Performance Analysis of Routing Protocols for Wireless Ad-Hoc Networks

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Abstract
Wireless ad-hoc networks are decentralized wireless networks that do not rely on an infrastructure, such as base stations or access points. Routing protocols in ad-hoc networks specify communication between routers and enable them to select routes between a source and a destination. The choice of the routes is performed by routing algorithms. In this paper, we use OPNET Modeler version 16.0 A to simulate three routing protocols for wireless ad-hoc networks in several Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) scenarios. We analyze route discovery time, end-to-end delay, download response time, and routing traffic overhead in static, less dynamic, and highly dynamic mobility scenarios. Simulation results indicate that Ad-Hoc On-Demand Distance Vector (AODV) protocol is the most flexible when compared to Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR) protocols in the case of movement. OLSR is the only protocol that meets the end-to-end delay requirements of less than 20 ms.

1. Introduction

Wireless ad-hoc networks are a collection of mobile nodes that make up a multihop autonomous system. Their decentralized nature makes them suitable for various applications that do not rely on a central node. These networks consist of multiple nodes and links. Each node requires a route for communication. Hence, each node participates in routing process by forwarding data to other nodes.

In this paper, we describe a comparative performance analysis of three routing protocols for mobile ad-hoc networks (MANETs): Ad-Hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), and Optimized Link State Routing (OLSR). In Section 2, we provide literature survey. Description of simulated network topologies is given in Section 3 while simulation scenarios are described in Section 4. Simulation results are discussed in Section 5. We conclude with Section 6.

2. Ad-Hoc Routing Protocols

Ad-hoc routing protocols control routing packets between computing devices in a mobile ad-hoc network. Nodes in ad-hoc networks are not aware of the network topology and have to discover it [1].

MANET routing protocols can be classified as unicast, multicast, and broadcast. The main goal of unicast protocols is to establish and maintain a route between a pair of nodes. They can be further classified as reactive (on-demand) and proactive (table-driven) routing protocols based on the method of acquiring information from the other nodes. In addition to these two main groups, there are hybrid routing protocols that combine the merits of both reactive and proactive routing protocols. The classification of ad-hoc protocols is shown in Figure 1. The advantage of on-demand routing protocols is that they generate less routing overhead compared to table-driven routing protocols. However, a source node may suffer from long delays required to obtain a route to a specific destination. The advantage of table-driven routing protocols is that a source node may obtain a routing path immediately if needed. However, they generate a high routing overhead [2].

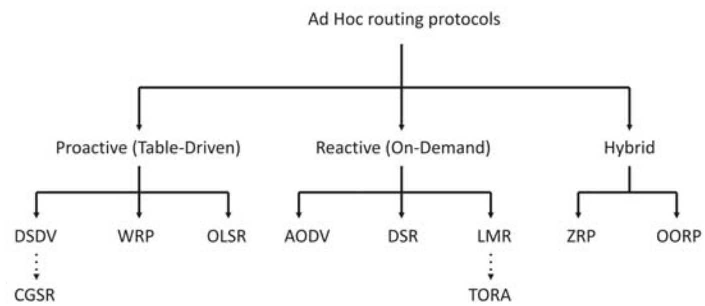

Figure 1: Ad-Hoc routing protocols.

2.1 Ad-Hoc On-Demand Distance Vector (AODV) Algorithm

AODV is one of the most popular reactive routing protocols and is suitable for a dynamic self-starting network and ad-hoc networks. It ensures loop-free routes even while repairing broken links. Since the protocol does not require global periodic routing advertisements, the overall bandwidth needed for the mobile nodes is considerably smaller than protocols that need such advertisements [1], [3].

AODV defines Route Request (RREQ), Route Reply (RREP), and Route Error (RERR) message types [1], [4]. These message types are received via UDP and, hence, the usual Internet Protocol (IP) header processing applies [4]. A source node initiates path discovery operation by sending RREQ packet to its neighbors in case it does not have a valid route to a specific destination but wishes to send a packet. The request is forwarded until the destination or an intermediate node responds with a "fresh enough" route. A reverse path may be established when intermediate nodes record the address of the neighbor in their routing tables. The destination or the intermediate node responds with a RREP that unicasts to the neighbor that first received the RREQ packet and routes back along the reverse path [3]. When the nodes in the network move and the network topology changes or the links in the active path break, the intermediate node that discovers this link failure propagates an RERR packet [1], [5]. AODV parameters are shown in Table 1.

Table 1: AODV parameters.

Attribute	Value
Route Discovery Parameters	Default
Active Route Timeout (seconds)	3
Hello Interval (seconds)	uniform (2, 2.1) uniform (10, 10.1)
Allowed Hello Loss	2
Net Diameter	16

2.2 Dynamic Source Routing (DSR) Algorithm

Dynamic Source Routing is an on-demand routing protocol based on the concept of source routing where each routed packet carries in its header a complete and ordered list of nodes through which packet traverses. Hence, intermediate nodes need not maintain up-to-date routing information in order to route the packets [6], [7]. The protocol consists of two major phases: route discovery and route maintenance.

When a source node wishes to send a packet to a destination, it obtains a source route by the route discovery mechanism. At first, a source node consults its route cache to determine whether it already has a route to the destination. If such a route is not available, it initiates route discovery by broadcasting a RREQ packet. The RREQ packet then answers with an RREP packet when RREQ reaches either the destination or an intermediate node with an un-expired route [5]–[7].

The route maintenance mechanism uses RERR packets and acknowledgments. RERR packets are generated to notify the source node that a source route is broken [3], [7]. DSR parameters are shown in Table 2.

Table 2: DSR parameters.

