ZRP versus DSR and TORA: A comprehensive survey on ZRP performance

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Abstract

Ad hoc networks are characterized by dynamic topology caused by node mobility, multihop wireless connectivity and channel non-deterministic behavior (interference, multipath, hidden and exposed node problem make the wireless channel very difficult to predict). The behavior of ad hoc networks must be analyzed in detail as a result of the pairing of the selected MAC and Routing protocols. We focus our studies in the routing layer while closely observing the developments in MAC layer. We present and examine analytical simulation results for the routing protocols DSR, TORA and ZRP especially focusing in ZRP and the impact of some of its most important attributes to network performance, using the well known network simulator OPNET 10.0.PL2.

1. Introduction

Many routing algorithms for ad hoc wireless networks today promise rapid network convergence, multi-hop routing capabilities and soft real-time performance. With the use of IEEE 802.11 as the underlying Mac layer a totally distributed wireless infrastructure can self organize and form a multihop wireless network. Some of the applications of ad-hoc networks can be in law enforcement, in emergency response in case of catastrophic events [1] as well as in various military applications. At the same time, a role for ad hoc networks exists also in construction sites, industry factories and public wireless networks in airports, stations, convention centers etc. The key factor that determines how efficiently a multihop wireless network reacts to topology changes and node mobility is the routing algorithm that provides routes for every node in the network. Several routing protocols have been proposed in the past both of proactive and reactive nature as well as and some that take a hybrid approach.

An analytical performance comparison of some of the most important algorithms is presented, like Dynamic Source Routing (DSR) [2],[3] and Temporary Ordered Routing Algorithm (TORA) [4],[5]. DSR is the main and most known protocol of the reactive family of protocols while TORA uses a unique approach in hop-by-hop routing, guiding every packet to its destination. We also evaluate Zone Routing Protocol (ZRP) [6] compared to the above protocols, which is a well known hybrid routing algorithm. Our implementation uses DSR as its Interzone Routing Protocol (IERP) and a simple but efficient link exchange protocol as Intrazone Routing Protocol (IARP). The impact of two main ZRP attributes in its performance is then evaluated, ZRP zone radius and IARP routing information update interval.

The performance regarding to end-to-end delay is examined and number of packets successfully routed to their destination. Finally the simulation results using OPNET 10.0.PL2 are presented and evaluated in order to pinpoint the good and bad aspects of every protocol.

2. Related Work

There are several other efforts related to our work, with more recent the work of Perkins, Royer, Samir R. Das and Manesh [7]. They evaluated DSR and AODV using NS-2 network simulator for 50 and 100 nodes in a rectangular space. The traffic and mobility models they used are the ones incorporated into NS-2. Their simulations didn't include ZRP, neither they tried to find the impact of specific attributes of DSR or AODV in network performance. The mobility models were not different but instead they used a uniform distributed speed of nodes between 0-20 m/sec. This doesn't help to examine network performance in various mobility scenarios since the nodes move in a mean 10m/sec speed. Even more the physical medium model of IEEE 802.11 in Ns-2 is not as sophisticated as OPNET's model is.

Another relative work has been presented by Broch, Maltz, Johnson, Hu, and Jetcheva [8]. They evaluated four ad hoc routing protocols including AODV and DSR. They also used Ns-2 to simulate 50-node network models with mobility and traffic scenarios similar to the scenarios Perkins et al did. But their traffic loads are kept very low and they use only 64 bytes packets. Such small packet size is of course a disadvantage for DSR since when packet size is small, the source routing information inside every packet becomes more and more burdening for the network. On the other hand we used an exponentially distributed packet size of 1024 bytes which makes the comparison fair between DSR, ZRP and TORA. They concluded that DSR is a very good and superior protocol network in low traffic situations. The above results are extended by our work since we test DSR, as well as TORA and ZRP to all kind of conditions regarding node mobility and network loads.

Besides comparison of ad hoc network several other papers have dealt with ZRP especially and tried to pinpoint the perfect zone radius value. Hass and Pearlman have done extensive research in ZRP and they have concluded that no fixed value of ZRP's zone radius attribute exists, but every time it is dependant on the networks conditions [9]. Even more they have shown that the use of further query control mechanism on ZRP enhances its performance in every network state [9]. The above work is also extended by trying to find the network conditions that make necessary the use of a higher or lower zone radius as well as IARP's Update Interval attribute, for ZRP to perform efficiently.

