*Hybrid gateway advertisement scheme for connecting mobile ad hoc networks to the Internet

Jeongkeun Lee(1), Dongkyun Kim(2) , J.J.Garcia-Luna-Aceves(3), Yanghee Choi(1), Jihyuk Choi(4), Sangwoo Nam(4)

(1)Seoul National University, Korea, (2)Kyungpook National University, Korea, (3)University of California at Santa Cruz, U.S.A., (4)Electronics and Telecommunications Research Institute, Korea

Abstract - When a node in a mobile ad hoc network wants to send data packets to the Internet, and therefore outside of its local ad hoc network, it has to obtain information about the available Internet Gateways: i.e. which one to use and how to get there. To accomplish this, nodes can utilize either a solicited gateway discovery mechanism or rely on unsolicited gateway advertisement packets sent by gateways. Obviously, the effectiveness of periodic and unsolicited advertisements depends entirely on the traffic and mobility patterns. The most important factors involved in sending unsolicited gateway advertisements are the *time interval* between sending two consecutive advertisements and the *TTL value* of the advertisement packet i.e., the gateway should carefully decide *when* to send advertisements, and the advertisement *flooding area* should be limited only to nodes that need to update their gateway information and their paths to the gateway. In this paper, two kinds of advertising schemes are proposed, which are based on the observation of traffic and mobility patterns, and are designed to avoid generating unnecessary packets in the MANET (Mobile Ad hoc Network), in addition to giving mobile nodes more opportunity to use the shortest path to the Internet.

KEY WORDS: MOBILE AD HOC NETWORKS, INTERNET ACCESS, GATEWAY ADVERTISEMENT, MOBILITY ADAPTIVE

I. INTRODUCTION

A mobile ad hoc network is defined as a collection of wireless mobile nodes forming an autonomous network without the aid of any infrastructure providing centralized administration. Recently, however, much work has been done on the integration of ad hoc networks with pre-established communication infrastructures such as the Internet [1, 2, 4] or cellular networks [3]. One part of providing such integration is node-to-gateway affiliation. The main issue involved in this case is when and how a mobile node obtains information about a gateway, such as its IP address, the global prefix used by the gateway and the path to the gateway. If the ad hoc network supports on-demand routing protocol, a mobile node can send a request for gateway information, whenever it needs this information. However, an alternative solution, involving the sending of unsolicited, gateway-initiated advertisements has recently become a topic of discussion.

The simulation study on MIPMANET [1] shows that periodic gateway advertisements can decrease the number of packet transmissions in mobile ad hoc networks, because they provide mobile nodes with more opportunities to use gateways situated closer to them. In the Internet Draft entitled *Global connectivity for IPv6 Mobile Ad Hoc Networks* [2], however, the authors claim that gateways should not send any unsolicited advertisements, as these would only generate unnecessary packets within the networks.

Whether gateways should advertise themselves or only respond to requests is similar to the question as to whether routing protocols should be reactive or proactive. Furthermore, the effectiveness of gateway advertisement depends on the traffic and mobility patterns. In addition, analyses of wireless networks [6] have revealed that only a small proportion of users are in need of the Internet connection at the same time. They have also revealed that the majority of users do not move very much, while there are a few users who are highly mobile, and that users fall into location-based sub-communities, each with its own movement and activity characteristics. With this in mind, we propose a hybrid scheme for sending gateway advertisements based on the temporal and spatial mobility characteristics of mobile nodes.

In the proposed scheme, in order to provide gateway information with minimum overhead, the use of a *Periodic Advertisement* is proposed. Simultaneously, every gateway sends its advertisement periodically. This can prevent the ad hoc network from being flooded with unnecessary advertisements, while still providing nodes with the chance of finding a better path to the Internet. Furthermore, in order to cope with dynamic changes in network topology, the *Adaptive Advertisement* is propagated only to nodes in need of gateway information and their neighboring nodes. Moreover, in addition to gateways, if intermediate nodes can reply to a request for gateway information, and if Expending

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Ring Search mechanism of DSR [5] or AODV [6] is utilized, *Adaptive Advertisement* can limit the scope of a gateway request message's flooding area. Because neighboring nodes of the source node will reply for gateway request message from the source node, eventually network-wide request message flooding is avoided. Implementing these schemes for well-known reactive ad hoc routing protocols requires only minor modifications.

The rest of this paper is organized as follows: Section II gives a more precise description of the hybrid gateway advertising schemes and related working examples. In section III, we evaluate the performance of the proposed advertising schemes. We conclude in Section IV.

