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Gateway Discovery in Ad hoc On-Demand Distance Vector (AODV) Routing for Internet Connectivity

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Abstract- *In this paper, we consider a mobile ad-hoc network (MANET) in which mobile nodes can access the Internet via a stationary gateway node or access point. These gateways act as bridges between a MANET and the Internet. Mobile nodes that are outside the transmission range of the gateway can continue to communicate with the gateway via a multi-hop connection with their neighboring nodes. Ad hoc On-Demand Distance Vector (AODV) ad hoc routing protocol was modified to support mobile devices in ad hoc networks to communicate with fixed device in the Internet. Thus, the problem of applying the modified AODV routing to MANET is considered in this paper. Network Simulator 2, NS 2 with Trace Graph 2, has been used to analyze the network under different scenarios (different topology , number of gateways , number of traffic sources and max speed of mobile nodes). Three proposed approaches for gateway discovery are implemented and investigated. Also, the effect of the mobile terminals speed and the number of gateways on the network performance are studied and compared.*

I. Introduction

The term MANET (Mobile Ad hoc Network) refers to a set of wireless mobile nodes that can communicate and move at the same time. No fixed infrastructures are required to allow such communications; instead, all nodes cooperate in the task of routing packets to destination nodes. This is required, since each node of the network is able to communicate only with those nodes located within its transmission radius R, while a source node S and a destination node D of the MANET can be located at a distance much greater than R. When S wants to send a packet to D, the packet may have to cross many intermediate nodes. For this reason, MANETs belong to the class of multi-hop wireless networks. Because these kinds of networks are very spontaneous and self-organizing, they are expected to be very useful. It is also highly likely that a user of the network will have the need to connect to the Internet. The Internet Engineering Task Force (IETF) has proposed several routing protocols for MANETs, such as Ad hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), Optimized Link State Routing Protocol (OLSR) and Topology Dissemination Based on Reverse-Path Forwarding (TBRPF). However, these protocols were designed for communication within an autonomous MANET [1], so a routing protocol needs to be modified in order to achieve routing between a mobile device in a MANET and a host device in a wired network (e.g. the Internet). To achieve this network interconnection, gateways that understand not only the IP suite, but also the MANET protocol stack, are needed. Thus, a gateway acts as a bridge between a MANET and the Internet and all communication between the two networks must pass through any of the gateways. The AODV routing protocol is one of the most developed and implemented routing protocols investigated by the IETF MANET working group. In this paper we used AODV after modification to achieve routing of packets towards a wired network. Although AODV was used in this study, our approach can be applied to any reactive MANET routing protocol and with some modifications to proactive MANET routing Protocols as well. This paper evaluates three approaches for gateway discovery. An interesting question is whether the configuration phase with the gateway should be initiated by the gateway (proactive method), by the mobile node (reactive method) or by mixing these two approaches. We have simulated these three methods in Network Simulator 2 (ns-2) and compare them by means of simulation. We also discuss the advantages and disadvantages of the three alternatives. The remainder of this paper is organized as follows: Section 2 gives an overview of AODV and presents an Internet access solution for MANETs. Section 3 investigates three gateway discovery strategies. The simulation results are presented and discussed in Sect. 4. Finally, Sect. 5 concludes this paper and gives some directions for future work.

II. Protocol Description

As mentioned above, AODV was originally designed for routing packets within a MANET and not between a MANET and a wired network. In order to achieve routing across the network interconnection, the routing protocol needs to be modified. After giving an overview of AODV, we present a solution, which is referred to as AODV+ [3], where AODV is extended to provide Internet access for mobiles node in a MANET.

<table>
<tr><td>Application</td><td rowspan="3">Application</td><td colspan="2" rowspan="3">Application</td></tr>
<tr><td>Presentation</td></tr>
<tr><td>Session</td></tr>
<tr><td>Transport</td><td>Transport</td><td colspan="2">Transport</td></tr>
<tr><td>Network</td><td>Network</td><td>Network</td><td>AD HOC Routing</td></tr>
<tr><td>Data Link</td><td>Data Link</td><td colspan="2">Data Link</td></tr>
<tr><td>Physical</td><td>Physical</td><td colspan="2">Physical</td></tr>
</table>

Figure 1: The OSI model, TCP/IP suite and MANET protocol stack.

