Connectivity Gateway Discovery in MANETs

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Abstract. The integration of mobile ad hoc networks into IP-based access networks demands the presence of a gateway which is responsible for propagating some configuration parameters by means of Modified Router Advertisement (MRA) messages. This function may be accomplished on demand by the mobile nodes (reactively), periodically activated by the gateway (proactively) or by combining the two approaches. In the proactive mechanisms, the interval of emission of the MRA messages (T) may significantly affect the network performance. The optimum value for T depends on the network conditions such as the position of the sources, the mobility of nodes, etc. Therefore, an autonomous and adaptive technique to dynamically configure T is strongly recommended. In this sense, a new adaptive gateway discovery mechanism is proposed in this paper. The adaptation is achieved by a control system which has been conveniently configured by means of an analytical model. Simulation results show that the proposed adaptive mechanism improves the conventional proactive schemes.

Keywords: Ad-hoc networks, hybrid networks, Gateway interconection.

1 Introduction

The use of wireless access to connect to external networks such as the Internet is a key issue for the ubiquitous computing paradigm. Under some specific geographical constraints, the deployment of a wireless infrastructure that guarantees the mobile nodes acces within a particular area is economically unfeasible. In

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these cases, the wireless networks could benefit from Mobile Ad Hoc NETwork (MANET) technology to reduce the costs related to the deployed equipment. Specifically, the use of multihop communications easily eliminates the existence of dead zones in wireless networks as well as it helps to extend the coverage area of GGSNs (Gateway GPRS Support Node) in the UMTS (Universal Mobile Telecommunications System). However, the use of MANET in this context prompts several technological challenges that need to be overcome. Concerning the architecture, the infrastructured networks offer an Access Router (or a GGSN in the UMTS), which provides the link to external hosts. In an IPv6 context, the Access Router periodically announces Router Advertisement (RA) messages which contain some configuration parameters such as the prefix information in order to allow mobile nodes to construct their own global IPv6 addresses [1]. These messages are generated with link-local addresses and therefore cannot be forwarded [2]. If only conventional Access Routers are used to connect MANET to the Internet, nodes placed outside the coverage area of the Access Routers will not obtain these configuration parameters and, consequently, will not be able to autoconfigure their own IPv6 addresses. This drawback is overcome by incorporating a gateway which is connected to the Access Router. Although the characteristics of the gateway differ in the proposed mechanisms, the most popular integration supports for Internet connectivity consider that the Access Router's firmware is customized to incorporate the gateway functionalities [3] [4]. In this sense, the gateway executes two main tasks. Firstly, it provides the ad hoc routing capabilities that are absent in conventional Access Routers so downlink traffic can be conveniently re-routed. On the other hand, the gateway generates 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 autoconfigure their own IPv6 addresses to be globally reachable by any terminal in the Internet.

In the global connectivity support [3], the emission of MRA messages could be accomplished by three different strategies. As in the case of ad hoc route discovery, the Internet gateway could disseminate this message periodically, i.e. proactively. On the other hand, in the reactive scheme MRA messages are generated only on-demand when the Internet gateway receives a Modified Router Solicitation (MRS) message emitted by an ad hoc node requiring a route to the Internet. The MRS could also be generated by mobile devices when either the information related to proactive MRA messages or the route established by their reception become invalid. Finally, the hybrid approach combines the previous techniques. MRA messages are broadcast in an area close to the Internet Gateway while the devices located outside this zone demand the MRA information by generating MRS messages [5].

In this paper we will focus on the proactive gateway discovery. Under this scheme, when a mobile node receives the MRA message, it updates the route entry to the gateway and then, rebroadcasts the advertisement message. As all nodes update their tables, nodes do not require to wait for a response to an MRS message to start communicating with any external destination node. The parameter T or the frequency with which MRA messages are generated by the Internet gateway clearly affects the network performance. A low T value could unnecessarily consume the limited MANET resources such as power and bandwidth. On the other hand, a high T value could lead to the storage of stale routing information in the nodes so when they route packets to the gateway, packets losses may result and nodes are obliged to send an MRS message in order to get a correct route to the gateway. Thus, the advertisement period must be carefully selected in order to prevent the MANET from being gratuitously flooded with control packets (MRA or MRS messages) .