Last but not least there hasn't been any related work and presented simulation results, regarding how DSR performs if used as an IERP part of ZRP. Since ZRP seems to boost the IERP protocol's performance by using the IARP infrastructure to reduce the flooding overhead of discovery packets, it is interesting to see how that will affect DSR's performance.

3. Protocols presentation

We shall make a small presentation of the three protocols we evaluate in this paper. A more thorough presentation of ZRP shall be made, since it is mainly the impact of its attributes to its performance that we want to focus on this paper. The two other protocols have been simulated using the standard values, introduced in the corresponding drafts.

3.1. Dynamic Source Routing (DSR)

The Dynamic Source Routing protocol is composed of two main mechanisms to allow the discovery and maintenance of source routes in the ad hoc networks.

Route Discovery: is the mechanism by which a source node wishing to send a packet to a destination node, obtains a source route to the destination. Route Discovery is used only when the source node attempts to send a packet to a destination and does not already know a route to that destination.

Route Maintenance: is the mechanism by which a node wishing to send a packet to a destination is able to detect, while using a source route to the destination, if the network topology has changed. If this is the case then it must no longer use this route to the destination because a link along the route broken. Route Maintenance for this route is used only when the source node is actually sending packets to the destination.

A routing entry in DSR contains all the intermediate nodes of the route rather than just the next hop information maintained in DSDV and AODV. A source puts the entire routing path in the data packet, and the packet is sent through the intermediate nodes specified in the path If the source does not have a routing path to the destination, then it performs a route discovery by flooding the network with a route request (RREQ) packet. Any node that has a path to the destination in question can reply to the RREQ packet by sending a route reply (RREP) packet. The reply is sent using the route recorded in the RREQ packet.

To limit the need for route discovery, DSR allows nodes to operate their network interfaces in promiscuous mode and snoop all (including data) packets sent by their neighbors. Since complete paths are indicated in data packets, snooping can be very helpful in keeping the paths in the route cache updated. To further reduce the cost of route discovery, the RREQs are initially broadcasted to neighbors only (zero-ring search), and then to the entire network if no reply is received. Another optimization feasible with DSR is the gratuitous route replies; when a node overhears a packet containing its address in the unused portion of the path in the packet header, it sends the shorter path information to the source of the packet (Automatic Route Shortening). Another important optimization includes the technique to prevent "Route reply Storms" : because many route replies may be initiated simultaneously a delay time proportional to the hop's-distance can be used in order to give higher priority to near nodes. In addition a method called "Packet Salvaging" is often used in DSR. When an intermediate node forwarding a packet detects through Route Maintenance that the next hop along the route for that packet is broken, if the node has another route to the packets ´s destination it uses it to send the packet rather than discard it. An interesting and a bit different approach of DSR is the DSR_flows described in [13].

To summarize we provide the basic characteristics of the Dynamic Source Routing (DSR):

- Uses source routing
- Provides loop-free routes
- Supports unidirectional links and asymmetric routes
- With the optimizations available it is a good choice for an ad hoc network

3.2. Zone Routing Protocol (ZRP)

Due to its importance we will give a more analytical description of the Zone Routing Protocol (ZRP). ZRP is an example of a hybrid reactive/proactive routing protocol based on parameter called routing zone. A routing zone (of radius p) is defined for each node and includes the nodes whose minimum distance in hops from the node in question is at most ρ hops. In ZRP each node is assumed to maintain routing information only for those nodes that are within its routing zone. Because the updates are only propagated locally, the amount of update traffic required to maintain a routing zone does not depend on the total number of network nodes (which can be quite large). We assume that a node learns its zone through some sort of a proactive scheme, which we refer to as IARP. For nodes outside the routing zone IERP is responsible for reactively discovering routes to destinations located beyond a node's routing zone. The IERP is distinguished from standard flooding-based query/response protocols by exploiting the structure of the routing zone. The routing zones increase the probability that a node can respond positively to a route query. This is beneficial for traffic that is destined for geographically close nodes.

