Implementation and Performance Evaluation of the Gateway Discovery Approaches in the Integrated MANET-Internet Scenario

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***Abstract*— The mobile ad hoc networks have become a major component of the future network development due to their ease of deployment, self-configurability, flexibility and independence on any existing network infrastructure. But most of the research in the field of ad hoc network is limited to stand-alone isolated networks. The demand for any time anywhere connectivity has increased rapidly with the tremendous growth of the Internet in the past decade and due to the huge influx of highly portable devices such as laptops, PDAs etc. In order to facilitate the users with the huge pool of resources and the global services available from the Internet and for widening the coverage area of the MANET there is a growing need to integrate these ad hoc networks to the Internet. For this purpose we need gateways which act as bridges between these two different protocol architectures. The gateway discovery in hybrid network is considered as a critical and challenging task and with decreasing pause time and greater number of sources it becomes even more complex. Due to the scarcity of network resources in MANET, the efficient discovery of the gateway becomes is a key issue in the design and development of future hybrid networks. In this paper the AODV reactive routing protocol is extended to support the communication between the MANET and the Internet. We have carried out a systematic simulation based performance evaluation of the different gateway discovery approaches using NS2 under different network scenarios. The performance differentials are analyzed on the basis of three metrics - packet delivery fraction, average end-to-end delay and normalized routing load.**

Keywords- Mobile ad hoc network, Internet, gateway discovery approaches, performance study, packet delivery fraction, average end-to-end delay, normalized routing load

I. INTRODUCTION

The Internet has grown significantly in the current decade to occupy a huge part of the lives of the common people. For example people present in any part of the world and connected to the Internet can communicate between them in almost no time using email. This plays an important role in the field of academics and research. For example students in distant areas can participate in the online classroom facilities provided by the top universities, they can download the study materials and discuss their problems online. The researchers and scientists in different parts of the world can work in groups and exchange their ideas instantaneously. Their distributed geographic presence no longer constrains the scope and rapid growth of research. On the other hand with the huge influx of mobile phones, laptops and personal digital assistants, mobility has become an indispensable part of our daily lives. These devices are highly portable and can be carried anytime anywhere.

With the increasing use of these devices there is a growing demand for the connectivity to the Internet while we are on the move.

A group of mobile devices can form a self-organized and self-controlled network called a mobile ad hoc network (MANET) [1-14]. The main advantage of these networks is that they do not rely on any established infrastructure or centralized server. These networks are autonomous where a number of mobile nodes equipped with wireless interfaces communicate with each other either directly or through other nodes. The communication is multi-hop and each node has to play the role of both the host as well as the router. But due to the limited transmission range of the MANET nodes, the total area of coverage is often limited. Also due to the lack of connectivity to the fixed network, the users in the MANET work as an isolated group. However, many applications require connection to the external network such as Internet or LAN to provide the users with external resources. In order to access the global services from the Internet and to widen the coverage area there is a growing need to connect these ad hoc networks to the Internet.

Due to the frequent movement of nodes and highly dynamic topology, routing in MANET is considered a highly challenging task. The MANET working group [15] in the Internet Engineering Task Force has proposed several routing protocols for communication within the mobile ad hoc network. These routing protocols can be broadly classified into two categories: proactive and reactive. In protocols following the proactive approach like DSDV [16], CGSR [17], STAR [18], OLSR [19], HSR [20], GSR [21] the nodes in the ad hoc network need to maintain consistent routing information from each node to all other nodes. In case of reactive routing protocols such as DSR [22, 23], AODV [24, 25], ABR [26], SSA [27], FORP [28], PLBR [29] the nodes need not maintain the routes to all other nodes. Routes to the destinations are determined only when required. In order to gain the advantages from both of these approaches, protocols like CEDAR [30], ZRP [31], and ZHLS [32] combine both the proactive and the reactive approaches. But as these protocols are designed mainly to handle the communication only within the ad hoc networks, they need to be modified when we need a mobile device in the MANET to communicate with a host computer on the Internet. For this purpose we need Internet Gateways (IGW). These gateways work as bridges between the different network architectures of MANET and the Internet and they need to understand the protocols of both the mobile ad hoc protocol stack and the TCP/IP protocol suite.

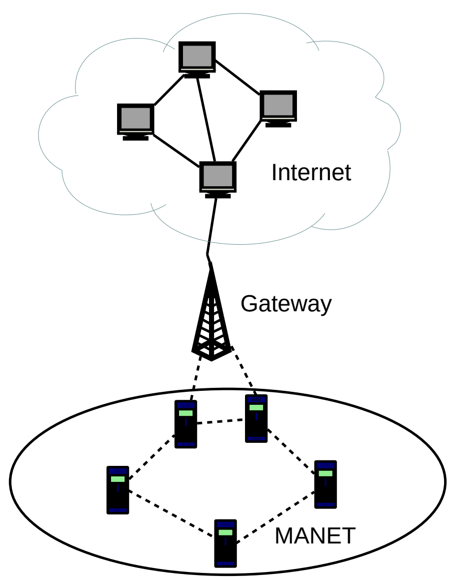

Figure 1. Hybrid Network

For a mobile node in the ad hoc network to communicate and send data to a computer in the Internet, it has to first discover the route to the gateway and forward the data packet to it. The gateway having the connectivity to the Internet, then sends the data packet to the host computer in the Internet. The gateway discovery approaches can be broadly classified into three categories- proactive, reactive and hybrid. The gateway itself initiates the proactive [33, 34] gateway discovery by periodically broadcasting the gateway advertisement message to inform the MANET nodes about the global connection information. Reactive [35, 36] discovery is invoked by the mobile node that needs to create a new route or modify the existing route to the gateway. Hybrid [37, 38] approach tries to combine the advantages of both.

