OPTIMIZED GATEWAY DISCOVERY IN HYBRID MANETS

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ABSTRACT

Mobile users are expected to demand access to the Internet anywhere and anytime. In a MANET context, a device which is about to connect to external hosts needs the route to the element which communicates the MANET with the Internet. This element is the Internet Gateway. To inform about its presence as well as about some configuration parameters, the Gateway sends MRA messages. In a similar way to ad hoc routing protocols, the Gateway can generate the messages on demand (reactively), periodically (proactively) or combining both previous strategies in a hybrid gateway discovery. Specifically, in the hybrid gateway discovery, the Gateway periodically sends the MRA messages in a restricted area. The nodes that are outside this area demand the Gateway information reactively. This gateway discovery requires the setting of the number of hops that define the proactive area, also called the TTL value. Network performance can be improved when the Gateway uses information such as the position of the sources to adjust the TTL value. In this paper, we transfer the decision about the dimensions of the proactive zone to the mobile nodes so more network conditions are taken into account. Simulation results show that the proposed gateway discovery outperforms other hybrid gateway discovery schemes.

KEYWORDS

Internet, Manet, Interconnection, wireless communications

1. INTRODUCTION

In future, anyone can access Internet from anywhere and anytime. In this ubiquitous Internet will require all wireless devices to interconnect with each other. The deployment of infrastructures for computing ubiquitous has great economic interest. The traditional access networks such as GSM (Global System for Mobile Communications), WLAN (Wireless Local Area Networks) or UMTS (Universal Mobile Telecommunications System) can not reach all places because they are costly. In this sense MANET (Mobile Ad Hoc Networks) can expand the areas of coverage of such networks in an efficient, reliable and with a low cost. In general terms, these already established networks provide an Access Router which allows the dynamic configuration of temporal IP addresses. With this purpose, the Access Router informs about the prefix information that it is managing with Router Advertisement (RA) messages. On receipt, mobile devices can construct an IP (Internet Protocol) address valid in the domain where they reside. According to the specifications where RA messages are defined [1], these messages cannot be propagated [2]. If this technology is applied as itself in a multihop wireless networks, those nodes that are outside the coverage area of the Access Router will not be able to obtain a valid IP address and, in turn, they will not be able to access the Internet. Therefore, interworking between conventional protocols and ad hoc network technologies must be studied. In this sense, the current solutions propose the inclusion of an Internet Gateway which is connected to the Access Router and complements it [3]. The Gateway carries out two main tasks. Firstly, it provides the ad hoc routing capabilities that are absent in conventional Access Routers so that the downlink traffic can be conveniently re-routed in the MANET. Secondly, the Gateway broadcasts Modified Router Advertisement (MRA) messages, which contain similar information to RA messages but which can be propagated in the MANET. As these messages are received by all the nodes in the MANET, they can configure their own IP addresses to be globally reachable by any terminal in the Internet.

As the Internet Gateway is the element which connects the MANET to external networks, all packets from and to the Internet must be routed by the Internet Gateway. Therefore, there must be a mechanism to find and create a route to the Gateway in the mobile nodes. This process is called the Gateway Discovery and it is supported by the analysis of MRA messages. When a mobile node receives an MRA message, it updates the route to the Internet Gateway which generated it. They are many studies in the literature research about the implementation of gateway discovery schemes. The schemes that execute this process can be classified as shown in Figure 1.

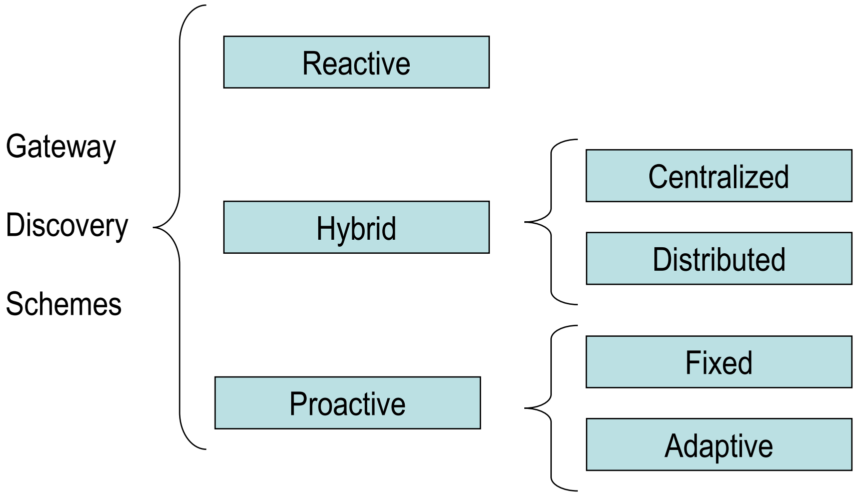

Figure 1. Classification of gateway discovery algorithms.

