Performance Comparison and Analysis of Three Gateway Discovery Protocols of Internet Connectivity for Ad Hoc Networks

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Abstract: In recent years, several gateway discovery protocols of Internet connectivity for ad hoc networks have been proposed. However, systematic performance evaluations and comparative analysis of these methods in a common realistic environment have not been performed yet. Thus, evaluating and comparing the performance of gateway discovery methods in different application environments will help people design and choose a proper protocol. In this paper, we firstly introduce the three representative gateway discovery methods, and then, according to the simulation results with NS2, we give a detailed comparison and analysis in various network scenarios. In conclusions, their perspectives are highlighted.

Key words: Mobile Ad Hoc Networks; Gateway Discovery; Performance Comparison; NS2

1. Introduction

Mobile Ad Hoc Networks (MANET)[1,2] are autonomous, unstructured networks that support multihop communication through IP routing. Because of its independence on pre–existing network infrastructure and its distributed organization, ad hoc network enables the spontaneous establishment of communication between network–enabled electronic devices (e.g. mobile phones, personal digital assistants). Especially in applications where information must be distributed quickly and is only relevant in the area around the sender, ad hoc communication has major advantages compared with "conventional" wireless systems, such as GSM and UMTS.

For many applications, however, it is desired that a self–organizing ad hoc network is somehow connected to a "conventional" network, in particular to the world–wide Internet and cellular networks. In this case, internetworking functionality between the protocols in the ad hoc network and the "conventional" network is needed and corresponding entity which implements internetworking functionality mentioned above is Internet Gateways (IGWs). Nodes of MANET which need global connectivity must discover IGWs firstly. In point of Internet gateway discovery, two main internetworking approaches: reactive and proactive are presented. These two types of behaviors are the same as ad hoc routing:

(1) Reactive discovery: A mobile node broadcasts a message throughout the MANET soliciting a connection to the Internet. An IGW receiving this message will reply to the mobile node, offering its services and an IP prefix address.

(2) Proactive discovery: All Internet gateways periodically broadcast their services and IP prefix addresses throughout the MANET. When the MN is connected to an IGW and receives an advertisement from another IGW, it may decide to connect to the new IGW, if it provides a better service.

Moreover, we can combine both approaches yielding a hybrid gateway discovery scheme[3], which

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provides a trade-off, i.e. between the advantages of proactive and reactive approaches, provides good connectivity while keeping the overhead costs low. In this approach, the periodical IGW advertisements are not flooded throughout the whole ad hoc network, but only sent to the mobile nodes that are in the vicinity of the IGW, i.e. the time to live (TTL) of those advertisement packets is limited. Nodes that are far have to solicit advertisements reactively instead. Note that throughout this paper, proactive and reactive approaches refer to the Internet gateway discovery approaches but not the ad hoc routings.

Through comparing the global connectivity performance of three kinds of gateway discovery approaches in different simulation scenarios, i.e. different sizes of internetworking ad hoc networks, various moving speeds of MANET nodes and different number of gateways, this paper draws the calculation that different approaches are suitable for given scenarios where they are applied. Further, a more adaptive gateway discovery scheme is presented.

This paper is organized as follows: Section 2 presents the gateway discovery methods that will be compared; Section 3 describes the simulation environment and presents the simulation results; Section 4 draws the conclusion and highlights the perspectives.

2. Studied Gateway Discovery Protocols Overview

2.1 Proactive Gateway Discovery

The proactive gateway discovery[4,5,6] mainly uses the agent discovery scheme of Mobile IP[7], so in fact it connects to the Internet by the foreign agent (FA) of Mobile IP. The agent advertisements sent by the FA then act as GWADVs. The process is like this: the Internet gateways (IGWs) periodically broadcast GWADVs to the whole MANET with a period of ADVERTISEMENT_INTERVAL. This message includes IGWs' IPv6 global address, network prefix address and lifetime, etc. Upon the receipt of this advertisement, mobile nodes resolute the global connectivity information, such as the route to FA, the IP address of FA and the care-of-address (COA) to configure a globally routable address and store a default route entry in its routing table. Whenever a mobile node receives a gateway advertisement, it should update its route entry.

2.2 Reactive Gateway Discovery

Reactive schemes allow the mobile nodes to broadcast gateway solicitations (GWSOLs) to find gateways as they are needed[8,9]. Most reactive gateway discovery schemes conform to the on-demand MANET routing protocols (such as DSR[10] and AODV[11,12]). The GWSOL is generically piggybacked by the route request message (RREQ) of MANET routing protocols. When global connectivity information is needed (e.g. the route to the gateways), each mobile nodes will create a RREQ_I message which having globally routing function to the ALL_MANET_GW_MULTICAST address, i.e. the IP address for the group of all gateways in a MANET to start the search. For these global connectivity RREQ_I messages, only gateways can unicast RREP_I message back to the originator as a response. Intermediate mobile nodes that receive them just rebroadcast again. From RREP_I messages, mobile nodes that originate RREQ_I can resolute global connectivity information, such as global address prefix, route to the responding gateway to satisfy their following global connectivity needs. This mechanism has similar process to the reactive gateway discovery method which integrates with the NDP protocol of IPv6[9].

