IAENG International Journal of Computer Science, 35:3, IJCS_35_3_13

Performance Analysis of Ad hoc Routing Protocols in Mobile WiMAX Environment

Farhat Anwar, Md. Saiful Azad, Md. Arafatur Rahman, and Mohammad Moshee Uddin

Abstract— **Worldwide Interoperability for Microwave Access (WiMAX) is a technology that bridges the gap between fixed and mobile access and offer the same subscriber experience for fixed and mobile user. Demand for such type of mobile broadband services and applications are growing rapidly as it provides freedom to the subscribers to be online wherever they are at a competitive price and other significant facilities such as increasing amounts of bandwidth, using a variety of mobile and nomadic devices etc. The earliest version of WiMAX is based on IEEE 802.16 and is optimized for fixed and nomadic access, which is further extended to support portability and mobility based on IEEE 802.16e, also known as Mobile WiMAX. However, frequent topology changes caused by node mobility make routing in Mobile WiMAX networks a challenging problem. In this paper, we focus upon those routing protocols especially designed for wireless networks. Here, we study and compare the performance of four ad hoc routing protocols (AODV, DSR, OLSR and ZRP) for Mobile WiMAX environment under the assumption that each of the subscriber station has routing capabilities within its own network. From our simulation, we found that ZRP and AODV protocols outperform DSR and OLSR.**

Index Terms— **AODV, DSR, Mobile WiMAX, OLSR and ZRP.**

I. INTRODUCTION

Today's broadband Internet connections are restricted to wireline infrastructure using DSL, T1 or cable-modem based connection. However, these wireline infrastructures are considerably more expensive and time consuming to deploy than a wireless one. Moreover, in rural areas and developing countries, providers are unwilling to install the necessary equipment (optical fiber or copper-wire or other infrastructures) for broadband services expecting low profit. Broadband Wireless Access (BWA) has emerged as a promising solution for "last mile" access technology to provide high speed connections. IEEE 802.16 standard for BWA and its associated industry consortium, Worldwide Interoperability for Microwave Access (WiMAX) forum promise to offer high data rate over large areas to a large number of users where broadband is unavailable. This is the first industry wide standard that can be used for fixed wireless access with substantially higher bandwidth than most cellular networks [1], [2]. Development of this standard facilitates low cost equipment, ensure interoperability, and reduce investment risk for operators. In the recent years, IEEE 802.16 working group has developed a number of standards for WiMAX. The first standard IEEE 802.16 was published in 2001 and focused on the frequency range between 10 and 66 GHz and required line-of-sight (LOS) propagation between the sender and the receiver [3]. This reduces multipath distortion, thereby increases communication efficiency. Theoretically IEEE 802.16 can provide single channel data rates up to 75 Mbps on both the uplink and downlink. Providers could use multiple IEEE 802.16 channels for a single transmission to provide bandwidths of up to 350 Mbps [4]. However, because of LOS transmission, cost-effective deployment is not possible. Consequently, several versions came with new features and techniques. IEEE 802.16-2004, has been developed to expand the scope to licensed and license-exempt bands from 2 to 11 GHz. IEEE 802.16-2004 specifies the air interface, including the Media Access Control (MAC) of wireless access for fixed operation in metropolitan area networks. Support for portable/mobile devices is considered in IEEE 802.16e standard, which is published in December 2005. WiMAX networks consist of a central radio Base Station (BS) and a number of Subscriber Stations (SSs). In Mobile WiMAX network, BS (which is fixed) is connected to public network and can handle multiple sectors simultaneously and SSs are mobile.

A number of wireless routing protocols are already designed to provide communication in wireless environment, such as AODV, OLSR, DSDV, ZRP, LAR, LANMAR, STAR, DYMO etc. Performance comparison among some set of routing protocols are already performed by the researchers such as among PAODV, AODV, CBRP, DSR, and DSDV [6], among DSDV, DSR, AODV, and TORA [7], among SPF, EXBF, DSDV, TORA, DSR, and AODV [8], among DSR and AODV [9], among STAR, AODV and DSR [10], among AMRoute, ODMRP, AMRIS and CAMP [11], among DSR, CBT and AODV [12], among DSDV, OLSR and AODV [13] and many more. These performance comparisons are carried out for ad-hoc networks but none for Mobile WiMAX. For this reason, evaluating the performance of wireless routing protocols in Mobile WiMAX environment is still an active research area and in this paper we study and compare the performance of AODV, DSR, OLSR and ZRP routing protocols.

Manuscript submitted July 24, 2008

F. Anwar. is with the Faculty of Engineering, IIUM, P.O. Box 10, 50728 Kuala Lumpur, Malaysia. (e-mail: farhat@iiu.edu.my).

M. S. Azad. is with the Faculty of Engineering, IIUM, P.O. Box 10, 50728 Kuala Lumpur, Malaysia. (Phone: 60146279987; e-mail: sazad_m684@yahoo.com).

M. A. Rahman. is with the Faculty of Engineering, IIUM, P.O. Box 10, 50728 Kuala Lumpur, Malaysia. (e-mail: arafatiiuc@yahoo.com).

