Adaptive Gateway Discovery in Hybrid MANETs

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***Abstract*—Gateway Discovery in Internet-connected MANETs allows the stateless address configuration as well as the update of the routes to external hosts. Similar to conventional ad hoc route discovery, this procedure could be accomplished employing three different methodologies: proactive, reactive and hybrid. In proactive gateway discovery, MRA messages are periodically sent each T_{MRA} interval. The election of T_{MRA} greatly influences the network performance (a low T_{MRA} could lead to unnecessary control packets meanwhile a high T_{MRA} could make nodes keep invalid routes to external hosts). The appropriate selection of T_{MRA} depends on the network conditions as the load, the node density or the node mobility. In order to automatically tune the T_{MRA} interval, in this work we present an algorithm for adaptive Gateway Discovery under the proactive scheme. The method allows optimizing the trade-off between experimented quality metrics offered by a MANET and the overhead of the original proactive algorithm.**

***Index Terms*—Mobile Ad Hoc Network, Gateway, Global Connectivity, Hybrid, Adaptive.**

I. INTRODUCTION

THE production of powerful mobile devices in conjunction with the extended use of some web services have prompted that Wireless Mesh Networks (WMN) are receiving significant attention nowadays. They consist of a set of installed and static access routers that provide multi-hop communication in their corresponding domains. Under this scheme, wireless devices can be easily interconnected to external hosts in the Internet.

For a further analysis of this sort of networks, they can be simplified into the union of multiple hybrid Mobile Ad hoc NETworks (MANET). To obtain connected ad hoc networks (or hybrid MANETs), it is necessary to introduce an access router that provides the link to external hosts. The characteristics of this access router differ in the proposed mechanisms. The most popular integration supports consider that specific access router that allows multi-hop communications should be installed in the areas where MANETs are expected to operate. Under this scheme, the access router is incorporated with extra functionalities so it behaves as an Internet Gateway.

The Internet Gateway announces the prefix information it processes by the emission of Modified Router Advertisement or MRA messages [1]. These messages provide the necessary information for stateless address configuration as well as for the activation of the Mobile IP technology [2] [3] [4].

The emission of MRA messages could be accomplished by three different strategies. As ad hoc route discovery, the Internet Gateway could broadcast this message periodically, i.e. proactively. On the other hand, in the reactive scheme the messages are generated only on-demand when the Internet Gateway receives Modified Router Solicitation (MRS) messages. The MRS could be also generated by mobile devices when the information related to proactive MRA messages or the route established by their reception become invalid. Finally, the hybrid approach combines the previous techniques as MRA messages are broadcasted in an area close to the Internet Gateway meanwhile the devices located out of this zone demand the MRA information by the generation of MRS messages.

In high-loaded scenarios, the proactive strategy outperforms. However, the performance of the network clearly depends on the interval of emission of MRA messages (the T_{MRA} interval). It seems appropriate to consider the T_{MRA} tuning in order to adapt it to several factors as the node mobility, the load or the node density so a better network performance could be achieved. In this paper, we propose a simple algorithm to adapt the T_{MRA} to the network conditions in order to minimise the load while maintaining and/or improving the network performance.

The rest of this paper is organised as follows. In section II, the related work is presented. Section III describes the proposed adaptive gateway discovery procedure. Section IV shows the simulation results aimed at evaluating the benefits of the proposal. Finally, section V concludes the paper.

II. RELATED WORK

Some of the previous works analyze the advantages and disadvantages of the three schemes (reactive, proactive, hybrid) for Gateway discovery in MANET. In these studies a constant value of the T_{MRA} is considered.

In [5] and in [6] M. Ghassemian et al. showed that the proactive policy offers a better quality of service in almost all scenarios. These studies verify that the underperformance of the reactive solution is especially notable as the mobility increases (or the link duration decreases) because the route re-

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solicitation becomes a very inefficient method in the situations where many link breaks occur. Nevertheless, the comparison results also indicate that the benefits of proactive discovery are achieved at the cost of augmenting the signaling overhead due to the broadcasted periodical advertisements of the gateways.

Although the scheme to detect gateways was initially evaluated under proactive and reactive methods, a hybrid method for this mechanism has also been studied by other authors. As instance, authors in [7] suggest fixing a maximum value for the numbers of hops (TTL or Time To Live) that the proactive gateways messages can move through the MANET. So, if a node wishing to connect to the Internet resides outside this range around the gateway, it will activate the reactive procedure. For the hybrid Gateway Discovery, some authors propose the analysis of the TTL value of MRA messages [8], in this technique is improved by dynamically adapting the maximum value of the TTL to the particular traffic conditions in the network. With this study, the proposed algorithms adapt the MRA messages to the zone where Internet connected nodes concentrate.