Although a lot of research has been done on the mobile ad hoc routing protocols [39], the area of hybrid networking has remained less regarded. In this work we have used the extended AODV reactive routing protocol to support communication between the MANET and the Internet. The basic idea is to use the extended route discovery procedure so that it can be used to find not only the destination mobile node but also to discover the gateway. The problem of gateway discovery in hybrid network is a challenging one and increasing node mobility and greater number of source nodes make it even more complex. Therefore, the efficient discovery of the gateway is a key issue in the integration of MANET and Internet. In this paper we have described the design and implementation of various gateway discovery approaches and studied the performance differentials of these approaches under different scenarios using ns2 based simulation.

The rest of the paper is organized as follows. Section 2 gives an overview of the related work on the integration of the MANET and the Internet. The issues involved in MANET-Internet connectivity are discussed in section 3. We investigate the different gateway discovery approaches in section 4. Section 5 and section 6 details the simulation model and the key performance metrics respectively. The simulation results are presented and analyzed in section 7. Finally section 8 concludes the paper and defines topics for future research.

II. Related Work

There are only few papers available in the literature on the connectivity of MANETs to the Internet.

In the proposal of Jonsson et al. [33] called MIPMANET the MANET nodes are provided internet access and Mobile IP [40,41] mobility by registering them with the foreign agent and using the concept of foreign agent care of address and tunneling. All data packets are tunneled from the mobile nodes to the foreign agent which then decapsulates and forwards them to the destination in the Internet. This proposal is based on AODV which handles the data traffic within the MANET. A visiting node is allowed to attach to a new foreign agent and leave the old one if the new foreign agent is closer than the old one by at least two hops. This is known as hand-off. Additionally a new algorithm called MIPMANET Cell Switching (MMCS) can be used to find when a MANET node should register with a new foreign agent.

Broch et al. [35] presented an initial approach for integrating the MANET with Mobile IP and Internet using Dynamic Source Routing (DSR) [22, 23]. In this work the notion of border routers was introduced. Each border router has two interfaces. DSR is used for the interface connected to the MANET whereas the interface connected to the Internet uses the normal IP routing approach for handling packets coming in and out of the MANET. The nodes which are within the range of the foreign agents act as gateways between the Internet and MANET. Foreign agents are discovered following the reactive approach. They handle the packet forwarding between the MANET and Internet.

Ratanchandani et al. [37] introduced a hybrid gateway discovery approach which combines the advantages of both the proactive and reactive approaches. This scheme uses AODV and two Mobile IP foreign agents for interconnecting the MANET with the Internet. The excessive flooding of the proactive approach is reduced by carefully controlling the TTL value of the foreign agent advertisement. This reduces the total number of hops that the advertisement can traverse. Thus only the mobile nodes close to the foreign agent receive the advertisement proactively. The nodes which are further away find the gateway following the reactive approach.

Hui Lei and Charles E. Perkins [41] proposed a solution incorporating the Mobile IP on top of a proactive approach for integrating the Ad Hoc routing protocol with the Mobile IP Routing protocol. A combined routing table is generated as a result. Within the ad hoc network routing is provided by the proactive routing protocol - *routed*. It is a modified version of the Routing Information Protocol (RIP) and is implemented on each MANET node. The integration of the protocols allows the foreign agents to take part in the ad hoc network routing. The foreign agent acts as a default router for each mobile node. The modified RIP forwards the agent advertisements and registration messages through multi-hop paths between the MANET nodes and the foreign agent.

Sun et al. [34] investigated the performance of the cooperation between AODV and Mobile IP. This interoperation enables the mobile nodes to connect to the Internet. AODV handles the route discovery and maintenance within the MANET. Mobile IP enables the MANET nodes to connect to the foreign agent and acquire the care of addresses. The foreign agent acts as the Internet Gateway (IGW).

Wakikawa et al. [36] in their work discussed how a MANET node can derive a globally routable IPv6 address based on the neighbor discovery protocol (NDP) of IPv6. The mobile nodes use this address to connect to the Internet. In this paper two different gateway discovery approaches are designed. The first one is periodic where the gateway floods the gateway advertisement (GWADV) messages at a certain time interval. In the second approach the mobile nodes reactively floods the gateway solicitation (GWSOL) messages.

