Performance Evaluation and Analytical Validation of Internet Gateway Discovery Approaches in MANET

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Abstract

The integration of MANET and Internet extends the network coverage and also increases the application domain of the MANET. The connection of ad hoc networks to the Internet is established via Internet gateways, which acts as a bridge between them. One of the key overhead components affecting the overall performance of this integration is the discovery and selection of Internet gateways as discovery time and handover delay have strong influence on packet delay and throughput. In this paper, the three Internet gateway discovery approaches have been implemented and then the impact of node mobility for two different cases have been examined in terms of performance metrics throughput, end-to-end-delay and routing overhead using network simulator NS2. Our simulation results reveal that the reactive Internet gateway discovery approach scale poorly with increase in number of traffic sources and node mobility to access Internet as compared to the proactive and hybrid gateway discovery approaches. However, reactive gateway discovery results higher throughput and lower end-to-end delay for the same situation than proactive and hybrid approaches. Hybrid Internet gateway discovery approach performance was always observed in between reactive and proactive approaches. The simulation results have also been analytically verified.

Keywords: *Mobile ad hoc network (MANET), Internet gateway discovery, Perormance analysis, AODV, NS2, Internet.*

1. Introduction

MANET applications need a connection to the world wide Internet [1]. For instance members of a conference, which have configured an ad hoc network to exchange information among each other, may need a connection to the Internet to download their emails. For such a scenario, integration of the Internet and the MANET is required. In order to realize such an interworking, an access point, i.e., Internet gateway, is required which has both wired and wireless interfaces. The challenge in interconnecting ad hoc networks to Internet stems from the need to inform ad hoc nodes about available Internet gateways while making a minimal consumption of the scarce network resources. So, an efficient Internet gateway discovery approach for ad hoc networks becomes one of the key elements to enable the use of hybrid ad hoc networks in future mobile and wireless networks. Due to the multi-hop nature of MANET, there might be several reachable Internet gateways for a mobile node at some point of time. If a mobile node receives Internet gateway advertisements from more than one Internet gateway, it has to decide which Internet gateway to use for its connection to the Internet. Several Internet gateway discovery approaches of interconnectivity between mobile ad hoc networks and Internet have been proposed in the literature. However, a comprehensive performance evaluation and comparative analysis of these approaches have not been performed yet. A comprehensive evaluation and performance comparison of Internet gateway discovery approaches in different scenarios will enable one to design and choose a proper Internet gateway discovery approach. This paper sheds some light onto the performance implications of the main features of each approach, presenting simulation results, which provide valuable information to MANET-Internet integration designers. Firstly, we introduce the three existing Internet gateway discovery approaches [2,3,13] and then, based on the simulation results with NS2 [4], we give a detailed comparison and analysis in various network scenarios. In this paper, we investigate the impact of traffic sources and mobility in terms of performance metrics throughput, end-to-end delay, and routing overhead on the three Internet gateway discovery approaches. We also compare the routing overhead obtained through our simulation with routing overhead computed through analytical model in the same scenario proposed by Ruiz et al. [5] for the three Internet gateway discovery approaches. Figure 1 shows an interworking scenario [1,6,7] in which a mobile node from ad hoc domain wants to communicate with a fixed node on the Internet.

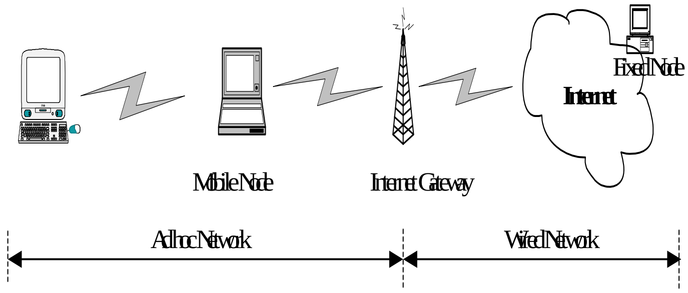

Figure 1: Internet access for ad hoc networks

The remainder of the paper is organized as follows: Related work about Internet gateway discovery approaches and their performance is presented in Section 2. We present the simulation environment, simulation results and its analysis obtained under various conditions, i.e., varying mobility in Section 3. Validation of our simulation results with analytic model has been presented in Section 4. Finally, the paper ends with concluding remarks in Section 5.

