Multi-path Routing Protocols in Wireless Mobile Ad Hoc Networks: A Quantitative Comparison

Georgios Parissidis, Vincent Lenders, Martin May, and Bernhard Plattner

Swiss Federal Institute of Technology
Communications Systems Group
Gloriastrasse 35, 8092 Zurich, Switzerland
{parissid, lenders, may, plattner}@tik.ee.ethz.ch

Abstract. Multi-path routing represents a promising routing method for wireless mobile ad hoc networks. Multi-path routing achieves load balancing and is more resilient to route failures. Recently, numerous multi-path routing protocols have been proposed for wireless mobile ad hoc networks. Performance evaluations of these protocols showed that they achieve lower routing overhead, lower end-to-end delay and alleviate congestion 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 present the results of a detailed simulation study of three multi-path routing protocols (SMR, AOMDV and AODV_Multipath) obtained with the ns-2 simulator. The simulation study shows that the AOMDV protocol achieves best performance in high mobility scenarios, while AODV_Multipath performs better in scenarios with low mobility and higher node density. SMR performs best in networks with low node density, however as density increases, the protocol's performance is degrading.

1 Introduction

The standardization of wireless communication (IEEE 802.11) [1] in 1997 for Wireless Local Area Networks (WLANs) offered the opportunity for inter communication of mobile, battery equipped devices and showed the way of a revolutionary method of communication that extends the well-established wired Internet. Nowadays, mobile devices are becoming smaller, lighter, cheaper and more powerful, addressing the augmenting needs of users. While radio communication for wireless networks is standardized and many problems have been resolved, networking protocols for intercommunication are still in experimental state. The successful and wide-spread deployment of ad hoc networks strongly depends on the implementation of robust and efficient network protocols.

Single path routing protocols have been heavily discussed and examined in the past. A more recent research topic for MANETs are multi-path routing protocols. Multi-path routing protocols establish multiple disjoint paths from a source to a destination and are thereby improving resilience to network failures

Y. Koucheryavy, J. Harju, and V.B. Iversen (Eds.): NEW2AN 2006, LNCS 4003, pp. 313–326, 2006.

and allow 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.

Up to now, no extensive simulations and quantitative comparison of multi-path routing protocols have been published. In the present paper, we fill this gap by presenting an evaluation and comparison of three wireless ad hoc multi-path routing protocols, namely SMR [2], and two modifications or extensions of AODV [3]: AOMDV [4] and AODV_Multipath[5]. With the help of the *ns-2* simulator, we examine the protocol performance under a set of network properties including mobility, node density and data load. The comparison focuses on the following metrics: data delivery ratio, routing overhead, end-to-end delay of data packets and load balancing. In addition, the AODV protocol is included as a reference single path routing protocol to compare multi-path with single path routing in general. In the context of the present work, we do not target 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 simulations we assumed a networking interface queue size of 64 packets.

The contribution of the present 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 demonstrate that multi-path routing is only advantageous in networks of high node density or high network load; and iii) we confirm 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

In this work, we 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:

1. *SMR* (Split Multi-path Routing) [2]
   SMR is based on DSR [6]. This protocol attempts 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. According to the original proposal of SMR, we configure our implementation to establish at maximum two link disjoint (SMR_LINK) or at maximum two node disjoint (SMR_NODE) paths between a source and a destination.
2. *AOMDV* (Ad hoc On demand Multi-path Distance Vector routing) [4]
   AOMDV extends AODV to provide multiple paths. In AOMDV each RREQ and respectively RREP defines an alternative path to the source or destination. Multiple paths are maintained in routing entries in each node. The routing entries contain a list of next-hops along with corresponding hop counts for each destination. To ensure loop-free paths 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, 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 suppressing duplicate RREQ at intermediate nodes.

   In our simulations we consider four *alternative* configurations of the AOMDV protocol depending on the type (link or node disjoint) and the maximum number of multiple paths the protocol is configured to provide:
   (a) *AOMDV_LINK_2paths*: Maximum two link-disjoint paths.
   (b) *AOMDV_LINK_5paths*: Maximum five link-disjoint paths.
   (c) *AOMDV_NODE_2paths*: Maximum two node-disjoint paths.
   (d) *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.
3. *AODV_Multipath* (Ad hoc On-demand Distance Vector Multi-path) [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.