M. M. Uddin is with the Faculty of Information Communication Technology, IIUM, P.O. Box 10, 50728 Kuala Lumpur, Malaysia (e-mail: mdmoshi@yahoo.com).

(Advance online publication: 21 August 2008)

For performing the simulation, we assume that each of the subscriber station maintain routing table for its own network, so that it can send data directly to the destination without the help of base station. However, if one subscriber station has to send data to a station located in another network, it must send data through the base station and vice versa.

II. WIRELESS ROUTING PROTOCOLS

A. Ad-hoc On-demand Distance Vector Routing Protocol (AODV)

Ad-hoc On-demand distance vector (AODV) [14] is another variant of classical distance vector routing algorithm, based on DSDV [4] and DSR [31]. It shares DSR's on-demand characteristics hence discovers routes whenever it is needed via a similar route discovery process. However, AODV adopts traditional routing tables; one entry per destination which is in contrast to DSR that maintains multiple route cache entries for each destination. The initial design of AODV is undertaken after the experience with DSDV routing algorithm. Like DSDV, AODV provides loop free routes while repairing link breakages but unlike DSDV, it doesn't require global periodic routing advertisements.

Apart from reducing the number of broadcast resulting from a link break, AODV also has other significant features. Whenever a route is available from source to destination, it does not add any overhead to the packets. However, route discovery process is only initiated when routes are not used and/or they expired and consequently discarded. This strategy reduces the effects of stale routes as well as the need for route maintenance for unused routes. Another distinguishing feature of AODV is the ability to provide unicast, multicast and broadcast communication.

AODV uses a broadcast route discovery algorithm and then the unicast route reply massage. The following sections explain these mechanisms in more detail.

A .1 Route Discovery

When a node wants to send a packet to some destination node and does not locate a valid route in its routing table for that destination, it initiates a route discovery process. Source node broadcasts a route request (RREQ) packet to its neighbors, which then forwards the request to their neighbors and so on. Fig. 1 indicates the broadcast of RREQ across the network.

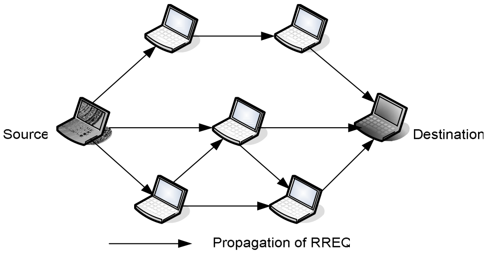

Fig. 1 *Propagation of RREQ throughout the network*

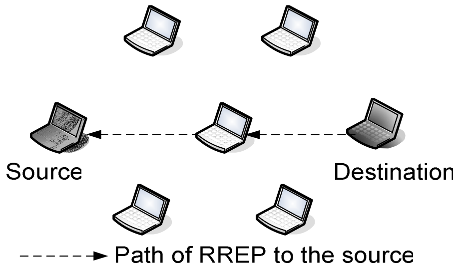

Fig. 2 *Reply of RREP towards the network*

To control network-wide broadcasts of RREQ packets, the source node use an expanding ring search technique. In this technique, source node starts searching the destination using some initial time to live (TTL) value. If no reply is received within the discovery period, TTL value incremented by an increment value. This process will continue until the threshold value is reached.

When an intermediate node forwards the RREQ, it records the address of the neighbor from which first packet of the broadcast is received, thereby establishing a reverse path. When the RREQ is received by a node that is either the destination node or an intermediate node with a fresh enough route to the destination, it replies by unicasting the route reply (RREP) towards the source node. As the RREP is routed back along the reverse path, intermediate nodes along this path set up forward path entries to the destination in its route table and when the RREP reaches the source node, a route from source to the destination established. Fig. 2 indicates the path of the RREP from the destination node to the source node.

A .2 Route Maintenance

A route established between source and destination pair is maintained as long as needed by the source. If the source node moves during an active session, it can reinitiate route discovery to establish a new route to destination. However, if the destination or some intermediate node moves, the node upstream of the break remove the routing entry and send route error (RERR) message to the affected active upstream neighbors. These nodes in turn propagate the RERR to their precursor nodes, and so on until the source node is reached. The affected source node may then choose to either stop sending data or reinitiate route discovery for that destination by sending out a new RREQ message.

B. Dynamic Source Routing (DSR)

The Dynamic Source Routing (DSR) [31] is one of the purest examples of an on-demand routing protocol that is based on the concept of source routing. It is designed specially for use in multihop ad hoc networks of mobile nodes. It allows the network to be completely self-organizing and self-configuring and does not need any existing network infrastructure or administration. DSR uses no periodic routing messages like AODV, thereby reduces network bandwidth overhead, conserves battery power and avoids large routing updates. Instead DSR needs support from the MAC layer to identify link failure.

DSR is composed of the two mechanisms of Route Discovery and Route Maintenance, which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the network. The following sections explain these mechanisms in more details.

