PERFORMANCE EVALUATION OF DIFFERENT WIRELESS AD HOC ROUTING PROTOCOLS

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ABSTRACT

One of the major challenges in wireless ad hoc network is the design of robust routing protocols. The routing protocols are designed basically to established correct and efficient paths between source and destination. In the recent years several routing protocols have been proposed in literature and many of them studied through extensive simulation at different network characteristics. In this paper we compare the performance of three most common routing protocols of mobile ad hoc network i.e. AODV, DSR and ZRP. Performance of these three routing protocols are analysed based on given set of parameters. We compare the packet delivery ratio, average end to end delay, average jitters and energy consumption behaviours of the AODV, DSR and ZRP.

KEYWORDS

Routing protocols, Wireless ad hoc network, Energy efficiency, Performance evaluation, Simulation, Mobility

1. INTRODUCTION

Mobile technology has strongly influenced our personal and professional lives in the recent time due to its applicability and versatility in different fields. Cellular phones, PDA, blue-tooth devices, and many hand-held computers enhanced our computing, communication skills and information accessing capabilities through their inherent advantages. Furthermore numerous traditional home appliances are blending with wireless technology, are extend the wireless communication to a fully pervasive computing environment. Mobile networking is emerging as one of the most pervasive computing technologies. There are typically two types of wireless networks: (i) infrastructure based, and (ii) infrastructure less. The first category requires access points or base stations to support communications, while the second type does not require such technology (or device) and commonly known as ad hoc network. Multi hop wireless networks in all their different form such as mobile ad hoc network (MANET) and vehicular ad hoc network (VANET), wireless sensor network(WSN), wireless mesh network(WMN), etc are coming under this category. In multi-hop technique destination nodes may be multiple hops away from the source node. This approach provides a number of advantages as compare to single-hop networking solution. Some of its advantages are (i) support for self configuration and adaption at low cost, (iii) support of load balancing for increasing network life, (iv) greater network flexibility, connectivity, etc[1], [2], [3]. However irrespective of these advantages it also suffered many challenges associated with unpredictable mobility, restricted battery capacity, routing, etc.[4]

The most fundamental problem of ad hoc network is how to deliver data packets efficiently among the mobile nodes. Since node's topology changes frequently that makes routing very problematic. Also low bandwidth, limited battery capacity and error prone medium adds further complexity in designing an efficient routing protocol. Estimation of end-to-end available

DOI : 10.5121/ijwmn.2012.4214

bandwidth is one of the key parameter as resource allocation; capacity planning, end-to-end file sharing, etc depends on it. As nodes are battery operated and it is always a cumbersome task to recharge them in most of the environments, for which proper utilization of available power is the key issue for power aware routing protocols. Flooding based routing protocols rely on message forwarding by broadcasting the message among them. This mechanism consumes a major portion of battery power at node level. Coverage and connectivity are also other consideration in ad hoc routing protocols along with load balancing and flow control mechanism. Most of the algorithms form a tree structure when nodes do not have location information in its local cache. However a tree based topology does not perform well in terms of energy efficiency and scalability. So far the works done on routing in ad hoc networks categorised as: (i) reactive, (on-demand) (ii) proactive (table driven) and (iii) hybrid (mixed). Reactive routing protocols establish path based on the requirements. However proactive based works differently, in this approach each node keeps the path information in the routing table and establish the path based on the routing table information. Reactive protocols are considered as the most suitable for networks with higher mobility. In contrast proactive protocols are best fit to the static networks where node information does not changes frequently but they suffered with *loop to infinity problem* when a link fails. Hybrid routing protocols in other hand carry some features of on-demand protocols and some from table driven protocols. Regardless its advantages very few works have been focused on hybrid protocols.

The remaining structure of the paper described as follows. Functionalities and working procedures of AODV, DSR and ZRP were discussed in section 2. Section 3 demonstrates the performance evaluation, comparison and simulation results of AODV, DSR, and ZRP. Related literature study is presented briefly in section 4. Conclusion is made on section 5.

2. BACKGROUND

2.1. Ad-hoc On-Demand Distance Vector Routing (AODV)

Perkin *et al.* first presented AODV in [5] which then standardize in IETF RFC 3561 in 2003[6]. It is an improvement on the DSDV [7] algorithm and modified message broadcasting procedure to minimize the number of required broadcasts by creating routes on a demand basis instead of maintaining a complete list of routes as observed in the DSDV algorithm. AODV makes use of destination sequence numbers to ensure all routes are loop-free and contain the most recent route information. The destination sequence number is to be included along with any routes the destination sends to requesting nodes. Given the choice between two routes to a destination, a requesting node is required to select the one with the greater sequence number. The greater sequence number indicates that route is a fresh route as compared to its counterpart. Three message types defined by AODV are: *Route Requests* (RREQs), *Route Replies* (RREPs), and *Route Errors* (RERRs).