More importantly, knowledge of the routing zone topology allows a node to efficiently continue the propagation of a query in the more likely case that destination cannot be found. This is achieved by a packet delivery service, called bordercasting routing protocol (BRP) that allows a node to direct a message to its peripheral nodes. In its simplest form, bordercasting could be implemented through network layer unicasting or multicasting of messages to the peripheral nodes. A more suitable implementation of bordercasting indirectly sends messages to peripheral nodes by forwarding them between adjacent nodes. The IERP operates as follows: the source node first checks whether the destination is within its zone. If so, the path to the destination is known, and no further route discovery processing is required. If the destination is not within the source's routing zone, the source bordercasts a route request to all its peripheral nodes. Now, in turn, all the peripheral nodes execute the same algorithm: they check whether the destination is within their zone. If so, a route reply is sent back to the source indicating the route to the destination (both hop-by hop and source routing are feasible, it depends on the reactive algorithm chosen). If not, the peripheral node forwards the query to its peripheral nodes, which in turn execute the same procedure. Because the routing zones heavily overlap, a node can be a member of many routing zones. It is very possible that the query will be forwarded to all the network nodes, effectively flooding the network. But a more disappointing result is that the IERP can result in much more traffic than the flooding itself, due to the fact that bordercasting involves sending the query along a path equal to the zone radius. This problem is addressed primarily through appropriate mechanisms of query detection and query termination. The ability to terminate an overlapping query thread depends on the ability of nodes to detect that a routing zone they belong has been previously queried. Clearly, the central node in the routing zone (which processed the query) is aware that its zone has been queried. In order to notify the remaining routing zone nodes without introducing additional control traffic, some form of "eavesdropping" needs to be implemented. The first level of query detection (QD1) allows the intermediate nodes, which transport queries to the edge of the routing zone, to detect these queries. In single channel networks, it may be possible for queries to be detected by any node within the range of a query-transmitting node. This extended query detection capability (QD2) can be implemented by using IP broadcasts to send route queries. Further improvements of the ZRP include caching the routes and using route maintenance techniques (i.e. if a link failure is detected instead of invoking a Route Discovery Phase or searching the source node’s cache for an alternate route, a local path repair is initiated. Thus after some number of repairs the there is a significant increase in the length of the path and so a Route Discovery procedure is initiated).

The basic characteristics of the ZRP: The protocol is based on a hybrid algorithm which combines reactive and proactive routing. For this purpose it uses the routing zone parameter.

- Fast convergence and very flexible algorithm. Its main advantage is that it can incorporate any newly developed protocol with little or none further effort.
- Provides multiple loop free routes increasing robustness and performance.
- Uses flat-routing instead of hierarchical and so it reduces the organization overhead.
- The protocol finds fast optimal routes, reducing the threat of congestion and minimizes route acquisition time.

Since the exchange of periodic updates is confined in a small, local area (inside the routing zone) compared to the whole network, ZRP greatly reduces the overhead by reducing the number of entries and the frequency of the periodic update packets.

The ZRP’s behavior can be adaptive based on the configuration of the network and the behavior of the users. ZRP can be applied to both small and large networks with high or low node mobility quite well.

3.3. Temporally Ordered Routing Algorithm (TORA)

The Temporally-Ordered Routing Algorithm (TORA) is a distributed routing protocol for multihop networks with a unique approach for routing the packets to their destination.

TORA is fully distributed, in that routers need only maintain information about adjacent routers (i.e., one-hop knowledge) and there is no centralized control. This is essential for all Ad Hoc routing protocols. Like a distance-vector routing approach, TORA maintains state on a per-destination basis. However, it does not continuously execute a shortest-path computation and thus the metric used to establish the routing structure does not represent a distance. The destination-oriented nature of the routing structure in TORA supports a mix of reactive and proactive routing on a per-destination basis. During reactive operation, sources initiate the establishment of routes to a given destination on-demand. This mode of operation may be advantageous in dynamic networks with relatively sparse traffic patterns, since it may not be necessary nor desirable to maintain routes between every source/destination pair at all times. At the same time, selected destinations can initiate proactive operation, resembling traditional table-driven routing approaches. This allows routes to be proactively maintained to destinations for which routing is consistently or frequently required (e.g., servers or gateways to hardwired infrastructure).

TORA is designed to minimize the communication overhead associated with adapting to network topological changes. The scope of TORA's control messaging is typically localized to a very small set of nodes near a topological change. A secondary mechanism, which is independent of network topology dynamics, is used as a means of route optimization and soft-state route verification. The design and flexability of TORA allow its operation to be biased towards high reactivity (i.e., low time complexity) and bandwidth conservation (i.e., low communication complexity) rather than routing optimality--making it potentially well-suited for use in dynamic wireless networks.

So TORA is offering the below main characteristics:

- Distributed execution,
- Loop-free routing,
- Multi-path routing,
- Reactive or proactive route establishment and maintenance,
- Minimization of communication overhead via localization of algorithmic reaction to topological changes.

