An Improved Approach for Working outside the MANET by Extending MANET Routing Protocol

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Abstract

Mobile ad-hoc network have the attributes such as wireless connection, continuously changing topology, distributed operation and ease of deployment. We present a design space analysis of the problem of providing Internet connectivity for mobile ad hoc networks (MANETs). 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 different protocols architectures. In this paper the AODV reactive routing protocol is extended to support the communication between the MANET and the Internet.

Keywords: *Packet delivery fraction, Average end-to-end delay, Average throughput, routing overhead, Loss of data packets.*

1. Introduction

MANET is a collection of wireless mobile nodes that communicate with each other using multi-hop wireless links without any existing network infrastructure or centralized administration [12]. Each node in the network behaves as a router and forwards packets to other nodes. For several military and civil applications, networking the mobile or static nodes with wireless links in an ad hoc manner can be necessary and effective [1].

In this paper our goal is to design Internet connectivity for MANETs that can handle node mobility, both within and in between networks, having continuous and uninterrupted Internet connections whenever there is at least one potential route to one or more gateways.

To achieve this network interconnection, gateways that understand not only the IP suite, but also the MANET protocol stack, are needed. Thus, a gateway acts as a bridge between a MANET and the Internet and all communication between the two networks must pass through any of the gateways.

This paper evaluates approaches for gateway discovery. An interesting question is whether the configuration phase with the gateway should be initiated by the gateway (proactive method), the mobile node (reactive method) or by mixing these two approaches. All of them are based on the number of physical hops to gateway as the metric for the gateway selection.

When using proactive routing protocols, also called "table driven" protocols, mobile nodes continuously evaluate routes to all reachable nodes and attempt to maintain up-to-date routing information. The advantages of this type of protocols are discovery of the shortest path through network and availability of routes at the time of need, this reduces delays. The drawback of proactive routing protocols is providing a resistance to network topology changes.

On the other hand, when mobile nodes use reactive routing protocols, also called "on-demand" protocols, route discovery operation is performed only when a routing path is needed, and it is terminated when a route or no route has been found. A very important operation in reactive routing is route maintenance. The advantages of this type of protocols are efficiency, reliability and less control overhead. However, a major lack is a long delay caused by a route discovery operation in order to transmit data packets. Hybrid approach tries to combine the advantages of both. These protocols perform variously depending on type of traffic, number of nodes, rate of mobility, etc.

There are various mobility models such as Random Way Point, Reference Point Group Mobility Model (RPGM), Manhattan Mobility Model, Freeway Mobility Model, and Gauss Markov Mobility Model etc that have been proposed for evaluation [2], [5].

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 so far. Section 3 describes the Routing Protocols for MANET whereas Section 4 analyzes the AODV routing protocol in detail. Section 5 describes the MANET Protocol Stack that supports AODV. Section 6 describes the integration of the

MANET and the Internet and the issues involved in MANET-Internet connectivity. The Enhanced AODV Routing Protocol which explains my work is described in Section 7. The different gateway discovery approaches are described in Section 8. The simulation setup and the network simulator-NS2 used are discussed in section 9. Also results are presented and analyzed in this section. Finally section 10 concludes the paper with future work.

2. Related Work

Mobile nodes in the Ad Hoc network need global addresses to communicate outside the MANET and node mobility should be properly dealt with [16][8]. Especially, when mobile nodes move to another area, their subnet changes and a new IP address must be obtained. Several solutions have been proposed to deal with the integration of MANETs to the Internet. Most of the proposed solutions require the addition of gateways and the routing protocols used within the Ad Hoc network. Since Internet gateways have two interfaces they are part of the Internet and the Ad Hoc network simultaneously. They understand the Internet protocol (IP) as well as a MANET routing protocol (e.g. AODV).
In this section we explore the most significant features of the main MANET interconnection mechanisms namely those from Wakikawa *et al [9]*, Jelger *et al.* [10], Singh *et al [11]* and Ros *et al.* Table I summarize the main features provided by each one.