2. Related Work

The proposal by Broch et al. [17] is based on integration of MANET with Mobile IP using a source routing protocol. They introduced a border router or gateway, which has two interfaces. Routing on Internet gateway's interface internal to the ad hoc network is accomplished using dynamic source routing (DSR) [18] protocol, while its interface connected to the Internet is configured to use normal IP routing mechanisms. Mobile nodes in an ad hoc network are assigned home addresses from a single network. The nodes within range of the foreign agent act as gateways between the ad hoc network and the Internet. As a reactive approach, foreign agent discovery is only done when required. Traditional IP routing is used on the Internet side, while within MANET, DSR protocol is used. Foreign agents are responsible for connecting the ad hoc network with the Internet.

Hamidian et al. [8] gave a solution, which provides Internet connectivity to ad hoc networks by modifying the AODV routing protocol. An "I" flag is added as an extension to AODV RREQ and RREP to locate the fixed node. If a mobile node fails to receive any corresponding route replies after one network-wide search, it assumes that the destination is a fixed node and is located in the Internet. Thus, it delivers the packets through an Internet gateway. Three methods of gateway discovery for a mobile node to access the Internet are provided: proactive, reactive and hybrid approach. All of them are based on the number of physical hops to gateway as the metric for the gateway selection.

In [11] the scalability of both approaches (proactive and reactive) is compared with respect to the number of Internet gateways by Ghassemian et al. The fixed access network together with the ad hoc fringe constitutes a multihop access network. AODV protocol manages routing in the ad hoc domain. The simulation results show that the proactive approach is more advantageous because the packet delivery ratio is higher and, although the signaling overhead is larger too, it is reduced for a higher number of Internet gateways, because the amount of periodical gateway advertisements is increased but more data packets are transmitted successfully. The hybrid gateway discovery approach is also compared. The hybrid gateway discovery represents a balance between the reactive and the proactive approaches when the number of Internet gateways increases is also reduced.

El-Moshrify et al. [15] proposed a solution in which mobile nodes can access the Internet via a stationary gateway node or access point. Three proposed approaches for gateway discovery are implemented and investigated. Also, the effect of the mobile terminals speed and the number of gateways on the network performance are studied and compared. A mobile node uses no load balancing approach to efficiently discover an Internet gateway in this proposal.

Kumar et al. [19] analyzed Internet connectivity of MANETs via fixed and mobile Internet gateways and pointed out limitations in the existing approaches. It provides a good insight to the research community for further modification and review.

Lakhtaria et al. [16] compared the performance of three gateway discovery protocols. The metrics taken for performance comparison were packet delivery ratio (PDR) and routing overhead.

3. Simulation Model and Performance Evaluation

To assess the performance of the three Internet gateway discovery approaches under the same conditions, we implemented them within the network simulator ns-2.34 [4] using Hamidian [8] approach. The Internet gateway selection function uses the criteria of minimum hops to the Internet gateway, in order to get a fair comparison among the three approaches. The simulations were conducted on an Intel Core 2 Duo processor at 2.53 GHz, 4 GB of RAM running Fedora Core 5.