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

Ad hoc On-Demand Distance Vector (AODV) is a reactive MANET routing protocol [5], where the reactive property implies that a mobile node requests a route only when it needs one. Consequently, the node maintains a routing table containing route entries only to destinations it is currently communicating with. Each route entry contains a number of fields such as *Destination IP Address*, *Next Hop* (a neighbour node chosen to forward packets to the destination), *Hop Count* (the number of hops needed to reach the destination) and *Lifetime* (the expiration or deletion time of the route). AODV guarantees loop-free routes by using sequence numbers that indicate how fresh a route is.

Route Discovery. When a route is needed, a node broadcasts a *route request* (RREQ) message and sets a timer to wait for the reception of a *route reply* (RREP)[4] . If the source does not receive any RREP before the RREQ timer expires, it broadcasts a new RREQ [4] with an increased time to live (TTL) value.

Route Maintenance. When an active link breaks, the node upstream of the break invalidates all its routes that use the broken link. Then, the node broadcasts a *route error* (RERR) message that contains the IP address of each destination that has become unreachable due to the link break.

II.2 Internet Access for Mobile Ad Hoc Networks

Whenever a mobile node is about to communicate with a fixed wired node, it searches its routing table for a route towards the destination. If a route is found, the communication can be established. Otherwise, the mobile node starts a route discovery process by broadcasting a RREQ message as described above. When an intermediate mobile node receives a RREQ message, it searches its routing table for a route towards the wired destination. If a route is found, the intermediate node would normally send a RREP back to the originator of the RREQ. But in that case, the source would think that the destination is a mobile node that can be reached via the intermediate node. This problem has been solved by preventing the intermediate node to send a RREP back to the originator of the RREQ if the destination is a wired node. Instead, the intermediate node updates its routing table and rebroadcasts the received RREQ message [4]. To determine whether the destination is a wired node or not, an intermediate node consults its routing table. If the next hop address of the destination is a default route (see Table 1), the destination is a wired node. Otherwise, the destination is a mobile node or a gateway [4].

Handover. If a mobile node receives gateway advertisements from more than one gateway, it has to decide which gateway to use for its connection to the Internet. In this solution a mobile node initiates a handover when it receives an advertisement from a gateway that is closer [7] (in terms of number of hops) than the one it is currently registered with.

Routing Table Management. Another issue that must be taken into consideration is how the routing table should be updated after a network-wide search without receiving any corresponding RREP. Once the source has determined that the destination is a fixed node located on the Internet, it has to create a route entry for the fixed node in its routing table. If the route entry for the fixed destination would not be created in the routing table, the source would not find the address to the fixed node in its routing table when the next data packet would be generated and hence, the source would have to do another time consuming network-wide search. Table 1 shows how the routing table of a mobile node should look like after creation of a route entry for a fixed node. The first entry tells the node that the destination is a fixed node since the next hop is specified by the default route. The second entry specifies which gateway the node has chosen for its Internet connection. The last entry gives information about the next hop towards the gateway.

Destination Address	Next Hop Address
Fixed node	Default
Default	Gateway
Gateway	IMN

Table 1. The routing table of a mobile node after creating a route entry for a fixed node

III. Gateway Discovery

How configuration phase with the gateway should be initiated by the gateway (proactive method), by the mobile node (reactive method) or by mixing these two approaches (hybrid method) will be discussed here.