Table 1
Summary of features of well known existing protocols.
P=Proactive, R= Reactive, H=Hybrid, A= Adaptive, RH=Routing Header, DR= Default Routing, OPT=Optional

	Wakikawa	Jelger	Singh	Ros
GW Discovery	P/R	P	H	A
Multiple Prefix	Yes	Yes	No	Yes
Stateless/ful	less	less	n/a	less
DAD	Yes	No	n/a	Opt
Header/Default	RH	DR	Both	n/a
Limited Flooding	No	Yes	No	Yes
Load Balancing	No	No	Yes	No
Complete Spec.	Yes	Yes	No	Yes

"Wakikawa" [9] defines two mechanisms, a reactive and a proactive one. In the reactive version, when a node requires global connectivity it issues a request message which is flooded throughout the MANET. When this request is received by a gateway, then it sends a message which creates reverse routes to the gateway on its way back to the originator.
Ratanchandani et al. [13] 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.

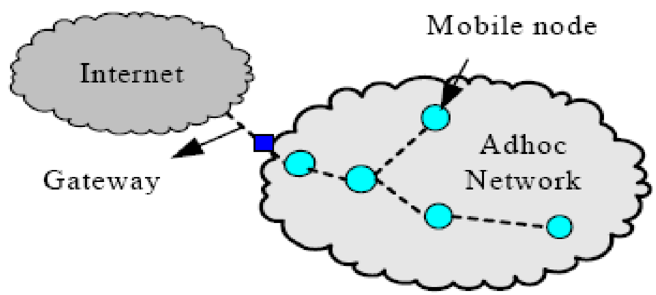

Fig. 1 Mobile Ad Hoc network connected with Internet

3. Routing Protocols for MANET

Routing protocols for MANETs can be broadly classified into three main categories:

3.1 Proactive routing protocols:

Every node in the network has one or more routes to any possible destination in its routing table at any given time.

3.2 Reactive routing protocols:

Every node in the network obtains a route to a destination on a demand fashion. Reactive protocols do not maintain up-to-date routes to any destination in the network and do not generally exchange any periodic control messages.

3.3 Hybrid routing protocols:

Every node acts reactively in the region close to its proximity and proactively outside of that region, or zone.

4. AODV (Adhoc on Demand Distance Vector)

There are two types of routing protocols which are reactive and proactive. In reactive routing protocols the routes are created only when source wants to send data to destination whereas proactive routing protocols are table driven. Being a reactive routing protocol AODV [14] uses traditional routing tables, one entry per destination and sequence numbers are used to determine whether routing information is up-to-date and to prevent routing loops. The maintenance of time-based states is an important feature of AODV which means that a routing entry which is not recently used is expired. The neighbors are notified in case of route breakage. Control messages used for the discovery and breakage of route are as follows:

4.1 Route Request (RREQ):

A route request packet is flooded through the network when a route is not available for the destination from source. The parameters are:

Table 2: Route Request Parameters

Source Address	Request ID Source	Sequence Number	Destination Address	Destination Sequence Number	Hop Count

A RREQ is identified by the pair source address and request ID, each time when the source node sends a new REQ and the request ID is incremented. After receiving of request message, each node checks the request ID and source address pair. The new RREQ is discarded if there is already RREQ packet with same pair of parameters. A node that has no route entry for the destination, it rebroadcasts the RREQ with incremented hop count parameter.

4.2 Route Reply (RREP):

Once find out the valid route to the destination or if the node is destination, a RREP message is sent to the source by the node.
The following parameters are contained in the route reply message:

Table 3: Route Reply Parameters

Source Address	Destination Address	Destination Sequence Number	Hop Count	Life Time

4.3 Route Error Message (RERR):

The neighborhood nodes are monitored. When a route that is active is lost, the neighborhood nodes are notified by route error message (RERR) on both sides of link.

4.4 Hello Messages:

The HELLO messages are broadcasted in order to know neighborhood nodes. The neighborhood nodes are directly communicated. In AODV, HELLO messages are broadcasted in order to inform the neighbors about the activation of the link. These messages are not broadcasted because of short time to live (TTL) with a value equal to one.
Route discovery process begins when one of the nodes wants to send packets. That node sends Route Request (RREQ) packets to its neighbors. Neighbors return RREP packets if they have a corresponding route to destination. However, if they don't have a corresponding route, they forward RREQ packets to their neighbors, except the origin node. Also, they use these packets to build reverse paths to the source node. This process occurs until a route has been found. The algorithm uses hello messages. If hello messages stop coming from a particular node, the neighbor can assume that the node has moved away and mark that link to the node as broken and notify the affected set of nodes by sending a link failure notification (a special RREP) to that set of nodes. These messages are broadcasted because with TTL value equal to one.
When a source node does not have routing information about destination, the process of the discovery of the route starts for a node with which source wants to communicate. The process is initiated by broadcasting of RREQ. On receiving RREP message, the route is established. If multiple RREP messages with different routes are received then routing information is updated with RREP message of greater sequence number. If the originator node does not receive a RREP message within a certain time interval, it exponentially increments the time interval and increases the diameter of the searching ring.
In conclusion, the simple design, the low routing overhead and the ring searching technique make AODV an attractive solution for networks in which the available bandwidth is limited and nodes can form organized groups.