4. Simulation Results

In this section the methodology is presented .This methodology is used in order to isolate the impact on network performance of the two attributes of ZRP, IARP's update interval and ZRP's zone radius.

4.1. Simulation platform, models and attributes

In our survey we have used the OPNET 10.0.PL2 simulator, including the wireless module to enable mobility of the wireless nodes and support more accurate wireless models for propagation, path loss, multipath fading and reception on wireless networks. The scenario that is simulated is 50 nodes in a 900m * 900m area using a 150m radius antenna. An image of the network as it appears in OPNET is presented in Figure 1.

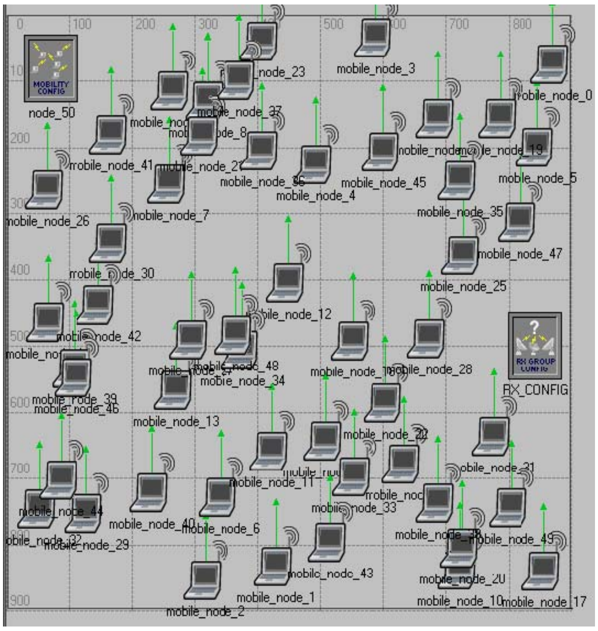


Figure 1. Topology of the simulated network.

The physical medium used is the well known 802.11 DSSS PHY at 2MBs mode. The MAC protocol used is also the 802.11 proposed MAC layer, configured in ad hoc mode. More precisely we use only the Distributed Coordination Function (DCF) of the protocol and not the Point Coordination Function (DCF), so there is no Point Coordinator and any centralized routing.

It has been mentioned in many papers that IEEE 802.11 Mac protocol doesn't perform well in multihop topologies as well as in TCP connections **[11]**, but since it is perhaps the most known and common to have been tested and implemented in hardware we choose to use it. In this paper we focus on the network layer protocol (routing sub-layer) and examine the performance of 3 of the most known routing protocols: DSR, TORA and ZRP with DSR as IERP protocol. Also the burst nature of bit errors that occur in the wireless medium leave little or none hope that a re-transmission in the wireless medium will outlast a bad condition in the channel and the packet will be transmitted correctly eventually. Even more in case of a collision, any attempt to solve this collision with retransmissions will eventually increase the end-to-end delay of the packet, thus making it obsolete. In order to offset this problem we have used a retry counter of 2 in the MAC layer instead of 7 that is defined in 802.11. More info on this problem can be found in **[12]** where extensive research on the subject was done by Willig et al. Also no fragmentation is used for long packets and no RTS-CTS packets are exchanged.

The models that are used in our simulation are the already modeled in OPNET 10.0.PL2 DSR and TORA, plus our own implementation of ZRP with DSR intergraded to be used as the IARP protocol. This

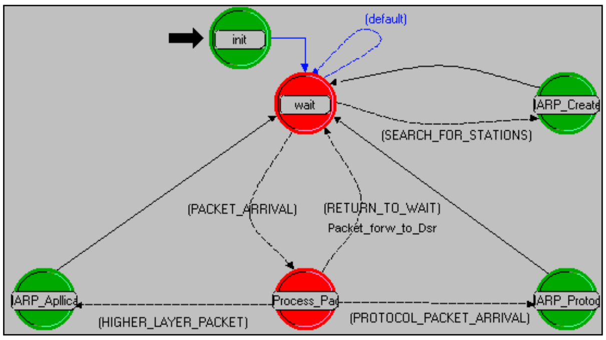
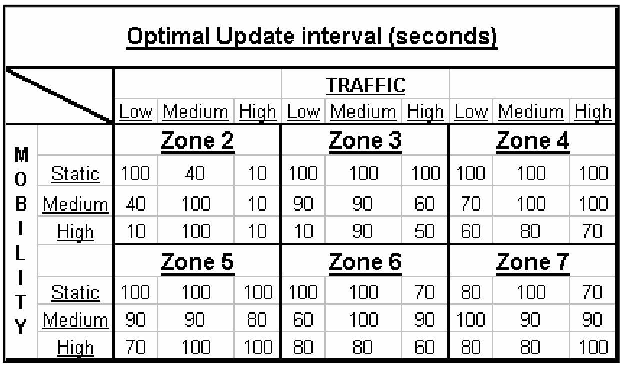


