saturation.

As the load increases the performance improvement increases up until a point. At very high loads the improvement is reduced, because both protocols reach saturation. Another effect to note is that, for high loads, the end-to-end delay drops for both protocols. At high loads, congestion is increased and traffic propagated through long paths has a higher probability of being dropped. Since the average end-to-end delay is measured only for packets which are successfully delivered, this results in reduced end-to-end delay. However, beyond this point, the network is saturated and can be seen from the goodput graph Figure 11. The system behaviour at high loads differs between static and mobile scenarios. In static scenarios, the end-to-end delay is constant when the network reaches saturation; the increased delay is caused by network congestion of data packets. However, in the mobile scenarios, the increased time required for a packet to propagate causes routes to become invalid more rapidly as a result of mobility and subsequently packets are dropped.

![Figure 12. Average End-to-End Delay versus Packet Rate for 100% of mobile nodes for maximum speeds of 5, 10 and 15 m/s](image-url)

The saturation behaviour is also verified by the mean path length characteristics shown in Figure 13. At high loads, the mean path length of the successfully delivered traffic is between 1 and 2 hops. MDSR-NDR for maximum speed of 5 m/s (M-RWP100/5) can deliver successfully traffic through longer paths for low and intermediate loads compared to other mobile intensities; expected since the mobile intensity is the lowest shown. Additionally, DSR mean path length starts and remains lower for all mobile intensities throughout the rate range. This is because DSR does not exploit the route request propagation performed by discovering multiple paths but instead a single path is communicated back to the route discovery instigator and the path becomes rapidly invalid.

![Figure 13. Mean Path Length versus Rate](image-url)
On the other hand, MDSR-NDR replies to multiple route requests and multiple paths become known to the instigator of the route discovery. Subsequently, even if a path breaks, the source node may exploit the alternative paths.

Figure 13 shows the normalised routing load for both protocols and it can be seen that the overhead injected to the network compared to the successfully delivered traffic initially increases. Further increases result in saturation and the successfully delivered traffic is reduced resulting in lower normalised routing load. The increased normalised routing load signifies higher number of route discoveries which result in lower goodput. MDSR-NDR has higher goodput, lower numbers of discoveries resulting in significant improvement in terms of the routing efficiency.

5.2.2. Variable percentage of mobile hosts

In the final set of experiments, all the nodes select their speed uniformly from [1, 5 m/s]; the remaining parameters are as before. The parameter that varies is the number of hosts being mobile. The experiments are conducted for 100%, 75%, and 25% of nodes being mobile and marked in the graphs as RWP100, RWP75 and RWP25 respectively.

The goodput, end-to-end delay and normalised routing load performance comparison follows the same pattern with that observed when the mobile intensity was varied by changing the maximum speed. Figures 15, 16, and 17 show the goodput, end-to-end delay, normalised routing load and mean path length respectively.

As the mobility intensity increases, the goodputs of both MDSR-NDR and DSR decrease. For all mobility intensities and packet rates, the multi-path protocol outperforms its unpath counterpart. The end-to-end delay varies with mobility intensity in a similar pattern to the one observed when the mobile intensity was varied by changing the speed. Additionally, similar are the observation for the normalised routing load and mean path length. Low percentage of mobile hosts, give higher protocol efficiency (routing load is reduced) and higher mean path length as expected.

In all mobile scenarios, it is clear that lower mobility intensity provides higher network performance in terms of goodput and end-to-end delay, with higher protocol efficiency. The mean path length is not considered as a performance metric.
but instead it is discussed to validate and understand the obtained results.

![Figure 16. Average End-to-End Delay versus Packet Rate for speeds selected between [1-5m/s] of 25%, 50% and 75% of mobile nodes.](image1)

![Figure 17. Normalised Routing Load versus Packet Rate for speeds selected between [1-5m/s] of 25%, 50% and 75% of mobile nodes.](image2)

6. FUTURE WORK

The experimentation presented has indicated that MDSR-NDR is a potential candidate to offer improved routing performance. There is further work that could be done to quantify its benefits or improve performance.

A second policy for cache maintenance could be examined, where the nodes, initiate route discoveries when $k$ paths from the cache are marked as invalid (where $k$ is less than the maximum number of paths a node can store for one destination $k < M$).

Using this policy for $k$ being small, will initiate more discoveries, but has the advantage of always having valid routes at hand and hence distributing load to more paths and reducing congestion. On the other hand, too frequent discovery initiation (larger $k$) will result in the opposite effect, where the network will be congested due the RREQ propagation (flooding). Therefore, the optimum parameter $k$ needs to be evaluated.

Our previous work [4] proposes two novel routing algorithms requiring global knowledge of the network in order to operate. It has been shown that they operate efficiently compared to other multi-path routing algorithms. This paper implemented and verified that multi-path routing has merits over its single-path counterpart. This opens up the possibility of combining both approaches in order to create a novel protocol capable of providing both load and energy awareness.

7. CONCLUSION

The proposed node disjoint multi-path algorithm is intended to offer improved performance in terms of goodput and end-to-end delay and exploit diverse longer paths that are available. Additionally, it is shown through an extensive range of simulation that the proposed routing algorithm enables the reduction in the congestion that is created by single path routing protocols, since the load of the network is distributed into
more than one path. MDSR-NDR has a clear benefit over the traditional DSR. Its advantage is its simplicity over other multi-path routing schemes proposed in the literature.

This is perhaps at odds with the views expressed by [9], [10] where it is suggested that multi-path approaches have limited merit. Indeed in [10] the results presented show that any multi-path approach should limit the number of paths to choose from, to be less than 3 and the mean path length to be a critical parameter. The authors of [9] claim that a load distribution is not achievable, unless large number of paths are known to each destination and as [10] states, if more than 3 paths are discovered then the overhead increases dramatically and renders load balancing infeasible.

In this paper, we do not intend to balance the load in the network, instead to distribute it and exploit more diverse paths and hence reduce congestion. In our work, mean path length is not seen as the critical parameter; rather we concentrate upon goodput, end-to-end delay and routing efficiency. These metrics benefit from the lower routing overhead introduced by MDSR-NDR.

Finally, in order to make the protocol more aware of the load, the cost function must be modified to be dependant upon the load of each individual path. This can be achieved by introducing a more complicated signalling mechanism which optimises the queue occupancy in the intermediate nodes. However, careful consideration in keeping the balance between the additional overhead introduced by the signalling scheme and the actual benefits it offers.

REFERENCES


