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OPNET을 이용한 MANET 프로토콜 분석

Analysis of MANET Protocols Using OPNET

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Abstract A Mobile Ad hoc Network (MANET) is characterized by multi-hop wireless connectivity, frequently changing network topology with mobile nodes and the efficiency of the dynamic routing protocol plays an important role in the performance of the network. In this paper, the performance of five routing protocols for MANET is compared by using OPNET modeler: AODV, DSR, GRP, OLSR and TORA. The various performance metrics are examined, such as packet delivery ratio, end-to-end delay and routing overhead with varying data traffic, number of nodes and mobility. In our simulation results, OLSR shows the best performance in terms of data delivery ratio in static networks, while AODV has the best performance in mobile networks with moderate data traffic. When comparing proactive protocols (OLSR, GRP) and reactive protocols (AODV, DSR) with varying data traffic in the static networks, proactive protocols consistently presents almost constant overhead while the reactive protocols show a sharp increase to some extent. When comparing each of proactive protocols in static and mobile networks, OLSR is better than GRP in the delivery ratio while overhead is more. As for reactive protocols, DSR outperforms AODV under the moderate data traffic in static networks because it exploits caching aggressively and maintains multiple routes per destination. However, this advantage turns into disadvantage in high mobility networks since the chance of the cached routes becoming stale increases.

Key Words : MANET, AODV, DSR, GRP, OLSR, TORA, OPNET, Performance

I. INTRODUCTION

With the development of wireless networks in recent years, mobile wireless communication in the world is becoming more significant and has increased in usage and popularity. In some emergency situations, such as fire and disaster, where mobile wireless networks can be utilized to establish an interoperable communication network, while the local infrastructure had been destroyed.

A Mobile Ad hoc network (MANET) [1] is a kind of wireless ad hoc network, which has mobile devices with self-configuring capability and is a network of mobile routers connected by wireless links. The terminals may be free to move randomly and organize themselves arbitrarily. In ad hoc network, nodes do not have a priori knowledge of topology of network around them, the route should be discovered. In this case, MANET routing protocols should be studied and utilized. Thus a key issue in MANETs is the necessity that the routing protocols must be able to respond rapidly to topological changes in the network. At the same time, due to the limited bandwidth available through mobile radio interfaces, it is imperative that the amount of control traffic generated by the routing protocols is kept at a minimum.

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The up-to-date standard protocols are classified into reactive and proactive protocols. Reactive protocols, such as AODV [2] and DSR [3], find the route only when there is data to be transmitted and as a result, generate low control traffic and routing overhead. On the other hand, proactive protocols like GRP [4] and OLSR [5] find the paths in advance for all source and destination pairs and periodically exchange topology information to maintain them.

In this paper, a systematic performance study of five routing protocols for a MANET was carried out, by comparing the simulated performance for each protocol using the OPNET modeler [6] under the varying network traffic, number of nodes and node's speed. The following section Ⅱ describes each routing protocol used in the study. In section Ⅲ, the simulated results under the various network conditions are shown and analysis of results and discussions are performed. Finally some conclusions are given in section Ⅳ.

II. MANET ROUTING PROTOCOLS

1. Ad hoc On-Demand Distance Vector(AODV)

AODV [2] is a reactive routing protocol and constructs the route when the route is needed. In ad hoc network, AODV offers quick adaptation to the dynamic link conditions, self-starting and multi-hop routing, low processing and low network utilization. The destination sequence number is used for each routing table entry to ensure loop freedom and identify the most recent path in ad hoc network.

In the AODV protocol, when a source node needs to know a path to the destination, a RREQ (Route Request) message is broadcasted in the network. Upon receiving such a message, a node examines its local route cache to check if a fresh route to the required destination is available. If so, the node unicasts a RREP (Route Reply) message to the source with information about the route. Otherwise, the RREQ is retransmitted using a pure flooding mechanism with local duplicate elimination. As an optimization, AODV employs an expanded ring search flooding algorithm, where a RREQ is issued with a increasing TTL (Time To Live) field. If no RREP message is received within a predefined time, the message is retransmitted with a larger TTL value. If still no reply, the TTL is increased in steps, until a certain maximum value. While this route discovery is performed, any data packets to the destination are buffered in the source node and after a route is established, the packets will be transmitted. If no route can be established, the packets are dropped. When a link is detected to be broken, the detecting node issues a RERR (Route Error) message to the neighbors who have been using a route over the now broken link. These nodes will then have to issue new RREQs to repair the broken routes [7].