In the proposal of Lee et al. [38] a hybrid gateway discovery scheme is presented and it is compared with a reactive approach. For handling the routing within the MANET it uses a source routing protocol. This limits the applicability and scalability of their scheme. In this approach only upon the detection of the topology change in MANET, advertisements are sent out by the gateway. In addition to that, advertisements are forwarded only to those MANET nodes that are either connected to the Internet or have made a movement. Furthermore, advertisements are generated, only if the ratio between the number of nodes connected to the Internet and the number of nodes forwarding the advertisements exceeds a specific value.

Tseng et al. [42] designed a new approach for integrating the MANET with the Internet. Their scheme involves multiple MANETs connected to the Internet. DSDV is used for handling the communication within a MANET whereas standard IP routing is used for interaction between different MANETs. Each MANET is controlled by one gateway which is equipped with wireless and wired interfaces. Every MANET has its own Time-to-Live (TTL) value equal to N. Only the mobile nodes which are within N hops from the gateway can register with it as the agent advertisements can only proceed up to N hops from the gateway. Number of hops is used as the metric by the nodes to choose between multiple gateways.

III. MANET AND INTERNET CONNECTIVITY

A. The basic protocol stack

Comparing the basic protocol stack for mobile ad hoc network with OSI model and TCP/IP suite, we get a better understanding of the differences in their protocol architecture. Figure 2 shows these protocol stacks.

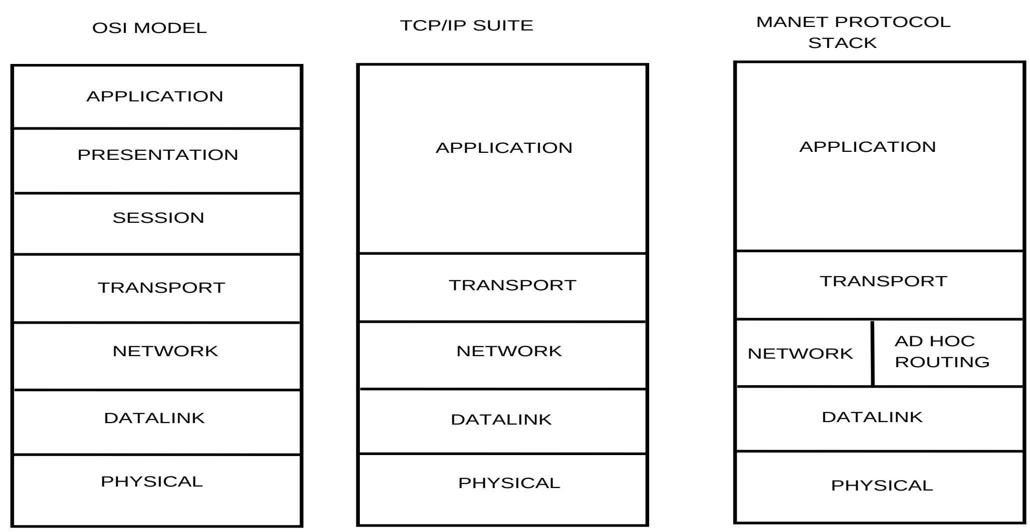

Figure 2. Basic Protocol Stack

OSI model provides a layered framework for communication between networked computers. TCP/IP suite was designed before the OSI model. The lower four layers are same as the OSI model. The topmost layer, i.e. the application layer is a combination of the application, presentation and session layer of the OSI model. The MANET protocol stack is similar to the TCP/IP suite. Only the network layer differs for these two protocol stacks. In case of MANET protocol stack, this layer is divided into two parts – network and ad hoc routing. Standard Internet routing protocols are used in the network part. MANET nodes use an ad hoc routing protocol for handling the routing within the ad hoc network. Mobile nodes run protocols that have been designed for the wireless channels and are capable of decentralized direct mode operation in the physical and data link layers. We have used IEEE 802.11 for our ns2 based simulation in this work.

Figure 3 shows the protocol architecture needed for interconnection between the MANET and the Internet. The Internet nodes use the TCP/IP suite and the MANET nodes use the MANET protocol stack discussed above. Whenever a mobile node wants to send a data packet to the Internet, it has to forward it to the gateway. The gateway then transmits the packet to the corresponding node in the Internet. Thus the gateway functions as a bridge between the MANET and the Internet. It has to translate between these two different protocols and must understand both. Therefore, it needs to implement both the MANET protocol stack and the TCP/IP suite.