III.1 Proactive Gateway Discovery

The proactive gateway discovery is initiated by the gateway itself. The gateway periodically broadcasts a *gateway advertisement* (GWADV) message with the period determined by ADVERTISEMENT_INTERVAL [2]. The advertisement period must be chosen with care so that the network is not flooded unnecessarily. The mobile nodes that receive the advertisement, create a (or update the) route entry for the gateway and then rebroadcast the message. To assure that all mobile nodes within the MANET receive the advertisement, the number of retransmissions is determined by NET_DIAMETER defined by AODV. However, this will lead to enormously many unnecessary duplicated advertisements. A conceivable solution that prevents duplicated advertisements is to introduce a "GWADV ID" field in the advertisement message format similar to the "RREQ ID" field in the RREQ message format (see Sect. 2.1). The advantage of this approach is that there is a chance for the mobile node to initiate a handover before it looses its Internet connection. The disadvantage is that since a control message is flooded through the whole MANET periodically, limited resources in a MANET, such as power and bandwidth, will be used a lot.

III.2 Reactive Gateway Discovery

The reactive gateway discovery is initiated by a mobile node that is to create or update a route to a gateway. The mobile node broadcasts a RREQ with an 'I' flag (RREQ_I) to the ALL_MANET_GW_MULTICAST [6] address, i.e. the IP address for the group of all gateways in a MANET. Thus, only the gateways are addressed by this message and only they process it. Intermediate mobile nodes that receive a RREQ_I are not allowed to answer it, so they just rebroadcast it. When a gateway receives a RREQ_I, it unicasts back a RREP_I which, among other things, contains the IP address of the gateway. The advantage of this approach is that control messages are generated only when a mobile node needs information about reachable gateways. The disadvantage of reactive gateway discovery is that a handover cannot be initiated before a mobile node looses its Internet connection.

III.3 Hybrid Gateway Discovery

To minimize the disadvantages of the proactive and reactive strategies, they can be combined into a hybrid proactive/reactive method for gateway discovery. For mobile nodes in a certain range around a gateway, proactive gateway discovery is used while mobile nodes residing outside this range use reactive gateway discovery to obtain information about the gateway. The gateway periodically broadcasts a GWADV message. Upon receipt of the message, the mobile nodes update their routing table and then rebroadcast the message. The maximum number of hops a GWADV can move through the MANET is determined by ADVERTISEMENT_ZONE. This value defines the range within which proactive gateway discovery is used. When a mobile node residing outside this range needs gateway information, it broadcasts a RREQ_I to the ALL_MANET_GW_MULTICAST address. Mobile nodes receiving the RREQ_I just rebroadcast it. When a gateway receives a RREQ_I, it sends a RREP_I towards the source.

Iv. Simulation

To be able to evaluate the implementation of the Internet draft "Global Connectivity for IPv6 Mobile Ad Hoc networks" in NS 2, some simulation scenarios must be run. In this section the simulation setup is presented followed by the obtained results. The simulations were conducted on an Intel Pentium 4 processor at 2.6 GHz, 512 MB of RAM running WinXP with Cygwin "Linux Platform "

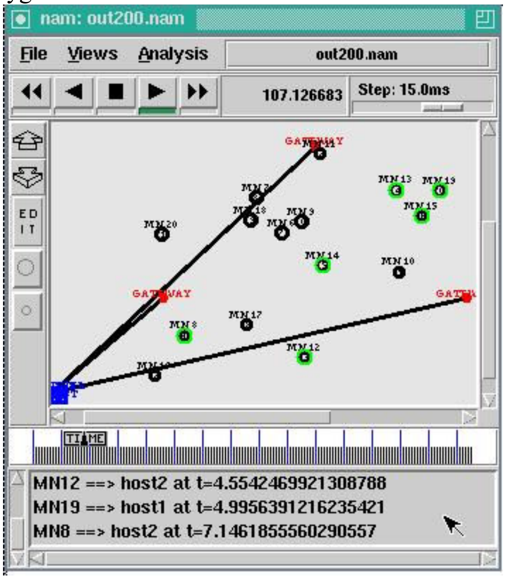

Fig. 2. Screenshot of the simulation scenario.