II. PROPOSED GATEWAY ADVERTISING SCHEME

Providing a full description of how to provide Internet connectivity with mobile ad hoc networks is beyond the scope of this paper. For example, the question of how to obtain a globally routable address and how to resolve destination addresses located outside of the ad hoc network will not be discussed here. Rather, this paper limits itself to describing schemes which support the gateway advertising mechanism. This mechanism can be applied to any architecture providing Internet connectivity for MANET. In the case of [2], only the Advertising Internet-Gateway Information needs to be modified, whether the implementation is MANET routing protocol based or NDP based. In the case where MIPMANET [1] is used, we apply the proposed hybrid advertising scheme to Foreign Agent Advertisements of Mobile IP.

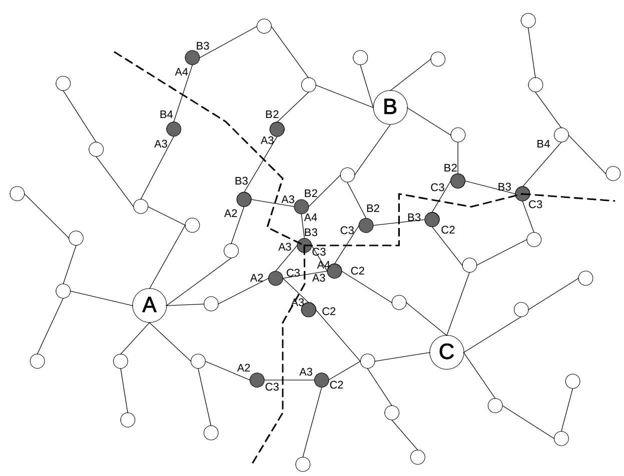


Fig. 1. Periodic Advertisement

Each mobile node needs to maintain gateway related information in two tables, namely the *Gw_Info_Table* and the routing table, which are used by the ordinary ad hoc routing protocol. Each entry in *Gw_Info_Table* contains the IP address of the gateway, the lifetime of this entry and any other general information concerning the gateway. Whenever a mobile node receives a gateway advertisement, it adds or updates *Gw_Info_Table* and the routing table. Thereafter, it decides whether to re-broadcast the advertisement or not according to a corresponding advertisement scheme. An intermediate node can generate a reply packet as a response to a request for gateway information only if the intermediate mobile node has a valid gateway entry in the *Gw_Info_Table* and a valid routing table entry or route cache entry for that gateway, where the term 'valid' means "not expired and the information or path can be used without validation".

In the discussion that follows, we assume that source routing is used, i.e., each data packet includes the path to be followed in the form of a sequence of nodes and each node knows the path to the other mobile nodes, which are in the process of communicating with itself (as in DSR). This assumption makes the discussion more straightforward.

A. Periodic Advertisement

With a relatively long time interval, t, between successive occurrences, all gateways initiate Periodic Advertisement simultaneously. Timer synchronization among neighboring gateways is needed to prevent unnecessary advertisement packet propagation. The propagation time of the advertisement packet is the sum of the random delays occurring at each intermediate node. Therefore, even if two different gateways initiate an advertisement at exactly the same time, it is not possible for two advertisement packets from these two gateways to arrive at the same node by travelling the same hop distance. So, tight synchronization is not required. It is not so difficult to achieve loose synchronization among adjacent gateways.

Periodic Advertising performed at widely spaced intervals does not generate a great deal of overhead, while still providing mobile nodes with a good chance of finding the shortest path to a previously used gateway or to an even closer gateway. When a mobile node receives gateway information from more than one gateway, it compares the hop distances to each gateway and only re-broadcasts the advertisement message for the gateway which is the shortest distance away. If multiple gateways are at the same hop distance away, the mobile node re-broadcasts only the advertisement packet that arrived first. Fig. 1 shows the result of Periodic Advertisement initiated by three Gateways (A, B and C). Note that the network is divided into three per-gateway flooding areas based on hop distance. Mobile nodes that received Advertisements from two or more gateways are marked as black nodes. The combination of a letter and a number on each link refers to the hop distance from each gateway.

B. Adaptive Advertisement

The goal of Adaptive Advertisement is to send gateway advertisement packets only when the gateway detects the movement of nodes, which would result in paths used by *Internet-joining mobile nodes* communicating with the gateway to be changed. Adaptive Advertisement is performed when needed, regardless of the time interval used for *Periodic Advertisements*. It can limit a flooding area to only those nodes in need of gateway advertisement. It also provides temporal and spatial proactiveness i.e., it provides gateway information and routes to a gateway, in advance, in order to cope with possible future gateway requests.