4. *AODV* (Ad hoc On demand Distance Vector) [3]
   We use the AODV as a reference 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.

Summarizing the presentation of the routing protocols, we list the essential properties of the multi-path protocols:

– SMR: The protocol calculates 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 maximum number of paths can be configured, as well as the hop difference between the shortest path and an alternative path. The protocol calculates link and node disjoint paths.
– AODV_Multipath: The protocol establishes only node disjoint paths. There is no limitation on the maximum number of paths.

3 Methodology

We next describe the methodology we used to compare the different routing protocols.

Simulation environment: We use a detailed simulation model based on ns-2 [7]. The distributed coordination function (DCF) of IEEE 802.11 [1] for wireless LANs is used at the MAC layer. The radio model uses characteristics similar to Lucent's WaveLAN radio interface. The nominal bit-rate is set to 2 Mb/sec and the radio range is limited to 250 meters; we also apply an error-free wireless channel model.

Movement model: We use the random waypoint model [8] to model node movements. The random waypoint movement model is widely used in simulations in spite of its known limitations [9]. The simulation time is 900 seconds while the pause time varies from 0 seconds (continuous motion) to 900 seconds (no mobility) [0,30,60,120,300,600,900 seconds]. Nodes move with a speed, uniformly distributed in the range [0,10m/s].

Network size and communication model: We consider 4 network sizes with 30, 50, 70, and 100 nodes in a rectangular field of size 1000m x 300m. We vary the number of nodes to compare the protocol performance for low and high node density. Traffic patterns are determined by 10, respectively 20 CBR/UDP connections, with a sending rate of 4 packets per second between randomly chosen source-destination pairs. Connections begin at random times during the simulations. We use the identical traffic and mobility patterns for the different routing protocols. Simulation results are averaged values of 20 scenarios with different seed. Data packets have a fixed size of 512 bytes and the network interface queue size for routing and data packets is set to 64 packets for all scenarios.

Scheduling of data packets: A sender uses all available paths to a destination simultaneously. Data packets are sent over each individual path with equal probability. When one path breaks, the source stops using that path but does not directly initiates a new route request. Only when all available paths are broken a new route request is initiated.

Protocol implementation: The original source code of AOMDV [4] and AODV_Multipath [5] protocols in ns-2 is used in our performance evaluation. The implementation of SMR in ns-2 is adopted from [10]. For all protocols, we extend the implementation to use multiple paths simultaneously.

Metrics: We use the following five metrics to compare the performance of the multi-path routing protocols.

1. *Routing overhead.* The routing overhead is measured as the average number of control packets transmitted at each node during the simulation. Each hop is counted as one separate transmission.
2. *Average number of paths.* The average number of paths is the amount of paths that are discovered per route request.
3. *Data packet delivery ratio.* The data packet delivery ratio is the ratio of the total number of delivered data packets at the destination to the total number of data packets sent.
4. *Average end-to-end delay of data packets.* The average end-to-end delay is the transmission delay of data packets that are delivered successfully. This delay consists of propagation delays, queueing delays at interfaces, retransmission delays at the MAC layer, as well as buffering delays during route discovery. Note here, that, due to the priority queuing of routing messages, queueing delays for data traffic packets can be higher that the normal maximum queuing delay of a 64 packet queue.
5. *Load balancing.* Load balancing is the ability of a routing protocol to distribute traffic equally among the nodes. We capture this property by calculating the deviation from the optimal traffic distribution.

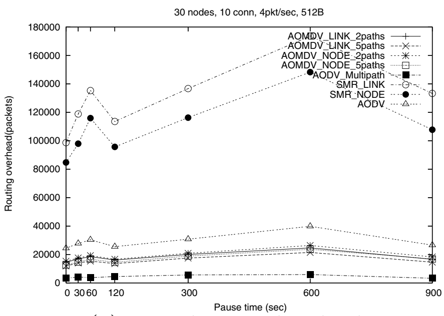
4 Simulation Results

We present in this section the simulation results for the comparison of the multipath routing protocols. In addition, we compare the results with the results obtained with AODV to emphasize the benefits of multi-path versus single path routing. The results are presented individually per routing metric. We summarize the main findings of the comparison at the end of this section.