In [9], the authors propose the utilization of an auto-regressive filter for the adjustment of T_{MRA} and their TTL value simultaneously. The proposed tuning is based on the changes of link stability, the traffic rate and the received MRS. However, no specific formulation is presented and no evaluation is shown. The utilization of auto-regressive filters in MANET has also been suggested for different adaptation in [10, 11].

In our proposal, the T_{MRA} is adapted by an auto-regressive filter which employs the count of the received MRS messages

III. PROPOSED ADAPTIVE GATEWAY SCHEME

The aim of this proposal is to adapt the interval of emission of MRA messages to the mobility and traffic conditions of the mobile ad hoc network so lower overhead is obtained while the losses do not increase. This scheme is based on the number of Modified Router Solicitation (MRS) messages generated by the mobile nodes in an interval of time called the MRS_COUNT_INTERVAL or T_{MRS}. The number of received MRS messages indicates the mobility and the necessity of update the routes to the Internet. We assume that all solicitation messages are forwarded to the Internet Gateway and no intermediate node that receives the requests replies on behalf of the Internet Gateway.

In this scheme, we estimate the expected behaviour of mobile nodes when they send the MRS messages, that is, we try to predict how many requests are expected to be received by the Internet Gateway in the next T_{MRS} interval. This decision is taken basing on the information about how the network is behaving at the present time and how it has behaved in last states.

Formally, a linear prediction is performed from a series of statistical captured parameters of the network in real time. Thus, a temporary sequence is created dynamically. Let *s[1],s[2],…, s[N]*, where *s[i]* denotes the number of MRS messages received by the Internet Gateway in interval *i* and $1 \le i \le N$. This sequence can be modelled as an auto-regressive process of *p*-th order as follows [12], [13] [14]:

$$\hat{s}^{(n)}[n] = -a_1^{(n)}s[n-1] - a_2^{(n)}s[n-2] - a_3^{(n)}s[n-3] - \ldots - a_p^{(n)}s[n-p] + q^{(n)}[n]$$

(Eq. 1)

where $p+1 \le \mathbf{n} \le N$ and *q[n]* is a white noise process. The prediction error is computed as:

$$e^{(n)}[n] = s^{(n)}[n] - \hat{s}^{(n)}[n]$$

(Eq. 2)

Utilizing this model, the information is estimated in the time *n* from the previous samples extracted from earlier states. In particular, we present real time estimation scheme based on a first order autoregressive model (AR), referred to as the AR-1. This model is sufficiently simple so it could be easily integrated into the network's nodes behaviour. However, the utilization of a higher order AR model can cause divergence problems under some circumstances because of the general statistical instabilities introduced by a larger order [14]. At this moment, it is worth emphasizing that we do not pretend to predict the exact value of the number of MRS messages that will be emitted during a certain interval, but whether certain previously established levels will be surpassed or not. This fact will indicate if the gateway must emit messages MRA more frequently to facilitate the transit of the packages sent by the nodes of the MANET towards outside hosts. Another intrinsic advantage that the autoregressive model of the samples presents is that the optimal parameters of the model can be obtained by means of the use of the equations of Yule Walker basing on the minimization of the average quadratic error [12][13][14]. In a AR(*p*) process, the autocorrelation sequence *{R(n)s(m)}* is related to the coefficients *{a(n)p (k)}* by means of the equations of Yule Walker given by:

$$Rs^{(n)}(m) = -\sum_{k=1}^{p} a_p^{(n)}(k)\, Rs^{(n)}(m-k)$$

(Eq. 3)

where m= 1,2,…,p.

In an AR model coefficient can be computed from:

$$a_1^{(n)} = -\frac{Rs^{(n)}(1)}{Rs^{(n)}(0)}$$

(Eq. 4)

If we had decided on filters of greater order, the coefficients by means of the algorithm of Levinson-Durbin would have been obtained in a similar way.

As it is observed in Equation 4, the computation of the coefficient implies to perform a good estimation of the autocorrelations *Rs(n)(0)* and *Rs(n)(1)*. In order to obtain good estimated coefficients, we chose the insesgated estimator defined in [13, 15].Then the autocorrelation coefficient can be computed as:

$$\hat{R}_s^{(n)}(m) = \frac{1}{N-m}\sum_{n=0}^{N-m-1} s^*[n]s[n+m] \qquad \text{(Eq. 5)}$$

where $m = 0,1,\ldots,N-1$ and $s[i]$ represents the number of MRS messages received in the i-th interval.

