Performance Comparison of Gateway Discovery Algorithms in Ad Hoc Networks with Mobile Nodes

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Abstract: **The connection of ad-hoc networks to the Internet is typically established via gateways. To start an Internet connection, gateways have to be discovered by the mobile nodes within the ad-hoc cluster. This paper presents a new gateway discovery algorithm based on HELLO messages of the AODV protocol and compares the performance of the new algorithm with standard proactive and reactive algorithms. NS-2 simulator is used to investigate the algorithms on the basis of the discovery time and the handover delay. Our results show good performance of the new HELLO message based algorithm in both terms.**

1. Introduction

Multihop wireless access networks are a key technology in future IP based mobile systems. Because of the limited transmission range of wireless nodes a variety of routing algorithms were developed to give mobile nodes (MN) in mobile ad-hoc networks (MANETs) connectivity, and to enable MNs to connect to the Internet. These routing algorithms must have a functionality to interact with gateways that act as an interface between a mobile ad-hoc network and the structured Internet. Ad-hoc On demand Distance Vector (AODV) [10] is a commonly used ad-hoc routing protocol.

In AODV, if a mobile network has no access to link layer information it uses HELLO messages for neighbourhood management. An interconnection between network layer and link layer protocols provides more efficiency in detecting link losses to neighbour nodes as suggested in [10]. If the actual link layer protocol does not provide information about connectivity to neighbour nodes AODV falls back to broadcasting the presence of a MN to its neighbours by sending HELLO messages periodically. These HELLO messages can also be used to spread information about an existing Internet gateway throughout the whole MANET without any additional protocol overhead caused by advertisements or solicitations which are used in the established gateway discovery expansions. The approach to gateway discovery given in this paper depends on improved HELLO packets and thus, needs no interaction with the link layer. Gateway discovery time and handover delay have strong influence on packet delay and throughput, since for Internet connectivity mobile nodes in a first step need to discover gateways.

The next section gives a short overview of the related work while section 3 explains the HELLO message based gateway discovery algorithm in more detail. In section 4 we present simulation results and investigate discovery time and handover performance. Finally, section 5 gives a conclusion and summarises the results.

2. Related Work

Several approaches to enhance ad-hoc routing protocols to support a MN accessing the Internet were developed. Firstly, there is a proactive approach that is based on gateway advertisements. These advertisements are flooded into the MANET by the Internet gateway periodically to indicate the presence of the gateway to the MANET attendants. Secondly, there is a reactive approach where MANET attendants reactively ask for gateway services by broadcasting solicitations. After receiving such a solicitation the gateway then will send a routing message back to the originator of the solicitation. Both approaches have in common that the MANET is flooded with routing routing messages.

Gateway discovery methods for ad-hoc networks that are based on the proactive and reactive algorithm have been discussed and investigated in [3] [4] and [7]. In [4] several parameters like the number of gateways within a MANET and the mobility of the MNs were investigated. In our paper the emphasis is on the interval times of gateway advertisements and mobile node solicitations as well as the influence of node mobility and traffic load to the new algorithm.

A hybrid gateway discovery algorithm is described in [5]. Advertisements are sent with a limited hop range (TTL) and distant nodes from a gateway that do not receive advertisements solicit for the gateway reactively. In [7] the proactive, reactive and the hybrid discovery algorithms are investigated with the aid of NS-2 [6] simulations in terms of packet delay and throughput. The time how long nodes need to discover gateways are not included into the results.

An alternative approach for gateway discovery using HELLO packets is described in [8]. In this paper a testbed is presented with a very small number of nodes within the cluster. Additionally, there is only one gateway implemented and therefore, no investigations on handovers were performed.

The newly developed algorithm for gateway discovery is also described in [1]. The paper investigates the principle functionality of the algorithm for gateway discovery time delay (when a MN is switched on in an already established ad-hoc cluster) and handover time when nodes perform handovers between two ad-hoc clusters. The performance of the HELLO algorithm in more realistic scenarios is not investigated in [1], e.g., the influence of node movement and additional traffic within the ad-hoc cluster has not been studied so far which is the aim of this paper.

3. Gateway Discovery Based on HELLO Messages

In the ad-hoc routing protocol AODV, HELLO packets are used for neighbourhood management if the MAC layer does not provide information about the reliability of links. Every network node, including gateway nodes, broadcasts HELLO messages periodically to indicate their presence to neighbour nodes. The TTL of HELLO messages is 1.