2. Dynamic Source Routing (DSR)

DSR [3] is a source-routed on-demand routing protocol. The whole path information is stored in node's caches. DSR protocol is designed mainly for mobile ad hoc networks of up to about two hundred nodes and is designed to work well even with very high rates of mobility. DSR protocol allows multiple routes to any destination and guarantees loop-free routing. It operates in networks containing unidirectional links and uses only "soft state" in routing and provides automatic route shortening by a node operating in the promiscuous mode.

The DSR protocol is composed of two main mechanisms: Route Discovery and Route Maintenance [8].

If the source does not have a routing path to the destination, then it performs a route discovery by flooding the network with a route request (RREQ) packet. If the neighbor nodes that receive a RREQ do not have routing information about the destination, they add their IP address in the RREQ and then rebroadcast it to other nodes. Any node that has a path to the destination in question can reply to the RREQ by sending a route reply (RREP) packet in which the route from source to destination is included. The reply is sent using the route recorded in the RREQ.

Unlike other protocols, DSR requires no periodic packets (e.g. Hello message in AODV) of any kind at any layer within the network for route maintenance. When sending a data packet to the destination, each node along the path checks the last maintenance time. If the time elapsed since the last maintenance checking is greater than the hold off time (default 0.25sec), then the node attaches a "Acknowledgement Request" to the data packet by piggybacking. The neighbor node who receives this piggybacked data packet will reply with an Ack packet.

To limit the need for route discovery, DSR allows nodes to operate their network interfaces in promiscuous mode and snoop all (including data) packets sent by their neighbors. Since complete paths are indicated in data packets, snooping can be very helpful in keeping the paths in the route cache updated.

To further reduce the cost of route discovery, the RREQs can be initially broadcasted to neighbors only (zero-ring search), and then to the entire network if no reply is received. Another optimization feasible with DSR is the gratuitous route replies; when a node overhears a packet containing its address in the unused portion of the path in the packet header, it sends the shorter path information to the source of the packet (Automatic Route Shortening). Another important optimization includes the technique to prevent "Route Reply Storms": because many route replies may be initiated simultaneously, a delay time proportional to the hops-distance can be used in order to give higher priority to near nodes. In addition a method called "Packet Salvaging" is often used in DSR. When an intermediate node forwarding a packet detects through Route Maintenance that the next hop along the route for that packet is broken, if the node has another route to the packets' destination it uses it to send the packet rather than discard it.

3. Geographic Routing Protocol (GRP)

Geographic routing (also called geo-routing or position-based routing) [9] is a routing principle that relies on geographic position information. It is mainly proposed for wireless networks and based on the idea that the source sends a message to the geographic location of the destination instead of using the network address. The idea of using position information for routing was first proposed in the 1980s in the area of packet radio networks and interconnection networks. Geographic routing requires that each node can determine its own location and that the source is aware of the location of the destination. With this information a message can be routed to the destination without knowledge of the network topology or a prior route discovery. There are various approaches, such as single-path, multi-path and flooding-based strategies. Each node has its own destination table and neighbor table that include whole network node actual position.

GRP protocol operation which is modeled in our simulation is described as follows.

① After initialization at t=0, there is a delay between 0 and 5 secs before sending out flooding packets.

② A flooding message is broadcasted to all nodes in the network. When receiving a flooding packet, a node updates the destination table and floods it to other nodes. If the receiving node is in the same basic quadrant as the destination node (=source node of the flooding packet), the actual position of the destination node is inserted into the destination table. If the node is not in the same quadrant, the position of the centre of the highest level neighbor quadrant is inserted into the destination table.

③ After a delay between 0 and 5 seconds, Hello packets are sent out on every 5 seconds. When receiving a Hello message, the neighbor information is added or updated to the neighbor table.