In order to have an adequate estimation of the coefficient, the system must wait during a certain number of intervals of fixed duration (MRS_COUNT_INTERVAL) so that several statistical data are captured. This time is denominated training time.

Figure 1 represents the flow diagram of our proposed algorithm. As it is shown, after the training period, we will begin to count the number of messages MRS in each MRS_COUNT_INTERVAL. Each count will happen to be a statistical sample, with which the temporary series will be updated dynamically to estimate the autocorrelations coefficients. With these coefficients, we are able to obtain the prediction coefficient and therefore we will characterise the AR(1) filter. When the AR(1) filter is computed, it is possible to verify the stability conditions that ensure an adequate utilization of the filter. In order to carry out this verification, the theory presented in [12][13][14] can be employed. If these conditions are fulfilled, we can perform the lineal prediction of messages number that is expected to be received in the following interval. This prediction is stored during a MRS_COUNT_INTERVAL to calculate the prediction error at the moment in which we know the real value of route requests towards gateway once the analysed interval is over. After the prediction, a comparison could be made to verify the asymptotic tendency of the predicted error sent by the nodes of the MANET.

In our proposal, we consider that when the number of received MRS messages is approximately negligible in comparison to the number of sent data packets, the period of emission of MRA messages (T_{MRA}) must be high taking a continuous value ($T_{MRA} \in$ [8-18] s) , since there are available valid routes to the gateway at that moment. On the other hand, if numerous MRS messages are being sent, the T_{MRA} must be the minimum. In our case, the minimum TMRA is established in 2 s.

Finally, in case that the computation of MRS messages results in an average result, the ADVERTISEMENT_INTERVAL also will be fixed to an average value, with two possible intervals ($T_{MRA} \in$ [2-4] s or TMRA $\in$ [4-8] s).

After fixing the T_{MRA} to a certain value, a new interval MRS_COUNT_INTERVAL must be occurred to perform a new prediction.