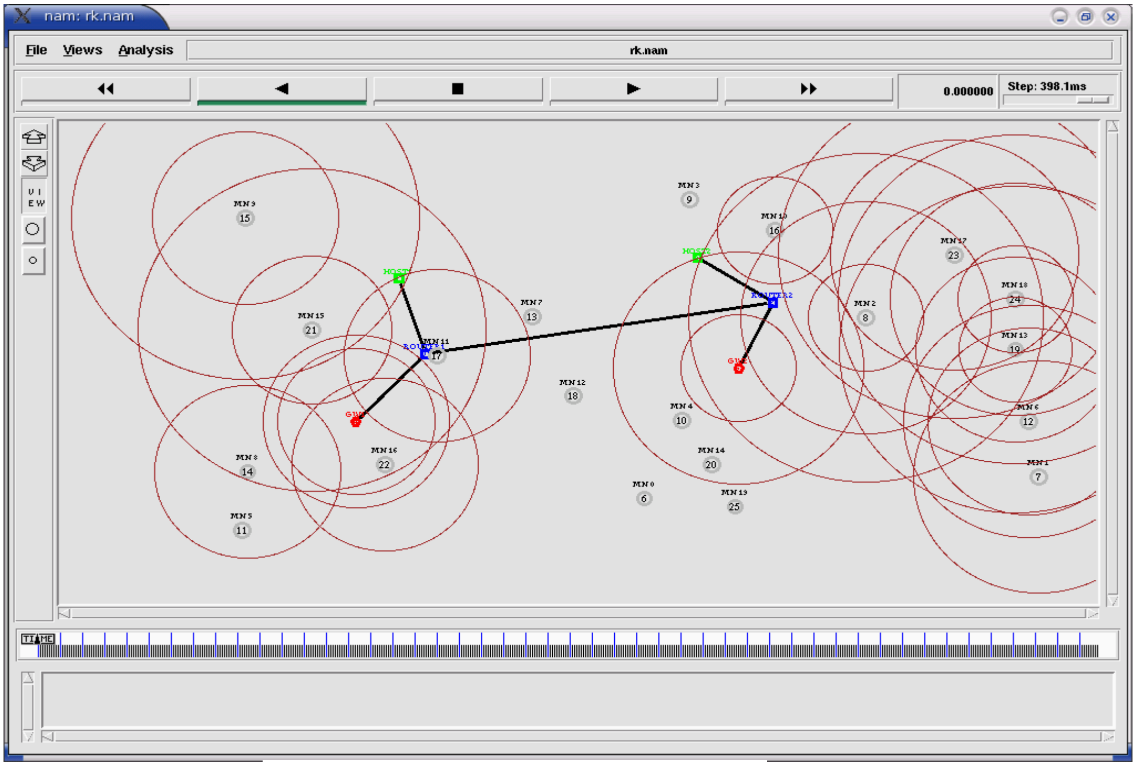

Figure 2: A snapshot of the simulation scenario

3.1 Simulation Model

The studied scenario consists of 20 mobile nodes randomly distributed over an area of 1200×500 m., two fixed hosts host1 and host2 (shown in green color) two routers (shown in blue colors) and two Internet gateways (marked as red colors) as depicted in Figure 2. All fixed links have a bandwidth of 10Mbps, which is enough to accommodate all traffic coming from the mobile nodes. In order to support wireless LAN in the simulator, the Distributed Coordination Function (DCF) of IEEE 802.11 is used as MAC layer protocol. A mobile node uses modified AODV protocol [12] to communicate with its peers and to access wired networks through an Internet gateway. All simulations were run for 500 seconds of simulation time. Two different cases (Case I and Case II) have been considered. In the first case, i.e., Case I, we take three CBR data sources as given in Table I. Mobile nodes MN7, MN12 and MN16 start sending data at t_{SIM} =5 second to host1 through one of the two Internet gateways. We then vary the node mobility as per data given in Table I. The traffic sources connected to mobile nodes MN12 and MN16 keep on sending data at constant rate, i.e., 320 Kbps (packet inter arrival time=0.0125 second, so data rate = (1/. 0125)*512*8=320 Kbps). In this way three different flows (fid=0, fid=1 and fid=2) are active in the network.

3.2 Movement Model

The mobility model used in this study is the Random Waypoint Model [9]. As per this model, a mobile node remains stationary for a specified pause time, after which it begins to move with a randomly chosen speed (0 to 20 m/s) towards a randomly chosen destination within the defined topology. The mobile node repeats the same procedure until the simulation ends. The random speed is chosen to be a value, which is uniformly distributed between a defined minimum and maximum value as given in Table 1. We generated mobile nodes movement pattern by using CMU's movement generator. The command used is:
$./setdest [-n num_of_nodes] [-p pausetime] [-s maxspeed] [-t simtime] \ [-x maxx] [-y maxy] > [outdir/movement-file]

