proxy-AODV : Extension of AODV For Partially Connected Ad hoc Networks

Dissertation

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by
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Dissertation Approval Sheet

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proxy-AODV : Extension of AODV For Partially Connected Ad hoc Networks

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CERTIFICATE OF COURSE WORK

This is to certify that **Mr. Anshuman Tiwari** was admitted to the candidacy of the M.Tech. Degree and has successfully completed all the courses required for the M.Tech. Programme. The details of the course work done are given below.

Sr.No.	Course No.	Course Name	Credits
		Semester 1 (Jul – Nov 2004)	
1.	IT601	Mobile Computing	6
2.	HS699	Communication and Presentation Skills (P/NP)	4
3.	IT603	Data Base Management Systems	6
4.	IT619	IT Foundation Laboratory	10
5.	IT623	Foundation course of IT - Part II	6
6.	IT694	Seminar	4
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8.	EE701	Introduction to MEMS (Institute Elective)	6
9.	IT610	Quality of Service in Networks	6
10.	IT628	Information Technology Project Management	6
11.	IT680	Systems Lab.	6
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13.	CS681	Performance Evaluation of Computer Systems and Networks	6
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Abstract

Ad hoc on-demand Distance Vector (AODV) is a routing scheme for delivering messages in a connected Mobile Ad hoc Network (MANET). In MANETs, a set of nodes are used to route the data on behalf of other nodes. This scheme relies on the assumption that nodes are distributed over the entire region and there exists connectivity between any source-destination pair in the network at all times. This scheme fail when the network is partially connected, i.e. when there is no single-hop or multi-hop path from source to destination.

The existing schemes for routing in partially connected ad hoc networks make assumptions like, source and destination never have a connected path, a set of mobile nodes with fixed route deliver the data, large storage space at nodes, etc. All these assumptions may not hold true in a resource constrained ad hoc network. We propose an extension to AODV, named *proxy*-AODV to remove the above assumptions. In situations where the network is connected our protocol behaves like normal AODV. When there is no connected path, we exploit mobility of nodes and use "store and forward" approach to deliver the data.

In *proxy*-AODV when source and destination are not connected. Then some of the nodes called proxy nodes are selected by source to hold the data on behalf of destination. Proxy nodes acts as source and try to deliver data to the destination.

Using extensive simulations in QualNet simulator, we show that our protocol provides good message delivery ratio while keeping the buffer occupancy at nodes under check.

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Abbreviations and Notations

Abbreviations

AODV	: Ad hoc On Demand Distance Vector
DLE	: Drop-Least-Encountered
DLR	: Drop-Least-Recently-Received
DOA	: Drop-Oldest
DRA	: Drop-Random
FIMF	: Ferry-Initiated Message Ferrying
p-AODV	: *proxy*-AODV
MANET	: Mobile Ad hoc Networks
NIMF	: Node-Initiated Message Ferrying
p-RRER	: *proxy*-RRER
p-RREP	: *proxy*-RREP
p-RREQ	: *proxy*-RREQ
RERR	: Route Error
RREP	: Route Reply
RREQ	: Route Request

Chapter 1

Introduction and Motivation

Mobile Ad hoc networks (MANET) are considered as promising communication networks in situations where rapid deployment and self-configuration is essential. In ad hoc networks, nodes are allowed to communicate with each other without any existing infrastructure. Typically every node should also play the role of a router. This kind of networking can be applied to scenarios like conference room, disaster management, battle field communication and places where deployment of infrastructure is either difficult or costly.

Many routing protocols exist to enable communication in ad hoc networks like, AODV [1], DSR [2], DSDV [3], etc. All these protocols assume that the source and destination nodes can reach each other using a single or multi-hop path. But, there exist situations when connectivity between source and destination cannot be guaranteed always. In this thesis we mainly focus on these kind of networks. We discuss more topology related details and the applicability of one of the existing routing schemes (AODV) on these networks in the forthcoming sections.

1.1 Partially Connected Ad hoc Network

An Ad hoc network with very less density of nodes, i.e. number of nodes per unit area, sometimes suffer from low level of connectivity. Due to limited transmission range of a node, and low density of nodes, a source may not be able to establish a path with destination all the time. We term such a network as a "partially connected network" or sparse ad hoc network. Basically, in a partially connected ad hoc network sometimes there exists no (single or multi hop) path between a given source and destination.

Figure 1.1 shows an instance of a partially connected network. The reachability of a node is shown using dashed lines in the figure. It can be seen that the source node S

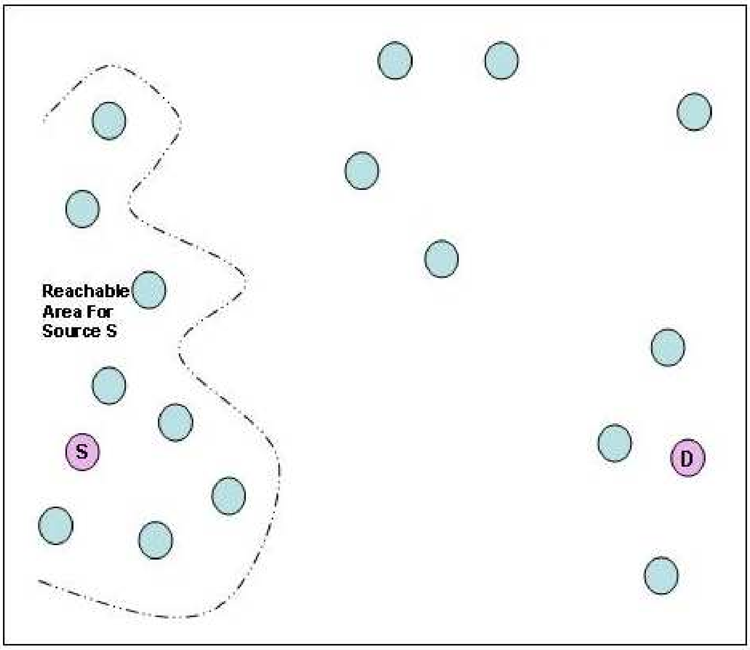


Figure 1.1: Network with partitions

cannot communicate with destination node D.

1.2 AODV

Ad hoc On Demand Distance Vector (AODV) [1] is a routing protocol designed for ad hoc mobile networks. AODV is a reactive protocol, capable of both unicast and multicast routing. It searches for routes between nodes only when desired by source node and maintains these routes only as long as they are needed by the sources.

1.2.1 Working of AODV

- AODV builds routes using a route request/route reply cycle. When a source node needs a route to a destination, it broadcasts a route request (RREQ) packet, as shown in figure 1.2.

- Nodes that receive this packet add backward pointers in their routing tables for the source. The nodes also keep track of source's IP address, current sequence number, and broadcast ID. The RREQ also contains the most recent sequence number for the destination, of which the source node is aware.