④ When having an application data packet to send, the node find the next-hop neighbor node that is closest in distance to the destination node.

If a neighbor node in the neighbor table is the destination, it is the next-hop.

If the destination node is in the same basic quadrant as this node, the next-hop node is the closest node to the destination that lies in the same basic quadrant among neighbor nodes.

If the destination is in the different quadrant and at least one neighbor node lies in the destination quadrant, the next-hop is the first found neighbor node that lies in the destination quadrant.

If the destination is in the different quadrant and none of neighbor nodes lies in the destination quadrant, the next-hop is the closest node to the center of destination quadrant among neighbor nodes.

⑤ When a node moves, the position of the node may be needed to update. The node checks if it is still in the same basic quadrant or has moved to a new quadrant.

If the node is still in the same quadrant, send out a flood of the new position of the node only if it has moved greater than the distance beyond which the node needs to flood its current position.

If the node has moved to a new quadrant, flood the new position of the node to all nodes in the same higher level neighborhood (quadrant). The node also updates its destination table. For example, information of the nodes that lie in the previous quadrant should be changed from node-type to quad-type information and the highest level neighbor quadrant between the node and destination nodes may be changed. Especially, exact location information of the nodes that lie in the current new quadrant should be gotten from the neighbor node that is in the current new quadrant. So the node gets the list of nodes that need the new exact location information and include it into a position request message and then send out the message to one of neighbor nodes that are in the same quadrant as this node. The neighbor node will refer to its destination table to get the information required from the list of a position request message and reply with the position response message. In case of no reply from the neighbor node within the predefined time, the node will choose another neighbor node and try again. When receiving a position response message from the neighbor, the node records the exact location information in the destination table.

4. Optimized Link State Routing Protocol(OLSR)

OLSR [5] is a proactive link state routing protocol. In OLSR, topology information is regularly exchanged with other nodes and so a route is available immediately when needed. OLSR does not require reliable transfer since updates are sent periodically and does not need in-order delivery because sequence numbers are used to prevent out-of-date information from being misinterpreted. OLSR uses hop-by-hop routing.

In OLSR, the use of Multipoint Relay (MPR) to minimize the overhead of flooding messages is the distinctive feature over other classical link state protocols. The MPR set of a node N is the minimal set of N's one-hop neighbors such that each of N's two-hop neighbors has at least one of N's multipoint relays as its one-hop neighbor. MPRs are selected to do the followings for optimization: Only MPRs (not every node) forward broadcast messages during the flooding process (reduces number of control packets) and link state information is generated only by MPRs and an MPR node advertises information only about links between itself and its MPR selectors (reduces size of control packets).

OLSR uses two kinds of control messages [10-12]: Hello and Topology Control (TC). Hello message is used for finding the information about the link status and the node's neighbors. The Hello message just can send only one hop away, so they are not forwarded anymore. But TC messages can broadcast throughout the entire network. TC message is used for broadcasting information about own advertised neighbors, which include at least the MPR Selector list. And also only MPRs can generate and forward the TC message.

All nodes periodically broadcast Hello messages to their one-hop neighbors and each node uses the neighbor list in the received Hello messages to determine its two-hop neighbors and an optimal MPR set. Subsequent Hello messages include the MPR set as well as the neighbor list and are utilized again for calculating a MS(N)(MPR Selector set N) which is the set of nodes that choose node N as its MPR. This MS information is sent by a TC message and each node forms a topology table. A routing table is calculated from this topology table.

5. Temporally Ordered Routing Algorithm(TORA)

TORA[13], which is an adaptive routing protocol for multihop networks, uses link-reversal algorithm (neither distance-vector nor link-state) and can simultaneously support both source-initiated, on-demand routing for some destinations and destination-initiated, proactive routing for other destinations. TORA possesses the following attributes: distributed execution, loop-free routing, Multipath routing, reactive or proactive route establishment and maintenance, and minimization of communication overhead via localization of algorithmic reaction to topological changes.

TORA is distributed, in that routers need only maintain information about adjacent routers (i.e., one-hop knowledge). Like a distance-vector routing approach, TORA maintains state on a per-destination basis. However, TORA 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). In our study, only reactive function of TORA will be exploited in the simulation.