Attribute	Value
⊟ Route Cache Parameters	(...)
- Max Cached Routes	Infinity
- Route Expiry Timer (seconds)	60 300
⊞ Route Cache Export	Do Not Export
⊞ Send Buffer Parameters	Default
⊟ Route Discovery Parameters	(...)
- Request Table Size (nodes)	16
- Maximum Request Table Identifi...	16
- Maximum Request Retransmissio...	16

2.3 Optimized Link State Routing (OLSR) Algorithm

Optimized Link State Routing is a proactive routing protocol. It periodically exchanges topology information with other network nodes. The periodic nature of the protocol creates a large amount of overhead. OLSR reduces this overhead by using Multi Point Relays (MPR). Each node selects MPRs as a set of neighboring nodes and only those MPRs are responsible for forwarding routing messages and network-wide traffic. Only the nodes that have been selected as MPRs by a neighboring nodes announce this information periodically. Hence, the selected node has the ability to reach the node that has selected it as an MPR [1], [8].

OLSR does not require reliable control message delivery because each node sends control messages periodically and, hence, can sustain reasonable loss of control messages. Each control message uses a sequence number, which is incremented for each message. Therefore, the protocol does not require sequenced delivery of messages [1], [8]. OLSR uses Topology Control (TC) messages to provide sufficient link state information to every network node to allow route calculation [1], [8]. OLSR parameters are shown in Table 3.

Table 3: OLSR parameters.

Attribute	Value
Willingness	Willingness Default
Hello Interval (seconds)	2 10 2 10
TC Interval (seconds)	5 5 25 25
Neighbor Hold Time (seconds)	6.0
Topology Hold Time (seconds)	15.0
Duplicate Message Hold Time (seconds)	30.0

3. OPNET Simulated Network Topologies

We developed OPNET model of an ad-hoc network to evaluate performance of three routing protocols in various environments.

Generic OPNET models for an ad-hoc network in a highly dynamic environment with UDP and TCP connection scenarios are shown in Figure 2 (top) and 2 (bottom), respectively. Note that the routing protocol and mobility differ in each scenario. Each scenario consists of 16 wireless local area network (WLAN) nodes that are connected via low power wireless connection with transmission power of 5 mW and packet reception-power threshold of -90 dBm. Each node covers an area of approximately 675 m. Each node can only see its neighboring nodes because the distance between neighboring nodes is approximately 500 m.

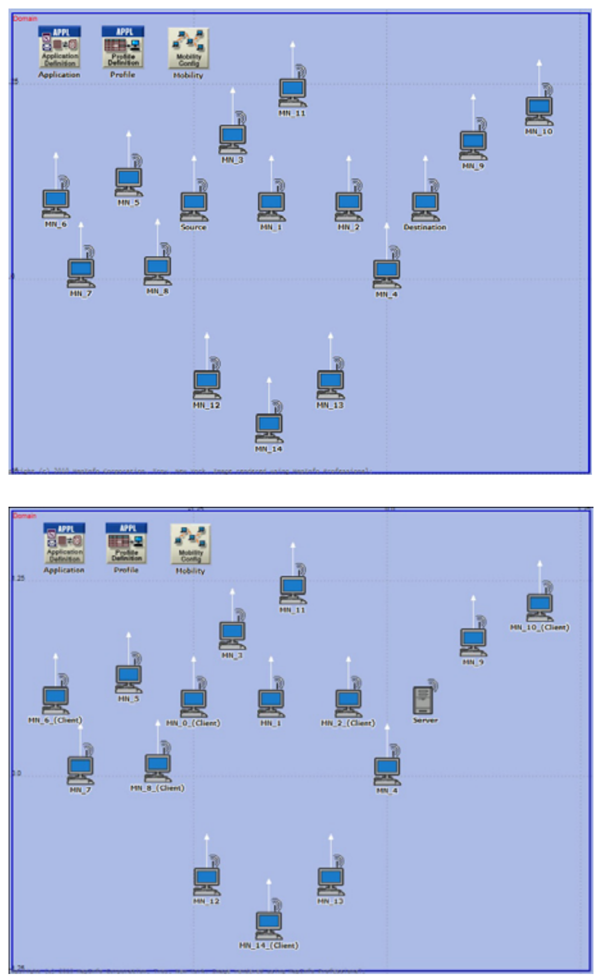

Figure 2: Generic OPNET model: UDP (top) and TCP (bottom) connection scenarios.

3.1 Node Mobility

Mobility is one of the main attributes in ad-hoc networks. Modeling movement of a set of nodes is essential for evaluating performance of an ad-hoc network [9]. In this project, we used a random waypoint model available in OPNET Modeler.

We created three mobility models: static, less dynamic, and highly dynamic. In a static mobility model, we identified the best results for each routing protocol. In a less dynamic mobility model, we used very low-speed movement (walking speed) for a few mobile nodes. In the highly dynamic mobility model, we created high-speed movement (driving in the city) for all mobile nodes. We identified the routing protocol with the best performance in dynamic environments and the routing protocol that is more suitable in mobility scenarios.

4. Simulation Scenarios

We used the OPNET Modeler 16.0.A to simulate wireless ad-hoc networks with three routing protocols: AODV, DSR, and OLSR. We also analyzed the effect of periodic routing advertisement under various mobility conditions.

The first scenario is a static scenario used to analyze a static ad-hoc network and to compare its performance with other scenarios. In this case, nodes are motionless and, hence, all routes are valid during the entire simulation time. In the second scenario, some nodes move with very low speed. The speed is comparable to human walk (1 m/s). In this paper, this scenario is called a less dynamic scenario. The third scenario includes high-speed nodes that move with maximum speed equal to the speed of cars in a city (50 km/h). The nodes may or may not move during this simulation run.

For each scenario, we consider two types of connections (UDP and TCP) and three ad-hoc routing protocols with various attributes. We created 48 simulation scenarios and analyzed route discovery time, end-to-end delay, download response time, and routing traffic overhead in TCP and UDP connection scenarios.