A path discovery process is initiated when a source node wishes to send a message to a destination node and does not have a valid route. The source broadcasts RREQ, recipients of RREQ forward the message if they don't have the path to the destination. The forwarding continues till message reach the destination. In other way a route can be determined when the RREQ reaches either the destination, or an intermediate node with a 'fresh enough' route to the destination. If the intermediate node finds a fresh enough route in its route cache then rather than forwarding RREQ it reply back to the source by RREP. Node receiving the request caches a route back to the originator of the request, so that the RREP are *unicast* from the destination along a path to that originator.

Each node maintains its own sequence number and a broadcast ID. The broadcast ID is incremented for every RREQ the node initiates. RREQ are uniquely identified with the sequence number and node's address. The source node, with its broadcast ID includes the most recent sequence number it has for the destination in the RREQ. Intermediate nodes reply to the RREQ with a RREP packet only if they have a route to the destination whose corresponding destination sequence number is equal or greater than the sequence number contained in RREQ. While forwarding the RREQ, intermediate nodes records address of the neighbors from which the first copy of the broadcast packet is received in its routing table. Node discarded the duplicate copies of the RREQ. Each route entry is associated with a timer, when the timer expire the route entry is discarded from the routing table. As the RREP travels back to the source using the reverse path, all intermediate nodes create a new route entry for destination.

A RERR message is send when a link break is detected in an active route. The RERR message indicates that path to destination is no longer reachable by way of the broken link. A node initiates RERR message under three situations. (i) If it detects a link break for the next hop of an active route in its routing table. (ii) If it gets a data packet destined to a node for which it does not have an active route (iii) If receives a RERR message from its neighbor. Figure 1 shows the message exchange between source and destination in AODV.

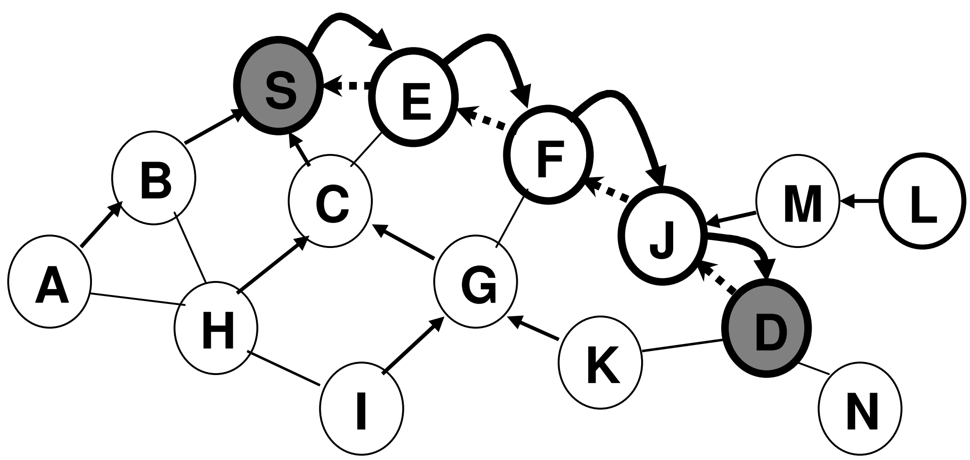


Fig. 1. Message Exchange between Source 'S' to the Destination 'D'

2.2. Dynamic Source Routing (DSR)

Johnson *et al.* proposed DSR which is available as a IETF draft in [8]. DSR is developed for multi-hop wireless networks and is very simple and efficient in term of path findings. The protocol consists of two main phases: (i) Route discovery and (ii) Route maintenance. Each, data packet contains the complete ordered list of nodes along the route in its header. This makes routing trivially loop-free and does not require up-to-date routing information in the intermediate nodes through which the packet is forwarded. This way other nodes along the route can easily cache the routing information for future use. Entries in the route cache are continually updated when new routes are learned. The basic operation of DSR is discussed below.

When a node needs to send a packet to other node it places a complete list of hops to follow in its packet header. It first checks its route cache and if doesn't find the destination in its route cache it start the proceedings to find the path. If it has a route to the destination, it will use this route to send the packets. Otherwise node initiates the route discovery by broadcasting a RREQ packet. RREQ contains sender and destination address. An intermediate node on receiving the packet checks destination address, if node knows the destination address, reply to the source otherwise it appends it's address to the route record and broadcasts it further. A node discards the request it has recently received from another route from the same initiator or the route record already contains its own address. In this way node in DSR prevents looping. Figure 2 and 3 shows the request and reply between source and destination.