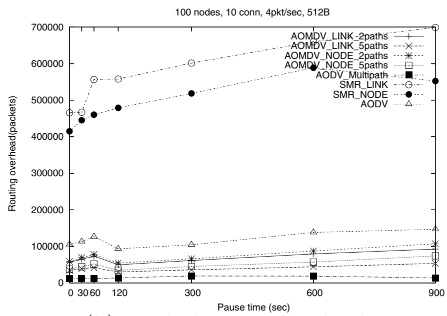
4.1 Routing Overhead

In general, SMR produces more control overhead than the AODV-based multipath routing protocols. This is caused by the fact that SMR rebroadcasts the same RREQ packets it receives from multiple neighbors. In the following, we discuss in detail the routing overhead for each individual scenario.

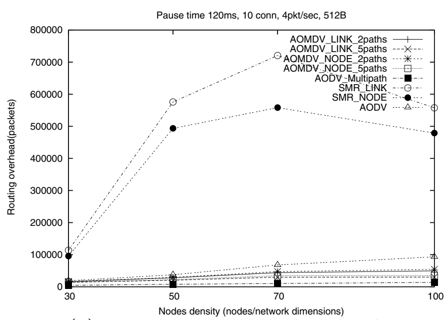
Low density, low load: The routing overhead in networks with low node density and low traffic load is shown in figure 1(a). We clearly observe the higher overhead of SMR compared to the AODV-based routing protocols. Interestingly, the version of SMR which computes link disjoint paths (SMR_LINK) produces more overhead than the variation which determines node disjoint paths (SMR_NODE). The reason 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

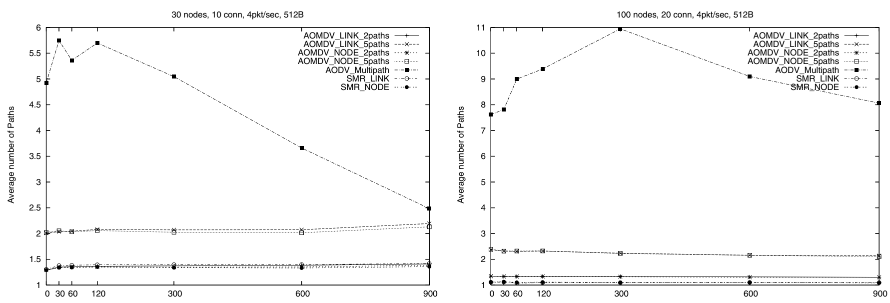
When comparing AODV, AOMDV, and AODV_Multipath, we see that all three protocols have a similar control overhead, only the overhead of AODV is slightly larger. Indeed, multi-path routing protocols require less control messages for routes to destination nodes that have been previously requested. Therefore, the saving in terms of overhead originates from connections with the same destination node.

High density, low load: In figure 1(b), we plot the routing overhead for a higher node density (100 nodes on a square of the same size as before). The absolute number of control packets at each node is higher than with 30 nodes. However, the trends remain the same.

Varying density, low load: The effect of node density on the routing overhead in a scenario with moderate mobility is illustrated in figure 1(c). The routing overhead augments slightly with increasing node density for the AODV-based protocols. However, the routing overhead of SMR starts to decrease when the number of nodes exceeds 50. The reason is that for more than 50 nodes, the network becomes congested and many control packets are dropped. We will see later that for such networks, the delivery ratio of data packets is below 10 %.

4.2 Average Number of Paths

We next look at the ability of the different routing protocols to find multiple paths. For this, we measured the average number of discovered routes per 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 the most paths. However, as we will see later when looking at the packet delivery ratio, many discovered paths are not usable when the nodes are very mobile. Note that AOMDV and SMR tend to find on average significantly less paths than their upper limit. AOMDV configured to find a maximum of 5 paths (node-disjoint or link-disjoint) finds approximately on average at most 2 paths. AOMDV and SMR when configured to find a maximum of 2 paths find approximately on average at most 1.4 paths.



(a) Low density, low load (b) High density, high load

Fig. 2. Average number of paths

4.3 Data Packet Delivery Ratio

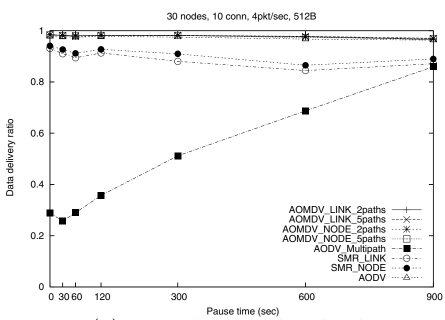
The data packet delivery ratio is now presented for the three different scenarios.

