A PERFORMANCE EVALUATION FOR AD HOC ROUTING PROTOCOLS IN REALISTIC MILITARY SCENARIOS

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***Abstract*—Most of performance analysis works for routing protocols in mobile ad hoc networks are based on simulation studies with several design parameters in commercial settings. For example, wireless LAN technologies in the 2.4 *GHz* ISM frequency band are generally assumed, offering data rates up to 2 *Mbps* within the range of 250 *m*. However, such propagation and network models are quite different from real-world military environments, where a few hundred MHz band (i.e., VHF or even HF) is used with very low data transmission rates (e.g., 384 *Kbps*). In this paper, we consider more realistic military scenarios and evaluate the performance of four well-known ad hoc routing protocols (i.e., AODV, DSR, LAR and OLSR) using QualNet. Our preliminary simulation results show that the DSR and LAR protocols achieve relatively good performance, compared to the other protocols.**

I. INTRODUCTION

Starting from the days of the packet radio networks (PRNet) [1] in the 1970s, a mobile ad hoc network (MANET) [2] has received great amount of research attention for a long duration. The ease of deployment without the existing infrastructure makes ad hoc networks an attractive choice for dynamic situations such as military operations, disaster recovery, and so forth. Especially, military communication environments have been considered as one of the original motivations for MANET, due to the need for battlefield survivability and rapid deployment of self-organizing mobile infrastructure [3].

Recent research in ad hoc networks has focused on medium access control (MAC) and routing problems, resulting in many different protocols proposed and some quantitative analysis work comparing the performance of these protocols [4],[5],[6]. Most of such performance analysis works are based on simulation studies with several design parameters in commercial settings. For instance, wireless LAN [7] technologies in the 2.4 GHz ISM frequency band are generally assumed, offering data rates up to 2 *Mbps* within the range of 250 *m*. This paper is motivated by the observation that such propagation and network models assumed by the current ad hoc networking simulations are quite different from real world military environments. In fact, a few hundred MHz frequency band (i.e., VHF or even HF) is used with very low data transmission rates (e.g., 384 *Kbps*) for the military scenarios [8]. Table I summarizes these differences in terms of a physical layer model. Networking environments such as network size, nodes' mobility model, and traffic patterns are quite different as well. For instance, the size of military networks is often far greater than that of their conventional counter parts both in the number of nodes and dimensions of the geographical areas they cover.

TABLE I
A UNIQUE PHYSICAL LAYER MODEL FOR MILITARY ENVIRONMENTS

Parameters	Military devices	Conventional devices
Frequency	30, 88, 300 *MHz*	2.4, 5 *GHz*
Propagation limits	-115 *dBm*	-110 *dBm*
Radio propagation model	Two-ray ground	Line-of-sight
Data rates	9.6~384 *Kbps*	2~54 *Mbps*
Transmit power	37 *dBm*	15 *dBm*
Receive sensitivity	-100 *dBm*	-90 *dBm*

In this paper, we consider realistic military ad hoc networks and conduct a performance analysis of well--known protocols for routing in conventional ad hoc networks. The routing protocols currently considered in our study include AODV [9], DSR [10], LAR [11], and OLSR [12]). The rest of the paper is organized as follows. Section II, as a background, reviews some key characteristics of the four well-known ad hoc routing protocols under study. Section III describes our simulation models and scenarios, followed by QualNet simulation results in Section IV. We conclude in Section V.

II. BACKGROUND

The existing protocols for ad hoc routing can be categorized as table-driven and on-demand scheme. Table -driven routing protocols (such as DSDV and OLSR) attempt to maintain consistent, up-to-date routing information from each node to every other node in the network. In these protocols, every node in network should maintain a table to store route information. Nodes are

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required to periodically propagate route update messages throughout the entire network for the change of network topology. On the other hand, on-demand routing protocols create route only when the needs arise. When a source node needs a route to a destination node, it starts a route discovery. For our performance comparison study, we pick up three representative on-demand protocols (i.e., AODV, DSR, and LAR) and one probably most well-known table-driven protocol, OLSR.