The aim of this paper is to present and evaluate an algorithm to automatically adapt the T parameter to the network conditions so that network performance is improved. Thus, the goal is to decrease control traffic without increasing loss nor delay of the user's packets. Our proposed algorithm is based on the estimation of the network connectivity from the percentage of nodes located in the transmission range of the gateway. In this sense, when there is a large number of neighbours, we assume that shorter routes are required for external communications. As shorter routes are usually associated to longer lifetimes, the routes could be updated less frequently, that is, the T could be set to a higher value [6]. The proposed tuning technique is supported by a control system which is configured by means of statistical properties regardless of the future location of the gateway or the topologies of the MANET.

The rest of this paper is organized as follows. In Section 2, we present the related work. Section 3 describes the proposed adaptive gateway discovery mechanism. A Simulation environment and results are presented in Section 4. Finally, conclusions are drawn in Section 5.

2 Related Work

The related work has been divided in two parts. The first part concerns some other adaptive algorithms presented in the related literature. The second section describes the model mobility patterns that will be employed in the simulations.

2.1 Adaptive Gateway Discovery Schemes

In gateway discovery mechanisms, the reception of MRA messages allows the stateless address configuration as well as the update of the routes to external hosts. In proactive schemes, the reception depends on the interval of emission of MRA messages (T). Additionally, in the hybrid gateway discovery mechanisms, the zone around the Gateway where these messages are proactively propagated, defined by the TTL (Time to Live) value, also determines which nodes receive the MRA messages. The optimum value of these two parameters clearly depends on the network conditions such as the position of the sources, the number of sources or the mobility conditions. Therefore, the TTL and the T values should be set according to the network conditions. As nodes in MANETs can move arbitrarily, the network conditions frequently vary so some algorithms have been proposed to dynamically set these two parameters.

Concerning the adjustment of the TTL value, one of the first adaptive algorithms was the Maximal Source Coverage (MSC)[7]. According to this proposal, the T is set to a fixed value. Meanwhile the gateway will send out the next advertisement message with the TTL equal to the minimum number of hops required to reach all of the sources that use this gateway to communicate with external hosts.

The optimization of the timing of MRA messages (set with the T parameter) was studied in [8]. In this approach, the authors suggest that 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). When 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.

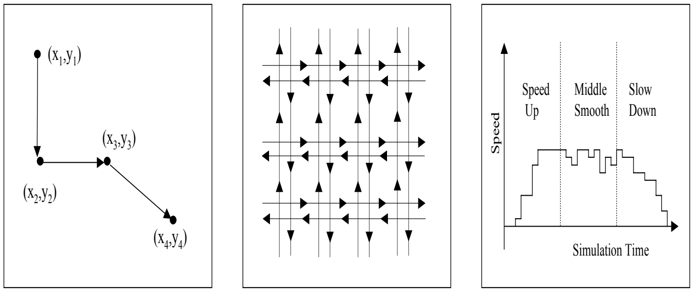
In [9], the authors suggest the use of an auto-regressive filter to simultaneously adjust the T and its TTL value. To do so, the authors recommend monitoring the traffic load in Internet gateways so that the T and TTL can be conviently set using a feedback controller. The proposed tuning is based on 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.

Another proposal to adapt the interval of emission of MRA messages is presented in [10]. In this proposal, the parameter T is dynamically tuned by means of estimating the number of reactive route solicitations that the nodes emit in a given time interval. With this purpose, the authors use an auto-regressive filter for the estimation. Although the proposal outperforms conventional proactive schemes in scenarios characterized by a low mobility, the benefits decrease when the network load increases and when the nodes speed increases.

In our proposal, the adjustment is based on the number of MRA messages retransmitted by the gateway neighbours. This parameter is assumed to be associated to the percentage of nodes that are close to the gateway and, therefore, have shorter routes for their external communications. Shorter routes are expected to have longer lifetimes [6] so their routes to the gateway do not need to be frequently updated. This indirect measurement of the network connectivity is employed to set the T parameter. So, if the network has a high connectivity, T can be increased. Initial results with this scheme were presented in [11].

