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A Comparison of Optimized Link State Routing with Traditional Ad-hoc Routing Protocols

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***Abstract*— The performance of mobile ad-hoc networks (MANET) is related to the efficiency of the routing protocols in adapting to frequently changing network topology and link status. This paper addresses the issue by comparing the relative performance of three key ad-hoc routing protocols: Destination-sequenced Distance Vector (DSDV), Ad-hoc On-demand Distance Vector (AODV) and Optimized Link State Routing (OLSR). The protocols are tested based on two scenarios, namely, tactical networks for ships and sensor-based network nodes. Four performance metrics were measured by varying the maximum speed of mobile hosts, network size and traffic load, to assess the routing capability and protocol efficiency. The simulation results indicate that AODV performs better than OSLR and DSDV in the first scenario. Although OLSR also performed relatively well, the associated high routing overhead is the dominant reason for not choosing it. On the other hand, OLSR emerged as the protocol of choice for sensor networks, where the high routing overhead is counteracted by consistently better performance in all other metrics. Due to the slow evolution of the sensor network topology, OLSR performed satisfactorily for best effort traffic but needed subtle adjustments to balance between latency and bandwidth to meet the requirements of delay-sensitive applications.**

I. Introduction

An ad-hoc network is often described as a collection of mobile platforms or nodes where each node can move freely and arbitrarily without the benefit of any fixed infrastructure except for the nodes themselves. They are often autonomous, self-configuring, and adaptive, which make them an excellent candidate for many unique military applications. The rapid adoption of wireless networking technology in the commercial sector using IEEE 802.11-based WLAN specifications is an excellent example. It provides a compelling platform where it is only prudent that the military would leverage and extend the capability of such wireless solutions to respond to its unique needs. This also results in a need to identify a new class of routing protocols.

Existing commercial routing protocols, such as the Open Shortest Path First (OSPF) standard [1], which uses periodic hello messages to determine network connectivity, were never designed to be used in an environment in which the network topology can change rapidly and in which nodes are connected by low data rate, high bit error links. It reinforces the fact that existing commercial protocols specifically developed for the wired infrastructure must be appropriately modified before they are used in the wireless ad-hoc networking environment.

Protocol development efforts for ad-hoc networks are widespread in the wireless networking research arena. These efforts are largely fueled by the formation of the mobile ad-hoc networking (MANET) working group within the Internet Engineering Task Force (IETF) in 1999, to develop a routing framework for IP-based protocols in ad-hoc networks. The latest among such works is the introduction of Internet draft RFC 3626 [2] or Optimized Link State Routing (OLSR) protocol. The OLSR protocol is an improvement over the older and less effective proactive routing protocol, the Destination-Sequenced Distance Vector (DSDV) protocol. It uses a different routing technique designed to adapt to a network which is dense and where data transmission is assumed to occur frequently between large numbers of nodes.

It is observed that most routing protocol research studies for MANET are generally focused on performance optimization for mobile nodes that have no constraints over the implementation of IEEE 802.11 physical channel. The nodes are always assumed to have the physical means for an elevated antenna which can efficiently transmit and find routes between communicating nodes. However, such an assumption does not necessarily hold true where rapid ad-hoc deployment of a surveillance mission is concerned. An example is the application of wireless sensor networks, where nodes typically operate autonomously and are very low profile. Therefore, it is useful to understand if the relative merits of MANET-based routing protocols would apply consistently well into the environmental characteristics of sensor networks.

Our goal is to carry out a systematic performance study of three ad-hoc network routing protocols using an open source network simulation tool called NS-2 [3]. The three routing protocols that will be investigated are, Ad-hoc On-Demand Distance Vector (AODV) protocol [4], Destination-Sequenced Distance Vector (DSDV) [5], and Optimized Link State Routing (OLSR). Both DSDV and OLSR are regarded as proactive routing protocols that utilize a table-driven technique by recording all routes they find between all source-destination pairs regardless of the use or need of such route. The OLSR protocol, however, is relatively new and the key concept used is that of multipoint relays (MPRs). The use of MPRs is to minimize routing overhead by reducing duplicated retransmissions of routing information in the same region. It is an optimization over a pure link state protocol and henceforth expected to perform better in large and dense ad-hoc networks [6].

