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HYBRID SCHEME FOR DISCOVERING AND SELECTING INTERNET GATEWAY IN MOBILE AD HOC NETWORK

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ABSTRACT

Global connectivity to Mobile Ad Hoc Network (MANET) is necessary to access the Internet services from the MANET. Nodes in a MANET that connect it to the Internet are called Internet gateways. Internet gateways need to be discovered and selected in an appropriate way to deliver more packets to the Internet and reduce end-to-end delay. Currently, there are proactive, reactive, and hybrid schemes to discover and select Internet gateways in MANET. However, these schemes do not scale well with the number of nodes, traffic load, and speed of the nodes in MANET. To make it scalable, we propose a new gateway discovery and selection scheme. In our scheme, the gateways advertise gateway advertisement messages only on-demand. Moreover, it contains the advertisements within a limit in order to make our scheme scalable. We also consider the interface queue length and the total number of neighbors along a route in addition to the hop count to bypass the loaded and dense route to the gateways in order to reduce the delay and packet loss. Simulation results show that our scheme scales well with the number of nodes, traffic load and the speed of the nodes in MAENT compared to that of other schemes. It also confirms that our scheme has less delay and packets drop than that of other schemes.

KEYWORDS

Internet, MANET, Integration, Internet Gateway Discovery, and Gateway Selection.

1. INTRODUCTION

A Mobile Ad Hoc Network (MANET) is formed by a group of mobile nodes without the aid of any centralized administration or established infrastructure. A pair of mobile nodes may communicate with each other either directly or indirectly with the help of the intermediate nodes. Since these kinds of networks are very spontaneous and self-organizing, many useful applications such as multimedia streaming, collaborative work, information dissemination and jungle telemetry can be supported by these networks and that's why they are very demanding in commercial arena specially in the emergency services like hospitals, ambulance, police and military applications etc.

In future, the Internet is likely to be different from its present state because mobile devices with various computational resources will dominate it. Wireless communication technology and the Internet are developing so quickly that there are numerous mobile devices around us and multiple wireless networks are serving these mobile devices all the time. A MANET is generally considered as a stand-alone network i.e. communication is only supported among the nodes within the ad hoc domain. This stand-alone nature limits the applicability of MANET to the scenarios those require external connectivity. Integration of MANET and Internet can

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provide global connectivity to MANET so that it no longer remains stand-alone. This integration allows mobile users in MANET to access the popular Internet applications such as e-mail, chat, instant messaging, file transfer etc. The integration expands both MANET and the Internet coverage range.

Integration of MANET with the Internet has recently become an active research area. To access the Internet from a MANET a subset of its nodes must have the interfaces to connect to the Internet directly. These nodes work as the Internet gateway, which facilitates other nodes to communicate outside the MANET. There might be multiple Internet gateways in a MANET. A mobile node in a MANET may be multi-hop away from the Internet gateways. In this case, the node has to use the Internet gateway through other intermediate nodes.

When a mobile node in a MANET wants to access the Internet, it needs to discover the available Internet gateways and selects the best one among them if multiple gateways are found. Therefore, it needs an efficient Internet gateway discovery and selection scheme that achieves high throughput, low delay and less network-overhead. Two types of schemes, reactive and proactive, have been proposed to discover and select Internet gateways in MANET. In proactive schemes [1-9], Internet gateways periodically broadcast gateway advertisement messages in the MANET. Each node that receives the advertisement message forwards the advertisement to other nodes until the message is flooded over the whole network. These schemes cost heavy routing load since the gateway advertisements are broadcasted periodically throughout the entire ad hoc network even if there is no such demand from the nodes in the MANET. However, the proactive schemes are blessed with higher rate of successful delivery and lower delay. In reactive schemes [1-3] [9-12], a mobile node broadcasts a gateway discovery message to discover Internet gateways in the network. Whenever a gateway receives the discovery message, it unicasts a gateway advertisement message back to the requestor. These schemes suffer from higher delay and lower packet delivery ratio since the nodes have to send a gateway discovery message every time they need a gateway. Reactive schemes scale poorly regarding the number of sources willing to access the Internet. Few research works [9] [13-19] proposed hybrid gateway discovery schemes where the dissemination of gateway advertisements is kept limited to a small area by setting appropriate Time to Live (TTL). Nodes outside the TTL coverage area reactively find their gateways. The performance of these schemes degrades if TTL is not adapted properly. Most of the existing hybrid schemes [9] [13-14] [16] do not adjust TTL value dynamically.

Gateway selection scheme selects the best gateway when it receives multiple gateway advertisements from multiple gateways. Gateway selection schemes proposed in [1-3] [5] [7] [9] [13-18] use hop count only to select a gateway. In these schemes, all the nodes always select the nearest gateway, a gateway may become a bottleneck under heavy traffic load and there is no remedy for this problem.

To deal with the problems in existing Internet gateway discovery and selection schemes we propose a new hybrid gateway discovery scheme where gateways will act reactively, however, broadcast a gateway advertisement message when they receive a gateway discovery message from a mobile node. The TTL of the gateway advertisement message will also be set to a value equal to the distance of the gateway from the requestor. Each mobile node will configure its gateway after receiving the gateway advertisement message. In our scheme, a node selects a gateway that promises optimal performance, after receiving the advertisement messages from multiple gateways. While selecting the best gateway, the node will consider the interface queue size and the total number of neighbors of each node along the route in addition to the hop count. We consider the number of packets waiting in the interface queue of a mobile node as its interface queue size. The use of interface queue size in the selection of a gateway, allows us to redirect a mobile node from a heavily loaded gateway to a less loaded one and the inclusion of the total number of neighbors of each node helps us to avoid a crowded area to reach the gateway.

The rest of the paper has been organized as follows. In Section 2 we review the current solutions for Internet gateway discovery and selection in MANET. Section 3 depicts our new hybrid Internet gateway discovery scheme. We also introduce the new metric used in the gateway selection scheme in this section. Simulation setup and analysis of simulation results comes in Section 4 and finally in Section 5 we conclude our paper with some future research guidelines.

2. RELATED WORKS

During the last decade, many works have been devoted to the study of ad hoc routing protocols, but the decade lacks adequate works to provide Internet connectivity to the nodes in MANET. Since Internet has made information more available and easier to access, the desire for having a MANET connected to the Internet is increasing. Typically, several gateways in a MANET connect the network to the Internet. The rest of the nodes discover the available gateways and select the best one among them.