3.3 Communication Model

The communication model is determined by four factors: number of sources, packet size, packet rate and the communication type. We used the CBR (constant bit rate) communication type, which uses UDP (User Datagram Protocol) as its transport protocol. CBR traffic has been used instead of TCP. The reason is that TCP performs poorly in ad hoc network because packets that are lost due to link failure and route changes trigger TCP's congestion avoidance mechanism [10]. Three and six sources are used to generate network traffic (CBR) with sending rate as given in Table I. The packet size of 512 bytes is used throughout the simulation. The traffic connection pattern is generated through CMU's traffic generator (cbrgen.tcl). The main parameters in cbrgen.tcl are "connections" (number of sources) and "rate" (packet rate). So, the command used is:

$ns cbrgen.tcl [-type cbr|tcp] [-nn nodes] [-seed seed] [-mc connections][-rate rate]

Table I: Simulation Parameters for Simulation Model

Parameters	Value
Number of mobile nodes	20
Number of sources	3 and 6
Number of gateways	2
Number of fixed nodes	2
Topology size	1200 meters × 500meters
Transmission range	250 meter
Traffic type	Constant Bit Rate (CBR)
Packet sending rate (Kbps) of mobile node MN7	8
Packet sending rate (Kbps) of mobile nodes MN8, MN10, MN12, MN16 and MN20 to host1 or host2	320 (fixed)
Packet Size	512 bytes
Mobile node speed	1,5,10,15 and 20 m/sec
Mobility model	Random Waypoint
Pause time	5 seconds
Link level layer	802.11 DCF
Carrier sensing range	500 meters
Simulation time	500 seconds
Wireless channel bandwidth	2 Mbps
Interface queue limit (wireless node)	50 packets
Interface queue limit (wired node)	50 packets
ADVERTISEMENT_ INTERVAL	5 seconds
ADVERTISEMENT_ZONE	4 hops
Wired link bandwidth	10 Mbps
Buffer management of wired nodes	Drop Tail

3.4 Performance Metrics

In order to investigate the effect of traffic load and mobility on three different gateway discovery approaches, we used the following performance metrics:

Throughput: It is defined as the ratio of total number of data bits (i.e. packets) successfully received at the destination to the simulation time.

End-to-End Delay: It is defined as the delay for sending packets from source node to the fixed host. This metric includes all possible delays caused by buffering during the Internet gateway discovery latency, route discovery latency, queuing at the interface queue, retransmission delays at the MAC layer, and propagation and transfer times.

Routing Overhead: It is defined as the ratio of the AODV packets to the data packets sent and received by all the mobile nodes.

3.5 Simulation Parameters

The common parameters for all the simulations are given in Table I similar with [11].

3.6 Simulation Results And Analysis

We present in this subsection the performance of three Internet gateway discovery approaches for the various metrics presented above.

Effect of Node Mobility

In this sub section, we examine the effect of node mobility on performance metrics throughput and end-to-end delay for the two cases studied earlier. For both the cases, i.e. for Case I and Case II, MN7 sends only at 8 Kbps.

Figure 3 shows the average throughput for CBR traffic at host1 (i.e. node MN7 $\rightarrow$ host1 with flow id 0) for the three Internet gateway discovery approaches for Case I where mobile node speed varies from 1 m/s up to 20 m/s with 5 seconds of pause time. At low speed, the throughputs of the three algorithms are almost similar

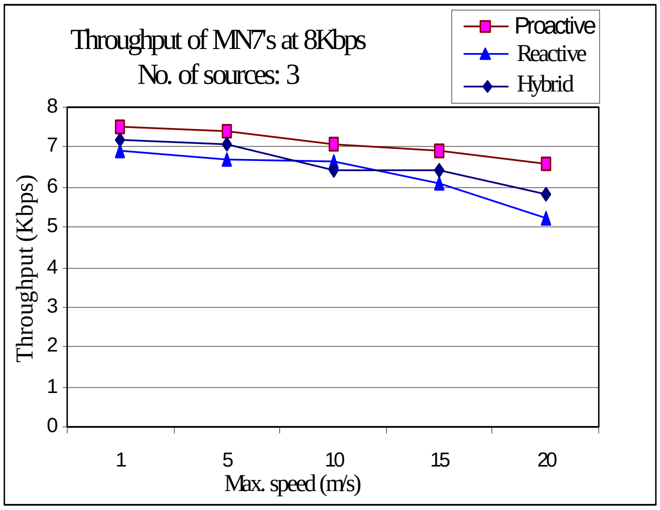

Figure 3: Throughput vs node mobility for Case I (Source: node MN7, Destination: host1, sources: 3)