A. Scenario

The studied scenario consists of 15 mobile nodes, 3 gateways, 2 routers and 2 hosts. The topology is a rectangular area with 1200 m length and 800 m width. A rectangular area was chosen in order to force the use of longer routes between nodes than would occur in a square area with equal node density. The three gateways are placed on each side of the area; their x,y-coordinates in meters are (250,200) , (600,500) and (950,200). All simulations are run for 600 seconds of simulated time. Six of the 15 mobile nodes are constant bit rate traffic sources. They are distributed randomly within the mobile ad hoc network. The time when the six traffic sources start sending data packets is chosen uniformly distributed within the first ten seconds of the simulation. After this time the sources continue sending data until one second before the end of the simulation. The destination of each of the sources is one of the two hosts, chosen randomly. A screenshot of the simulation scenario is shown in Figure 2. The six mobile nodes that are marked with a ring are the sources. The three hexagonal nodes are the gateways and the four square nodes are the two hosts and the two routers.

B. Movement Model

The mobile nodes move according to the "random waypoint" model which is the model used in NS 2 for random movement. Each mobile node begins the simulation by remaining stationary for *pause time* seconds. It then selects a random destination in the defined topology area and moves to that destination at a random speed. The random speed is distributed uniformly between zero (zero not included) and some *maximum speed*. Upon reaching the destination, the mobile node pauses again for *pause time* seconds, selects another destination, and proceeds there as previously described. This movement pattern is repeated for the duration of the simulation.
The movement patterns are generated by CMU's1 movement generator. All simulation parameters are given in Table 2.

C. Communication Model

In the scenario used in this study, six mobile nodes communicate with one of two fixed nodes (hosts) located on the Internet through a gateway. As the goal of the simulations was to compare the different approaches for gateway discovery, the traffic source was chosen to be a constant bit rate (CBR) source. Each source mobile node generates packets every 0.2 seconds in this study. In other words, each source generates 5 packets per second. Since each packet contain 512 bytes of data, the amount of generated data is 5*512*8 bit/s = 20 kbit/s, for each source.
The traffic connection pattern is generated by CMU's traffic generator (cbrgen.tcl). The main parameters in cbrgen.tcl are "connections" (number of sources) and "rate" (packet rate)

Parameter	**Value**
Transmission range	250 m
Simulation time	600 s
Topology size	1200 m x 800 m
Number of mobile nods	15
Number of sources	6
Number of gateways	3
Traffic type	constant bit rate
Packet rate	5 packets/s
Maximum speed	1 m/s
Packet size	512 bytes
Pause time	5 s
ADVERTISEMENT_INTERVAL	varied from 2-60 seconds
ADVERTISEMENT_ZONE	3 Hobs

Table (2)

D. Performance Metrics

In comparing the gateway discovery approaches, the evaluation has been done according to the following three metrics:

 The packet delivery ratio is defined as the number of received data packets divided by the number of generated data packets.

 The Average end-to-end delay is defined as the time a data packet is received by the destination minus the time the data packet is generated by the source.

 Load Traffic and its effect when changing Advertisement Interval to the average end-to- end delay

 The overhead is defined as the total number of AODV messages transmitted during the simulation. For AODV messages sent over multiple hops, *each* transmission of the message (each hop) counts as one transmission.

E. Simulation Results & Discussion

In this section the effect of varying gateway advertisement intervals is studied. Since gateway advertisements are not sent in the reactive gateway discovery approach, the results for this approach are constant and independent of the advertisement interval. Each data point is an average value of 5 runs with the same communication model, But different randomly generated movement patterns.
For packet delivery ratio when using 3 gateways and 6 sources of connections as shown in figure (1.a) , when changing advertisement interval different results for hybrid and proactive are obtained although the ratio is constant when using reactive method and this is expected because reactive is independent of advertisement interval any more . for hybrid and proactive they get better results when using small advertisement interval and we can deduce that number of gateways and their places have great effect on obtained results
Using different load traffic with different advertisement interval to get average end-to-end delay, figure (1.b) shows that for low load traffic the difference is very small for all advertisement intervals but for High load traffic there will be big difference in delay when changing advertisement interval
As shown in figure (1.c) AODV overhead changing in hybrid and proactive according to advertisement interval, the proactive has the biggest overhead when using short interval, then hybrid, although reactive is constant.

