Analysis QOS Parameters for Single Path and Multipath Routing Protocols of MANETs

S. R. Biradar[1], Sawal Kishore Singh[2], Subir Kumar Sarkar[3],

[1] *MITS, Lakshmangrah - 332311*
[2] *National Institute of Technology, Patna-800005*
[3] *Jadavpur University, Kolkata-700032*

[1] srbiradar@gmail.com

Abstract— In this paper we compared single path and multipath routing protocols over mobile ad hoc wireless networks using ns-2 simulator. Simulation results are presented by varying number of source, pause time and node mobility.

Keywords— AODV, AOMDV, Routing, ns-2, Simulation

I. Introduction

Multipath routing protocols for MANETs main objectives are to provide reliable communication and to ensure load balancing as well as to improve quality of service (QoS) of MANETs. The main objectives of MANET are providing a solution to the user connected anytime, anywhere to a network. This kind of network is spontaneous, self-organized and self-maintained. The primary challenge of routing in such an environment is to cope with node mobility, which leads to frequently changing network topology. Several routing protocols [1, 2, 3, 4] have been proposed in the literature for ad hoc networks. Most of these protocols assume cooperative network settings, where nodes are willing to receive, and transmit packets. The key idea behind all these protocols is to establish and maintain loop-free paths to respective destinations while achieving a good balance among important performance metrics.

Multipath routing protocols establish multiple routes from source to destination. The main advantage of discovering multiple paths is that the bandwidth between links is used more effectively with greater delivery reliability. It also helps during times of the network congestion. Multiple paths are generated on demand or by using a proactive approach and are of great significance because routes generally get disconnected quickly due to node mobility. The main objectives of multipath routing protocols are to provide reliable communication and to ensure load balancing as well as to improve quality of service (QoS) of ad hoc and mobile networks. Other goals of multipath routing protocols are to improve delay, to reduce overhead and to maximize network life time. The many multipath routing protocols were proposed for MANETs [5]. They can be classified according to different criteria. Based on the number of paths that are discovered from a route request, the routing protocols are divided into single path [2, 5] and multipath [7, 8]. On-demand multipath routing protocols [6, 12] establish multiple paths to a given destination in a single-route discovery phase. Multiple paths to a destination provide better fault-tolerance to path breaks. In the case of on-demand multipath protocols a new route discovery (which typically requires a network-wide flooding of a route request message) is necessary only when all paths to a given destination break. Thus, they provide an (overhead) efficient means to recover from routing failure compared to single-path on-demand routing protocols.

Another feature of the routing protocols is the number of the discovered paths that are actually used for sending data. Some protocols use only a single path for the communication, while others distribute the data through different channels. The ad hoc network is more prone to both link and node failures due to expired node power or node mobility. As a result, the route used for routing might break down for different reasons. To increase the routing resilience against link and node failures, one solution is to route a message via multiple disjoint paths simultaneously. Thus, the destination node is still able to receive the message even if there is only one routing path exist. The multipath approach takes advantage from the large and dense networks. The route discovery process in the multipath protocols may be initiated either when the active path collapses or when all known paths towards the destination are broken [9]. The route discovery may stop when a sufficient number of paths are discovered or when all possible paths are detected. Multipath routing protocols can be node-disjoint [10] or link-disjoint [11] if a node (or a link) cannot participate in more than one path between two end nodes.

Multiple paths can be used as backup route or be employed simultaneously for parallel data transmission. The multiple paths obtained can be grouped into three categories:

Disjoint: This group can be classified into node-disjoint and link-disjoint. In the node-disjoint multipath type, there are no shared nodes between the calculated paths that links source and destination. The link-disjoint multipath type may share some nodes, but all the links are different.

Inter-twisted: The inter-twisted multipath type may share one or more route links.

Hybrid paths: The combination of previous two kinds.

Many disjoint multipath routing techniques [13, 14, 15, 16, 17, 18, 19, 20] have been proposed for ad hoc networks, which have focused on improving the reliability of routing using path disjointness. In [13] proposed a node-disjoint multipath routing protocol for traffic load-balancing. They introduce a correlation factor for a set of multiple paths between source and destination, which measures the disjointness of paths in the set. The routing algorithm selects the set of multiple paths with minimum correlation so as to minimize the interference between transmissions in the individual paths. Saha et al. [15] proposed a maximally zone-disjoint multipath routing, which computes a set of zone-disjoint shortest paths for traffic load-balancing. Disjoint multipath source routing proposed in [17], statically multiplexes the data traffic over multiple disjoint paths at all nodes on the primary path. The stability based multipath routing algorithm proposed in [16] computes a set of stable independent (disjoint) multiple paths, which can be used for a longer time to recover from the path breakage.