and quite good but as node speed increases, due to frequent link changes and connection failures, packet drops occur and throughput starts decreasing. However, the proactive and hybrid approaches have larger throughput than the reactive approach at higher node speed. Reactive discovery results in lower throughput as the source continues to send data packets, which get lost due to link breaks until a route error packet is received by the sending mobile node.

For Case II, throughput of mobile node MN7 decreases with speed. In this case proactive discovery gives lower throughput as compared to others at higher node speeds (Figure 4).

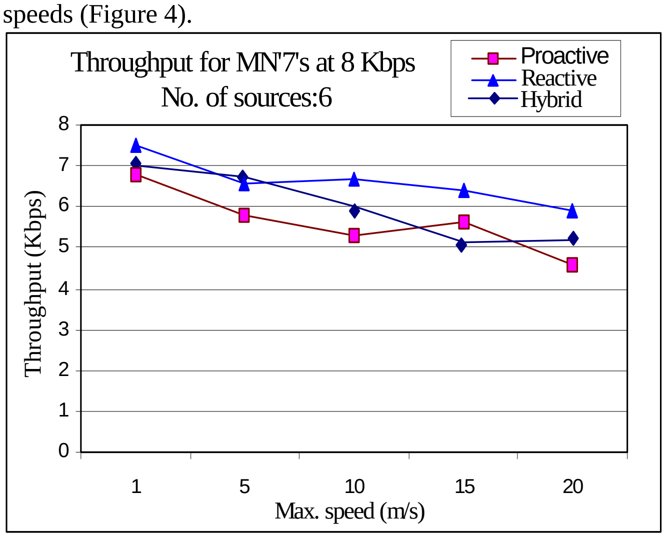

Figure 4: Throughput vs node mobility for Case II (Source: node MN7, Destination: host1, sources: 6)

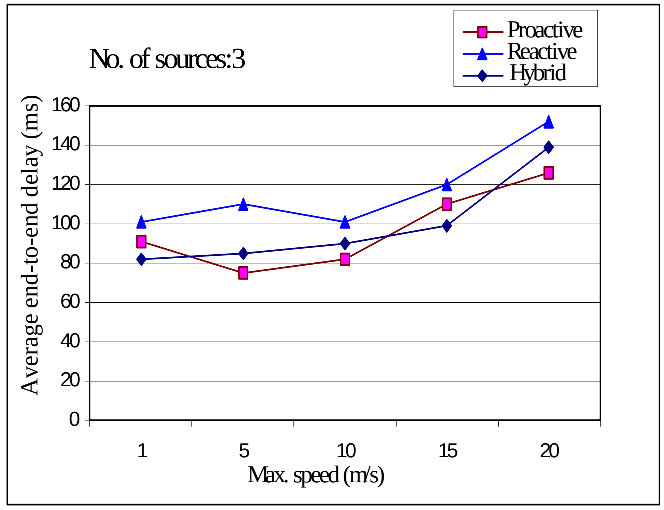

Figure 5: Average end-to-end delay vs node mobility for Case I (Source node MN7, Destination node host1, sources: 3)

Performance of hybrid gateway discovery remains in between proactive and reactive for both the cases (see Figure 3 and Figure 4). Moreover throughputs of MN7 are lower in the three gateway discoveries when the traffic sources are increased form 3 to 6. Figure 5 and Figure 6 show average end-to-end delay of MN7 for the three gateway discovery approaches for mobile node speed from 1 m/s up to 20 m/s, pause time of 5 seconds and number of sources 3 and 6. Figure 5 represents the average end-to-end delay for CBR traffic (for flow id 0 between mobile node MN7 and host1) for Case I on the three discovery approaches as mobility increases.