2.1. Internet Gateway Discovery Schemes

Recently the issue of Internet connectivity to MANET has been addressed by [1-24]. MIPMANET [3] was designed to provide nodes in the ad hoc networks with access to the Internet and the mobility services of IP. A foreign agent (FA) in MIPMANET [3] acts as an access point and provides Internet connectivity to an entire ad hoc network. It uses a single IP address as a care-of-address and a reverse tunneling to provide Internet access to the nodes. Each FA in the MANET broadcasts foreign agent advertisement messages periodically. Mobile nodes in the network use ad hoc on-demand distance vector (AODV [25]) routing protocol for routing within the MANET. FAs have the MIPMANET Internetworking Unit (MIWU) that is inserted between the FA and the ad hoc network. MIPMANET uses MIPMANET Cell Switching (MMCS) algorithm to handover between foreign agents. Belding-Royer et al. [22] proposed Mobile IP for IPv4 ad hoc networks using AODV routing protocol. In that proposal, a node first has to determine the location of the destination node before it starts sending packets to that destination. Here, a FA unicasts a route reply (F-RREP) message when it receives a FA discovery message from a mobile node. Mobile nodes use the F-RREP messages to determine the location of the destination nodes. It is capable of routing packets to FA using default route. A disadvantage of this proposal is that, a mobile node has to know that the destination of a packet is not within the ad hoc network before sending it to the FA, which in turn increases the delay for connection setup.

In [1], the authors discussed the technique to provide global Internet connectivity to IPv6 MANET environment using on-demand routing. The paper proposed two Internet gateway discovery schemes: proactive gateway discovery scheme using periodic gateway advertisement messages from the gateway and reactive gateway discovery scheme by flooding gateway discovery messages from the nodes. Lee at el. [13] proposed two gateway advertisement schemes based on the observation of traffic and mobility pattern of nodes to avoid unnecessary routing overhead in MANET. However, the scheme relies on source routing protocol that limits the applicability and scalability of the solution.

In addition to the reactive or proactive gateway discovery schemes [1-12] there are some research works [9] [13-19] that proposed hybrid gateway discovery schemes. In the hybrid schemes, the time-to-live (TTL) value of the gateway advertisements is kept limited to certain boundary in order to contain the proactive discovery within an optimum range. These schemes are mainly designed to minimize the disadvantages of proactive and reactive schemes i.e. to provide good connectivity and low overhead. However, these schemes require some intelligent adaptation of the TTL value. In [19] authors proposed a load-adaptive access gateway discovery protocol that defined a proactive range for the gateway advertisement which is dynamically adjusted according to the changing network conditions. Nevertheless, the gateway advertisement scheme is effective when there are only fixed sized packets in the network. Here the authors used the network size and the number of nodes in the network to compute the initial proactive range, which is unlikely because there may be no good technique to know the size and the number of nodes in a MANET.

2.2. Internet Gateway Selection Schemes

If a node discovers multiple gateways then it has to decide which one is to use. Majority of current gateway selection schemes [1-3] [5] [7] [9] [13-18] [22] use hop count to select the best gateway, and they always select the nearest gateway with the hop count metric. If all the mobile nodes always select their nearest gateway then the nearest gateway may become bottleneck under heavy traffic load, also there might be congested nodes along the route to the gateway. That is, hop count based selection schemes choose a gateway that might have less capacity and difficult to reach. As a result, network performance degrades with the hop count metric.

Few research works [4] [6] [8] [10-12] [19-20] considered traffic load in addition to the hop count to select the best gateway. Each of these research works treated traffic load differently than the others. Kumar et al. [4] considered the number of packets waiting in the interface queue of the nodes to select a gateway. Khan et al. [6] considered the number of packets waiting in the routing queue of the nodes to select a gateway. However, both of these works converted the number of packets into equivalent hop count without proper justification, which may not provide the actual traffic load information. Le-Trung et al. [10] proposed a hybrid metric for Internet gateway selection that provides load-balancing of intra/inter-MANET traffic. However, the selection scheme introduces extra routing load and requires high processing power consumption to compute the hybrid metric. Li et al. [11] considered the speed of the nodes along with node’s available energy and traffic load to select a gateway. Zhanyang et al. [12] also considered the speed of the nodes to compute the gateway selection metric. Nevertheless, obtaining the speed of a node impose additional cost which may limit the applicability of the work. QoS-enabled access gateway selection scheme proposed in [19] considered the packet arrival rate of a gateway in an interval as the traffic load. It uses a Decision Function (DF) that considered the traffic load and hop count to select a gateway. In this case, each intermediate node needs to piggyback its load information periodically on data packets, which increase the header size of the data packets. In [20], the authors proposed a gateway selection scheme based on hop count, gateway load and path quality, and make use of a hybrid search approach which is based on orthogonal genetic algorithm and sensitivity analysis. The authors have used the maximum packet queue size, average packet queue size and an index α to compute the gateway load. However, the computation of average packet queue size depends on the periodical gateway advertisement and better average can only be obtained for smaller advertisement interval. The authors did not talk about how to select the value of α either. In [20], the authors used the variance in arrival times of periodical gateway advertisement broadcast messages in order to evaluate the quality of the path between mobile nodes and the gateway. However, the computation of the variance needs an intelligent selection of a history window in order to express how long history needs to be considered when calculating the mean value and variance. This makes their selection scheme effective for periodical gateway advertisement only with small advertisement interval. Nevertheless, periodical gateway advertisement with small advertisement interval results in tremendous routing load in the network.

3. PROPOSED INTERNET GATEWAY DISCOVERY AND SELECTION SCHEME

In this section, we describe our proposed Internet gateway discovery and selection scheme for MANET. At first, we present the network architecture that our scheme is based on. After that, we describe our Internet gateway discovery scheme. We also show the computation of the metrics that are used in our Internet gateway selection scheme.

3.1. Network Architecture

We assume a regular MANET consists of two types of nodes. One type of nodes has Internet connectivity, we call them Internet gateways, and the other type of nodes that don't have Internet connectivity but they can access the Internet through the Internet gateways. We call this second type of nodes simply, mobile nodes.

We assume all the nodes in our MANET have equal transmission range. Nodes can communicate directly with each other if they fall in each other's transmission range. Nodes who are not within each other's transmission range can also communicate indirectly via one or more intermediate nodes. Nodes can join or leave the network anytime. Nodes are free to move in any direction. We did not impose any Internet bandwidth limitation on the Internet gateways

Internet gateways in our MANET can access the Internet themselves. However, the mobile nodes have to access the Internet through an Internet gateway. For this reason, mobile nodes have to discover the gateways first. We describe our gateway discovery scheme in Section 3.2. If multiple gateways are discovered by a mobile node, the best gateway must be selected to access the Internet. We describe our gateway selection scheme in Section 3.3. Any MANET routing protocol such as AODV [25], OLSR [26] and DSR [27] can be used to route the packets within our network.