In TORA, the network topology is represented as a Directional Acyclic Graph (DAG) by means of an ordered quintuple (t, oid, r, d, i), which includes the logical time t of a link failure, the unique ID oid of the node that defines the new reference level, reflection bit r which indicates 0=original level, 1=reflected level, integer d to order nodes relative to reference level, and a unique ID i of the node. The triplet (t,oid,r) is called the reference level. And the tuple (d,i) is said to be an offset within that reference level. The height of a node is defined using a quintuple and like water flowing, a packet goes from upstream to downstream according the height difference between nodes.

TORA has three basic operations [14]: route creation, route maintenance and route erasure. Each node maintains a neighbor table containing the height of the neighbor nodes. In a route creation operation, initial height of a destination neighbor is (0,0,0,0,dest) and heights of all other nodes is NULL (-,-,-,-,i). The source which requires a link to a destination broadcasts a query (QRY) packet containing the destination's ID. A node with a non-NULL height responds by broadcasting a update (UPD) packet containing the height of its own. On receiving a UPD packet, a node sets its height to one more than that of the UPD generator. A node with higher height is considered as upstream and the node with lower height is considered as downstream. In this way, a directed acyclic graph is constructed from the source to the destination and multiple paths to a destination may exist.

The DAG in TORA may be disconnected because of node mobility. Therefore, route maintenance operation is an important part of TORA. TORA has the unique feature that control messages are localized into a small set of nodes near the occurrence of topology changes.

After losing its last downstream link, the node generates a new reference level and broadcasts the reference to its neighbors. Therefore, links are reversed to reflect the topology change and adapt to the new reference level. The erase operation in TORA floods clear (CLR) packets through the network and erase invalid routes.

III. SIMULATION ENVIRONMENT AND RESULTS

1. Simulation Environment

Simulations are conducted by using the OPNET [6]. The OPNET provides a comprehensive development environment supporting the modeling of communication networks and the simulation and performance evaluation of the systems. IEEE 802.11 WLAN is used as a data link layer: each node has nominal bandwidth of 11 Mbps.

The purpose of our simulations is to uncover in which situations the individual protocols have their strengths and weaknesses, rather than to promote one protocol as generally better than the others.

All our simulation scenarios are based on the following basic parameters:

- number of nodes : 37 mobile nodes in scenario 1 and 3, varied in scenario 2
- network area : 3600 x 4200 ㎡ field
- user traffic : UDP data packet, 1024 bytes/packet, variable packet interval with exponential distribution
- node movement : static in scenario 1 and 2, dynamic with random waypoint model[15] in scenario 3

Unless otherwise stated when describing the simulation results, the simulations are conducted with scenarios conforming to the above parameters and the default values of parameters recommended by each protocol standard and the OPNET.

2. Simulation Results

Simulations have been conducted with varying data traffic and varying number of nodes and varying mobility to examine the routing protocols in different environments. The primary goal of a routing protocol is to provide best routes between nodes in the network with minimal control traffic. Thus comparisons have been done on the following: packet delivery ratio, routing overhead (control traffic volume), and end-to-end packet delay.

Scenario 1: Effect of Data Traffic in Static Network

In figure 1, the control traffic (routing overhead) of each protocol is shown as a function of total data traffic generated by all nodes. In the figure, the proactive protocols (OLSR and GRP) consistently presents almost constant overhead regardless of an increase in data traffic, while the reactive protocols (AODV and DSR) show a sharp increase to some extent. This can be explained by the fact that in proactive protocols, routing control messages are exchanged periodically, regardless of data traffic. On the contrary, in reactive protocols, if there is no route to a destination for a newly generated data packet, the route discovery procedure should be performed by broadcasting a route request message and receiving a reply message. Thus the routing overhead increases in proportion to the data traffic to a certain extent, after that it would change little because the probability of already knowing a route to a destination for a new data packet would be increased according to the data traffic.