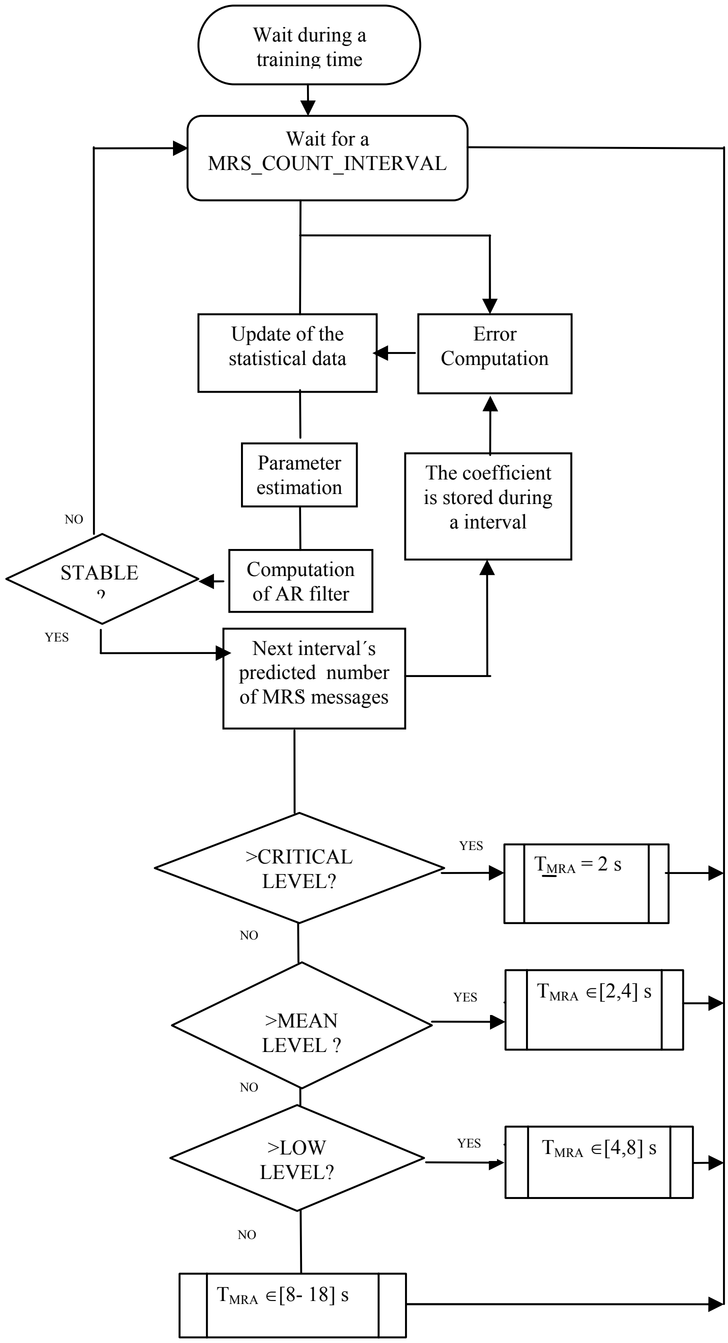

Figure 1. Flow diagram of proposed algorithm

IV. SIMULATION RESULTS

Due to the difficulties associated to real tests, the improvements of adaptive 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 [15]. This module has been integrated into the Network Simulator tool, ns-2.30 on Linux [16].

The simulation scenarios consider a 1500 m x 300 m area where the access router is located in the center. The ad hoc network is formed by 50 mobile nodes whose movements are based on the commonly used Modified Random Way-Point model [17]. To evaluate different mobility scenarios, we have varied the maximum speed as shown in Table 1. In order to reach stability in the results, nodes movements are initiated with the Michigan Distribution Function [17].

Table 1 summarizes the set of parameters considered in the simulations.

As recommended in [18], below metrics were used for the performance analysis of the proposed mechanism:

- PDR (Packet Delivery Ratio): It is defined as the proportion between the received data packets and the originated ones by the sources.
- End-To-End Delay. It represents the average value of the time the received data packets take to reach the destination from their origin. This parameter includes the time the nodes stay in the internal queues, the retransmissions at the MAC level, and the forwarding through multiple intermediate nodes.
- Normalized Overhead. It corresponds to the ratio between the total control packets and the received data packets. Each hop of the control packets is computed as a new control packet.

Table 1 Simulation parameters

Simulation Area	1500 m x 300 m
No. of Mobile nodes	50
Mobility pattern	Random WayPoint Model
Minimum speed	1 m/s
Maximum speed	Different cases are considered: 1, 2.5,5,7.5,10
Uplink Trafic pattern	10 CBR sources. Rate= 9 packets/s. Packet size= 512 Bytes
Simulation Time	2000 s
Transmission Range	250 m
Number of runs/ point	3
Ad hoc routing protocol	AODV
Link Level Layer	802.11b (CTS/RTS enabled)
Internal Node Queue	64 packets
MRA interval(for the non adaptive method)	2,4,8
Levels of adaptive proposed algorithm	CRITICAL_LEVEL= 200 MRS MEAN_LEVEL = 100 MRS LOW_LEVEL = 30 MRS

To facilitate the understanding and to show the general tendencies of proposed mechanism performance, the results of the different simulations have been also interpolated through a linear regression, resulting in the straight lines of the figures.

Figure 2 shows the packet delivery ratio with three cases with three different typical values for $T_{MRA..}$ As the figure shows, the packet delivery ratio decreases when T_{MRA} increases. The reason is that the short advertisement intervals result in more gateway information (RREP_I and MRA packets). When the advertisement interval increases, a mobile node receives less gateway information and consequently it does not update the route to the gateway as often as for short advertisement intervals. The figure also shows that when speed increases, PDR is decreased. It is observed that our adaptive mechanism reduces the losses of data packets due to the benefit of the prediction. The above mentioned improvement is done more notably to low speeds, due to the fact that the nodes change his position more slowly, with which the prediction is more reliable.

Figure 3 shows that the normalized overhead increases when T_{MRA} is short. The AODV normalized overhead is dominated by the periodically broadcasted MRS and MRA messages. The adaptive scheme outperforms in scenarios characterized by low speeds but the network performance degrades when the maximum speed of mobile devices decreases. This effect is due to the incapability of the proposed adaptive scheme to detect the cause of MRS messages. Basically, these messages can be generated in two main events. Firstly, MRS messages will be emitted when the stored route becomes invalid because of the mobility of the nodes. Under these circumstances, the decrement of T_{MRA} could lead to an improvement of the network performance as the routes are updated more frequently. However, MRS messages could also be generated by the nodes when they detect collisions in the transmission of the packets (The link layer detection mechanism in AODV). In this case, the mobile node assumes that the route is invalid and it consequently sends a MRS message to the Gateway even when the stored route is still valid. The gateway could decrement the T_{MRA} unnecessarily and, even worse, it would augment the load in the network and, as a consequence, the number of collisions as this parameter is usually proportional to the load. Therefore, the network performance degrades under these circumstances.

