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Low interference routing for wireless ad-hoc networks

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ABSTRACT

LOW INTERFERENCE ROUTING FOR WIRELESS AD-HOC NETWORKS

by
Mohit Gupta

In this thesis the primary focus is on the problem of interference between messages. The thesis discusses why the messages are blocked in a system? How adding a message impacts the cost of all other available links, which can be established in the system.

This thesis analyzes how the availability of channels, increase in number of nodes and increase in the transmission range help in increasing the number of messages that can be handled in the network. It is also analyzes how critical is the selection of the maximum transmission range MTR, transmission range TR and required transmission range RTR.

Therefore, the focus is on the method of tagging or evaluation of cost for developing any communication link between two nodes. The thesis proposes a system of evaluation of cost of each link and then utilizes the standard Dijikstra's algorithm to evaluate the cost of each message route from its source to its destination.

Chapter 2 explains the proposed algorithms with examples and the way to evaluate the cost of the links, subsequently Chapter 3 discusses the actual simulation environment, the cost matrix, distance matrix and the comparison of various selections of number of nodes in the system (N), maximum transmission range (MTR) and the number of available channels for each node (Ch).

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by
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LOW INTERFERENCE ROUTING FOR WIRELESS AD-HOC NETWORKS

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To my parents

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CHAPTER 1

INTRODUCTION

1.1 Wireless Ad-Hoc Networks

A wireless ad-hoc network is a collection of mobile/semi-mobile nodes with no pre-established infrastructure, forming a temporary network. Each of the nodes has a wireless interface and communicates over either radio or infrared. Laptop computers and personal digital assistants communicate with each other are some examples of nodes in an ad-hoc network. Nodes in an ad-hoc network are often mobile [1], but can also consist of stationary nodes, such as access points to the Internet. Semi mobile nodes can be used to deploy relay points in area where relay points might be needed temporarily.

Figure 1.1 shows a simple ad-hoc network with three nodes. The outermost nodes are not within transmitter range [2] of each other. However, the middle node can be used to forward packets between the outer most nodes. The middle node is acting as a router and the three nodes have formed an ad-hoc network.

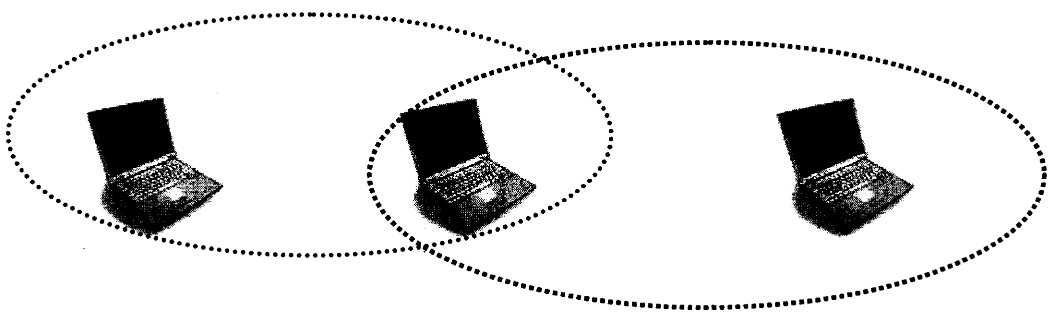

Figure 1.1 Example of a simple ad-hoc network with three participating nodes.

An ad-hoc network uses no centralized administration. This is to be sure that the network won't collapse just because one of the mobile nodes moves out of transmitter range of the others. Nodes should be able to enter and leave the network as they wish. Because of the limited transmitter range of the nodes, multiple hops may be needed to reach the other nodes. Every Node wishing to participate in an ad-hoc network must be willing to forward packets for other nodes. Thus every node acts as both a host and a router. A node can be viewed as an abstract entity consisting of a router and a set of affiliated mobile hosts (Figure1.2). A router is an entity, which among other things runs a routing protocol.

Ad-hoc networks are also capable of handling topology changes and malfunctions in nodes. It is fixed through network reconfiguration. For instance, if a node leaves the network and causes link breakages [3], affected nodes can easily request new routes and the problem will be solved. This will slightly increase the delay but the network will still be operational.

Wireless ad-hoc networks take advantage of the nature of the wireless communication medium. In other words in a wired network the physical cabling is done a priori restricting the connection topology [4] of the nodes. This restriction is not present in the wireless domain and, provided that the two nodes are within the transmitter of each other, an instantaneous link between them may form.

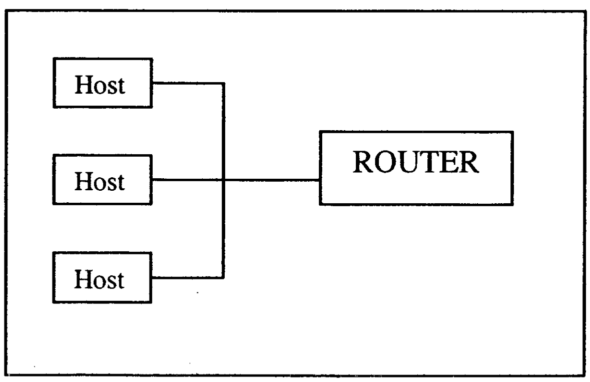

Figure 1.2 Block diagram of mobile node acting both as host and as router.

There is no clear picture of what these kinds of networks will be used for. The suggestions vary from document sharing at conferences to infrastructure enhancements and military applications.

In areas where no infrastructure such as the Internet is available an ad-hoc network could be used by a group of wireless mobile hosts. This can be the case in areas where a network infrastructure may be undesirable due to reasons such as cost or convenience. Examples [5] of such situations include disaster recovery personnel or military troops in cases where the normal infrastructure is either unavailable or destroyed.

Other examples include business associates wishing to share files in an airport terminal, or a class of students needing to interact during a lecture. If each mobile host wishing to communicate is equipped with a wireless local area network interface, the group of hosts may form an ad-hoc network.

1.2 Conventional Routing Protocols

There are conventional routing protocols [6] such as Link State and Distance Vector but the problem is that in a wireless network the topology is changing very often. As the number of nodes can be large, potential number of destinations is also large. This requires large and frequent exchange of data among the network nodes. This is in contradiction with the fact that all updates in a wireless interconnected ad-hoc network are transmitted over the air and thus are costly in resources such as bandwidth, battery power and CPU. Because both link-state and distance vector tries to maintain routes to all reachable destinations, it is necessary to maintain these routes and this also wastes resources for same reason as above.

Another characteristic for conventional protocols are that they assume bi-directional links, e.g. that the transmission between two hosts works equally well in both direction. In the Wireless radio environment this is not always the case. Because many of the proposed ad-hoc routing protocols have a traditional [7] routing protocol as underlying algorithm, it is necessary to understand the basic operation for conventional protocols like distance vector, link state and source routing.

1.2.1 Link State

In link-state routing, each node maintains a view of the complete topology with a cost for each link. To keep these costs consistent; each node periodically broadcasts the link costs of its outgoing links to all other nodes using flooding. As each node receives this information, it updates its view of the network and applies a [8] shortest path algorithm to choose the next-hop for each destination.

Some link costs in a node view can be incorrect because of long propagation delays, partitioned networks etc. Such inconsistent network topology view can lead to formation of routing loop. These loops are however short-lived because they disappear in the time it takes a message to traverse the diameter of the network.

1.2.2 Distance Vector

In distance vector each node only monitors the cost of its outgoing links, but instead of broadcasting this information to all nodes, it periodically broadcasts to each of its neighbors an estimate of the shortest distance to every other node in the network. The receiving nodes then use this information to recalculate the routing tables, by using a shortest path algorithm.

Compared to link-state, distance vector is more computation efficient, easier to implement and requires much less storage space. However it is well known that distance vector can cause the formation of both the short lived and long lived routing loops. The primary cause for this is that the nodes choose their next hops in a completely distributed manner based on information that can be stale.

1.2.3 Source Routing

Source routing means that each packet must carry the complete path that the packet should take through the network. The routing decision [9] is therefore made at the source. The advantage with this approach is that it is very easy to avoid routing loops. The disadvantage is that each packet requires a slight overhead.

1.2.4 Flooding

Many routing protocols use broadcast to distribute control information, that is, send the information from an origin node to all other nodes. A widely used form of broadcasting is flooding and operates as follows. The origin node sends its information [10] to its neighbors (in the wireless case, this means all nodes that are within transmitter range). The neighbors relay it to their neighbors and so on until the packet has reached all nodes in the network. A node will relay a packet once and to ensure this some sort of sequence number can be used. This sequence number is increased for each new packet a node sends.

1.3 Problems of Conventional Routing Protocol in Ad-hoc Networks

Treating each mobile host as a router, may often work, there are a number of problems with this approach:

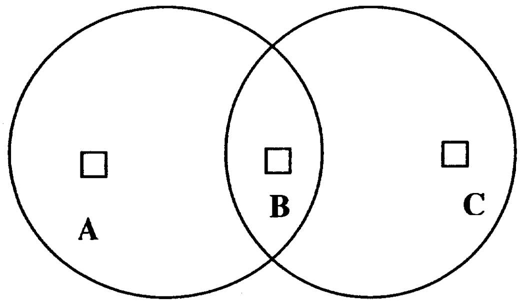

Figure 1.3 Three nodes within transmission range.