5. MANET Protocol Stack

Figure 2 shows the protocol stack of MANET which consists of five layers: physical layer, data link layer, network layer, transport layer and application layer. It has similarities to the TCP/IP protocol suite. As can be seen, the OSI model's session, presentation and application layers are merged into one section, the application layer in MANET and TCP/IP suite.

OSI is a layered framework for the design of network systems that allows for communication across all types of computer systems. Because TCP/IP was designed before the OSI model, its layers do not correspond exactly to the OSI layers. The lower four layers are the same in both models but the fifth layer in the TCP/IP suite (the application layer) is equivalent to the combined session, presentation and application layers of the OSI model.
The main difference between MANET and TCP/IP suite protocol stacks lies in the network layer. MNs (which are both hosts and routers) use an ad hoc routing protocol to route packets. In the physical and data link layer, MNs run protocols that have been designed for wireless channels. In this paper work, the standard IEEE 802.11 is used as simulation tool.

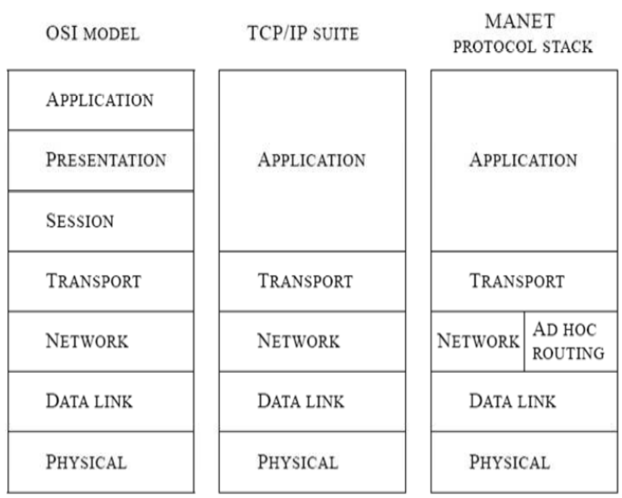

Figure 2: OSI Model, TCP/IP Protocol Suite and MANET Protocol Stack

When extended AODV MANET routing protocol is considered, the network layer is divided into two parts: The fixed network and Ad Hoc Routing in the MANET. The protocol used in the fixed network part is Internet Protocol (IP) and the protocol used in the ad hoc routing part is AODV.
In the transport layer, the User Datagram Protocol (UDP) is used in this work. The Transmission Control Protocol (TCP) is not used because different research works revealed that, TCP does not perform well in MANETs. This is because of the fact that, in wired networks, lost packets are almost always due to congestion but in MANETs, lost packets are more often caused by other reasons like link breakage due to mobility or interference [15].

6. Connectivity of MANET with Internet

Whenever a MN is to send packets to a fixed network, it must transmit the packets to a GW [3]. The protocol stacks involved during communication between a MANET and the fixed Internet node is shown in Figure 3. A GW acts as a bridge (not the network device) between a MANET and the Internet. Therefore, it has to implement both the MANET protocol stack and the TCP/IP suite.

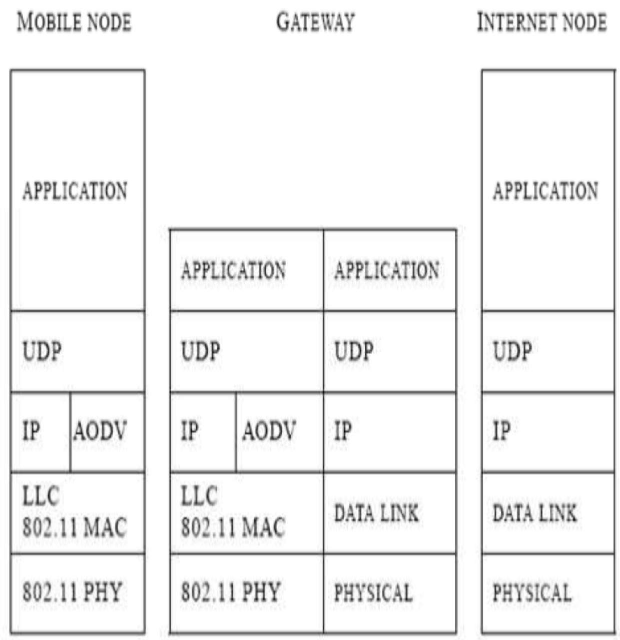

Figure 3: The Protocol Stack Used By Mobile Node, Internet Node and Gateway

7. Enhanced AODV Protocol

The enhanced AODV MANET routing protocol to support the three types of GWDAs.