Therefore, every mobile node should be aware of Internet-joining mobile nodes. A mobile node, namely node X, can distinguish Internet-joining mobile nodes by analyzing the source and destination IP addresses of the data packets relayed by node X. For example, if the source IP address field contains a gateway IP address, then the destination node is an Internet-joining node. When the basic MANET routing protocol is DSR, node X can distinguish Internet-joining nodes by looking at the First Hop External bit and the Last Hop External bit in the DSR source route option. These two bits show that the first/last hop indicated by the DSR Source Route option is an arbitrary path in a network external to the DSR network. There is no doubt that this method is simpler than comparing the source and destination IP addresses with the gateway IP address.

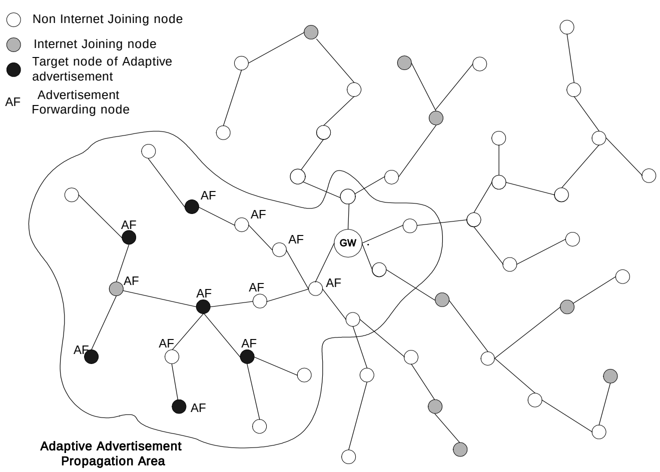


Fig. 2. Adaptive Advertisement

When node X detects any topological changes, which can affect the paths of Internet-joining nodes, it establishes itself as an AF(Advertisement Forwarding) node and updates the timer used for the AF indicator. Node X can conclude that a change has occurred when it receives or generates 1) a *Route Error message* for an Internet-joining mobile node or a gateway, or 2) a *gateway Join message* or 3) a *data packet generated right after acquiring a new route to and from a gateway* via the route discovery process. These conditions indicate that some kind of topological changes have occurred and that they can affect the paths of Internet-joining mobile nodes. Condition 2) is optional and refers to a message being sent from a mobile node to a gateway to register at a gateway, such as in the case of a Foreign Agent Registration message in Mobile IP. In the case of condition 2), new node to gateway affiliations are established, so there are likely to be some mobile nodes, that want to know the path to a gateway or seek other gateway information. With the assumption that DSR [5] source routing protocol is being used, condition 3) can be implemented by checking to see if there is a change of source route included in the data packets that are coming from a gateway or heading to a gateway. This is not burdensome, since the intermediate node examines the source routes of all data packets it forwards, according to the original DSR protocol definition.

Each gateway keeps a record of control and data packets that represent node movement. Every X seconds, corresponding to the minimum Advertisement time interval, a gateway computes the Regulated Mobility Degree (RMD). This value is the ratio of the number of target Internet-joining nodes to the number of AF nodes and it represents the benefit of performing Adaptive Advertisement divided by the cost of Adaptive Advertisement.

$$
\begin{aligned}
RMD &= \frac{\#\text{ of target Internet Joining nodes}}{\#\text{ of Advertisement Forwarding nodes}} \\
&= \frac{\text{Benefit of Adaptive Advertisement}}{\text{Overhead of Adaptive Advertisement}}
\end{aligned}
\qquad (1)
$$

If the computed RMD value is bigger than the given threshold value β , the gateway sends *Adaptive Advertisements*. The value of β ranges from 0.0 to 1.0. If β is set to zero, a gateway will send Adaptive Advertisements whenever node mobility is detected. If value of β is one, Adaptive Advertisement process will hardly be performed. In the case of source routing protocol, the RMD is easily computed by examining the source route paths to the target nodes. Whenever a mobile node X receives an Adaptive Advertisement packet, it checks whether or not it is itself an AF node. Only AF nodes and *k* non-AF nodes are allowed to re-broadcast *Adaptive Advertisement* packets. To accomplish this, the advertisement packet carries a counter (initialized to zero), which is incremented by one, whenever a non-AF node is visited. The advertisement packet is dropped when the counter exceeds the value of *k*. The concept of k-path-locality flooding comes from the study on Query Localization [7]. This scheme helps to limit the scope of the flooding area to only target *Internet-joining mobile nodes* and their neighboring nodes, while still offering mobile nodes gateway information.