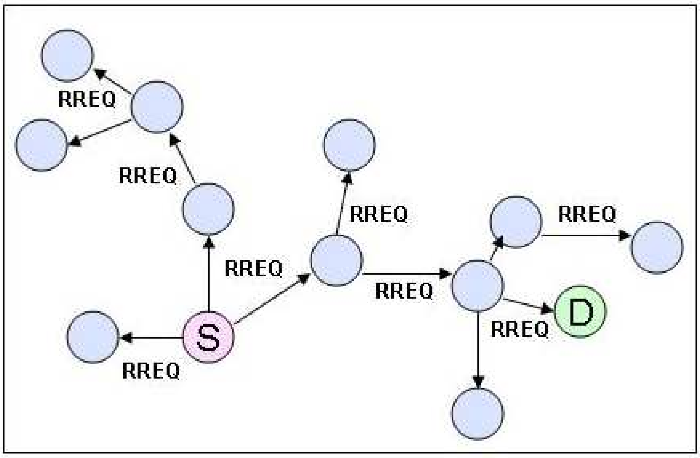


Figure 1.2: Node S broadcasts RREQ

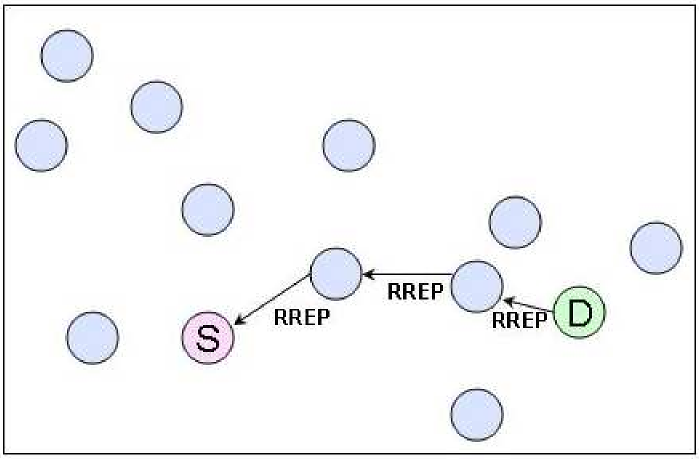


Figure 1.3: Node D send RREP to Node S

- A node receiving the RREQ may send a route reply (RREP) in the following cases:
  - If it is the destination (shown in figure 1.3).
  - If it has a route to the destination with sequence number greater than or equal to that contained in the RREQ, indicating that it has recent information about the destination.

If none of the above cases are satisfied then the RREQ is forwarded using a broadcast. The broadcast ID is used by nodes to detect already processed RREQs. If they receive a RREQ which they have already processed, they discard the RREQ and do not forward it.

- After establishing the path source sends data to destination, as shown in figure 1.4

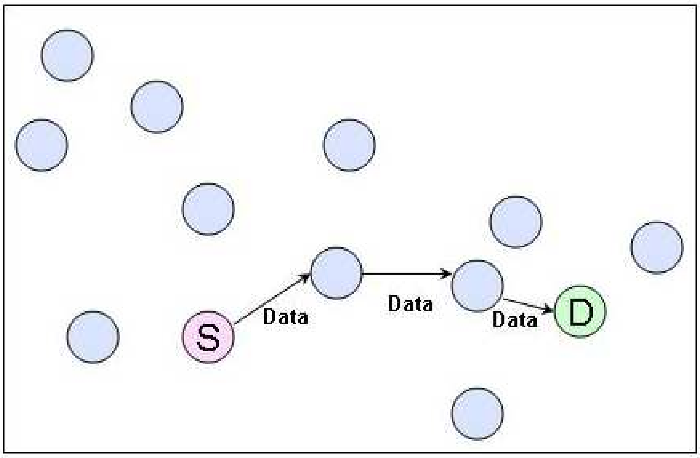


Figure 1.4: Node S send data to node D

1.2.2 AODV over Partially Connected Ad hoc Networks

AODV [1] delivers data in a MANET with the assumption that the network is connected. AODV, fails when the network is partially connected, source and destination are in different partitions. Figure 1.5 shows the fraction of time for which the source and destination nodes are connected via a single/multi-hop path using AODV routing protocol. Connectivity in the network is very low for less number of nodes in the network. As the density of nodes increases, connectivity improves.

1.3 Motivation and Problem Statement

Consider an example scenario of local communication of a village. Due to less number of users, it would not be cost-effective for network service providers to install base-stations to cover all areas. Assuming that an ad hoc network is used for communication, due to less users the ad hoc network is sparsely populated. Most of the communication in these networks is not time critical in nature and hence some delay can be tolerated.

In the above scenario the existing routing protocols for ad hoc networks can not deliver messages because they always assume a connected path from source to destination. And the schemes which are available to deliver messages in such kind of delay tolerant

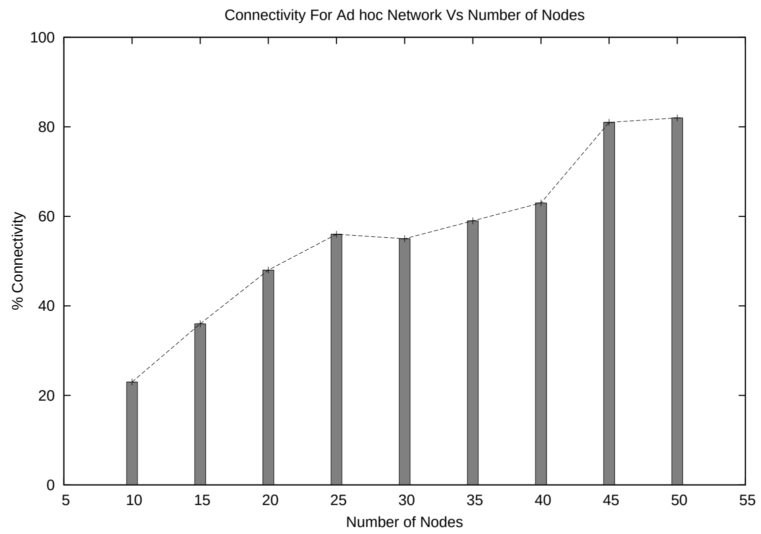


Figure 1.5: AODV: Connectivity Vs Number of Nodes : SimTime 300, Network Area 1.5 sq. km.

networks [4] are inappropriate because of the assumptions made by them. Epidemic routing approach [5] assume unlimited capacity of buffer, source and destination are always disconnected, and use a broadcast approach for delivery. Message ferry approach [6] assumes a delivery node named ferry which has predetermined route. Only the ferry nodes are responsible for delivery of data, hence the ferry becomes a single point of failure for the scheme.

To communicate over all kind of partially connected ad hoc networks, we need a effective protocol which makes no assumptions about the capability of the nodes or the network. We propose a new protocol *proxy*-AODV, an extension of AODV, to facilitate communication over such partially connected ad hoc networks.

1.4 Thesis Outline

proxy-AODV behaves in the same way as AODV in connected ad hoc network and uses "store and forward" concept when source is not able to find a connected path to destination.

The major contribution of this work are :

- An insight into the problem of communication over partially connected ad hoc network.

- A new approach to solve the problem in a generalised manner.
- Extensive simulation results to prove the effectiveness of the approach.

In this thesis, chapter 2 discusses the existing schemes available for communication over partially connected network. It also discusses the reasons why they are not effective for our scenario.

In chapter 3, we present our proposed protocol for a partially connected ad hoc network. We then discuss the simulation setup and the results of simulations in chapter 4. Finally we present conclusions and future work in chapter 5.

Chapter 2

Literature Survey

In this chapter we discuss about related work of partitioned network. The schemes "Epidemic Routing for Partially Connected Ad Hoc Networks" [5], "Wearable computers as packet transport mechanisms in highly-partitioned ad-hoc networks" [7], "A message ferrying approach for data delivery in sparse ad hoc networks" [6] [8] and "Sending Messages to Mobile Users in Disconnected Ad-hoc Wireless Network" [9] are able to deliver data in partially connected networks. Here we discuss [5] and [6] in detail.

2.1 Epidemic Routing Scheme

Epidemic routing scheme [5], is an early, brute force approach to deliver a message in a disconnected network. This approach makes use of the mobility of hosts. Hosts makes a hash table entry for message stored in a table called vector table. Hosts use this vector table to exchange message with neighbouring nodes. With the help of vector table, nodes will come to know about messages stored in the other node. Only those message which are not buffered by the other node will be transferred. In this manner each node distributes messages which are buffered by it. This is a transitive distribution of message, and message will reach the destination which is on other partition of network with the help of mobile nodes. Consider an example for the above scheme.

2.1.1 Example

- Say at time T1 source S wants to send data to destination D, S will broadcast the message which will stored by the neighbouring nodes N1 and N2. This propagation's of message is shown in figure 2.1.