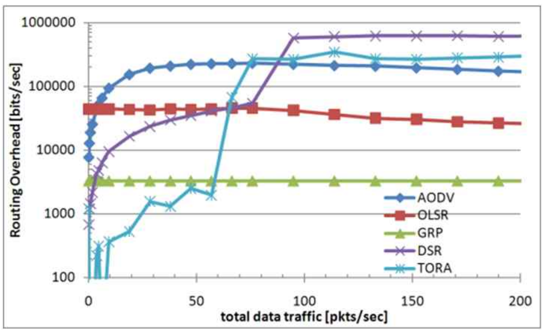

Figure 1. Routing Overhead with varying data traffic

Figure 2 shows the data packet delivery ratio, i.e. number of received / number of sent using the five protocols under the data traffic variation. We observe that OLSR presents the best packet delivery ratio in static networks. But this would not be true in mobile networks as shown later in scenario 3.

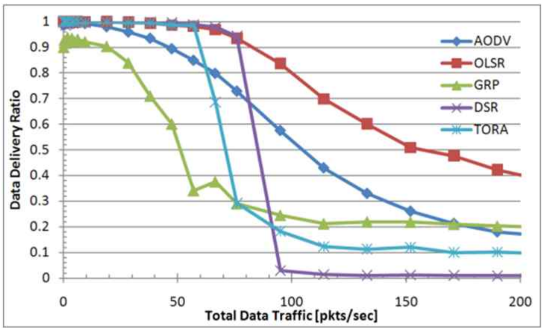

Figure 2. Packet Delivery Ratio with varying data traffic

Figure 3 presents the average packet delay, i.e. the delay from a packet has been transmitted until it is received. In the figure, it is clear that the reactive routing protocols (AODV and DSR) present higher delay than the proactive protocols (OLSR and GRP). In proactive protocols, when a packet arrives at a node, it can immediately be forwarded or dropped. In reactive protocols, if there is no route to a destination, packets to that destination will be stored in a buffer while a route discovery is conducted and this behavior has a tendency to cause longer delays.

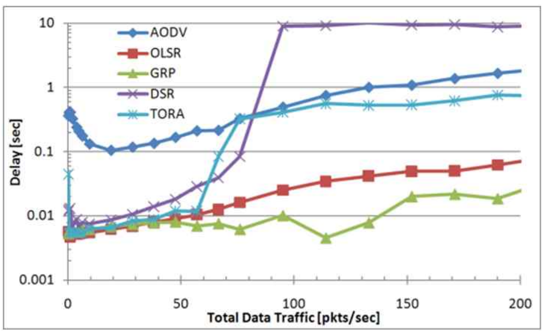

Figure 3. Delay with varying data traffic

Scenario 2: Effect of Number of Nodes in Static Networks

Figure 4 and figure 5 show the simulation results for routing overhead and packet delay with varying number of nodes in static networks. Each graph in the figure is a simulation result with different total data traffic, i.e. 1, 10, 50, 100 packets/sec respectively.

