A Quantitative Study of Multi-path Routing Protocols in Wireless Ad Hoc Networks

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Abstract. In wireless adhoc network single path routing does not provide load balancing and have some other problems also the solution to all this is Multi-path routing, which represents a promising routing method for wireless mobile ad hoc networks. It achieves load balancing and is more robust to route failures. Various multi-path routing protocols have been suggested for wireless mobile ad hoc networks and their performance evaluations showed that they achieve lower routing overhead, lower end-to-end delay and improved congestion control in comparison with single path routing protocols. However, a quantitative comparison of multi-path routing protocols has not yet been conducted. In this work, we discusses the results of a simulation study of three multi-path routing protocols (SMR, AOMDV and AODV Multipath). Their simulation shows that the in high mobility applications AOMDV protocol achieves best performance, while in low mobility and higher node density application AODV Multipath performs better. SMR works best in low node density networks, as density increases, the protocol's performance decreases.
Keywords :- Adhoc Networks , Routing , AODV,SMR,load Balancing .

Introduction : The wireless communication standards (IEEE 802.11) [1] in 1997 for Wireless Local Area Networks (WLANs) has open the opportunity for the communication of mobile nodes, the nodes are battery powered devices. 802.11 showed a revolutionary method of communication that outspreads the traditional wired Internet. Mobile devices nowadays are becoming smaller, lighter, cheaper and more powerful, fulfilling the increasing needs of users. Radio communication for wireless networks is also standardized and many problems have been solved, networking protocols for intercommunication are still in experimental state. The wide-spread organization of ad hoc networks strongly depends on the implementation of more robust and efficient networking protocols. Earlier this network was operated with single path routing protocols .Single path routing have several limitations for MANET. A more successful approach for MANETs are multi-path routing protocols. These protocols establishes multiple disjoint paths for data transmission from a source to a destination. And this technique lowers the risk of network failures and also support for network load balancing.

These effects are particularly interesting in networks with high node density (and the corresponding larger choice of disjoint paths) and high network load (due to the ability to load balance the traffic around congested networks). A comparison of multiple multi-path protocols is therefore particularly interesting in scenarios of highly congested and dense networks. In the present paper, we fill this gap by presenting an evaluation and comparison of three wireless ad hoc multipath routing protocols, namely SMR [2], and two modifications or extensions of AODV [3]: AOMDV [4] and AODV Multipath [5]. We will also discuss the protocol performance under a set of network properties including mobility, node density and data load. The discussion mainly focuses on the following metrics: data delivery ratio, routing overhead, end-to-end delay of data packets and load balancing. In addition, to compare multi-path with single path routing in, the AODV protocol is included as a reference single path routing protocol.

In this context, we are not targeting at achieving high performance values or proposing a new protocol that outperforms existing protocols. Furthermore, our study focuses on application scenarios applied in small mobile devices with limited power and memory resources such as handhelds or pocket PCs. Therefore, in our performance comparison study we have assumed a networking interface queue size of 64 packets. The impact of this paper is three-fold:

i) We show in the comparison that: AODV Multipath performs best in static networks with high node density and high load; AOMDV outperforms the other protocols in highly mobile networks; SMR offers best load balancing in low density, low load scenarios.

ii) We discusses that multi-path routing is only advantageous in networks of high node density or high network load. and

iii) We will also discuss that multi-path routing protocols create less overhead compared to single path routing protocols.

The remainder of this paper is organized as follows. In section 2 we present the routing protocols that are used in the performance evaluation. The methodology of the performance evaluation as well as the simulation environment are presented in section 3. The results of the quantitative comparison of multi-path routing protocols are discussed in section 4. Related work and concluding remarks are presented in sections 5 and 6, respectively.

2 Routing Protocols: Now we will consider multi-path routing protocols with the following fundamental properties:

(i) The routing protocol provides multiple, loop-free, and preferably node-disjoint paths to destinations.