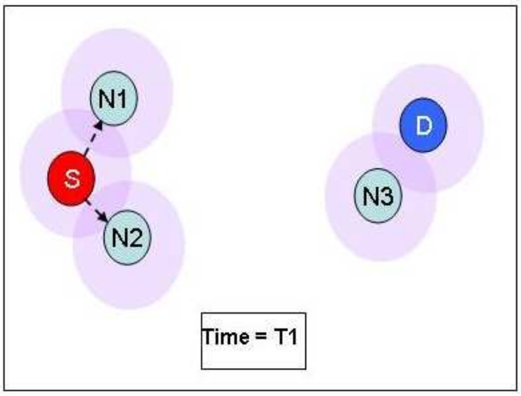


Figure 2.1: Network instance at time T1

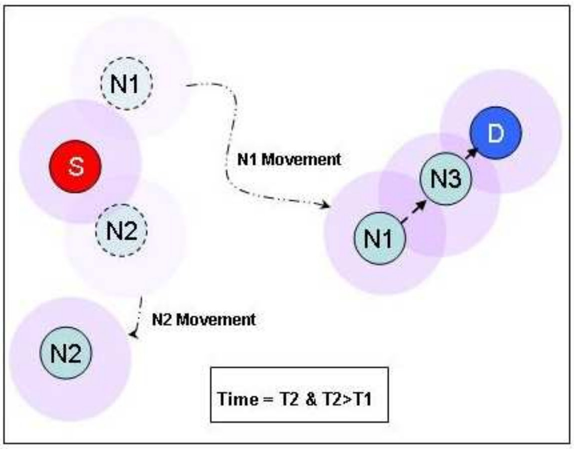


Figure 2.2: Network instance at time T2

- Suppose after a time delay, time T2, node N1 will move near to destination. Then N1 is able to deliver the data to the destination D. This is shown in figure 2.2.

2.1.2 Pros and Cons of Epidemic Routing Scheme

Epidemic routing [5] is a very simple and effective approach, but it do not consider the constraints on the resource limitation.

Handling Buffer

Nodes are having limited buffer to store messages. Epidemic scheme [5] is a flooding scheme due to this sometimes nodes memory will be exhausted. To deal with this kind of situation, authors of “Wearable computers as packet transport mechanisms in highly-partitioned ad-hoc networks" [7] proposed to drop the message whenever there is shortage of memory. They talk about four different kinds of dropping strategies. They are:

- Drop-Random(DRA): The packet to be dropped is chosen at random.
- Drop-least-Recently-Received(DLR): The packet that has been in the host buffer for longest time duration is dropped.
- Drop-oldest(DOA): The packet that has been in the network for longest duration is dropped.
- Drop-Least-Encountered(DLE): The packet is dropped on the basis of the likelihood of delivery.

2.2 Message Ferrying Approach

In message ferry approach [6], authors proposed two approaches to communicate. They assume the presence of delivery node called ferry node, which have a predefined path to move and regular nodes which follow random mobility but also remain stationary most of the time. Approaches are Node-Initiated Message Ferrying (NIMF) and Ferry-Initiated Message Ferrying (FIMF) approach.

2.2.1 Node-Initiated Message Ferrying

In NIMF approach, a node will move towards known route of ferry if it has data to transmit or receive. The node comes close enough to default path of ferry so that ferry will be in transmission range of node.

Example

Figure 2.3 explains the working of NIMF approach. In this node S wants to send data and node R wants to receive data, so they come closer to the default route of ferry.

2.2.2 Ferry-Initiated Message Ferrying

In FIME approach, the ferry broadcast its location periodically. When a node wants to send or receive messages via the ferry, it sends a service_request message to the ferry using

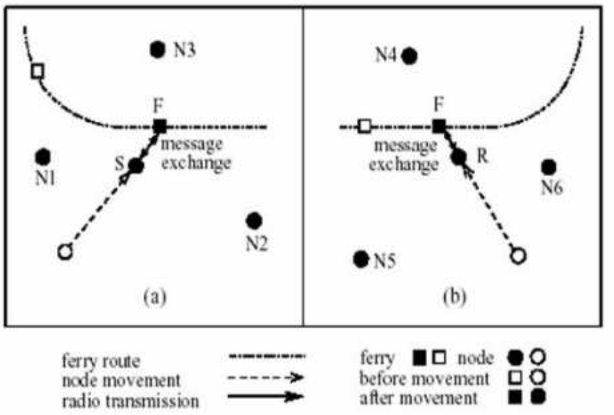


Figure 2.3: Node-Initiated Message Ferrying

source of figure is [6]

its long range radio. This message contains the information of node location. According to this information ferry will adjust their route to meet the transmission range of requested node. After finishing the data transfer ferry will return to its default route.

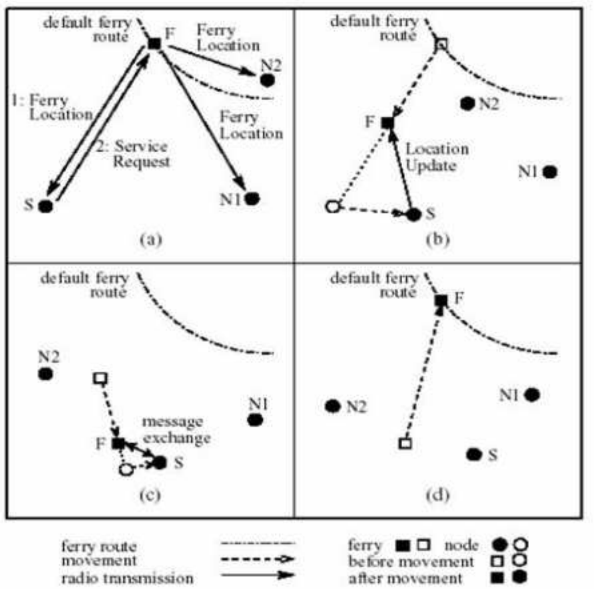


Figure 2.4: Ferry-Initiated Message Ferrying

source of this figure is [6]

Example

Figure 2.4 explains the working of FIMF approach. Here node S wants to send data. So node S sends a service request to the ferry and according to the service requester ferry adjust its moving path from default route towards node S. After collecting message ferry returns to its default path.

2.2.3 Pros and Cons of Message Ferrying Approach

Message Ferrying Approach delivers the messages efficiently and the nodes have significantly less overhead as compared to the ferry node. However. if the ferry node fails,then the system as a whole fails. So this is less reliable and more susceptible to failure. Also, it is required to fix the default route of the ferry node. This itself is challenging and involves a number of issues.

2.2.4 Replace Message Ferry

In message ferrying approach, ferry node is a central point of failure for the system. New approaches have been proposed which focus on the reliability of the systems. One of the solution to this problem is replacement of ferry as proposed in [8]. They proposed two protocols - either change the ferry node when the current ferry node fails, or change the ferry node periodically. The first method is centralised approach where successor ferry is always decided by the present ferry. Later is a distributed way of choosing the ferry node. Here each node declares its willingness to become ferry and on the basis of vote, one node will be chosen as ferry node.

2.3 Designing System for Sparse Networks

In "Messaging in Difficult Environment" [10] problems encountered in implementing communication in partially connected networks are discussed. The major issues in such kind of environments like, asynchronous message delivery, routing and fragmentation, naming system, reliability have been discussed.

In epidemic [5] approach, authors start with assumption that source and destination will never have connected path, which is a very restrictive assumption even for a sparse ad hoc networks. Message Ferry [6] approach can work only for static kind of partitioned network because of fixed route of ferry node. To eliminate these assumptions we propose a new routing protocol *proxy*-AODV, which is discussed in next chapter.