2.2 Mobility Patterns

The performance evaluation of adaptive algorithms is usually carried out with just one type of scenario and one mobility pattern. The scenario is usually rectangular while the Random WayPoint Model (RWP) [12] is massively used as mobility pattern [10][11][13] . One of our goals was to verify if our proposed algorithm was able to reasonably adjust the T parameter under other mobility



a) Random WayPoint Model b) Manhattan Mobility Model c) Smooth Mobility Model

Fig. 1. Mobility Patterns

conditions. With this purpose, in addition to the well-known RWP, the analysis of the proposed algorithm uses other two mobility models: the Manhattan Mobility Model [14] and the Smooth Mobillity Model [15]. The mobility patterns employed are briefly described in the following sections and some properties of them are depicted in Fig. 1.

Random Waypoint Model (RWP). The Random Waypoint model is commonly employed 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 [16].

Manhattan Mobility Model (MH). The Manhattan model emulates the movement of automobiles on streets defined by a rectangular grid-type map [14]. It can be useful in modeling 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 temporal 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 directions.

Smooth Mobility Model (SM). In [15] the authors define one movement as an entire motion from the time that a node starts to the moment when it stops moving. Based on the physical law of a smooth motion, a movement in the smooth model contains three consecutive moving phases: Speed Up phase, Middle Smooth phase, and Slow Down phase.

The parameters that we have employed in the different scenarios are the same as those defined in [15]: the time slot Δt of each step is set to 1 second, the memory parameter ζ is equal to 0.5, and the range of each moving phase duration time is set to [6, 30] seconds.

3 Proposal for Adaptive Gateway Discovery

In the proposals of proactive gateway discovery schemes, the interval of emission of MRA messages (T) is fixed to a constant value. However, as it has been remarked, the optimum value of T depends on the network conditions such as the load, the node mobility, the number of traffic sources, etc. This dependence is shown in Fig. 2 where the normalized routing overhead, that is, the number of control packets required to receive a data packet, is computed for different T values and for the scenarios A and B described in Table 1. Figure 2 shows that for low values of T, the MRA messages are gratuitously emitted as they are not employed to update the routes. On the other hand, when T is set to a high value, the mechanism behaves as a reactive gateway discovery scheme and, in some cases, the proactive gateway discovery outperforms the reactive ones. The graphic proves that there is an optimum value for T but it also illustrates that this value depends on the characteristics of the network. Specifically, for scenario A, the optimum T value corresponds to 7 seconds while for scenario B, the optimum T value is 17 seconds.

Figure 2 confirms the need for developing an algorithm that enables the gateway to dynamically set T to the optimum value. In our proposal, the gateway adjusts T taking into account the number of received MRA messages which are

Table 1. Simulation parameters

	Common Parameters
Simulation Area	1500 x 300 m^2
Mobility Pattern	Random WayPoint Model
Gateway	One in the center
Traffic	10 Constant Bit Rate sources
Rate	15 packet/s
	Scenario A
Maximum speed	5 m/s
Minimum speed	1 m/s
	Scenario B
Maximum speed	2 m/s
Minimum speed	1 m/s

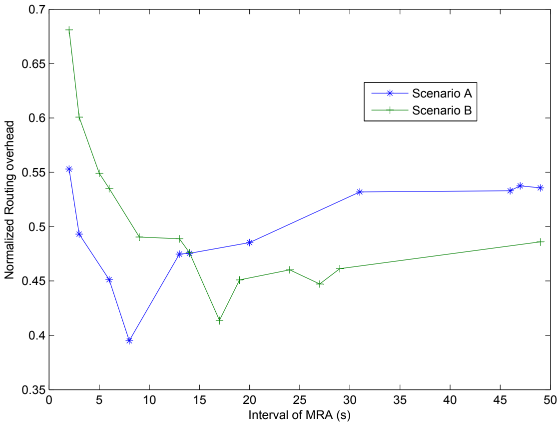


Fig. 2. Optimum T values for different Scenarios

retransmitted by its neighbours. This measurement provides an evidence of the network connectivity. In other words, when the gateway receives many MRA messages from its neighbours, it means that all these nodes have appropriately updated the routing entry to the gateway. Additionally, when the number of neighbours is high, we may assume that most routes to external hosts are composed of a low number of hops. This characteristic could lead to routes with a longer lifetime [6]. Under these circumstances, the routes do not need to be frequently updated so T could be incremented. On the other hand, when the gateway receives few MRA messages from its neighbours, it should decrease T to guarantee that nodes keep a valid route to the gateway when they require connection to the Internet. In order to determine the optimum T value as a function of the number of received MRA messages, we have employed the control system function shown in Fig. 3. The number of MRA messages received by the gateway is the input of this function while T is its output. The measurement of the number of received MRA messages will be carried out throughout T. The message count is carried out in a simple way: when the gateway sends an MRA message, it counts the number of copies of the recently generated MRA message during the next second. If no MRA message is received, the gateway sends the message again.