The gateway node may set a flag in the HELLO-header to mark its HELLO messages as gateway originated. Thus, surrounding nodes are aware of that gateway and can use it for Internet communication. According to [3] this flag is called the I-flag and HELLO messages with gateway information are called HELLO_I messages.

In a further step, the gateway aware nodes may include the newly received gateway information into their own HELLO messages to spread the gateway's address deeper into the ad-hoc cluster. Therefore, they again set the I-flag to indicate that this HELLO message contains gateway information and additionally include the gateway's address into the destination field of the HELLO-header. With the I-flag set receiving nodes know that this HELLO_I message contains gateway information.

If a specific network node does not receive gateway information within its last HELLO period the node stops including gateway information and continues with standard HELLO messages. This interruption may happen due to node movement.

If a node is located in the multihop range between two gateways it may receive gateway information from both gateways (handover) and then it has to decide which gateway would perform best for the MNs Internet connectivity. The actual implementation of the HELLO based gateway discovery algorithm uses the hop count to the gateway as a metric. This hop count is included into HELLO_I messages in the HOPCOUNT field of the header. The gateway node sets this value to zero and every node receiving a gateway originated HELLO_I message will increase the hop count by one and creates or updates its routing table entry pointing to the gateway. As a result, the surrounding MNs of a gateway have a route to that gateway with a hop distance of one. Then every gateway aware node sets the HOPCOUNT field in its own HELLO_I messages to 1.

More details on the HELLO gateway discovery algorithm are explained and discussed in [1]. In the next section, the performance of this algorithm is compared to the well-known proactive and reactive approaches in terms of gateway discovery delay and handover time.

4. NS-2 Simulations and Results

4.1. Simulation Scenario and Parameters

In [1] the focus is on the principle functionality of the HELLO algorithm in terms of gateway discovery time and handover time. The focus of our paper is on more realistic scenarios with the HELLO based gateway discovery algorithm and therefore node movement is added to the simulations as well as different traffic loads.

The simulation scenario of [1] to investigate the gateway discovery time is firstly expanded by node movement and secondly with additional cluster traffic. The simulation parameters are discussed next.

In an area of 400 meters times 1000 meters a number of mobile nodes (small circles) are positioned randomly. They act as ad-hoc network attendants. The gateway (GW) is located in the upper part of the area. The physical radio range of each node is defined as a circle with a diameter of 250 m around the node. Figure 1 depicts the scenario.

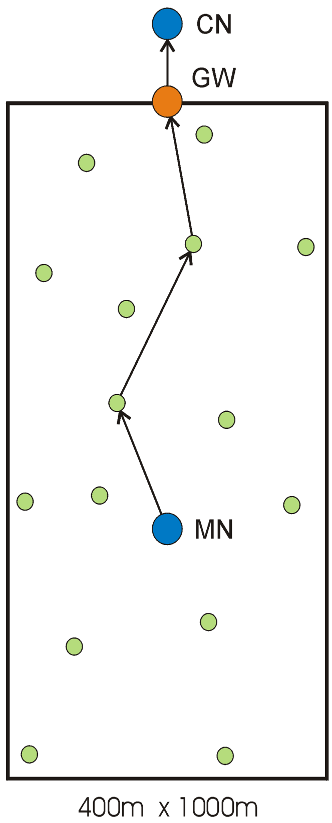

Figure 1: Scenario topology

The main simulation parameter is the interval time. In the proactive algorithm this is the time between two consecutive gateway advertisement messages. For the reactive algorithm the interval time is the time out of one gateway solicitation request followed by a standard route request as described in [3]. For the classical proactive and reactive approaches the HELLO period is fixed at 1 second. The HELLO period is the interval time and therefore the simulation parameter of the simulations with the new HELLO algorithm. Note that end-user systems with an HELLO interval of 15 or 30 seconds would perform very badly in detecting link losses and therefore, in end-user systems always short HELLO periods should be chosen. As a consequence, the results of the following simulations of the HELLO algorithm with interval times of 15 and 30 seconds must be interpreted as a completion to compare the three algorithms.