Low density, low load: As expected, in sparse networks with low traffic load, multi-path routing does not improve the performance compared to single path routing in terms of successful packet delivery. As we see in figure 3(a), the packet delivery ratio in this scenario is equal for AODV and all variants of AOMDV independent of the node mobility.

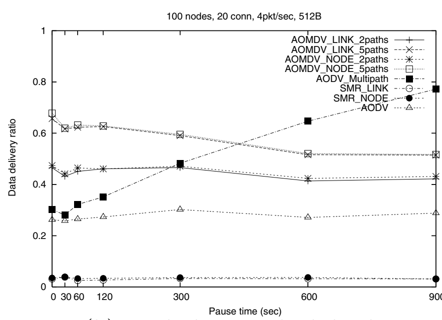
Surprisingly, the performance of SMR and AODV_Multipath is even worse compared to single path routing. AODV_Multipath severely suffers from packet losses when the network becomes dynamic. This is mainly because the protocol finds much more paths than the other protocols (see figure 2(a)) and a source tries to use all of them until *all* become stale. Detecting that a route is stale is time-consuming since with 802.11, a broken link is only detected by retransmitting a packet at the MAC layer multiple times without receiving an acknowledgement. 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: Figure 3(b) shows the benefits of multi-path routing versus single path for dense networks with high traffic load. In this case, both AODV_Multipath and AOMDV clearly outperform AODV. Comparing AODV_Multipath and AOMDV, the performance 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.

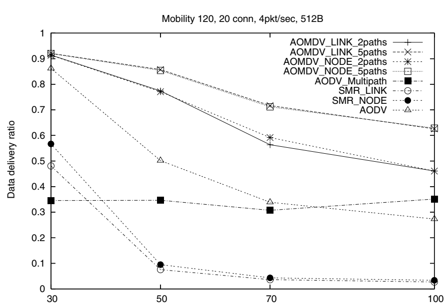
Apparently, SMR has a very poor performance in this scenario (below 5 % delivery ratio). This is easy to understand when we consider the routing overhead of SMR (see figure 1). SMR produces an extensive amount of control packets which overloads the network dramatically. The network is so congested that only routing packets are queued and most of the data packets are dropped.



(a) *Low density, low load*



(b) *High density, high load*



(c) *Varying density, high load*

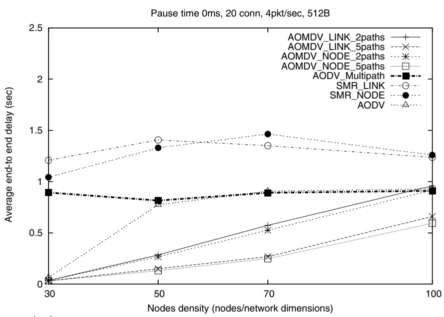
Fig. 3. Data packet delivery ratio

Varying density, high load: In figure 3(c), we also plot the packet delivery ratio versus the node density for a network with a large amount of traffic. We fixed the pause time to 120 seconds (moderate mobility) which is in favor of AOMDV as we have seen in the previous figure. By increasing the network density, we see that protocol's performance decreases except AODV_Multipath. We conclude that the performance of AOMDV_Multipath is independent of the network density when the amount of traffic is high.

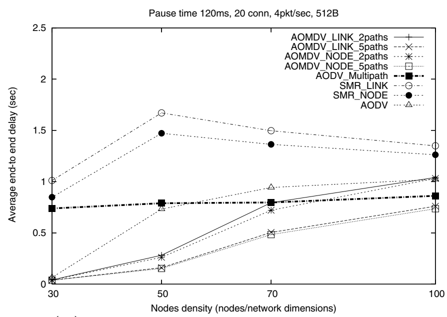
4.4 Average End-to-End Delay of Data Packets

We have just seen that multi-path routing outperforms single path routing in terms of delivered data packets when the traffic load in the network is high. We now compare the average end-to-end delay of the multi-path routing protocols in these scenarios. We differentiate between three cases: high node mobility with a pause time of 0 sec (see figure 4(a)), moderate node mobility with a pause time of 120 sec (figure 4(b)) and no node mobility (900 sec pause time, see figure 4(c)).