For the experiments, the latest release of NS-2 (ns-2.29 [7]) is used. NS-2 is a discrete event simulator widely used in the networking research community. In general, the NS-2 installation will include all software extensions – contributed code developed by the Monarch research group in Carnegie Mellon University (CMU) for simulating multihop wireless networks. It contains a detailed model of the physical and link layer behavior of a wireless network based on the 802.11 specifications and allows arbitrary movement of nodes within a network area. The AODV and DSDV protocols are also provided as part of the NS-2 installation. The simulation for OLSR is implemented using 3rd party software called UM-OLSR, Version 8.8.0 that is developed by the University of Murcia, Spain [8].

The first objective is to benchmark the performance of the routing protocols based on the technical characteristics of conventional platform-based communication nodes such as a naval patrol vessel. In the context of mobility, a group mobility model is used to simulate movements of military tactical networks. The second objective is to evaluate the scalability of these routing protocols and their performance by extending the simulations to model for higher density and very low profile mobile nodes.

Four important performance metrics are evaluated – packet delivery fraction, average end-to-end delay of data packets, routing overhead, and normalized routing load. The first two metrics are the most important for best effort traffic. The routing overhead and routing load metric evaluate the efficiency of the routing protocol.

II. SHIP PLATFORM NODE SCENARIO

A. *Influence of Mobility Rate*

For a better understanding of how the mobility rate affects routing protocol performance, the node speed is increased from 5m/s (about 10knots/hr) to 25m/s (about 50knots/hr) in steps of 5m/s with the number of nodes kept constant, i.e., 20 nodes with a group size of five in a one kilometer squared area. Each node has a pause time of two seconds to simulate a high mobility environment. The traffic type is CBR with a 512 byte data packet. The application agent is sending at a rate of 10 packets per second whenever a connection is made. All peer to peer connections are started at times uniformly distributed between zero and 200 seconds. Each data point presented for this simulation is an average of 3 runs with a different starting seed for the random generator when it loads the mobile nodes into the simulation area, each lasting 200 seconds. The default parameters of the 914MHz Lucent WaveLAN DSSS radio interface model are used. The maximum data rate is set at 2 Mbps, and the IEEE 802.11 distributed coordination function (DCF) is used as the MAC layer protocol. Table 1 summarizes the simulation parameters.

Mobility	
Number of Nodes (N)	20
Map Size	1000m x 1000m
Mobility Model	RPGM
Pause Time	2s
Speed	5-10-15-20-25m/s
Simulation Time	200s
Traffic	
Traffic Type	Constant Bit Rate
Connection Rate	10 pkts/sec
# of connections	10
Packet Size	512 bytes

Table 1. Simulation parameters of ship nodes

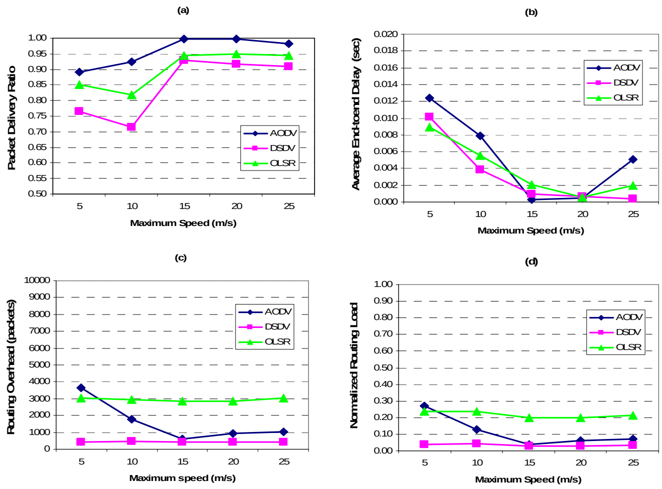

Figure 1. Results of varying mobility rate on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

Figure 1 depicts the performance metrics as a function of the mobility rates. Figure 1a shows the packet delivery ratio (PDR) for all protocols, which are all >72%. It can be seen that AODV and OLSR generally performed better than DSDV. In all cases, the PDR of AODV and OLSR are also higher as the maximum node speed is increased. Intuitively, the PDR is expected to drop at very high levels of mobility as more timeouts are expected to expire before a failure link is declared lost, and in part to the time needed to propagate information on topology change across the network. However, the PDR results showed otherwise and the trace files had to be inspected. This results from using the cluster-based mobility configuration with the RPGM model, as most of the traffic connections are found to be made within the clusters (recall that group size of five is defined) and <20% of the traffic is involved in intercluster connections. As the ship nodes have a relatively good communications infrastructure, the effective range is about 550 m for a transmit power of about 24.5 dBm (280 mW) with a carrier sense threshold of -78dBm. This provides an explanation to why the intercluster connections had little effect on the PDR performance.