4.1 OPNET Model of UDP Connection

In UDP connection scenarios, a two-hour interval of the Matrix III movie trace [4] was streamed from the source node to the destination node using various routing protocols and attributes. We created 24 simulation scenarios for UDP connection case but we choose only nine scenarios for the comparison analysis.

The faster the nodes find a route, the faster they may send the video, which causes smaller end-to-end delay. Hence, to identify the best video streaming performance for a variety of AODV and DSR attributes, we examine route discovery time. Each scenario has different route discovery time, as shown in Figure 3. In case of AODV scenarios shown in Figure 3 (top), AODV routing protocol with hello message interval of 2 s has better route discovery time as compared to other scenarios. In all DSR scenarios shown in Figure 3 (bottom), DSR routing protocol with route expiry timer of 300 s has better route discovery time.

OLSR is a proactive routing protocol and has a route to the destination before it begins sending data. This results in smaller end-to-end delay in streaming video packets in comparison to AODV and DSR.

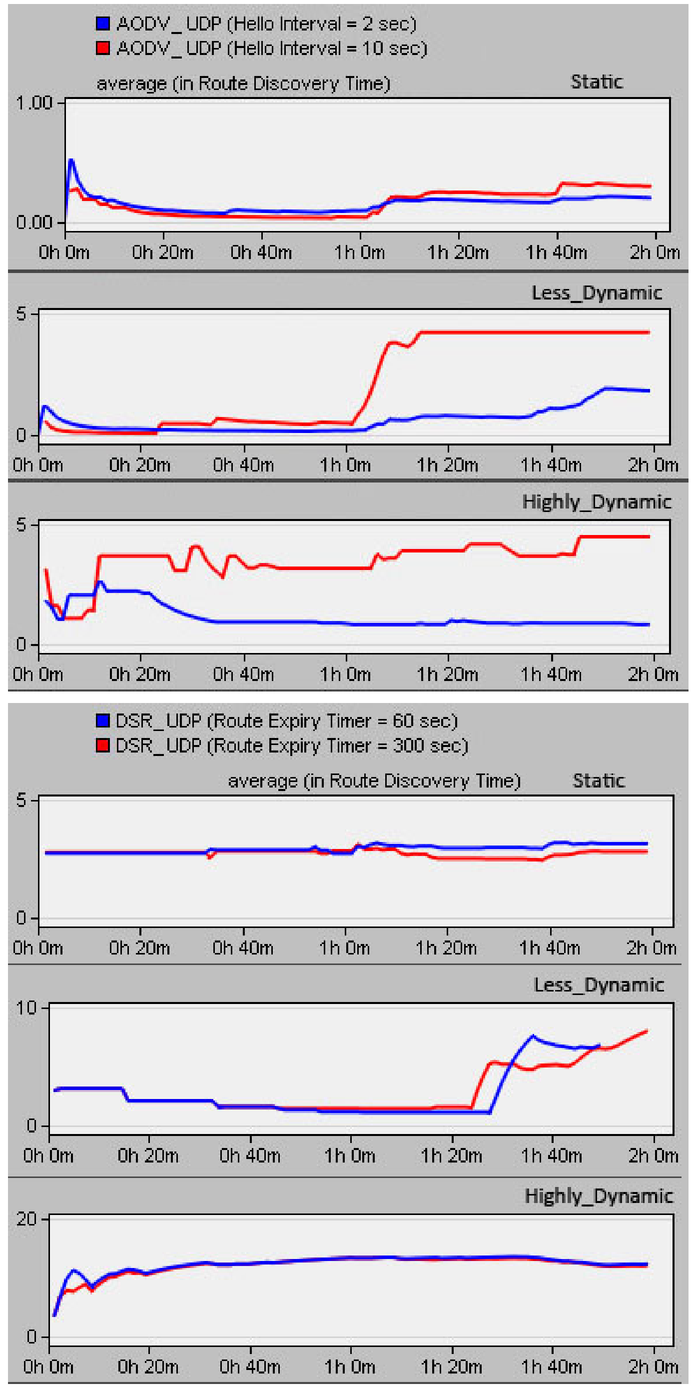

Figure 3: Average route discovery time in the UDP connection scenarios: AODV (top) and DSR (bottom) cases.

Comparison of packet end-to-end delay in various scenarios with OLSR routing protocol is shown in Figure 4. The OLSR routing protocol with hello message interval of 2 s and topology control message interval of 5 s performs better in finding a route to the destination and in dealing with the node movement.

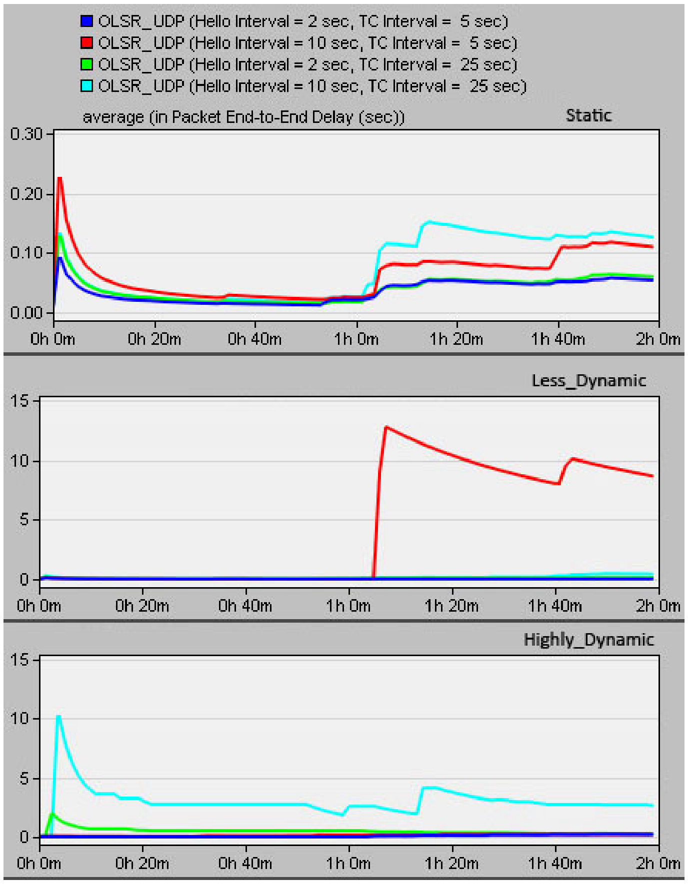

Figure 4: Average packet end-to-end delay in the UDP connection scenarios for OLSR case.