- **AODV (Ad-hoc On-demand Distance Vector) Routing:** AODV is an improvement of DSDV to on-demand scheme. It minimize the broadcast packet by creating route only when need. In DSDV, every node in network should maintain route information table and participate in routing table exchange. When source node wants to send data to the destination node, it first initiates route discovery process. In this process, source node broadcasts Route Request (RREQ) packet to its neighbors. Neighbor nodes which receive RREQ forward the packet to its neighbor nodes. Neighbor nodes which receive RREQ forward the packet its neighbors, and so on. This process continues until RREQ reach to the destination or the node who know the path to destination. When the intermediate nodes receive RREQ, they record in their tables the address of neighbors, thereby establishing a reverse path. When the node which knows the path to destination or destination node itself receive RREQ, it send back Route Reply (RREP) packet to source node. This RREP packet is transmitted by using reverse path in formation in route table of each intermediate node. When the source node receives RREP packet, it can know the path to destination node and it store the discovered path information in its route table. That is the end of route discovery process. And then AODV perform route maintenance process. In route maintenance process, each node periodically transmits a Hello message to detect link breakage.

- **DSR (Dynamic Source Routing):** One of the important features in DSR is using source routing. In source routing, ach packet to be routed carrying in its header the complete, ordered list of nodes through which the packet must pass. That is, source node knows the entire path to the destination. And intermediate nodes don't need to maintain route information table for neighbor's address. This source routing information is stored in cache and updated when the node discover new route. DSR also consist of two mechanisms (Route Discovery and Route Maintenance process). In route discovery process, DSR also uses RREQ and RREP likely to AODV. However in DSR, intermediate nodes don't need to maintain route table because hop-by-hop path information (reverse path information) is stored in RREQ header when RREQ is forwarded form intermediate nodes. When destination node which knows the path to destination receives this RREQ packet, it sends back RREP to source node using header stored in RREQ packet. When the source node receive RREP packet, it know the entire path to destination node and store the discovered path in cache. Route maintenance process is accomplished through the use of Route Error (RRER) packets. RRER packets are generated when the link is broken due to mobility of nodes.

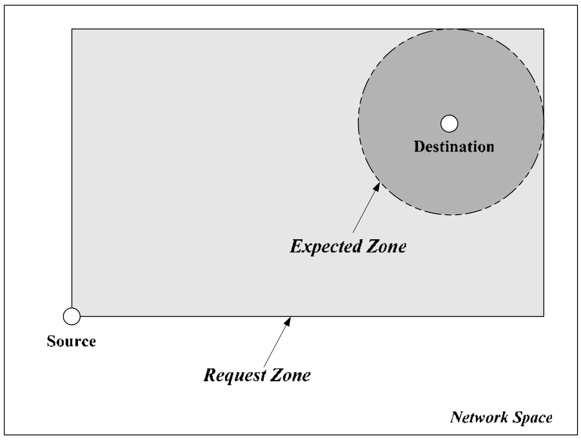

Fig. 1. Expected and request zones in location aided routing protocol

- **LAR (Location Aided Routing):** Compared to other ad hoc routing protocols, LAR utilizes location information to improve the performance of entire network.[1] LAR limits the broadcasting range of RREQ by using request zone, thereby reducing the transmission traffic. To reduce the broadcasting range, LAR defines two zones: request zone and expected zone (See the Fig. 1). Expected zone defines the range that destination node can move in. To define expected zone, LAR assume that source node know the location and velocity of destination node. Request zone defines the smallest rectangle that includes the location of source node and expected zone. RREQ broadcast in limited to this request zone. For example, when the node in request zone receives RREQ, it forwards the packet normally. However when the node not in request zone receives RREQ, it drop the packet.

- **OLSR (Optimized Link State Routing):** OLSR is based on link-state algorithm and table-driven scheme. Each node discovers and maintains topology information of networks, and builds a shortest path tree to achieve preferred paths to destinations. It conducts periodic exchange of messages to maintain topology and link states information of network at each node. Each node in network selects a set of node in its neighborhood, which forwards its packets. This set of selected neighbor nodes is called the MPR (multi-point relay). In OLSR, only the MPR exchanges the topology information of network periodically. By selecting the MPR, OLSR reduces the flooding of control overheads as compare to the other table-driven routing protocols, because only the MPRs of a node can forward its broadcast messages.

[1] In LAR, each node is assumed to know its current location using some of techniques in the recent literatures [17], [18], [19], [20]

In recent, several researches [13], [14], [15], [16] concerning on the military ad hoc networks have been conducted. Most of these researches focused on the proposal of new protocols or methods of applying ad hoc networking scheme to military environments. All of these researches also did not consider realistic physical and channel specification of military radios. But we concentrated on evaluating exact performance of conventional well-known ad hoc routing protocols under realistic military communication environments.