(ii) The multiple paths are used simultaneously for data transport and

(iii) Multiple routes need to be known at the source. Multi-path routing protocols that have been proposed for mobile ad hoc networks and satisfy the above-mentioned requirements are:

a. SMR (Split Multi-path Routing) [2].

SMR is based on DSR [6]. The main role of this protocol is to discover maximally disjoint paths. The routes are discovered on demand in the same way as it is done with DSR. That is, the sender floods a Route Request (RREQ) message in the entire network. However, the main difference is that intermediate nodes do not reply even if they know a route to the destination. From the received RREQs, the destination then identifies multiple disjoint paths and sends a Route Replay (RREP) packet back to the source for each individual route. Original proposal of SMR, was configured to establish at maximum two link disjoint (SMR LINK) or at maximum two node disjoint (SMR NODE) paths between a source and a destination.

b. AOMDV (Ad hoc On demand Multi-path Distance Vector routing) [4].

AOMDV as the name suggest extends AODV to give information about multiple paths. In AOMDV each route request (RREQ) and respective route reply (RREP) defines an alternative path to the source or to the destination. These multiple paths are maintained in routing table as entries for each node. The routing table entries contain a list of next-hops along with corresponding hop count for each destination. To make sure that the paths are loop-free AOMDV introduces the advertised hop count value at node i for destination d. This value represents the maximum hop-count for destination d available at node i. Consequently, the alternate paths at node i for destination d are accepted only with lower hop count than the advertised hop count value. Node-disjointness is achieved by rejecting duplicate RREQ at intermediate nodes. In our discussion we have considered four alternative configurations of the AOMDV protocol depending upon the type (link or node disjoint) and the maximum number of multiple paths the protocol is configured to provide . These four configurations are

i. AOMDV LINK 2paths: Maximum two link-disjoint paths.
ii. AOMDV LINK 5paths: Maximum five link-disjoint paths.
iii. AOMDV NODE 2paths: Maximum two node-disjoint paths.
iv. AOMDV NODE 5paths: Maximum five node-disjoint paths.

To avoid the discovery of very long paths between each source-destination pair the hops difference between the shortest path and the alternative paths is set to five for all AOMDV protocol configurations.

c. AODV Multipath Algorithm (Ad hoc On-demand Distance Vector Multi-path Algorithm) [5]. AODV Multipath is an extension of the AODV protocol designed to find multiple node-disjoint paths. Intermediate nodes are forwarding RREQ packets towards the destination. Duplicate RREQ for the same source-destination pair are not discarded and recorded in the RREQ table. The destination accordingly replies to all route requests targeting at maximizing the number of calculated multiple paths. RREP packets are forwarded to the source via the inverse route traversed by the RREQ. To ensure node-disjointness, when intermediate nodes overhear broadcasting of a RREP message from neighbor nodes, they delete the corresponding entry of the transmitting node from their RREQ table. In AODV Multipath, node-disjoint paths are established during the forwarding of the route reply messages towards the source, while in AOMDV node-disjointness is achieved at the route request procedure.

d. AODV (Ad hoc On demand Distance Vector) [3]. This algorithm uses the AODV as a base protocol on demand single path routing protocol. AODV is used as a benchmark to reveal the strengths and the limitations of multi-path versus single path routing.

Now we will summarize all the routing multipath protocols we have discussed by listing the essential properties: –

SMR: The protocol's objective is to calculate link and node disjoint paths. The maximum number of paths is set to two. The source is aware of the complete path towards the destination.

AOMDV: The protocol calculates link and node disjoint paths. The maximum number of paths can be configured, as well as the hop difference between the shortest path and an alternative path can also be established.

AODV Multipath: The protocol establishes only node disjoint paths. There is no limitation on the maximum number of paths.