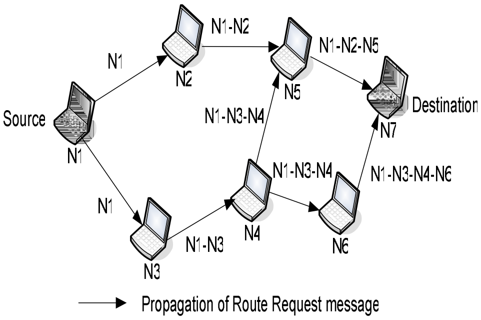

Fig. 3 *Propagation of route request message across the network*

B .1 Route Discovery

When a mobile node has a packet to send to some destination, it first checks its route cache to determine whether it already has a route to the destination. If it has an unexpired route, it will use this route to send the packet to the destination. On the other hand, if the cache does not have such a route, it initiates route discovery by broadcasting a route request packet.

Each node receiving the route request packet searches throughout its route cache for a route to the intended destination. If no route is found in the cache, it adds its own address to the route record of the packet and then forwards the packet to its neighbors. This request propagates through the network until either the destination or an intermediate node with a route to destination is reached. Fig. 3 demonstrates the formation of the route record as the route request propagates through the network.

Whenever route request reaches either to the destination itself or to an intermediate node which has a route to the destination, a route reply is unicasted back to its originator. Fig. 4 illustrates the path of the RREP from the destination node to the source node

B .2 Route Maintenance

In DSR, route is maintained through the use of route error packets and acknowledgments. When a packet with source route is originated or forwarded, each node transmitting the packet is responsible for confirming that the packet has been received by the next hop. The packet is retransmitted until the conformation of receipt is received. If the packet is transmitted by a node the maximum number of times and yet no receipt information is received, this node returns a route error message to the source of the packet. When this route error packet is received, the hop in error is removed from the host's route cache and all routes containing the hop are truncated at that point.

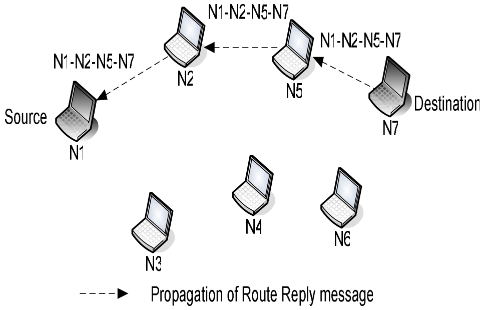

Fig. 4 *Propagation of route reply message towards the source*

C. Optimized Link State Routing (OLSR)

The Optimized Link State Routing (OLSR) [18] protocol inherits the stability of the pure link state algorithm and is an optimization over the classical link state protocol, adopted for mobile ad hoc networks. It is proactive in nature and has the advantage of having routes immediately available when needed. The key concept used in this protocol is that of multipoint relays (MPRs). MPRs are selected set of nodes in its neighbor, which forward broadcast messages during the flooding process. OLSR reduces the size of control packet by declaring only a subset of links with its neighbors who are its multipoint relay selectors and only the multipoint relays of a node retransmit its broadcast messages. Hence, the protocol does not generate extra control traffic in response to link failures and additions. The following section describes the functionality of OLSR in details.

C .1 Neighbor Sensing

For detecting the neighbor, each node periodically broadcasts its HELLO messages, which contains the information of the neighbors and their link status. The protocol only selects direct and bidirectional links, so that the problem of packet transfer over unidirectional links is avoided. HELLO messages are received by all one-hop neighbors, but they are not relayed further. These messages permit each node to learn the knowledge of its neighbors up to two hopes and help performing the selection of its multipoint relays.

C .2 Multipoint Relay Station

Each node of the network selects its own set of multipoint relays from periodically broadcasted hello messages. The MPR set is selected by a node in a manner so that consists of a subset of one hop neighbors, which covers the entire two hop neighbors of the node. For example, in Fig. 5, node N2 selects nodes N1 and N6 to be the MPR nodes. Since these nodes cover all the nodes (N7, N8, N9 and N4), which are two hops away from it.

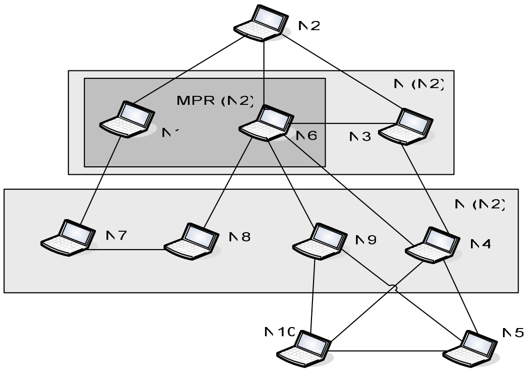

Fig. 5 *An example of Multi Point Relay (MPR) selection*

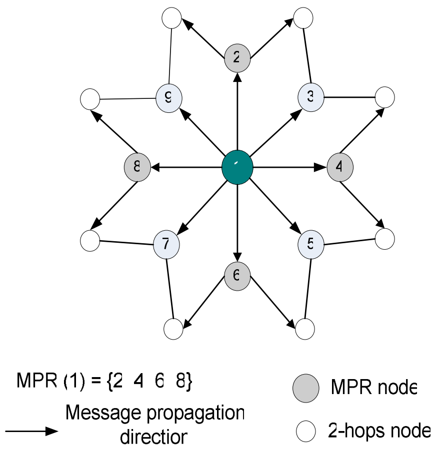

Fig. 6 *An example of flooding using MPR nodes*

Multipoint relays of a node are stated in its subsequent HELLO messages, so that the information reaches to the multipoint relays themselves. Multipoint relay set is recalculated when either a change in the neighborhood is detected or a change in the two hop neighbor set with bi-direction link is detected.