III. SIMULATION MODEL

Using the QualNet network simulator [21], [22], comprehensive simulations are made to evaluate the protocols explained above. Qualnet provides a scalable simulation environment for multi-hop wireless ad hoc networks, with various medium access control protocols such as CSMA and IEEE 802.11. We modified its channel and physical layer settings to apply more realistic military scenarios. Note that we use a PRC-999K device [23], as a reference model.

We use 802.11 DCF and UDP protocols for MAC and a transport protocols, respectively. Also, CBR traffic is utilized in our study. As the TCP-based application protocols such as telnet or FTP show unstable performance in mobile wireless communication, it can not evaluate precise performance of routing protocol itself. Our CBR application model sends one packet per second, which represents relatively low traffic patterns in military environments. Each packet size is 512 *Bytes*.

In military environments, operational network size is very large as compare to conventional case. Hence, we make our network size as a rectangular flat space of 12×22 Km^2. Nodes in our simulation are assumed to move according to the "random way point" mobility model [24]. We fixed a pause time to 20 seconds. We ran our simulations with movement pattern for 7 different maximum speeds of node: 1, 5, 9, 13, 17, 21, and 25 meter per second (*m/s*).

To compare the routing protocols, we evaluate them by 4 measurements: Packet delivery radio, average end-to-end delay, control packet overhead, and average energy consumption.

IV. SIMULATION RESULTS

We first compare the four routing protocols by varying maximum speed of nodes. In this scenario, we ran 100 nodes in the network. We then compare them by varying the network density from 100 to 200 nodes in network, with the fixed moving speeds of 1 *m/s* (approximately a walking speed of soldiers).

A. Packet Delivery Ratio

Performance results of packet delivery ratio are shown in Figure 2 and 3. Figure 2 shows packet delivery ratio of routing protocols according to the increase of node's maximum speed. As the nodes maximum speed increase, a packet delivery rate of protocols decreases. This because, in higher speeds, more frequent link breakage may occur and

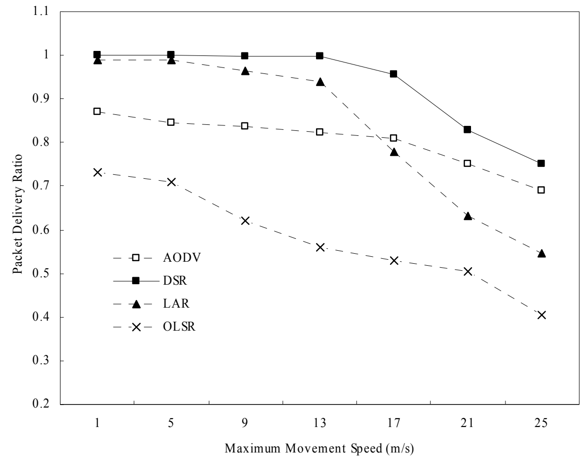

Fig. 2. Packet delivery ratio in terms of nodes' maximum moving speed

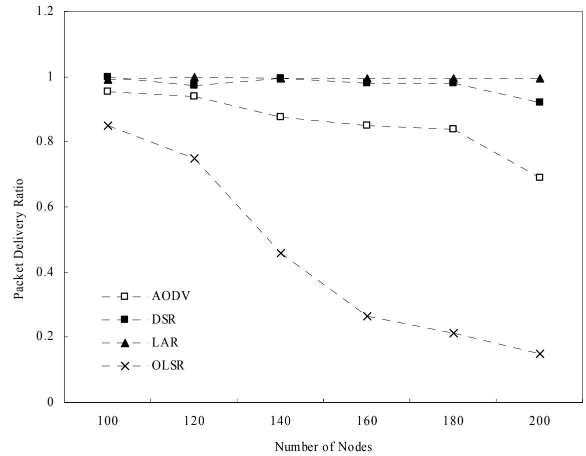

Fig. 3. Packet delivery ratio in terms of number of nodes

therefore a packet loss rate increases. In the figure, on-demand routing protocols (DSR, LAR, AODV) show a better packet delivery rate than a table-driven protocol (OLSR). Because on-demand routing protocols can reflect topology change in route information right away, it seems to be adequate to frequent movement environments. Among the on-demand routing protocols, DSR and LAR routing protocols show better performance than AODV. DSR which is using source routing can reduce total number of route control packets, resulting in less network congestion. LAR which is using location information can limit the broadcasted zone of route control packets. These characteristics can lead to better performance in packet delivery rate.