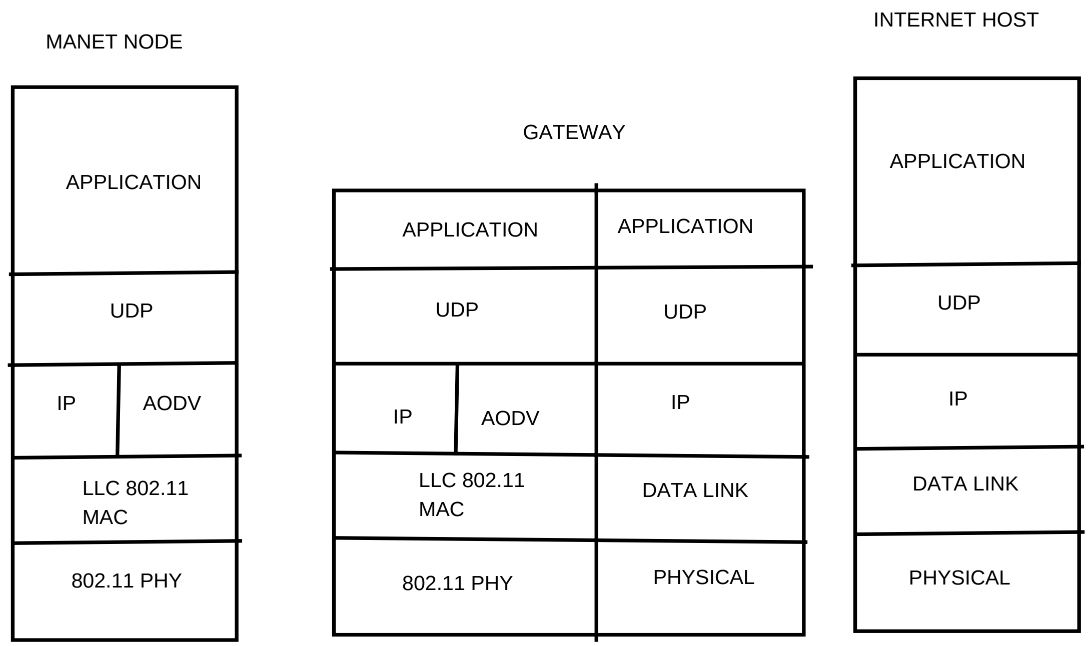

Figure 3. Protocol Architecture for Interconnection between MANET and Internet

B. Extended Route Request and Route Reply Message

The standard mobile ad hoc routing protocols are not designed to perform the gateway discovery. Hence, extensions of the existing mobile ad hoc routing protocols are needed for the integration of MANET and Internet. In this work the route discovery mechanism of AODV is extended to find not only the routes to other mobile nodes but also to the gateways.

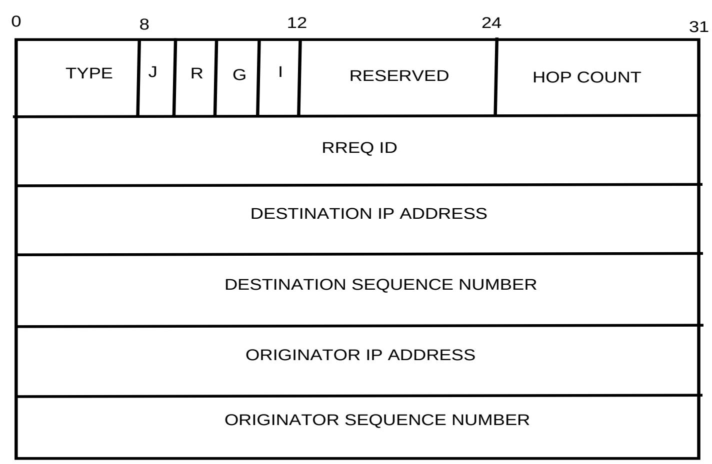

Figure 4. Format of Extended RREQ (RREQ_I) Message

The extended route request message contains one additional field than the normal RREQ message of AODV. This field contains a flag called the Internet Global Address Resolution Flag or the I-flag. The RREQ message extended with this I-flag is termed as RREQ_I message and is used to indicate that the source node has requested for global route discovery.

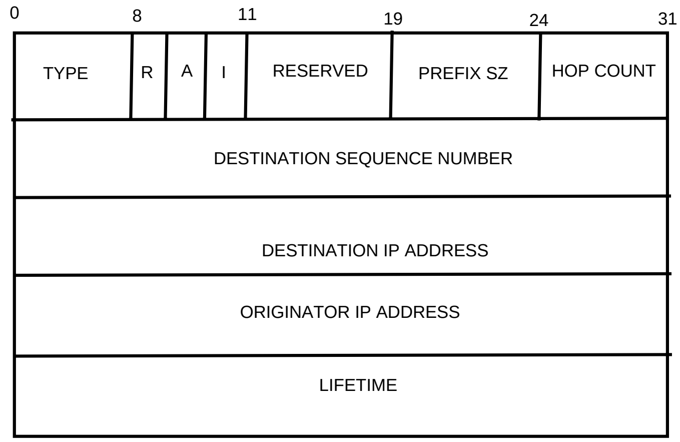

Figure 5. Format of Extended RREP (RREP_I) Message

The RREP message is similarly extended by the Internet Global Address Resolution Flag or the I-flag. The RREP message extended with the I-flag is known as RREP_I message. This flag is used for global address resolution. It indicates that the gateway information is carried by the RREP_I message.

IV. Gateway Discovery Approaches

Depending on who initiates the gateway discovery, these approaches can be broadly classified into the following three categories.