For node movement the random waypoint model was used. The additional traffic load in the MANET is generated by one third of 15 nodes with CBR data traffic in order to stress the gateway discovery algorithms. Other 5 nodes act as data sinks. The rest of 5 nodes are for forwarding data traffic within the MANET cluster. In the following the total generated traffic of all 5 nodes is used. More details on simulation parameters can be found in Table 1.

Nodes per MANET cluster	15
Size of one cluster	400 m x 1000 m
Radio range of one node	250 m
Total simulation time	300 s
Traffic type	CBR
CBR packet size	500 Bytes
CBR traffic load	0, 0.2, 8 Mbit/s
HELLO_INTERVAL: proactive, reactive HELLO	 1 s Simulation parameter
Node pause time	1 s
Node maximum speed	10 m / s
MN's speed (handover)	5 m / s

Table 1: General simulation parameters

The simulation results are depicted in Figures 4.2. and 4.3. For every algorithm there are graphs marked with a cross which stands for simulations with node movement only. The graphs marked with triangles and squares are for the results with 200 kbit/s and 8 Mbit/s, respectively. The traffic rates were chosen in respect to the IEEE 802.11b standard which saturates at approx. 7 Mbit/s net traffic.

4.2. Simulation Results for Gateway Discovery Time

To investigate the gateway discovery time, MN is switched on at t_{SIM} = 100 seconds among the other nodes after the MANET is already established. At the same time a CBR data source at the MN starts creating packets addressed for the CN to trigger the MN's routing agent to perform the implemented algorithms.

The mean discovery time value is calculated by averaging the discovery times of a number of simulation runs. In [1] a theoretical approach for the gateway discovery time without node movement and traffic is given. Since in [1] all nodes are static, the actual random topology of a specific simulation run was either able to give an averageable value or not. Now, due to the nodes' mobility more than 99% of all simulation runs did succeed and grant a computable value to the discovery time statistic. Some simulation runs contribute a very long discovery time if the random movement topology does provide a route from the MN to the GW later in the simulation. Then the MN has to wait longer for an advertisement or it processes the whole solicitation interval again. As a result, the averaged discovery times will be increased compared to the results in [1]. For the HELLO algorithm the discovery time is expected to be dramatically increased because node movement disrupts the forwarding of gateway information in HELLO messages as described above.

Firstly it can be observed that with only the node movement and no traffic the offset of every graph is about 6 to 7 seconds compared to [1]. Thus, node movement has a clear influence on gateway discovery times as expected. With increasing interval time, the proactive algorithm shows no impact in terms of advertisement losses since the slope of the graph remains at 0.5. The reactive algorithm shows a slightly increased slope of 0.2. This can be interpreted as the loss of some solicitation requests or answers. In that case the MN has to wait for the time out of its request which is equal to the interval time. The HELLO algorithm shows worst impact on node movement since HELLO_I messages get lost due to the forwarding mechanism.

With additional traffic load the offsets of the proactive algorithm as well as the slopes of the resulting graphs are slightly increased with increasing traffic load. This can be interpreted as advertisements collide with data packets and then the MN has to wait for the next advertisement from the gateway.

The reactive algorithm shows no impact in the presence of low traffic load but is clearly influenced by higher traffic rates. With high traffic rates a solicitation request may collide with data traffic and then the MN waits for the time out of the solicitation (=interval time) plus the time out of one standard route request which is altering with gateway solicitations in the discovery process [3]. Thus, the mean discovery time is increased to more than 30 seconds for an interval time of 1 second and increased to 63 seconds with an interval time of 30 seconds.

The HELLO based algorithm is also influenced by MANET traffic. For short interval times this influence is less compared to long interval times. Short intervals lead to a mean discovery delay of 4 to 6 seconds. With increasing interval time the discovery time is increased to a maximum of 41 seconds (30 second interval). Thus, the traffic load as well as the node movement have clear influence on the HELLO algorithm.

4.3. Simulation Results for Handover Simulations

To investigate the handover performance of the algorithms the scenario was extended as follows. A second cluster of the same shape and size is added to the first scenario but it is shifted horizontally to the right by 651 meters. This distance ensures that network nodes of one cluster do not receive packets from nodes of the other cluster (radio range is 250 meters and the resulting gap is 251 meters). Network nodes of both clusters stay within their home cluster only and do not change into the other cluster. Every cluster has an attached gateway node that both are connected to the same destination node (CN). Data traffic from the MN is directed to that destination node. The MN is located in the left cluster and starts moving at t_{SIM} = 100 seconds to the right cluster with a speed of 5 meters/second to simulate a handover. The results of the simulation are depicted in Figure 4.3.