The first level of classification (reactive, hybrid, proactive) is based on the TTL (Time-to-live) of MRA messages. The emission of MRA messages may be accomplished on demand from the mobile nodes (reactive), periodically activated by the Gateway (proactive) or combining the previous approaches (hybrid). In the hybrid scheme, MRA messages are periodically broadcast in an area close to the Internet Gateway while the devices located outside this zone demand the MRA information by generating Modified Router Solicitation (MRS) messages [4]. The proactive zone is defined by the TTL value in the MRA messages, that is, the number of retransmissions that an MRA message can have. By adjusting the TTL value, the hybrid gateway discovery can behave as proactive (the TTL set to the network diameter) or as reactive (the TTL set to 0). We can divide the proactive schemes in fixed and adaptive approaches. In the fixed algorithms the interval of emission of MRA messages (T) does not change while in adaptive schemes this value is adapted dynamically as a function of some characteristic of network. The hybrid schemes can also be classified according to the decision on the retransmissions of the MRA messages. When the decision to broadcast the MRA does exclusively depend on the TTL value set by the GW, the algorithm is centralized. In contrast when the MANET nodes use additional parameters for this decision, the algorithm is distributed. Since hybrid gateway discovery is able to emulate all gateway discovery schemes, in this paper we will focus on optimizing it. The contribution of this paper is the proposal and evaluation of a technique by which the process of determining the proactive area is distributed in the MANET. As a main difference to conventional hybrid schemes [5], we propose that the area where the MRA messages are propagated will not be exclusively decided by the Gateway but the nodes in the MANET will also participate in this decision. By distributing this decision, more network conditions are taken into account.

The remainder of the paper is structured as follows. In Section 2, we present a complete description about some other solutions that aim at adapting the TTL to the network conditions. In Section 3, our algorithm is described. This algorithm is evaluated by simulations which are shown in Section 4. Finally, Section 5 draws the main conclusion of our work.

2. RELATED WORK

In the hybrid schemes the interval (*T*) and the Time to Live (TTL) should be adapted to the network conditions. One of the first adaptive and centralized algorithms was the Maximal Source Coverage (MSC) [5]. In this proposal, the *T* is set to a fixed value while the gateway will send out the next advertisement message with the TTL equal to the minimum number of hops required to reach all the sources that use this gateway to communicate with external hosts. A hybrid and adaptive centralized algorithm is [6], the authors propose the use of an auto-regressive filter to simultaneously adjust the *T* and its TTL value. To do so, the authors recommend monitoring the traffic load in Internet gateways so that the *T* and TTL can be set suitably using a feedback controller. The proposed tuning is based on the changes of link stability, the traffic rate and the number of received MRS. However, no specific formulation is presented and no evaluation is shown.

In [7], the authors present a distributed scheme in which the appropriateness of broadcasting an MRA message depends on the number of active sources that communicate with external hosts as well as the number of intermediate nodes that forward packets to the Internet gateway. With these two parameters, the authors define the so-called Regulated Mobility Degree (RMD). If this factor exceeds a pre-established threshold, the MRA message is sent. The main difficulty of this proposal is determining the threshold as it also depends on the network conditions.

In [8] the Adaptive Distributed gateway Discovery (ADD) is presented. In this work, there is a new distributed strategy: only the mobile nodes that are relaying data packets are able to forward the MRA messages.

Our proposal also adjusts the TTL value of the MRA to the network conditions. To do so, we incorporate a policy in the mobile nodes so that they decide about the retransmission of the MRA messages. This algorithm is explained in the next Section.

3. SELECTIVE FORWARDING

In the proposed algorithm, the gateway also sends MRA messages every *T* seconds as conventional hybrid gateway discoveries. However, in this scheme the mobile nodes decide whether to forward them or not according to the residual lifetime of the route to the Gateway. Computing the exact residual lifetime of any route is not a trivial task [9], so in this paper we propose the use of two parameters to estimate the route residual lifetime. These parameters, which are conventionally kept in the route caches, are:

- Number of hops to the Gateway. Route lifetimes strongly depend on the number of hops that it contains [10]. In this sense, a route composed of few nodes is expected to endure longer that a path with more hops. Then, the characteristics of interconnection to the Internet are clearly affected by distance to GW. This fact is shown in Figure 2, which represents the cumulative distribution function of the route lifetime obtained with different scenarios, nodes and speeds. As shown in Figure 2, when the number of hops to the gateway increases, the mean route time decreases.

