Journal of Theoretical and Applied Information Technology
20th July 2013. Vol. 53 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

PERFORMANCE EVALUATION OF ROUTING PROTOCOLS IN LARGE-SCALE MOBILE AD HOC NETWORKS

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ABSTRACT

A mobile ad hoc network (MANET) is a collection of wireless mobile nodes communicating with each other using multi-hop wireless links without any existing network infrastructure or centralized administration. Efficient routing protocols can provide significant benefits to mobile ad hoc networks, in terms of both performance and reliability. Many routing protocols for such networks have been proposed so far. Amongst the most popular ones are Dynamic Source Routing (DSR), Ad hoc On-demand Distance Vector (AODV), Destination-Sequence Distance-Vector (DSDV), Temporally-Ordered Routing Algorithm (TORA,) and Location-Aided Routing (LAR). Research efforts have not focused in evaluating the performance of these protocols when applied to large-scale wireless networks. In this paper we present our observations regarding the behavior of the above protocols, in large-scale mobile ad hoc networks (MANETs). We consider wireless mobile terminals spread over a large geographical area, and we perform extensive simulations, using NS-2 simulator.

Keywords: *Mobile Ad-hoc Network (MANET), Routing Protocols AODV (Ad-hoc on demand distance vector), DSDV (Destination Sequenced distance vector), DSR (Dynamic Source Routing)*

1. INTRODUCTION

In [15] an ad hoc network, mobile nodes communicate with each other using multi-hop wireless links. Such networks find applicability in military environments, wherein a platoon of soldiers of fleet of ships may construct an ad hoc network in the region of their deployment, as well as in nonmilitary environments, such as classrooms and conferences room. Military network environments typically require quality-of-service (QoS) for their mission critical applications.

In nonmilitary environments, multimedia applications also require routes satisfying QoS requirements. There is no stationary infrastructure such as base stations in ad hoc networks. Each node in the network also acts as a router, forwarding data packets for other nodes which in such a network moves arbitrarily, thus network topology changes frequently and unpredictably. Moreover, bandwidth, energy and physical security are limited. These constraints, in combination with network topology dynamics make routing protocols in ad hoc networks challenging (compared to the wired network as well as the mobile IP network).

Goal of this paper is to carry out a systematic performance study for four typical routing protocols of ad hoc networks, which include one distance vector routing protocol DSDV [10] and three on-demand routing protocols AODV, DSR and TORA. DSDV is a table-driven protocol based on the classical Bellman–Ford mechanism. The improvements made to Bellman–Ford algorithm include freedom from loops in the routing table. Every mobile node in the network maintains a routing table in which all of the possible destinations within the network and the number of hops to each destination are recorded.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

While AODV, DSR and TORA share the on-demand behavior in that they initiate routing activity only in the presence of data packets in need of a route, many of their routing mechanism are different. AODV uses a table-driven routing framework and destination sequence numbers, DSR uses a source routing, whereas TORA uses a link reversal routing mechanism. Commonly, the latter three have a less routing load and the former has a less end-to end delay.

The related works of Sung-Ju et al. [11] evaluate five kinds of typical routing protocols (WRP, FSR, DSR, LAR and DREAM). Their simulation works model a network of varying mobility speeds and 50 mobile hosts placed randomly within a 750 · 750 m area. Radio propagation range for each node is 200 m and channel capacity is 2 M bit/s.
Biao et al. [12], Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu and Jorjeta Jetcheva [13] investigate the routing protocols of AODV, DSDV, DSR and TORA.

The former simulation modeled a network of 60 mobile hosts and varying pause times, the latter modeled sceneries with 50 nodes and pause time of 0, 30, 60, 120, 300, 600 and 900 s, respectively.
Das et al. [13] carried out the simulation analysis to AODV and DSR. Their simulation has a model of 50 (the first group of experiment) and 100 (the second group of experiment) nodes at varying pause times.