Chapter 3

proxy-AODV Protocol

p-AODV is the extension proposed for AODV routing protocol, which enables AODV to deliver data in a sparse and partitioned ad hoc network. *p*-AODV uses "store and forward" and proxy concept to deliver the data.

In partially connected ad hoc networks, the destination is not always reachable. In our protocol we need a proxy node to relay messages to the destination. Proxies are nodes that have high probability of reaching the destination. In our scheme, when a source sends a request for a destination and the destination is not reachable, then some of the nodes in the network will choose to become the proxy for the destination.

3.1 Motivation For Selecting AODV

We have chosen AODV routing protocol of ad hoc network because of some simple reasons.

- It is a "popular" protocol for ad hoc networks.
- Our approach needs least modification in AODV as compare to that in other schemes like DSR, TORA, DSDV.

Apart from above, the advantage of AODV is that it creates no extra traffic for communication along existing links. Also, distance vector routing is simple, and doesn't require much memory or calculation. Table 3.1 shows comparison of four protocol, [11]. performance of AODV is good in terms of bandwidth and energy conservation. We assume that the bandwidth and the enrgy are the scarce resources for the partially connected network.

Metrics	DSDV	AODV	DSR	TORA
Scalability	4	2	3	1
Delay	1	3	2	4
Routing Overload	4	2	1	3
Packet Drop	4	1	2	3
Routing Acquisition Time	1	2	4	3
Throughput	3	1	2	4
Adaptability to Dynamic Environment	4	2	3	1
Bandwidth Conservation	4	1	3	2
Energy Conservation	4	2	1	3

Table 3.1: Comparison of four routing protocol

(1 for the best, 4 for the worst)

3.2 *proxy*-AODV

To get the details of the protocol we discuss the entities, events, issues, and then explain working of protocol with a example. Before going in to details we give overview of protocol.

3.2.1 Overview of Protocol

- *proxy*-AODV build routes using a Route Request(RREQ)/proxy Route Request (PRREQ)-Route Reply (RREP)/proxy route reply (PRREP) query cycle. When a source needs a route to a destination, it broadcasts a RREQ packet across the network.

- Nodes receiving this packet update their information for the source node and set up backwards pointers to the source node in the routing tables. In addition to the source node's IP address, current sequence number, and broadcast ID, the RREQ also contains the most recent sequence number for the destination of which the source node is aware.

- A node receiving the RREQ may send a route reply (RREP) in the following cases:

  - If it is the destination node.

  - If it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ.
  - If this is the last RREQ retry, the node checks its eligibility to become a proxy (explained in section 3.2.3) and sends a PRREP to the source if it satisfies all the criteria.

  If none of the above conditions are met, then the node re-broadcasts the RREQ. Nodes keep track of the RREQ's source IP address and broadcast ID. If they receive a RREQ which they have already processed, they discard the RREQ and do not forward it.

- If source node gets the reply from original destination then after establishing the path, source sends data to destination. If it receives a PRREP, then it stores this proxy reply and waits for more replies. After the expiry of timer source will select some of the proxy replies and send data to only those proxies.

- After getting data from original source, a node stores it and periodically checks for new locality (defined in section 3.2.2).

- When a node detects that it is in a new locality (defined in section 3.2.3) it initiates a PRREQ i.e. proxy-RREQ, for destination on behalf of source. This is similar to a RREQ being sent by the source to the destination. And same types of event triggered like RREQ.

- If a proxy node gets a route reply from original destination then it deliver its data to the destination, or it again create one or more proxy.

- A proxy node can delete the stored data in following cases:
  - After delivering data to original destination.
  - After end of tolerant time (defined in section 3.2.3).

3.2.2 Entities

In AODV a node can be a source, destination or can be an intermediate node for a communication, In *p*-AODV a node can be one or more of below

- Node: A node is a device with routing capability. A node can also be source/Destination/*proxy*-node/intermediate-node .
  - Source: The node which wants to send data.
  - Destination: The node which is the final destination of data.
  - *proxy*-node: The node which can be the proxy-source/proxy-destination/ both.
    - *proxy*-source: The proxy-node will become a proxy-source when sends 'hosted data of source' to destination/*proxy*-destination.
    - *proxy*-Destination: A node will become proxy-destination when it is selected by source/*proxy*-source to host data when destination is not connected to source/proxy-source.
- Locality for a Node: Locality means surrounding/neighbours of a node.

3.2.3 Issues and Parameters

Proxy node as mentioned in the section 3.2.2 had the following issues related to it.

- Which node will become a proxy node ?
- How will a source choose among the several proxy replies ?
- When will a node decide that it is in a new locality ?
- When will a proxy node drop the stored data packets ?

Eligibility to Become A Proxy

A node can check its eligibility to become a proxy on the basis of the following parameters:

- "Number of entries in the Routing Table." If a node has large number of routing entries, it implies that the node is well connected to the network and there is a fair chance to get the data delivered.
- "Degree of Mobility." It is the number of neighbours seen by node per unit time. If degree of mobility of a node is high, it implies, that the node is meeting new nodes frequently or is having fairly good number of neighbours.

- "Distance from the Source." If a node finds that it is far enough from the source then there can be a high possibility that it is more closer to the destination.
- "If the node is already storing some data for a concerned destination." then it can be used to avoid creating more proxies in the network.

Out of four parameters mentioned above we consider "Number of Entries in the Routing Table" as the parameter to check the proxy eligibility. Primary reason behind this is its simplicity, and good approximation of connectivity. Secondly the routing table entry count is also a good indicator for the degree of mobility.

Choosing Between *proxy* Route Replies

This issue can be resolved by the same parameters that are used for checking the proxy eligibility. A node which is contending for becoming proxy sends the parameter values (used to checking proxy eligibility) to the source. The source chooses the best proxy based on these parameters. We can also put a limit to the maximum number of proxies that are allowed to be chosen for a given destination.

New locality

A node is said to be in a new locality if it moves to a new place or its neighbours change. In our experiments, we periodically check for new locality and use routing table entries to compare two instances of locality.

Dropping of Packets in Proxy Nodes

As we assume a delay tolerant network, proxies are allowed to drop the stored packets after a particular timeout duration, which is a user defined parameter. The packets can also be deleted once data is delivered to the destination.

3.2.4 Events

In this section, we define the working of *p*-AODV with respect to the different events.

- **Node has data to send :** This event is depicted in flowchart 3.1. A node initiates a RREQ message if it is the original source of this message, or it initiates a PRREQ message if it is storing data on behalf of other node.