Figure 2. FSM of ZRP model in OPNET.

implementation is using a standard link status update protocol as IARP. This protocol is based on frequently broadcasts of every node's link status, and by this way a link status table stationed in every node is created. Then using the standard Dijkstra Algorithm, with a few alterations to support multiple routes to destination if there are any with the same metric count, a full list of routes to all stations in the zone is created and bordercast routes are chosen. The finite state machine of this implementation is shown in Figure 2.

In order to configure ZRP to perform optimally in the given network state, it was tried to pinpoint the optimal update interval for every zone radios in every scenario. It was also accomplished by using simulation sequences to predetermine the optimal update interval of IARP for all 9 states of the network. Update interval's range was from 10 to 100 seconds. The optimal Update Interval was chosen based primarily on the packets delivered ratio and secondarily on the end-to-end-delay. The selected Update Intervals are shown in Table 1. While they are not in any way generic and tight to the general performance of ZRP in every network state, we can extrapolate some general conclusions. At start, it was concluded that for static mobility, ZRP performs best with a high update interval, except from the zone 2 scenarios. Zone 2 results don't seem to follow any logic at all and seems random. We came to the conclusion that update interval plays as bigger role as the zone is getting wider, in opposite to small zone radius where the results seem random. For zones 3 and 4 it is obvious that as the mobility gets higher, the update interval is getting lower, which is very logical , since this way IARP can follow better the topological changes inside the zone. Finally for zones 5 and higher it seems that the extra overhead of proactive protocol traffic starts to kick in and even though we should see lower updates for higher mobility, update interval varies from 60 to 100 seconds without a certain pattern. The only exception was the fact that for static scenarios, the update interval was most of the time 100 seconds. In low traffic the logic of higher mobility needing lower update interval stands, up to zone 6, since the network is able to handle the extra overhead. But in the cases of medium and high traffic this is not possible, so no extra conclusions can be made on the networks behavior.



Optimal Update interval (seconds)

		TRAFFIC								
		Low	Medium	High	Low	Medium	High	Low	Medium	High
M O B I L I T Y		Zone 2			Zone 3			Zone 4		
	Static	100	40	10	100	100	100	100	100	100
	Medium	40	100	10	90	90	60	70	100	100
	High	10	100	10	10	90	50	60	80	70
		Zone 5			Zone 6			Zone 7		
	Static	100	100	100	100	100	70	80	100	70
	Medium	90	90	80	60	100	90	100	90	90
	High	70	100	100	80	80	60	80	80	100

Table 1. Optimal update interval of IARP for every scenario.

The final simulations were carried out using the predetermined values of update interval for every zone radius ranging from 2 to 7. By this way we tried to identify the performance impact of both the zone radius and update interval to the network performance and mainly to end-to-end delay and packet delivery ratio.

The mobility patterns vary from static (0 m/sec), medium (2,77m/sec=10km/h) to high (7,33 m/sec=30km/h). In medium mobility pattern a 100 sec pause time is used, while in high mobility pattern, a 50 sec pause time is used. ZRP has been measured using Zone Radius ranging from 2 to 7 to test the protocol performance. Using an even higher zone radius in our model is not of interest since then ZRP would be almost proactive using IARP to get routes to stations up to 8 hops away. This is because our simulated network consists of 50 nodes, so finding a node which is even further away is not likely since the diameter of the network will be somewhere between 6-8 hops.

4.2. Simulation sequences

The simulation sequences are shown in Table 2.