Multipath protocols [12, 21, 22] based on distance-vector routing scheme have been proposed for ad hoc networks. Other multipath routing protocols have been also proposed for ad hoc networks [9, 23, 24]. Multipath Source Routing (MSR) [23, 25] extends DSR's route discovery and route maintenance phases to compute multiple node-disjoint paths. It also proposes a mechanism to distribute load over multiple paths, based on the RTT measurement. SMR [14] finds maximally disjoint multiple paths and uses a per-packet allocation scheme to distribute data packets on to multiple paths. This enables the effective utilization of network resources and avoids nodes from being congested. SMR computes only two paths to each destination. All the above protocols are based on the source routing protocol DSR. They cannot scale to large networks because source routing requires every data packet to carry full path to the destination. AODV-BR [21] calculates multiple paths without any extra control overhead. In this protocol, neighboring nodes hear the route reply transmissions by being in promiscuous mode, and store a route to the destination through the neighbor that transmitted the reply packet. The newly discovered paths are called a backup path. But, effectively nodes on the primary path contain only single path to the destination. It is the neighboring nodes who store backup paths. When a node on the primary path moves away due to mobility, it loses connection to its immediate downstream node on the path. Then, the node broadcasts the future data packets that it receives for that destination, assuming that any of its neighbors would have stored a backup path to the destination. The node also sends a route error packet to the source node, informing the route disconnection. Maxemchuck [26] proposed a routing mechanism called dispersity routing for store and forward data networks. It discusses the ways of splitting data and dispersing them over multiple paths to achieve smaller average and variance in delay. The popular link-state protocol OSPF [27] can find multiple paths of equal cost. In [28], Ad hoc On-demand Multipath Distance Vector (AOMDV) [12] is a multipath routing protocol based on AODV [29], which can compute both node-disjoint and two segment link-disjoint paths. It uses a notion of advertising-hop count to form an invariant that ensures loop freedom. Further, in large networks two segment link-disjoint paths also take considerable amount of time to recover the route break, as route error has to traverse multiple hops to inform the route disconnection to the node that has alternate path(s).

Ad hoc On-demand Distance Vector Multipath (AODVM) is also a multipath routing protocol based on AODV. It proposes a routing framework to provide robustness to route breaks. The protocol computes node-disjoint paths between source and destination. Through simulation results, it shows that only a few such multiple paths can be found in the network and hence they cannot provide much robustness. In order to increase robustness to route breaks, AODVM assumes the existence of a set of reliable nodes in the network and place them at the junctions of the link-disjoint multiple paths. A mechanism to identify such reliable nodes in the network would be a good addition to the protocol.

In [18] proposed a stable node-disjoint multipath routing, which applies the path accumulation feature of DSR and AODV. But, this path accumulation feature requires the route request packet to carry the full path it has traversed. This requirement increases the size of route request packet, particularly in large networks where paths between nodes are longer. Disjoint multipath routing [19] proposed by Abbas and Jain tries to reduce the effect of path diminution problem in finding node-disjoint multiple paths. As this routing technique also requires the route request packets to carry the traversed path, it suffers from the same disadvantage as the previous protocol. In [30], Ducatelle et al. propose a hybrid multipath routing based on ant colony optimization framework for traffic load-balancing. Multipath fresnel zone routing [31] proposed to take the capacity of intermediate nodes into consideration for selecting disjoint multiple paths. It evaluates the capacity and the transmitting cost of different intermediate nodes, and formulates end-to-end paths of different capacity and cost. Then the protocol forwards the traffic through these different paths, by adjusting the amount of traffic on each path based on path capacity and congestion conditions.

Roy et al. [32] compared the two disjoint multipath techniques that use omni-directional and directional antennas, respectively. They showed through simulations that directional antennas help in computing multiple paths efficiently, when compared to omni-directional antennas. Fault tolerant routing proposed in [33] uses a path estimation mechanism for selecting a reliable route. This algorithm relies on destination nodes sending feedback to source nodes, about the packet delivery capacity of multiple paths, which may increase the control overhead in the network. Also, there is some protocol complexity involved in implementing the path estimation mechanism. All the disjoint multipath routing techniques discussed above compute maximally disjoint multiple paths, whose availability is very less due to the disjointness constraint imposed in the path selection. Hence, disjoint multiple paths cannot provide efficient fault-tolerance towards route breaks. Also, these techniques involve considerable delay and overhead in selecting disjoint multiple paths. The multipath routing mechanisms proposed in [34, 35] use path redundancy for ensuring confidentiality to data transmission over ad hoc networks, which are not closely related to fault-tolerant multipath routing techniques

IV MULTIPATH ROUTING PROTOCOLS

Ad hoc On-demand Multipath Distance Vector (AOMDV) [11, 12] is an extension to the AODV protocol for computing multiple loop-free and link-disjoint paths. AOMDV is a reactive hop-by-hop routing protocol which finds node/link-disjoint multiple paths. In AOMDV when a source has packets to send to a destination and finds no routes in its routing table, it invokes a route discovery by broadcasting RREQ packets. Route discovery in AOMDV is similar to AODV. A RREQ packet in AOMDV includes all fields as that in AODV. Besides, it includes an additional field called the last hop, i.e., the neighboring node of the source. This information and the next-hop information, i.e., the node from which to receive the RREQ, are used to achieve link-disjointness (shown in Figure 1) for reverse paths to the source. A node may receive multiple duplicate RREQ packets. For each packets received, it examines if an alternate reverse path to the source can be formed such that loop-freedom and link-disjointness are preserved.