Fig.2 shows that the flooding area of an adaptive advertisement message is limited to the *Adaptive Advertisement Propagation Area*, which is smaller than the network-wide flooding area. The gray colored Internet-Joining nodes are in the process of communicating with nodes on the Internet. However, the gateway receives Route Error messages only for the black colored nodes, while the intermediate nodes, situated between the gateway and the black nodes, mark themselves as AF nodes, because only the black nodes are moving. When the gateway computes the RMD value as being bigger than the threshold β , Adaptive

Advertisement is initiated and propagated to nodes in a solid line (in this case, the value of k is one).

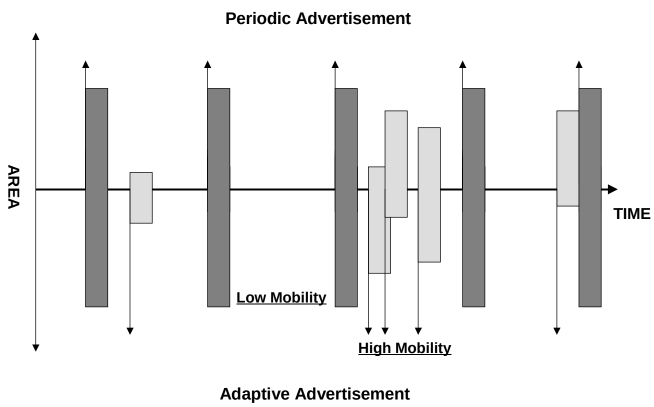


Fig. 3. Time-varying proactiveness

C. *Time varying proactiveness*

Figure 3 shows the combination of the effects of *Periodic Advertisement* and *Adaptive Advertisement*. The X-axis represents time and the Y-axis represents the Advertisement Propagation Area. When the average node mobility is low and the RMD value is smaller than β , Adaptive Advertisement is not performed. However, when many Internet-joining nodes move, multiple Adaptive Advertisements are initiated from the gateway. If an Internet-joining node is located in a rectangular area regardless of color, it already has valid gateway information and knows the path to the gateway, so it is not necessary to perform gateway discovery. In this case, we can say that this node acquires gateway information proactively, so we call this proposed scheme is hybrid – basically working reactively, but working proactively when it is needed.

III. Performance evaluation

To evaluate our proposed scheme, the two Periodic Advertisement and Adaptive Advertisement schemes as well as pure reactive gateway discovery scheme based on [2] were implemented using a Qualnet network simulator [9]. We used the DSR routing protocol [5] as the underlying ad hoc routing protocol in the simulation. Because Qualnet does not support wired network - wireless network connection with the DSR protocol, we extended Qualnet to enable data communication between nodes within MANET and nodes in the wired Internet. The special IP address, namely DSR_INTERNET_NODE_ADDR, is reserved to represent a node in the Internet. When a MANET node wants to send data packets to the DSR_INTERNET_NODE_ADDR, this node performs the gateway discovery process, and then the data packets destined to DSR_INTERNET_NODE_ADDR are delivered to the chosen gateway. Having received a data packet from the MANET node, the gateway node echoes a same-size data packet back to the source MANET node instead of the original destination DSR_INTERNET_NODE. This echoed packet plays a role as an acknowledgement message or a replied data packet from the DSR_INTERNET_NODE. In implementing the Adaptive Advertisement scheme, only option 1) a *Route Error message* is adopted for simplicity of implementation. It is expected that the implementation of option 2) and option 3) will lead to better performance results.

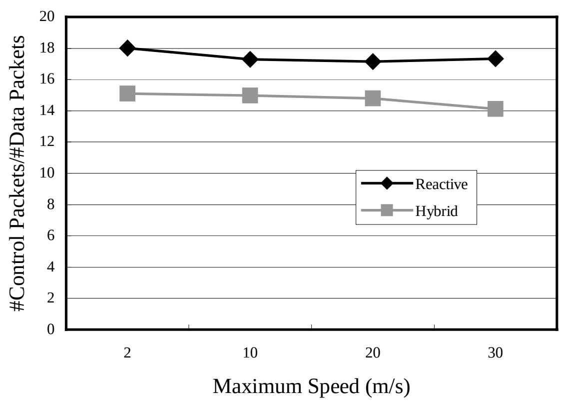
In our model, 35 mobile hosts move around a rectangular region of size 3000 m X 1500 m according to the random-waypoint mobility model. The node's speed is uniformly distributed between 0 – 2 m/sec (walking speed), 0 – 10 m/sec (downtown driving speed), 0 – 20 m/sec (suburban driving speed) and 0 – 30 m/sec (highway driving speed), and the pause time is commonly set to 20s. Each node has a radio range of 340 m. Two gateway nodes are placed at (750,750) and (2250,750). In addition, a CBR datagram workload model is used. All simulations had been run for 600 simulated seconds and their results were derived by an average of 15 runs with different random seed values.