A. Proactive Gateway Discovery

The gateway itself starts the proactive gateway discovery by periodically broadcasting the gateway advertisement (GWADV) message. This message is an extended version of the RREP_I message containing the additional RREQ ID field form the RREQ message and is transmitted at regular intervals after the expiration of the gateway's timer (ADVERTISEMENT_INTERVAL). The mobile nodes which are within the transmission range of the gateway, receive the advertisement and either create a new route entry or update the existing route entry for the gateway in their routing table. After this, a mobile node checks to find whether a GWADV message with the same originator IP address and same RREQ ID has already been received within the same time interval. If it is not so then the new advertisement is rebroadcasted, otherwise it is discarded. This solves the problem of duplicated advertisement messages and allows the flooding of the advertisement message through the whole network with controlled congestion.

B. Reactive Gateway Discovery

In this approach a mobile node that wants to find a new route or update an existing route to the gateway, initiates the gateway discovery. If a source mobile node wants to communicate with an Internet node, it first performs the expanding ring search technique to find the destination within the ad hoc network. When it obtains no corresponding route reply even after a network-wide search, the source mobile node broadcasts a RREQ_I message to the ALL_MANET_GW_MULTICAST address. This is the IP address for the group of all gateways. Thus only the gateways receive and reply to this message. The intermediate mobile nodes receiving this message simply rebroadcast it after checking the RREQ ID field, to avoid any kind of duplicate broadcast. After receiving the RREQ_I, the gateways unicast back RREP_I message to the source node. The source then selects one of the gateways based on the hop count and forwards the data packet to the selected gateway. Next, the gateway sends the data packet to the destination node in the Internet.

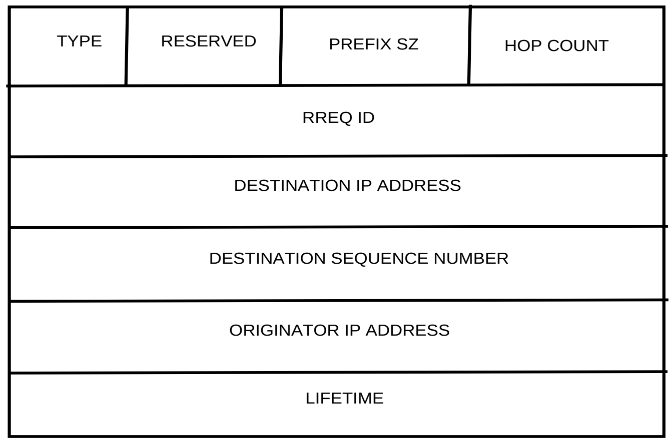

Figure 6. Format of Gateway Advertisement (GWADV) Message

C. Hybrid Gateway Discovery

In the hybrid gateway discovery approach the gateway periodically broadcasts the GWADV message. The TTL is set to ADVERTISEMENT_ZONE so that the advertisement message can be forwarded only up to this maximal number of hops through the ad hoc network. The mobile nodes within this region receive this message and act according to the proactive approach. The nodes outside this region discover the default routes to the gateways using the reactive approach.

V. SIMULATION MODEL

We have done our simulation based on ns-2.34 [43, 44, 45, 46] which has the support for the simulation of multi-hop wireless ad hoc network completed with physical, data link and medium access control (MAC) layer models. NS is a discrete event simulator. It was developed by the University of California at Berkeley and the VINT project [43]. Our main goal was to measure the performance of the different gateway discovery approaches under a range of varying network conditions. We have used the Distributed Coordination Function (DCF) of IEEE 802.11[47] for wireless LANs as the MAC layer protocol. DCF uses RTS/CTS frame along with random back off mechanism to resolve the medium contention conflict.

As buffering is needed for the data packets which are destined for a particular target node and for which the route discovery process is currently going on, the protocols have a send buffer of 64 packets. In order to prevent indefinite waiting for these data packets, the packets are dropped from the buffers when the waiting time exceeds 30 seconds. The interface queue has the capacity to hold 50 packets and it is maintained as a priority queue. The interface queue holds both the data and control traffic sent by the routing layer until they are transmitted by the MAC layer. The control packets get higher priority than the data packets.

A. Mobility Model

Inclusion of a mobility model is necessary in order to evaluate the performance of a protocol for ad hoc network in a simulated environment. Here in our work we have used the random waypoint model. This model is a simple and common mobility model and is widely used for the performance evaluation of MANET protocols in simulated environment. The mobile nodes are initially distributed over the entire simulation area. In order to ensure randomness in the initial distribution, data gathering has to start after a certain simulation time. A mobile node starts simulation by waiting at one location for a specified pause time. After this time is over, it randomly selects the next destination in the simulation area. It also chooses a random speed uniformly distributed between a maximum and minimum speed and travels with a speed v whose value is uniformly chosen in the interval $(0, v_{max})$. Then the mobile node moves towards its selected destination at the selected speed. After reaching its destination, the mobile node again waits for the specified pause time before choosing a new way point and speed.

B. Movement Model

In the simulation environment the mobile nodes move according to our selected random waypoint mobility model. We have generated the movement scenario files using the *setdest* program which comes with the NS-2 distribution. These scenario files are characterized by pause time. The total duration of our each simulation run is 900 seconds. We have varied our simulation with movement patterns for ten different pause times: 0, 100, 200, 300, 400, 500, 600, 700, 800, 900 seconds. These varying pause times affect the relative speed of the mobile nodes. A pause time of 900 seconds corresponds to the motionless state of the nodes in the simulation environment as the total duration of the simulation run is 900 seconds. On the contrary when we choose the pause time of 0 second, it indicates continuous motion of the nodes. We have performed our experiment with two different numbers of source nodes: 10 source nodes and 20 source nodes. As slight changes in the movement pattern will have significant effect on the protocol performance, we have generated scenario files with 100 different movement patterns, 10 for each value of pause time. In order to compare the performance based on the identical scenario, each of the gateway discovery approaches was run with these 100 different movement patterns.