Figure 4 shows the behavior of the End-To-End Delay. It decreases with smaller intervals of $T_{MRA.}$ The reason is that the periodic gateway information sent by the gateways allows the mobile nodes to update their route entries for the gateways more often, resulting in fresher and shorter routes. It is observed that the adaptive mechanism reduces the delay because the nodes will have available routes towards gateway when they require them and when these routes are not necessary, the adaptive scheme will not contribute to saturate the network with unnecessary control packages

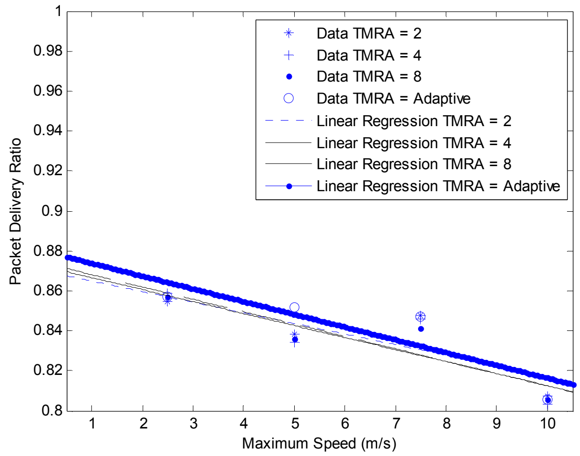

Figure 2. Packet Delivery Ratio versus Maximum Speed.

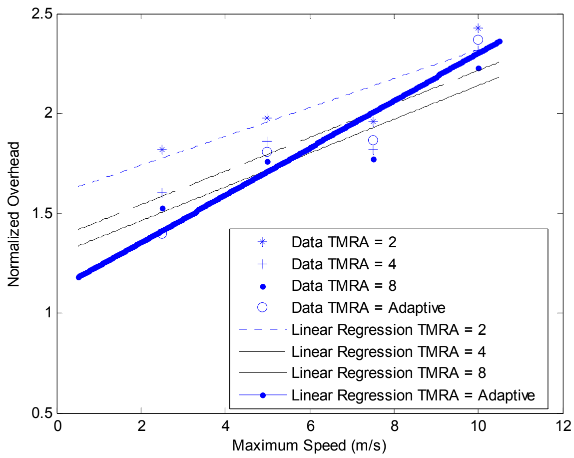

Figure 3. Normalized Overhead versus Maximum Speed.

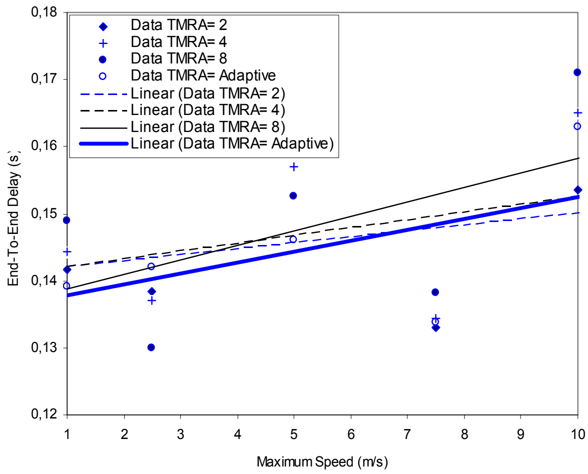

Figure 4. End-To-End Delay versus Maximum Speed.

Summarizing when contrasted with the case of a fixed timing, the results of our mechanism show its ability to reduce the losses and delay without augmenting the protocol overhead in scenarios characterized by a lower maximum speed.

V. CONCLUSIONS

This paper has presented a new method to optimize the process that enables the Internet connectivity in multi-hop Ad-hoc networks. In particular, the method has been applied to the mechanism of “Global Connectivity for IPv6 Mobile Ad Hoc Networks” in which the nodes conform their IP address basing on the prefix broadcasted by a specific entity which acts as a gateway between the MANET and the conventional Internet wireless Router. The gateway routes and centralizes all the downlink and uplink traffic between the Internet and the MANET.

The internal ad hoc routes to the gateway can be either reactively demanded by the nodes or proactively updated by means of Modified Router Advertisement messages that are periodically broadcasted from the gateway.

The suggested optimization method permits to adapt the proactive mechanism to the mobility conditions of the networks. This adjustment is performed as a function of the estimation of the reactive route solicitations from the nodes.

The benefits of the proposals have been evaluated for several simulated mobility scenarios. The adaptive method has been compared to the conventional non adaptive schemes for which the time between MRA messages is set to be constant. When contrasted with the case of a fixed timing, the results of our mechanism show its ability to reduce the losses and delay while reducing the protocol overhead

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