- Transmission between two hosts over a wireless network doesn't necessarily work equally well in both directions. Even though host A in Figure 1.3 may receive a routing update from B indicating that B is closest to C, and thus would be the first hop on A's shortest path to C, host A may in fact be unable to transmit packet back to B. Figure 1.3 represents the transmission range of all hosts as equal and uniform on all sides of the host, but radio and infrared propagation doesn't always work so nicely in reality[12]. Thus some routes determined by conventional routing protocols may be not work in some environments.

- Many "links" between routers seen by the routing algorithm may be redundant. Rather than a single router (mobile host B) between A and C, there may be many mobile hosts within A's range and perhaps equally good for forwarding packets to C. Wired networks, on the other hand are usually explicitly configured to have only one (or a small number) of routers connecting any two networks. The redundant paths in the wireless environment unnecessarily increases the size of routing updates that must be sent over the network, and increases the CPU overhead required to process each update and to compute new routes.

- Periodically sending updates wastes network bandwidth. Often, nothing will change from one routing update to the next but each router (mobile host) must continue to send updates so that the other host will continue to consider routes through that router is valid. Routing updates from mobile hosts outside each other's transmission range will not interfere with each other, but where many mobile hosts are within transmission range of each other, their routing updates will consume each other, and their routing updates will consume each other's network bandwidth.

- Periodically sending routing updates wastes battery power. Most mobile hosts in an ad hoc network will be operating on battery power, and transmitting each packet expends a significant amount of battery power (transmitting a packet, in effect, launches a portion of the host's battery power into the air). Although receiving a packet generally requires less power than sending one, the need to receive these periodic routing updates effectively prevents a host from conserving its own battery power by putting itself into "sleep" or "standby" mode when not otherwise busy.

- Conventional routing protocols are not designed for the type of dynamic topology changes that may be present in ad-hoc networks. In conventional networks, links between routers occasionally go down or come up and sometimes the cost of a link may change due to congestion, but routers don't generally move around dynamically, shifting major portions of the network topology back and forth. Mobile host though may be characterized by such dynamic movement, because they are after all, mobile. Convergence to new stable routes after such dynamic changes in topology may be quite slow, particularly with distance vector algorithms. The speed of convergence may be improved by sending routing updates more frequently, but such a shift only wastes more bandwidth and battery when topology changes are less dramatic.

1.4 Classification of Routing Protocols

Routing protocols can be classified into different categories depending on their properties.

1. Centralized vs. Distributed: One way to categorize the routing protocols is to divide them into centralized and distributed algorithms, all route choices are made at central node, while in distributed algorithms, and the computation of routes is shared among the network nodes.

2. Static vs. Adaptive: Another classification of routing protocols relates to whether they change routes in response to the traffic input patterns. In static algorithms, the route used by source-destination pairs is fixed regardless of traffic conditions. It can only change in response to a node or link failure. This type of algorithm cannot achieve high throughput under a broad variety of traffic input patterns. Most major packet networks uses some form of adaptive routing where the routes used to route between source-destination pairs may change in response to congestion.

3. Reactive vs. Proactive: A third classification that is more related to ad-hoc networks is to classify the routing algorithms as either proactive or reactive. Proactive protocols attempt to continuously evaluate the routes within the network, so that when a packet needs to be forwarded, the route is already known and can be immediately used. The family of Distance-Vector protocols is an example of proactive scheme. Reactive protocols on the other hand invoke a route determination procedure on demand only. Thus when a route is needed, some sort of global search procedure is employed. The family of classical flooding algorithms belongs to the reactive group. Proactive schemes have the advantage that when a route is needed, the delay before actual packet can be sent is very small. On the other side proactive schemes needs time to converge to a steady state. [11] This can cause problems if the topology is changing frequently.

1.5 Desirable Properties in Ad-hoc Routing Protocols

This section describes the different ad-hoc routing protocols and the properties, which are desirable in conventional routing protocols to make them suitable for ad-hoc networks.

1. Distributed Operation: The protocol should of course be distributed. It should not be dependent on a centralized controlling node. This is the case even for stationary networks. The difference is that the nodes in an ad-hoc network can enter/leave the network very easily and because of mobility the network can be partitioned.

2. Loop Free: To improve the over all performance, we want the routing protocol to guarantee that the routes supplied are loop-free. This avoids any waste of bandwidth or CPU consumption.

3. Demand based operation: To minimize the control overhead in the network and thus not wasting network resources more than necessary, the protocol should be reactive. This means that the protocol should only react when needed and that the protocol should not periodically broadcast control information.

4. Unidirectional link support: The radio environment [15] can cause the formation of unidirectional links. Utilization of these links and not only the bi-directional links improves the routing protocol performance.

5. Security: The radio environment is especially vulnerable to impersonation attacks, so to ensure the wanted behavior from the routing protocol, we need some sort of preventive measures. Authentication and encryption is probably the way to go and

the problem here lies within distributing keys among the nodes in the ad-hoc network.

6. Power conservation: The nodes in an ad-hoc network can be laptops and thin clients, such as PDAs that are very limited in battery power and therefore uses some sort of stand-by mode to save power. It is therefore important the routing protocol has support for these sleep modes.

7. Multiple routes: To reduce the number of reactions to topological changes and congestion multiple routes can be used. If one route has become invalid, it is possible that another stored route could still be valid and thus saving the routing protocol from initiating another router discovery procedure.

8. Quality of service support: Some sort of Quality of Service support is probably necessary to incorporate into the routing protocol. This has a lot to do with what these networks will be used for. It could for instance, be real-time traffic support.

1.6 Proposed Protocols by MANET

IEFT has a working group named MANET (Mobile Ad-hoc Networks) that is working in the field of ad-hoc networks. They are currently developing routing specifications for an ad-hoc IP network that support to scaling to a couple of hundred nodes.

None of the proposed protocols from MANET [13] have all these properties but it is necessary to remember that the protocols are still under development and is probably extended with more functionality. Currently there are six routing protocol drafts:

1.6.1 AODV Ad-hoc On Demand Distance Vector

Ad-hoc On Demand Distance Vector routing protocol enables multi-hop routing between participating mobile nodes wishing to establish and maintain ad-hoc network. AODV is based upon the distance vector algorithm. The difference is that AODV is reactive, as opposed to proactive protocols like DV, i.e. AODV requests a route when needed and does not require nodes to maintain routes to destinations that are not actively used in communication. As long as the endpoints of a communication connection have valid routes to each other, AODV does not play any role.

1.6.2 ZRP Zone Routing Protocol

Zone Routing Protocol is a hybrid of reactive and a proactive protocol. It divides the network into several routing zones and specifies two totally detached protocols that operate inside and between the routing zones. These two protocols are [15] IARP-Intrazone Routing Protocol & IERP Interzone Routing Protocol.

1.6.3 TORA Temporally Ordered Routing Algorithm

Temporally Ordered Routing Algorithm is a distributed routing protocol. The basic underlying algorithm is one in a family referred to as link reversal algorithms. TORA is designed to minimize reaction to topological changes. A key conception its design is that control messages are typically localized to a small set of nodes. It guarantees that all routes are loop-free (temporary loops may form), and typically provides multiple routes for any source/destination pair. It provides only the routing mechanism and depends on Internet MANET Encapsulation Protocol (IMEP) for other underlying functions.

1.6.4 DSR Dynamic Source Routing

The Dynamic Source Routing protocol (DSR) is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of the two main mechanisms of "Route Discovery" and "Route Maintenance", which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network. All aspects of the protocol operate entirely on-demand, allowing the routing packet overhead of DSR to scale automatically to only that needed to react to changes in the routes currently in use. The protocol allows multiple routes to any destination and allows each sender to select and control the routes used in routing its packets, for example for use in load balancing or for increased robustness. Other advantages of the DSR protocol include easily guaranteed loop-free routing, support for use in networks containing unidirectional links, use of only "soft state" in routing, and very rapid recovery when routes in the network change. The DSR protocol is designed mainly for mobile ad hoc networks of up to about two hundred nodes, and is designed to work well with even very high rates of mobility.

1.6.5 CEDAR Core Extraction Distributed Ad-hoc Routing

CEDAR dynamically establishes a *core* of the network, and then incrementally propagates link state of stable high bandwidth links to the nodes of the core. Route computation is on-demand, and is performed by core hosts using local state only. CEDAR is proposed as a QoS routing algorithm for small to medium size ad-hoc networks consisting of tens to hundreds of nodes. CEDAR does not compute optimal routes because of the minimalist approach to state management, but the trade-off of robustness and adaptation for optimality is believed to be well justified in ad-hoc networks.