4.2 OPNET Model of TCP Connection

TCP connection scenarios consist of six client nodes that download 50 Kbytes of data from the server with different start times having uniform distribution between 20 s and 80 s. After 180 s, the client nodes restart downloading the data.

In the scenarios with the DSR routing protocol, we used tw two o route expiry timers: 60 s and 300 s. In the first case, the route to the File Transfer Protocol (FTP) server expires after 60 s and source node has to find a new route to send another file. In the second case, the route to the server remains valid and the client node may use the route to request another file. We choose one scenario in each routing protocol scenario for comparison. Unlike the case with UDP connection scenarios, we here consider wireless delay. Average wireless delays for AODV, DSR, and OLSR are shown in Figure 5. AODV with hello message interval of 2 s has the minimum wireless delay, as shown in Figure 5 (top). The DSR with route expiry timer of 60 s has the minimum wireless delay, as shown in Figure 5 (middle). The OLSR routing protocol with hello message interval of 2 s and topology control message interval of 5 s has the minimum wireless delay, as shown in Figure 5 (bottom).

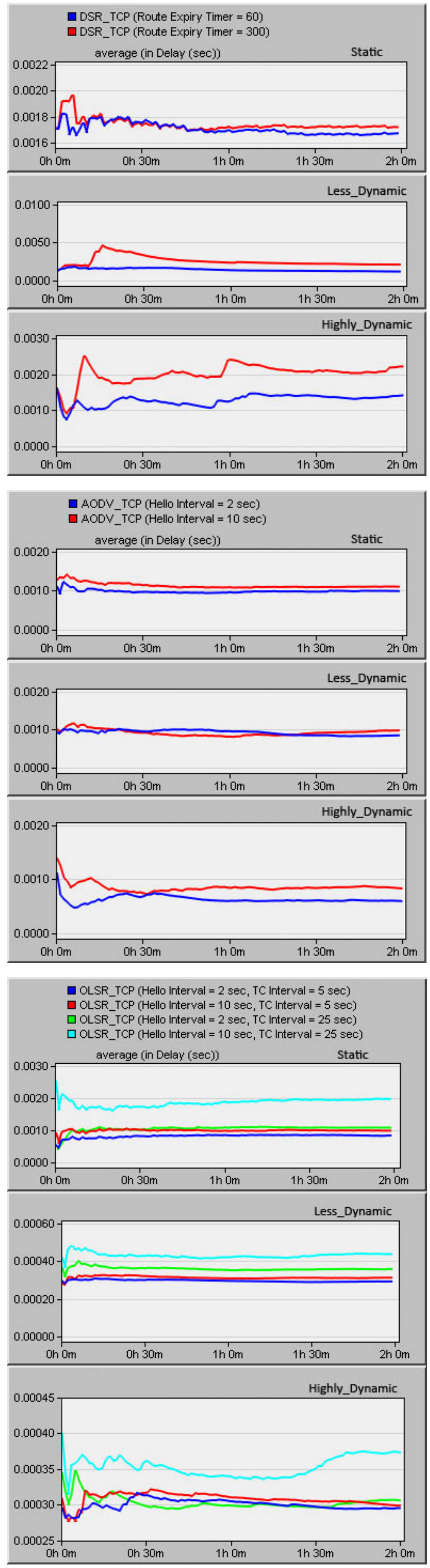

Figure 5: Average wireless delay in the TCP connection ad-hoc network: AODV (top), DSR (middle), and OLSR (bottom) cases.

5. Simulation Results

In this Section, we compare the three routing protocols. We first consider route discovery time as one of the most important factors in on-demand routing protocols. We then consider packet end-to-end delay in UDP connection scenarios streaming a video over the network, and download response time in TCP connection scenarios downloading a file from an FTP server through several network nodes. Finally, we show the routing traffic overhead generated throughout the ad-hoc network employing each routing protocol.

5.1 Route Discovery Time

Route discovery time is an important factor in on-demand routing protocols. It causes large delays if the route discovery operation fails to find a route to the destination. Route discovery time for AODV and DSR routing protocols in UDP connection scenarios is shown in Figure 6. In the static UDP scenario, the route discovery phase in AODV is approximately 10 times faster than the route discovery phase of DSR in a static ad-hoc network. In case of less and highly dynamic UDP networks, AODV again has smaller route discovery time.

The route discovery phase in AODV routing protocol is independent of the network topology, as shown in Figure 6. This implies that the changes in network topology do not affect the performance of route discovery phase of AODV in video streaming network. Unlike AODV, route discovery phase in DSR depends on network topology. The DSR route discovery time is higher in scenarios that include movements and the continuously changing topology, as shown in Figure 6.