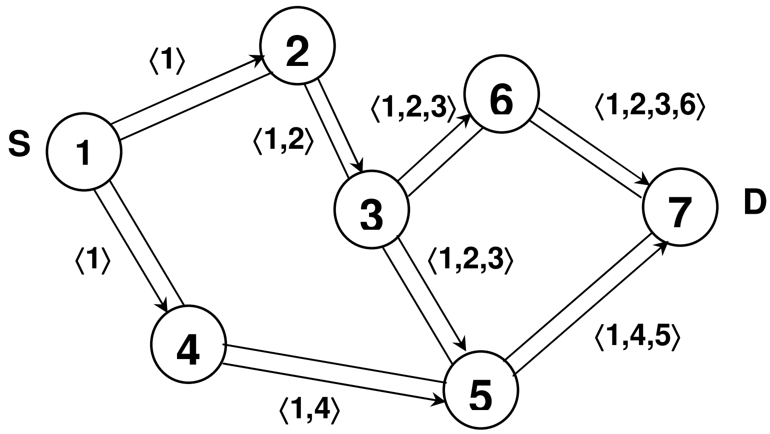


Fig. 2. Request message propagation in DSR, between S to D.

The route maintenance is accomplished through the use of route error packets and acknowledgements. Each node broadcast packets and waits for acknowledgements. If node doesn't receive an acknowledgement after forwarding a packet, it sends an acknowledgement request. If node doesn't receive any reply within a specific time it then generates RERR message and sends it to the sender of the packet.

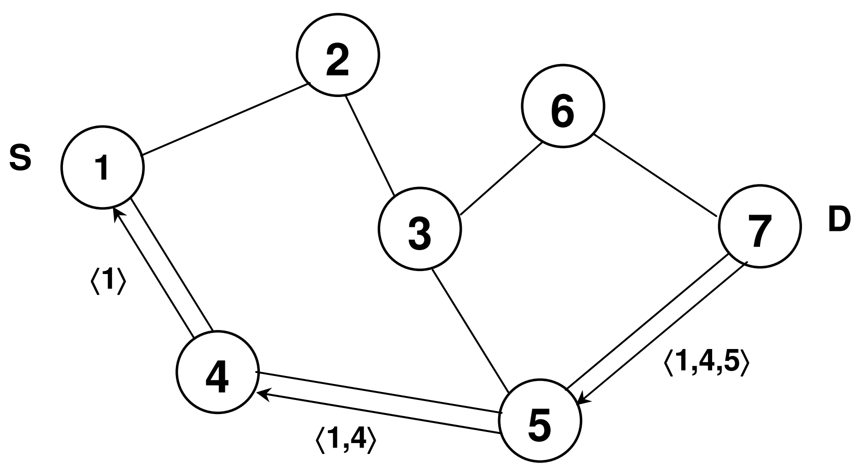


Fig. 3. Reply message propagation between D to S

2.3. Zone Routing Protocol (ZRP)

ZRP [9] is the first hybrid category protocol which effectively combines best features of reactive and proactive routing protocols. It employs concept of proactive routing scheme within limited zone (within the r-hop neighborhood of each node), and uses reactive approach beyond that zone. The two routing schemes used by ZRP are: (i) Intra-zone routing protocol (IARP) and (ii) Inter-zone routing protocol (IERP). The main components of ZRP are discussed below.

The first protocol to be part of ZRP is IARP, which is a pro-active, table-driven protocol. The protocol is used when a node wants to communicate with the interior nodes of it's zone. It allows local route optimization by removal of redundant routes and the shortening the routes if a route with fewer hops has been detected, as well as bypassing link failures through multiple hops, thus leveraging global propagation. IARP is used to maintain routing information and provides route to nodes within zone.

The second protocol which is the part of ZRP is IERP. It uses the *route query* (RREQ)/ *route reply* (RREP) packets to discover a route in a way similar to typical on-demand routing protocols. In ZRP, a routing zone consists of a few nodes within one, two, or a couple of hops away from each other. It works similar to a clustering with the exception that every node acts as a cluster head and a member of other clusters. Each zone has a predefined zone centred at itself in terms of number of hops. Within this zone a table-driven-based routing protocol is used. This implies that route updates are performed for nodes within the zone. Therefore, each node has a route to all other nodes within its zone. If the destination node resides outside the source zone, then an on-demand search-query routing method can be used.

ZRP also uses *Bordercast Resolution Protocol* (BRP). When intended destination is not known, RREQ packet is broadcast via the nodes on the border of the zone. Route queries are only broadcast from one node's border nodes to other border nodes until one node knows the exact path to the destination node. ZRP limits the proactive overhead to only the size of the zone, and the reactive search overhead to only selected border nodes. The IARP in ZRP must be able to determine a node's neighbours itself. This protocol is usually a proactive protocol and is responsible for the routes to the peripheral nodes. Figure 4 shows the components of ZRP.