3.2. Internet Gateway Discovery

When a mobile node in the MANET wants to access the Internet, at first it has to find a gateway. Like [4] [6] [9], a mobile node in our gateway discovery scheme looks in its routing table to find a default route i.e. a route to a gateway. If the mobile node finds a default route, it uses the route to send packets to the gateway i.e. to the Internet.

However, if the mobile node does not find a route to a gateway in its routing table, we propose it to start a gateway discovery process by broadcasting a gateway discovery (GWDSC) message in the MANET. While broadcasting the GWDSC message, we propose the requesting mobile node to set an initial time to live (TTL) value for the message and start a timer to wait for the reception of the gateway advertisement message from the gateways. Figure 1 shows the format of the GWDSC message.

<table>
<tr><td>0</td><td colspan="4">8</td><td>12</td><td>24 31</td></tr>
<tr><td><i>Type</i></td><td><i>J</i></td><td><i>R</i></td><td><i>G</i></td><td><i>I</i></td><td><i>Reserved</i></td><td><i>Hop Count</i></td></tr>
<tr><td colspan="7"><i>RREQ_ID</i></td></tr>
<tr><td colspan="7"><i>Destination IP Address</i></td></tr>
<tr><td colspan="7"><i>Destination Sequence Number</i></td></tr>
<tr><td colspan="7"><i>Originator IP Address</i></td></tr>
<tr><td colspan="7"><i>Originator Sequence Number</i></td></tr>
</table>

Figure 1. Format of GWDSC messages in our scheme

In our scheme, upon receipt of a GWDSC message, an intermediate node creates a reverse route entry for the requestor in its routing table and forwards the GWDSC message to its neighbors. In this way, a GWDSC message reaches one or more Internet gateways in the network if there is any.

We propose an Internet gateway to broadcast a gateway advertisement (GWADV) message when triggered by a GWDSC message. We also propose to set the TTL value of the GWADV message equal to the distance of the gateway from the requesting mobile node. In our scheme, we control the TTL value of the GWADV message to contain the dissemination of the GWADV message to a certain range, which helps to reduce the routing overhead to an extent. We allow gateways to broadcast GWADV messages only in response to GWDSC messages in order to avoid unnecessary flooding of GWADV messages in the network.

In addition to the conventional fields, we have added two new fields in the GWADV message header. We name these new fields ***Q*** and ***N*** respectively. We use the ***Q*** field to represent the total interface queue size of nodes along a route from a gateway to a mobile node. We use ***N*** field to represent the total number of neighbors of the nodes along a route from a gateway to a mobile node. We use the Hello messages of ad hoc routing protocols to obtain the neighbor information of a gateway or a mobile node.

We propose an Internet gateway to populate these two fields before flooding a GWADV message. We also propose intermediate nodes to update these two fields while forwarding the message to the next nodes. The modified structure of a gateway advertisement message header in our scheme is given in Figure 2.

<table>
<tr><td>0</td><td>8</td><td>19</td><td>24 31</td></tr>
<tr><td><i>Type</i></td><td><i>Reserved</i></td><td><i>Pref. Sz.</i></td><td><i>Hop Count</i></td></tr>
<tr><td colspan="4"><i>Broadcast_ID</i></td></tr>
<tr><td colspan="4"><i>Destination IP Address</i></td></tr>
<tr><td colspan="4"><i>Destination Sequence Number</i></td></tr>
<tr><td colspan="4"><i>Source IP Address</i></td></tr>
<tr><td colspan="4"><i>Lifetime</i></td></tr>
<tr><td colspan="4"><i>Q</i></td></tr>
<tr><td colspan="4"><i>N</i></td></tr>
</table>

Figure 2. Format of GWADV Message in our scheme

Upon receipt of a GWADV message, we propose a mobile node to decrement the TTL first and to configure the corresponding gateway if it does not have a gateway configured yet. In this way, more nodes in the network will have the opportunity to configure their gateway without broadcasting a GWDSC message, i.e., our scheme will reduce the GWDSC message broadcast to a significant level. Mobile nodes that already have their gateway configured should reconfigure the gateway if the corresponding gateway seems better. A GWADV message is forwarded to the neighbors if the TTL value is not zero. In this way, we allow the GWADV message to reach to the requesting mobile node. Therefore, in our scheme, a GWADV message helps not only the requesting mobile node but also the other nodes in the network to configure their gateway. As a result, our proposed scheme helps a mobile node in a MANET to hand off to a better gateway even before its current Internet connection is broken.

However, if the requesting mobile node does not receive any GWADV message before the timer expires, we propose the node to broadcast a new GWDSC message with an increased TTL value. We propose the requesting mobile node to increase the TTL value linearly. We increment the TTL value linearly to experience less routing overhead (GWDSC messages). We allow this process to continue until either the requesting mobile node receives a GWADV message or it broadcasts a GWDSC message with a pre-defined maximum TTL value.

Thus, our gateway discovery scheme consists of on-demand GWDSC messages like reactive scheme, broadcast of GWADV messages like proactive scheme and limited TTL value for GWADV messages like hybrid scheme. That is, our scheme combines the bests of the three conventional Internet gateway discovery schemes and can provide efficient and faster discovery of Internet gateways.

3.3. Internet Gateway Selection

We propose a new composite metric to select the best gateway when a mobile node receives multiple gateway advertisement messages from multiple gateways; we call this new metric ***gateway-cost*** (***gc***). Our metric ***gc*** is composed of three factors: hop count, interface queue size and total number of neighbors.

Like [1-3] [5] [7] [9] [13-18] [22], we consider hop count to select the best gateway. It denotes the number of nodes or routers between a mobile node and an Internet gateway. This factor allows a mobile node to reach the Internet using minimum number of hops which facilitates the rapid convergence and resource thriftiness of the network.

We consider the interface queue size of each node along a route to a gateway. Interface queue size of a node denotes the number of packets waiting in the interface queue of that node. If the size of the interface queue of each node along a route to a gateway is less, then more packets can be sent to the Internet using that route and the packets will have to wait less. Thus, we consider interface queue size of each node to allow fair distribution of the network load among the gateways and congestion prevention in the network.

We consider the total number of neighbors of each node along a route to a gateway. This factor helps a mobile node to select a gateway whose path is least dense. A least dense path is more likely to have least contention and best to use to reach the gateway. As far as we know, nobody used this factor to select a gateway in a MANET before us.