The above mentioned works consider the simulation model with a constant network size and a varying pause times or mobility speeds. These works do not take into account the influence on the protocols when the mobile node's pause time is invariable but the network size is changing. On the contrary, this paper considers the simulation model with a dynamic network size and an invariable pause time which should be zero under weakest case. So we investigate performances of the routing protocols from different categories under various network scenarios (e.g., different network size, mobility speeds, etc.). This paper systematically discuses the performance evaluation and comparison of four typical routing protocols, AODV, DSDV, DSR, LAR and TORA, in ad hoc networks, which take the QoS (Normalized routing load, Average end-to-end delay, Throughput, Overhead). The rest of the paper is organized as follows. Section 2 presents the wireless ad hoc routing protocols. Section 4 presents the simulation experiment details, gives simulation results and performance analysis of the typical routing protocols, and concluding remarks are made in Section 5.

2. WIRELESS AD HOC ROUTING PROTOCOLS

In this section we briefly describe the on-demand protocols [2] that we investigate. A more detailed description is presented in [3], [8].

2.1 The Ad Hoc On Demand Distance Vector (Aodv)

The Ad hoc On-demand Distance Vector routing protocol [4] does not maintain global routing information for the whole network. Nodes that do not belong to a route do not need to maintain information about that route. Such nodes do not send or receive topology-update packets; hence they have information only for their active routes.

A node considers a route as active, if it sends, receives or forwards packets for that route and if there is at least one data packet transmitted through this route within a fixed time interval. Hence in AODV, route discovery packets are initiated and broadcasted only when a source desires to contact an intended destination for which is does not have a valid route. Furthermore, changes in network topology must be sent only to those nodes that will need this information. Thus, AODV dynamically establishes route table entries. Every node maintains an increasing counter in order to replace unused or broken routes. A disadvantage of AODV is that it does not support asymmetric links. That is, AODV is capable of supporting only symmetric links between nodes, both of which are able to send packets to each other.

2.2 THE DYNAMIC SOURCE ROUTING PROTOCOL (DSR)

The Dynamic Source Routing protocol [5] also allows mobile sources to dynamically discover paths towards any desired destination. Every data packet includes a complete list of nodes, which the packet must pass before it reaches the destination. Hence, all nodes that forward or overhear these packets may store routing information for future use. DSR can support fast network topology changes and service even asymmetric links; it can successfully find paths and forward packets in unidirectional link environments. Moreover, like AODV, it has a mechanism for on-demand route maintenance, so there are no periodic topology update packets. When link failures occur, only

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

nodes that forward packets through those links must receive proper routing advertisements. In addition, DSR allows source nodes to receive and store more than one path towards a specific destination. Intermediate nodes have the opportunity to select another cached route as soon as they are informed about a link failure.

A source that desires to send data to a particular destination, first, checks to verify that it has a route in its cache for that destination. If it does, it will use that route by placing (in the data packet header) the sequence of hops that the packet must follow to reach the destination. If there is no such route stored in the local cache, then the source will initiate a new path discovery process, by broadcasting a Route Request to its neighborhood. This message contains the source and destination addresses, a request ID and an ordered intermediate node address list, through which this message has passed. This node list is initially blank when the message leaves the source node (it has not yet visited any other node). Thereafter, every other node that receives this request message parses it to see if it is the intended destination. If it is, it will reply with a Route Reply (RREP) back to the source, after attaching the list with all intermediate nodes through which the request message passed. If it is not and has already received a similar request with the same ID from the same source, it will discard this request message. If it is not and it sees that its own address is included in the message list, it will discard this request message. Else it will append its own address in this list and then it will further broadcast it to its neighbors.