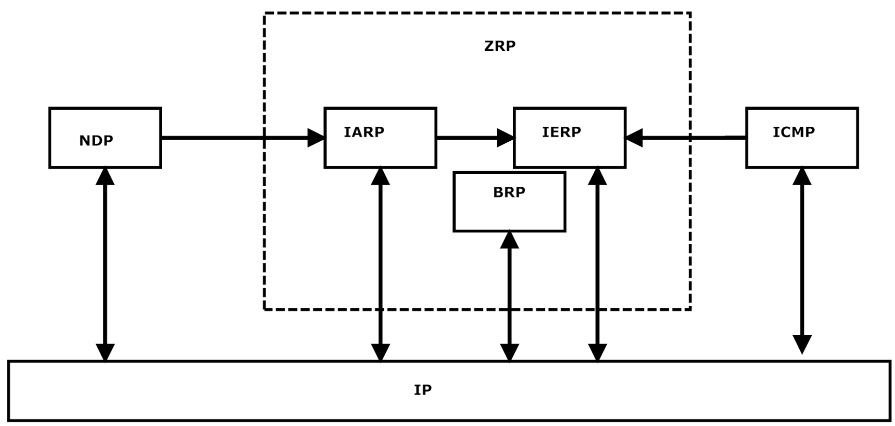


Fig. 4.. Components of ZRP

3. PERFORMANCE EVALUATION

3.1 Network Simulator

Qualnet network simulator [10] is used here for simulating multihop ad hoc wireless network routing protocols. It is a commercial version of GloMoSim [11] and is developed by Scalable Network Technology. It is extremely scalable and can supports high fidelity models of networks of thousands of nodes. In a discrete event simulator like Qualnet, the simulation performed only when an event occurs. It is based on event scheduler, which contains any events that needs to be processed and stepped through. Processing of an event may produce some new events. These new events are inserted into event scheduler. QualNet is modelling software that predicts performance of networking protocols and networks through simulation and emulation. The simulator is written in C++ while it's graphical toolkits are implemented in Java. Every protocols in QualNet starts with an initialization function which takes an inputs and configures the protocol. Event dispatcher activated when an event occurs in a layer. The simulator checks the type of event and calls appropriate event handler to process. At the end of the simulation finalization function is called to print out the collected statistics. Figure 5 shows the event handling process in QualNet.

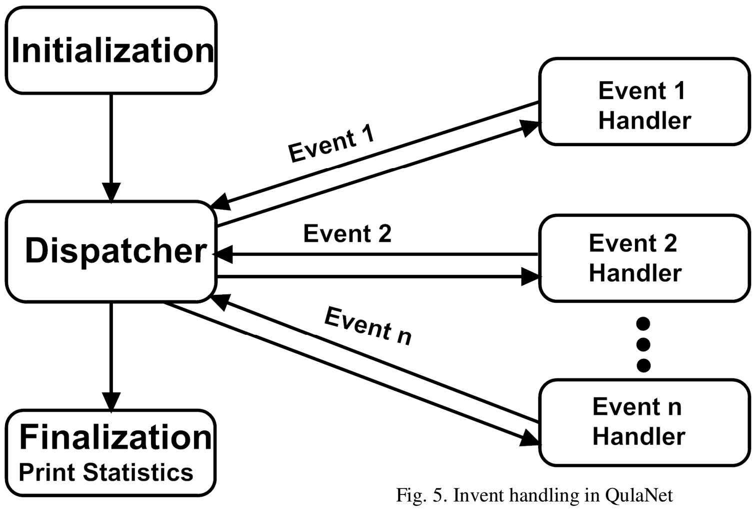


Fig. 5. Invent handling in QulaNet

3.2 Simulation Environment

Our evaluation is based on the simulation of 36 nodes deployed randomly in a square area of (1500m × 1500m) flat surface for a simulation time of 200s. IEEE 802.11 DCF is used as the MAC protocol. The radio model uses bit rate of 2 Mbps and has a radio range of 250 meters. We generated 45 different scenarios with varying movement patterns and communication patterns. Since each method was changed in an identical fashion for which direct comparisons are made from simulator.

Mobility Model

Random way point (RWP) mobility model is used in our simulation which is characterised by a pause time. Node remains stationary for a certain periods of time (known as pause time). At the end of that time node choose for a random destination in (1500m × 1500m) simulation space area. The node moves to the destination at a speed in the range [0, max]. When node reaches the destination it waits for time equal to pause time and starts moving for another destination. It repeats this behaviour for the entire given simulation time. We simulate with 5 different pause times: 0, 25, 50, 100s and 200s. The pause time of 0 seconds represent the continuous motion while pause time of 200 represents no motion. As the movement pattern is very sensitive to performance measurement, we generate 15 different movement patterns, three for each value of pause time. All three routing protocols were run for the same 15 movement pattern. We test with maximum speed movement of 10, 15 and 20 m/s.