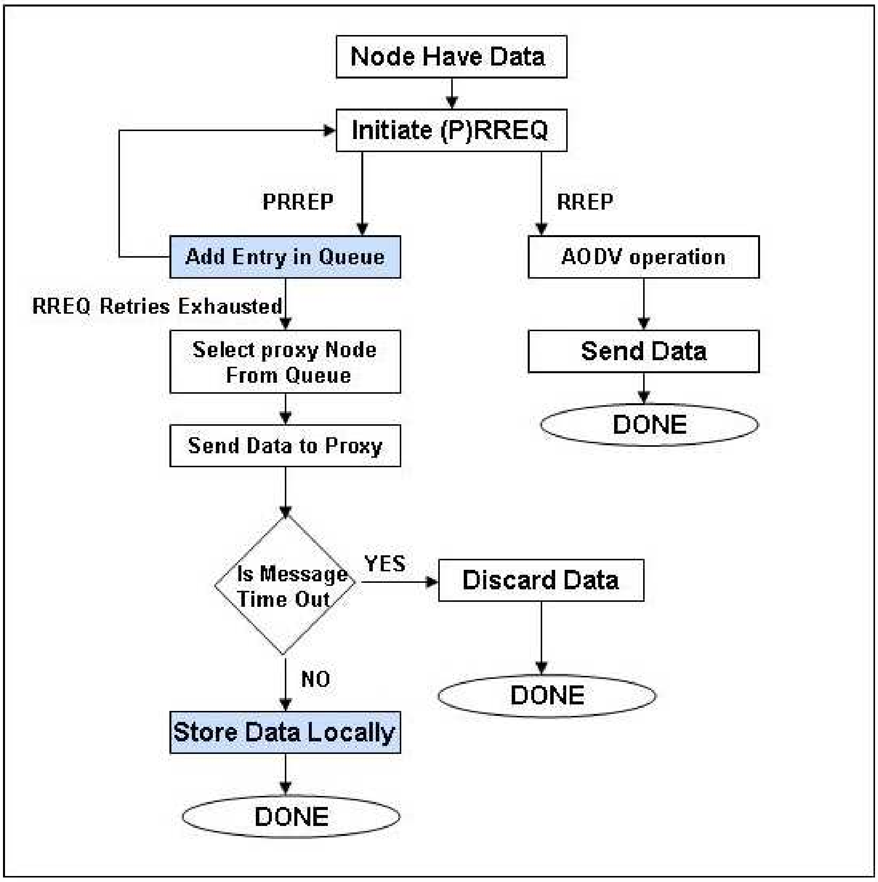


Figure 3.1: Node has data

- **Node Receives a (P)RREQ :** We can see in flowchart 3.2, when a node receives a (P)RREQ it checks whether, it is the destination for this request. If it is the destination then the node sends a back RREP otherwise this node is not the original destination for this request then this node makes calculation for proxy selection parameters, if the parameter values are above some defined threshold then, the node sends a PRREP. At the end it simply forwards the (P)RREQ.

- **Node Receives a (P)RREP** This situation is also shown in figure 3.1. When a proxy/original source gets a original reply from a node. It simply sends data to destination. If node gets a proxy reply then it will store this reply in a data structure and wait for route retries time out and then used some functions to evaluate the proxy route replies to choose some nodes to become proxy.

- **A node receives a HELLO message :** Whenever a node receives HELLO message it updates data structure like routing table and neighbourhood list to keep

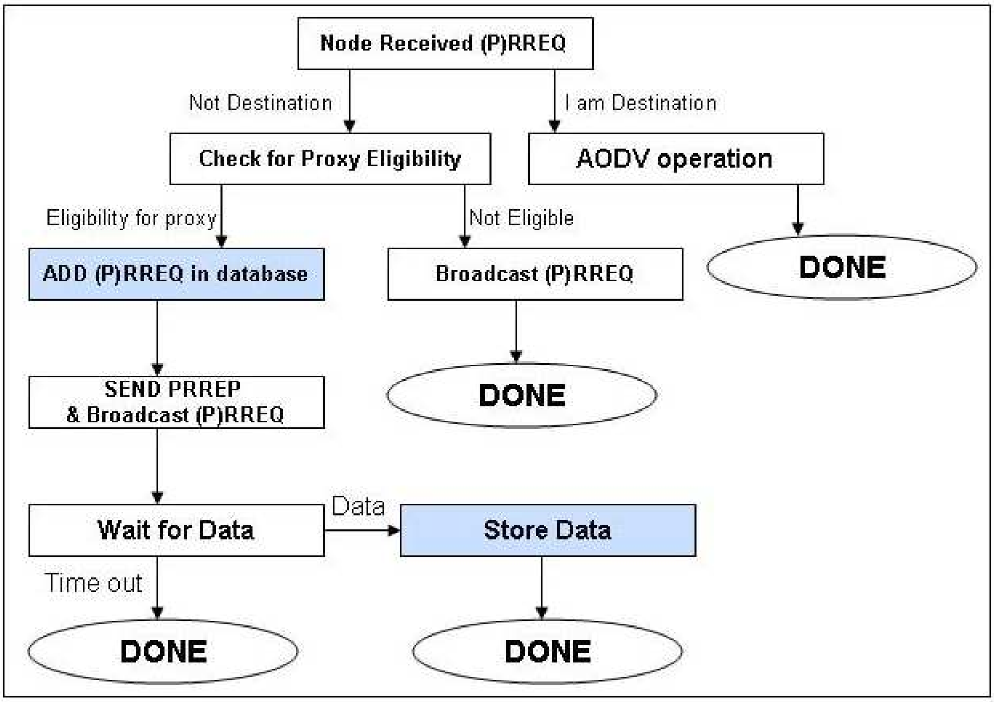


Figure 3.2: Node listen (P)RREQ

track of its neighbours.

- **A node receives a RERR message :** Updates the routing table entry if it exists for the node.
- **A node senses a new locality :** When a node realizes that it is in a new locality then it checks for locally stored data. If it finds some data then it initiates a proxy route request for that data. The flow for this event is depicted in flowchart 3.1

3.3 *p*-AODV with Example

We now explain the working of the *p*-AODV with the help of a simple example. This will help in understanding the various aspects of the protocol more easily. Consider different events in the partially connected network.

Figure 3.3 to 3.5 show the sequence of *p*-AODV protocol when a source S wants to send a data to destination D and there is no connected path between them.

- Initially source S broadcasts a RREQ for node D as shown in figure 3.3

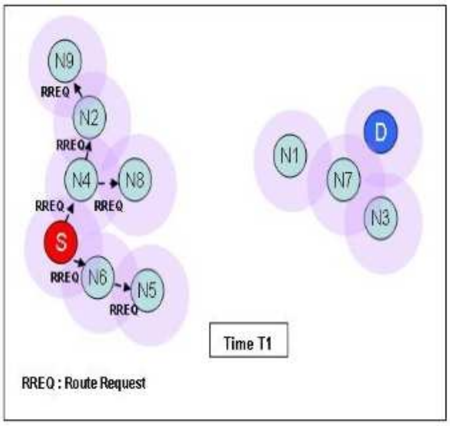


Figure 3.3: S wants to send data to D, S sends RREQ

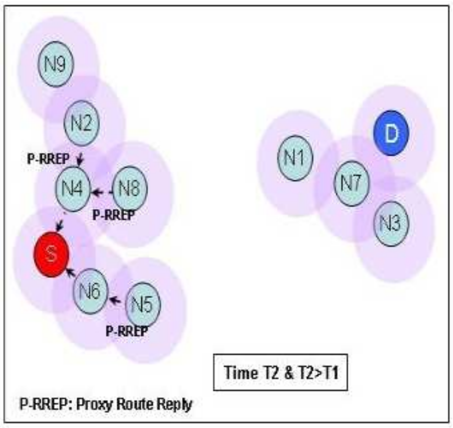


Figure 3.4: proxy node sent *proxy* reply to source

- Source S gets a Proxy route reply from node N2, N5 and N8, figure 3.4. Source stores these proxy replies.
- After waiting for original RREP uptill the timeout of last RREQ retry, source chooses N5 and N8 to keep data on behalf of original destination, figure 3.5.

So from the above sequence we can say that source, N5 and N8 all three are the source for the same data. As nodes are mobile, we can assume that after some time there can be two different possibilities.

- Case 1 : source/*proxy*-Node moves near to the destination.
- Case 2 : source/*proxy*-Node moves to new part of the network area.