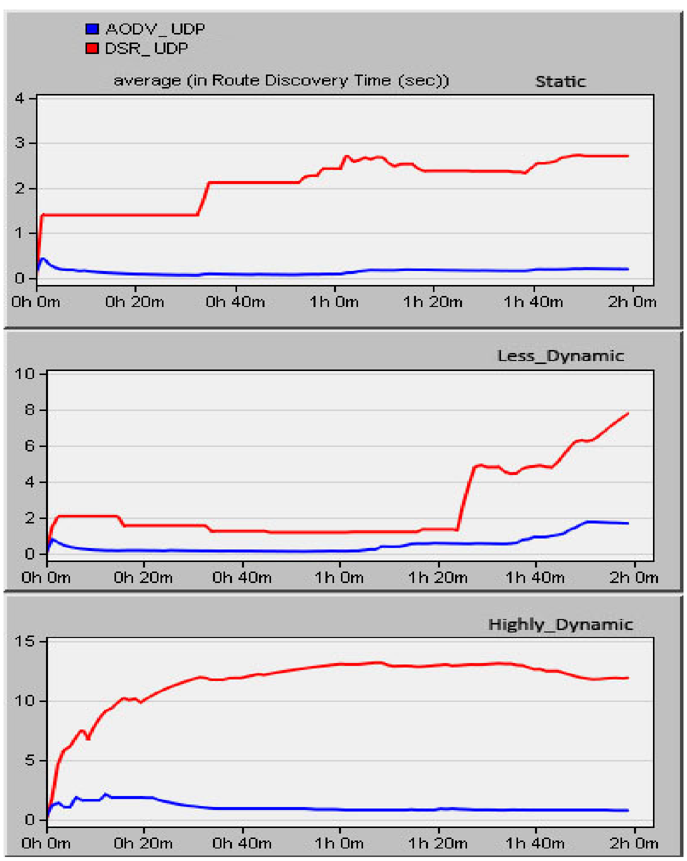

Figure 6: Average route discovery time (s) in UDP connection ad-hoc network scenarios: AODV and DSR cases.

Simulation results shown in Figure 7 indicate that for TCP connection scenarios, finding routes for AODV routing protocol are almost instantaneous while DSR routing protocol takes more time to discover routes.

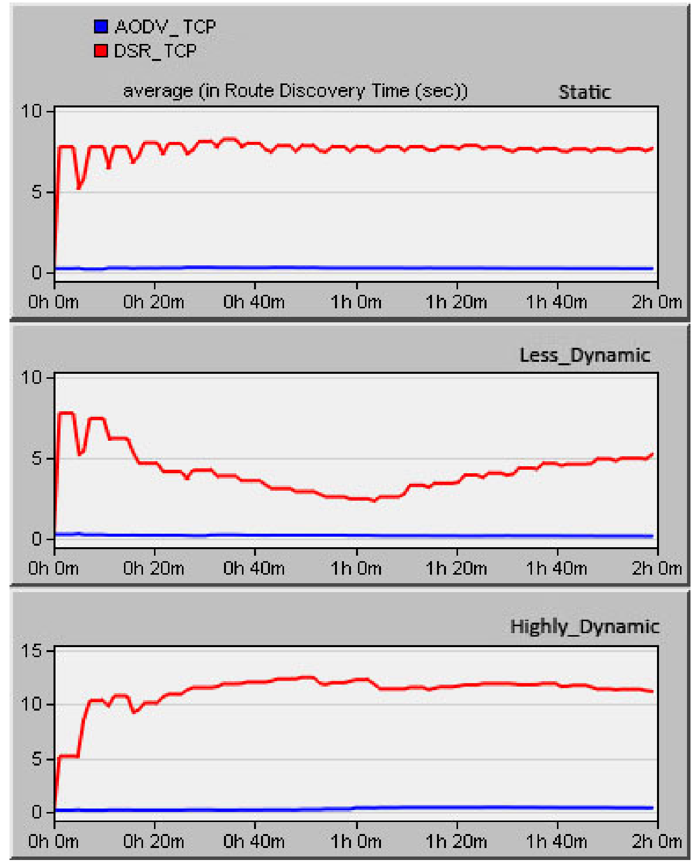

Figure 7: Average route discovery time (s) in TCP connection ad-hoc network scenarios: AODV and DSR cases.

5.2 End-to-End Delay/Download Response Time

Finding routes faster implies delivering data with less delay. The simulation results for UDP connection scenarios are shown in Figure 8. The end-to-end delay in the static network for all three routing protocols is less than approximately 0.5 s for most simulation scenarios. As we expect from the route discovery time, the AODV end-to-end delay is almost constant for all mobilities. However, the DSR end-to-end delay grows as mobility increases. The OLSR has the smallest delay in all mobility scenarios because it is a proactive routing protocol and it discovers routes before attempting to send any data. Hence, the OLSR routing protocol has a general overview of network topology and every node in OLSR has at least one valid route to each reachable destination [10].

Download response time in TCP connection scenarios is shown in Figure 9. Although the route discovery time for DSR is higher than the AODV route discovery time, it has the smallest download response time. DSR download response time is also smaller than download response time for OLSR. DSR has the smallest download response time, which might be due to DSR source routing. DSR uses source routing, which implies that a destination node does not need to discover a new route to the source node in order to send back the acknowledgement for each TCP packet.