Whenever a node p in a MANET receives a GWADV message from a gateway q, we propose it to calculate gc using eq. (1):

$$gc_q = hc_q + \frac{Q}{Q+1} + \frac{N}{N+1} \qquad (1)$$

$$q \in V_{GW} \qquad Q = \sum_{i=1}^{hc_q} int\_q\_size_i \qquad N = \sum_{i=1}^{hc_q} n_i$$

Where V_{GW} is the set of Internet gateways present in the network, hc_q is the number of hops from q to p, $int\_q\_size_i$ represents the interface queue size of node i along the route from gateway q to node p, n_i represents the number of neighbors of node i along the route from gateway q to node p.

When a mobile node receives multiple GWADV messages from multiple gateways, we select the gateway with the lowest gc.

We give more emphasis on the hop count because it is always better to select a shorter route to minimize network delay and to optimize network resource usage. A packet routing through a shorter path also have better chance to face less network adversaries, such as bit error and congestion. Although the queue size and the number of neighbors along the route help us to avoid the gateways having bad route to reach, these two are actually less significant factor compared to hop count. Thus, if the two factors are kept intact like the hop count in the computation of the metric gc, then our selection scheme may choose a gateway which is not closest in terms of hop count. As a result, a mobile node in a MANET has to travel a longer route to reach an Internet gateway in the MANET. A longer route not only increases delay or consumes network bandwidth and node energy but it also involves more intermediate nodes to forward packets to an Internet gateway. A route to a gateway with higher number of intermediate nodes has better chance to suffer from more congestion and collision compared to that of smaller routes. Consequently, this fact may cause more packets drop and route re-discoveries in the network. For this reason, we give less emphasis on these two factors. To do so, we individually adjust these two factors so that they can contribute positively in the computation of the gateway selection metric ***gc*** but their individual contribution always remains less than 1. Therefore, our metric ***gc*** selects the gateway whose path is not only less loaded and less dense but also shortest.

4. PERFORMANCE EVALUATION

To evaluate the performance of our proposed Internet gateway discovery and selection scheme, we implemented our scheme in ns-2 [28] network simulator and compared the results with that of the proactive, reactive and hybrid schemes that were proposed in [29]. We also modified the MANET routing protocol AODV [25] to route packets between a gateway and a mobile node.

4.1. Performance Metrics

We compare all the Internet gateway discovery and selection schemes based on three performance metrics namely Internet Packet Delivery Ratio, Average End-to-End Delay, and Normalized Control Overhead. These are the standard performance metrics that are also used by many research works [4] [6-12] [19] to evaluate Internet Gateway Discovery and Selection Schemes.

The Internet Packet Delivery Ratio (IPDR): IPDR is defined as the ratio between the total number of data packets received by the corresponding destination hosts in the Internet and the total number of data packets sent to the Internet by all the mobile nodes in the MANET.

The Average End-to-End Delay: It is defined as the average time needed to send a data packet from a node to a host in the Internet. It is computed in milliseconds (ms).

The Normalized Control Overhead (NCO): NCO is defined as the ratio between the total number of AODV messages transmitted by the nodes in MANET and the total number of data packets received by the hosts in the Internet.

We vary the number of nodes in MANET from 10 to 30 to see the network behavior under different traffic load. The number of neighbors of each node also varies with the number of nodes in the MANET. We vary the speed of the nodes from 2 to 30 m/s which allows us to compare the performance of the schemes in different speeds, such as walking speed (2 m/s), downtown driving speed (10 m/s), suburban driving speed (20 m/s), and highway driving speed(30 m/s) [13].

4.2. Simulation Setup

This section describes the network scenario, the movement model, the communication model, and the simulation parameters that we have used in our study.

4.2.1. Scenario

Like [11] [14] [19-20], our simulated network is spanning in a standard area of $1000x1000m^2$. Each mobile node in our simulation has a wireless transmission range of 250 meter, which is the standard range and also used by the other research works [4] [6] [9] [10] [11] [15] [19-21]. This transmission range ensures no network partitioning.

We have considered 4 Internet gateways in the MANET in our simulation scenarios in order to load balance the Internet traffic. We assume a higher Internet bandwidth for gateways compared to that of the MANET nodes. We set the Internet bandwidth of each gateway to 10 Mbps.

We ran our simulations for 500 units of simulation time. According to our observation, 500 units of simulation time is high enough to see the steady behavior of the network in different scenarios. The seed time for each node to send data packets is considered 0.5 units of the simulation time. This seed time confirms that all the schemes start their gateway discovery process before the nodes start sending the data packets to the Internet. A screenshot of a simulation scenario is given in Figure 3. In the figure, the red-colored hexagonal nodes represent the gateways, the blue-colored square nodes represent the Internet hosts and the green-colored circular nodes represent the mobile nodes.

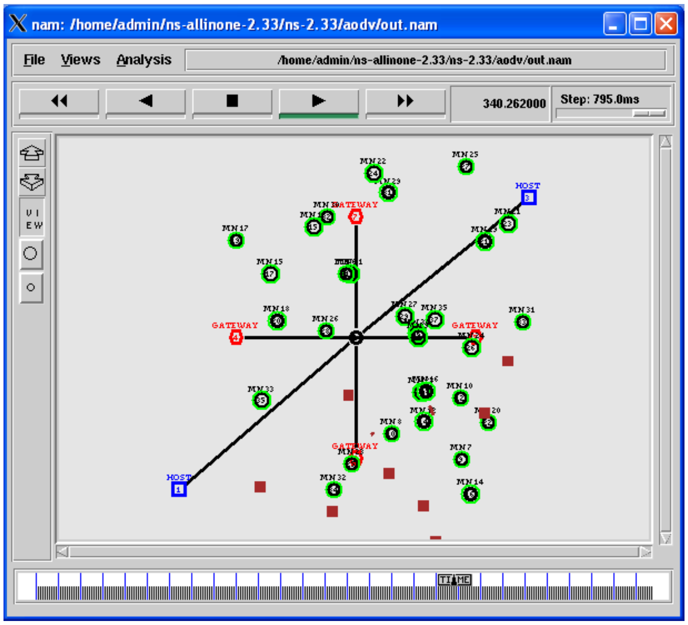

Figure 3. Screenshot of a Simulation Scenario

4.2.2. Movement Model

We used the Random Waypoint Movement Model [30] as the mobility model for our simulation. It is the benchmark mobility model that has been used in many research works [3-4] [6-9] [11-21] in order to evaluate network protocols in MANET. According to this model, a mobile node remains stationary for a certain period called *pause time*. After the *pause time* is over the node selects a destination randomly and moves to that destination at a random speed. The random speed is distributed uniformly between zero (zero not included) and some maximum speed. We set the maximum speeds between 2 to 30 m/s for different scenarios. When the node reaches the destination, it again remains stationary for the *pause time* period and repeats the same procedure until the end of the simulation. We set the *pause time* to 20 seconds in our simulations which is good enough for a node to change the movement direction.