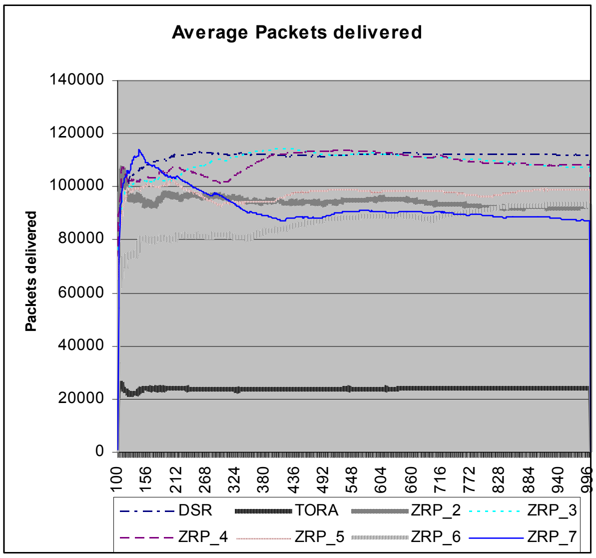


Figure 3. Application packet delivered

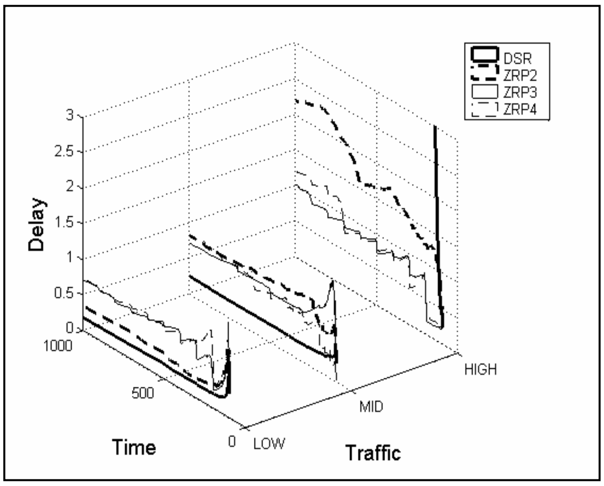


Figure4. End-to-end delay for static scenarios

Each simulation sequence lasts 1000 sec and the collection of statistics starts after 100 sec leaving enough time for the network to stabilize its performance and the routing algorithms to make an initial network topology discovery. The simulations were divided in categories based on the nodes mobility and network traffic. The wireless physical medium is the 2.4 GHz DSSS in 2Mbit/sec mode without use of RTS-CTS packets and with a transmitter power of 0,001 watts. In this mode the maximum transmission range is set to 150m. The 3 mobility scenarios include a static scenario and two scenarios that nodes move with a speed and pause time of: 10km/h, 100sec pause time and 30km/h with a 50 sec pause time respectively.

Network traffic generation is as follows:

Every node has 4 packet generators that send data packets to 4 different destinations in the network. Every traffic generator has 3 different profiles: Low, Medium and High traffic. All traffic generators create packets using an inter-arrival time which is based on an exponential distribution with a set mean outcome. For Low Traffic a mean outcome of 3 sec has been set, for Medium is 1 sec and for High Traffic a 0.5 sec mean inter-arrival time was used. Application packet size is calculated using an exponential distribution of 1024 mean size.

Nine simulation scenarios are defined, based on the table 2, ranging from ‘low mobility–low traffic’ to ‘high mobility-high traffic’.

4.3. Simulation Results

In this section the simulation results for end-to-end delay on delivered packets is presented respectively to the number of packets delivered to the destination node. The final graphs were created using Matlab’s 3-D graphic library in order to avoid presenting nine 2-D graphs, since OPNET is not capable of producing 3-D graphs.

Mobility		
Static	Medium	High
0 m/sec, 0 sec pause	2,77 m/sec, 100 sec pause	8,33 m/sec, 50 sec pause
Traffic Generators Interval		
3 sec	1 sec	0,5 sec

Table 2. Simulation scenarios.