1.6.6 OLSR Optimized Link State Routing Protocol

The Optimized Link State Routing Protocol (OLSR) is developed for mobile ad hoc networks. It operates as a table driven and proactive protocol, thus exchanges topology information with other nodes of the network regularly. The nodes which are selected as a multipoint relay (MPR) by some neighbor nodes announce this information periodically in their control messages. Thereby, a node announces to the network, that it has reachability to the nodes which have selected it as MPR. In route calculation, the MPRs are used to form the route from a given node to any destination in the network. The protocol uses the MPRs to facilitate efficient flooding of control messages in the network. OLSR inherits the concept of forwarding and relaying from HIPERLAN (a MAC layer protocol) which is standardized by ETSI.

CHAPTER 2

MATHEMATICAL MODEL

2.1 Problem of Blocking in Ad-hoc Networks

Ad-hoc networks are dynamic in nature and hence the major challenge is to be able to maintain connectivity amongst all nodes and for this purpose the transmission range needs to be selected with care. If higher transmission range is selected then the interference level or the number of channels blocked increases, hence the challenge in ad-hoc networks remains to be able to select the most appropriate value for transmission range.

2.2 Assumptions

1. At anytime the coordinates of all nodes in the network are known.
2. All nodes have requisite computational capabilities to find out their neighbors.
3. A node can communicate with its neighbor if both nodes have at least one channel available to set up a link.
4. Routing table updates are sent within the network at interval of time $t <$ expected time in which the network topology can be expected to change.
5. The nodes in the network have enough bandwidth to handle the updates.
6. Network is considered to be blocked if and only if there is at least one node, which has no available channels to communicate with other nodes.
7. Before a message is added in the network, all nodes in the network have got equal number of channels available for communication.

2.3 Limitations

Since ad-hoc networks are supposed to dynamic in nature, hence, to keep a track of the position of all nodes in the network is a complex task. The network is generated randomly at an instance of the simulation performed. Hence, there is a sizable probability that some nodes may completely be isolated in the network and may not be communicate with the rest of the nodes in the network. This situation is not considered as a state of blocking.

2.4 Definitions

2.4.1 Ad-hoc Networks

The IETF (Internet Engineering Task Force) working group on MANET (mobile ad-hoc networks) focuses on networks consisting of hundreds of stations. A network in this experiment is an ad-hoc network with nodes ranging from a minimum of 20 nodes and maximum of 100 nodes in an area of 20 units by 20 units.

2.4.2 Hop Count

Because an ad-hoc network is infrastructure less, a message should traverse several intermediate nodes to reach a destination node from the source node. Hop count is defined as pair wise transmissions required for a packet to reach the destination from the source. Since the transmission range impacts the length of one loop, it also influences the hop count.

2.4.3 Node

A node is an entity in the network, which has the capability to communicate with others and transmit messages. There are various types of nodes which take part in communication, source node represented by S, intermediate node represented by I and destination node represented by D.

2.4.4 Link

A link is a connection, which exits between two nodes via which a message is communicated. It is a one-hop count transmission. It is represented by L.

2.4.5 Path

A path is a set of links which exist between a randomly selected source S_i and a destination node D_i. It is end-to-end flow and may consist of one or many links.

2.4.6 Cost for Constant Power (Non Adaptive)

The cost of going from node N_i to N_j = number of nodes which are located within the area of the circle of radius equal to the transmission range. The constant power is an approach where in all stations in the network use the same constant transmission power. The stations don't change the transmission based on network conditions.

2.4.7 Cost for Variable Power (Adaptive)

The cost of going from node Ni to Nj is the number of nodes which are located within the area of the circle of radius equal to the transmission range. The variable power is an approach where in all stations in the network use variable transmission power. The stations change the transmission power based on network conditions.

2.4.8 Blocking

In the simulation, after randomly generating a set of nodes in the network, the impact of adding more messages in the system is studied until the first node which has no channels left for communication is identified. At this point, the network is considered to be blocked, although certain messages may be still added.

2.4.9 Transmission Range (TR)

It is the distance to which the node can send its message and block all the corresponding channels for all nodes within the same radius.

2.4.10 Cost of Link

It is α to number of channels (ch_1, ch_2, ch_3 ......ch_n) which get blocked for all nodes which lie in radius r of the circle with center as the origin of the link.

2.4.11 Cost of Path

It is the summation cost of all links (l_1, l_2, l_3.......l_n), which take part in transfer of message from Source S_i to destination D_i.

2.4.12 Maximum Transmission Range (MTR)

It is directly proportional to the transmission power, which is directly proportional to the energy storing capacity of the node. It is equal to the maximum possible distance to which a node can transmit a message.

2.4.13 Neighbor

A node N_j is considered to be a neighbor of node N_i if it lies within the (radius of the circle r = MTR for constant power) and (radius of the circle r = RTR for variable power) with center as node N_i.

2.4.14 Capacity of Network

It is the total number of messages, which can be handled by the network at any instant of time. This value varies as the topology of the network changes but can be considered to be constant at a finite instant of time, which tends to zero. This instant of time is less than the time t in which the topology of the network is expected to change. It is represented by M.

2.4.15 Incremental Factor

This factor determines the amount by which the cost of usage of a node in a link increases when one of its channels has already been used up in a link for a different path. This factor can be dependent on a various number of factors such as density of nodes in the transmission range, or the number of channels used up. In this experiment it is a constant number and can be changed as per the requirement. It is represented by F.

2.5 Proposed Approaches

In this thesis, a comparison is made between the number of messages, which can be handled by the network in various situations, constant power, adaptive network with constant power and adaptive network with variable power & conventional shortest path algorithm.

2.5.1 Constant Power

Consider the case of constant power when all nodes are within the region R cannot vary the transmission range.

Example of Constant Power

In Figure 2.1 source S wants to transmit a message to node D. The maximum transmission range (MTR) for each node is r but the required transmission range (RTR) to transmit from S to D is dist (S, D).

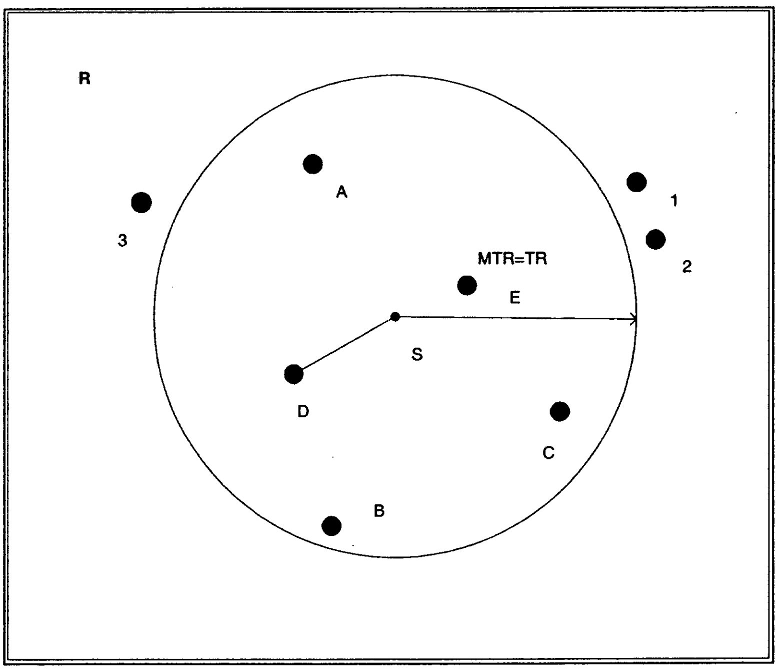

Figure 2.1 Transmission using constant power.

Here, TR = MTR (for constant power), dist (S, D) = $\sqrt{|(x_s^2 - y_s^2) + (x_D^2 - y_D^2)|} < r$, where r is the MTR > RTR, cost (S, D) = $\sum$\{number of nodes bounder by circle of radius r with center (x_S, y_S)\}, where (x_i, y_i) denote the coordinates of any node in the region R.

Therefore, all nodes within the circle c, (S, A, B, C, D,E) of area $\prod r^2$ will have frequency f_i blocked. Any node lying outside the area can however reuse the frequency but cannot communicate with any node lying within the region bounded by the circle C. Thus, it can be said that a channel has been blocked because a link has been established between S_i and D_i at frequency f_i. In the example above no link can be established between nodes (1, 2, 3) and nodes (A, B, C, D, S) at frequency f_i.

2.5.2 Variable Power

In the case of variable power the transmission power [23] is variable although the maximum transmission range MTR is still a constant value. The TR α dist (N_i,N_j), where $N_i,N_j \in R$.

Example of Variable Power

In the figure 2.2 source S wants to transmit a message to node D. The maximum transmission range (MTR) for each node is r but the required transmission range (RTR) to transmit from S to D is dist (S, D) and in variable power approach the transmission power can be tuned or varied as per the RTR.