C .3 MPR Information Declaration

Each node in the network periodically broadcasts specific type of control messages called Topology Control (TC) message to build the intra-forwarding database needed for routing packets. Fig. 6 illustrates an example of flooding using MPR nodes throughout the network. A TC message is comprised of MPR selection set and with a sequence number, incremented when the MPR selector set changes. Information gained from TC messages is used to build the topology table in which it records the information about the topology of the network. A node records information about the multipoint relays of other nodes in this table and then based on this information, the routing table is calculated.

C .4 Routing Table Calculation

Each node maintains a routing table which allows it to route the packets from source to destination. The routing table is calculated from the information it receives through TC messages. In these routing tables it stores the information of the route to each node in the network. The route entries in the routing table comprises of destination address, next-hop address and estimated distance to destination. The information is only updated when a change in the neighborhood is detected or a route to any destination is expired or a better route is detected for a destination.

D. Zone Routing Protocol (ZRP)

Zone Routing Protocol (ZRP) [20] is a hybrid protocol which combines the advantages of both proactive and reactive schemes. It was designed to mitigate the problems of those two schemes. Proactive routing protocol uses excess bandwidth to maintain routing information, while reactive protocols suffers from long route request delays and inefficiently flooding the entire network for route determination. ZRP addresses these problems by combining the best properties of both approaches. Each node in ZRP, proactively maintains routes to destinations within a local neighborhood, which is referred as a routing zone. However, size of a routing zone depends on a parameter known as zone radius. Fig. 7 illustrates an example of routing zone (for node N1) of radius 2 hops. Nodes N1 through N11 are members of node N1's routing zone, whereas node N12 lies outside. Here, N8 through N11 are border nodes, whereas nodes N2 through N7 are interior nodes.

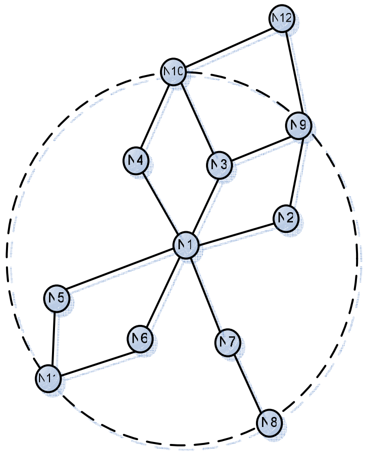

Fig. 7 *A Routing Zone of radius 2*

D .1 Intrazone Routing Protocol (IARP)

In ZRP, each node maintains the routing information of all nodes within its routing zone. Nodes learn the topology of its routing zone through a localized proactive scheme, referred as an Intrazone Routing Protocol (IARP). No protocol is defined to serve as an IARP and can include any proactive routing protocol, such as distance vector or link state routing. Different zone may operate with different proactive routing protocols as long as the protocols are restricted within the zone. A change in topology only affects the nodes inside the zone, even though the network is quite large.

D .2 Interzone Routing Protocol (IERP)

The Interzone Routing Protocol (IERP) is responsible for reactively discovering routes to the destination beyond a node's routing zone. This is used if the destination is not found within the routing zone.

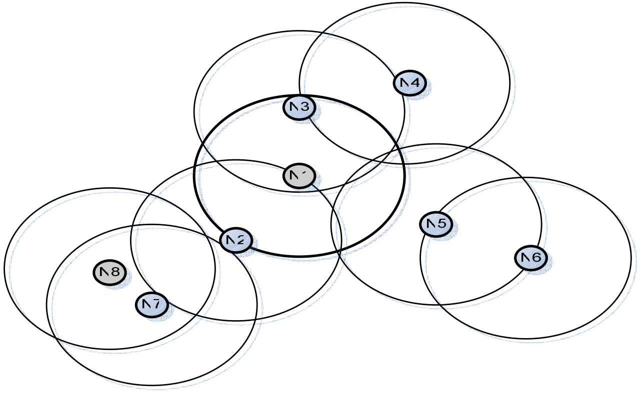

Fig. 8 An example of IERP operation

The route request packets are transmitted to all border nodes, which in turn forward the request if the destination node is not found within their routing zone. IERP distinguish itself from standard flood search by implementing this concept called bordercasting. The bordercasting packet delivery service is provided by the Bordercast Resolution Protocol (BRP). An example of route discovery procedure is shown in Fig. 8. Source node N1 desires to communicate with node N8. To find a route, N1 first checks whether N8 is within its routing zone. As N8 lies outside N1's routing zone, N1 bordercasts a route request to all its border nodes (i.e. N2 and N3). Nodes N2 and N3 then determine that N8 is not in their routing zones and therefore bordercast the request to their border node. Node N7, which is a border node of N2, recognizes N8 as one of its interior node and responds to route request, indicating the forwarding path N1 → N2 → N7 → N8.