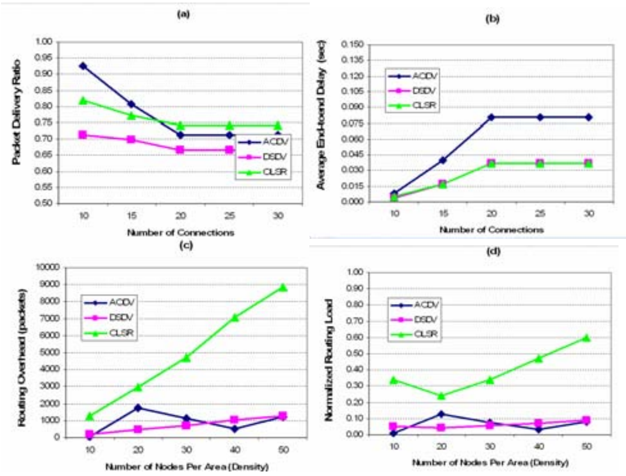

Figure 2. Results of varying node density on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

The graphs for the routing overhead packets (ROH) and normalized routing load (NRL) metrics have similar shapes, since in these scenarios the PDR is generally very high. As a result, only the level of both curves changes, i.e., NRL is actually ROH divided by the number of delivered data packets. In Figure 1d, although the NRL of OLSR is about four times higher than AODV, the effects on the average end-to-end delay are not significant (see Figure 1c). For the simulation, the traffic load per connection is only 41 kbps with a full load of approximately 410 kbps when there are ten connections, which represents less than 25% of the overall network throughput of 2 Mbps. Therefore, with the group mobility configuration, the routing protocols will provide better results at higher mobility and the PDF will remain stable at >91% from 15m/s onwards.

B. *Influence of Node Density*

The density of nodes should have a significant influence on the routing protocols performance. In general, low density may cause the network to be frequently disconnected and high density increases the contention, resulting in a low per node throughput. In the second set of simulations, the number of nodes per simulation area is increased from 10 to 50 nodes with the rest of the simulation parameters remain unchanged. The goal is not to find the optimal density of nodes, but rather to study how the protocols would scale to different node densities.

Figure 2 shows the performance metrics of the protocols as a function of node density. An important observation is that the protocols actually delivered close to 100% of data packets (Figure 2a) despite being in a scenario with a density of only 10 nodes per area, which is not expected in a frequently disconnected network. The reason for this was discussed in the earlier observation of the trace files. Otherwise, the effects of disconnected network due to low node density are evident from the results of 20 and 30 nodes per area, where the PDR improved gradually from around 71% to greater than 91% in all cases as the node density is increased vis-à-vis improvement in network connectivity. However, Figure 2c and 2d revealed a potential problem with OLSR as the routing loads appeared to scale linearly with an increase in node density, although the effect is counteracted by a relatively high PDR and low latency as compared to DSDV and AODV. One of the reasons for the massive amount of routing overheads in OLSR is due to the default setting of the Hello packet and topology control intervals, which are two and five seconds, respectively. For DSDV, the periodic update of routes is set at 15 sec by default. As a result, when the proactive protocols are compared at a node density of 50 nodes, OLSR has effectively six times more routing overhead than DSDV. Secondly, while OLSR utilizes MPRs to reduce routing overhead, the implementation did not perform well as a result of the randomness in node positions as the different clusters or group leaders can move in different bearings. In this case, the MPR flooding method is inefficiently used.