In this control system, we have adopted a linear relationship between the number of received MRA messages and the optimum T value. The decision to employ this function was based on the extensive simulations conducted, and the results of these simulations are presented in Fig. 4. The parameters of these simulations are similar to the Table 1. The plot shows the number of received MRA message versus the number of gateway neighbours. Although a percentage of the MRA messages is lost due to the interferences and collisions, the relationship between these variables can be considered linear.

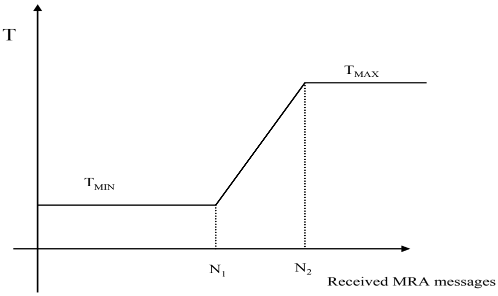


Fig. 3. Output function of the control system

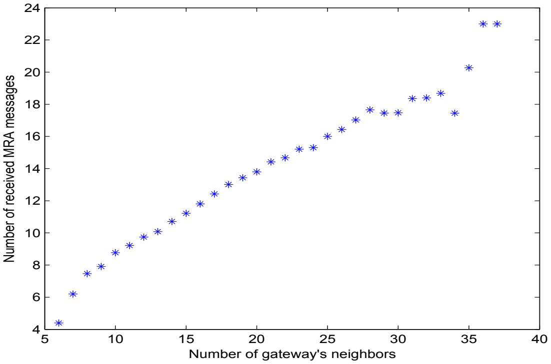


Fig. 4. The number of received MRA messages versus the number of gateway neighbours

In order to conveniently set the parameters N_1 and N_2 in the control system, the probability p that a node is located in the coverage area of the gateway is obtained. The gateway can always compute this probability regardless of the mobility model chosen. The probability may depend on a variety of factors including the number of mobile nodes, the topology or even the gateway location. Once the expression of p is obtained, the probability that there are n nodes in the coverage area can be computed as:

$$g(n) = \binom{N}{n} p^n (1-p)^{N-n} \tag{1}$$

It is a binomial distribution where N is the total number of mobile nodes in the MANET. In some integration supports such as the popular Global Connectivity [3], the gateway implements additional functionalities based on the registration that the mobile node performs when it enters the MANET. Under these circumstances, the gateway can easily know the number of nodes that form

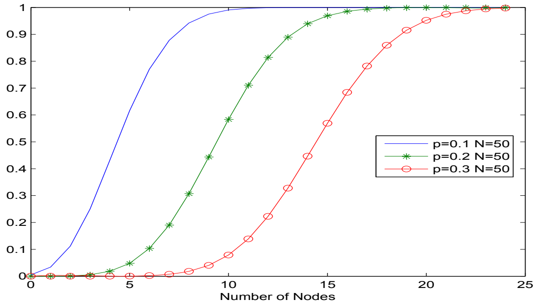


Fig. 5. Cumulative distribution function of the number of nodes that are the gateway neighbours

the MANET. If N is known, the p value can be obtained from the average value of the MRA messages received.

We can obtain the cumulative density function of g(n), that is, G(n) as shown in Fig. 5 with several p values. The values of N_1 and N_2 have been chosen from the linear zone of *G(n)*. N_2 will be set to the mean number of MRA messages received and N_1 the mean divided by 4. Thus the values of N_1 and N_2 are dynamic and change whenever an MRA message is sent by the gateway. By choosing N_2 as the average of the MRA messages received, we do not need to know the value of either N or p, and the algorithm adapts to changes in the number of active nodes or speed.