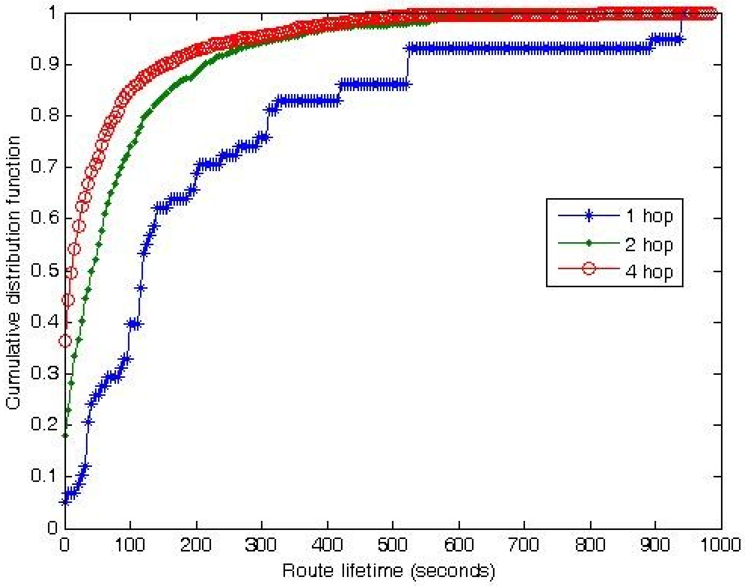

Figure 2. Cumulative distributions function of Gateway Route lifetime in Internet-connected MANETs .

- Route Expiration Time. In reactive ad hoc routing protocols, learnt routes are stored in caches during an interval along which the route is considered to be valid. When this interval is over, if the route has not been employed, the entry is removed from the cache. On the other hand, every time the route is used without any transmission error, its expiration time is updated. Specifically, in AODV (Ad Hoc On Demand Distance Vector), route expiration is increased in ActiveRouteTimeout seconds when it is used [12]. Roughly, our algorithm assumes that those routes whose expiration time is far to expire do not need to be frequently updated because they have been recently discovered or recently used without any transmission error.

- Relaying for some other nodes. With this variable, we measure if the node is an active source or if it is relaying for some traffic sources. In this way, the MRA messages will be propagated to the areas where updated routes to the Internet are needed.

With these three parameters, our algorithm makes MRA messages propagate exclusively in those areas where active sources with unstable routes exit. Additionally, as any node in the MANET may unexpectedly start a communication with an external host, the Gateway periodically generates an MRA message which is mandatorily propagated in the whole MANET. To differentiate these two operations, we have added a new flag to the MRA messages [3]. The flag has been called Selective Forwarding (SF). When set, the mobile nodes decide about the appropriateness of retransmitting it or not. Under these circumstances, MRA message is forwarded by mobile nodes with active routes as long as the lifetime is about to end. Mathematically, this condition is expressed in the Equation (1):

$$Expiration\ Lifetime \leq T \cdot hop \qquad (1)$$

where T is the interval of emission of MRA messages, while *hop* is the number of hops that the route to the Gateway contains. When this condition holds and the node is acting as a relay for other data sources, the MRA message is retransmitted. Independently of the number of hops that they contain, all routes when used or discovered increase their expiration lifetime with a constant value. With the expression in Equation (1), we are demanding long routes (composed by a significant number of hops) to be updated more frequently than short routes.

The selection of a linear function between the expiration lifetime and the number of hops is based on the analysis of the gateway route lifetimes in Internet-connected MANETs. The results of the analysis are summarized in Table 1. The table includes the correlation coefficient between different functions and the average value of the expiration lifetime associated to the routes to the gateway in different network conditions (traffic, mobility and density of nodes). These data have been obtained in the same scenario used for Figure 2. The table also includes the *p*-values for testing the hypothesis of no correlation. If p-value is small, say less than 0.05, then the correlation can be assumed significant.

Table 1. Correlation coefficient and p-value of various functions.

Functions	$T{\cdot}hop$	$\log(T{\cdot}hop)$	$e^{T{\cdot}hop}$
Correlation coefficient	0.9021	0.7808	0.7204
P-value	0.0139	0.0668	0.1063

As shown in the table, the highest correlation coefficient and the lowest p-value is given for the linear function, that is the function chosen for the selective algorithm.

On the other hand, when the SF in the MRA message is cleared, the nodes must retransmit the message. These MRAs, which we will call them mandatory MRAs, are sent in the following two cases:

- The last mandatory MRA was sent *Tmandatory* seconds ago.
- The ratio between the number of MRS messages sent by the GW and data sources is higher than 50 %. With this condition, the Gateway can detect the situations with a high mobility where it is more convenient to update all the routes to the Gateway proactively.

Figure 3 illustrates the process of retransmitting the MRA messages in the mobile nodes.