7.1 The Enhanced Route Request

The enhanced RREQ message contains exactly the same fields with the same functions as the ordinary RREQ message, except for a flag as shown in Figure 4. This flag is called ‘Internet-Global Address Resolution Flag’ and is referred to as the I-flag. The, I-flag is used for global address resolution. It indicates that the source node requests global connectivity. The RREQ_I message plays the same role as the router solicitation message of ICMP. The RREQ_I message is used to reactively discover a gateway.

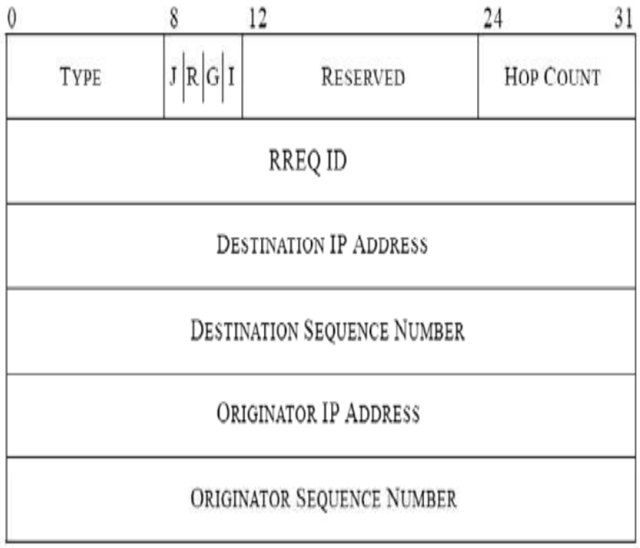

Figure 4: Enhanced Route Request Message Format

7.2. The Enhanced Route Reply

The enhanced RREP message contains exactly the same fields with the same functions as the ordinary RREP message, except for a flag. 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. The RREP_I message plays the same role as the router advertisement message of ICMP.

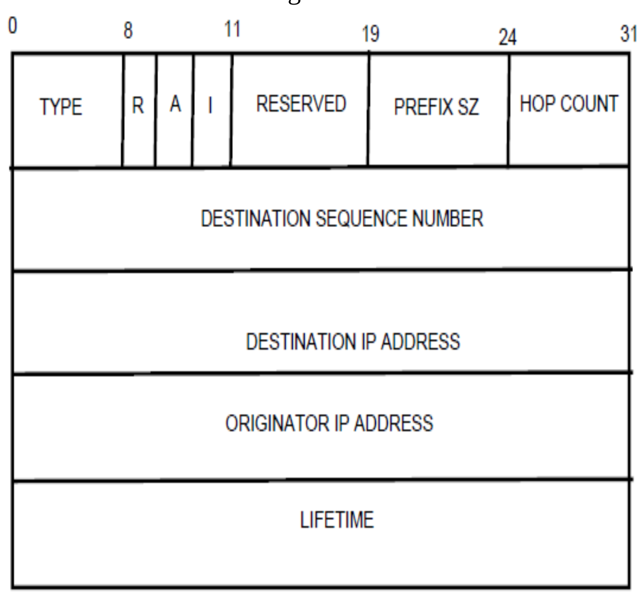

Figure 5: The Enhanced Route Reply Message Format

7.3. The Gateway Advertisement (GWADV)

GWADV is approximately a RREP_I message but it is extended to have a GWADV_ID, just like the RREQ ID of the RREQ packet in AODV MANET routing protocol. The GWADV_ID helps to avoid duplicated advertisement messages. When a MN receives a GWADV, it first checks to determine whether a GWADV with the same originator IP address and GWADV_ID already have been received during the last broadcast ID save seconds. If such a GWADV message has not been received, the message is rebroadcasted. Otherwise, if received, the newly received GWADV is discarded. Hence, duplicated GWADVs are not forwarded.