Concerning the limits of the T values, the standard value of 2 seconds has been chosen for T_{min} while the value of 20 seconds has been chosen for T_{max}. As shown in Fig. 2, when the T value outlasts 20 seconds, the normalized overhead is kept constant as the gateway discovery algorithm basically behaves as a reactive scheme.

4 Performance Evaluation

Due to the difficulties associated to real tests, the benefits of the adaptive gateway discovery have been verified by the use of simulations. In this sense, it was necessary to develop a software module that includes the algorithm in the Global Connectivity support [3]. This module has been integrated into the open source Network Simulator tool, ns-2.29 on a Linux machine [17]. Three different simulation settings, each one with a different mobility pattern, are defined and used in order to evaluate the performance of our proposal. In spite of this, there are several common parameters for the three simulations, presented in Table 2.

4.1 Scenarios

In order to evaluate the ability of the proposed algorithm to adjust the T parameter to the network conditions in a variety of scenarios, the simulations have been

Table 2. Common Simulation parameters

Transmision range	250 m
Ad hoc Protocol	AODV (Ad Hoc On Demand Distance Vector Routing) Local repair disabled
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	10 sources Rate: 15 packet/s

Table 3. Features of the Simulation Scenarios

Parameters	**SCENARIO I**	**SCENARIO II**	**SCENARIO III**
Simulation Area	1500 x 300 m^2	600 x 600 m^2	2500 x 500 m^2
Number of Nodes	50	75	100
Gateways Location	(750,150) m	(0,0) (600,600) m	(625,250) m (1875,250) m

implemented in three different environments, each one with a different density of nodes, surface and gateway position. The characteristics are shown in Table 3:

- Scenario I. The first of the environments is a rectangular area with the gateway located in the center of the topology.
- Scenario II. The second environment is a square area. There are two gateways located in opposite corners of the square.
- Scenario III. The last one is wide rectangular area. There are also two gateways.

4.2 Results

In this section, we present simulation results based on our Adaptive Gateway algorithm (AGW), and compare them to the MSC and the RMD described in Section 2.1. RMD parameters are set equal to the reference [8].

The simulation time is 500 seconds, according with [18]. Since we are interested in studying the behavior of MANET in a steady state, the first 50 seconds of the simulation are considered a warm-up period and they are not computed in the analysis.

The algorithms are tested using the following metrics::

- Packet Loss Rate (PLR). Packet loss rate 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.

- The Normalized Routing Overhead (NRO). Defined as the total number of control packets divided by the total number of received packets. For this computation, each hop that a control packet makes is considered a new control packet.

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

The results are summarized in the following tables. The values correspond to the average measurements computed from 26 simulations. The improvement has been measured as (2). This parameter gives us an idea about the efficiency of our algorithm, with its value over 5% in almost all cases.

$$Improvement = 100\left[1 - \frac{NRO(AGW)}{min(NRO(AGW), NRO(MSC))}\right] \tag{2}$$

Table 4 shows the results when the RWP model is employed. The worst delay is obtained for the scenario II due to the position of the gateway at the corners and because the nodes are prone to concentrate in the center in the RWP [19], which means a greater number of hops are required to reach the gateway. Our proposed scheme, the AGW, always obtains better results for the three metrics used.

Table 5 illustrates the results associated to the MH model. Now delays in scenarios I and II are similar, but the third one is related to the lowest Delay. The PLR and NRO decrease from the scenario I to III. Based on these three metrics, the AGW is again better.

Table 6 shows the results obtained with the SM model. The three metrics decrease from scenario I, with the highest values to the third scenario, where the worst performance is achieved. Again, AGW outperforms the other algorithms.