Traffic Pattern

For the above comparison of routing protocols constant bit rate (CBR) traffic patterns are used. The network contains four CBR traffic sources and packet size is 512 bytes. Packets are send from source nodes in 1s interval and total 100 items are send from each source. Single communication patterns are taken in conjunction with 15 movement patterns which provides 45 different scenarios.

Energy Model

The energy consumption of radio interface depends upon different type of operation mode. We considered the energy model where energy E consume by a node to transmit k bit can be expressed as:

$$E = P_{active} \times T_{active} + P_{sleep} \times T_{sleep} + P_{idle} \times T_{idle}$$

Where P_{active}, P_{sleep}, P_{idle} are the power consumptions in active, sleep and idle state respectively and T_{active}, T_{sleep} and T_{idle} are the duration of time that a transceiver stays in respective states. In active state a node either transmits or receives packets, while in idle state it waits for traffic to participate. When a node in active state transmits or receives packets the network interface of a node decrements the energy based on certain parameter such as size of the packets, bandwidth of channel, NIC characteristics etc. According to the specification of NIC modelled we consider the energy consumption of 200mA in receiving mode and 230mA in transmitting mode using 3.0 V supply voltage.

3.3 Performance Metrics

Following metrics have been chosen to compare the routing protocols

Throughput (Packet delivery ratio): It is the ratio of packets received at destination to the packet sent by the source node. Protocols with better packet delivery ratio are considered as the efficient protocols; however this parameter depends upon many other factors also.

Average end-to-end delay: It is the average time a packets takes to reach the destination. It considers all types of delay such as queuing delay, route discovery delay, interface delay, etc. It is also known as the average time between sending and successfully receiving a packet. Sometimes it is also known as *path optimality*.

Average jitter: Jitter is referred as measure of the variability over time of the packet latency across a network. When a network has constant latency it has no variation (or jitter). Packet jitter is expressed as an average of the deviation from the network mean latency.

Energy consumption behaviour: Energy is consumed when node transmit and receives packets and processed a packets. Energy also consumed in idle state. Energy consumption of a node mainly depends on the state of a mobile node. The message sending mechanism and carrier sensing methods plays a vital role on energy consumptions along with traffic pattern.

3.4 Simulation Results

We have done simulations using three node movement speeds. A maximum speed of 10, 15, and 20 m/s is used for comparing AODV, DSR and ZRP. Pause time is varied from minimum 0 pause value to maximum value equal to simulation time. Pause time 200 represents that nodes are static and 0 pause time means they are fully mobile.

3.4.1 Throughput at varying pause time

The throughput is calculated as the average number of packets received per amount of time, this is expressed:

*Throughput= (Total bytes received * 8) / (Last packet received - First packet received)*

Figure 6 to 8 shows throughput verses pause time. As expected reactive routing protocols AODV and DSR are giving better throughput as compared to ZRP. Both at high and at low mobility (high mobility when pause time is zero and low mobility when pause time is maximum) and in different movement speed DSR giving better results in comparison to AODV. All the methods deliver a greater percentage of originated data packets at low mobility.

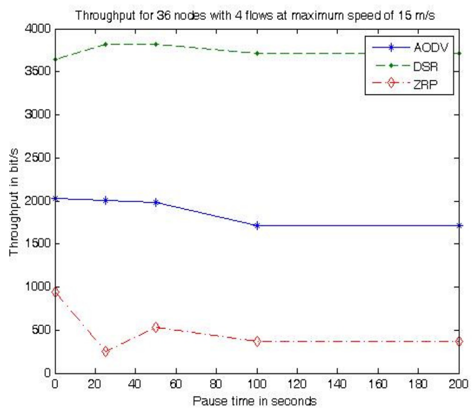


Fig. 6. Throughput at maximum speed of 10 m/s

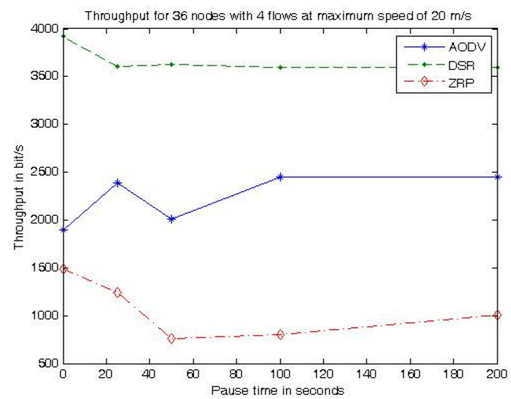
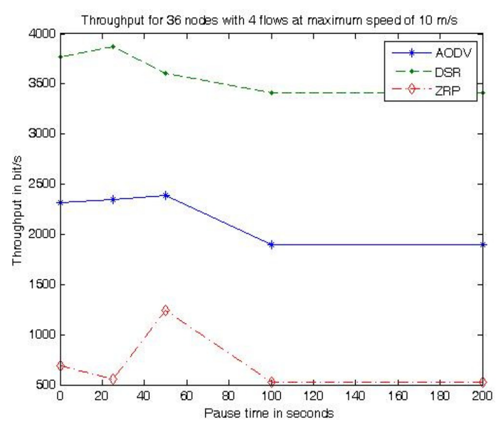