Upon establishing a reverse path to the source, an intermediate node checks if it has any valid path to the destination. If so, it generates RREP packets, including a forwarding path not used in any previous RREPs for this RREQ, and sends the RREP back to the source through the reverse path. Otherwise, it checks if it has forwarded this request before and forwards it if not. Upon receiving an RREQ packet, the destination tries to form a reverse path to the source. Then, it generates an RREP packet for each RREQ copy that arrives through a loop-free path to the source. Multiple RREPs intend to increase the probability to find multiple disjoint paths.

Upon receiving an RREP packet, an intermediate node checks if it can form a loop-free and disjoint path to the destination using the same rule as when it receives an RREQ packet. If not, it drops the RREP. Otherwise, it checks if there is any reverse path to the source that has not been used to forward an RREP for this route discovery. If so, it chooses one of the unused reverse paths to forward the RREP. Otherwise, it drops the packet.

Loop-freedom is guaranteed by satisfying the following sufficient conditions:

Sequence rule: For each destination, multiple paths maintained by a node should have the same sequence number, i.e., the highest known destination sequence.

For the same destination sequence number: a node never advertises a route shorter than one already advertised, and never accepts a route longer than one already advertised. More details and a proof of correctness are available in [12]. Route maintenance is also very similar to AODV. Upon link breakage of the last path to the destination, a node generates or forwards an RERR packet.

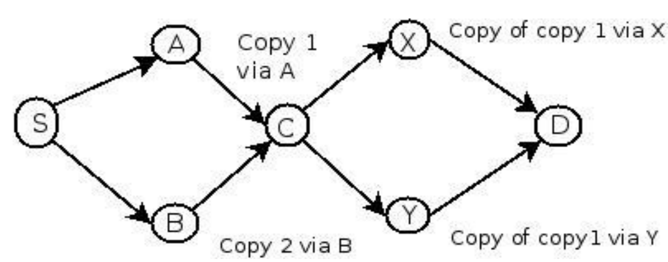

Figure 1 Route discovery process in AOMDV

V PERFORMANCE COMPARISON OF SINGLE PATH AND MULTIPATH ROUTING PROTOCOLS

Simulation Environment: Network simulation ns-2 is with distributed coordination function of IEEE 802.11 for wireless LANs is used. The radio model uses characteristics similar to Lucent's WaveLAN radio interface. The bit rate is set to 2Mbps and the radio range is limited to 250 meters and an error free wireless channel model is used.

Movement Model: The random waypoint model is used to model node movements. Simulation time is 1000 seconds while the pause time varies from 0 seconds (continuous movement) to 1000 seconds (no mobility) [0, 50, 100, 250, 500, and 1000 seconds]. We vary the node speed 1m/s, 10m/s and 20m/s to compare the protocols performance for low and high mobility. Nodes speed uniformly distributed in the ranges of 0 to 1 m/s, 0 to 10 m/s and 0 to 20 m/s.

Network size and communication model: The network size of 40 mobile nodes in rectangular area of size 1000m x 1000m. Traffic pattern used up to 20 CBR/UDP connections, with 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 model pattern for different routing protocols. Data packets have fixed size of 512 bytes and the interface network queue size for routing is set to 50 packets for all scenarios.

Scheduling data packets: In AOMDV sender uses all available paths to a destination simultaneously. Data packets are sent over each individual path with equal probabilities. When one path breaks, the source stops using that path but does not initiate a new route discovery process. Only when all available paths are broken then a new route discovery process is initiated. In case of AODV, if existing route fails, it initiates the route discovery process.

Simulation results of AOMDV with AODV are compared to emphasize the advantages and disadvantage of multipath versus single path routing in ad hoc networks.

Packet Delivery Ratio :

Figure 2, 3 and 4 shows the packet delivery ratio of the originated application data packets each protocol was able to deliver, as a function of node mobility, pause time and network load. For both routing protocol, PDR is very high for low offered traffic load, and low PDR for high offered load. Routing protocols does well in low traffic 1 or 5 sources, delivery ratio is between 80% to 100%. In case of high traffic load 20 sources, PDR is less than 40%. Traffic load has lot of impact on routing protocols. Nodes speeds also affect the PDR metric, as node speed increase performance degrades. The reason is that the AOMDV source waits until all existing path break before sending a new route request and the probability that two paths break is lower if they are node disjoint.

Routing Overhead:

Figure 5, 6, and 7 shows the number of routing protocol packets sent by each protocol in obtaining the packet delivery ratio as shown in Figure 2, 3 and 4 respectively. In AOMDV protocol control overhead is almost independent of pause time. As the number of sources increase, routing overhead also increase. For low traffic AODV routing load is low, but in case of high load AOMDV uses less routing packets. Overhead is almost constant in low traffic. In the following we discuss in detail the routing overhead for each scenario.

Low mobility: The routing overhead in networks with low traffic is shown in Figure 5a. We clearly observe the higher (at least 50 times) over head of AOMDV compared to the AODV routing protocol. When comparing AODV and AOMDV, the high traffic (20 CBR) multipath routing protocols requires less control messages, approximately it saves at least 40000 routing packets compared to AODV shown in Figure 5d.

Moderate Mobility: In Figure 6 show the routing overhead for moderate mobility, the control over head is similar to low mobility shown in Figure 5. In case of low traffic control over head is almost independent of pause time. AODV overhead is low in low traffic few hundred routing packets are required but in case of high traffic it needs approximately 150000 routing packets.