Using 1m/s as max speed to measure AODV Overhead it brings similar results but less overhead in all methods as shown in figure (1.d)

In figure (2.a) there are 2 gateways used in our scenario with max speed of 10m/s and topology of 800 * 500 m. As shown proactive and hybrid methods have less average end to end delay then reactive method , that is because the periodic gateway information sent by the gateways in proactive and hybrid methods allow the mobile nodes to update their route entries for the gateways more often, resulting in fresher and shorter routes. With the reactive approach a mobile node continues to use a route to a gateway until it is broken. In some cases this route can be pretty long (in number of hops) and even if the mobile node is much closer to another gateway it does not use this gateway, but continues to send the data packets along the long route to the gateway further away until the route is broken. Therefore, the end-to-end delay increases for these data packets, resulting in increased average end-to-end delay for all data packets. Also figure (2.a) verifies the result in of paper [4]. Results obtained by our simulation are the same as in [4] for the same conditions.

In figure (2.b) similar results obtained using three gateways with same scenario. The figure also shows that the average end-to-end delay is decreased slightly for short advertisement intervals when the advertisement interval is increased. At the first thought this might seem unexpected. However, it can be explained by the fact that very short advertisement intervals result in a lot of control traffic which leads to higher processing times for data packets at each node. Moreover, since the AODV messages are prioritized over data packets, these have to wait in the routing queue until the AODV messages are sent, resulting in higher end-to-end delay.

Using four gateways different results obtained as in figure (2.c) that's due to many AODV packets sent from four gateways which have big effect in traffic on network which affect the delay especially in proactive method at short interval.

Figure (3.a) shows Average End-to-End Delay with Advertisement Interval between 2 and 60 seconds at max speed = 0.5 m/s. The proactive and hybrid methods have higher end to end delay then reactive method. When using low speed and short advertisement interval result in a lot of control traffic in proactive and hybrid methods which lead to higher processing times for data packets at each node. Moreover, since the AODV messages are prioritized over data packets, these have to wait in the routing queue until the AODV messages are sent, resulting in higher end-to-end delay. So for low speeds using reactive method is the best.

Figures (3.a), (3.b), (3.c), (3.d) and (3.e) show Average End-to-End Delay with Advertisement Interval at different max speeds from 1m/s to 20m/s. As figures show , increasing max speed of nodes movement result in increasing average end-to-end delay for the three methods used proactive , hybrid and reactive.

V. *Conclusion*

Changing in max speed of nodes movement in the network has big effect on average end-to-end delay , for small speeds 0.5 m/s the average delay is around 38ms although for big speed 20m/s the average delay is around 250ms. Changing number of gateways has small effect in average end-to-end delay , but when we increase the number of gateways we obtained high delay in proactive method that is because of High traffic generated by gateways .

References

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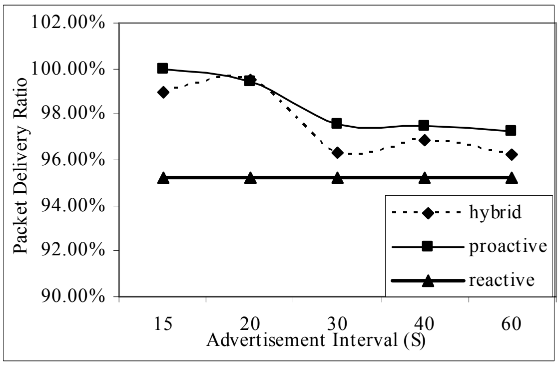
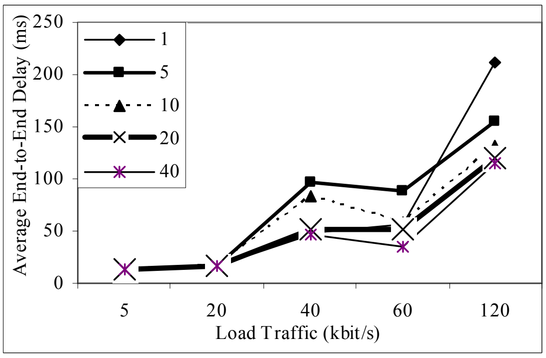
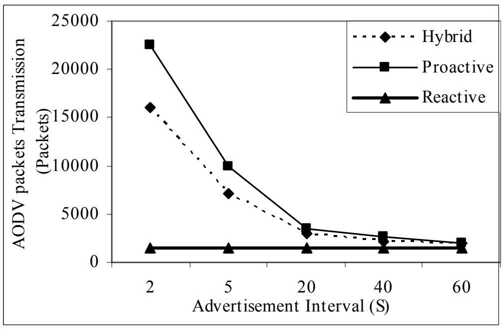