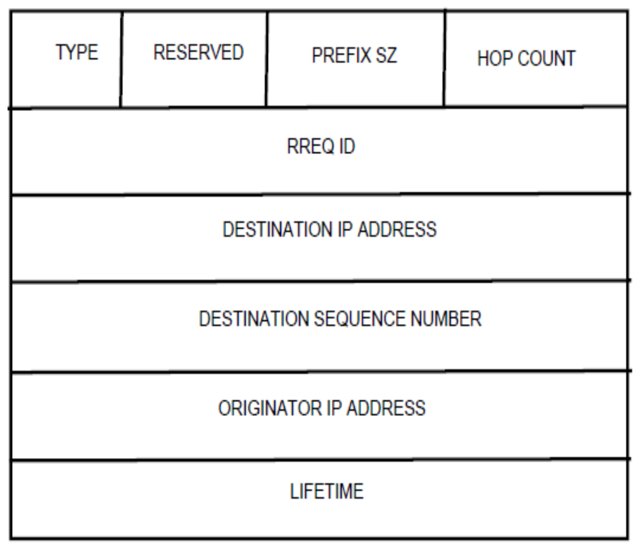

Figure 6: GWADV Message Format

7.4. The Default Route (Route to the Gateway)

The MN needs a route to a gateway, which it uses as its default route to send packets to the Internet. This GW information can be obtained in three different ways. One option is to rely on periodically advertised messages from the gateway (GWADVs), or by sending a RREQ_I to the ALL_MANET_GW_MULTICAST address (i.e. by sending to the GW nodes' group address). There is also a third option, for the sake of updating the default route entry, the GW nodes are made to reply RREQ messages with RREP_I messages, as a result, a MN can get default route by sending RREQ message to the gateway. However, this happens only when a MN is performing radial ring search before it gets the information, whether the destination node is within the ad hoc network or in the fixed network.

7.5 Gateway Operation upon Reception of RREQs

When a gateway receives a RREQ, it looks in its routing table searching for the destination IP address specified in the RREQ message. If the address is not found in the routing table, the gateway has to send a RREP_I back to the originator of the RREQ. On the other hand, if the gateway finds the host route in its routing table, it should not unicast back a RREP_I to the originator of the RREQ "because the destination is then assumed to be inside the MANET". Also "A gateway replies every received RREQ with a RREP_I."

8. Gateway Discovery

There are three types of GWDAs depending on the GW configuration phase initiation and also on the method of route update. If the configuration phase is initiated by the gateway, proactive method is used. But, if the initiation is made by a MN, reactive method is used. The combination of these two methods is called hybrid proactive/reactive method. The basic difference between the algorithms is highlighted below.

8.1 Proactive Gateway Discovery

The proactive GW discovery is initiated by the GW itself. The GW periodically broadcasts a GWADV message which is transmitted after expiration of the gateway's advertisement interval timer that is the time between two consecutive advertisements must be chosen with care so that the network is not flooded unnecessarily. All MNs residing in the gateway's transmission range receive the advertisement.
Upon receipt of the advertisement, the MNs that do not have a route to the GW create a route entry for it in their routing tables. MNs that already have a route to the GW update their route entry for the gateway. Next, the advertisement is forwarded by the MNs to other MNs residing in their transmission range. To assure that all MNs within the MANET receive the GW advertisement. The number of retransmissions is determined by network diameter.
However, this will lead to enormously many unnecessary duplicated advertisements. This is disadvantage. Limited resources in a MANET, such as power and bandwidth, will be excessively used.

8.2 Reactive Gateway Discovery

The reactive GW discovery is initiated by a MN that is to initialize or update information about the gateway. The MN broadcasts a RREQ_I to IP address for the group of all gateways in a MANET. Thus, only gateways are addressed by this message and only they process it. Intermediate MNs that receive the message just forward it by broadcasting it again. Since the message format is RREQ, which has a unique request id field duplicated RREQ_Is are discarded. Upon receipt of a RREQ_I, a GW unicasts back a RREP_I which, among other things, contains the IP address of the gateway.
The advantage of this approach is that RREQ_Is are sent only when a MN needs the information about reachable gateways. Hence, periodic flooding of the complete MANET, which has obvious disadvantage, is prevented.