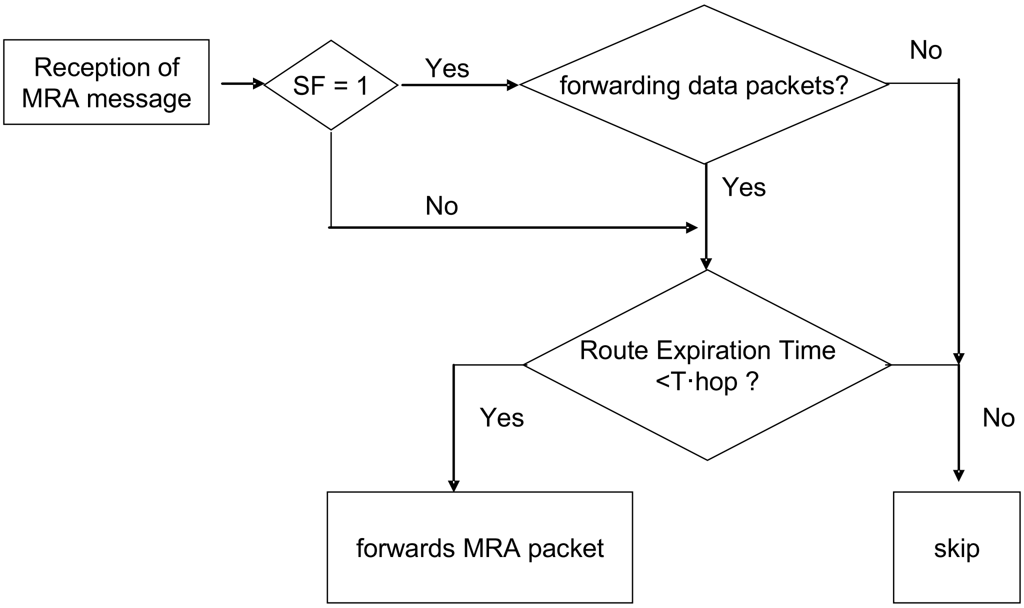

Figure 3. Decision about the retransmission of MRA messages in MANET nodes.

4. SIMULATION RESULTS

Due to the difficulties associated to real tests, the benefits of our proposal for distributed gateway discovery have been verified by the use of simulations. It was necessary to develop a software module that includes the algorithm in the Global Connectivity support [11]. This module has been integrated into the open source Network Simulator tool, ns-2.31 on a Linux machine [13]. For a comparative evaluation, we have also implemented the RMD and the ADD algorithms described in Section 2. RMD parameters are set according to [7]. We have compared the algorithms under different mobility patterns and different traffic conditions. In all the scenarios, the simulation time is set to 1000 seconds. Since we are interested in studying the behaviour of MANET in a steady state, the first 100 seconds of the simulations are considered a warm-up period and they are not computed in the analysis. The mobile nodes move in a rectangular area where the gateway is located in the centre of topology. Other simulation characteristics are presented in Table 2.

Table 2. Scenarios Characteristics.

Simulation Area	1500 x 300 m2
Number of Nodes	50
Gateway Location	(750,150) m
Transmission Range	250 m
Simulation Time	1000 s
Runs per Point	100
Ad hoc Protocol	AODV (Ad Hoc On Demand Distance Vector Routing) Local repair disabled ActiveRouteTimeout 10 s
Link Layer	Link layer detection enabled 802.11 RTS/CTS enabled
Mobility pattern	Maximum speed: 2 to 5 m/s Pause Time: 10 s
CBR (Constant Bit Rate)	10 sources Length 128 bytes
Integration Support	Global Connectivity T : 5 s
Distributed Proposal	Tmandatory: 20 s

The algorithms are tested using the following metrics:

- Packet Loss Rate (*PLR*): it is defined as the ratio of the number of lost packets to the total number of packets transmitted by the sources.
- End-to-End delay (*Delay*): it represents the average time that the received packets take to reach the destination; i.e., the node in the external network, from their origins. To avoid the inclusion of factors external to the MANET, we will consider the delay from the MANET sources to the Internet Gateway.
- Normalized Routing Overhead (*NRO*): defined as the total number of control packets divided by the total number of received packets. For this computation, each time a control packet is retransmitted, it is considered as a new control packet.

These parameters provide an estimation of the network performance. Firstly, *PLR* and *Delay* are the two most important parameters from the users' point of view. The *NRO* is an important measurement in energy limited devices as it provides an estimation of the battery consumption.

The number of simulations has been conditioned by the confidence intervals of *NRO*, so that the simulations have been performed to ensure that intervals do not overlap, with a minimum of 100 simulations for each maximum speed and traffic rate.

In the next sections, we present the results for each mobility model that we have considered. We have compared our proposed algorithm, the Selective Forwarding (SF) gateway discovery to the RMD, to the Reactive Gateway Discovery (REA) and to the ADD. These algorithms have been chosen from among those referred to section 2 because they show their ability to obtain reduced *delay*, *PLR* and *NRO*.

4.1. Random Waypoint Model

The Random Waypoint Model is commonly used in the MANET research community. The implementation of this mobility model is as follows: at every instant, a node randomly chooses a destination and moves towards it with a speed chosen randomly (according to a uniform distribution) from [1, V_{max}], where V_{max} is the maximum allowable velocity for every mobile node. When the destination is reached, the node stops for a duration defined by the 'pause time' parameter. After this duration, the node again chooses a new random destination within the area and repeats the whole process again until the simulation ends. A minimum and not null speed for the nodes movements is set according to [14].