Four important performance metrics are evaluated: 1) *control overhead* – i.e. the average number of routing control packets transmitted per a data packet generated by the source, 2) *packet delivery fraction* – measured as the ratio of the number of data packets delivered to the destination and the number of data packets generated by the source, 3) *end-to-end delay* – measured as the average end-to-end latency of data packets.

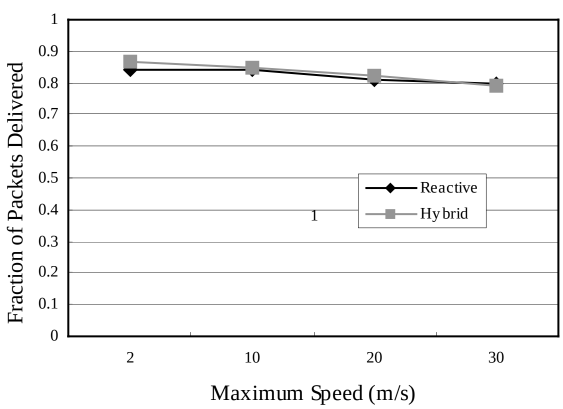
At first, only the *Periodic Advertisement* scheme is evaluated by using different values of the time interval parameter. Based on the results of this evaluation, a fixed value of the parameter, 30 seconds, is used when the *Adaptive Advertisement* scheme is evaluated together with the Periodic Advertisement one. We use the RMD threshold β of value 0.6 and the value of k is 1. Other parameters such as the *Gw_Info_Table* entry lifetime are set according to [2]. We compare the two schemes to the pure reactive protocol based on [2].

The figure 4 shows the various performance metrics for the pure reactive scheme and our proposed hybrid one. In the performance plots, x-axis refers to maximum speed i.e. 2, 10, 20 and 30 m/s. Note that the hybrid scheme is able to reduce control overhead and the savings are approximately 20% when compared to the pure reactive scheme. Consequently, the delay is minimized even though the figure 4 shows an unstable line with some unexpected delay fluctuation because in the case of a route loss, data packets are buffered at an intermediate node and the intermediate node tries to retransmit them. The packet delivery fraction slightly increases when the hybrid scheme is used since the Periodic and Adaptive advertisement schemes offer timely gateway information and the fresh path to the gateway.

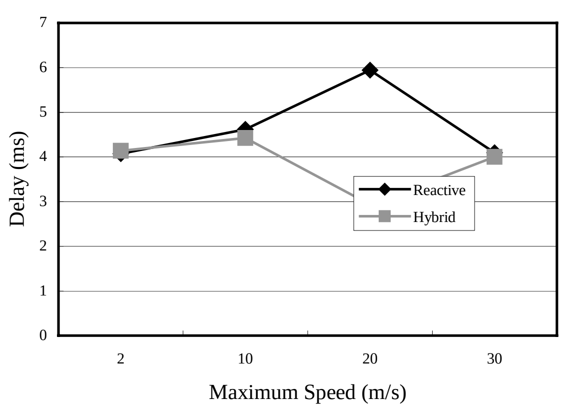
We performed the simulation with more traffic patterns. The results show less control overhead, shorter delay and increased packet delivery fraction.



(a) Control overhead



(b) Packet delivery fraction



(c) End-to-end delay

Fig. 4. Various performance metrics

III. CONCLUSION

It is not easy to design a hybrid MANET routing scheme compromising between traditional reactive routing protocols and proactive routing protocols. However, in the case that most of data packets are destined to or originated from specific nodes, such as the Internet gateway nodes, it is possible. In this paper, the hybrid gateway advertisement scheme is proposed and evaluated compared to the pure reactive gateway discovery scheme. Performance evaluation results demonstrate reduction of routing overheads, lower end-to-end delay and increased packet delivery fraction.

Future work includes system scaling studies and parameter analysis. More tests will be done with other underlying routing protocols and implementation of option 2) and option 3) of the Adaptive Advertisement scheme.

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