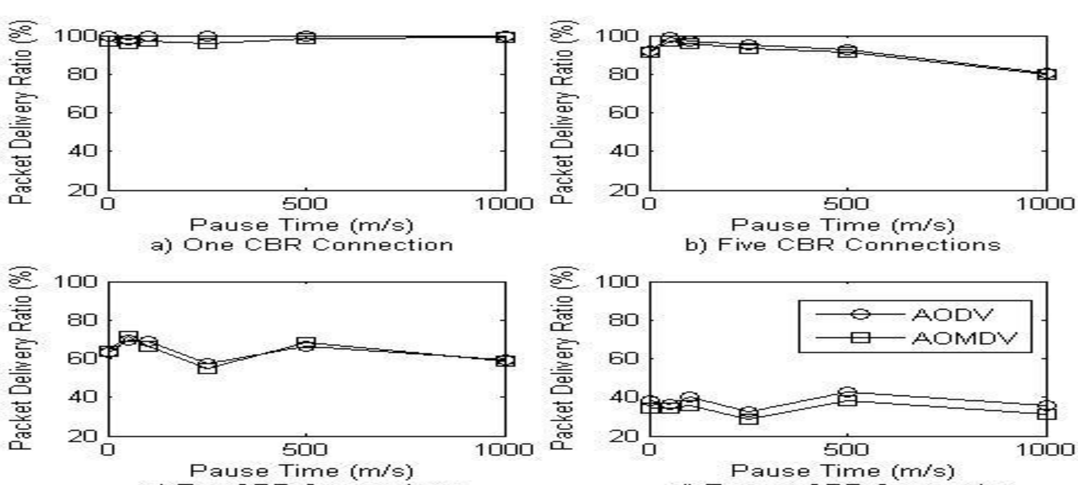

Figure 2 Comparison of the packet delivery ratio of application data packets successfully delivered as a function of pause time. Speed 1m/s

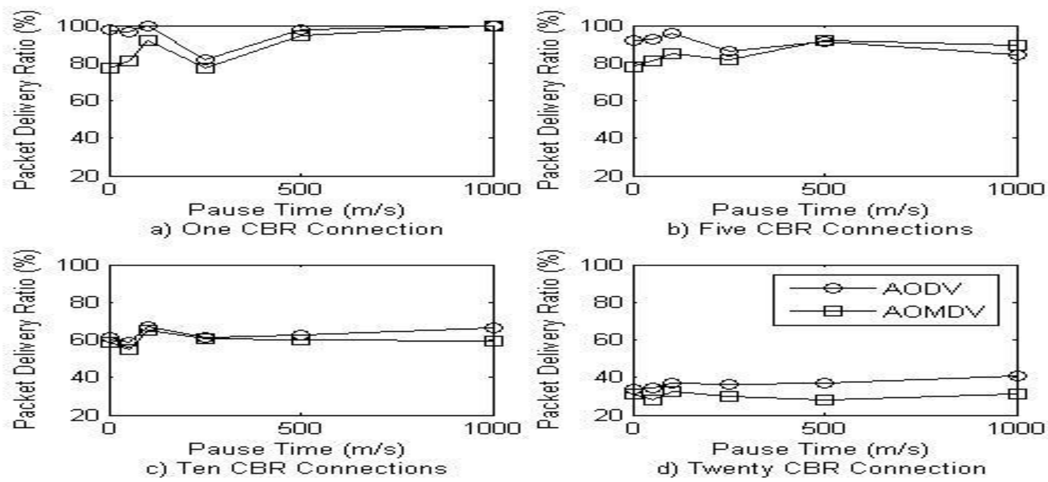

Figure 3 Comparison of the packet delivery ratio of application data packets successfully delivered as a function of pause time. Speed 10m/s

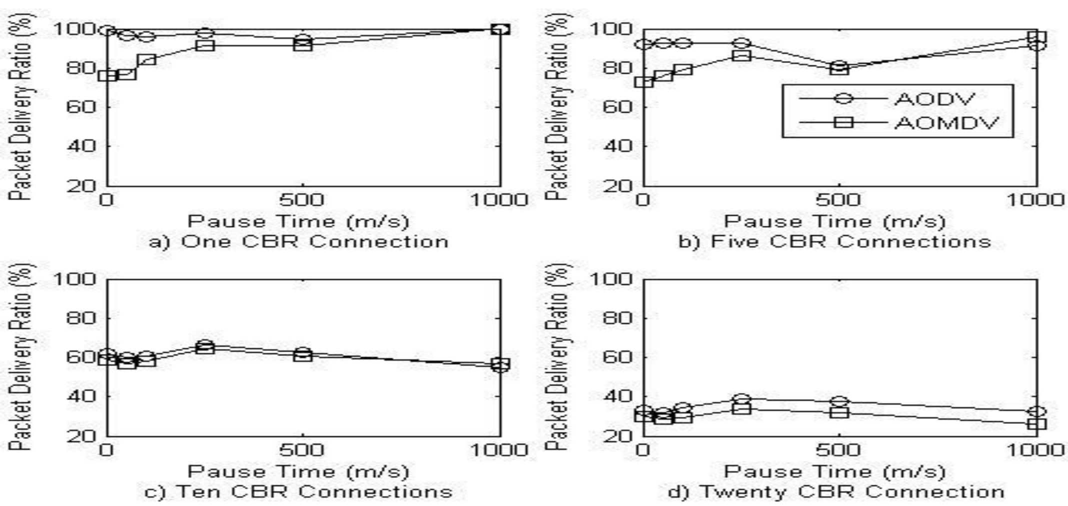

Figure 4 Comparison of the packet delivery ratio of application data packets successfully delivered as a function of pause time. Speed 20m/s