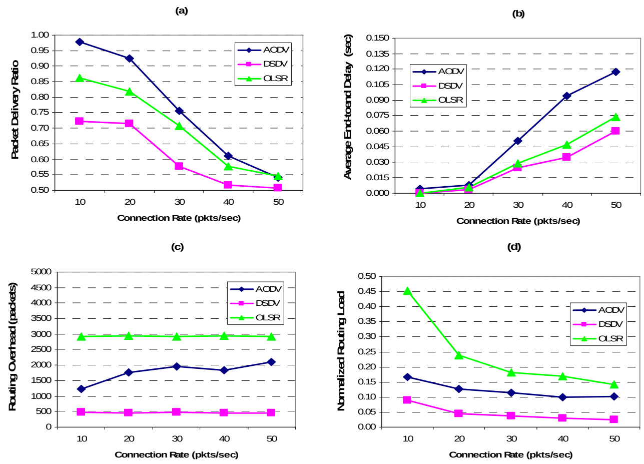

Figure 3. Results of varying connection rate on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

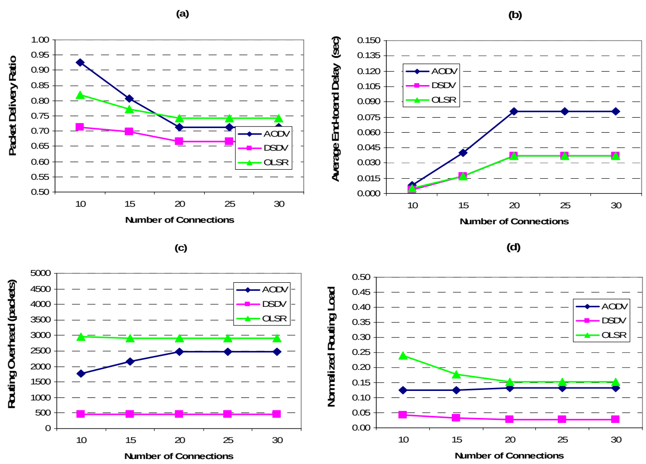

Figure 4. Results of varying number of data connections on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

Lastly, as in the case of mobility test, AODV clearly performs better in terms of PDR, while at the same time maintaining a very low routing load and low average end-to-end delay.

C. Influence of Network Loading

Figures 3 and 4 depict the effects of network loading on the performance metrics by increasing either the connection rate or the number of data connections from 10 to 50 and 10 to 30, respectively.

Figures 3a and 4a show that the PDR for all protocols have a declining trend when the connection rate is increased, although the case is less obvious when the increasing number of data connections. As the node density is low it is more likely to result in network fragmentation as the protocols react to topology changes. Because the connection rate is high, each link breakage resulted in more dropped packets, which explains the low PDR from a connection rate of 20 pkts/sec onward. Both AODV and OLSR reacted consistently to the two network loading conditions. The latency of AODV increased significantly from 5 ms to 117 ms and 3 ms to 37 ms, whereas the latency of OLSR increased from 2 ms to 80 ms and 5 ms to 37 ms when the connection rate and number of connections were increased. All the protocols appeared to follow an increasing trend in network latency when the network load was increased. This is consistent with the declining PDR in Figure 3a, but Figure 4a showed that the protocols are less affected by the increase in number of connections, and OLSR actually performed marginally better than AODV and DSDV.

From Figure 3c and 4c, the results for DSDV always demonstrated a lower ROH than AODV and OLSR. The advantage is a factor of 5-to-6 times. When either the connection rate or number of connections increases, the NRL for OLSR slowly approaches the routing efficiency of AODV. The NRL indicated a factor of 1.4 to 2 times performance differentials between the routing efficiencies of AODV and OLSR. So, AODV is better than OLSR in that metric. In fact, the margin is bigger when the network load is light. In addition, it can be seen that AODV outperformed OLSR by a factor of up to 5 times in NRL, i.e., when there are 10 connections sending at individual data rate of 41 kbps, OLSR with NRL of about 0.45 will need to send out approximately one routing packet for every two data packets.

III. SENSOR NODE BASED SCENARIO

In this scenario, the objective is to analyze how well the routing protocols scale with the size of a sensor network. The context of a sensor network in this paper is defined as an autonomous, multihop, wireless network with nondeterministic routes over a set of physical layers that can serve numerous sensor applications without manual reconfiguration. The simulation focuses mainly on the constraints of the physical environment on overall routing performance and does not address how the routing behavior may potentially affect the dynamics of what the higher layer applications may impose.