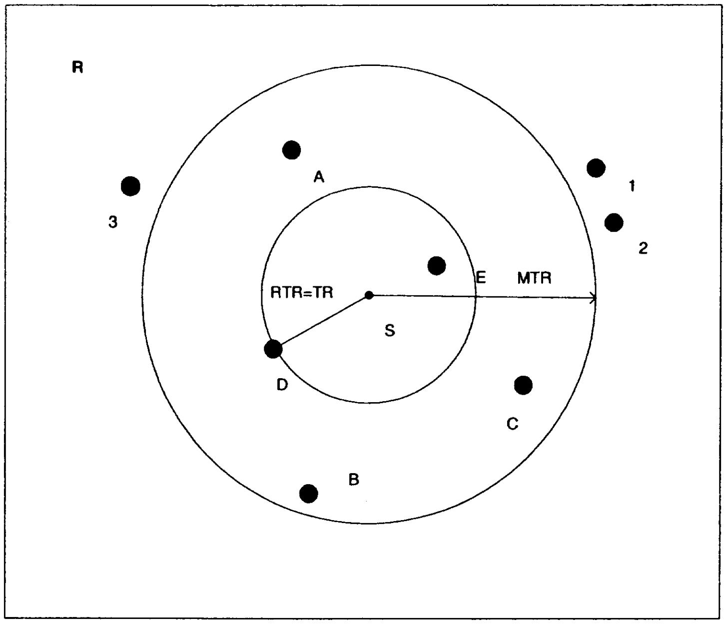

Figure 2.2 Transmission using variable power.

Here,TR = RTR (for variable power) ,dist(S,D) = $\sqrt{|(x_s^2 - y_s^2) + (x_D^2 - y_D^2)|} < r$, where r is the MTR > RTR, cost(S,D) = $\sum$\{number of nodes bounder by circle of radius TR with center (x_s,y_s)\}, where (x_i,yi) denote the coordinates of any node in the region R.

Therefore, all nodes within the circle c, (S, E, D) of area $\prod(TR)^2$ will have frequency f_i blocked. Any node lying outside the area can however reuse the frequency but cannot communicate with any node lying within the region bounded by the circle c. Thus it can be said that a channel has been blocked because a link has been established between S_i and D_i at frequency f_i.

In the example above no link can be established between nodes (1, 2, 3, A, B, C, D) and nodes (S, E) at frequency f_i. However, it can be observed that the area $\prod (TR)^2 < \prod r^2$ and the number of nodes with frequency f_i are lower than constant power. Therefore, a higher number of messages can co-exist in the region R.

There are always a limited number of channels allocated to nodes participating in an ad-hoc network. As and when more messages are introduced in the network the number of channels available in the network reduces. Therefore, it is possible to reach a situation when the number of channels Ch (N_i) = 0 and hence any message originating at node N_i gets blocked due to unavailability of a frequency to communicate with any other node could be at dist(N_i,N_j) < r and N_i,N_j Є R.

2.5.3 Adaptability with Constant Power

It is understood that each node in the network has pre-designated number of channels which can be used to transmit messages within the region R to all nodes which ε R. Thus as in the above discussed case of constant power if a node within the circle of radius r is required to be used for transmission of message to a neighbor node then the cost at which it is available is much higher when one of its channels (f_i) is blocked that when none of the channels was blocked. Therefore, by introducing adaptability in the system, the cost of all possible paths is incremented such that for choosing a link the cheapest way is selecting the nodes with least number of channels utilized. This can be understood in detail by considering the Figure 2.3 below.

Example of Adaptability with Constant Power

In constant power, the transmission range TR=MTR cannot be varied according to RTR. As can be illustrated by figure 2.3 above there are two circles named C_1, which has center as S and circle C_2 that has center D. Both the circles have equal radius since in constant power TR=MTR.

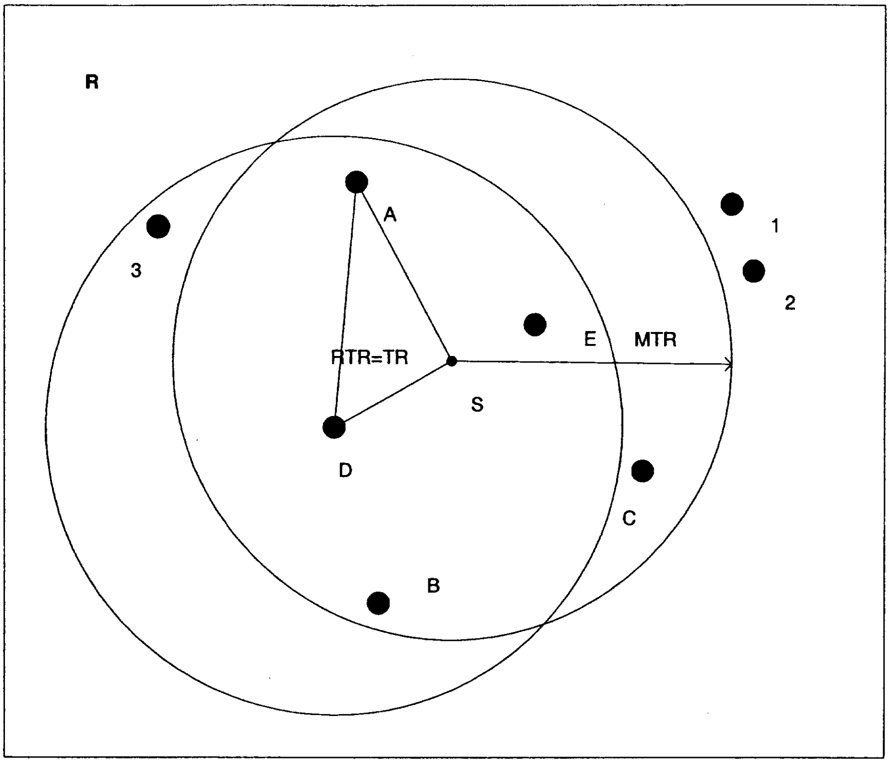

Figure 2.3 Transmission using adaptability with constant power.

Consider that three messages need to be communicated sequentially one after the other between node (N_i, N_j) where (N_i, N_j) ε R. Let the first message be S→ D, Cost (S, D) = 6, once this path is existing in the network and another message has to be sent from S→ E, then Cost (S, E) = (6 + F). On adding the third message in the network while the rest of the two are existing in the network from D→ A the Cost (D, A)= (6+F+F). The cost (D,A) 2F higher than 6 because both the nodes D and A have two channel each already blocked.

2.5.4 Adaptability with Variable Power

By introducing adaptability in the variable power approach, it is expected to get the best results. There are least number of nodes which get channels blocked and the utilization of nodes with blocked channels is done in the order in which the nodes with maximum channels available are utilized first and subsequently the others are brought into use for transmission of messages.

Consider a situation in which the destination node is more than one hop far. There is more than one path to reach the destination. How the variable power approach allows choosing a path where in lesser number of channels per node are blocked is demonstrated below.

Example for Comparison of Constant Power with Variable Power

In Figure 2.4, there are 5 nodes, which lie, in the region R. The source of the message is represented by node S and the destination D. Considering the case of constant power the most suitable path for sending the message from source S to destination is S→C→ D. Therefore, the number of hops H =2 for the path S→C→D is less than S→A→B→D where H=3, also Σ{dist(S,C),dist(C, D)} < Σ{ dist(S,A) dist(A,B), dist(B,D)}.

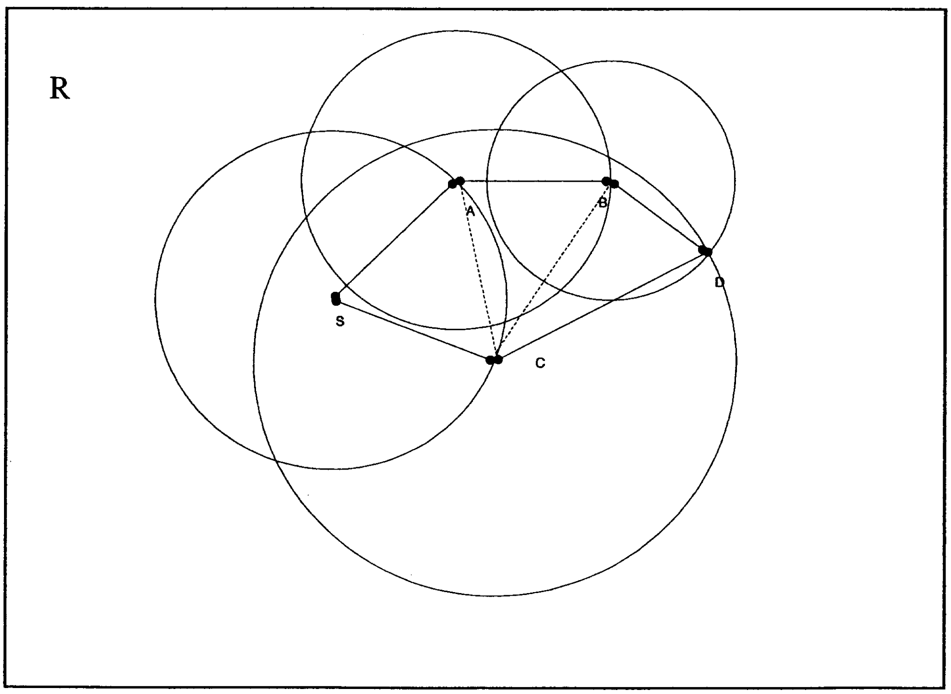

Figure 2.4 Comparison of constant power with variable power.