2.3 Hybrid Gateway Discovery

The hybrid gateway discovery approach is a combination of the proactive and reactive approaches. This approach affords Internet connectivity for MANET on the basis of balancing the advantages of proactive and reactive approaches. Provides 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[3,13,14].

The gateway periodically broadcasts a GWADV message. Upon receipt of the message, the mobile nodes update their routing tables and then rebroadcast the message. The maximum number of hops with which 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 has a need of 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 to the source.

3. Performance Evaluation

3.1 Simulation Scenario

In order to evaluate the performance of the three gateway discovery methods, we have implemented a prototype in the Network Simulator 2[15] with mobility extensions. We study three topologies: a 10-node network over a 330m*330m square area, a 20-node network over a 670m*670m area and a 60-node network over a 1300m*1300m area. For the first and second networks, 1 IGW is placed at one corner of the simulator area. For the third network, 2 IGWs are placed at opposite corners. In the hybrid approach, all of them use a TTL=3 for their advertisements and both in the proactive and hybrid approaches, the advertisement interval is set to a fixed value of 15 seconds. Each of the gateways is connected to a router and the routers are connected to each other. Additionally, each router has a fixed node connected to it.

There are five constant bit rate (CBR) traffic sources distributing randomly within the ad hoc network. The destination of each of the data sessions is the correspondent node in the wired network. The CBR data packets are 512 bytes and the sending rate is 10 packets per second. Each node has a radio range of 250m and moves according to the random waypoint model[16]. Nodes move at a maximum speed randomly ranging from 0 to 20 m/s. Five different maximum speeds are used, which are 0, 5, 10, 15, 20 m/s. The pause time is consistently 10 seconds. Each data point representing an average value of 5 runs with the same traffic modes, but randomly generates mobility scenarios. Table 1 summarizes other parameters used in the simulation.

Table 1 Simulation Parameters

Beacon Interval	10 s
Registration Lifetime	30 s
Agent Advertisement Lifetime	30 s
Time between solicitation	5 s
Simulation Time	600s

3.2 Performance Metrics

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

① Packet delivery ratio: defined as the number of received data packets divided by the number of generated data packets.

② End to end delay: defined as that the time when a data packet is received by the destination minus the time when the data packet is generated by the source.

③ Routing overhead: defined as the total number of control packets which includes gateway discovery sent out during the simulation time.

3.3 Simulation Results

From the principle of the three gateway discovery methods, we know that as the number and the maximum speed of mobile nodes increase, the total control overhead and the end to end delay will increase accordingly. It can be seen clearly in Fig. 1, Fig. 3, Fig. 4 and Fig. 5. Because the number of mobile nodes and moving speed increase, the repeated packages and the frequency of link break also increase.

Fig. 2 shows that the packet delivery ratio decreases when the number and the maximum speed of mobile nodes increase. This is an expected result for the reason that the break of the link will cause the lost packets to increase and successful received packets to decrease.

When the network is not so large (10-node and 20-node), the three gateway discovery methods have very high packet delivery ratios, especially when the number of mobile nodes is small. We can also see that the effects on the three methods are the same when the mobility changes. Fig. 1 shows that the proactive method has a higher control overhead than reactive and hybrid. But as the moving speed increases, the global connectivity performance of proactive method is better than those of other two methods. The reactive approach can get the lowest control overhead in almost all scenarios, but it has a relatively larger packet delivery ratio and end to end delay. The hybrid approach has a similar performance to the reactive approach. So we can conclude that when the number of mobile nodes is small and the moving speed is not so high, using the reactive and hybrid methods is advisable. When the moving speed increases, the proactive method can afford a small delay though it is at the expense of higher control overhead.