The physical profile of a sensor node is assumed to be no smaller than 0.1m and has sufficient energy for extended transmission placed in a simulation area of 200m by 200m. The grid size is made small to avoid incurring long simulation runtime and in part due to low mobility of the nodes. The mobility is to account for the drifting effect of the sea surface which is not necessarily stationary. Also, instead of limiting the broadcast range of the 802.11 radios to simulate communications range of sensor nodes as suggested in [9], a similar effect is achieved by reducing the antenna height from a default value of 1.5m to 0.1m. As such, traffic connections are established via a generic MAC algorithm rather than an imposed hypothetical bound which limits the number of nodes that can receive any broadcast message that is sent. Another key area that is considered for the sensor networking scenario is that the data traffic is not generated in an N-by-N fashion. Instead, there is a designated sink node that will either pull or receive data generated by other sensor nodes. This unique traffic pattern is modeled by modifying the generated traffic files by hand, in which two specific nodes are designated as sink nodes. The two sink nodes are created to simulate node redundancy for operational availability and at least 50% of CBR sources created will be destined to either one of the sink nodes. The rest of the simulation parameters are varied accordingly to analyze the effects of mobility, node density, and network loading have on the protocol performance.

A. Influence of Mobility Rate

During this experiment, the number of nodes is kept constant, i.e., there is only one cluster of 50 nodes. The node speed is varied from 0.5m/s to 2.5m/s in steps of 0.5m/s. Each node has a pause time of 100s to simulate a low mobility environment. The traffic type is CBR with 512 byte data packets. The application agent is sending at a rate of 10 packets per second whenever a connection is made. All peer to peer connections are started at times uniformly distributed between zero and 100 seconds. The averaging of the data points is not done for this simulation because of very long simulation runtime with OLSR. The same 802.11 radio interface at a 2 Mbps data rate is used.

Figure 5 depicts the performance metrics as a function of the mobility rates. Figure 5a shows a declining trend in PDR for all protocols when the maximum node speed is increased. Both AODV and OLSR outperformed DSDV as expected, at a margin of at least 20% higher in PDR. DSDV is unable to effectively deliver data in a dynamic network populated by a large number of nodes. Since sensor nodes are typically low in mobility, the result is actually more significant at node speed of 0.5m/s or below. At the lowest maximum speed of 0.5m/s, the PDR of OLSR reached the level of 92%, which is significantly better than AODV (76%) and DSDV (69%).

Figure 5b provides a result that is consistent with the theoretical performance capability of proactive protocols in a fixed network. With a network of a large number of nodes with low mobility, the occurrence of link outage is relatively small, so we expect proactive protocols to yield low route latency as compared to reactive protocol. However, in the case DSDV, it is clear that the very low average end-to-end delay is a direct result of the low PDR which indicated a biased preference to short paths with low delays by the protocol. While this may be a good routing strategy for best effort traffic, it will not work well for supporting higher priority traffic such as voice and video, which require a good balance of high PDR and low latency.

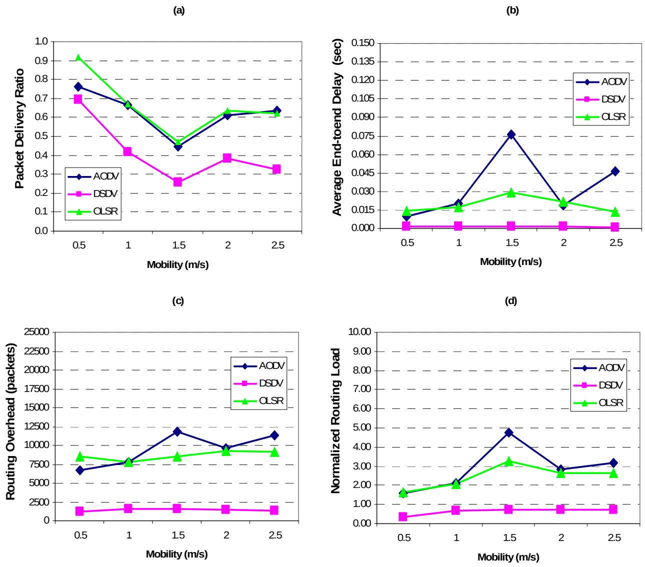

Figure 5. Results of varying mobility rate on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

The ROH and NRL performance differentials between DSDV and the other two protocols are as explained in Section A of this chapter. The significant point is that OLSR has generally performed better than AODV in all metrics concerning the influence of node mobility on routing protocols.