4.2.3. Communication Model

We allowed all the mobile nodes in the network to access the Internet, i.e., each mobile node sends data packets to the hosts in the Internet. Each mobile node in our simulation uses Constant Bit Rate (CBR) traffic to send packets to the corresponding hosts in the Internet. We wish to see the performance of different schemes under heavy traffic load. For this reason, we allow each mobile node to generate 10 packets per second and send them to the Internet. Like [4] [6] [9-12] [14-15] [19-21], we permit each mobile node in the MANET to generate packets of size 512 bytes. By varying the number of nodes, we actually varied the traffic load in different simulation scenarios.

4.2.4. Parameters

Table 1 gives the values of some simulation parameters that are used for most of the simulation scenarios.

Table 1. Common parameters used in most of the simulation scenarios.

Parameter	**Value**
Number of Internet gateways	4
Number of hosts in the Internet	2
Topology size	1000 x 1000 m^2
Transmission range	250 m
Internet BW	10 Mbps
Mobility Model	Random Waypoint
Traffic type	CBR
Packet size	512 bytes
Pause time	20 s
Simulation time	500 s

4.3. Result Analysis

Figures 4, 5 and 6 report IPDR, average end-to-end delay, and NCO respectively by varying the number of nodes but setting the maximum speed of a node to 30 m/s. In these figures we labelled our scheme as "interactive". We have taken the average of 10 simulation run results for each data point plotted in the figures.

When there are fewer nodes (less than 20) in the network, the total traffic generated by them is comparatively less. As a result, there is less congestion in the network which helps the nodes to deliver the packets to the gateways with less dropout and the gateways can also forward the packets to the Internet with ease. However, when the number of nodes in the network increases, the traffic load in the network also starts to increase.

Increased traffic load results in more congestion and more collisions in the network. As a result more packets are waiting in the interface queue of the forwarding nodes and getting dropped if the waiting time exceeds its limit. These facts reduce the packet delivery ratio and increase the end-to-end delay. Thus, IPDR decreases (Figure 4) and the average end-to-end delay increases (Figure 5) with the increase in the number of nodes in all the schemes. The periodic GWADV messages in the network in the other schemes help the nodes to have updated gateway information and achieve higher IPDR (Figure 4) with fewer nodes in the network.

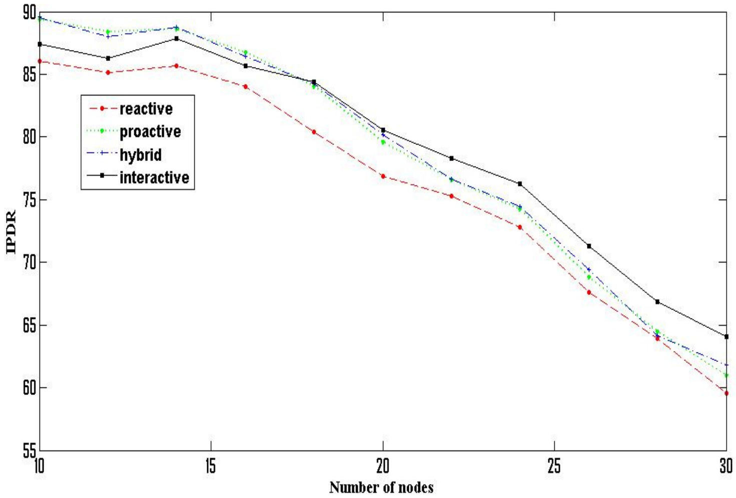

Figure 4. IPDR of all schemes against the number of nodes

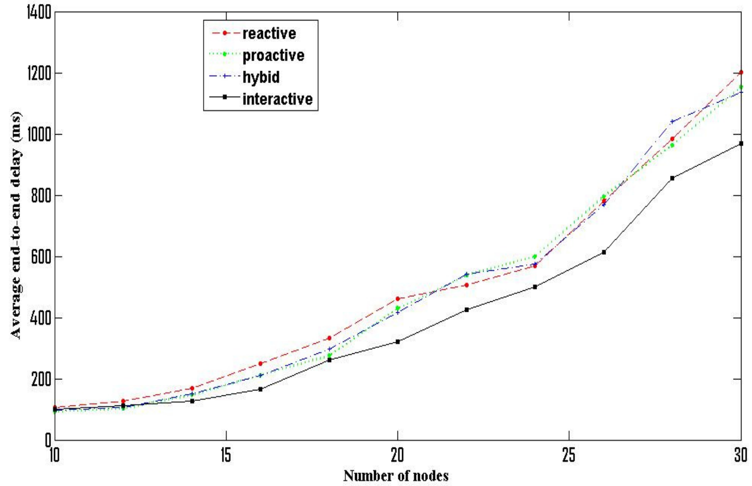

Figure 5. Average end-to-end delay of all schemes against the number of nodes

However, IPDR in our scheme started to exceed the IPDR of other schemes when the number of nodes is 20 or more. The average end-to-end delay obtained from our scheme is also better than that of other schemes (Figure 5). By avoiding the forwarding nodes having longer interface queue as well as the route to the gateway having higher concentration of neighbor nodes our scheme suffers from less packet drop and less waiting. For these reasons, IPDR is higher and the average end-to-end delay is lower in our scheme compared to that of other schemes while the number of nodes in MANET is increasing beyond 20.

From Figure 6 we can see that our scheme out performs the other schemes with respect to NCO performance metric. NCO obtained from all the schemes increase with the number of nodes in the network. Traffic load in the network increases as the number of nodes in MANET increases, which in turn increases the packet drop as explained earlier. Since NCO is the ratio between the number of routing packets and the number of successfully delivered data packets, it increases when there are less delivered data packets. As our scheme suffers from less packet drop than that of the others, it yields less NCO than that of others. Again, a gateway in our scheme broadcasts a GWADV message in response to a GWDSC message.