The results for *delay*, *PLR* and *NRO* are presented in Table 3, Table 4 and Table 5 respectively. The parameter N_p represents the number of packets per second generated by each source. The results show that the delay is clearly reduced in the SF discovery while losses and overhead are similar to the values obtained with the RMD scheme and the reactive gateway discovery. It is important to note that the delay has a non-monotonical behavior as for low data rates (2 packets/s), the delay is higher than for 9 packets/s. We consider that this effect is caused by the route discoveries procedures. Indeed, with a low data rate, there is a high probability that the packet needs to wait for discovering a valid route to the Internet Gateway. However, when the rate increases, more packets will benefit from a previous route discovery so they can be immediately sent through the already learnt route. In order to confirm this hypothesis, we have computed the percentage of packets that need to wait for a valid route to the Internet Gateway. In a high mobility scenario, for a data rate of 2 packets/s, the transmission of 2.25 % packets are delayed to discover valid routes while for a data rate of 9 packets/s, just 1.57 % packets demand a route discovery procedure.

Table 3. RWP Scenarios: *delay* results.

	Delay(s) in low mobility conditions				**Delay(s) in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.0152	0.0115	0.0246	**0.0118**	0.0208	0.0174	0.0335	**0.0181**
3	0.0101	0.0080	0.0103	**0.0080**	0.0136	0.0113	0.0139	**0.0112**
4	0.0104	0.0079	0.0118	**0.0080**	0.0126	0.0108	0.0143	**0.0105**
5	0.0084	0.0068	0.0090	**0.0065**	0.0099	0.0087	0.0106	**0.0083**
6	0.0089	0.0075	0.0094	**0.0071**	0.0101	0.0091	0.0107	**0.0083**
7	0.0080	0.0073	0.0103	**0.0065**	0.0090	0.0080	0.0116	**0.0074**
8	0.0086	0.0080	0.0081	**0.0068**	0.0095	0.0088	0.0089	**0.0080**
9	0.0086	0.0081	0.0079	**0.0067**	0.0093	0.0088	0.0085	**0.0078**
10	0.0096	0.0094	0.0106	**0.0076**	0.0108	0.0104	0.0119	**0.0091**
11	0.0116	0.0106	0.0137	**0.0084**	0.0126	0.0125	0.0149	**0.0103**
12	0.0168	0.0151	0.0173	**0.0127**	0.0185	0.0184	0.0190	**0.0153**
13	0.0270	0.0247	0.0330	**0.0217**	0.0308	0.0296	0.0376	**0.0263**
14	0.0454	0.0434	0.0509	**0.0394**	0.0523	0.0510	0.0587	**0.0464**
15	0.0727	0.0716	0.0763	**0.0664**	0.0826	0.0814	0.0867	**0.0756**

Table 4. RWP Scenarios: *PLR* results.

	***PLR* in low mobility conditions**				***PLR* in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.0152	0.0115	0.0246	**0.0118**	0.0208	0.0174	0.0335	**0.0181**
3	0.0101	0.0080	0.0103	**0.0080**	0.0136	0.0113	0.0139	**0.0112**
4	0.0104	0.0079	0.0118	**0.0080**	0.0126	0.0108	0.0143	**0.0105**
5	0.0084	0.0068	0.0090	**0.0065**	0.0099	0.0087	0.0106	**0.0083**
6	0.0089	0.0075	0.0094	**0.0071**	0.0101	0.0091	0.0107	**0.0083**
7	0.0080	0.0073	0.0103	**0.0065**	0.0090	0.0080	0.0116	**0.0074**
8	0.0086	0.0080	0.0081	**0.0068**	0.0095	0.0088	0.0089	**0.0080**
9	0.0086	0.0081	0.0079	**0.0067**	0.0093	0.0088	0.0085	**0.0078**
10	0.0096	0.0094	0.0106	**0.0076**	0.0108	0.0104	0.0119	**0.0091**
11	0.0116	0.0106	0.0137	**0.0084**	0.0126	0.0125	0.0149	**0.0103**
12	0.0168	0.0151	0.0173	**0.0127**	0.0185	0.0184	0.0190	**0.0153**
13	0.0270	0.0247	0.0330	**0.0217**	0.0308	0.0296	0.0376	**0.0263**
14	0.0454	0.0434	0.0509	**0.0394**	0.0523	0.0510	0.0587	**0.0464**
15	0.0727	0.0716	0.0763	**0.0664**	0.0826	0.0814	0.0867	**0.0756**

Table 5. RWP Scenarios: *NRO* results.