III. SIMULATION ENVIRONMENT

The overall goal of this simulation study is to analyze the performance of different existing wireless routing protocols in Mobile WiMAX environment. The simulations have been performed using QualNet version 4 [22], a software that provides scalable simulations of Wireless Networks and a commercial version of GloMoSim [23]. In our simulation, we consider a network of 50 nodes (one source and one destination) that are placed randomly within a 1000m X 1000m area and operating over 500 seconds. Multiple runs with different seed numbers are conducted for each scenario and collected data is averaged over those runs.

A two-ray propagation path loss model is used in our experiments with lognormal shadowing model. The parameters we used to configure PHY802.16 for Subscriber Station (SS) and Base Station (BS) are given in table I.

The MAC802.16 is chosen as the medium access control protocol. The specific access scheme is CSMA/CA with acknowledgements. MAC layer parameters used in this paper is given in table II.

The network layer may affect the QoS if it has fewer queues, as it will queue packets of different service types into one queue [5]. Even if the application sets a high precedence for its packets, they may be blocked by lower precedence packets in network queues. Therefore, in order to fully guarantee the service types, we configure 8 queues at the network layer.

The node movements (except base station) in these experiments are modeled using the random waypoint mobility model [24], [25] with mobility speed ranging from 10 km/h to 100 km/h. We choose this range because WiMAX support medium mobility unlike cellular system [26]. A node randomly selects a destination and moves towards that destination at a predefined speed. Once the node arrives at the destination, it stays in its current position for a pause time between 0 and 30 seconds. After that it selects another destination and repeats the same.

A distinctive feature of 802.16e is its QoS support. It has five service classes to support real time and non-real time communications. They are Unsolicited Grant Service (UGS), Extended Real-time Polling Service (ertPS), Real-time Polling Service (rtPS), Non-real-time Polling Service (nrtPS) and Best Effort (BE) [5], [27]. In this simulation, we use UGS service to support real-time data streams consisting of fixed-size data packets issued at periodic intervals.

Table I: Important parameters for PHY802.16

Variable Parameters	**SS**	**BS**
Antenna Gain	-1 dBi	15 dBi
Transmission Power	15.0 dBm	30.0 dBm
Antenna Height	1.5 m	32 m
Common Parameters	**Value (both BS and SS)**	
System Channel Bandwidth	20 MHz	
FFT Size (N_{FFT})	2048	
Cyclic Prefix	8.0	
Temperature	290.0 K	
Noise Factor	10.0	

Table II: Important parameters for MAC802.16

Parameters	**Value**
SS Wait DCD Timeout Interval	25 S
SS Wait UCD Timeout Interval	25 S
Service Flow Timeout Interval	15 S
MAC Propagation Delay	1 US
BS Frame Duration	20 MS
BS TDD DL Duration	10 MS
BS Transmit / Receive Transition Gap	10 US
BS Receive / Transmit Transition Gap	10 US
Transition gap for SS to switch from transmit to receive or vice versa	4 US
BS DCD Broadcast Interval	5 S
BS UCD Broadcast Interval	5 S

To evaluate the performance of routing protocols, both qualitative and quantitative metrics are needed. Most of the routing protocols ensure the qualitative metrics. For this reason, we use four different quantitative metrics to compare the performance. They are

1) Packet Delivery Ratio: The fraction of packets sent by the application that are received by the receivers [28].
2) Routing overhead: The routing overhead describes how many routing packets for route discovery and route maintenance need to be sent in order to propagate the data packets.
3) Average End-to-end delay: End-to-end delay indicates how long it took for a packet to travel from the source to the application layer of the destination. [29].
4) Throughput: The throughput is defined as the total amount of data a receiver R actually receives from the sender divided by the time it takes for R to get the last packet [30].

IV. SIMULATION RESULTS

Fig. 9 shows the packet delivery ratio of AODV, DSR, OLSR and ZRP as a function of mobility speed. All these four protocols have packet delivery ratio of 100% when the nodes are stationary. However, packet delivery ratio decline when nodes begin to move. When looking at the packet delivery ratio (Fig. 9) it can easily be observed that ZRP and AODV perform much better than DSR and OLSR. Initially (10 km/h) all these protocols show poor performance. AODV demonstrate better performance when node mobility is between 20 km/h to 50 km/h. ZRP shows better performance in higher mobility than other three protocols. DSR and OLSR show nearly the same behavior. However, in highly mobile situation, DSR demonstrate poor performance than other three protocols.