2.3 The Location Aided Routing Protocol (Lar)

Routing overhead can be decreased, by giving location information to the mobile terminals, with use of the Global Positioning System (GPS) for route discovery. Two Location-Aided Routing algorithms that use location information have been proposed [6], showing how a route discovery protocol, based on flooding, can be improved. If a node S wants to send data to a node D, for which it knows the previous location L at time t0 and node D's speed u, then S expects that D will be located within an "expected zone" at time t1, a circular area of radius u(t1-t0) and centre L. If node S does not know the previous location L, then the "expected zone" for node D will be considered as the whole network geographical region and the algorithm will follow the basic flooding as in the DSR algorithm.

The two LAR algorithms in [6] use flooding with one modification; the source node S defines a "request zone" for the route request. An intermediate node will forward the request message, only if it is located within the request zone. If the request zone includes the expected zone, the probability of finding node D will be increased. The request zone may also include other neighboring request zones. The two schemes give terminals the capability of determining whether they belong to a requested zone or not, so as to know if they should forward certain route request messages. The interested reader may find more details in [6], wherein both schemes are simulated and evaluated.

2.4 Temporally Ordered Routing Algorithm (Tora)

The Temporally-Ordered Routing Algorithm (TORA) [7], [9] is a distributed routing protocol for multi hop 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

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

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 flexibility 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.

2.5 Destination-Sequence Distance-Vector (Dsdv)

Destination-Sequence Distance-Vector (DSDV) [18] is a link-state table-driven protocol where all nodes maintain routing tables that include all possible destinations and the required number of hops to reach them [4]. Each route table lists all available destinations and their costs, which are the number of hops. Each node periodically broadcasts to its neighbors an update for its destination and number of hops necessary to reach them. Each mobile node is committed to relay data packets to others upon request. DSDV uses the distance-vector routing algorithm to select which route to use. The routing tables are always kept current. Updates can be periodic or upon on major changes to the network status. DSDV updates the routing tables by sending full dump or incremental packets. Full dump routing updates carry all the routing information; incremental routing updates only carry the last change since the last full dump update. A full dump packet is sent relatively infrequently, while the incremental packets are smaller and sent more frequently.

DSDV protocol has two main advantages; first, DSDV always selects the route that has the shortest path with the minimum number of hops. Second, it also guarantees loop-free paths to all destinations.

3. PRVIOUS WORK

Most of the previous work [2] is limited on performing simulations for ad hoc networks with a limited number of nodes deployed in small geographical areas. The authors in [13] compare four ad hoc routing protocols using a maximum number of 50 nodes but their traffic load is relatively low, since the data packet size is 64 bytes, the maximum number of sources is 30 and every source node transmits 4 packets / sec. The authors in [16] compare three routing protocols, AODV, DSR and STAR, for which they used two simulators as well: GlomoSim and NS- 2. They assume a relatively small geographical region. An interesting approach is also followed in [19], which introduces a new mobility metric: the relative terminal speeds rather than absolute pause times and speeds. A thorough work is presented in [17], in which the authors have performed an extensive performance evaluation between DSR and AODV, in which the basic mobility metric is the node pause times.

Our work differs in that we extend our observations to large-scale deployments. We observe and comment on the behavior of each protocol. And we compare these protocols in terms of overhead, knowing that the overhead is very important as a metric to deduce the protocol better, also in order to deduct the context of use of each protocol. In addition our work introduces the behavior of TORA and LAR protocols in specific scenarios.

4. SIMULATION AND EVALUATION METRICS

4.1 Performance Metrics

The following metrics are used in varying scenarios to evaluate the different protocols:

1) Packet delivery ratio: This is defined as the ratio of the number of data packets received by the destinations to those sent by the CBR sources.

2) Normalized routing load: This is defined as the number of routing packets transmitted per data packet delivered at the destination. Normalized routing load gives a measure of the efficiency of the protocol.

3) Average end-to-end delay of data packets: This is defined as the delay between the time at which the data packet was originated at the source and the time it reaches the destination. Data packets that get lost en route are not considered. Delays due to route discovery, queuing and retransmissions are included in the delay metric.