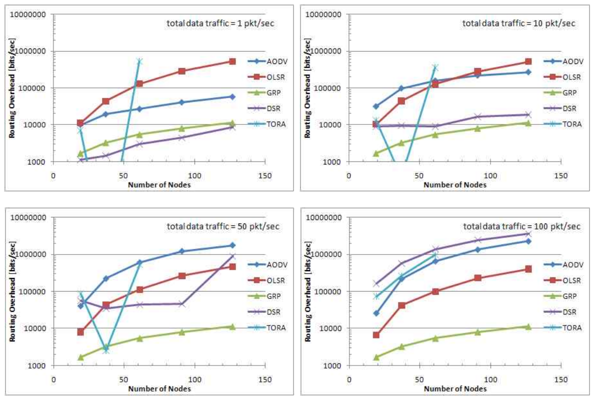

Figure 4. Routing Overhead with varying number of node

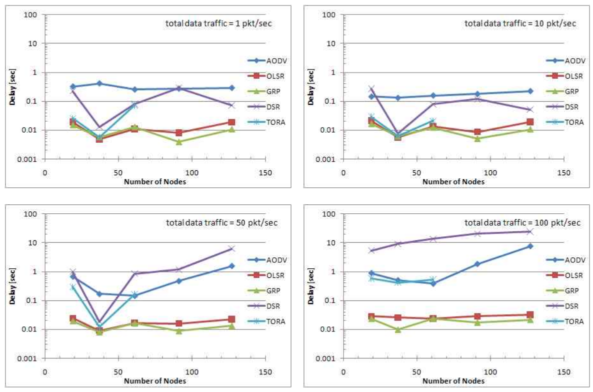

Figure 5. Delay with varying number of node

From the figure 4, it can be seen that routing overheads in all protocols are increased according to the number of nodes in static networks. By comparing four graphs in the figure we also notice the overhead changes only in the reactive protocols when the data traffic increase. In other words, the control traffic of proactive protocols, OLSR and GRP, exhibits the expected characteristics of being independent of the traffic pattern, while the control traffic, generated by the AODV and DSR reactive protocols, increases with an increased data traffic.

The delays of all protocols in figure 5 are not much changed even though number of nodes increase from 19 to 127. But in case of reactive protocols, especially in DSR protocol, the delay variations according to the total data traffic are relatively enormous.

Scenario 3: Effect of Speed in Mobile Networks

In this section, we describe the effect of speed changes in Mobile Networks. The legend of the graph in this section means total data traffic rate [pkts/sec] in mobile networks.

Figure 6 shows the total control traffic(routing overhead) generated by all nodes as a function of the node mobility. Only the GRP among routing protocols is affected by the mobility and the amounts of control traffic generated by other protocols remain constant relatively. From the graphs it can be confirmed that the proactive protocols, OLSR and GRP, are not influenced by data traffic volume, while the reactive protocols are increased a lot.

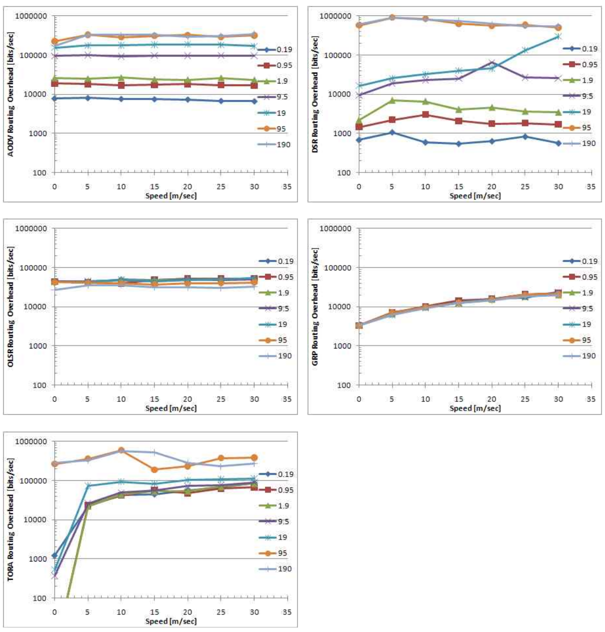

Figure 6. Routing Overhead with varying speed

In figure 7, we present the data packet delivery ratio, i.e. number of received / number of sent using the five protocols under various mobility scenarios.

The packet delivery ratio in proactive protocols, OLSR and GRP, decreases as the speed increases, while the AODV remains constant. The delivery ratio of AODV is higher in mobility case than that of OLSR and GRP. Within proactive protocols, the delivery ratio of OLSR is slightly higher in high mobility case than that of GRP. Even though it is reactive protocol, the DSR protocol is affected a lot by the speed change.

Considering both figure 2 and figure 7, we observe that the data packet delivery ratio of OLSR is higher than that of other protocols in static networks, while AODV shows the best performance in mobile networks with moderate data traffic. In a word, an advantage to OLSR is noticed in static networks, while AODV has an advantage in largely mobile networks.

The delays for all protocols in figure 8 are not much changed even though the speed increases. Figure 8 also shows that the delay performance of proactive protocols is better than that of reactive protocols. In the figure, the two proactive protocols, OLSR and GRP, perform roughly equivalent and manage to deliver data packets with around 0.01 sec delay. On the other hand, AODV and DSR reactive protocols have delays around 0.1~1 sec.