Look at the cost involved in each individual links involved in the two possible paths S→C→ D and S→A→B→D. Cost as described above is the number of nodes, which are blocked for a frequency f_i.

Therefore, Cost (S, A) = 2, Cost (A, B) = 2, Cost (B, D) = 2, Cost (S, C)= 3, Cost(C, D)= 5. Hence, the cheapest path is S→A→B→D although H= 3. Here the Cost (S→A→B→D)=6. According to shortest path, the cheapest path was S→C→D, but the Cost (S→C→D)=8, hence, is not selected by Dijikstra's algorithm.

2.5.5 Conventional Shortest Path Algorithm

The choice of path in the shortest path algorithm will be quite similar to the case of constant power where the cost of all links is set to 1. This path will also be the path of least number of hops.

Example of Conventional Shortest Path Algorithm

In the Figure 2.5, the source node is 1 and the destination node is 4. Although the shortest path as can be easily determined is the hypotenuse of the triangle which is formed by the nodes (1, 2, 3, 4, 5), the shortest path selected by accounting the number of hops made is smaller if the path from 1→ 4 is 1→5→4. The hop count for 1→2→3→4 is H= 3 whereas the hop count for the path 1→5→4 is H=2.

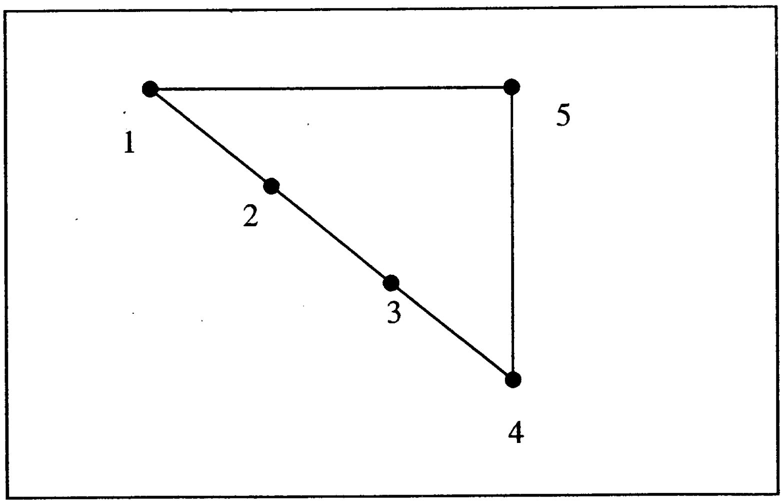

Figure 2.5 Path selection in conventional shortest path algorithm.

2.5.6 Conventional Shortest Path Algorithm with Adaptability

The choice of shortest path with adaptability is a regular approach. Hence it is expected that the results obtained by this approach will be better than conventional shortest path algorithm, as the utilization of channels is being constantly tracked but the number of nodes getting affected by the constant radius is not accounted for. Hence the system is not properly optimized.

Example using Conventional Shortest Path Algorithm with Adaptability

In Figure 2.6, assume that two messages need to be transferred from 1→ 4 consecutively. Based on hop count the cheapest path which will be selected by Dijikstra's algorithm is 1 → 5 → 4 but once the two links 1→5 & 5→4 have been established, two channels of node 5 are blocked and one channel each of node 1 and 4 , thus, if another message has to be added into the system from node 1 to node 4 then the path which it will select is 1→2→3→4 since the cost for using node 5 has been incremented twice by the incremental factor F.

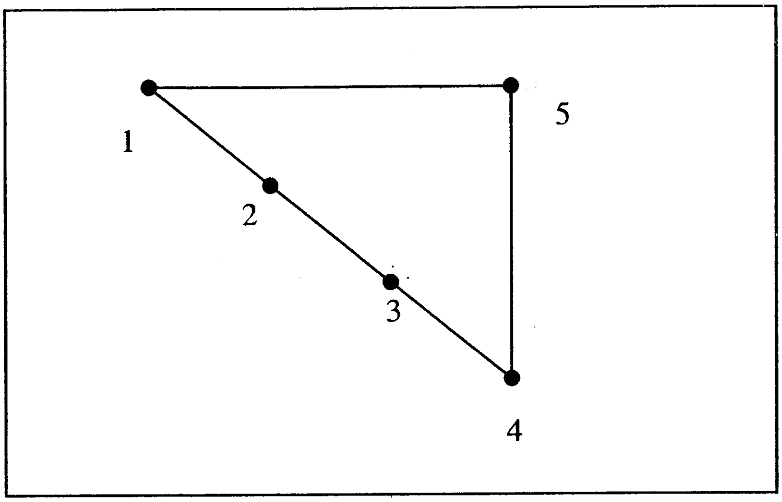

Figure 2.6 Path selection using adaptable shortest path algorithm.

CHAPTER 3

EXPERIMENT AND RESULTS

3.1 Assumptions

1. Assume that all nodes are located in the area bound by x (0 to 20) and y (0 to 20).

2. With increase in number of nodes we actually increase the density of the number of nodes located in the area bound by x (0 to 20) and y (0 to 20).

3. All nodes are randomly generated using function in Java; an instance of this class is used to generate a stream of pseudorandom numbers. The class uses a 48 bit seed (timestamp), which is modified using a linear congruential formula.

3.2 Description of Algorithm

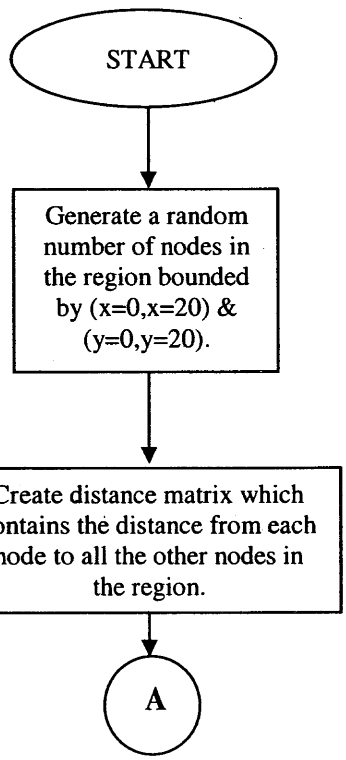

Figure 3.1 Flow-chart for the simulation.