8.3. Hybrid Gateway Discovery

To minimize the disadvantages of proactive and reactive gateway discovery, the two approaches can be combined. This results in a hybrid proactive/reactive method for gateway discovery. For mobile nodes in a certain range around a gateway, proactive gateway discovery is used. Mobile nodes residing outside this range use reactive gateway discovery to obtain information about the gateway.
The gateway periodically broadcasts a RREP_I message (see Figure 5) which is transmitted after expiration of the gateway's timer, ADVERTISEMENT_INTERVAL (see Table 5). All mobile nodes residing in the gateway's transmission range receive the RREP_I. Upon receipt of the message, the mobile nodes that do not have a route to the gateway create a route entry for it in their routing tables. Mobile nodes that already have a route to the gateway update their route entry for the gateway. Next, the RREP_I is forwarded by the mobile nodes to other mobile nodes residing in their transmission range. The maximal number of hops a RREP_I can move through the mobile ad hoc network is ADVERTISEMENT_ZONE (see Table 5). This value defines the range within which proactive gateway discovery is used.
When a mobile node residing outside this range needs gateway information, it broadcasts a RREQ_I to the ALL_MANET_GW_MULTICAST address. Mobile nodes receiving the RREQ_I just rebroadcast it. Upon receipt of this RREQ_I, the gateway unicasts back a RREP_I.

9. Network Simulator (NS2)

Network Simulator 2(NS2), is a discrete event NS. The University of California at Berkeley and the VINT project [4] has developed it. It is popular for its extensibility (due to its open source model). NS2 is popularly used in the simulation of routing and multicast protocols, among others, and is heavily used in researches based on ad hoc networks. NS supports an array of popular network protocols, offering simulation results for wired and wireless networks.

NS2 supports system programming language C++ for detail implementation and scripting language TCL for configuring and experimenting with different parameters quickly. NS-2 has all the essential features. NS is written in C++, with an OTcl interpreter. The C++ part, which is fast to run but slower to change, is used for detailed protocol implementation. The OTcl part, on the other hand, which runs much slower but can be changed very quickly, is used for simulation configuration.

9.1 Simulation Scenario

In order to evaluate the performance of the three gateway discovery methods, I used the network simulator ns-2 (ns-2.31).
First, the source code of AODV in ns-2 was extended to provide access to mobile stations. Then the three gateway discovery methods were implemented.
The simulations were conducted on an Intel(R) Core™ i3 CPU processor at 2.40 GHz, 3 GB of RAM running cygwin in Windows XP.
The mobile nodes move according to the "random waypoint" model. The movement patterns are generated by CBR's movement generator (setdest).
The traffic connection pattern is generated by CBR traffic generator (cbrgen.tcl).

9.2 Simulation Environment

The Simulation environment is setup, by placing two GW nodes, which are fixed and are connected to two routers on the fixed network. Each router is connected to a host in the fixed network. The routers are also connected to each other to facilitate routing from any GW to any host in the fixed network. The GW nodes are located at (150,300) and (850,300).
At the third layer i.e. the network layer, extended AODV is used as the ad hoc routing protocol, whereas DCF is used at the MAC sub layer with its default values for the contention parameters. Finally, at the physical stations use IEEE 802.11 DSSS.
The parameters that are common for all simulations are given in Table 4 and the parameters that are specific for some simulations are shown in Table 5.

Table 4: Parameters for Simulation

Parameter	Value
Transmission Range	250 m
Simulation Time	1000 s
Simulation Area	1000 × 700
Number of Mobile Nodes	6,12,18,25 mobile nodes
Number of Sources	1
Number of Gateways	2
Traffic Type	CBR
Packet Rate	5 packets/s
Packet Size	512 bytes
Pause Time	2 s
Maximum Speed	10 m/s

Table 5: Specific Parameters Used in Some Simulations

Parameter	Value
ADVERTISEMENT_INTERVAL	5 Seconds
ADVERTISEMENT_ZONE	3 Hops

ADVERTISEMENT_INTERVAL is used when proactive and hybrid discovery methods are used.
ADVERTISEMENT_ZONE is used for hybrid gateway discovery method and defines the range within which proactive gateway discovery is used.

9.3 Screenshot

A screenshot of the simulation scenario is shown in Figure 7. The eighteen mobile nodes that are marked with a ring are the sources. The two hexagonal nodes are the gateways and the four square nodes are the two hosts and the two routers.