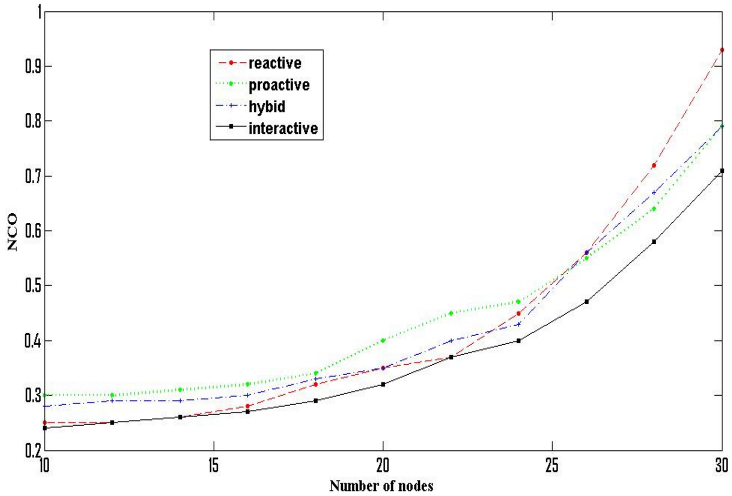

Figure 6. NCO of all schemes against the number of nodes

Not only the requesting mobile node gets the gateway information from the GWADV message but also the other nodes get the same information without transmitting their own GWDSC messages. This technique allows many mobile nodes to bypass the gateway discovery phase. As a result, they do not overwhelm the network by broadcasting GWDSC messages. For this reason, we have less routing packets in our scheme than that of other schemes, i.e., less NCO.

Figures 7, 8, and 9 report the same performance metrics respectively by varying the speed of the nodes but using only 30 mobile nodes. We have taken the average of 10 simulation run results for each data point plotted in the figures.

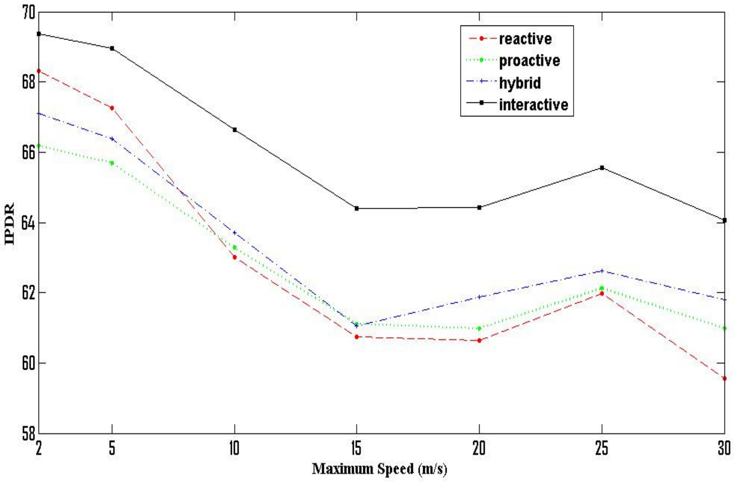

Figure 7. IPDR of all schemes against the speed of nodes

Figure 7 shows that IPDR obtained from all the schemes is high at the low speed, i.e. at 2m/s; it starts to decrease with the increase in the speed. The reason behind this fact is that the routing tables of the mobile nodes become obsolete when the nodes move with the high speed. As a result, more packets are dropped by the nodes in the network due to having no routes or obsolete routes to the gateways and the IPDR is reduced. Our scheme performs better than the other schemes by selecting gateways that have less dense route and the forwarding nodes on the route that have shorter queue lengths.

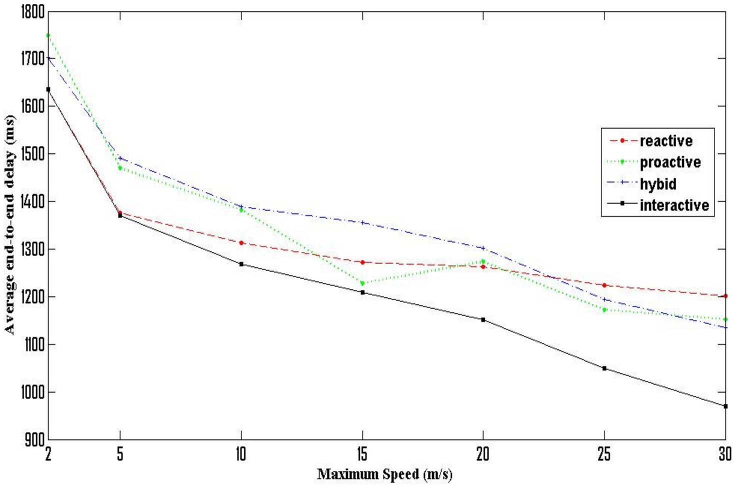

Figure 8. Average end-to-end delay of all schemes against the speed of nodes

We can see from Figure 8 that the average end-to-end delay in all the schemes decreases at the higher speeds. At the higher speeds the entries in the routing tables become obsolete quickly. Higher number of packets are dropped in the network for not having the routing entry. This reduces the average length of the interface queue in the network. Because of these shorter queue lengths, packets do not need to wait much in the network to get delivered. Our scheme avoids the routes having longer queue lengths and higher concentration of neighbor nodes. For this reason, our scheme experiences the lowest end-to-end delay.

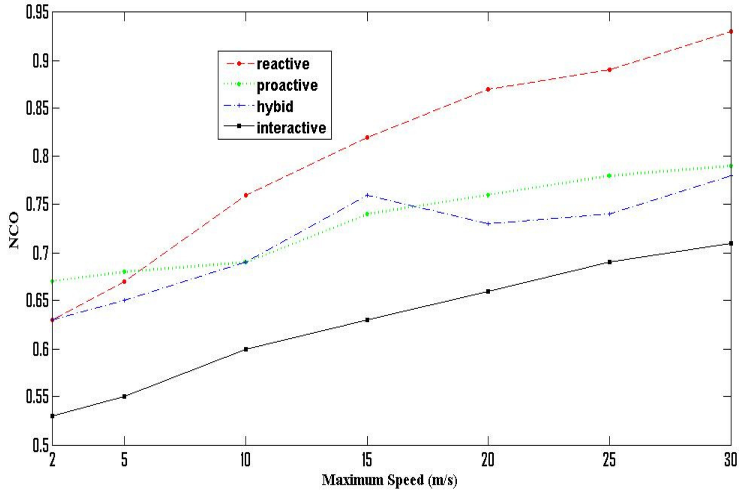

Figure 9. NCO of all schemes against the speed of nodes

Figure 9 shows that NCO, which is the ratio between the number of routing packets and the number of packets successfully delivered, increases with the speed of the mobile nodes in every scheme. Since the routing tables of the mobile nodes become obsolete when the nodes move with the high speed, nodes in the network suffer from having no routes or obsolete routes to the gateways. This fact causes more packet drops and more route re-discoveries. As a result NCO of all the schemes increases as the speed of the mobile nodes increases. However, our scheme has less NCO than that of the other schemes because it has less packet dropouts and it requires less routing packets compared to that of the other schemes.