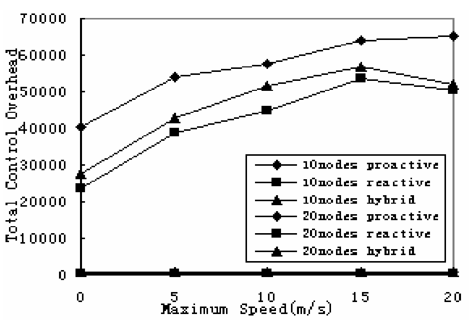

Fig. 1 Total Control Overhead

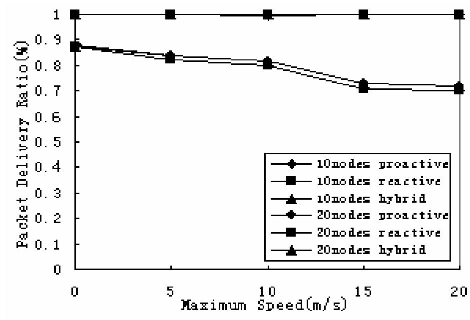

Fig. 2 Packet Delivery Ratio

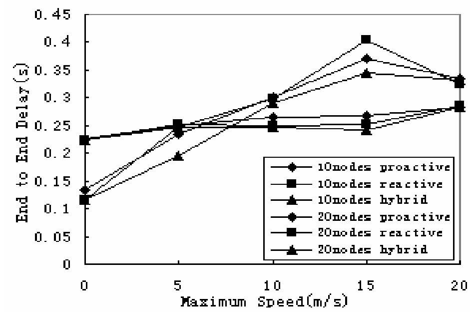

Fig. 3 End to End Delay

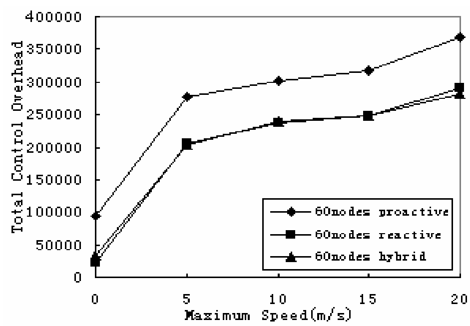

Fig. 4 Total Control Overhead (60 nodes)

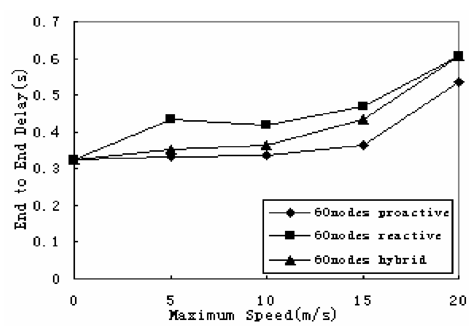

Fig. 5 End to End Delay (60 nodes)

When the network is large (60 mobile nodes), the hybrid approach which integrates the advantages of proactive and reactive methods behaves much better than the other two approaches do. Through broadcasting the gateway advertisements in the vicinity of gateway, mobile nodes can find the nearest gateway, and have a good switching performance and a low delay. Mobile nodes that are far away from the gateway will broadcast GWSOL to get global connectivity information when they need. This method can guarantee the global connectivity information to be received in time and the control overhead brought by GWSOL will not become a burden to the MANET. Taken as a whole, the hybrid method achieves excellent connectivity while keeping overhead costs low when connecting various scale ad hoc networks to the Internet.

4. Conclusions and Future Work

In this paper, the proactive, reactive and hybrid gateway discovery methods are introduced and analytically modeled in ad hoc networks. The comparison results tell us that for scenarios where average link durations are shorter, the proactive approach has a better performance with respect to delay. Thus it is suitable for delay sensitive applications. For longer link durations, the reactive approach is more efficient, as it does not introduce periodical overhead to the ad hoc network. The hybrid approach is a compromise between reactive and proactive approaches which gets a reasonable low overhead with shorter end to end delay. And it has a good adaptability. This comparison provides us with useful information when we want to design networks.

Moreover, we find that the advertisement interval and radius in hybrid approach is a pivotal factor to the whole network's overhead and packet delivery ratio. Sometimes, to a certain MANET whose parameters are clear we can find a suitable broadcast interval and radius through experiments. But it is not a universal method. In fact, the gateway can not know the characteristics of connected ad hoc network clearly beforehand, and these characteristics and interconnectivity demands are dynamic. For example, to a large scope of MANET, if there are only a few mobile nodes connecting to the Internet, the best gateway discovery approach to be used is reactive. If we use the proactive or hybrid method, the control overhead will be large and necessary for the rebroadcast of mobile nodes. So the gateway discovery should be adaptive to the MANET. The latest researches pay more attention to bring an adaptive gateway discovery approach based on the dynamic tuning of the scope of the gateway advertisements. In reference [17], the author proposed a mechanism that when mobile nodes found the network change it broadcasted the advertisement proactively. And only those nodes that are signed as FA can rebroadcast this advertisement. This can largely limit the advertisement flooded in the whole network. The author also gave an expression to tell the gateway when to make this change[18]. Another research proposed an expression based on the analysis of control overhead in proactive and reactive methods. Following this expression the gateway can adjust the next scope of advertisement adaptively[19]. This method can control the flooding of the advertisement in a certain degree.

The next research is to design a commonly adaptively gateway discovery method. In the MANET, many parameters dynamically change, such as the number of mobile nodes and its active areas, the nodes' average density, the moving speed, and the number of mobile which has Internet connectivity and the distance from gateway. At present, the adaptive methods can only be adaptive to a single character of them, so there is no commonly used method. So we are to design a highly adaptive protocol. This protocol can find the Internet nodes and the distance to the gateway automatically. Moreover it can know the change of MANET nodes' density and the average moving speed. According to this information, the gateway can select a best discovery method and automatically adjust the frequency and scope of GWADV when it uses the hybrid method. We think that this highly self-adaptive scheme is very important to the common use of MANET.

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