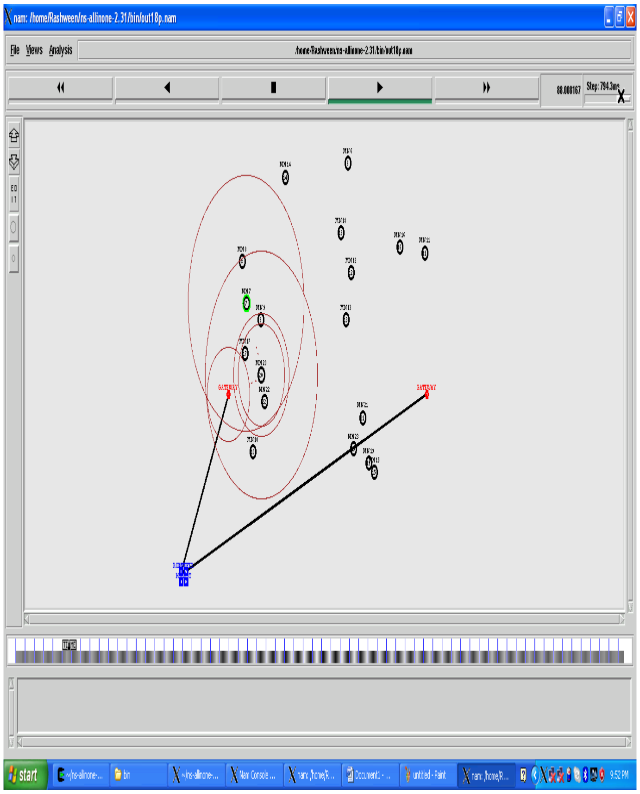

Figure 7: Screenshot of Simulation Environment

9.4 Simulation Results

9.4.1. Packet Delivery Ratio V/s Number of Nodes:

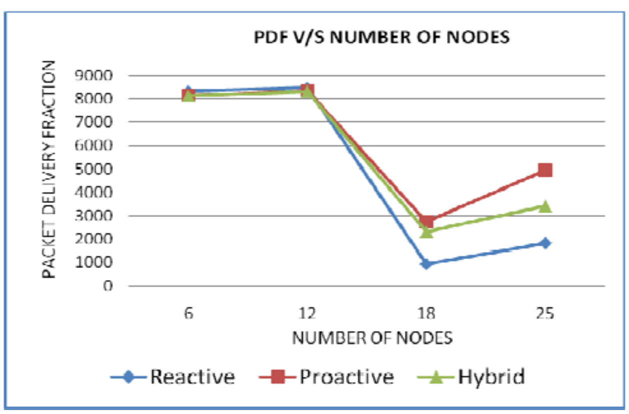

Figure 8: Packet Delivery Fraction V/S Number of Nodes

From the simulation results 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 from the gateway, routes from 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.

9.4.2 Average End To End Delay V/s Number of Nodes:

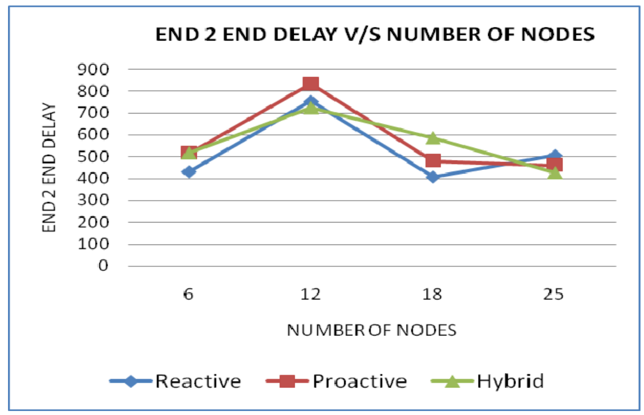

Figure 9: End To End Delay V/S Number of Nodes

In terms of the average end-to-end delay, the delay for reactive and hybrid gateway discovery approaches is much less as compared to the proactive gateway discovery when we increase the number of nodes. When the number of nodes is less, all the approaches suffer from greater average end-to-end delay.

9.4.3. Average Throughput V/s Number of Nodes

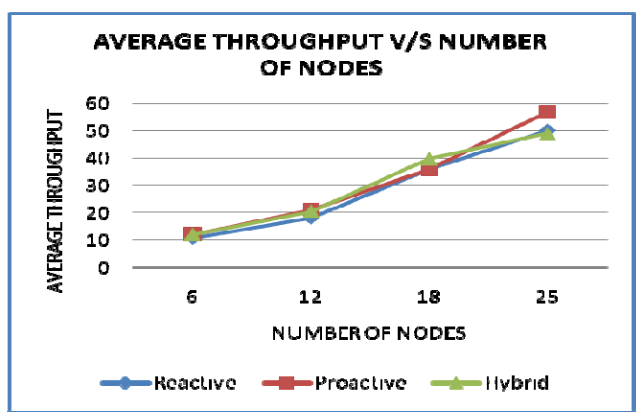

Figure 10: Average Throughput V/s Number of Nodes

As far as average throughput is concerned, when the number of nodes is less, then all three approaches have almost same throughput. But when the number of nodes is increased, the proactive approach outperforms than the reactive and hybrid approaches.