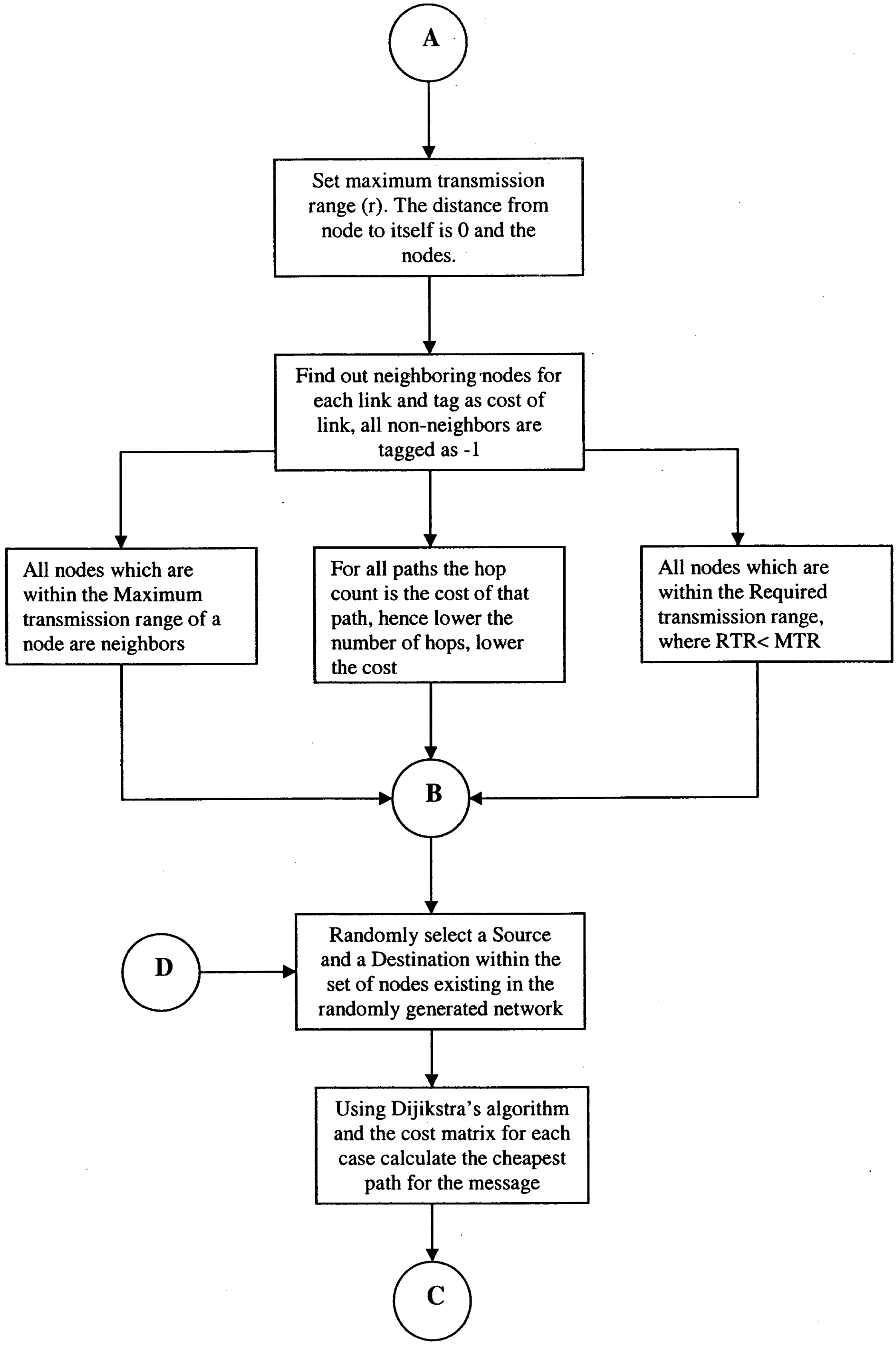

Figure 3.1 Flow-chart for the simulation (Continued).

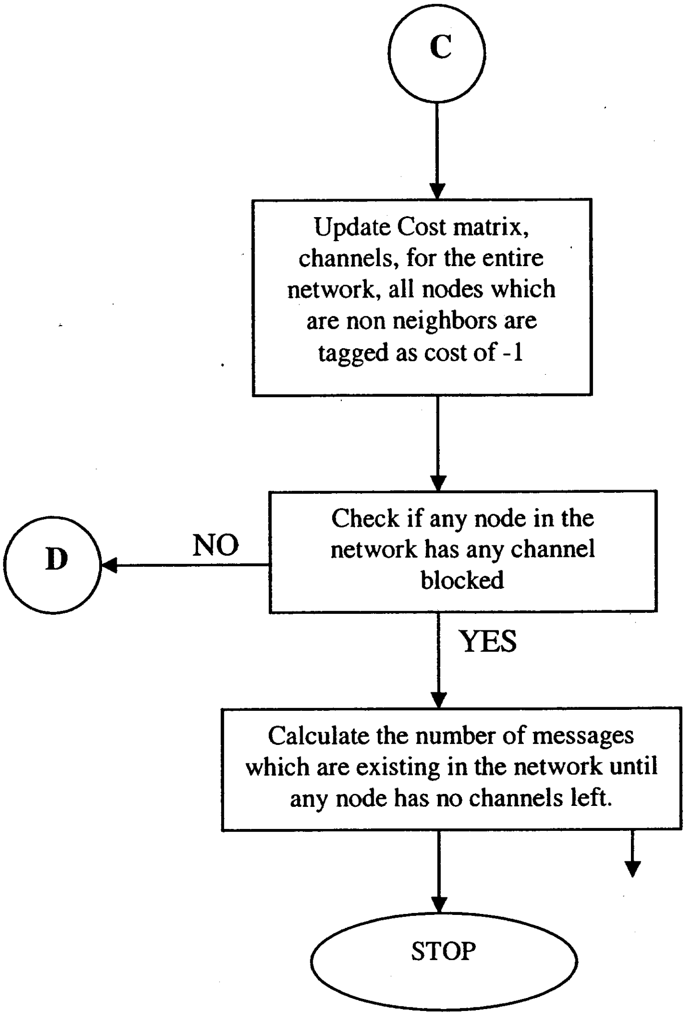

Figure 3.1 Flow-chart for the simulation (Continued).

Random nodes are generated in a predefined area. For simplicity, consider a two dimensional area although in practicality the space in question is three-dimensional but this assumption doesn't affect the accuracy of experiments performed in anyway.

The density of nodes can be increased or decreased as required to perform the study experiment. Each node is assigned a predefined number of channels, which it can use to communicate with any of its neighbors.

When a message needs to be sent from one node to the other, assuming both and sources are direct neighbors, it need not be important that it goes directly to the destination without any hop. It is attempted to reduce the number of channels blocked per link in the network. Dijikstra's algorithm is used to see how the best path is selected if it exists.

The next step is to add multiple randomly generated messages from randomly generated sources and destination. With each message being added into the network the cost matrix is updated.

This process of adding messages and updating the costs of every possible link is repeated until the first node, which has no available channels, is detected in the network of nodes. It is that this instant when it is assumed that a message originating at this node as source or any other message which requires this node to participate in the network will get blocked.

Consider this as a checkpoint because at this moment a message can be blocked in the network due to unavailability of the channels at a particular node. Do not consider unavailability of a neighbor for link establishment as a state of blocking. If a node has no neighbors within its maximum communication range then the network cannot participate in forming an ad-hoc network.

A path with the minimal cost for a given source and destination is selected as the routing path. This path can be constructed using a classical shortest path algorithm, where at the first step, the cost of all links is found. The complexity of this problem is around O (N^2 log (N)), where N is the number of nodes. The same information about the cost of the links used by all routers is noted,. This can be locally calculated and broadcasted in the same way, as positional information. Thus, the complexity of the proposed approach is the same as for the shortest path routing.

3.3 Simulation Setup

The table below illustrates the coordinates of the points, which are in the region R and are considered during the experiment. The entire network comprises of 20 nodes randomly generated. The coordinates are listed below.

Table 3.1 Actual Coordinates in Simulation

Node	X	Y
0	7	11
1	7	0
2	13	12
3	4	16
4	12	4
5	7	15
6	4	19
7	15	8
8	5	6
9	8	0
10	4	17
11	19	15
12	13	13
13	5	4
14	4	3
15	0	1
16	7	3
17	7	5
18	18	5
19	17	3

Table 3.2 illustrates the distance matrix, which is a constant matrix and doesn't change until the nodes change their position. Thus every time the position of nodes within an ad-hoc network change positions the distance matrix is evaluated again and the same is circulated to all nodes in the network. In our algorithm we make decisions based on the position of nodes at any instant of time. .

Table 3.2 Distance Matrix

N	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
0		11	6	5	8	4	8	8	5	11	6	12	6	7	8	12	8	6	12	12
1	11	**0**	13	16	6	15	19	11	6	1	17	19	14	4	4	7	3	5	12	10
2	6	13	**0**	9	8	6	11	4	10	13	10	6	1	11	12	17	10	9	8	9
3	5	16	9	**0**	14	3	3	13	10	16	1	15	9	12	13	15	13	11	17	18
4	8	6	8	14	**0**	12	17	5	7	5	15	13	9	7	8	12	5	5	6	5
5	4	15	6	3	12	**0**	5	10	9	15	3	12	6	11	12	15	12	10	14	15
6	8	19	11	3	17	5	**0**	15	13	19	2	15	10	15	16	18	16	14	19	20
7	8	11	4	13	5	10	15	**0**	10	10	14	8	5	10	12	16	9	8	4	5
8	5	6	10	10	7	9	13	10	**0**	6	11	16	10	2	3	7	3	2	13	12
9	11	1	13	16	5	15	19	10	6	**0**	17	18	13	5	5	8	3	5	11	9
10	6	17	10	1	15	3	2	14	11	17	**0**	15	9	13	14	16	14	12	18	19
11	12	19	6	15	13	12	15	8	16	18	15	**0**	6	17	19	23	16	15	10	12
12	6	14	1	9	9	6	10	5	10	13	9	6	**0**	12	13	17	11	10	9	10
13	7	4	11	12	7	11	15	10	2	5	13	17	12	**0**	1	5	2	2	13	12
14	8	4	12	13	8	12	16	12	3	5	14	19	13	1	**0**	4	3	3	14	13
15	12	7	17	15	12	15	18	16	7	8	16	23	17	5	4	**0**	7	8	18	17
16	8	3	10	13	5	12	16	9	3	3	14	16	11	2	3	7	**0**	2	11	10
17	6	5	9	11	5	10	14	8	2	5	12	15	10	2	3	8	2	**0**	11	10
18	12	12	8	17	6	14	19	4	13	11	18	10	9	13	14	18	11	11	**0**	2
19	12	10	9	18	5	15	20	5	12	9	19	12	10	12	13	17	10	10	2	**0**