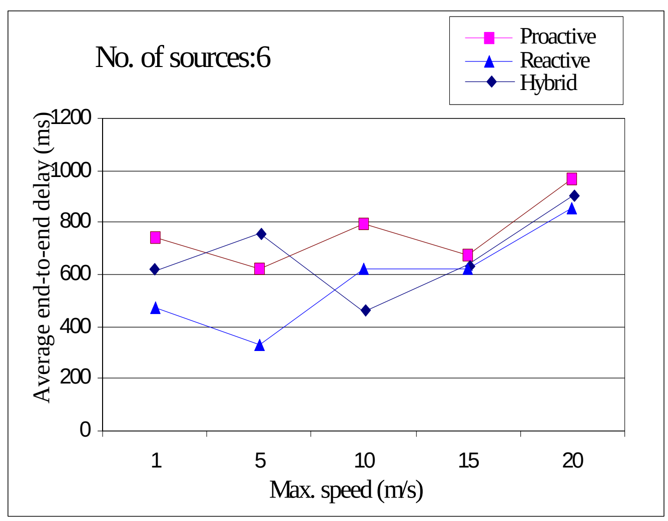

Figure 6: Average end-to-end delay vs node mobility for Case II (Source: node MN7, Destination: host1, sources: 6)

As the figure shows, the average end-to-end delay is lower for the hybrid and proactive approaches than for the reactive approach and increases rapidly with mobile node speed. This is because mobile nodes update their route entries for the gateways more frequently in case of either proactive or hybrid discovery approach which results in shorter and fresher routes. This increases average end-to-end delay in case of reactive discovery approach.
Figure 6 depicts the variation in the average end-to-end delay of packets with mobile node speed for six sources (Case II). In this case, proactive discovery results in higher average end-to-end-delay due to high node mobility compared to reactive and hybrid. But at higher mobility, the difference in end-to-end delay for the three gateway discovery approaches becomes lesser.

4. Validation of Simulation Results with Analytical Model

Ruiz et al. [5] presented an analytic model for the above three Internet gateway discovery approaches for analyzing scalability issue. Gateway discovery overhead is used as performance metric to measure the scalability of an Internet gateway discovery approach. It is the total number of control messages associated with the discovery of an Internet gateway.

This metric gives information about the control overhead to provide Internet connectivity. Table II shows a summary of basic parameters used in the model. Metric chosen for a route to the Internet gateway is the hop count

Table II: Notations used in the derivation

Notations	Meaning
N	Total number of nodes in a square lattice covering a certain area.
N_G	Number of Internet gateways
$N - N_G$	Number of ad hoc nodes
S	Number of active sources communicating with fixed nodes.
t	The time interval during which all sources send CBR traffic to the fixed nodes through Internet gateways
λ_{adv}	The rate at which GWADV messages are being sent out by Internet gateways
λ_{dur}	A parameter used to compute route duration time λ_{dur}

as this metric enables a mobile node to select the nearest Internet gateway to communicate with hosts in the Internet.

4.1 Reactive Gateway Discovery Overhead

In reactive gateway discovery, a source node discovers an Internet gateway reactively. Therefore, in this case gateway discovery overhead includes Internet gateway route request broadcast messages, plus Internet gateway reply messages from every Internet gateway to the source. The overhead of the reactive Internet gateway discovery for one source is given by the following equation [5]

$$R_{overhead} = [F_{overhead} + (R1_{overhead} \times \lambda_{dur} \times t)] \times S \quad (1)$$

where, $F_{overhead}$ gives the number of messages needed to realize that a destination is a fixed node and is given by the following equation

$$F_{overhead} \sum_{j \in (1,3,5,7,30)} N_r(j) \quad (2)$$

Given a broadcast message with time to live (TTL) equal to x, $N_r(x)$ is the number of nodes forwarding this message .