	***NRO* in low mobility conditions**				***NRO* in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.5150	0.3794	0.6531	**0.3522**	0.7447	0.6178	0.9443	**0.5947**
3	0.3271	0.2762	0.3742	**0.2557**	0.4859	0.4317	0.5557	**0.4100**
4	0.2816	0.2246	0.3403	**0.2149**	0.4007	0.3501	0.4842	**0.3324**
5	0.2363	0.1893	0.2896	**0.1808**	0.3289	0.2910	0.4031	**0.2778**
6	0.2174	0.1697	0.2581	**0.1646**	0.2940	0.2586	0.3490	**0.2509**
7	0.1974	0.1532	0.2529	**0.1511**	0.2682	0.2314	0.3436	**0.2197**
8	0.1862	0.1410	0.2125	**0.1400**	0.2546	0.2154	0.2905	**0.2066**
9	0.1766	0.1378	0.2156	**0.1335**	0.2353	0.2012	0.2874	**0.1946**
10	0.1794	0.1393	0.2148	**0.1351**	0.2377	0.2037	0.2846	**0.1926**
11	0.1903	0.1478	0.2255	**0.1426**	0.2478	0.2180	0.2938	**0.2061**
12	0.2250	0.1872	0.2649	**0.1778**	0.2936	0.2634	0.3458	**0.2439**
13	0.3130	0.2701	0.3746	**0.2584**	0.3930	0.3600	0.4703	**0.3369**
14	0.4387	0.4053	0.5225	**0.3892**	0.5390	0.5154	0.6421	**0.4816**
15	0.6112	0.5936	0.7361	**0.5602**	0.7245	0.7126	0.8725	**0.6695**

4.2. Manhattan Mobility Model

The Manhattan model emulates the movement of automobiles on streets defined by a rectangular grid-type map [9]. It can be useful in modelling movement in an urban area where a pervasive computing service between portable devices is provided. The grid is composed of a number of horizontal and vertical streets. The mobile node can move along the grid of horizontal and vertical streets on the map. At an intersection of a horizontal and a vertical street, the mobile node can turn left, right or go straight with certain probability. The Manhattan mobility model is also expected to have high spatial dependence and high temporary dependence as it imposes geographic restrictions on node mobility too.

For our simulations, in the grid there is a street every 100 meters both horizontally and vertically. The streets are two-way and the probability of turning at intersections is the same for all the directions.

The simulation results are shown in Table 6, Table 7 and Table 8. Comparing with the results for the RWP, we realize that the *delay* is higher. This is due to the limitations of movement imposed by the model, making the routes to the GW longer, and therefore, the *delay* increases. *PLR* and the *NRO* are also higher: if route to the Gateway is longer, the probability of collisions and losses also increase. The new algorithm **SF** also gets good results for this mobility model, although the improvement is somewhat smaller than for the RWP model.

Table 6. Manhattan Scenarios: *Delay* results.

	Delay(s) in low mobility conditions				**Delay(s) in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.1025	0.0947	0.0983	**0.0905**	0.1002	0.1048	0.1007	**0.0936**
3	0.0776	0.0761	0.0713	**0.0764**	0.0833	0.0783	0.0825	**0.0770**
4	0.0741	0.0730	0.0713	**0.0705**	0.0768	0.0752	0.0751	**0.0716**
5	0.0704	0.0652	0.0656	**0.0631**	0.0706	0.0687	0.0706	**0.0657**
6	0.0698	0.0661	0.0663	**0.0636**	0.0711	0.0686	0.0689	**0.0664**
7	0.0666	0.0618	0.0621	**0.0616**	0.0668	0.0650	0.0678	**0.0628**
8	0.0651	0.0609	0.0629	**0.0597**	0.0651	0.0632	0.0646	**0.0621**
9	0.0635	0.0613	0.0600	**0.0594**	0.0661	0.0614	0.0654	**0.0612**
10	0.0659	0.0621	0.0642	**0.0609**	0.0678	0.0655	0.0694	**0.0633**
11	0.0770	0.0711	0.0728	**0.0710**	0.0811	0.0783	0.0803	**0.0749**
12	0.1065	0.0968	0.1004	**0.0962**	0.1167	0.1102	0.1184	**0.1081**
13	0.1564	0.1451	0.1449	**0.1430**	0.1717	0.1657	0.1756	**0.1631**
14	0.2224	0.2110	0.2159	**0.2047**	0.2433	0.2347	0.2499	**0.2353**
15	0.2962	0.2850	0.2852	**0.2818**	0.3183	0.3130	0.3232	**0.3139**

Table 7. Manhattan Scenarios: *PLR* results.