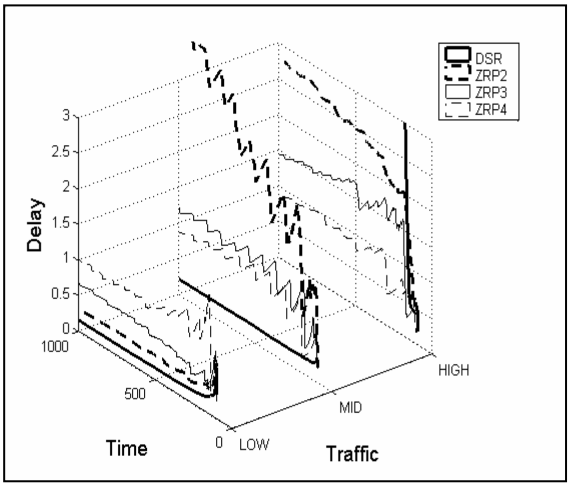


Figure 5. End-to-End delay for low mobility

The presented results are only the results from DSR and ZRP using zones 2, 3 and 4. This is because TORA was found to have the worst by far deliver ratio and the best delay, ranging from 0,0025 to 0,00125 seconds. This lead us to the conclusion that only one or two hop routes were discovered since the delay was very low for 7-8 hops routes that should have been discovered also. Since TORA was unable to handle multihop routes and even the delay graph had no important information to show other than a straight line near to zero, it was chosen not to be included in the graphs for the sake of readability. Instead a representative graph of application traffic successfully routed to the destination is shown. It is clear that TORA is performing poorly in these scenarios, while all the other protocols have a 10% variation of traffic received. This can be seen in Figure 3 where TORA is stuck at 23.000 packets/sec delivered while all the other protocols are delivering more than 80.000 packet/sec .

In the other hand, ZRP using 5, 6 and 7 zone radius demonstrated worse performance both in delay and packet delivery ratio than when using zone 2 to 4, so the 3 graphs also had no important information. Again for the sake of readability of the graphs, they were omitted.

In the figures 4, 5 and 7 the average end-to-end delay of the network is presented divided by mobility. Each figure contains all three scenario results categorized by traffic conditions for a certain mobility scenario.

It is obvious in the static scenarios that all protocols have similar performance, but DSR stands out in low and medium traffic. In high traffic scenarios DSR suffers greatly from the nature of its discovery procedure. The flooding of Route Request messages throughout the protocol handicaps network performance, leading in the destabilization of the network. On the other hand ZRP manages to carry out its task in high network traffic, especially ZRP with zone radius 3 that has the lowest delay.

This can also be observed in the MAC delay diagram of these scenarios where, DSR suffers greatly from congestion in the network. As already said this congestion is the result of flooding the network with Route Request messages from DSR. In ZRP the control of RREQ flooding through the use of bordercasting, results in the reduction of the protocol overhead and manages to keep the network stable. In fact the greater the zone radius the less network bandwidth is spend in broadcasting RREQ messages. The overhead of proactive traffic from IARP is more than the gained network bandwidth from controlling RREQ flooding, once the zone radius is set to zone radius 4 or more. That shows us that this is a classic example of a golden section problem. That is why ZRP 3 and 4 are giving almost the same results. It seems that in between them is the balance between proactive traffic overhead and RREQ messages flooding overhead.

The network performance results do not change much in the low nobility scenarios where DSR continues to outperform all ZRP variances. In high traffic simulation scenarios, DSR is not able to maintain the network stable and for once more we experience dramatically high delay. In that case ZRP with zone radius set to 4, manages to maintain an end-to-end delay of less than a second while ZRP with zone set to 3 is a little higher, at 1.5 seconds average end-to-end delay. The Mac delay graph is similar to Figure 6 and once more DSR is destabilized because of network congestion due to its flooding RREQ messages. ZRP variances with zones 5, 6 and 7 were between the graphs of ZRP with zones set to 2 and 3. But the number of packet delivered successfully was half than the ZRP 2 so like TORA there was not any useful information in their behavior and they seem not to be able to handle this network conditions.

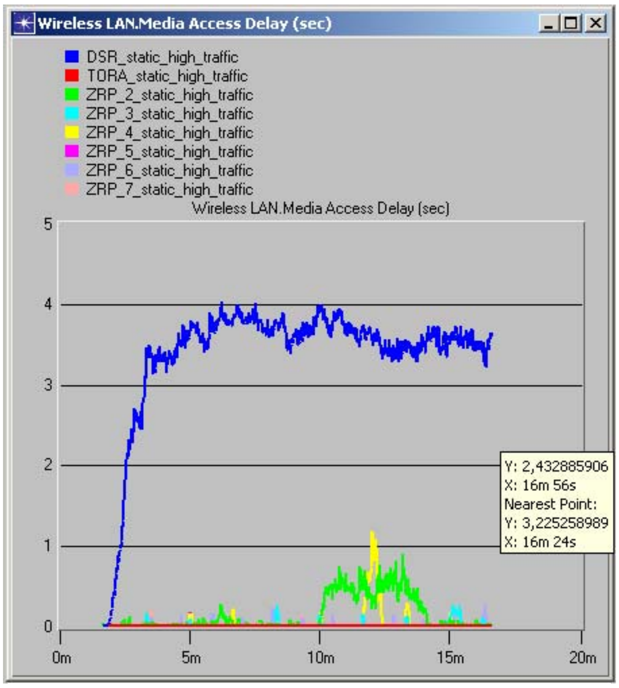


Figure 6.Typical Mac delay of DSR - high traffic.