From the above analysis of the results, we can conclude that our gateway discovery and selection scheme performs better than all other existing schemes in terms of packet delivery ratio, end-to-end delay, and network overhead with different size of MANET and with different speed of mobile nodes in the MANET. Thus, the proposed gateway discovery and selection scheme will scale well with the number of nodes, the traffic load and the speed of the nodes.

4.4. Statistical Analysis of the Simulation Results

We perform a statistical test to show that our scheme provides significant performance improvement over the other schemes.

We use the paired two-sample two-tailed t test to determine whether the improvement in the performance metrics i.e. IPDR, average end-to-end delay, and NCO in our scheme is significantly better than that of the reactive scheme. We compare two schemes in each data points given in the figures from Figure 5 to 10. Since each data point is the average of ten simulation run results, we simply measure the results of the reactive and interactive schemes in each run as the before and the after means respectively in order to get our t test results.

In our t test, the level of significance (**alpha**) is 0.05, the sample size (**n**) is equal to 10 and the degrees of freedom (**df**) is equal to (**n** – 1) = 9. The Critical t value ($\mathbf{T_{critical}}$) for two tailed t test with **df** = 9 and **alpha** = 0.05 is 2.26215 [31]. We compare the t values ($\mathbf{T_{value}}$) obtained from the t tests with the critical t value ($\mathbf{T_{critical}}$) to determine whether there is a significant difference between the "reactive" and our "interactive" schemes. If a $\mathbf{T_{value}}$ is greater than the $\mathbf{T_{critical}}$ then we reject the null hypothesis and if a $\mathbf{T_{value}}$ is smaller than the $\mathbf{T_{critical}}$ then we accept the null hypothesis.

4.4.1. T test for IPDR

Table 2. T test results on IPDR in Figure 4.

Speed (m/s)	**Schemes**	**Mean**	**Variance**	$\mathbf{T_{value}}$	$\mathbf{T_{value} - T_{critical}}$	**Remarks**
2	reactive	68.313	35.14162	2.252716	-0.00944	accept H_0
	interactive	69.384	36.42932			
5	reactive	67.25	24.86528	3.899695	1.637538	reject H_0
	interactive	68.965	17.72547			
10	reactive	63.004	10.56805	6.589359	4.327202	reject H_0
	interactive	66.634	13.93272			
15	reactive	60.745	7.684339	14.07569	11.81353	reject H_0
	interactive	64.4	7.034222			
20	reactive	60.653	9.665534	8.291875	6.029718	reject H_0
	interactive	64.421	4.958988			
25	reactive	61.981	9.239654	8.397143	6.134986	reject H_0
	interactive	65.551	5.000868			
30	reactive	59.55	13.85924	10.7013	8.439143	reject H_0
	interactive	64.061	9.760157			

Table 3. T test results on IPDR in Figure 7.

No. of nodes	**Scheme**	**Mean**	**Variance**	**T stat**	$\mathbf{T_{value} - T_{critical}}$	**Remarks**
10	reactive	86.075	24.62596	3.278258	1.016101	reject H_0
	interactive	87.402	18.21993			
12	reactive	85.181	8.546321	4.332188	2.070031	reject H_0
	interactive	86.304	6.662849			
14	reactive	85.692	12.84706	7.06506	4.802903	reject H_0
	interactive	87.891	13.06741			
16	reactive	84.01	5.872689	2.43274	0.170583	reject H_0
	interactive	85.701	8.154557			
18	reactive	80.374	12.1318	4.28	2.02	reject H_0
	interactive	84.404	10.37456			
20	reactive	76.882	10.8134	8.44477	6.18	reject H_0
	interactive	80.584	7.326204			
22	reactive	75.261	9.802143	7.111317	4.84916	reject H_0
	interactive	78.303	7.697712			
24	reactive	72.8	4.1636	13.83014	11.56798	reject H_0
	interactive	76.284	4.032316			
26	reactive	67.614	9.775161	5.8816	3.619443	reject H_0
	interactive	71.259	8.515699			
28	reactive	63.924	6.573827	6.61801	4.355853	reject H_0
	interactive	66.891	4.941062			
30	reactive	59.55	13.85924	10.7013	8.439143	reject H_0
	interactive	64.061	9.760157			

To perform the t test on IPDR of Figures 4 and 7, our null hypothesis and the alternate hypothesis are as follows:

> H_0: The two means of the IPDR of the reactive and our interactive schemes are not significantly different.
>
> H_a: The two means of the IPDR of the reactive and our interactive schemes are significantly different.

T test results on IPDR of Figures 4 and 7 are given in Tables 2 and 3 respectively. From Tables 2 and 3, we see that the difference between the $\mathbf{T_{value}}$ and the $\mathbf{T_{critical}}$ is positive for most of the cases (we reject the null hypothesis), i.e., our interactive scheme provides higher IPDR than the reactive scheme for most of the cases with a confidence level 95%.

4.4.2. T test for Average end-to-end delay

Table 4. T test results on average end-to-end delay in Figure 5.

Speed (m/s)	Scheme	Mean	Variance	T stat	T_{value} - $T_{critical}$	Remarks
2	reactive	1635.244	111306.2	0.00015	-2.26201	accept H_0
	interactive	1635.79	102155.4			
5	reactive	1375.798	168763.5	0.073861	-2.1883	accept H_0
	interactive	1370.436	118051.5			
10	reactive	1312.123	59996.24	0.878159	-1.384	accept H_0
	interactive	1269.379	63131.87			
15	reactive	1271.642	33214.52	1.243227	-1.01893	accept H_0
	interactive	1209.519	43261.78			
20	reactive	1263.175	39371.22	3.049494	0.787337	reject H_0
	interactive	1151.85	28371.26			
25	reactive	1223.248	12716.83	3.932532	1.670375	reject H_0
	interactive	1050.294	24786.76			
30	reactive	1201.496	33353.4	8.879538	6.617381	reject H_0
	interactive	970.025	21784.99			

Table 5. T test results on average end-to-end delay in Figure 8.