Figure 3 show packet delivery ratio according to the increase of network density. As the network density increases, there is an increase of radio interferences and collisions between nodes due to hidden/exposed terminals. Table-driven protocol (OLSR) shows poor performance as the network density becomes packet delivery rate. This is because DSR and LAR can reduce the network congestion by reducing route control packets.

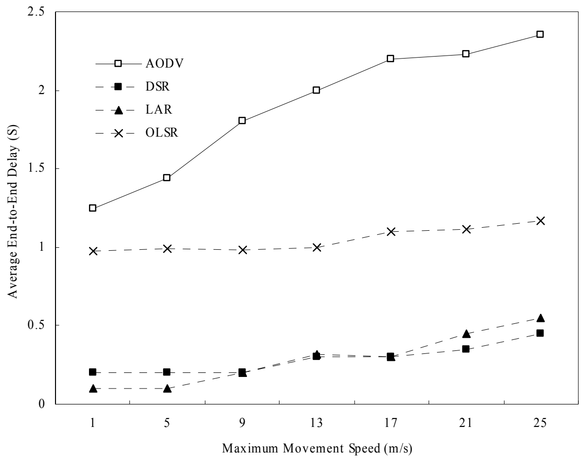

Fig. 4. Average end-to-end delay in terms of nodes' maximum moving speed

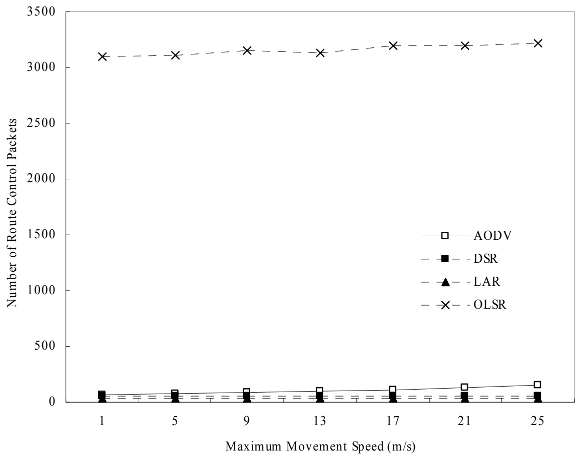

Fig. 6. Control packet overhead in terms of nodes' maximum moving speed

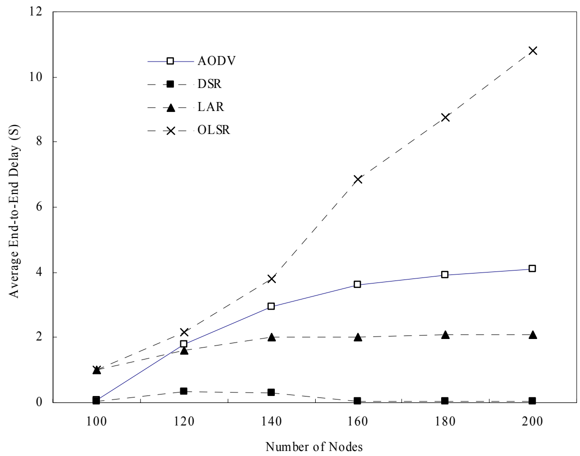

Fig. 5. Average end-to-end delay in terms of number of nodes

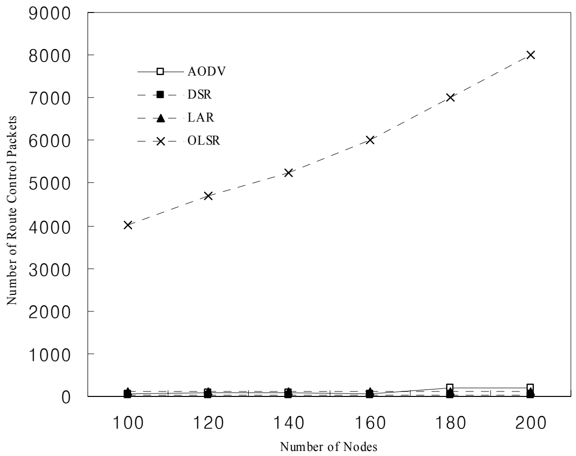

Fig. 7. Average end-to-end delay in terms of number of nodes

B. Average End-to-End Delay

Figure 4 and 5 show simulation results on the aspect of average end-to-end delay performance. Figure 4 shows an average end-to-end delay of routing protocols by varying the nodes' maximum movement speed. The increase of movement speed induces topology change frequently and therefore the probability of broken links also grows. Broken links may cause additional route recovery process and route discovery process. Because of this reason, the average end-to-end delay of packet increase as node speed increases.