C. Communication Model

In our simulation environment the MANET nodes use constant bit rate (CBR) traffic sources when they send data to the Internet domain. We have used the *cbrgen* traffic-scenario generator tool available in NS2 to generate the CBR traffic connections between the nodes. Data packets transmitted are of 512 bytes. We have used two different communication patterns corresponding to 10 and 20 sources. Data packets are sent by each source at the rate of 5 packets/second. The complete list of simulation parameters are shown in Table 1.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of Mobile nodes	50
Number of sources	10,20
Number of gateways	2
Number of hosts	2
Transmission range	250 m
Simulation time	900 s
Topology size	1200 m X 800 m
Source type	Constant bit rate
Packet rate	5 packets/sec
Packet size	512 bytes
Pause time	0,100,200,300,400,500, 600,700,800,900 seconds
Maximum speed	20 m/sec
Mobility model	Random way point
Gateway discovery approaches	Proactive, reactive and hybrid

D. Hybrid Scenario

We have used a rectangular simulation area of 1200 m x 800 m. The choice of rectangular area instead of square area was made in order to ensure longer routes between nodes. In our simulation we have used two ray ground propagation model. Our mixed scenario consists of a wireless and a wired domain. The simulation was performed with the first scenario of 50 mobile nodes among which 10 are sources, 2 gateways, 2 routers and 2 hosts and the second scenario of 50 mobile nodes among which 20 are sources, 2 gateways, 2 routers and 2 hosts. One of the two hosts in the wired domain is chosen randomly as the required destination for each data session. Each host is connected to the gateway through a router. For our hybrid network environment we have two gateways located at each side of the simulation area and running both extended AODV and fixed IP routing protocols. Their x,y-coordinates in meters are (200, 400) and (1000, 400). Every communication between the wired and wireless part goes through the gateway. In our two simulation scenarios 10 and 20 mobile nodes respectively act as constant bit rate traffic sources. They are initially distributed randomly within the MANET. These sources start sending data packets after the first 10 seconds of simulation in order to ensure that the data packets are not dropped due to the lack of routes not yet established. They stop sending data packets 5 seconds before the end of the simulation so that the data packets sent late get enough time to reach their destinations.

For our mixed simulation scenario we have turned on hierarchical routing in order to route packets between the wired and the wireless domains. The domains and clusters are defined by using the hierarchical topology structure. As the gateways act as bridges between the wired and wireless domains they need to have their wired routing on. In the simulation setup we have done this by setting the node-config option –wiredRouting on. After the configuration of the gateways, the wireless nodes are reconfigured by turning their wiredRouting off.

VI. PERFORMANCE METRICS

We have primarily selected the following three parameters in order to study the performance comparison of the three gateway discovery approaches.

Packet delivery fraction: This is defined as the ratio between the number of delivered packets and those generated by the constant bit rate (CBR) traffic sources.

Average end-to-end delay: This is basically defined as the ratio between the summation of the time difference between the packet received time and the packet sent time and the summation of data packets received by all nodes.

Normalized routing load: This is defined as the number of routing packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission.

VII. SIMULATION RESULTS AND ANALYSIS

In this section we have studied the effect of the three gateway discovery approaches under varying pause time and increasing number of sources, on the performance of the hybrid ad hoc network.