4) Throughput: The amount of data transferred from one place to another or processed in a specified amount of time. Data transfer rates for disk drives and networks are measured in terms of throughput. Typically, throughputs are measured in kbps, Mbps and Gbps.

5) Overload is the extra information which is needed to deliver the packet to its right destination. It depends on the routing protocol which you are using for communication.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Routing Overhead = Total packet size – payload size. The simulator for evaluating routing protocols is implemented with the network simulation version 2 (ns2) [1].

Our simulation models the network size with 1200mx1200m, and with 50, 100, 125 and 600 mobile hosts placed randomly. Radio propagation range for each node is 250 m and channel capacity is 2 M bit/s. The node mobility speed is varying between 5 m/s and 35 m/s generated by uniform distribution. And the pause time is varying between 0s and 250s which means the node is not always moving in the entire simulation period. Each simulation executes for 250s.The simulation altogether produces 50 kinds of stochastic topologies, each group of nodes corresponds 10 kinds and the collected data is the averaged over those 10 runs.

We've used a similar model with [16], [17] to compare the impact of using large-scale topologies (600 nodes) in the performance of the protocols as opposed to the case when a limited number of nodes (50-100) are used. The traffic sources are of continuous bit rate (CBR). The source-destination pairs are chosen randomly from the set of the network's nodes and are the same throughout the duration of the simulation. The data packet is chosen to be 512 bytes and the channel bandwidth 2 Mbps. As a mobility model we utilize the random waypoint in a rectangular field 1200m x 1200m with 600 nodes. Each simulation is run for 250s (simulation time). We've used the same performance metrics as in [16], [17], to be able to directly compare our findings: average end-to-end delay of data packets, normalized routing overhead, Packet delivery ratio, Throughput and overhead.

For our simulations we use 40 sources generating packets with a fixed rate of 4 packets/ seconds. In Figure 1, we depict the Packet Delivery Fraction (PDF) for three of the routing protocols upon investigation (DSR, AODV and LAR).
As we observe, there is an important degradation of PDF for the AODV as opposed to that of LAR and DSR.

What is most important is that there is a non-trivial difference between the PDF of AODV measured for 600 nodes and that measured in [17], for 50 nodes. A possible explanation could be that the route discovery process of AODV causes very long delays for large scale networks, due to the amount of control packets transmitted. These delays result in packets (waiting in the queues) being dropped. One should not be surprised by the fact that the end-to-end average delay of AODV appears to be small, as it refers only to delivered packets.

Figure 2 depicts the Average delay in seconds for LAR, DSR and AODV. For this metric, DSR is demonstrating a bad performance as opposed to that achieved for a 50 nodes topology ([17]). A possible explanation for this result could be the aggressive use of route caching in DSR. For a large number of nodes the cache size can increase significantly resulting to increase in delay. Furthermore choosing stale routes can further increase the delay. For the normalized routing overhead, the results are depicted in Figure 3. There is a dramatic increase in the routing overhead for both DSR and AODV, as compared to the 50 nodes topology, in [17]. This is expected, as many more packets are needed for the route discoveries, especially for AODV, where each of its route discoveries typically propagates to every node. DSR limits the amount of routing packets by making use of cached routes. Another observation is that LAR performs much better than the other two, since it makes use of the nodes' location, decreasing the number of routing packets broadcasted.