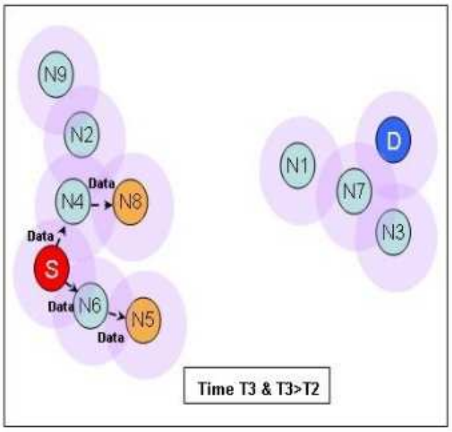


Figure 3.5: Source send data to *proxy* node

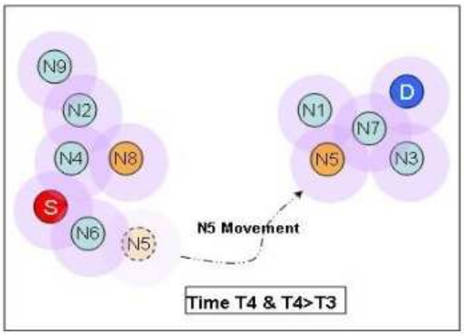


Figure 3.6: *proxy* node moves near to destination

To show the effect of case 1 we assume that node N5 moves near to the destination. This condition is showed in figure 3.6 and 3.7.

- N5 sends a proxy route request on behalf of source S, this is similar in function to route request function of AODV.
- N5 gets the *proxy*-RREP from node A6 and RREP from destination D.
- N5 sends data only to the original destination destination D.

In case 2 let node N8 move to a new locality which is still not connected with the final destination. This instance is depicted in figure 3.8.

- Node N8 sends a PRREQ on behalf of original source S.
- Say N8 receives *P*RREP message from A3.
- Node N8 sends data to node A3.

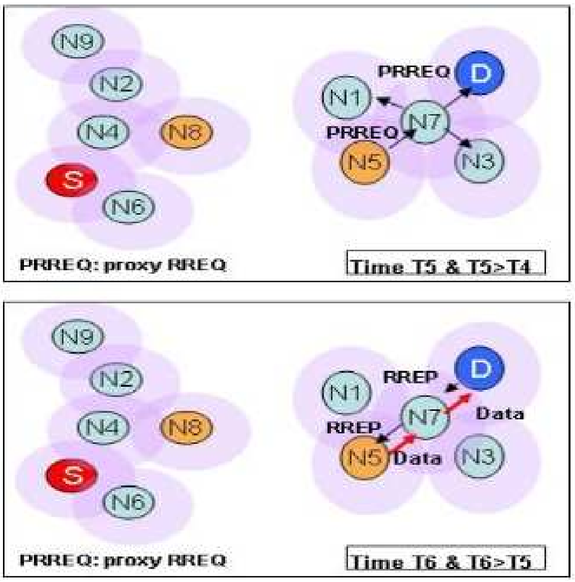


Figure 3.7: *proxy* node deliever data to destination

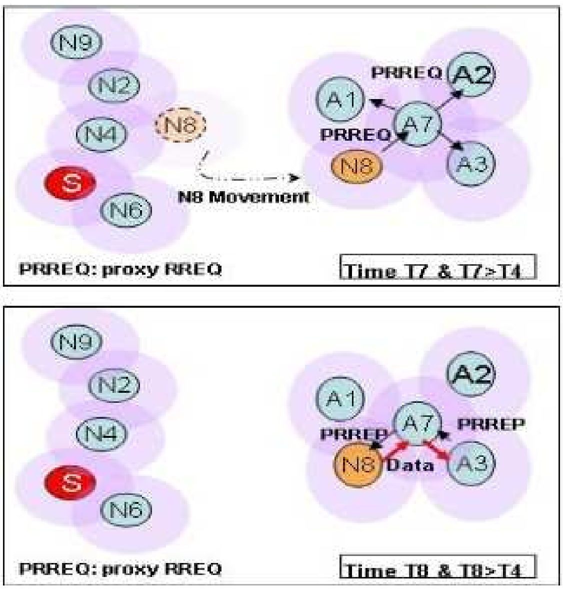


Figure 3.8: *proxy* node enters new locality

Chapter 4

Simulation Experiments and Results

In this chapter we simulate our protocol on simple custom made scenarios to validate the working of our protocol. Later we show the results on more general scenarios and then compare the performance of p-AODV with flooding approach. All simulations are performed on QualNet Simulator[1] v3.9 [12].

4.1 *p*-AODV in a Simple Scenario

For p-AODV, we have defined different node entities like source, destination, proxy-source, proxy-destination in section 3.2.2. There exist different communication opportunities between these nodes as shows in table 4.1:

Case	From	To	Description
1	Source	Destination	Same like AODV
2	Source Node (delayed data of its own stored locally)	Destination	*proxy*-AODV
3	Source Node	Proxy Node	*proxy*-AODV
4	Source/Destination	Intermediate Node	Same like AODV
5	Proxy Node	Destination	*proxy*-AODV
6	Proxy Node	Proxy Node	*proxy*-AODV

Table 4.1: Cases for communication between nodes in p-AODV protocol operation

All these instances are captured in two simple simulations to check the validity and working of our protocol.

[1]QualNet Simulator is provided to us under the QualNet University Program

- **Topology 1** : Consider two nodes in a topology as depicted in figure 4.1. The Source and Destination are far apart so that there is no direct communication possible between them. In this scenario the source moves near to the destination and delivers the message. This topology simulates Case 2 as mentioned in table 4.1. The number of message packets delivered is shown in the table 4.1. The percentage of message delivered depends on the buffer size of a node, here buffer size is limited to 50 messages.

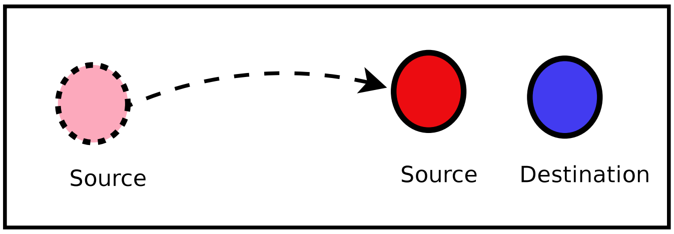


Figure 4.1: p-AODV Simple Scenario : Source reaches to destination

- **Topology 2** : Consider four nodes as depicted in figure 4.2. Source delivers data to proxy 1, then proxy 1 delivers that data to proxy 2. Finally, proxy 2 will deliver the data to the destination. This topology covers Cases 3, 5, and 6 from table 4.1. In this case very less number of packets are stored by proxy because of less time contact with original source.

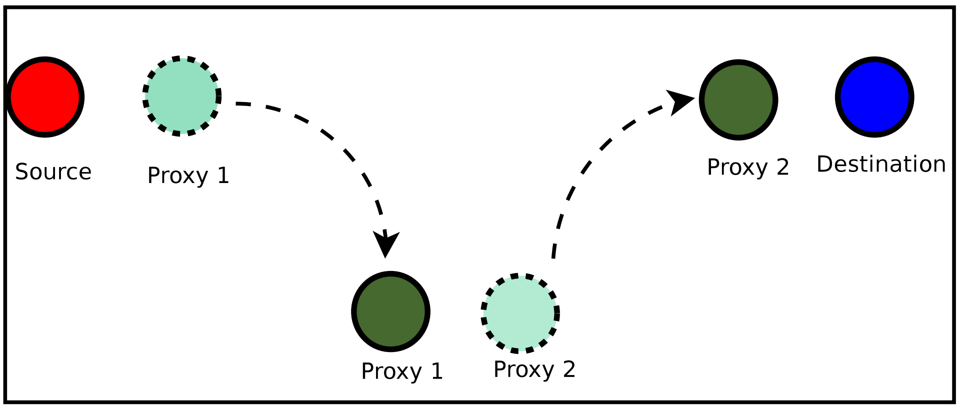


Figure 4.2: p-AODV Simple scenario : proxy reaches the destination

Case	Generated	Stored in Source	Last Proxy Node	Delivered to Destination
Topology 1	150	50	50	50
Topology 2	150	50	10	10

Table 4.2: Number of packets delivered

4.2 Simulation Model and Setup

In this section we discuss the simulation setup that we had for experiments. Simulations are performed for *p*-AODV approach and Flooding approach. The common parameters for the simulation setup are specified in table 4.2. The source and destination are places sufficiently far apart to ensure that they are not within direct reach of each other. Still sometimes we get direct connectivity between the source and the destination in-spite of there distance and it increases with increase in number of nodes. We can refer graph 1.5 of section 1.2.2 to see the connectivity for aodv.