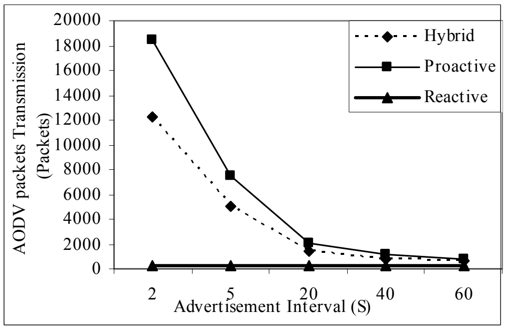
a. Packet Delivery Ratio



b. Load Traffic vs Average End-to-End Delay with Different Advertisement Interval

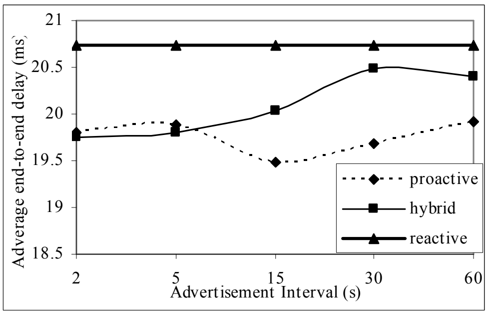


c. AODV Overhead 10 m/s

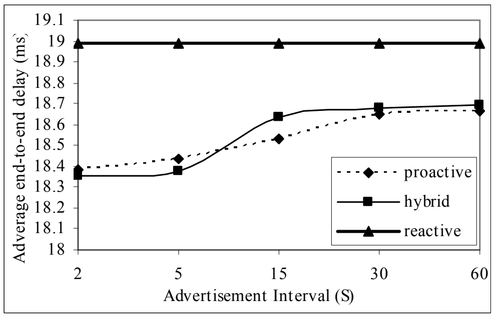


d. AODV Overhead 1m/s

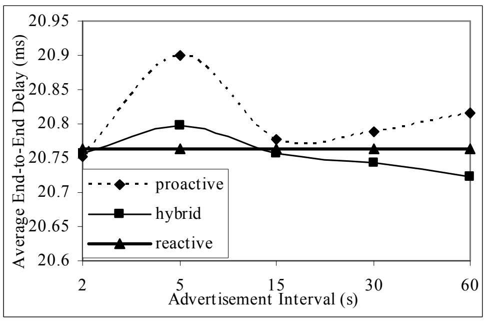
Figure 1. Advertisement Interval Effect on Ad-Hoc Network



a. Average End-to-End Delay (2 Gateways)

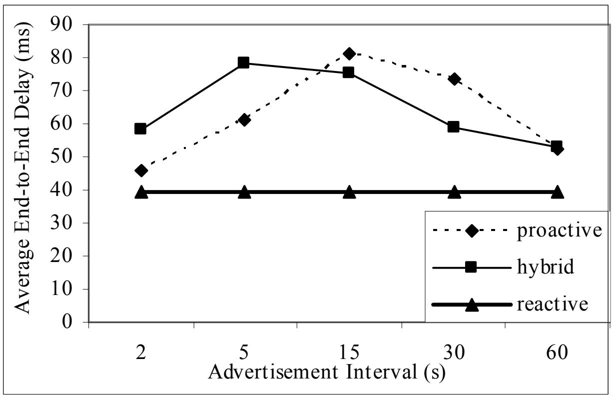


b. Average End-to-End Delay (3 Gateways)