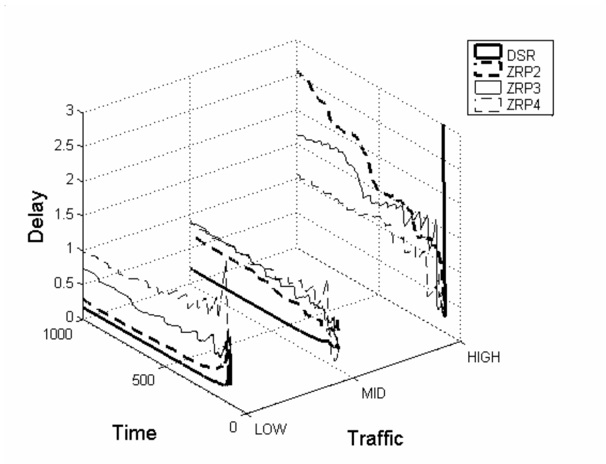


Figure 7. End–to-End delay for high mobility scenarios

A noticeable fact is that for low traffic ZRP 2 outperforms ZRP 3 and ZRP 4. But when the network starts to get congested due to higher application traffic, this changes and ZRP 3 is now the best ZRP variant in medium traffic. In high traffic scenarios, ZRP 4 is dominant and manages to keep end-to-end delay below 0.75 seconds. This is a very interesting fact, which drives us to the conclusion that higher zone radius variants are more efficient to handle higher traffic scenarios, while DSR and ZRP 2 are dominant in low and medium traffic scenarios.

The results from high mobility scenarios come to strengthen this conclusion since the network demonstrates the same behavior. DSR also outperforms all variants of ZRP in low and medium traffic scenarios. Unfortunately it suffers in high traffic, while ZRP seems to be able to handle low traffic conditions better by using a low zone radius. As the traffic load gets higher, it performs better by using a higher zone radius. Again ZRP 4 is the more suitable protocol variant for handling extreme network conditions like the ones in the high mobility – high traffic scenario, as it is shown in Figure 5.

A most noticeable fact is that mobility didn't have any major effect in the way this routing protocols perform other than a slight increase in the end-to-end delay. That shows that these protocols are managing to keep up with any topology changes up to a node speed of 30km/h with very satisfactory results. So it seems that for such mobility conditions the main problem that ad hoc wireless networks face is the congestion problem in MAC layer, even when it is mainly produced by the protocol itself and not by application traffic like DSR's case in high traffic.

5. Conclusions

Three important ad hoc routing protocols have been presented and evaluated through the well known OPNET simulator. Their main characteristics have been presented and a thorough evaluation has been carried out for ZRP and two of its main attributes, Zone Radius and IARP Update Interval against DSR and TORA. Regretfully TORA was not up to the task and it performed poorly throughout all the simulation sequences, hence putting itself out of competition. In particular while it demonstrated a close to zero delay, the packet deliver ratio was less than 25% of its closest competitor as it is obvious in Figure 3.That drives us to the conclusion that it was not able to deliver packets more than 2 or 3 hops away, hence demonstrating really low packet delay, but very bad delivery ratio.

DSR on the other hand performed admirably and it would be the clear winner if not for its bad behavior in high traffic cases. There is where ZRP takes over the task of maintaining the network stable and does it well with little end-to-end delay increase.

Update interval attribute of ZRP seems to play some role after the zone is more than 3 - 4 hops. Its impact is suggesting that in case of high mobility a lower update interval is needed, while in static cases a high update interval is better. In fact in static cases the use of a high interval update results also in less transmissions and hence in minimal power consumption.

Zone radius attribute is clearly having a great impact in ZRP performance. To be more precise, zone radius should be configured to as low as 2 hops in case of low traffic and mobility scenarios, but as the traffic increases so must the zone radius. We demonstrated how ZRP can maintain a network stable by using a higher zone radius when the traffic load increases, thus using more proactive traffic to establish and maintain routes to possible destinations, while minimizing the impact of DSR's RREQ broadcast overhead, with the use of bordercasting and early termination techniques.

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