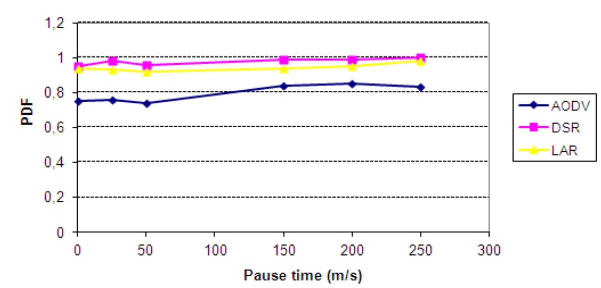

Figure 1: Packet Delivery Fraction Vs Pause Time

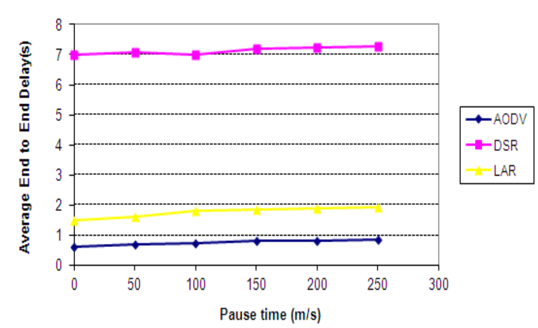

Figure 2: Average end to end delay Vs Pause Time

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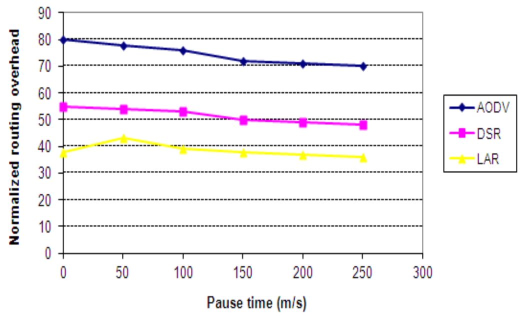

Figure 3: Normalized Routing Overhead Vs Pause Time

The throughput for the network is shown in Figure 4 for four protocols (AODV, DSR, DSDV and TORA), which reflects the usage degree of the network resources for the typical routing protocols. For the convenience to comparison, Figure 4 only demonstrates the throughput-changing curve with the number smaller than 60.

With an offered load of 1 packets/s the maximum throughput is approximately 4500 kbps. Throughput increases quickly for AODV, DSR and DSDV with increased number of nodes. TORA on the other hand has difficulties in finding routes when number increases, which is clear from Figure 5, where the throughput drops slightly with the number smaller than 60. Compared to AODV and DSR, the relatively lower throughput for DSDV is caused by packets that are sent (and lost) before routes have converged initially in the network. Note that all simulations are started without any established routes.

In detail, when the number of nodes is smaller than 30, DSR shows the better throughput characteristic, next are AODV and DSDV. With the network size bigger than 30 and smaller than 60, AODV has the best throughput, next are DSR and DSDV. Considering the results, we think that AODV has a high reliability in a high-speed and large-scale environment, and along with the increase number of nodes, DSDV also displays the better throughput characteristic. The reliability of TORA is worst.

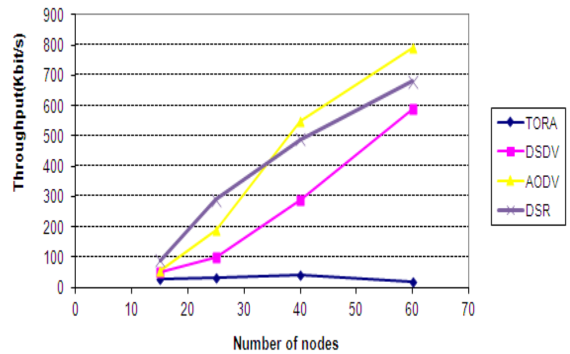

Figure 4: Throughput Vs Pause Time

To find a route, the routing algorithm, during the process of discovery/maintenance of routes spreads more control packets in the network. To measure this signaling overhead, we calculated the extra information which is needed to deliver the packet to its right destination during the simulation time. We can notice in these figures, the overload values according to the modes speed in the network.

The algorithm DSR gives the best performance in terms of overload than all other algorithms. The difference between DSR and other routing protocols is due to the fact that more mechanisms introduced in DSR to maintain the paths. A large amount of overhead for DSR protocol is shown in figure 7 when the node velocity is greater than 25m/s. We note that the DSDV and TORA protocols are highly recommended for use in the scenarios with many nodes and highly mobile (see Figure 6 and Figure 7).