Figure 5 shows an average end-to-end delay of routing protocols according to the increase of network density. As the density of network becomes high, the probability of collision is also increases. For this reason, the average end-to-end delay rises as the network density becomes high in common. In the case of OLSR, periodic route update causes frequent collision in high network density. This can lead to the degradation of performance in delay. But the on-demand routing protocols keep up good performance in delay as the network density becomes high. LAR shows the best performance because it reduces the signal traffic of network by limiting the broadcast region of control packets using the concept of request zone and expected zone.

C. Control Packet Overhead

Control packet overhead performances of four routing protocols are shown in Figure 6 and 7. Figure 6 shows control overhead of routing protocols according to increase of node maximum speed. OLSR performs the worst among all the protocols. Since OLSR is the table-driven protocol, the routing table at every node maintains exhaustive information about the network topology. While on the other hand, as on-demand protocol searches for a route whenever a need arises for it. Thus all on-demand protocols show good performance in control packet overhead. Especially DSR and LAR show remarkable performance in control overhead. Figure 7 shows control overhead of routing protocols according to the increase of network density. In the case of OLSR, the number of route control packet is directly proportional to the number of nodes, since the number of MPR (Multi-Point Relay) which broadcast periodic route update and hello message is increased as the number of node in network becomes high. In this figure, On-demand protocols present good performance as was expected.

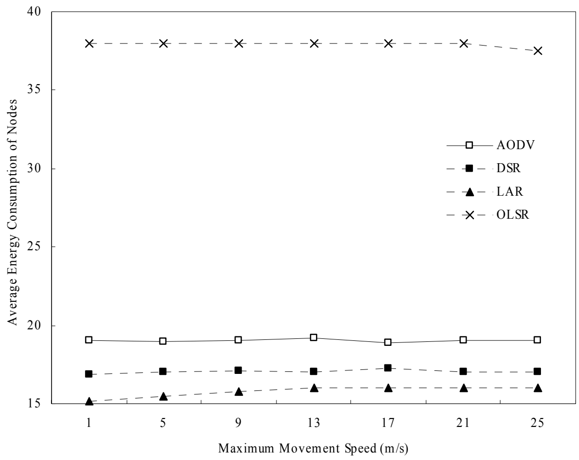

Fig. 8. Average energy consumption in terms of the number of ndoes

D. Average Energy Consumption

Figure 8 shows the average energy consumption of nodes according to the increase of node maximum speed. LAR and DSR protocol perform particularly well. LAR can prevent unnecessary broadcast of control packet using request zone. And DSR can reduce control packet header by using local route cache. These characteristics of LAR and DSR lead to the economy in the increase of network density.

V. CONCLUSION

Mobile ad hoc networks (MANETs) can be applied to many situations without the use of any existing network infrastructure or centralized administration. In military environment, there is a need for the network to route packets through dynamically mobile nodes. MANETs can be considered as the solution for this highly mobile and dynamic military network. However it is not appropriate to directly apply conventional mobile ad hoc networks scheme to military network, since military communication system is different from conventional counter parts both in device's physical layer specification and networking environment. Therefore we first consider these particularities of military communication system to out simulation, and evaluate the performance of four ad hoc routing protocols (AODV, DSR, LAR, and OLSR) on the assumed military environment.

In our simulation results, on-demand routing protocols perform well in high movement speed and high network density environment. But the table-driven routing protocol, OLSR shows the worst performance because its periodic route update and hello messages become the severe overhead in highly mobile and dense network. Among the on-demand routing protocols, DSR and LAR show particularly good performance with every measurement metric, therefore we can conclude that DSR and LAR are suitable for military ad hoc routing protocol. Especially we expect that LAR can be easily adapted to military communication system because military communication devices commonly support GPS system.

VI. CONCLUSION

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