Fig. 7. Throughput at maximum speed of 15 m/s



3.4.2 Average end to end delay

The average end to end delay (E2ED) refers the difference between the origination time of the packet and final destination time at which packet reached the destination. This is calculated as:

E2ED= ((Sum of the delays of each CBR packet received)/ number of CBR packets received)

However in our simulator, also consider transmission time for calculating average E2ED in CBR. Figure 9 to 11 shows E2ED at different node speeds. The average E2ED of ZRP is high as compared to DSR and AODV. The delay of DSR and AODV are nearly matched in all mobility and pause time. E2ED of ZRP is more unpredictable due to IARP and IERP protocols working functionality.

Fig. 9. Average end to end delay at maximum speed of 10 m/s

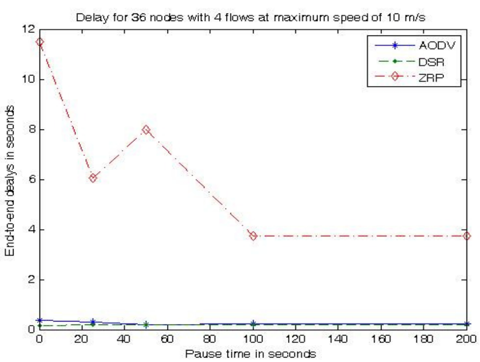
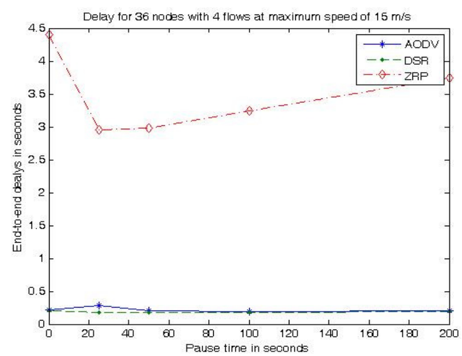


Fig. 10. Average end to end delay at maximum speed of 15 m/s



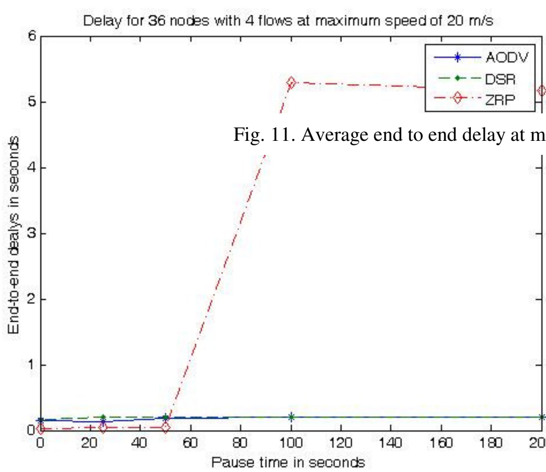


Fig. 11. Average end to end delay at maximum speed of 20 m/s

3.4.3 Average jitter

In order to find the average jitters in the networks following calculations are made. When CBR servers receive N packets from client, i = 1 to N; and if N is greater than 2 then jitter (J) can be calculated as:

$$J(i) = delay(i+1) - delay(i)$$

$$Avg.\ J = (j(1) + J(2) + \ldots + J(N-1)) / (N-1)$$

Figure 12, 13 and 14 shows the average jitter at different pause time and node mobility. It is observed that average jitters of AODV at high mobility is less than 0.1s. The average jitters of ZRP are worst in comparison to AODV and DSR.