Network	
Size	1.5km x 1.5km
Simulation Time	300s to 1300s in steps of 200s
Number of Nodes	5 to 30 in steps of 5
Node Placement	Random
Mobility Model	Random Way-point
Traffic	
Traffic Type	VBR
Packet Size	512 Bytes
Inter Packet Time	3s

Table 4.3: Simulation Setup

Setup For *p*-AODV

There are some parameters specific to *p*-AODV.

- Every node checks its eligibility to become proxy on the basis of their "routing table size." We vary the routing table size from 1 to 5.

  The reason for choosing these values is that average routing table size in the network is in the range of 3 to 4.

- There is no restriction on proxy number size. Hence, a proxy-source/source can send data to all the RREPs.

- A node will check for new locality periodically (every 5 seconds). Node will assume it is in new environment if number of previous routing table entry and present routing table entry having difference of two. And node will generate PRREQ.

4.3 Performance Metrics

These are the metrics we calculated to see the performance of protocol.

- **Percentage of Message Delivered.** This is the percentage of generated packets that are received at the destination.

$$\frac{count(total\ packets\ received)}{count(total\ packets\ sent)} * 100$$

- **Avg. Delay for a packet to reach destination.** This is average delay from the time the packet is generated t_g at the source to the time the packet is delivered at the destination t_d.

$$\frac{1}{N}\sum_{i=0}^{i=N} t_d^i - t_g^i$$

- **Percentage of Duplicate Packets.** This is a measure of the redundant packets received at the destination.

$$\frac{count(total\ packets\ received) - count(unique\ packets\ received)}{count(total\ packets\ received)}$$

- **Cost of memory requirement for a node over total simulation time** This is a measure of the time for which the buffer is occupied at a given node j.

$$\frac{\sum i = 0 i = N B_i}{N}$$

  Where B_i represents the buffer occupancy for node i and N is the number of nodes.

4.4 Results

In graphs each point is the average of 20 simulation runs. we start with the explanation of the performance of p-AODV then discuss about flooding approach. We conclude this section with the comparison between them.

4.4.1 *p*-AODV with single parameter

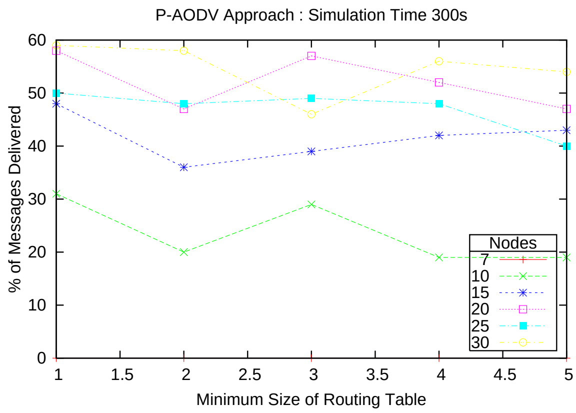
In this section we show the performance of p-AODV. The delay tolerance of messages is taken to be 300s in these simulations.

- The Message delivered percentage graph is shown in figure 4.3. It shows that most of the time, p-AODV with proxy selection parameter as table size 1 performs better as compared to higher table sizes. This happens because, many nodes become eligible for becoming a proxy sooner using this relaxed criteria. This in turn leads to faster propagation of message. Though at a cost of increased flooding in the network and increased buffer occupancy in the node.

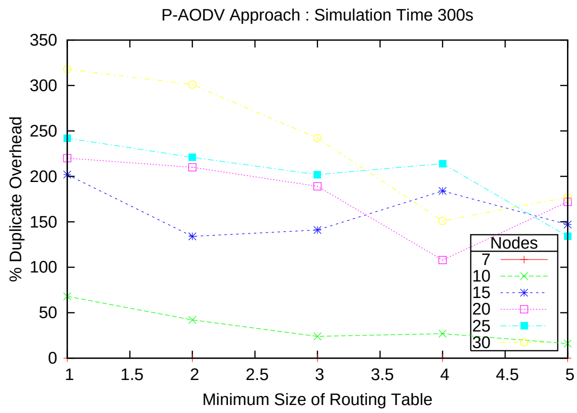
  For more number of nodes in the network, the proxy selection criteria of table size plays a lesser role in message delivery percentage. This is because of the increased node density in the network. In graph we can also see that as the number of nodes increases the percentage of message is also increasing which is expected.

- The average delay for delivery of messages is shown in figure 4.4. We can see that in many cases increasing the number of nodes also increases the average delay for a packet. This phenomenon is counter-intuitive, because increase in number of nodes should have improved the chances of message delivery. The reason for this being, overall increase in the network load because of more number of packets floating around, leading to increase in contention at medium access layer. Also some packets may be received very late because of a long proxy path followed, this increases the average delay. For less number of nodes, the delay increases with increase in proxy table size. For less number of nodes delay will increase because they were not able to find good number of proxies as table size increases.

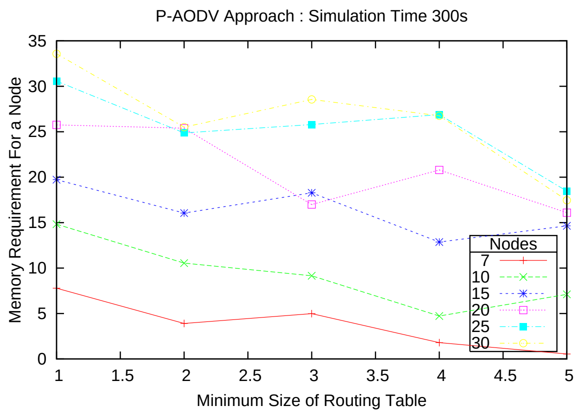
- The percentage of duplicate packets is shown in figure 4.3. We can see that as the proxy selection criteria of routing table size is increased, duplication of packets



(a) Message Delivered Percentage



(b) Duplicates Overhead



(c) Memory Consumption Per Node

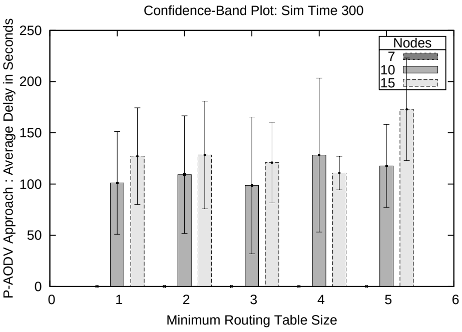
Figure 4.3: *P*-AODV Graphs : Proxy selection on routing table : SimTime 300

decreases. The rate of reduction in duplicate packets increases as number of nodes increase.

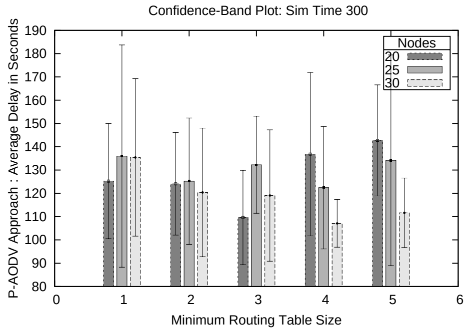
- The cost of memory consumption is shown in figure 4.3. As the criteria to for proxy selection becomes stricter, the number of proxies in the network reduces. Hence, the message is duplicated at lesser nodes in the network. The cost stabilises as the criteria to become a proxy-node becomes harder (higher table size).

4.4.2 Flooding Approach

In flooding approach source or proxy source delivers data to all nodes connected to it without checking any condition. We simulate this approach to compare the results of this



(a) Average Delay I



(b) Average Delay II

Figure 4.4: *P*-AODV Graphs : Proxy selection on routing table : SimTime 300

approach with the results of our *proxy*-AODV approach.