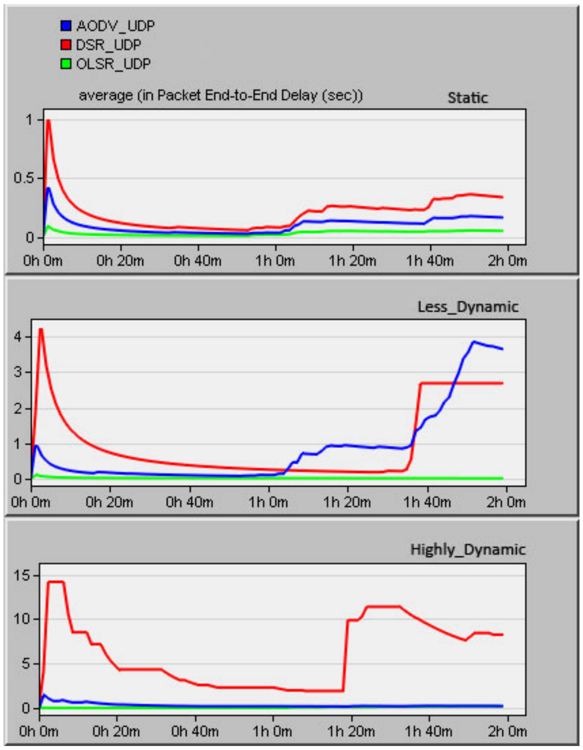

Figure 8: Average packet end-to-end delay (s) in UDP connection ad-hoc network: AODV, DSR, and OLSR cases.

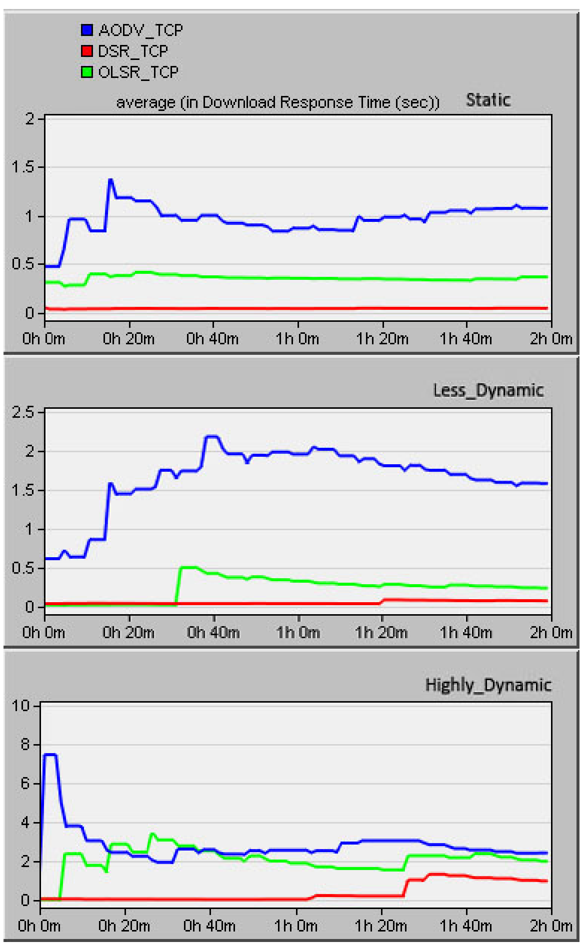

Figure 9: Average download response time (s) in TCP connection ad-hoc network scenarios: AODV, DSR, and OLSR cases.

5.3 Routing Traffic Overhead

Routing traffic is another important factor in ad-hoc networks and may be a determining factor in networks such as wireless sensor networks (WSNs).

Average routing traffic sent and received throughout the UDP connection ad-hoc network for AODV, DSR, and OLSR is shown in Figure 10. As expected, OLSR has much larger routing traffic overhead in comparison to AODV and DSR. Figure 10 also illustrates an interesting result in case of OLSR routing. The protocol sends approximately 5,500 bps and receives approximately 14,000 bps of routing traffic, which implies that each packet is duplicated approximately three times. Note that the sent and received routing traffic overhead is constant in DSR and is approximately the same in AODV.

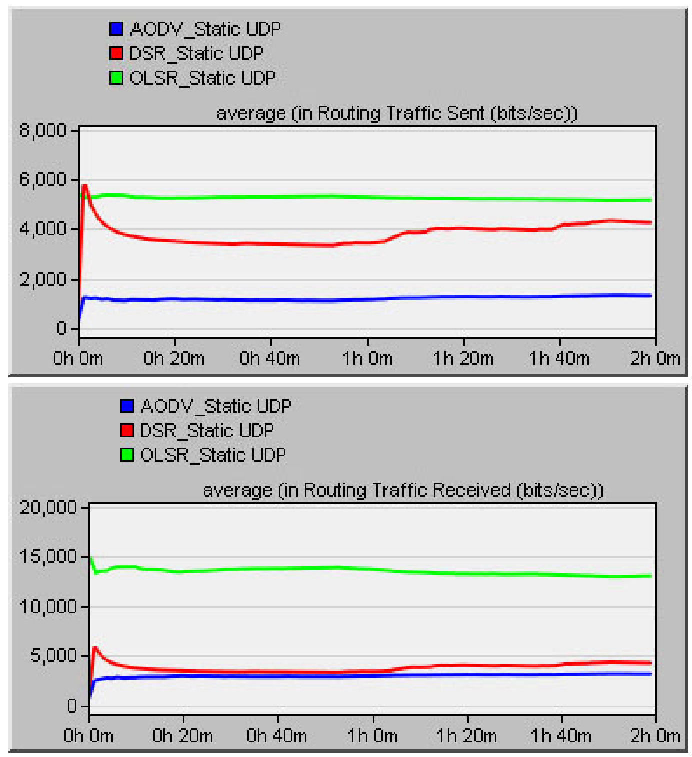

Figure 10: Average routing traffic sent (top) and received (bottom) in the static ad-hoc network with UDP connections: AODV, DSR, and OLSR cases.

Simulation results for less dynamic UDP connection ad-hoc network are shown in Figure 11. The only difference in routing traffic sent and received in less dynamic UDP connection network compared to static UDP connection network is a slight increase in routing traffic sent and received. DSR has tendency to send more routing traffic throughout the network in comparison to static network is illustrated in Figure 11.

The DSR sends more routing traffic in presence of highly dynamic nodes and in video streaming scenario, as shown in Figure 12.