Fig. 12. Average jitters at maximum speed of 10 m/s

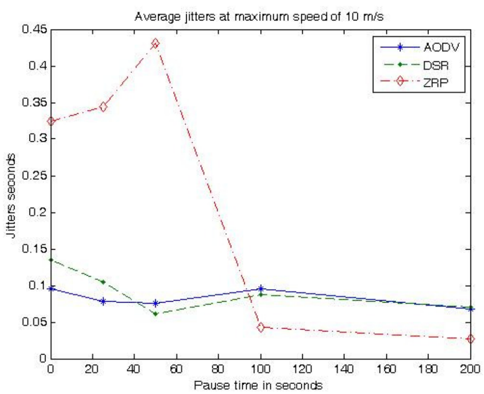


Fig. 13. Average end to end delay at maximum speed of 15 m/s

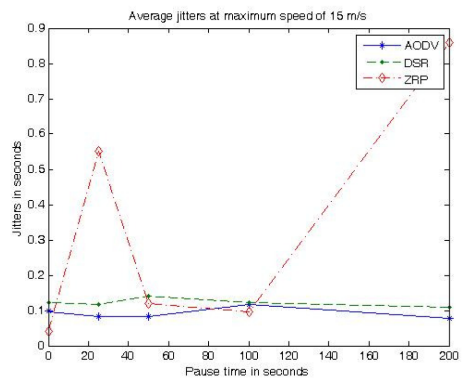
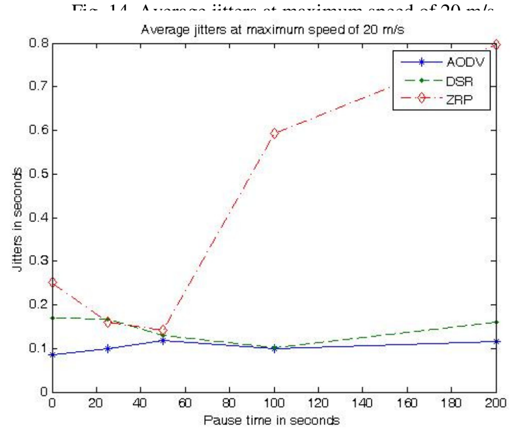


Fig. 14. Average jitters at maximum speed of 20 m/s



3.4.4 Energy consumption behaviour

Energy consumptions of three routing protocols at transmit, receive and idle state is depicted through figure 14, to 16. The source nodes of CBR traffic send the packets at the power in which they have assigned. Intermediate nodes between source and destination forward the packets to destination and acts as relay nodes. The nodes those aren't participating in the packet exchange remain in idle for the entire simulation time. In the absence of suitable sleep strategy idle nodes remain active for entire communication periods; hence the idle power consumption in a network is greater in comparison to active state power consumptions. The situation goes to worst condition when most of the nodes are remain in idle state. The energy consumptions in transmit/receive state also vary based on the routing strategy used by the routing protocols.

It is observed that AODV is energy efficient in all cases. AODV uses active route cache path finding for which it consume less energy both in path finding and maintenance process. DSR is energy in-efficient as compared to AODV and ZRP. Energy consumed by DSR is higher both in transmitting and receiving states. One of the main causes of higher energy consumption is it's increase packet header size which increases in each increase of hop counts. Idle state power consumptions is depend on the MAC layer power management strategy for which it is almost independent of routing protocols. All three routing protocol consumes nearly same energy in idle state. We doesn't considered the sleep power consumption in this analysis as sleep state consume very less power [12] and need power management support from MAC layer.