Fig. 10 shows the number of routing protocol packets sent by each protocol obtaining the packet delivery ratios shown in Fig. 9. AODV, ZRP and DSR have less routing overhead when the nodes are stationary. However routing overhead increases when the nodes begin to move. DSR has considerably less overhead because of its on-demand routing nature. ZRP requires sending more routing packets due to its proactive scheme, namely the frequent hello packets to update the routing table within the local zone than DSR. Though AODV uses on-demand routing scheme, it always has higher routing overhead than DSR. Due to aggressive caching, DSR will most often find a route in its cache and therefore rarely initiate a route discovery process unlike AODV. OLSR demonstrates almost constant routing overhead in different mobility scenarios (0 km/h to 100 km/h), which is higher than other three protocols.

Fig. 11 shows the average end-to-end delay from the source to the destination's application layer. OLSR and ZRP demonstrate less delay than other two protocols due to their proactive nature. They regularly update their routing table. In case of AODV and DSR, which are reactive in nature, have higher delay. Among these two reactive routing protocols, AODV demonstrate better performance. In higher mobility scenarios (80 km/h to 100 km/h), AODV has lower delay than ZRP. DSR performs worst, because DSR often uses stale routes due to the large route cache, which leads to frequent packet retransmission and extremely high delay times.

Fig. 12 shows the throughput comparison of AODV, DSR, OLSR and ZRP. We measure the "throughput" at the receiver. When the nodes are stationary, all four protocols provide almost same throughput which is around 4000 bps. Throughput decline when nodes begin to move. From the figure it can easily be observed that ZRP and AODV perform better than DSR and OLSR. Although in higher mobility scenario (60 km/h to 100 km/h) AODV, DSR and OLSR demonstrate nearly same performance. AODV demonstrate better performance when node mobility is between 20 km/h to 50 km/h. ZRP shows better performance in higher mobility than other three protocols. DSR performs better than OLSR in low mobility. However, OLSR demonstrate better performance in higher mobility.

V. CONCLUSION

A performance comparison of four different ad hoc routing protocols (AODV, DSR, OLSR and ZRP) is performed here using different mobility scenarios. Simulation has been conducted in Mobile WiMAX environment. From the result of our studies, it can be said that, on an average ZRP and AODV perform better than DSR and OLSR. In case of DSR, it has less routing overhead, but average end to end delay is higher. However in case of OLSR, it has higher routing overhead, but average end to end delay is less. For other metrics (packet delivery ration and throughput), DSR and OLSR demonstrate poor performance.

REFERENCES

[1] Ghosh, A., Wolter, D.R., Andrews, J.G. and Chen, R., "Broadband ad hocaccess with WiMax/802.16: current performance benchmarks and future potential," *Communications Magazine, IEEE,* Vol.43, Iss.2, February 2005, pp. 129-136.

[2] Mohammad A. Hasan, "Performance Evaluation of WiMAX/IEEE 802.16 OFDM Physical Layer," *Masters Thesis,* Dept. of Electrical and Communications Engineering, Communications Laboratory, Helsinki University of Technology, Finland, June 2007

[3] Kejie Lu and Yi Qian, "A Secure and Service-Oriented Network Control Framework for WiMAX Networks," *IEEE Communications Magazine*, May 2007, pp. 124-130.

[4] C. E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," SIGCOMM, London, UK, August 1994, pp. 234-244.

[5] QualNet documentation, "QualNet 4.0 Model Library: Advanced Wireless"; Available: http://www.scalable-networks.com/products/qualnet/download.php#docs

[6] A. Boukerche, "Performance Evaluation of Routing Protocols for Ad Hoc Ad hocNetworks," *Mobile Networks and Applications*, vol. 9, Kluwer Academic Publishers, 2004, pp. 333-342.

[7] Broch, D. A. Maltz, D. B. Johnson, Y-C Hu and J. Jetcheva, "A Performance Comparison of Multihop Ad hocAd Hoc Network Routing Protocols," *In Proceedings Of MOBICOMM*, October 1998.

[8] S. R. Das, R. Castaneda and J. Yan, "Simulation Based Performance Evaluation of Mobile Ad Hoc Network Routing Protocols," *In Proceedings of Seventh International Conference on Computer Communications and Networks*, 1998.

[9] S. R. Das, C. E. Perkins and E. M. Royer, "Performance Comparison of Two On-Demand Routing Protocols for Ad Hoc Networks," *In Proceedings Of INFOCOM 2000*, Tel-Aviv, Israel, March 2000.

[10] Hong Jiang, "Performance Comparison of Three Routing Protocols for Ad Hoc Networks," *Communications of the ACM*, vol. 37, August 1994.

[11] J. Broch, D. A. Maltz, David B. Johnson, Y. Hu and J. Jetcheva, " A Performance Comparison of Multi-Hop Ad hocAd Hoc Network Routing Protocols," *Proceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking*, MobiCom'98, October 1998, pp. 25-30.

[12] A. Boukerche, "Performance Comparison and Analysis of Ad Hoc Routing Algorithms," *In Proceedings of IPCCC 2001*, USA, April 2001, pp. 171-178.