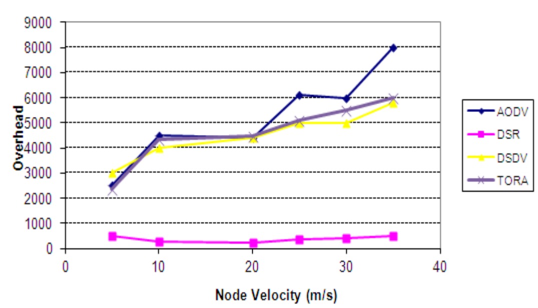

Figure 5: *Overhead Vs Node Velocity (Number Of Nodes is 50)*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

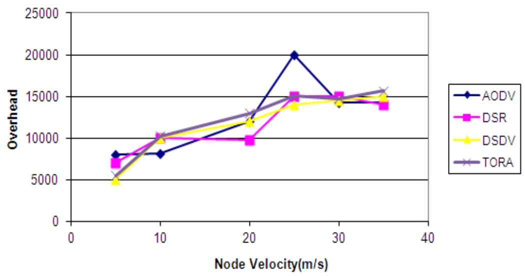

Figure 6: Overhead Vs Node Velocity (Number Of Nodes is 100)

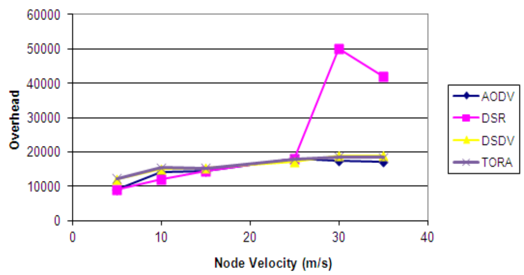

Figure 7: Overhead Vs Node Velocity (Number Of Nodes is 125)

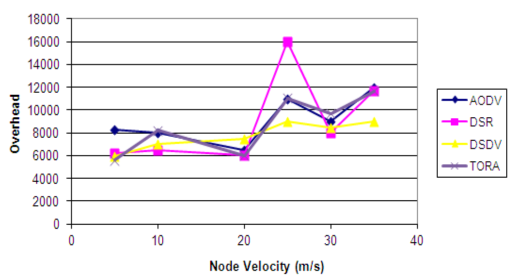

Figure 8: Overhead Vs Node Velocity (Number Of Nodes is 150)

5. CONCLUSION

This paper discusses the simulation model for the variable network size and whose mutual connection in the network topology, it is appropriate to use the model to appraise the scalability and the ability to support QoS of the above four kinds of protocols for ad hoc network. it systematically discuses the performance evaluation and comparison of four typical routing protocols of ad hoc networks with the different simulation model and metrics, and drew more complete and valuable conclusions.

We have presented a detailed performance comparison of important routing protocols for mobile ad hoc Wireless networks. The results of the simulations yield some interesting conclusions: AODV suffers in terms of packet delivery fraction (PDF) but scales very well in terms of end-to-end delay. DSR on the other hand scales well in terms of packet delivery fraction but suffers an important increase of end-to-end delay, as compared to its performance achieved in small scale topologies. Also, the effect of maximum connections is severe on TORA, which seems unable to route large amounts of traffic. LAR, seems to scale very well, in terms of all metrics employed but it requires additional hardware for getting the nodes location.

From the results obtained one can come to the conclusion that both major routing protocols, AODV and DSR, have important drawbacks when it comes to scalability. Therefore this work can motivate further research on improving the current protocols and/or create new ones to meet the challenges of large-scale wireless networks.

6. ACKNOWLEDGMENTS

The authors thank the reviewers for their valuable comments that helped to improve the paper. The work is supported by laboratory networks in Hassan 1er University.

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

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