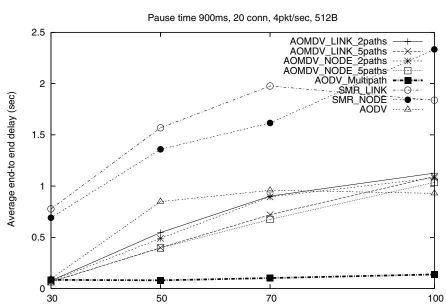
End-to-end delay for the SMR protocol is higher than all protocols. In low mobility and low node density scenarios end-to-end delay is approximately 650ms, while in higher mobility and node density the end-to-end delay augments to 1200ms. The high routing overhead of SMR penalizes data packets, therefore high buffering delays contribute to high end-to-end delay.



(a) *Case 3: High mobility, high load.*



(b) *Moderate mobility, high load.*



(c) *No mobility, high load.*

Fig. 4. End-to-end delay

AODV_Multipath is an exception as the protocol converges in low mobility scenarios (in bold in figures 4(a), 4(b), 4(c)). In high mobility, end-to-end delay is approximately 900 ms, while in moderate mobility and no mobility decreases to 750 ms and 200 ms respectively.

AOMDV achieves the smallest end-to-end delay compared to the other protocols, including the AODV, in high and moderate mobility. The average number of hops a data packet travels with multi-path routing is higher than with single path routing. Data packets are equally distributed among all available paths independent of hops difference between the shortest and an alternative path towards the same destination. However, in a congested network, multi-path routing AOMDV manages to distribute the traffic on less congested links and data packets experience smaller buffering delay on intermediate nodes.

AOMDV_LINK_5paths and AOMDV_NODE_5paths, achieve in general lower end-to-end delay than AOMDV_LINK_2paths, AOMDV_NODE_2paths, AODV, AODV_Multipath and SMR with regard to node density and mobility. Taking into consideration figure 2(b) that presents the average number of paths that are available at each sender for high node density and data load versus mobility we observe that multi-path routing is beneficial if the number of multiple paths is between 2 and 3. The high number of multiple routes that AODV_Multipath calculates is not awarded with better performance as many paths break with higher probability. Therefore multi-path routing becomes beneficial if it provides one or two additional link or node disjoint paths.

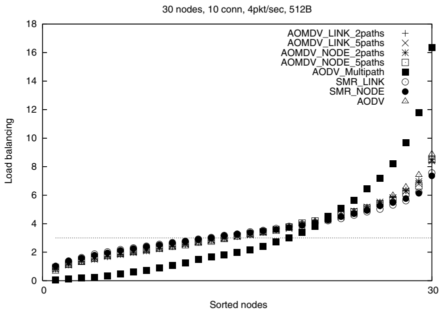
4.5 Load Balancing

Load balancing is the ability of a routing protocol to equally distribute the traffic among all nodes. Load balancing is for example useful to maximize the network lifetime when the networked devices are battery-powered. It is also helpful to distribute the traffic equally to avoid single bottlenecks in the network where most traffic is passing trough. We first look at load balancing in sparse networks with low load and then consider networks with increased node density.

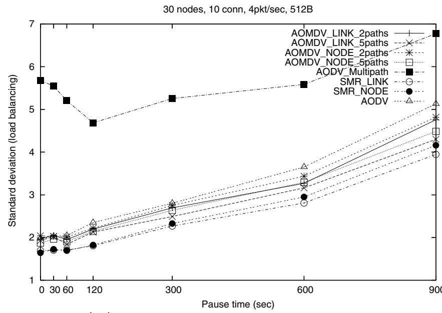
Low density, low load: In figure 5(a) load balancing with low node density, low data load, and moderate mobility (120s pause time) is presented. We sorted the nodes according to the number of data packets they forwarded on the x-axis and plot the percentage of data packets each node has forwarded on the y-axis. Since there are 30 nodes in the network, an optimal load balancing would result in 3.33 %. We see that SMR and AOMDV achieve a better distribution of the traffic between the different nodes.

We also plot the results in the low density and low data load case for different pause times in figure 5(b). Instead of plotting the percentage of forwarded packet, we plot the standard deviation from the average value. Thus, a value of 0 results in optimal load balancing. SMR and AOMDV have lower standard deviation than AODV_Multipath independent of node mobility. Furthermore, increased mobility result in better load balancing of the data traffic among the nodes. However, this result is intuitive as mobility favors data traffic dispersion.