	***PLR* in low mobility conditions**				***PLR* in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.0180	0.0136	0.0163	**0.0146**	0.0206	0.0170	0.0215	**0.0185**
3	0.0135	0.0103	0.0121	**0.0107**	0.0150	0.0123	0.0155	**0.0135**
4	0.0121	0.0103	0.0113	**0.0106**	0.0138	0.0116	0.0144	**0.0118**
5	0.0117	0.0094	0.0102	**0.0096**	0.0120	0.0104	0.0126	**0.0106**
6	0.0120	0.0103	0.0107	**0.0102**	0.0131	0.0105	0.0136	**0.0110**
7	0.0112	0.0099	0.0094	**0.0101**	0.0119	0.0103	0.0127	**0.0103**
8	0.0126	0.0107	0.0106	**0.0109**	0.0121	0.0113	0.0124	**0.0120**
9	0.0135	0.0124	0.0120	**0.0118**	0.0137	0.0120	0.0137	**0.0119**
10	0.0174	0.0153	0.0171	**0.0151**	0.0185	0.0164	0.0193	**0.0158**
11	0.0287	0.0248	0.0275	**0.0247**	0.0308	0.0286	0.0317	**0.0274**
12	0.0530	0.0467	0.0496	**0.0471**	0.0587	0.0548	0.0609	**0.0537**
13	0.0924	0.0848	0.0884	**0.0836**	0.1017	0.0961	0.1060	**0.0948**
14	0.1387	0.1312	0.1346	**0.1312**	0.1501	0.1442	0.1547	**0.1443**
15	0.1876	0.1808	0.1832	**0.1790**	0.1996	0.1942	0.2042	**0.1936**

Table 8. Manhattan Scenarios: *NRO* results.

	***NRO* in low mobility conditions**				***NRO* in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.5758	0.4131	0.6064	**0.4325**	0.7409	0.5886	0.7582	**0.6155**
3	0.3998	0.3013	0.4145	**0.3196**	0.5082	0.4218	0.5260	**0.4418**
4	0.3365	0.2542	0.3603	**0.2697**	0.4258	0.3501	0.4384	**0.3616**
5	0.3018	0.2214	0.3223	**0.2318**	0.3685	0.3030	0.3854	**0.3119**
6	0.2748	0.2056	0.2911	**0.2129**	0.3324	0.2724	0.3519	**0.2816**
7	0.2526	0.1920	0.2705	**0.1975**	0.3048	0.2486	0.3235	**0.2586**
8	0.2470	0.1826	0.2712	**0.1914**	0.2918	0.2368	0.3182	**0.2463**
9	0.2474	0.1897	0.2728	**0.1914**	0.2879	0.2375	0.3045	**0.2417**
10	0.2760	0.2099	0.3062	**0.2170**	0.3284	0.2674	0.3522	**0.2719**
11	0.3802	0.3019	0.3915	**0.3095**	0.4489	0.3873	0.4636	**0.3797**
12	0.5964	0.4973	0.5936	**0.5075**	0.6830	0.6024	0.7214	**0.6063**
13	0.8917	0.7897	0.8909	**0.7851**	0.9877	0.9123	1.0303	**0.9082**
14	1.1706	1.0767	1.1841	**1.0996**	1.2706	1.1929	1.3223	**1.2031**
15	1.4307	1.3467	1.4285	**1.3386**	1.5160	1.4383	1.5423	**1.4462**

4.3. Time-variant Community Mobility Model

Many researchers analyze the performance of various routing algorithms using mobility models such as the RWP and MM. Recently there is an ever-increasing interest in using other patterns of mobility, including those considered a realistic mobility pattern. In this sense, the Time-variant Community Mobility Model (TVCM) [15] is a realistic model obtained from traces of wireless LAN (Local Area Network). The authors incorporate in these models two mobility characteristics: skewed location visiting preferences and periodical re-appearance. The TVCM includes communities that the mobile nodes are visited often. In our simulations we define two random communities in a MANET scenario. The simulation results are shown in Table 9, Table 10 and Table 11.

Table 9. TVCM Scenarios: *Delay* results.

	Delay(s) in low mobility conditions				**Delay(s) in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.0117	0.0132	0.0110	**0.0119**	0.0168	0.0193	0.0179	**0.0173**
3	0.0112	0.0125	0.0107	**0.0114**	0.0155	0.0178	0.0169	**0.0170**
4	0.0114	0.0129	0.0110	**0.0117**	0.0159	0.0175	0.0175	**0.0149**
5	0.0111	0.0125	0.0103	**0.0116**	0.0153	0.0182	0.0165	**0.0149**
6	0.0118	0.0137	0.0118	**0.0122**	0.0149	0.0162	0.0160	**0.0145**
7	0.0120	0.0142	0.0114	**0.0122**	0.0159	0.0183	0.0171	**0.0158**
8	0.0127	0.0148	0.0125	**0.0124**	0.0162	0.0190	0.0175	**0.0165**
9	0.0134	0.0149	0.0132	**0.0128**	0.0167	0.0202	0.0183	**0.0169**
10	0.0142	0.0164	0.0140	**0.0138**	0.0176	0.0206	0.0186	**0.0173**
11	0.0152	0.0174	0.0152	**0.0151**	0.0185	0.0217	0.0197	**0.0185**
12	0.0172	0.0194	0.0169	**0.0161**	0.0215	0.0238	0.0229	**0.0201**
13	0.0284	0.0282	0.0280	**0.0237**	0.0319	0.0323	0.0355	**0.0287**
14	0.0495	0.0522	0.0490	**0.0430**	0.0505	0.0548	0.0550	**0.0527**
15	0.0714	0.0729	0.0712	**0.0599**	0.0676	0.0717	0.0721	**0.0705**

Table 10. TVCM Scenarios: *PLR* results.