The first observation for the proactive, reactive, and HELLO algorithms is that the handover times are doubled for simulation with node movement (without traffic) compared to simulations with static nodes like in [1]. For every algorithm the resulting graphs with no traffic

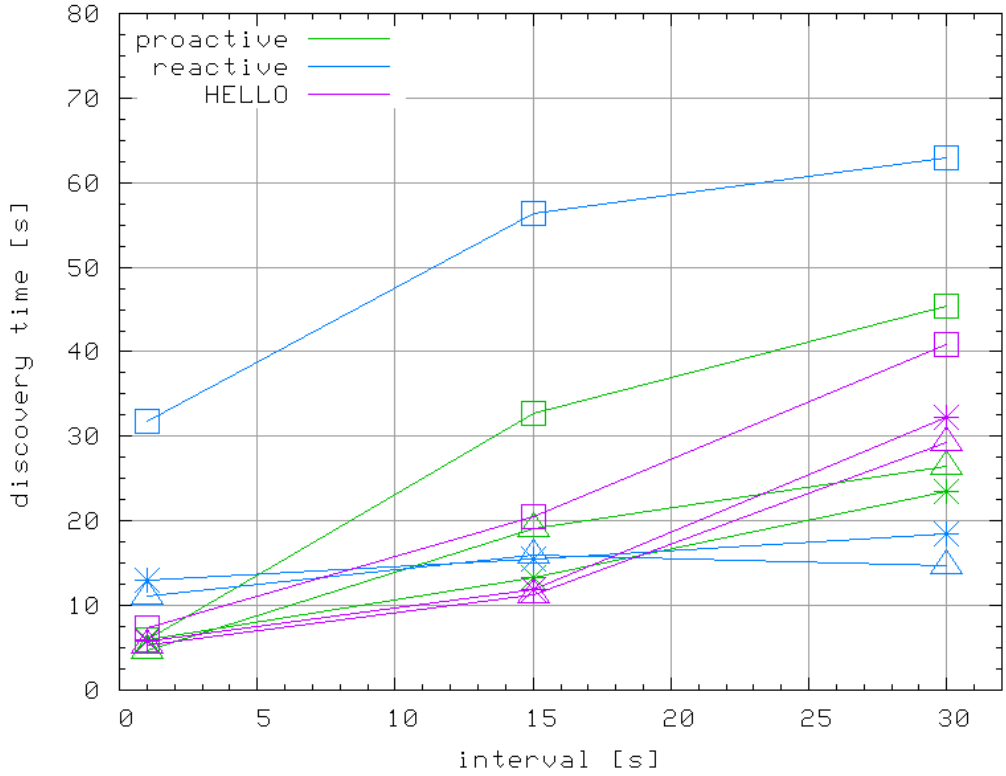

Figure 2: Min and max Discovery times

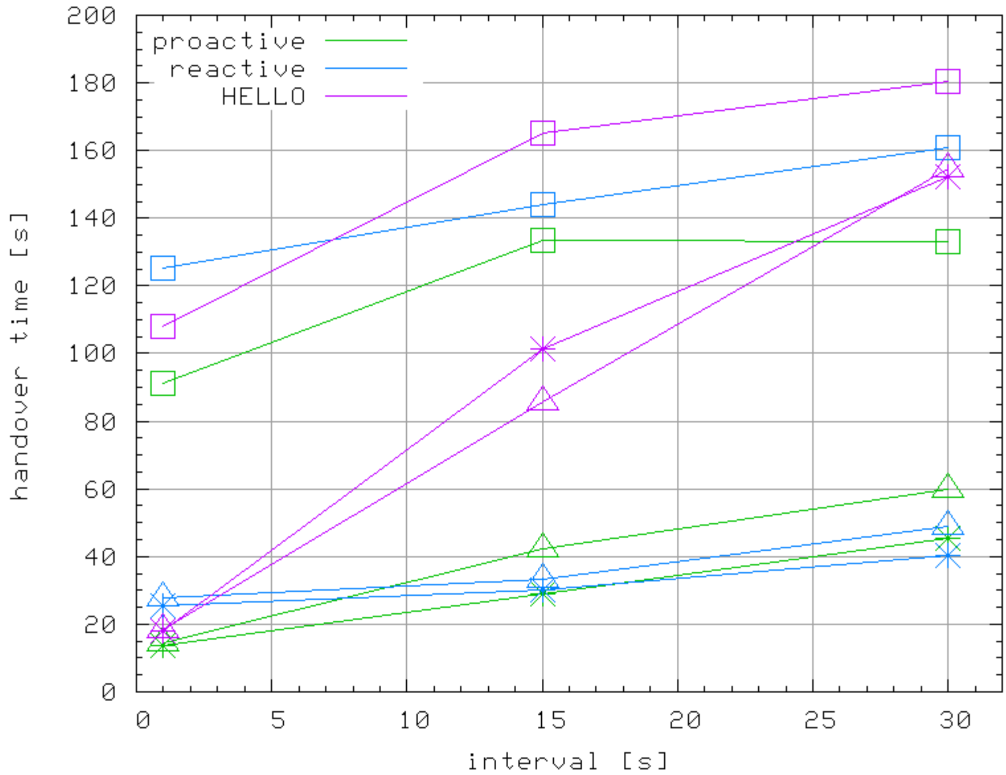

Figure 3: Min and max Handover times

and medium traffic (200 kbit/s) are almost comparable and thus, the algorithms show less impact on minor traffic load. With high traffic rates (8 Mbit/s) each of the three graphs is dramatically increased to a minimum of 90 seconds (proactive, 1 second interval) and a maximum of 180 seconds (HELLO, 30 second interval). A handover offset of 0.2 seconds is included into the results. This offset is caused by the gap between the two MANET clusters.

The bad scalability of the HELLO algorithm in terms of interval time is a result from the neighbourhood management routines of the AODV protocol. Therefore, the graph of the HELLO algorithm with interval times of 15 and 30 seconds is for completing the algorithms and long interval time for the HELLO algorithm should not be used in end-user systems.

5. Conclusion

For the Internet connectivity in wireless ad-hoc networks gateways need to be discovered by mobile network members. Therefore ad-hoc routing protocols were expanded by gateway discovery features. This paper discusses a newly developed gateway discovery protocol which is based on HELLO messages of the AODV protocol. The new algorithm uses no gateway advertisement messages or solicitation requests to distribute gateway information in a MANET. The HELLO based algorithm is investigated in terms of gateway discovery time when a network node among other nodes is switched on and the handover time if a mobile node performs a handover procedure between two ad-hoc clusters. The simulation results of the established proactive and reactive gateway discovery expansions are compared with the results of the new HELLO message based algorithm.