A. Packet Delivery Fraction (PDF) Comparison

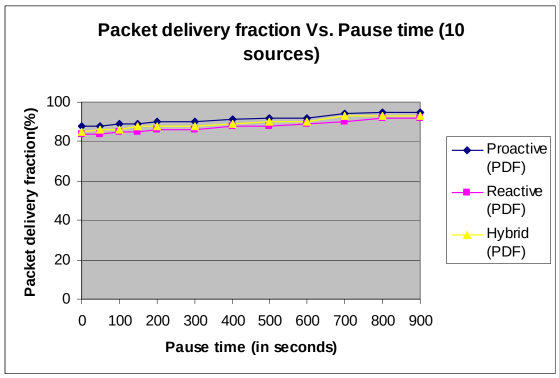

Figure 7. Packet Delivery Fraction Vs. Pause Time for 10 sources

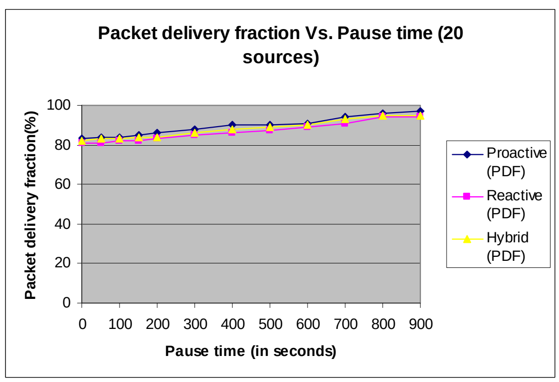

Figure 8. Packet Delivery Fraction Vs. Pause Time for 20 sources

The packet delivery fraction is measured under varying pause time with 10 and 20 number of sources. From Figure 7 and Figure 8 we see that the proactive approach has better packet delivery performance than the reactive approach. This happens because - due to the periodic update of route information form the gateway, routes form all the nodes to the gateway are always available. As a result majority of the packets are delivered smoothly. In case of reactive approach, a node wishing to send data to the destination needs to find the route to the gateway first. This takes a certain amount of time and no packet can be sent during this period due to the unavailability of routes. Moreover, in case of proactive approach, due to regular exchange of gateway information, routes are always optimized and the nodes have fresher and shorter routes to the destination. This reduces the chances of link breaks and increases the packet delivery ratio. On the other hand in reactive approach, a node continues to use a longer route until it is broken even if an alternate shorter route is available. With longer and older routes, the chances of link breaks and the dropping of packets also increase. This reduces the packet delivery fraction. The packet delivery performance of the hybrid approach falls between that of the proactive and reactive approaches.

From the figure it is evident that the packet delivery performance deteriorates with decreasing pause time in all three approaches. Due to high mobility and frequent link breaks, nodes won't be able to send data packets to the gateway thereby reducing the packet delivery ratio. In the reactive approach, the routes are not optimized and nodes continue to maintain longer routes. As pause time decreases, the topology becomes highly dynamic. Due to the frequent link breaks, the older routes tend to become stale quickly. But the source node continues to send packets through these stale routes until it receives RERR message from a mobile node having a broken link. With longer routes it takes greater time for the source node to receive RERR. As a result, during this time greater numbers of packets are dropped. Furthermore, with decreasing pause time, the reactive approach needs to invoke more route discoveries due to the frequent link breaks. This increases the amount of control traffic which leads to congestion in the network and greater route discovery latency. Due to unavailability of routes during this period, packets get dropped which ultimately results in reduced packet delivery performance.

From the figure we also see that as the number of sources is increased, initially the packet delivery performance becomes better. This is due to the fact that with less number of sources, the channel capacity is not fully utilized. Therefore, increasing the number of sources also increases the packet delivery ratio. However, when the number of sources is increased more, there will be high volume of traffic in the network leading to congestion. Due to greater control traffic, less portion of the channel is left for the data. This ultimately reduces the packet delivery ratio.

B. Average End-to-End Delay Comparison

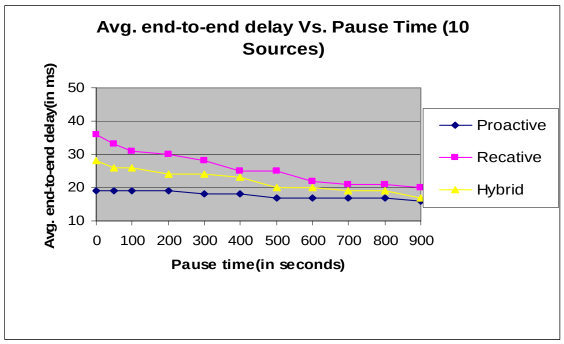

Figure 9. Average End to End Delay Vs. Pause time for 10 Sources

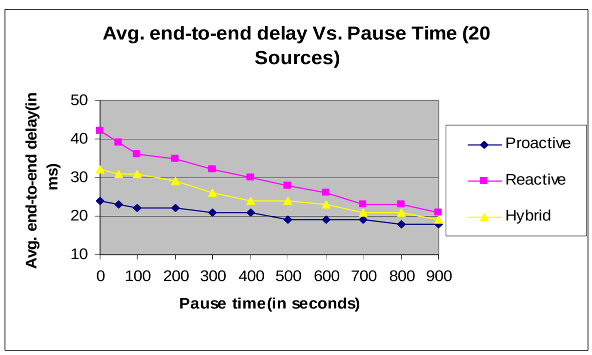

Figure 10. Average End to End Delay Vs. Pause time for 20 Sources

From Figure 9 and Figure 10 we see that the average end-to-end delay with the proactive and hybrid gateway discovery approach is less in comparison to the reactive gateway discovery. In proactive approach, due to periodic route updates from the gateway, routes are optimized regularly and the nodes have fresher and shorter routes to the gateway. Moreover, all the routes are maintained all the time. This instant availability of the fresher and shorter routes enables the nodes to deliver packets to their destinations with less delay. In reactive approach, a node needs to find a route to the gateway first before sending the packet. This initial path setup delays the delivery of the packets.

From the figures we also see that the average end-to-end delay increases with decreasing pause time and increasing number of sources. As the nodes become more mobile, the links break more frequently. This together with the greater number of sources, necessitates the reactive route discovery process to be invoked more often thus causing huge amount of control traffic. The data traffic also increases with more number of sources. This results in more collisions, more retransmissions and further congestion in the network. Consequently the constrained channel increases the route discovery latency which in turn increases the average end-to-end delay. In the absence of any regular route update mechanism, reactive approach suffers from older and longer routes which increase the chances of link breaks, leading to further delay.