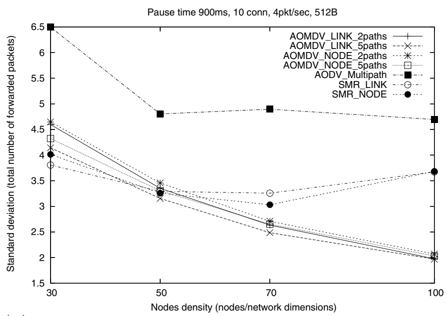
Varying density, low load: To circumvent the effect of mobility, we illustrate the standard deviation of the total forwarded data packets from the optimum value in static scenarios versus node density in figure 5(c). AOMDV and SMR disseminate data across all nodes better than AODV_Multipath.



(a) *Low density, low load, 120 s pause time.*



(b) *Low density, low load.*



(c) *Varying density, low load, 900 s pause time.*

Fig. 5. Load balancing

4.6 Discussion of the Results

In Table 1, we summarize the performance of each multi-path routing protocol for the different metrics. We differentiate three network regimes: (a) low density and low load, (b) high density, high load and low mobility, and (c) high density, high load, and high mobility. Recapitulating 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.

Table 1. Comparison of multi-path routing protocols. (++: very good, +: good, 0: neutral, -:poor). (a) Low density, low load, (b) High density, high load, low mobility (c) High density, high load, high mobility. (AODV_M corresponds to AODV_Multipath.)

	(a)			(b)			(c)		
	AOMDV	AODV_M	SMR	AOMDV	AODV_M	SMR	AOMDV	AODV_M	SMR
Routing overhead	++	++	0	+	++	-	+	+	-
Packet delivery ratio	++	0	+	+	+	-	++	0	-
Average e2e delay	+	+	+	+	++	0	+	+	+
Load balancing	+	0	++	+	+	+	+	0	0

5 Related Work

Multi-path routing is not a new concept and has already been proposed and implemented in packet and circuit switched networks. In circuit switched telephone networks, alternate path routing was proposed in order to increase network utilization as well as to reduce the call blocking probability. In data networks, the Private Network-to-Network Interface (PNNI) signalling protocol [11] was proposed for ATM networks. With PNNI, alternate paths are used when the optimal path is over-utilized or has failed. In the Internet, multi-path routing is included in the widely used interior gateway routing protocol OSPF [12]. Multi-path routing alleviates congestion by re-routing data traffic from highly utilized to less utilized links through load balancing. The wide deployment of multi-path routing is so far prevented due to the higher complexity and the additional cost for storing extra routes in routers.

However, wireless ad hoc networks consist of many features that differentiate them from conventional wired networks. The non-employment of multi-path routing in the standardized routing protocols used in the Internet today does not imply that multi-path routing is not an appropriate and promising solution for wireless mobile ad hoc networks. The unreliability of the wireless medium and the dynamic topology due to nodes mobility or failure result to frequent path breaks, network partitioning, and high delays for path re-establishments.

The above-mentioned characteristics of mobile ad hoc networks constitute multi-path routing a very promising alternative to single path routing as it provides higher resilience to path breaks especially when paths are node disjoint [13], [14], alleviates network congestion through load balancing [15] and reduces end-to-end delay [16], [17].

In [18] the effect of the number of multiple paths on routing performance has been studied using an analytical model. The results show that multi-path routing performs better than single path if the number of alternative paths is limited to a small number of paths. Simulation results of demonstrated that with multi-path routing end-to-end delay is higher since alternate paths tend to be longer. However, a radio link layer model is not included in the simulations, thus multiple interference is not captured.

Most of the multi-path routing protocols are implemented as extensions or modifications of existing single path routing protocols like the proactive DSDV [19] and OLSR [20], or the reactive on demand protocols: AODV [3] or DSR [6]. Analysis and comparison of single path and multi-path routing protocols in ad hoc networks has been conducted in [21]. There, protocol performance is examined with regard to protocol overhead, traffic distribution, and throughput. The results reveal that multi-path routing achieves higher throughput and increases network capacity. As the dimensions of mobile ad hoc networks are spatially bounded, network congestion is inherently encountered in the center of the network since shortest paths mostly traverse the center of the network. Thus, in order to route data packets over non-congested links and maximize overall network throughput, a protocol should target at utilizing the maximum available capacity of the calculated multiple routes. The authors concluded that routing or transport protocols in ad hoc networks should provide appropriate mechanisms to push the traffic further from the center of the network to less congested links.