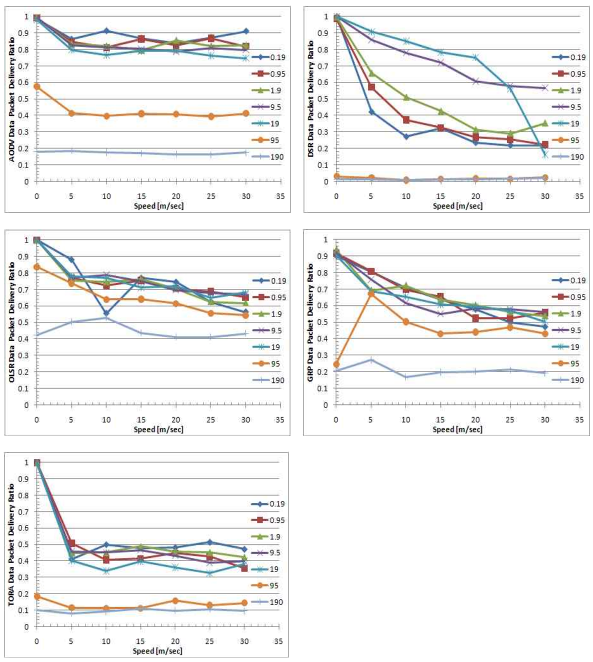

Figure 7. Packet Delivery Ratio with varying speed

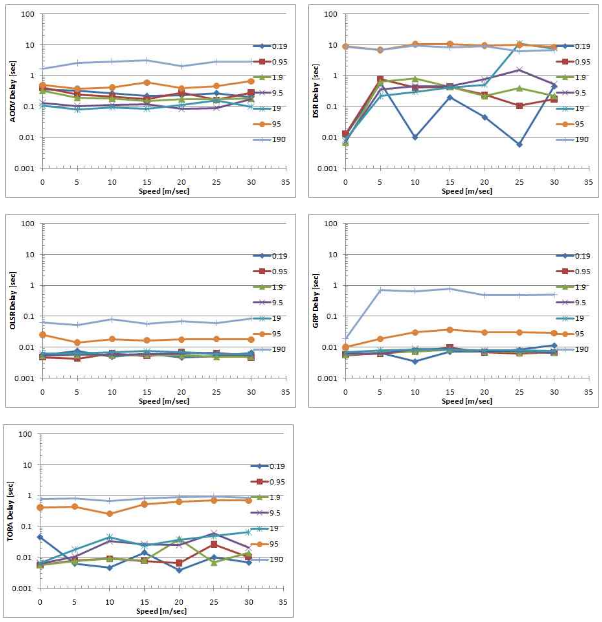

Figure 8. Delay with varying speed

because reactive protocols, such as AODV and DSR, find the route only when there is data to be transmitted and as a result generate low control traffic and routing overhead. On the other hand, Proactive protocols like GRP and OLSR find paths in advance for all source and destination pairs and periodically exchange topology information to maintain them.

When comparing each of proactive protocols in static and mobile networks, OLSR is better than GRP in the delivery ratio while overhead is more. As for reactive protocols, DSR outperforms AODV under the moderate data traffic in static networks because it exploits caching aggressively and maintains multiple routes per destination. But this advantage turns into disadvantage in high mobility networks since the chance of the cached routes becoming stale increases.

IV. CONCLUSIONS

In this paper, five representative routing protocols (AODV, DSR, GRP, OLSR, and TORA) for MANET have been compared in the view of their packet delivery ratio, end-to-end delay and routing overhead to understand the advantages and disadvantages of each protocol. For this purpose, we developed three sets of experiments by using OPNET modeler for analyzing the effect of data traffic pattern, number of nodes, and node mobility.

The following is a list of key findings obtained from our experiments.

In static networks, OLSR has the best packet delivery ratio with varying data traffic. On the other hand, AODV shows the best performance in mobile networks with moderate data traffic volume.

When comparing proactive protocols (OLSR, GRP) and reactive protocols (AODV, DSR) with varying data traffic in the static networks, proactive protocols consistently presents almost constant overhead while the reactive protocols show a sharp increase to some extent. As for an average packet delay, reactive protocols present higher delay than proactive protocols

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