	***PLR* in low mobility conditions**				***PLR* in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.0035	0.0041	0.0033	**0.0040**	0.0090	0.0093	0.0087	**0.0090**
3	0.0026	0.0029	0.0024	**0.0025**	0.0060	0.0069	0.0061	**0.0066**
4	0.0022	0.0023	0.0019	**0.0021**	0.0052	0.0058	0.0055	**0.0058**
5	0.0018	0.0019	0.0014	**0.0018**	0.0049	0.0052	0.0055	**0.0051**
6	0.0018	0.0019	0.0016	**0.0018**	0.0047	0.0049	0.0057	**0.0048**
7	0.0019	0.0019	0.0015	**0.0017**	0.0048	0.0050	0.0056	**0.0049**
8	0.0023	0.0021	0.0021	**0.0019**	0.0050	0.0051	0.0056	**0.0052**
9	0.0021	0.0021	0.0019	**0.0016**	0.0049	0.0050	0.0061	**0.0047**
10	0.0018	0.0021	0.0014	**0.0017**	0.0047	0.0048	0.0057	**0.0045**
11	0.0037	0.0030	0.0025	**0.0024**	0.0063	0.0064	0.0074	**0.0056**
12	0.0057	0.0064	0.0051	**0.0048**	0.0106	0.0109	0.0115	**0.0090**
13	0.0159	0.0160	0.0154	**0.0125**	0.0191	0.0196	0.0226	**0.0180**
14	0.0316	0.0343	0.0298	**0.0265**	0.0344	0.0388	0.0377	**0.0387**
15	0.0552	0.0583	0.0541	**0.0482**	0.0552	0.0619	0.0584	**0.0633**

Table 11. TVCM Scenarios: *NRO* results.

	***NRO* in low mobility conditions**				***NRO* in high mobility conditions**			
Np	RMD	REA	ADD	**SF**	RMD	REA	ADD	**SF**
2	0.3140	0.2286	0.3227	**0.2186**	0.5449	0.4841	0.5504	**0.4378**
3	0.2180	0.1576	0.2262	**0.1337**	0.3691	0.3251	0.3660	**0.2960**
4	0.1701	0.1176	0.1705	**0.1023**	0.2866	0.2479	0.2856	**0.2320**
5	0.1348	0.0961	0.1353	**0.0837**	0.2377	0.2016	0.2414	**0.1870**
6	0.1198	0.0829	0.1232	**0.0736**	0.1983	0.1665	0.1985	**0.1582**
7	0.1125	0.0746	0.1135	**0.0669**	0.1814	0.1498	0.1843	**0.1413**
8	0.1105	0.0709	0.1144	**0.0649**	0.1727	0.1355	0.1749	**0.1315**
9	0.1019	0.0656	0.1029	**0.0599**	0.1566	0.1244	0.1599	**0.1188**
10	0.0845	0.0566	0.0859	**0.0514**	0.1408	0.1122	0.1446	**0.1066**
11	0.0970	0.0671	0.0934	**0.0543**	0.1440	0.1177	0.1458	**0.1109**
12	0.1234	0.0970	0.1230	**0.0775**	0.1730	0.1460	0.1755	**0.1372**
13	0.2051	0.1733	0.2028	**0.1371**	0.2430	0.2090	0.2572	**0.2008**
14	0.3289	0.3004	0.3267	**0.2430**	0.3526	0.3425	0.3635	**0.3446**
15	0.4687	0.4448	0.4708	**0.3698**	0.4686	0.4700	0.4790	**0.4746**

This type of movement presents results intermediate between the RWP and Manhattan models. *Delay* is similar to the RWP and *NRO* is the lowest of all. SF outperforms again to the other algorithms.

5. CONCLUSIONS

Interconnection of MANET to IP-based access networks is supported by an Internet Gateway. The gateway announces itself with MRA messages proactively, reactively or in a hybrid scheme. This paper presents an algorithm to optimize the hybrid gateway discovery in

MANETs. The technique transfers the decision about retransmitting MRA messages to the nodes in the MANET. Basically, zones with unstable but employed routes to the Internet Gateway are prone to receive the MRA messages while in stable zones the overhead originated by MRA messages are avoided. The evaluation of the algorithm shows the goodness of the proposal. The simulations were performed with various types of movements including synthetic and realistic mobility models.

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