6 Conclusions

The objective of the present paper is to provide a quantitative comparison of multi-path routing protocols for mobile wireless ad hoc networks. At the same time, we examine and validate the advantages and the limitations of multi-path 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 achieves best performance in scenarios with low mobility and higher node density. 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 demonstrate that the establishment and maintenance of multiple routes result in protocol performance degradation. We found that the use of two, maximum 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.

Compared to single path routing, our results validate the 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. Furthermore, even when multiple disjoint paths are longer than the shortest path, the overall average end-to-end delay is smaller, particularly in high density scenarios. We conclude that multi-path routing in general, distributes the traffic over uncongested links and, as a consequence, the data packets experience smaller buffering delays.

References

1. IEEE: Ieee 802.11. IEEE Standards for Information Technology (1999)
2. Lee, S., Gerla, M.: Split multipath routing with maximally disjoint paths in ad hoc networks. Proceedings of the IEEE ICC (2001) 3201–3205

3. Perkins, C.E., Belding-Royer, E.M., Das, S.: Ad hoc on-demand distance vector (aodv) routing. RFC 3561 (2003)
4. Marina, M., Das, S.: On-demand multipath distance vector routing in ad hoc networks. Proceedings of the International Conference for Network Procotols (ICNP) (2001)
5. Ye, Z., Krishnamurthy, Tripathi, S.: A framework for reliable routing in mobile ad hoc networks. IEEE INFOCOM (2003)
6. D., J., D, M.: Dynamic source routing in ad hoc wireless networks. Mobile Computing (ed. T. Imielinski and H. Korth), Kluwer Academic Publishers. Dordrecht, The Netherlands. (1996)
7. ns 2: Network Simulator: (http://www.isi.edu/nsnam/ns/.)
8. Broch, J., Maltza, D.A., Johnson, D.B., Hu, Y.C., Jetcheva, J.: A performance comparison of multi-hop wireless ad hoc network routing protocols. Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking. Dallas, Texas, United States. (1998) 85–97
9. Bettstetter, C., Resta, G., Santi, P.: The node distribution of the random waypoint mobility model for wireless ad hoc networks. IEEE Transactions on Mobile Computing **2**(3) (2003) 257–269
10. Wei, W., Zakhor, A.: Robust multipath source routing protocol (rmpsr) for video communication over wireless ad hoc networks. ICME (2004)
11. Forum, A.: Private network-to-network interface specification version 1.0. http://www.atmforum.com/standards/approved#uni (1996)
12. version 2, O.S.P.F.O.: (Rfc 2328)
13. Tsirigos, A., Haas, Z.: Multipath routing in the presence of frequent topological changes. IEEE Communications Magazine **39** (2001)
14. Valera, A., Seah, W.K.G., Rao, S.V.: Cooperative packet caching and shortest multipath routing in mobile ad hoc networks. IEEE INFOCOM (2003)
15. Ganjali, Y., Keshavarzian, A.: Load balancing in ad hoc networks: Single-path routing vs. multi-path routing. IEEE INFOCOM (2004)
16. Wang, L., Shu, Y., Dong, M., Zhang, L., Yang, O.: Adaptive multipath source routing in ad hoc networks. IEEE ICC **3** (2001) 867–871
17. Pearlman, M.R., Haas, Z.J., Sholander, P., Tabrizi, S.S.: On the impact of alternate path routing for load balancing in mobile ad hoc networks. Proceedings of the 1st ACM international symposium on Mobile ad hoc networking & computing. MobiHoc (2000)
18. Nasipuri, A., Castaneda, R., Das, S.R.: Performance of multipath routing for on-demand protocols in mobile ad hoc networks. Mob. Netw. Appl. **6**(4) (2001) 339–349
19. Perkins, C., Bhagwat, P.: Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. In: ACM SIGCOMM'94 Conference on Communications Architectures, Protocols and Applications. (1994) 234–244
20. Jacquet, P., Muhlethaler, P., Qayyum, A.: Optimized link state routing protocol. Internet draft, draft-ietf-manet-olsr-00.txt (1998)
21. Pham, P., Perreau, S.: Performance analysis of reactive shortest path and multipath routing mechanism with load balance. INFOCOM, San Francisco, CA, USA (2003)