The average routing traffic sent and received in the ad-hoc network in TCP connection scenarios is shown in Figures 13, 14, and 15. These results show that although DSR routing traffic in video streaming scenario increases as nodes movement increases, DSR has consistent results in file downloading and it generates the least amount of routing traffic compared to AODV and OLSR. OLSR shows the same results in UDP connection scenario and it generates a very large amount of traffic sent and received.

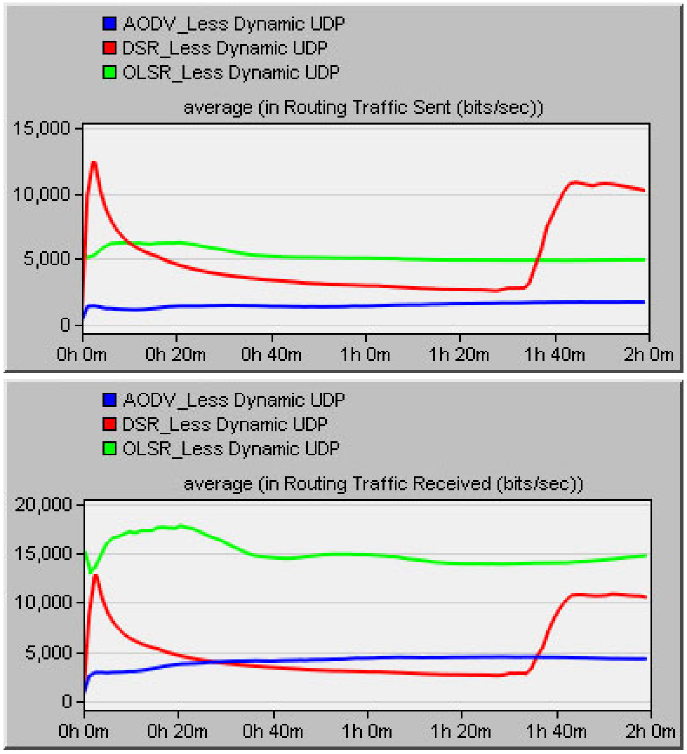

Figure 11: Average routing traffic sent (top) and received (bottom) in the less dynamic ad-hoc network with UDP connections: AODV, DSR, and OLSR cases.

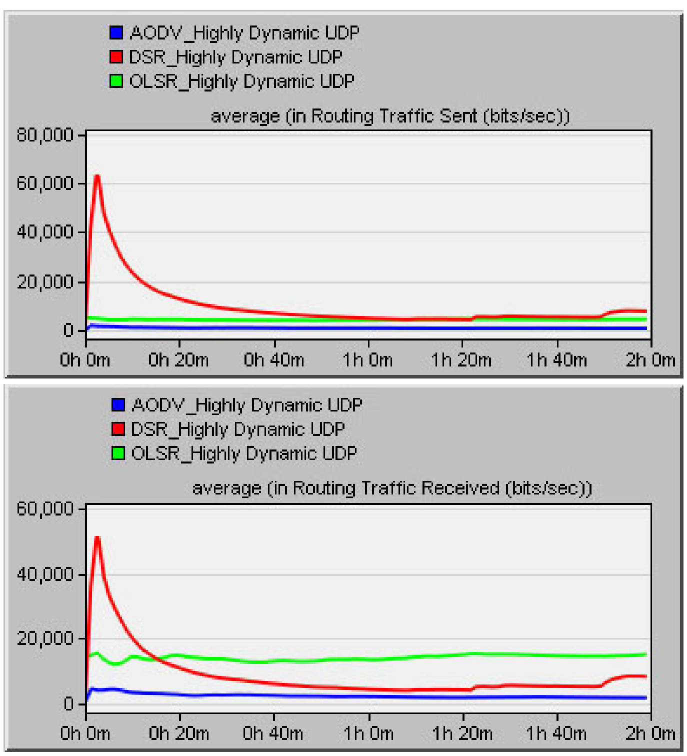

Figure 12: Average routing traffic sent (top) and received (bottom) in the highly dynamic ad-hoc network with UDP connections: AODV, DSR, and OLSR cases.

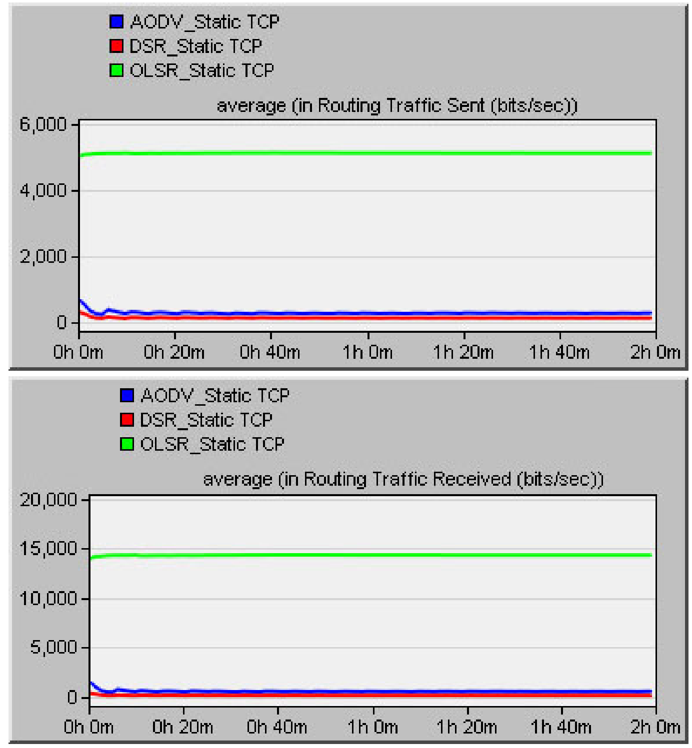

Figure 13: Average routing traffic sent top) and received (bottom) in a static ad-hoc network in TCP connection scenarios: AODV, DSR, and OLSR cases.