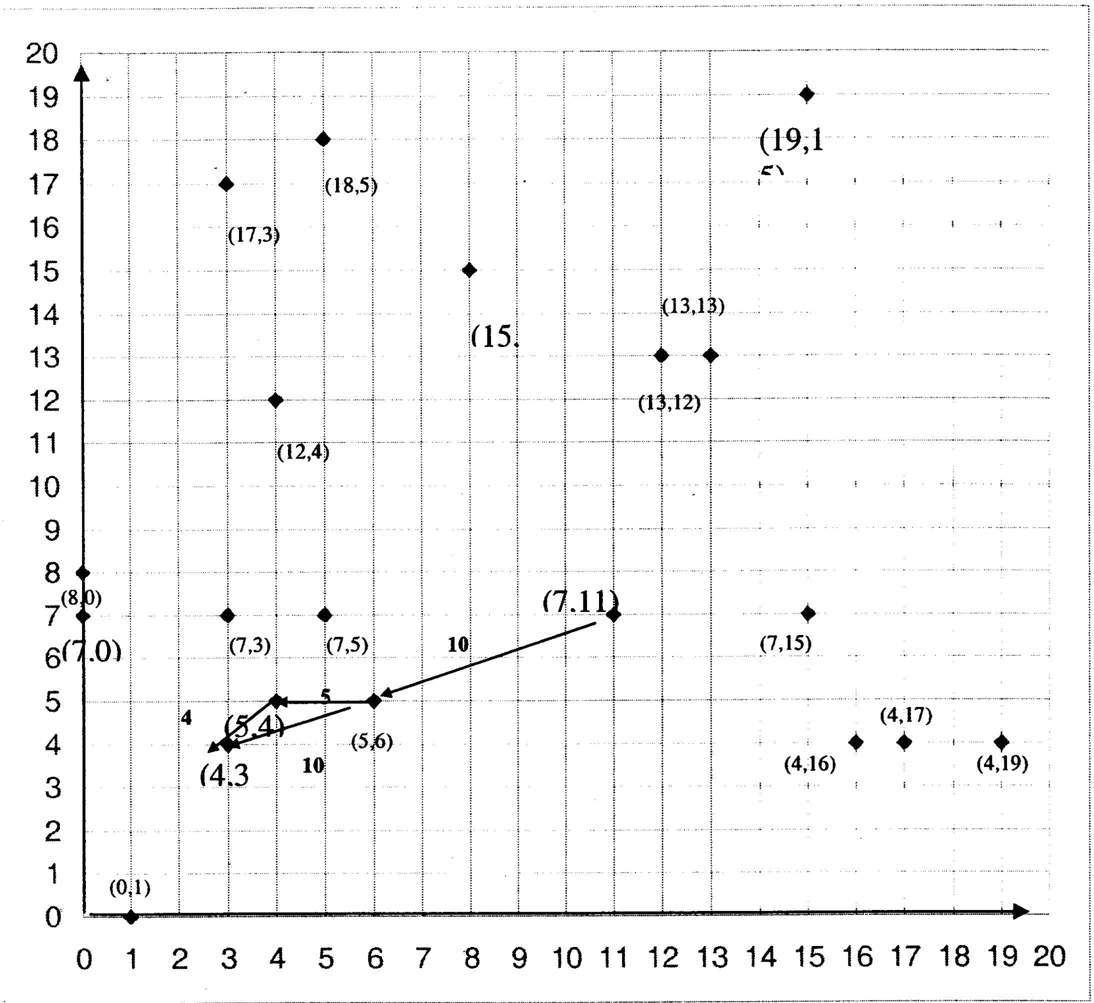

Figure 3.2 Actual positioning of the nodes within the network.

In the above example, a set of random nodes are generated with x and y coordinates. Using the above example it is shown, how the proposed adaptable algorithm for ad-hoc networks proves to be more efficient in selecting the path for the message from its source to its destination.

Here node (7,11) is the source node and the destination is node (4,3). The system for constant power or non-adaptive routing traces the path from node (7,11) to node (5,6) at a cost of 10 and finally to the destination node at a cost of 10, hence the total cost of message is 20. Here 20 refers to all the nodes which have at least one channel blocked, node (5,6) has 2 channels blocked.

Table 3.3 Updated Cost Matrix for Constant Power

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	-1	10	10	-1	10	-1	-1	10	-1	10	-1	10	-1	-1	-1	-1	10	-1	-1
1	-1	0	-1	-1	7	-1	-1	-1	7	7	-1	-1	-1	7	7	-1	7	7	-1	-1
2	5	-1	0	-1	-1	5	-1	5	-1	-1	-1	5	5	-1	-1	-1	-1	-1	-1	-1
3	4	-1	-1	0	-1	4	4	-1	-1	-1	4	-1	-1	-1	-1	-1	-1	-1	-1	-1
4	-1	7	-1	-1	0	-1	-1	7	-1	7	-1	-1	-1	-1	-1	-1	7	7	7	7
5	6	-1	6	6	-1	0	6	-1	-1	-1	6	-1	6	-1	-1	-1	-1	-1	-1	-1
6	-1	-1	-1	3	-1	3	0	-1	-1	-1	3	-1	-1	-1	-1	-1	-1	-1	-1	-1
7	-1	-1	5	-1	5	-1	-1	0	-1	-1	-1	-1	5	-1	-1	-1	-1	-1	5	5
8	10	10	-1	-1	-1	-1	-1	-1	0	10	-1	-1	-1	10	10	-1	10	10	-1	-1
9	-1	7	-1	-1	7	-1	-1	-1	7	0	-1	-1	-1	7	7	-1	7	7	-1	-1
10	4	-1	-1	4	-1	4	4	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
11	-1	-1	2	-1	-1	-1	-1	-1	-1	-1	-1	0	2	-1	-1	-1	-1	-1	-1	-1
12	5	-1	5	-1	-1	5	-1	5	-1	-1	-1	5	0	-1	-1	-1	-1	-1	-1	-1
13	-1	7	-1	-1	-1	-1	-1	-1	7	7	-1	-1	-1	0	7	7	7	7	-1	-1
14	-1	7	-1	-1	-1	-1	-1	-1	7	7	-1	-1	-1	7	0	7	7	7	-1	-1
15	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	2	0	-1	-1	-1	-1
16	-1	7	-1	-1	7	-1	-1	-1	7	7	-1	-1	-1	7	7	-1	0	7	-1	-1
17	8	8	-1	-1	8	-1	-1	-1	8	8	-1	-1	-1	8	8	-1	8	0	-1	-1
18	-1	-1	-1	-1	3	-1	-1	3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	3
19	-1	-1	-1	-1	3	-1	-1	3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	0

Whenever a channel at a node is blocked the cost of using it in the network for transmitting any message subsequently, increases. Therefore, the reuse of a node to form path in the network highly discouraged unless it becomes mandatory. This is made possible by adaptively increasing the cost of the node by IR as the number of channels at each available node reduces.

Here is a case of constant power, where the distance to which a node can transmit is not variable hence if a node can communicate to maximum of distance r omni-directionally (In this experiments two dimensional area has been considered for simplicity.). Hence, all nodes within the circle of radius r are blocked as soon as a link (unidirectional) is established from a source (placed at the center of the circle) and any other node within the area.

Table 3.4 Updated Channel Matrix

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
8	9	9	9	10	9	10	10	8	9	9	10	9	9	9	10	9	8	10	10

It is assumed that all nodes have initially got fixed number of channels and as when a link is formed we decrement the available channels at that node. The above channel matrix shows how the channels are decremented after the links have been established.

Using the approach where it is possible to vary the transmission range as per the required transmission range Dijikstra's algorithm, select the links from node (7,11) to node (5,6), node (5,6) to node (5,4), node (5,4) to node (4,3). The total cost of the path is 19 as compared to the case of constant power where the cost was 20.

Table 3.5 Cost Matrix for Variable Power

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	-1	7	6	-1	4	-1	-1	6	-1	7	-1	7	-1	-1	-1	-1	7	-1	-1
1	-1	0	-1	-1	7	-1	-1	-1	7	1	-1	-1	-1	4	4	-1	2	5	-1	-1
2	5	-1	0	-1	-1	5	-1	2	-1	-1	-1	5	1	-1	-1	-1	-1	-1	-1	-1
3	4	-1	-1	0	-1	3	3	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4	-1	7	-1	-1	0	-1	-1	5	-1	5	-1	-1	-1	-1	-1	-1	5	5	7	5
5	3	-1	6	2	-1	0	4	-1	-1	-1	2	-1	6	-1	-1	-1	-1	-1	-1	-1
6	-1	-1	-1	2	-1	3	0	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
7	-1	-1	2	-1	5	-1	-1	0	-1	-1	-1	-1	5	-1	-1	-1	-1	-1	2	5
8	5	7	-1	-1	-1	-1	-1	-1	0	7	-1	-1	-1	5	4	-1	4	5	-1	-1
9	-1	1	-1	-1	6	-1	-1	-1	7	0	-1	-1	-1	6	6	-1	2	6	-1	-1
10	4	-1	-1	1	-1	3	2	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
11	-1	-1	2	-1	-1	-1	-1	-1	-1	-1	-1	0	2	-1	-1	-1	-1	-1	-1	-1
12	5	-1	1	-1	-1	5	-1	2	-1	-1	-1	5	0	-1	-1	-1	-1	-1	-1	-1
13	-1	5	-1	-1	-1	-1	-1	-1	4	7	-1	-1	-1	0	4	7	4	4	-1	-1
14	-1	6	-1	-1	-1	-1	-1	-1	4	7	-1	-1	-1	1	0	6	4	4	-1	-1
15	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2	1	0	-1	-1	-1	-1
16	-1	6	-1	-1	7	-1	-1	-1	6	6	-1	-1	-1	2	6	-1	0	2	-1	-1
17	8	7	-1	-1	7	-1	-1	-1	3	7	-1	-1	-1	3	4	-1	3	0	-1	-1
18	-1	-1	-1	-1	3	-1	-1	2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	1
19	-1	-1	-1	-1	3	-1	-1	3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	0

Table 3.6 Updated Channel Matrix

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
9	10	10	9	10	9	10	10	8	10	10	10	10	8	9	10	10	9	10	10

It is observed that the number of channels per node blocked in the case of constant power is much higher than the case of variable power when the number of channels blocked is lower. Thus, it has been proved that Adaptive variable power routing is more efficient than routing strategies.