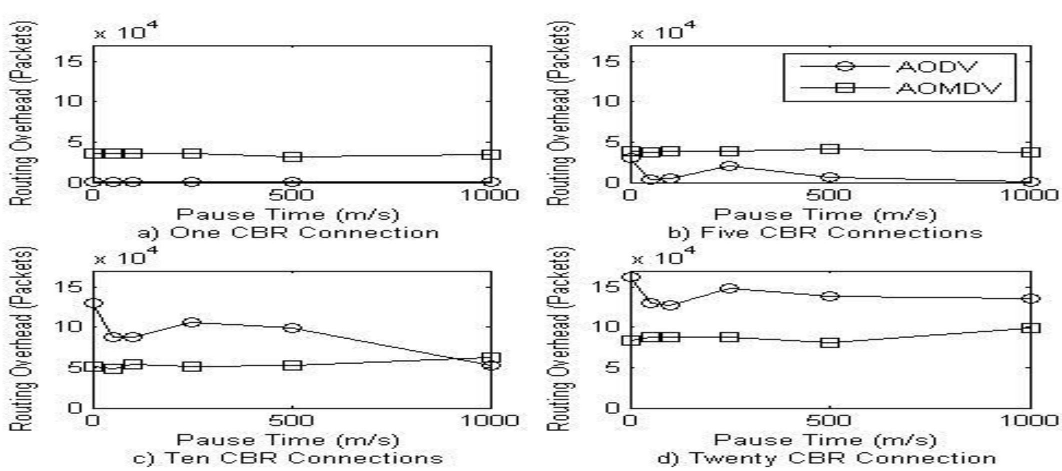

Figure 5 Comparison of the number of routing packets sent as a function of pause time. Speed 1m/s

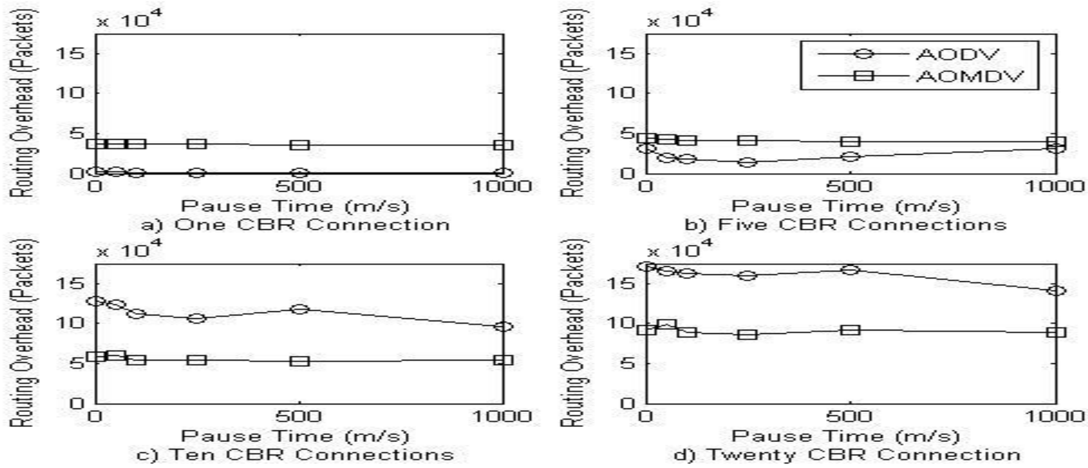

Figure 6 Comparison of the number of routing packets sent as a function of pause time. Speed 10m/s

High Mobility: In Figure 7 AODV routing over head is almost constant in low traffic as a function of pause time, but in case of high traffic routing overhead decline as a function of pause time increase. AOMDV routing is not affected by pause time. When number of connection changed from 1 to 5 only it contributed approximately 10000 routing packets. Whereas, number of connection varied from 10 to 20, control over head also double.

Overall in low traffic AODV performs better than AOMDV and in high traffic AOMDV is preferred compared to AODV and nodes mobility and pause time has little impact.

Average end-to-end delay:

The mobile node speeds are 1m/s, 10m/s and 20m/s to obtain Figure 8, 9 and 10 respectively. The multipath outperforms single path routing in terms of delivered data packets when the traffic load in the network is high.