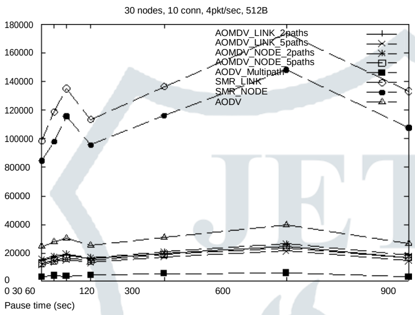
4 Simulation Results

In this section we will discuss the simulation results for the comparison of the multipath routing protocols. Also we will present a comparative study of the results with the results obtained with AODV to highlight the advantages of multi-path routing over single path routing. We summarize the main findings of the comparison at the end of this section.

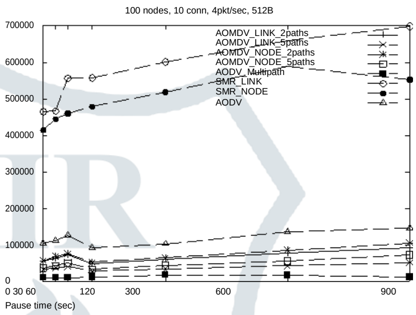
4.1 Routing Overhead

In general, SMR produces more control overhead as compared to the AODV-based multi-path routing protocols. This is because the SMR rebroadcasts the same RREQ packets it receives from multiple neighbors. In our further discussion, we will focus on routing overhead for each individual scenario.

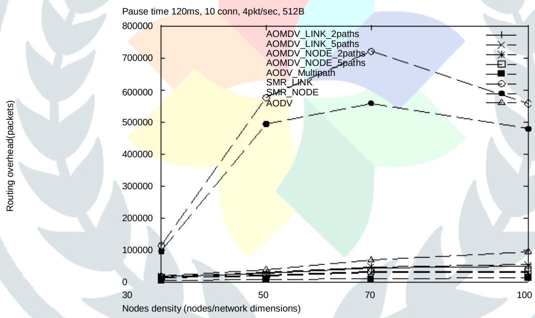
- **Low density, low load**: The routing overhead in networks with low node density and low traffic load is shown in figure 1(a). We can observe the higher overhead of SMR compared to the AODV-based routing protocols. Also, the improved version of SMR which computes link disjoint paths (SMR LINK) also produces more overhead than the variation which determines node disjoint paths (SMR NODE). The reason behind it is that the source waits until all existing paths break before sending a new route request, and the probability that two paths break is lower if they are node-disjoint than otherwise.



(a) Low density, low load



(b) High density, low load



(c) Varying density, low load

Fig. 1. Routing overhead

If we closely see the comparison among AODV, AOMDV, and AODV Multipath, we see that control overhead is same for all three protocols, except the overhead of AODV is slightly higher. Indeed, multi-path routing protocols require less control messages for routes to destination nodes that have been previously requested. Therefore, the saving in terms of overhead originates from connections with the same destination node.

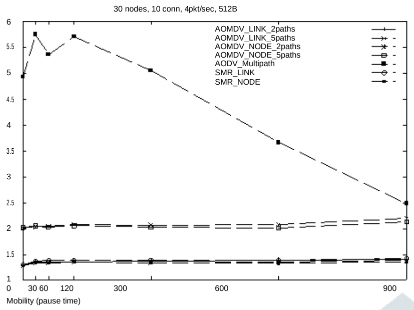
High density, low load: The graph in figure 1(b) depicts the routing overhead for a higher node density (100 nodes on a square of the same size as before). Also the number of control packets at each node is kept higher than 30 nodes, then also the trend remains the same.

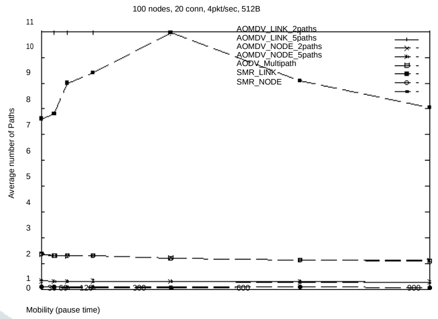
Varying density, low load: In this graph the effect of node density on the routing overhead in a scenario with moderate mobility is illustrated. The routing overhead increases slightly with increasing node density. However, the routing overhead of SMR starts decreasing with the increase in number of nodes more than 50. The simple reason behind it is the congestion of the network if the network have more than 50 nodes, the network becomes congested and it may drop many control packets. Later we will discuss that for such networks, the delivery ratio of data packets is below 10 %.