We found very short gateway discovery times for the HELLO algorithm when a mobile node is switched on in an already established ad-hoc network and the HELLO algorithm scales best with high data traffic rates in the ad-hoc network. This is explained by the unsynchronized sending of HELLO messages of the nodes. Thus, a specific mobile node gets gateway information with the first received HELLO_I message from a neighbour node and therefore it does not have to wait for a gateway advertisement nor it has to broadcast a solicitation for a gateway.

When a MN is performing a handover procedure the HELLO message based algorithm performs worst with increasing interval time since then the MN needs more time to detect the loss of connectivity to neighbour nodes. A node recognises the loss of connectivity after three consecutive missed HELLO messages until it starts rediscovery routines. Note that for the proactive and reactive algorithm the interval time of HELLO messages is fixed at 1 second but for the HELLO algorithm the interval time is a simulation parameter. Therefore, the results need to be interpreted with care and the HELLO based algorithm with a fixed 1 second interval shows best performance in terms of gateway discovery time and very good performance in handover time and is only outperformed by the proactive algorithm with 1 second interval which causes much overhead due to periodic flooding the MANET with broadcast messages.

HELLO messages are used for neighbourhood management in systems where no cross link information is provided by layer 2. In systems with information from layer 2 no HELLO messages are needed but the investigated algorithm for distributing gateway information in ad-hoc networks can be transferred to be used with IP packets. For this purpose the gateway information can be included into an IPv6 header to spread gateway information in MANETS. As a result, nodes would get gateway routing information without advertisements or solicitations.

The impact on the HELLO based gateway discovery algorithm on higher layers as well as different node densities is subject to future work.

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