$R1_{overhead}$ represents the overhead of the reactive discovery of the gateway for one source and can be computed by the following equation [5]

$$R1_{overhead} = N + N_G \times \sqrt{N} \quad (3)$$

4.2 Proactive Gateway Discovery Overhead

In proactive approach, Internet gateways periodically broadcast Internet gateway messages (GWADV) to an entire ad hoc network. Therefore, total overhead in number of messages required in this approach can be computed by the following equation

$$P_{overhead} = S \times F_{overhead} + \lambda_{adv} \times t \times (N+1) \times N_G \quad (4)$$

4.3 Hybrid Gateway Discovery Overhead

The hybrid gateway discovery approach has the combined overhead of proactive and reactive approaches. The number of nodes within a scope of s hops from any Internet gateway G_i is given by the following equation

$$N_r^{G_i}(s) = \frac{s \times (s+3)}{2} \quad (5)$$

with $s \in [0, \sqrt{N} - 1]$

The probability of a given ad hoc node receiving a GWADV message from any of the Internet gateways is given by

$$P_c(s) = \frac{\sum_{i=1}^{N_G} N_r^{G_i}(s)}{N - N_G} \quad (6)$$

The overall overhead of the hybrid gateway discovery approach is due to the following overhead:

- overhead to realize that the destinations are outside MANET.
- overhead in broadcasting of GWADV messages over s hops by each Internet gateway.
- overhead needed by those sources not covered by the GWADV messages. These nodes find Internet gateways and create a default route.

Therefore, the total overhead in number of messages required by the hybrid approach can be computed by the following equation

$$H_{overhead} = S \times F_{overhead} + \lambda_{adv} \times t \times (N_r^G(s) + 1) \times N_G + R1_{overhead} \times \lambda_{dur} \times t \times S \times (1 - P_c(s)) \quad (7)$$

The Internet gateway discovery overheads of the three Internet gateway discovery approaches when the number of active traffic sources are 3 and 6 are computed using the approaches obtained through analytical model and simulation above analytic model. The results obtained with analytic model and simulation for the scenario considered (with parameters taken from Table I, and t=500 s, λ_{adv} =1/5 as Internet gateway advertisement interval is 5 sec) is listed in Table III. These simulated results are compared with the analytical results in Table III. We can see that all the figures are quite similar, taking into account that the model and the simulated environment have many differences (simulated area, mobility, MAC layer, etc), so some deviation is expected.

From the analytical results obtained from analytical model given by Ruiz et al. [5]) and with our simulation results, it can be concluded that as the number of traffic sources and mobility increase, reactive approach incurs higher overhead than proactive and hybrid approaches. Therefore the reactive approach shows poor scalability as number of sources connecting to the Internet increases. Hybrid gateway discovery approach incurs minimum overhead. This validates our simulation results for scalability issue.

5. Conclusions

In this paper, we considered Internet connectivity of ad hoc networks via Internet gateways. AODV routing protocol for ad hoc networks has been modified to offer enhanced Internet connectivity and then we investigated in depth the effect of traffic sources and node mobility on the three Internet gateway discovery, viz. reactive, proactive and hybrid for providing inter-connectivity between ad hoc networks and Internet. The performance metrics chosen are throughput, average end-to-end delay and routing overhead. To assess the performance of this idea, simulation has been carried out using NS2 Simulator [4] for two different cases (number of active sessions, i.e., for 3 and 6 sources). At low mobility, the performance of proactive and hybrid gateway discovery is better as compared to reactive discovery. They result in higher throughput, lower end-to-end delay compared to reactive approach. But as number of sources and node mobility increases, the reactive gateway discovery outperforms proactive and gives similar performance with hybrid discovery approach. Reactive gateway gives higher throughput and lower end-to end delay than proactive approach. However reactive approach shows poor scalability as number of sources connecting to Internet increases which is confirmed by comparing routing overheads obtained through our simulation and routing overheads computed through analytical model [5]. Performance of hybrid gateway discovery approach always remains in between reactive and proactive approaches. However, the overall performance of the three Internet gateway discovery approaches are very much dependent on the prevailing network conditions.

Table III: Routing overheads of the three Internet gateway discovery

No. of sources	Overheads of Internet gateway discovery approaches (Number of messages)					
	Proactive approach		Reactive approach		Hybrid approach	
	Simulation	Analytical	Simulation	Analytical	Simulation	Analytical
3	12605	14475	13989	14668	10078	8205
6	18283	20670	25934	29336	20384	11012

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