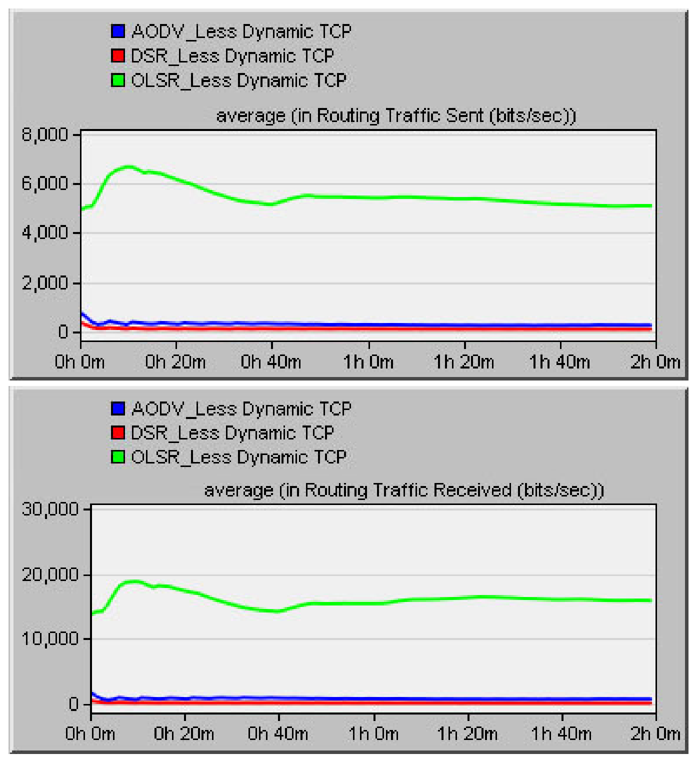

Figure 14: Average routing traffic sent (top) and received (bottom) in a less dynamic ad-hoc network in TCP connection scenarios: AODV, DSR, and OLSR cases.

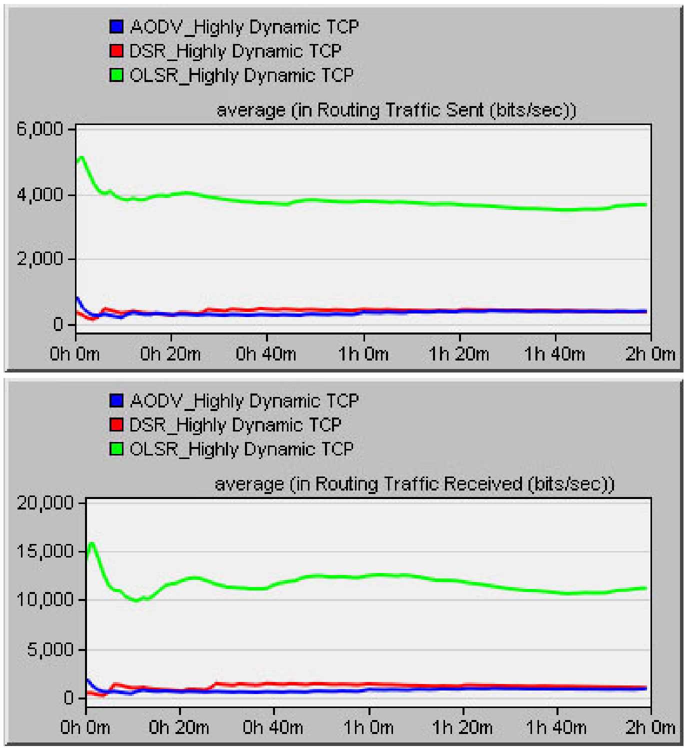

Figure 15: Average routing traffic sent (top) and received (bottom) in a highly dynamic ad-hoc network in TCP connection scenarios: AODV, DSR, and OLSR cases.

6. Conclusions

In this paper, we compared performance of various wireless ad-hoc routing protocols with a simulation study of 16 wireless LAN nodes in various environments. Based on the simulation results, AODV is the most flexible protocol among the three protocols and performs better in presence of movement while generating low routing traffic overhead. Scaling of MANET routing protocols such as AODV, DSR, and OLSR depends on node count, node density, traffic intensity, traffic path hop count, and network bandwidth [11].

AODV: Simulation results indicate that AODV is the most flexible routing protocol in the presence of movement. It also generates the least routing traffic overhead in most scenarios and it discovers routes very fast.

DSR: In video streaming scenarios, DSR does not perform well, especially in presence of movement. In addition to large end-to-end delay in video streaming, DSR also suffers from less flexibility in presence of movement and as the movement increases, the route discovery time and routing traffic overhead increases. In case of TCP connection scenarios, DSR shows good performance only in download response time and has low routing traffic overhead. Due to the use of caching and its inability to expire out of date routes, the performance of DSR becomes poor in highly mobile network. However, DSR is inflexible in video streaming scenarios. It can handle movement in the network employed for transferring files.

OLSR: In the UDP connection simulation scenario with streaming a video over the network, only the OLSR routing protocol maintained the demand for end-to-end delay value less than 20 ms while other two protocols suffered from large end-to-end delay. The OLSR protocol generates large routing traffic overhead in order to always have at least one route to every network node. In case of TCP connection scenarios, OLSR does not perform well. It generates large overhead in order to always know the network topology. OLSR outperforms the reactive routing protocols at higher speeds even though its routing load is even higher [12]. It does not have smaller download response time than DSR. In the presence of movement, DSR and OLSR impose large routing traffic overhead in an ad-hoc network and may fail to perform in conditions with limited resources available (buffer, bandwidth, and power).

Acknowledgments

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