Hybrid approach combines the proactive and reactive approaches in order to reduce the excessive delay of the reactive approach. In the simulation done in our work, the gateways broadcast the gateway advertisement messages periodically up to three hops away and the nodes beyond that region follow the reactive gateway discovery approach. As a result the average end-to-end delay becomes less than that of the reactive approach but more than that of the proactive approach.

C. Normalized Routing Load Comparison

In terms of normalized routing load the reactive approach outperforms the proactive and hybrid approaches. In the reactive approach, the gateway discovery is initiated only when a mobile node needs to send a data packet which results in comparatively less routing overhead. As hybrid approach is a combination of proactive and reactive approaches, its normalized routing load lies between them.

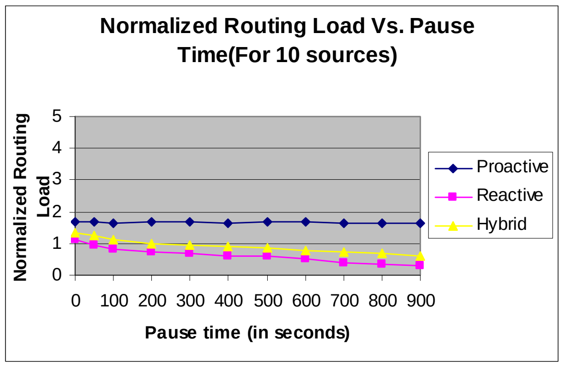

Figure 11. Normalized Routing Load Vs. Pause Time for 10 Sources

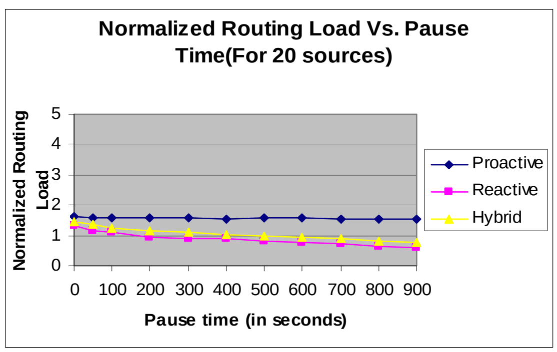

Figure 12. Normalized Routing Load Vs. Pause Time for 20 Sources

The normalized routing overhead of the proactive approach remains almost constant for a particular advertisement interval irrespective of the pause time. Whereas in case of reactive approach with decreasing pause time, the gateway discoveries need to be invoked more often due to frequent link breaks. Moreover, as the reactive approach continues using longer and older routes and does not use route optimization until the route is broken, the chances of link breaks also increases. This further adds to the number of route discoveries. With this greater number of gateway discoveries, the control traffic also increases, which ultimately results in higher normalized routing load.

From the figures we see that the normalized routing load decreases for the proactive approach with more number of sources. The amount of control overhead remains almost same for a particular advertisement interval irrespective of the number of sources in case of the proactive gateway discovery mechanism. But with increasing number of sources the number of received data packets increases. This leads to the reduced normalized routing load of the proactive approach.

In case of reactive approach, with greater number of source mobile nodes, the number of gateway discovery also increases. This causes higher volume of control overhead. More number of sources with higher volume of data traffic also creates congestion in the network which causes further collisions, more retransmissions and newer route discoveries. This further adds to the already increased control overhead resulting in higher normalized routing load.

VIII. Conclusion

In this paper we have described the design and implementation of the various gateway discovery approaches and carried out a detailed ns2 based simulation to study and analyse the performance differentials of these approaches under different scenarios. From the simulation results we see that the proactive approach shows better packet delivery performance than the reactive approach mainly due to the instant availability of fresher and newer routes to the gateway all the time. With greater number of sources, although initially the packet delivery performance becomes better but later when the number of sources is increased more, due to congestion the packet delivery ratio drops. In terms of the average end-to-end delay, the proactive and hybrid gateway discovery approaches outperform the reactive gateway discovery. As we decrease the pause time and increase the number of sources, all the approaches suffer form greater average end-to-end delay. As far as normalized routing overhead is concerned, the reactive approach performs better than the proactive and hybrid approaches. In case of the proactive approach the normalized routing load remains almost constant for a particular advertisement interval irrespective of the pause time. With more number of sources, the number of received data packets increases for the proactive approach which accounts for its reduced normalized routing load. Whereas for the reactive approach, with decreasing pause time and increasing number of sources, the number of gateway discoveries and as a result the amount of control traffic also increases, which ultimately results in higher normalized routing load. The hybrid approach being a combination of proactive and reactive approaches, its normalized routing load lies between them.

In this work our main focus was on evaluating the performance of the three gateway discovery approaches under varying pause time and different number of sources. However, to have an in-depth idea of the performance characteristics of these approaches we need to consider many other issues. In our future work, we plan to study the performance of these gateway discovery approaches under other network scenarios by varying the network size, the number of connections, distance between the gateways, the mobility models and the speed of the mobile nodes etc.

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