- Percentage of Message Delivered: In figure 4.5, percentage of messages delivered increases as the number of nodes increase. Also, as the time increases, the percentage of Message delivered increases. There is a sharp increase in the performance for from 5nodes to 10nodes. As the time increases, the message delivery percentage stabilises.

- Average delays are shown in figure 4.6. All the delay values are in the range of 100s to 200s. This is because of increased flooding in the network.

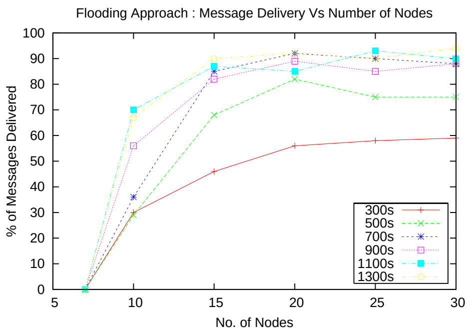
- Percentage of Duplicate Overhead: As time increases, the duplicate overhead increases with a higher rate. Also for increasing number of nodes in the network, the duplicate overhead increases.

- Cost of Memory consumption per node of graph is shown in figure 4.5, As number of nodes increases the cost of memory consumption increases. This is because more flooding is observed in the network. As time increases, the buffer is occupied for longer duration of time and hence increasing the cost.

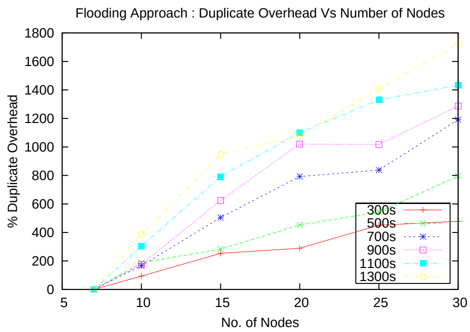
4.4.3 Comparison of *p*-AODV and Flooding Approach

In figure 4.7, we present comparison between flooding and *p*-AODV approach. In this we can see that

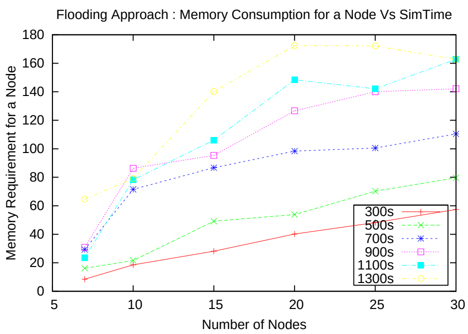
- Message Delivery Percentage in graph 4.7 shows that flooding approach has better percentage delivery in comparison to proxy approach. The reason for this behaviour



(a) Message Delivered Percentage

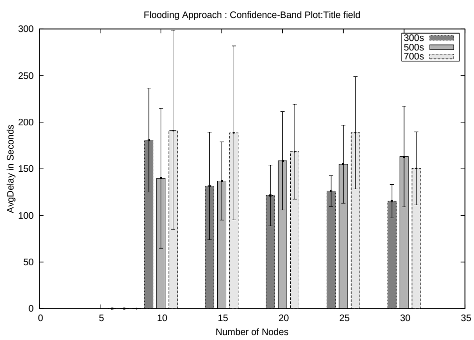


(b) Duplicates Overhead

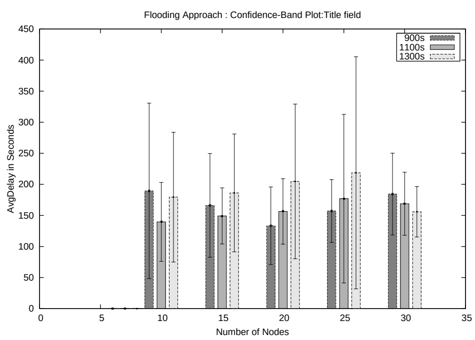


(c) Memory Consumption Per Node

Figure 4.5: Flooding Approach

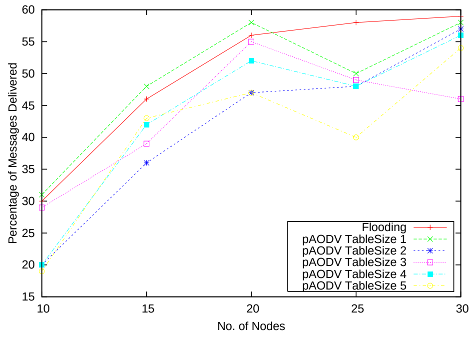


(a) Average Delay I

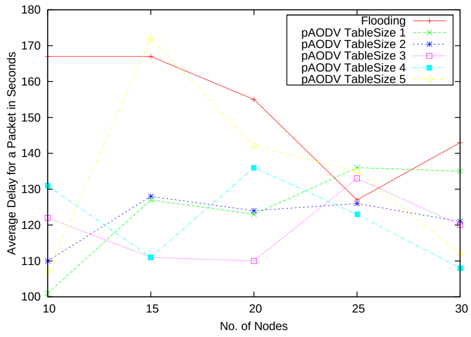


(b) Average Delay II

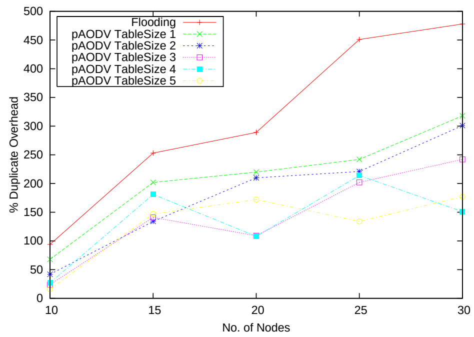
Figure 4.6: Flooding Approach



(a) Percentage of Message Delivery



(b) Average Delay For a Packet



(c) Percentage of Duplication Overhead

Figure 4.7: Comparison Between Flooding and *proxy*-AODV performance

is that flooding makes every node a proxy. Hence, the chances of any proxy to reach near the destination and deliver the data are very high.

- The graph for average delay in figure 4.5 shows that *p*-AODV consistently maintains a lower delay time as comparison to flooding approach.

- In Duplicate Overhead graph of figure 4.5, we can see that flooding approach is leading the graph and its very obvious because more of the nodes will reach to destination as number of nodes will increases. The duplication of *p*-AODV is also increasing but with low rate in comparison to flooding approach.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

From the discussion in the previous chapters, we have seen that p-AODV performs better in terms of overhead on networks and average consumption of memory per node. We can also say that it is equally good as compared to flooding approach in terms of message delivery.

There is a trade off between "Load on Network" and "Message Delivery Efficiency". If we impose less restrictions on proxy selection, then the probability of message delivery increases. But, at the same time load on network and nodes increases. If we impose strict restrictions on proxy selection criteria, then message delivery probability decreases.

To perform better in terms of message delivery percentage and at the same time maintain low load on network and nodes, we propose some extensions in the future work section.

5.2 Future Work

This project can be enhanced in two different directions:

- Improve the proxy selection function in terms of parameters and their values to improve efficiency.
- Add more features to protocols, like acknowledgement for data.

A combination of both the above extensions will provide a self tuning system. For example, an acknowledgement from destination to source can be used as carrier to distribute value of duplication and percentage of message delivered. This will help other nodes to regulate their parameters and their values while choosing the proxy, according to their requirement of message delivery. And to stop flooding of this feedback a node is allow to drop acknowledgement on the basis of its TTL field and last information flooding time. On the other hand, node can free messages from buffers of respective sequence number.

We can also apply "proxy" and "store and forward" concept with other routing protocol of ad hoc network like DSDV, DSR. This will give us a opportunity to compare two popular protocol.

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