9.4.4. Routing Overhead V/s Number of Nodes:

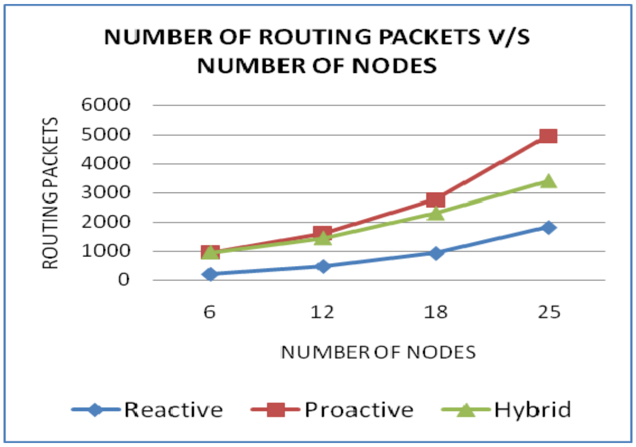

Figure 11: Number of routing packets v/s Number of Nodes

In case of routing packets, the proactive approach clearly outperforms reactive and hybrid approaches.

9.4.5. Loss of Packets V/s Number of Packets:

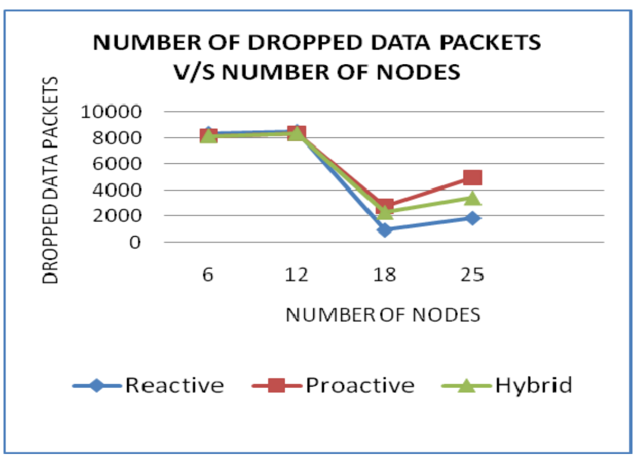

Figure 12: Number of Dropped Data Packets V/s Number of Nodes

For number of dropped data packets, when number of nodes is less, all three approaches remains almost constant. With more number of nodes, the number of dropped data packets increases for the proactive approach because congestion increases. Whereas for the reactive approach, with increasing number of nodes, the number of dropped data packets, decreases because it sends packets only when there is a need. The hybrid approach being a combination of proactive and reactive approaches, its number of dropped data packets lies between them.

10. Conclusions

In the paper, MANET routing protocol-AODV has been extended to route packets, not only within a MANET but also between a wireless MANET and the wired network. The communication between the wireless and the wired network must pass through these nodes, which are referred to as gateways. In this thesis work, three methods for detection of these gateways have been presented, implemented and compared.

The three methods for gateway detection are referred to as reactive, proactive and hybrid gateway discovery. The comparison between these methods provides us useful information.

Regarding the packet delivery ratio in proactive gateway discovery 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. This reduces the packet delivery fraction. The packet delivery performance of the hybrid approach falls between that of the proactive and reactive approaches.

In terms of the average end-to-end delay, the reactive gateway discovery suffers from less average end-to-end delays compared to proactive and hybrid gateway discovery approach.

As far as average throughput is concerned, initially, when the number of nodes is less, all three approaches have almost same throughput. But when the number of nodes is increased, the proactive approach performs better than the reactive and hybrid approaches.

In case of routing packets, the proactive approach clearly outperforms reactive and hybrid approaches.

For number of dropped data packets, when number of nodes is less, the reactive approach has more number of dropped data packets. With more number of nodes, the number of dropped data packets increases for the proactive approach because congestion increases.

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