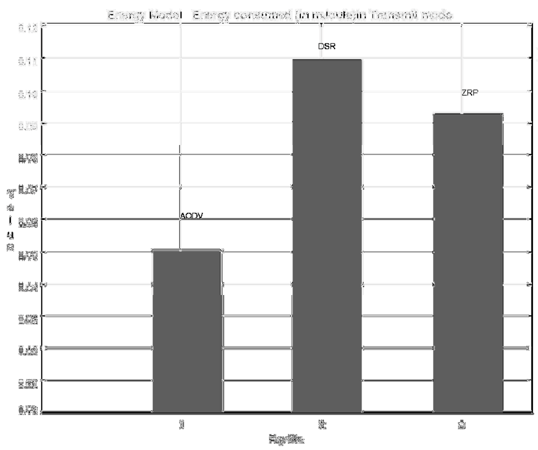


Fig. 15. Energy Consumed (in m Joule) in Transmit mode

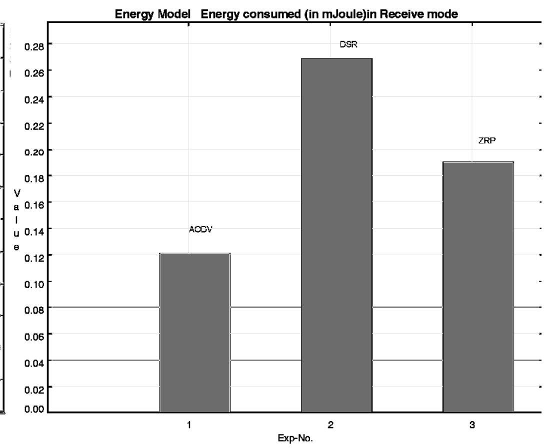


Fig. 16. Energy consumed (in M Joule) in Received mode

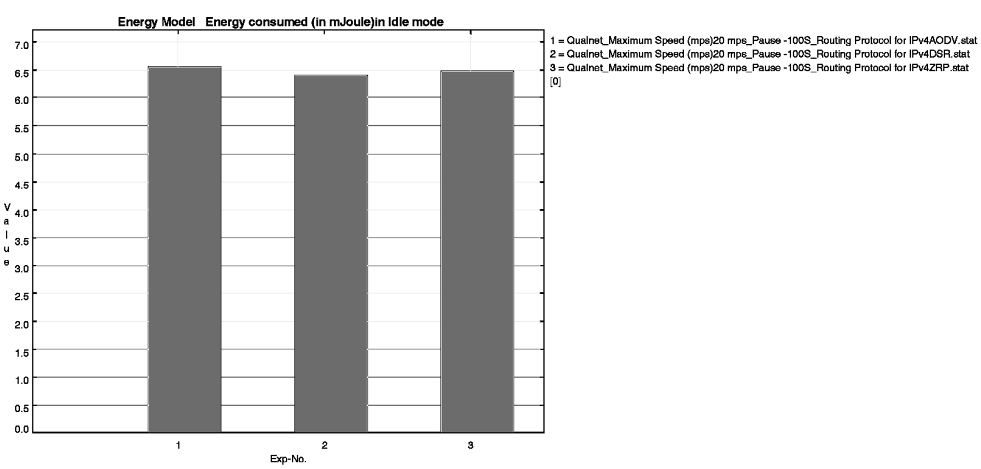


Fig. 17. Energy consumed in idle mode

4. RELATED WORKS

We would like to introduce some study based on comparison of different routing protocols in wireless ad hoc networks. This section focused on literature review pertaining to routing in wireless ad hoc networks.

Broch, *et al.* [13] evaluated four ad hoc routing protocols including AODV and DSR. They used 50 node models with variable mobility and traffic scenarios. Packet delivery fraction, number of routing packets, and distribution of path lengths were used as performance metrics. Simulation results reveal that DSR demonstrated vastly superior routing load performance, and somewhat superior packet delivery and route length performance.

Das *et al.* [14] use MAC and physical layer models to study interlayer interactions and their performance implications. The simulation were done on the *ns-2* [15] and consider the radio model similar to Lucent's WaveLAN radio interface and random waypoint mobility with pause time from 0 to 500 seconds. In two different scenarios, 50 and 100 nodes were utilized with an area size of 1500m/300m respectively 2200m/600m. Even both DSR and AODV share similar on-demand behaviour, their differences in the protocol mechanics can lead to significant performance differentials. The performance differentials are analyzed using varying network load, mobility, and network size. Based on the observations, the authors made some suggestions about how the performance of either protocol can be improved. The simulation results suggest that AODV outperforms DSR in more stressful situations (i.e. larger network, higher mobility). However DSR showed advantage in the general lower routing overhead and in low mobility.

A mix set of reactive, proactive and hybrid protocols are analysed under realistic scenarios by Hsu *et al.* [16]. The paper demonstrates performance comparison of several protocols using the network and traffic configuration from the live exercise. The comparison shows that AODV performed better in term of throughput and lower average delay. The OLSR [17] showed good resilience to link state situation, while packet delivery ratio curve of DSR revels that when the delay in the network grows and network size increase the DSR delivers larger percentage of traffic.

Another work [18] compares performances of AODV, DSDV, TORA [19] based on four performances metrics: average delay, packet delivery fraction, routing load and varying network size. The authors suggest that that AODV exhibits a better behavior in terms of average delay as compared to TORA and DSDV. In less stressful situation, the packet delivery fraction of, the TORA outperforms DSDV and AODV.

In [20] OLSR and LAR1 [21] are compared using RWA mobility. It is found that OLSR has better end to end delay performance in comparison to LAR1. Ref [22] combined the LAR protocol with a probabilistic algorithm and presented a new location based routing protocol called LAR-1P. The modified protocol gives better message transmission at different node density. Authors suggest that their protocol can give better throughput at increasing node density.

Beaubrun and Molo [23] propose a formulation of the routing problem in multi-services MANETs, as well as the implementation of an adaptation of the DSR. Simulation results suggest that DSR enables to provide end-to-end delay less than 0.11 s, as well as packet delivery ratio higher than 99% and normalized routing load less than 13%, for low mobility level and low traffic intensity.

5 CONCLUSIONS

This paper evaluates the performances of three most common routing protocols in wireless ad hoc network. DSR is purely reactive in nature and it's path finding is very effective for which its throughput is high as compared to its main counterpart AODV. However DSR suffers with scalability issue. It's performance at fast moving scenario and at dense network is the major issue of concern. In our case the network density was low for which it gives better packet delivery ratio but we suspect its performance in term of throughput may degrade when the node density will increase. AODV is energy efficient both in transmitting and receiving states. Energy consumption of AODV is better as compared to DSR and ZRP for which it is considered as the most energy efficient protocols. However its performance is not properly compared with the other energy efficient routing protocols such as cone based topology control (CBTC) [24], XTC [25], SPAN [26], etc. ZRP provides very low throughput but its routing overheads is low. In this study we have focused on some metrics but metrics like network life time and battery power utilization is not properly studied at different mobility and node speed. Network life time with different flow is another challenging task can be analysed. In future we will focus in measuring the battery power utilization and network life time analysis at different mobility and traffic load.

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