[13] S. Azad, A. Rahman and F. Anwar, "A Performance Comparison of Proactive and Reactive Routing Protocols of Mobile Ad-hoc NETwork (MANET)," *Journal of Engineering and Applied Sciences 2(5)*, 2007, pp 891-896.

[14] C. E. Perkins and E. M. Royer, "Ad Hoc On-demand Distance Vector Routing," *In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, New Orleans, LA, February 1999, pp. 90-100.

[15] Charles E. Perkins, *Ad hoc networking*, Addison-Wesley publication, 2001, Ch. 5.

[16] Elizabeth M. Royer and C-K Toh "A Review of Current Routing Protocols for Ad-Hoc Mobile Ad hocNetworks," *IEEE Personal Communications*, April 1999, pp. 46-55.

[17] Hong Jiang, "Performance Comparison of Three Routing Protocols for Ad Hoc Networks," *Communications of the ACM*, vol. 37, August 1994.

[18] T. Clausen, P. Jacquet, A. Laouiti, P. Mulethaler, A. Qayyum and L. Viennot, "Optimized Link State Routing Protocol," *In Proceedings of IEEE INMIC*, Pakistan, 2001.

[19] P. Jacquet, P. Mahlethaler and A. Qayyum, "Optimized Link State Routing Protocol," *IETF MANET*, Internet Draft "draft-ietf-MANET-olsr-02.txt," July 2000.

[20] Spilios Giannoulis, Christos Antonopoulos, Evangelos Topalis, Stavros Koubias "ZRP versus DSR and TORA: A comprehensive survey on ZRP performance," *Emerging Technologies and Factory Automation, 2005. ETFA 2005,* vol. 1, September 2005.

[21] Abudhahir Buhari and Mohamed Othman, "Efficient Query Propagation by Adaptive Bordercast Operation in Dense Ad Hoc Network," IJCSNS International Journal of Computer Science and Network Security, VOL.7 No.8, August 2007, pp. 101-108.

[22] QualNet Network Simulator; Available: http://www.scalable-networks.com.

[23] GloMoSim Simulator; Available: http://pcl.cs.ucla.edu/projects/glomosim.

[24] D.B. Johnson and D.A. Maltz. ”Dynamic Source Routing in Ad Hoc Ad hocNetworks,” *In Mobile Computing, edited by T. Imielinski and H. Korth*, Kluwer Publishing Company. 1996, Ch. 5, pp. 153-181.

[25] Sung-Ju Lee, Mario Gerla, and Ching-Chuan Chiang, “On-Demand Multicast Routing Protocol,” *Ad hocAdaptive Mobility Laboratory*, Computer Science Department, University of California, Los Angeles, IEEE, 1999; http://www.cs.ucla.edu/NRL/wireless.

[26] “Mobile WiMAX: Personal Broadband Services for Enhancing Lifestyles and Productivity,” *White Paper, WiMAX Forum*, 2006.

[27] “Can WiMAX Address Your Applications?,” *Prepared by Westech Communications Inc. on behalf of the WiMAX Forum*, October 24, 2005.

[28] Jorjeta G.Jetcheva and David B. Johson, “A Performance Comparison of On-Demand Multicast Routing Protocols for Ad Hoc Networks,” *school of computer science, computer science department*, Pittsburgh, December 15, 2004.

[29] David Oliver Jorg, “Performance Comparison of MANET Routing Protocols In Different Network Sizes”, *Computer Science Project,* Institute of Computer Science and Applied Mathematics, Computer Networks and Distributed Systems (RVS), University of Berne, Switzerland, 2003.

[30] Uyen Trang Nguyen and Xing Xiong, “Rate-adaptive Multicast in Mobile Ad-hoc Networks*,” IEEE International Conference on Ad hocand Mobile Computing, Networking and Communications 2005 (WiMob 2005),* Montreal, Canada, August 2005.

[31] D. B. Johnson and D. A. Maltz, “Dynamic Source Routing in Ad-Hoc Ad hocNetworks," *Mobile Computing, ed. T. Imielinski and H. Korth,* Kluwer Academic Publishers, 1996, pp. 153-181.