No. of nodes	Scheme	Mean	Variance	T stat	T_{value} - $T_{critical}$	Remarks
10	reactive	106.402	905.7582	1.694366	-0.56779	accept H_0
	interactive	99.414	1294.542			
12	reactive	125.905	1023.625	3.23106	0.968903	reject H_0
	interactive	110.932	1015.462			
14	reactive	167.781	771.3989	7.235256	4.973099	reject H_0
	interactive	125.581	617.7584			
16	reactive	248.456	5355.004	4.078866	1.816709	reject H_0
	interactive	165.631	902.1428			
18	reactive	333.069	3229.179	4.859085	2.60	reject H_0
	interactive	260.976	3166.544			
20	reactive	461.234	4367.612	4.626608	2.36	reject H_0
	interactive	320.915	3509.737			
22	reactive	507.213	3056.937	2.085241	-0.17692	accept H_0
	interactive	426.488	9503.946			
24	reactive	568.126	2542.479	1.885491	-0.37667	accept H_0
	interactive	499.204	7242.416			
26	reactive	779.692	20805.49	5.547239	3.285082	reject H_0
	interactive	613.58	15840.75			
28	reactive	982.681	7900.833	3.393468	1.131311	reject H_0
	interactive	853.974	16227.58			
30	reactive	1201.496	33353.4	8.879538	6.617381	reject H_0
	interactive	970.025	21784.99			

To perform the t test on average end-to-end delay of Figures 5 and 8, our null hypothesis and the alternate hypothesis are as follows:

H_0: The two means of the delay of the reactive and our schemes are not significantly different.

H_a: The two means of the delay of the reactive and our schemes are significantly different.

T test results on delay of Figures 5 and 8 are given in Tables 4 and 5 respectively. From Tables 4 and 5, we see that our interactive scheme provides lower average end-to-end delay than the reactive scheme for most of the cases with a confidence level 95%.

4.4.3. T test for NCO

Table 6. T test results on NCO in Figure 6.

Speed (m/s)	**Scheme**	**Mean**	**Variance**	**T stat**	**T_{value} - $T_{critical}$**	**Remarks**
2	reactive	0.634	0.01785	4.03458	1.772423	reject H_0
	interactive	0.526	0.006582			
5	reactive	0.68	0.036778	4.24356	1.981403	reject H_0
	interactive	0.553	0.012779			
10	reactive	0.764	0.008649	7.38037	5.118213	reject H_0
	interactive	0.6	0.005756			
15	reactive	0.826	0.021404	5.95741	3.695253	reject H_0
	interactive	0.632	0.008951			
20	reactive	0.871	0.013877	7.81772	5.555563	reject H_0
	interactive	0.658	0.002929			
25	reactive	0.895	0.011072	7.70752	5.445363	reject H_0
	interactive	0.694	0.002761			
30	reactive	0.930	0.019662	6.30933	4.047173	reject H_0
	interactive	0.708	0.002529			

Table 7. T test results on NCO in Figure 9.

No. of nodes	**Scheme**	**Mean**	**Variance**	**T stat**	**T_{value} - $T_{critical}$**	**Remarks**
10	reactive	0.248	0.000262	2.44949	0.187333	reject H_0
	interactive	0.244	0.000227			
12	reactive	0.251	0.000143	0.317999	-1.94416	accept H_0
	interactive	0.252	0.000196			
14	reactive	0.261	0.000521	1.86052	-0.40164	accept H_0
	interactive	0.256	0.000293			
16	reactive	0.278	0.000596	2.75085	0.488693	reject H_0
	interactive	0.265	0.000428			
18	reactive	0.321	0.00061	6.81516	4.55E+00	reject H_0
	interactive	0.287	0.000357			
20	reactive	0.353	0.001312	4.30187	2.04E+00	reject H_0
	interactive	0.324	0.000804			
22	reactive	0.374	0.000671	0.58277	-1.67939	reject H_0
	interactive	0.37	0.000778			
24	reactive	0.449	0.001588	3.8512	1.589043	reject H_0
	interactive	0.403	0.001446			
26	reactive	0.559	0.004766	3.53363	1.271473	reject H_0
	interactive	0.474	0.003329			
28	reactive	0.724	0.007604	7.96496	5.702803	reject H_0
	interactive	0.583	0.002934			
30	reactive	0.930	0.019662	6.30933	4.047173	reject H_0
	interactive	0.708	0.002529			

To perform the t test on NCO of Figures 6 and 9, our null hypothesis and the alternate hypothesis are as follows:

H_0: The two means of the NCO of the reactive and our schemes are not significantly different.

H_a: The two means of the NCO of the reactive and our schemes are significantly different.

T test results on NCO of Figures 6 and 9 are given in Tables 6 and 7 respectively. From Tables 6 and 7 it is evident that our interactive scheme provides lower NCO than that of the reactive scheme for most of the cases with a confidence level 95%. All the t test results prove that our scheme is significantly better than the reactive scheme in terms of packet loss, end-to-end delay, and network overhead.

5. CONCLUSION

To rescue the network from the problems of current Internet gateway discovery and selection schemes, we presented a new gateway discovery and selection scheme. Our scheme uses a triggered broadcast of gateway advertisement messages at the gateways when being hit by gateway discovery messages. We also bounded the dissemination of the gateway advertisement messages up to the requesting mobile node from the gateway. We combined hop count, traffic load (interface queue length), and the total number of neighbors along a route to the gateway in order to formulate a new metric for gateway selection. Our metric chooses the gateway which is not only closest but also has the route from the mobile node with less load and less dense. We compared our gateway discovery and selection scheme with the other schemes in terms of three performance metrics: Internet Packet Delivery Ratio, Average End-to-End Delay and Normalized Control Overhead. Simulation results show that our scheme outperforms other schemes.

A number of open issues remain. In this research work, we consider the gateways to be stationary. In a hybrid environment, it is very likely that there will be a mixture of stationary and mobile gateways. Therefore, mobility of the gateways is an important issue in the gateway discovery and selection process and needs to be considered with due diligence. We considered much higher Internet bandwidth for the gateways compared to that of the MANET. However, higher Internet bandwidth might not be available at the gateways and it might be a serious bottleneck for the Internet traffic of the MANET. We allowed the gateway to broadcast gateway advertisement message when it is being hit by a gateway discovery message without considering the current traffic load at the gateway. If the current load is higher and new Internet traffic is directed towards this gateway by a gateway selection algorithm at the MANET nodes which does not consider the current traffic at the gateway, the new Internet traffic at the heavily loaded gateway might increase serious congestion in the network. In our future work, we will consider these open issues.

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