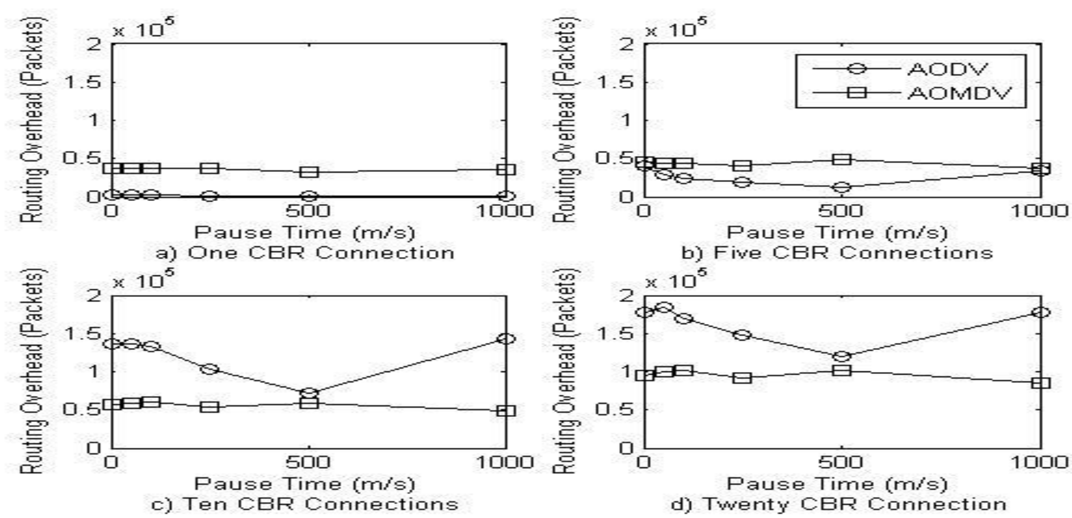

Figure 7 Comparison of the number of routing packets sent as a function of pause time. Speed 20m/s

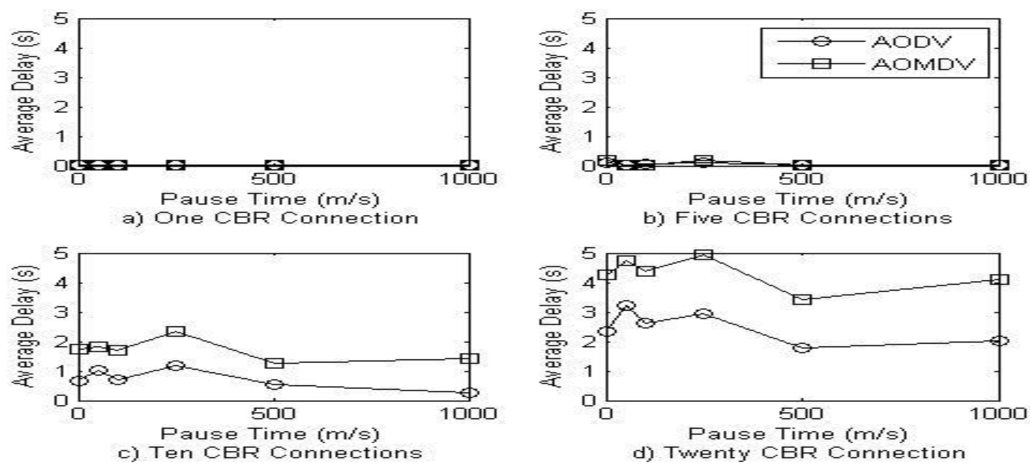

Figure 8 Comparison of the average end-to-end delay experienced by the data packets as a function of pause time. Speed 1m/s

Now we compare end-to-end delay of three different cases low (1m/s) mobility, moderate (10m/s) mobility and high (20m/s) mobility are compared. AOMDV shows higher delay compared to AODV (up to 1 to 2 seconds) in case of higher traffic load 10 and 20 sources. For low traffic load both routing protocol produce almost produce same delay, difference is less than (0.2) seconds. In high mobility and high traffic AODV routing protocols average delay is reduced with increasing pause time.

Table 1 has given performance comparison both single path AODV and multipath AOMDV routing protocols, "high" denotes the best performance, "low" the worst. We summaries the performance of multipath and single path routing protocols for the different metrics. We find that: Multipath routing achieves in general better performance than single path routing in high traffic loads and vice versa. Detail results of single path and multipath are shown in the appendix - C

Table 1 Single vs Multipath results

Traffic Sources	PDR		Routing Overhead		End-to-end delay	
	AODV	AOMDV	AODV	AOMDV	AODV	AOMDV
1 and 5	High	High	Low	high	low	low
10	low	Low	High	low	Average	High
20	low	low	High	low	Average	High