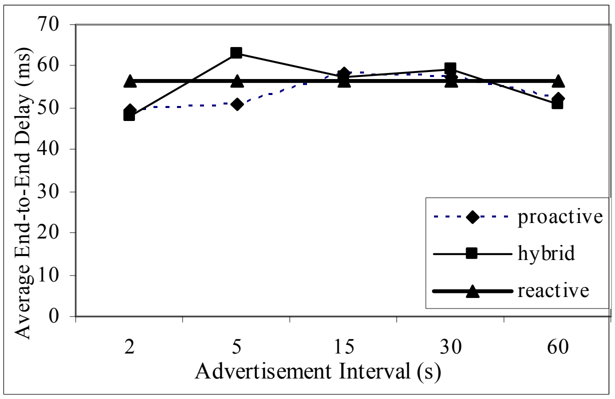


c. Average End-to-End Delay (4 Gateways)

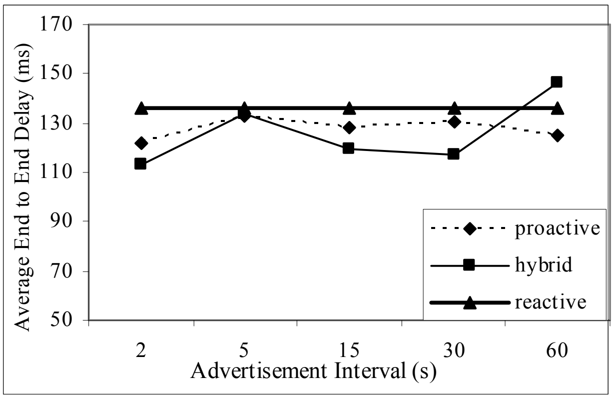
Figure 2. Effect of Number of Gateways on Average End-to-End Delay



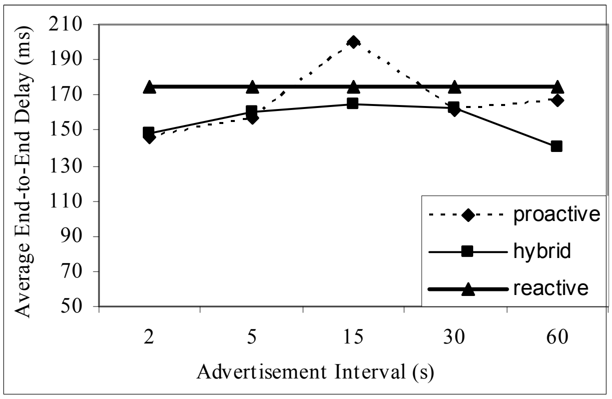
a. Average End to End Delay at (0.5 m/s)



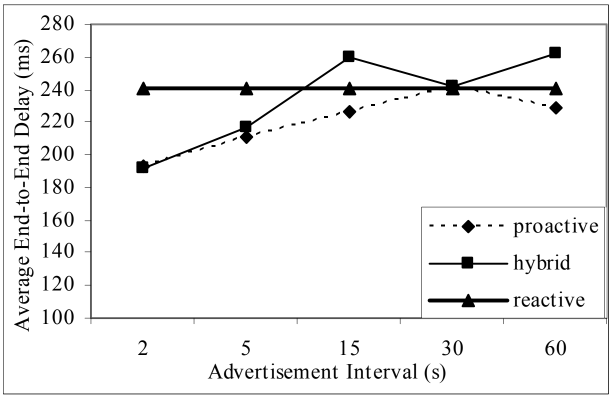
b. Average End to End Delay at (1 m/s)



c. Average End to End Delay at (5 m/s)



d. Average End to End Delay at (10 m/s)



e. Average End to End Delay at (20 m/s)

Figure 3. Effect of Speed of Mobile Nodes on Average End-to-End Delay