For all movements, the PLR is greater in the first scenario even if just one gateway exists. In this scenario, in terms of NRO the mobility pattern that

Table 4. Results with the RWP model

RWP		SCENARIO I		SCENARIO II		SCENARIO III	
		Max Speed (m/s)		Max Speed (m/s)		Max Speed (m/s)	
Metric	T	2	5	2	5	2	5
Delay (s)	RMD	0.0738	0.0862	0.1745	0.3367	0.0309	0.0377
	MSC	0.0689	0.0858	0.1252	0.2820	0.0303	0.0346
	AGW	**0.0686**	**0.0800**	**0.1069**	**0.1756**	**0.0254**	**0.0274**
PLR	RMD	0.0507	0.0650	0.0179	0.0459	0.0096	0.0120
	MSC	0.0524	0.0629	0.0278	0.0529	0.0106	0.0129
	AGW	**0.0472**	**0.0862**	**0.0153**	**0.0243**	**0.0057**	**0.0075**
NRO	RMD	0.3852	0.5163	0.1659	0.2592	0.1427	0.2185
	MSC	0.3928	0.4827	0.1678	0.2645	0.1484	0.2252
	AGW	**0.3604**	**0.4539**	**0.1548**	**0.2458**	**0.1333**	**0.2017**
	Improv. (%)	**6.44**	**5.97**	**6.69**	**5.17**	**6.59**	**7.69**

Table 5. Results with the MH model

MH		SCENARIO I Max Speed (m/s)		SCENARIO II Max Speed (m/s)		SCENARIO III Max Speed (m/s)	
Metric	T	2	5	2	5	2	5
Delay (s)	RMD	0.0782	0.1547	0.0725	0.0860	0.0216	0.0329
	MSC	0.0763	0.1538	0.0659	0.0797	0.0211	0.0316
	AGW	**0.0695**	**0.1535**	**0.0543**	**0.0701**	**0.0194**	**0.0274**
PLR	RMD	0.0627	0.0903	0.0137	0.0216	0.0022	0.0053
	MSC	0.0632	0.0908	0.0142	0.0216	0.0023	0.0056
	AGW	**0.0571**	**0.0864**	**0.0111**	**0.0201**	**0.0019**	**0.0047**
NRO	RMD	0.27	0.6180	0.1435	0.2062	0.0681	0.1204
	MSC	0.3	0.6293	0.1527	0.2095	0.0736	0.1268
	AGW	**0.2461**	**0.579**	**0.1355**	**0.198**	**0.0615**	**0.1143**
	Improv. (%)	**8.85**	**7.99**	**5.57**	**3.98**	**9.69**	**5.07**

Table 6. Results with the SM model

SM		SCENARIO I Max Speed (m/s)		SCENARIO II Max Speed (m/s)		SCENARIO III Max Speed (m/s)	
Metric	T	2	5	2	5	2	5
Delay (s)	RMD	0.1523	0.2350	0.0861	0.1603	0.0230	0.0247
	MSC	0.1485	0.2308	0.0822	0.1381	0.0200	0.0238
	AGW	**0.1464**	**0.2307**	**0.0588**	**0.0983**	**0.0197**	**0.0231**
PLR	RMD	0.0857	0.1288	0.0160	0.0368	0.0013	0.0018
	MSC	0.0862	0.1289	0.0167	0.0349	0.0018	0.0035
	AGW	**0.0827**	**0.1289**	0.0122	0.0283	**0.0010**	**0.0016**
NRO	RMD	0.6121	0.8503	0.1155	0.1885	0.0476	0.0781
	MSC	0.6132	0.8503	0.1285	0.1959	0.0904	0.1429
	AGW	**0.5761**	**0.7975**	**0.1089**	**0.18**	**0.0417**	**0.073**
	Improv. (%)	**5.88**	**6.21**	**5.71**	**4.51**	**12.39**	**6.53**

offers the best features is the MH while the SM provides the worst performance. For scenarios II and III, NRO is the best when the SM is used to model node mobility.

The comparison between the RMD and MSC algorithms illustrates that the RMD scheme is better regarding PLR and NRO, but not in the Delay metric. However, Delay, PLR and the NRO are always improved when the proposed adaptive discovery scheme is employed as shown in Table 4 , Table 5 and Table 6.

5 Conclusions

This paper presents a new method to optimize the process that enables Internet connectivity in multi-hop ad hoc networks. The optimization minimizes the control overhead by dynamically tuning the interval of emission of MRA messages (T) as a function of network connectivity. For this purpose, the algorithm estimates the network connectivity by means of the number of MRA messages received. The algorithm outperforms other schemes regardless of the node speed, the location of the gateways and the mobility patterns. The reduction of the overhead is a very desirable characteristic in mobile ad hoc networks because of node limitations regarding battery resources.

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