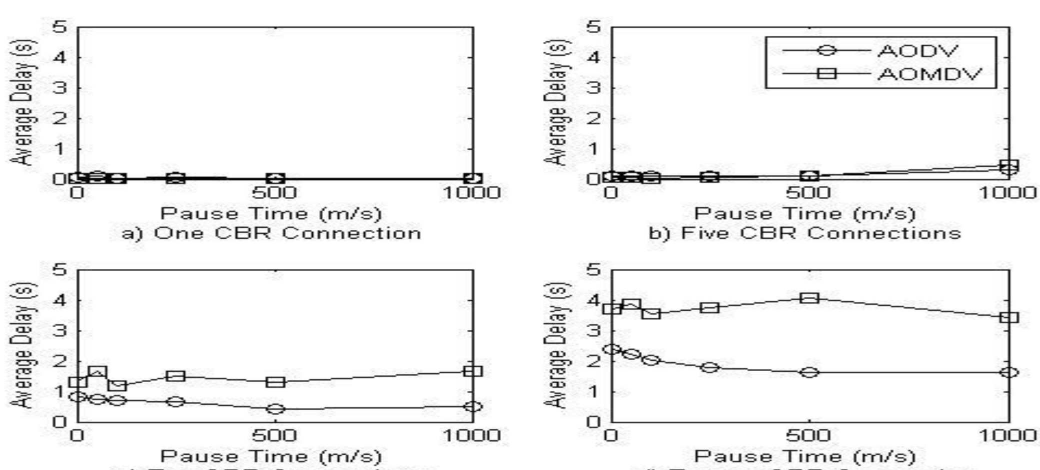

Figure 9 Comparison of the average end-to-end delay experienced by the data packets as a function of pause time. Speed 10m/s

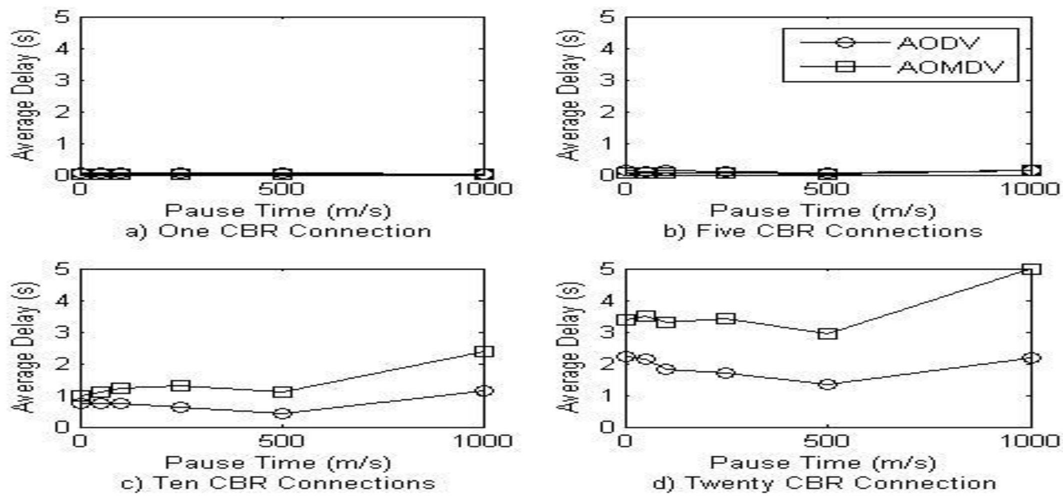

Figure 10 Comparison of the average end-to-end delay experienced by the data packets as a function of pause time. Speed 20m/s