B. *Influence of Node Density*

As the scenario is to model a sensor field for this simulation, the number of nodes per simulation area is increased from 20 to 100 nodes with the rest of the simulation parameters remaining unchanged. The effective radio range for 802.11 with 0.1 m node height with two-ray path propagation model is 36.7 meters. So, in the context of sensor networks, the 20 to 100 nodes per area represents a density of ≈ 5.2 to 10.6.

Figure 6 shows the performance metrics of the protocols as a function of node density. As Figure 6a shows, there is a general down trend of PDR for all protocols when the node density is increased. Although OLSR performs relatively well amongst the three protocols, the result actually contradicts the theory that OLSR will perform better in a large and dense network [6]. It can be seen that at 20 nodes per area, the PDR of OLSR is almost 100% but dropped gradually to 58% at 100 nodes per area. However, a scalability modeling of ad-hoc routing protocols research done in [10] provided a distinctive argument to this. Specifically, in some relatively low density scenarios, the proportion of PDR can increase as more nodes are added because network fragmentation is reduced. But for some high density scenarios, adding nodes can result in good quality N-hop route being replaced by poor quality (N-1)-hop route. This effect is clearly visible in results of this simulation.

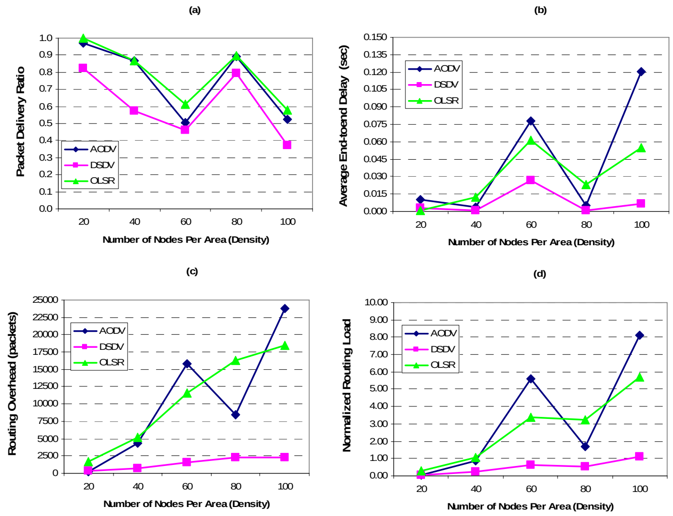

Figure 6. Results of varying node density on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

Both AODV and DSDV have similar NRL, which are approximately 0.05 for 20 nodes, whereas the NRL for OLSR is higher at 0.3. AODV and OLSR introduced more ROH as the number of nodes increased, with the load of AODV growing faster than for OLSR (see Figure 6c and 6d). At 100 nodes, the NRLs for AODV and OLSR are 8.1 and 5.7, respectively. That means that for every data packet sent, AODV will require an additional eight routing overhead packets as opposed to about six for OLSR. This is a serious concern because with more packets sent, the chance of collision will be higher in a contention based network. This causes the delay of the application to increase indirectly. Figure 6b provides a proof of this effect. In general, OLSR is more scalable than AODV with respect to the number of nodes per area. It seems that 40 nodes per area is the turning point. For more than 40 nodes, OLSR performs better than AODV in PDR, NRL and average end-to-end delay.

C. *Influence of Network Loading*

Figures 7 and 8 depict the effects of network loading on the performance metrics by increasing either the connection rate or the number of data connections from 10 to 50 and 10 to 30 respectively.

Figures 7a and 8a show that the PDR for all protocols have a declining trend when the connection rate is increased. The PDR of OLSR dropped from 92% to 33% when the connection rate is increased from 10 to 50, AODV dropped from 76% to 25%, while that of DSDV dropped from 69% to 34%. The PDR for all protocols dropped more gradually with increasing number of connections. Both AODV and OLSR are able to maintain >50% PDR in the latter case.