4.2 Average Number of Paths

To investigate the routing protocols ability to find multiple paths, in our study we checked for the average number of discovered routes by the protocol for each route request. The result is plotted for the low density and low load scenario in figure 2(a) and for the high density and high load scenario in figure 2(b). AODV Multipath is clearly the protocol which finds almost all possible paths. Though, any discovered paths are not useful when the nodes are in mobility. Another noticeable fact is that AOMDV and SMR generally find less number of paths than their upper limit. In our case AOMDV is configured to find a maximum of 5 paths (node-disjoint or link-disjoint) but it approximately looks for at most 2 paths. AOMDV and SMR when configured to find a maximum of 2 paths then it finds approximately on an average at most 1.4 paths.

Figure 2 : Average numbers of path





a. .Low density ,low load b. High density, high load

4.3 Data Packet Delivery Ratio

Now we will discuss the data packet delivery ratio

Low density, Low load: Multi-path routing does not improve the performance in networks having low traffic load as compared to single path routing in terms of successful packet delivery. The packet delivery ratio in this scenario is equal for AODV and all variants of AOMDV independent of the node mobility. Surprisingly, the performance of SMR and AODV Multipath is even worse compared to single path routing. AODV Multipath severely suffers from packet losses when the network becomes dynamic. This is mainly because the protocol finds much more paths than the other protocols (see figure 2(a)) .SMR overloads the network with control messages and data packets are dropped at full buffers of intermediate nodes. Even in the static case (900 seconds pause time), SMR and AODV Multipath have a packet delivery ratio which is approximately 10% below the ration of AODV.

High density, high load: For high density systems AODV Multipath and AOMDV performs better than AODV. Although the performance of AODV Multipath and AOMDV strongly depends on the node mobility in the network. When the network is static, AODV Multipath achieves the best performance (almost 80% delivery ratio). When the network is highly mobile (pause time less than 400 seconds), AOMDV has a higher delivery ratio. Similarly other factor like Average End-to-End Delay of Data Packets can also be taken into consideration

4.4 Discussion of the Results

Considering the performance evaluation of the three multi-path routing protocols, we find that

1. Multi-path routing achieves in general better performance than single path routing in dense networks and networks with high traffic load.
2. AOMDV achieves the best performance in scenarios with high node mobility.
3. AODV Multipath performs best in relatively static scenarios.
4. The performance of SMR is poor in dense networks and networks with high traffic load because of the immense control traffic generated.

5 Conclusions

The objective of the present paper is to provide a quantitative study of multi-path routing protocols for wireless ad hoc networks. At the same time, we examine and validate the advantages and the limitations of multipath versus single path routing in general. Our study shows that the AOMDV protocol is more robust and performs better in most of the simulated scenarios.

The AODV Multipath protocol performs best in low mobility and higher node density scenarios. SMR performs best in networks with low node density, however the immense routing overhead generated in high node density degrades protocol's performance.

In addition, we also discuss that establishment and maintenance of multiple routes result in protocol performance degradation. We found that the use of two or three, paths offers the best tradeoff between overhead and performance. Furthermore, protocols with high routing overhead perform badly since the routing messages fill the queues and generate data packet losses. If single path routing, is compared with multipath, the study validates better performance of multi-path routing, especially in networks with high node density. Despite the increased routing overhead per route, the total routing overhead is lower. The study concludes that multi-path routing in general, distributes the traffic over uncongested links and, as a consequence, the data packets experience smaller buffering delays.

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