REFERENCES

1. Zygmunt J. Haas, Marc R. Pearlman, The performance of query control schemes for the zone routing protocol, in: Proceedings of SIGCOMM'98, 1998.
2. D. B. Johnson and D.A. Maltz, Dynamic source routing in ad-hoc wireless networks, Mobile Computing, Kluwer Academic Publishers (1996), pp. 152–181.
3. Vincent D. Park, M. Scott Corson, A highly adaptive distributed routing algorithm for mobile wireless networks, in: Proceedings of INFOCOM'97, 1997.
4. Rendong Bai and M. Singhal, Doa: Dsr over aodv routing for mobile ad-hoc networks, IEEE Transactions on Mobile Computing 5 (10) (2006), pp. 1403–1416.
5. M. Tarique, K.E. Tepe, S. Adibi and S. Erfani, Survey of multipath routing protocols for mobile ad hoc networks, Journal of Network and Computer Applications 32 (2009), pp. 1125–1143.
6. C. Perkins, E. Royer, S. Das, Ad hoc on-demand distance vector routing, in: Proc. of the Workshop on Mobile Computing Systems and Applications, IEEE, February 1999, pp. 90–100.
7. A. P. Subramanian, A.J. Anto, J. Vasudevan and P. Narayanasamy, Multipath power sensitive routing protocol for mobile ad hoc networks, Proc. of the 1st IFIP/TC6 Working Conference on Wireless On-Demand Network Systems (WONS'2004), LNCS vol. 28, Springer-Verlag (2004), pp. 171–183.
8. A. Nasipuri, S.R. Das, On-demand multipath routing for mobile ad hoc networks, in: Proc. of INFOCOM'99, IEEE, 1999, pp. 64–70.
9. S. -J. Lee, M. Gerla, Split multipath routing with maximally disjoint paths in ad hoc networks, in: Proceedings of IEEE International Conference on Communications 2001, vol. 3, June 2001, pp. 867–871.
10. Jie Wu, An extended dynamic source routing scheme in ad hoc wireless networks, Telecommun. Syst. 1 (2003) (4), pp. 61–75.
11. M. Marina and S. Das, Ad hoc on-demand multipath distance vector routing, ACM Mobile Comput. Commun. Rev. 6 (2002) (3), pp. 92–93.
12. M. K. Marina and S.R. Das, On-demand multi path distance vector routing in ad hoc networks, Proceedings of the Ninth International Conference on Network Protocols, IEEE Computer Society, Washington, DC, USA (2001), pp. 14–23.
13. K. Wu, J. Harms, Performance study of a multipath routing method for wireless mobile ad hoc networks, in: Proceedings of Ninth International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems, August 2001, pp. 99–107.
14. A. Tsirigos, Z.J. Haas, Multipath routing in mobile ad hoc networks or how to route in the presence of frequent topology changes, in: Proceeding of IEEE Military Communications Conference, vol. 2, October 2001, pp. 878–883.
15. D. Saha, S. Toy, S. Bandyopadhyay, T. Ueda, S. Tanaka, An adaptive framework for multipath routing via maximally zone-disjoint shortest paths in ad hoc wireless networks with directional antenna, in: Proceedings of IEEE Global Telecommunications Conference, vol. 1, December 2003, pp. 226–230.
16. J. Shi, Z. Ling, S. Dong, Z. Jie, A stability-based multipath routing algorithm for ad hoc networks, in: Proceedings of 14th IEEE Proceedings on Personal, Indoor and Mobile Radio Communications, vol. 1, September 2003, pp. 516–520.
17. N. Wisitpongphan, O.K. Tonguz, Disjoint multipath source routing in ad hoc networks: transport capacity, in: Proceedings of IEEE 58th Vehicular Technology Conference, vol. 4, October 2003, pp. 2207–2211.
18. X. Li, L. Cuthbert, Stable node-disjoint multipath routing with low overhead in mobile ad hoc networks, in: Proceedings of The IEEE Computer Society's 12th Annual International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunications Systems, October 2004, pp. 184–191.
19. A. M. Abbas, B.N. Jain, Path diminution in disjoint multipath routing for mobile ad hoc networks, in: Proceedings of 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, vol. 1, September 2004, pp. 130–134.
20. P. Papadimitratos, Z.J. Haas, E.G. Sirer, Path set selection in mobile ad hoc networks, in: MobiHoc '02: Proceedings of the 3rd ACM International Symposium on Mobile Ad hoc Networking & Computing, 2004, pp. 23–29.
21. S. -J. Lee, M. Gerla, AODV-BR: Backup routing in ad hoc networks, in: IEEE WCNC'2000, vol. 3, September 2000, pp. 1311–1316.
22. A. Valera, W.K.G. Seah and S.V. Rao, Cooperative packet caching and shortest multipath routing in mobile ad hoc networks, IEEE INFOCOM 2003 1 (2003) (April), pp. 260–269.
23. L. Wang, L. Zhang, Y. Shu, M. Dong, Multipath source routing in wireless ad hoc networks, in: Proceedings of Canadian

Conference on Electrical and Computer Engineering 2000, vol. 1, March 2000, pp. 479–483.
24. A. Nasipuri, R. Castaneda and S.R. Das, Performance of multipath routing for on-demand protocols in mobile ad hoc networks, Mobile Networks and Applications (MONET) 6 (2001) (4), pp. 339–349.
25. L. Wang, Y. Shu, M. Dong, L. Zhang, O.W.W. Yang, Adaptive multipath source routing in ad hoc networks, in: Proceedings of IEEE International Conference on Communications, vol. 3, June 2001, pp. 867–871.
26. N. F. Maxemchuk, Diversity routing in store and forward networks, Ph.D. thesis, University of Pennsylvania, May 1975.
27. J. Moy, OSPF version 2, RFC 1247, 1991.
28. S. Vutukury, J.J. Garcia-Luna-Aceves, MDVA: A distance-vector multipath routing protocol, in: Proceedings of the IEEE INFOCOM, 2001, pp. 99–107.
29. A.E. Perkins, E.M. Royer, Ad-hoc on-demand distance vector routing, in: Proceedings of the IEEE WMCSA'99, New Orleans, LA, February 1999, pp. 90–100.
30. F. Ducatelle, G.D. Caro, L.M. Gambardella, Ant agents for hybrid multipath routing in mobile ad hoc networks, in: Proceedings of the Second Annual Conference on Wireless on demand Network Systems and Services (WONS), January 2005.
31. Y. Liang, S.F. Midkiff, Multipath fresnel zone routing for wireless ad hoc networks, in: Proceedings of 2005 IEEE Wireless Communications and Networking Conference, vol. 4, March 2005, pp. 1958–1963.
32. S. Roy, S. Bandyopadhyay, T. Ueda, K. Hasuike, Multipath routing in ad hoc wireless networks with omni directional and directional antenna: a comparative study, in: IWDC '02: Proceedings of the 4th International Workshop on Distributed Computing, Mobile and Wireless Computing, 2002, pp. 184–191.
33. Yuan Xue, K. Nahrstedt, Fault tolerant routing in mobile ad hoc networks, in: 2003 IEEE Wireless Communications and Networking, vol. 2, March 2003, pp. 1174–1179.
34. L. -P. Chou, C.-C. Hsu, F. Wu, A reliable multipath routing protocol for ad-hoc network, in: Proceedings of 10th IEEE International Conference on Networks, August 2002, pp. 305–310.
35. K.-L. Lee, X.-H. Lin, Y.-K. Kwok, A multipath ad hoc routing approach to combat wireless link insecurity, in: Proceedings of IEEE International Conference on Communications, vol. 1, May 2003, pp. 448–452.