As Figure 7b shows, for connection rate of 10 pkts/sec, all the protocols have relatively small latency of <14ms. The latency increases gradually with the connection rate until it reached 40 pkts/sec where the latency of AODV and OLSR increased more rapidly than that of DSDV. The difference in latency between the load at 40 pkts/sec and 50 pkts/sec is about three times, i.e., from 75 ms and 240 ms, which is significant. If the sensor network is to support time-sensitive applications a connection rate of 40 pks/sec, which translates to a data rate of 164 kbps per connection, seems to be the highest throughput that may be used, albeit with penalty of low PDR.

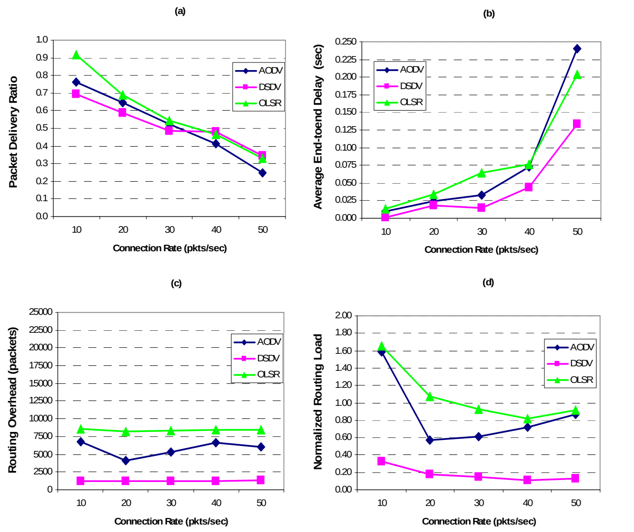

Figure 7. Results of varying connection rate on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

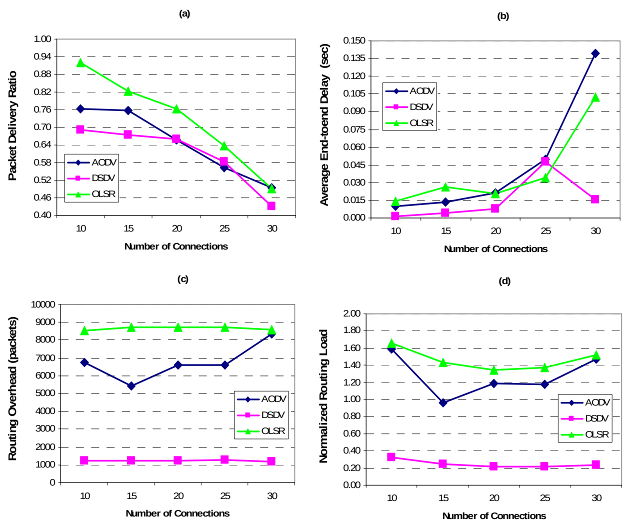

Figure 8. Results of varying number of data connections on (a) PDR (b) average end-to-end delay (c) ROH and (d) NRL

For DSDV, the number of protocol packets appeared to be determined mostly by the mobility and network size. The NRL stayed relatively constant at between 0.12 to 0.32 with increasing connection rates and number of connections (Figure 7d and 8d). The NRL for OLSR is less affected by the network load due to the increase in the number of connections as opposed to increasing connection rates. At either end of the network load OLSR performed better than AODV. Otherwise, the graphs in Figure 7c and 8c indicate that the advantage of a better PDR for OLSR is offset by a poorer average end-to-end delay at medium network loads.

IV. Conclusions

This paper provides a performance analysis of three different mobile ad-hoc routing protocols, namely, DSDV, AODV and OLSR by means of simulation using an open source network simulator software called NS-2. In an ad-hoc network environment where the mobile nodes are expected to inherit high group mobility such as the tactical ship networks, the classic AODV remains the protocol of choice, as opposed to OLSR and DSDV. Although OLSR is a vast improvement over the older proactive or table-driven DSDV protocol, it did not perform as well as AODV in an open and dynamic networking environment akin to operations of that in a littoral theatre.

On the other hand, OLSR has emerged as the best protocol to use in the sensor network based scenario. It has consistently outperformed AODV and most definitely DSDV in all cases. Although the poor ROH of OLSR has continued to be a concern, in this case, the exception is that even AODV would have similar ROH problems due to the high node density and low node mobility network environment. AODV failed to perform as well in this scenario especially when the node density is increased. This is due in part to its poor routing strategy in a network that has relatively static topology. It also scaled poorly when the density is in the region of 100 nodes or more.

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