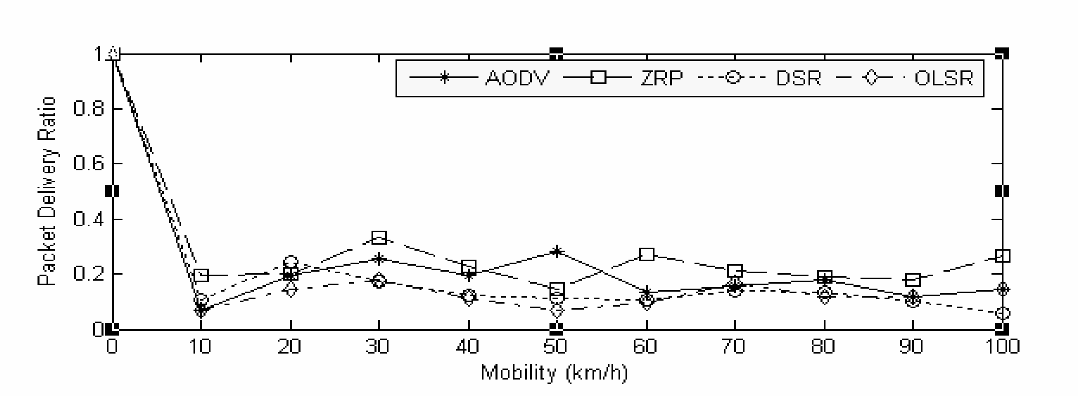

Fig. 9 *Packet Delivery Ratio*

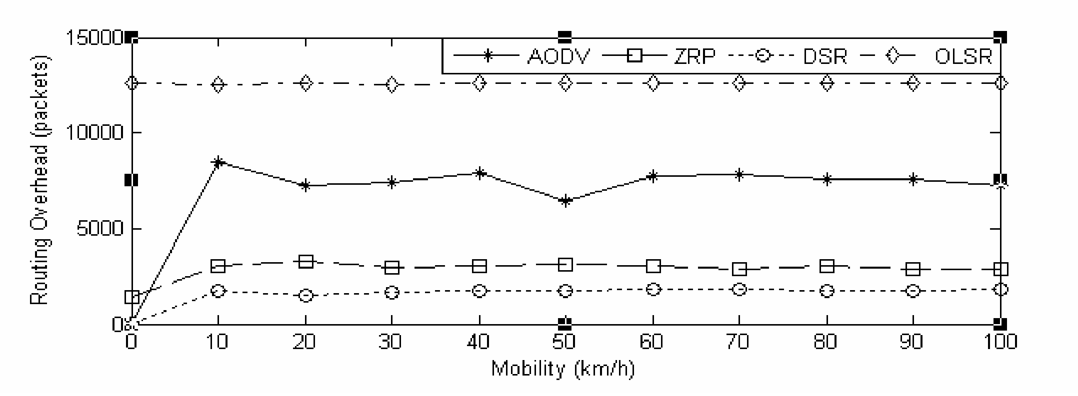

Fig. 10 *Routing Overhead*

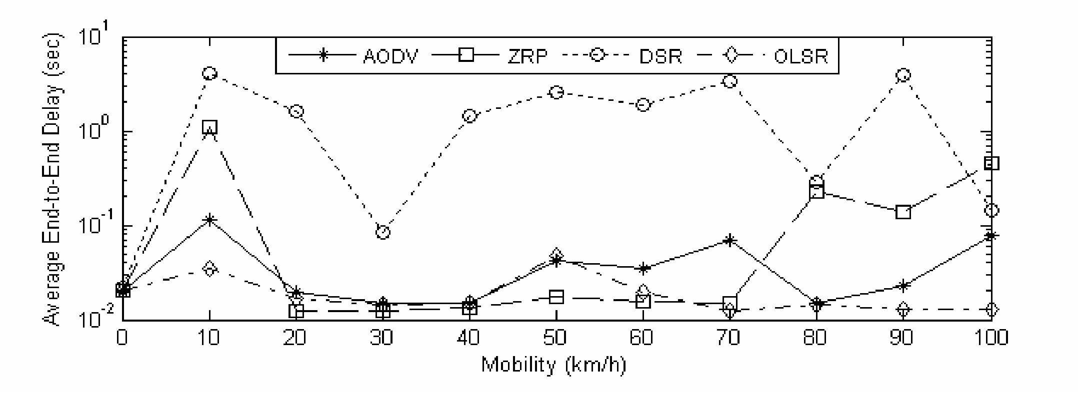

Fig. 11 *Average End-to-End Delay*

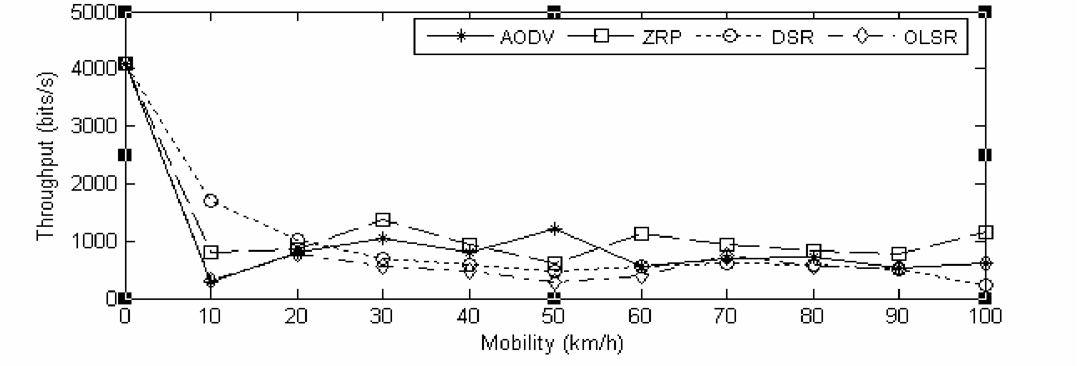

Fig. 12 *Throughput*