3.4 Reasons for Blocking in Ad-hoc Network

In this simulation, a randomly generated set of nodes is created within a bound area, hence, with addition of each node the density of nodes in the bounded area increases. Each node is expected to have routing capabilities and has a set number of channels allocated for communication with other nodes, which are its neighbors. A message cannot be delivered from a source S to destination D if S has no other node, which has D as its neighbor, or if D is not a direct neighbor.

Another reason to blocking can be that a required node to establish a link in the required path of the message from its source S to destination D has no available channel, which it can allocate to the message. The topology of an Ad-hoc network is random and the cost updation and the availability of the nodes with channels have to be updated at intervals smaller than the expected time interval within which the topology of the network changes.

3.5 Results of Simulation

Table 3.7 Results for Transmission Radius=5, Channels=5

N,r=5,c-5	CP: Adaptive	VP: adaptive	CP	VP	Shortest Path: Adaptive	SP
20	3.429	3.821	2.592	3.23	2.872	2.63
30	3.191	3.526	2.44	2.976	2.732	2.43
40	3.18	3.496	2.43	2.78	2.83	2.46
50	3.253	3.49	2.8	2.91	2.98	2.76
60	3.377	3.614	3	3.02	3.1	2.97
70	3.329	3.468	2.98	3.2	2.89	2.86
80	3.376	3.459	2.86	3.21	3.01	2.98
90	3.42	3.499	3.01	3.08	3.04	2.98
100	3.379	3.397	2.98	3.12	3.07	3.02

Table 3.8 Results for Transmission Radius=5, Channels=10

N, r=5,c-10	CP: adaptive	VP: adaptive	CP	VP	Shortest Path: Adaptive	SP
20	6.993	8.155	4.73	4.78	4.71	4.64
30	6.775	8.007	5.1	5.38	5.45	5.3
40	7.173	8.812	4.97	5.74	5.87	5.35
50	7.407	9.204	5.97	6.12	6.38	6.02
60	7.669	9.649	5.91	6.2	6.43	6.23
70	7.713	9.7565	5.84	5.91	6.31	6.3
80	7.757	9.864	5.91	6.1	6.39	6.33
90	7.853	9.819	5.88	6.02	6.38	6.27
100	7.784	9.891	5.72	6.15	6.43	6.32

Table 3.9 Results for Transmission Radius=8, Channels= 10

N, r=8,c=10	CP: adaptive	VP: adaptive	CP	VP	Shortest Path: Adaptive	SP
20	7.148	9.15	5.23	5.32	6.412	6.2
30	11.195	15.28	528	5.81	6.43	6.28
40	7.425	13.23	5.31	5.67	6.6	6.45
50	7.443	9.774	5.38	5.82	6.65	6.43
60	7.482	11.23	5.42	5.62	6.63	6.48
70	7.482	12.13	5.483	5.832	6.57	6.51
80	7.489	9.963	5.51	5.67	6.61	6.42
90	7.496	10.064	5.67	5.75	6.805	6.68
100	7.495	9.953	6.12	6.21	6.812	6.7

Table 3.10 Results for Transmission Radius=18, Channels=20

N, r=18,c=20	CP: adaptive	VP: adaptive	CP	VP	Shortest Path: Adaptive	SP
20	19.706	23.004	8.2	8.81	11.23	11.02
30	19.724	22.3	8.52	8.57	11.21	10.89
40	19.742	22.542	8.91	9.01	12.12	11.23
50	19.732	22.925	9.01	9.43	12.42	12.31
60	19.722	23.308	9.21	9.43	12.75	12.68
70	19.745	23.436	9.33	9.47	12.48	12.43
80	19.737	23.936	9.37	9.51	12.76	12.69
90	19.731	24.075	9.72	9.83	15.23	14.32
100	19.731	24.454	9.73	9.91	15.83	14.96

3.5.1 Comparison of Adaptive Constant Power with Constant Power

Figure 3.3 to 3.6 are used to demonstrate the advantage of having adaptive nature.

Case 1: N=(20,30,40,50,60,70,80,90,100), MTR=5, Ch=5, IR=0(Non Adaptive), IR=3 (Adaptive).

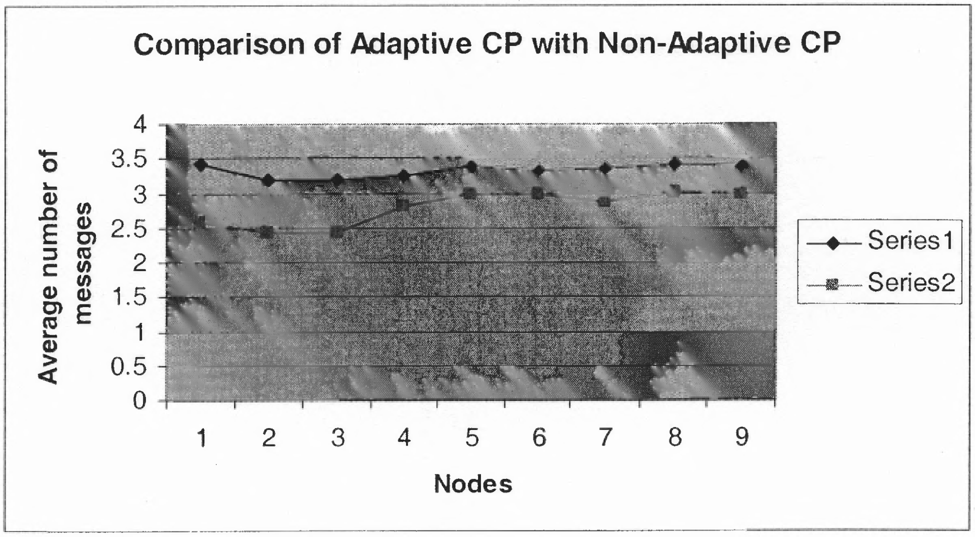

Figure 3.3 Comparison of adaptive constant power (series 1) with non adaptive constant power (series 2) R=5, Ch=5.

Case 2: N=(20,30,40,50,60,70,80,90,100), MTR=5, Ch=10, IR=0(Non Adaptive), IR=3 (Adaptive).

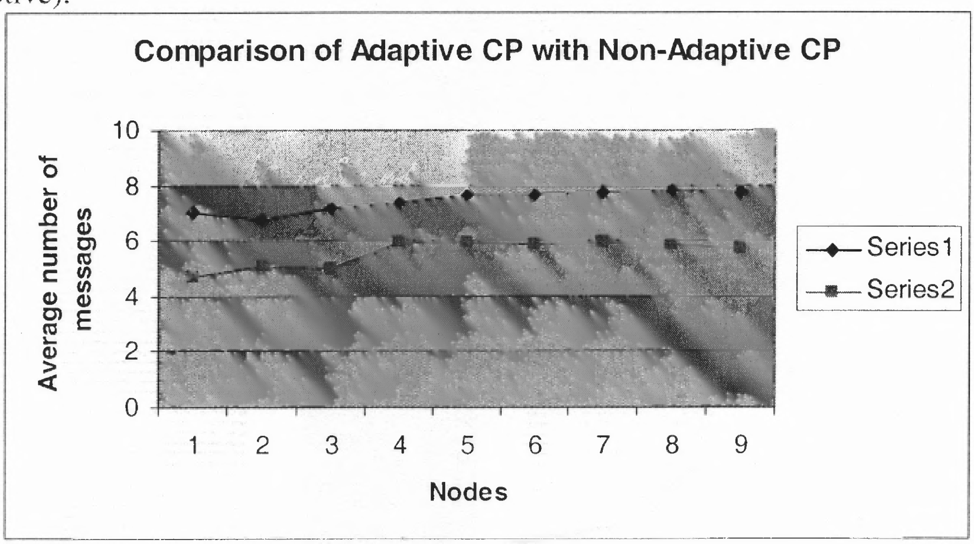

Figure 3.4 Comparison of adaptive constant power (series 1) with non adaptive constant power (series 2) R=5, Ch=10.

Case 3: N=(20,30,40,50,60,70,80,90,100), MTR=8, Ch=10, IR=0(Non Adaptive), IR=3 (Adaptive).

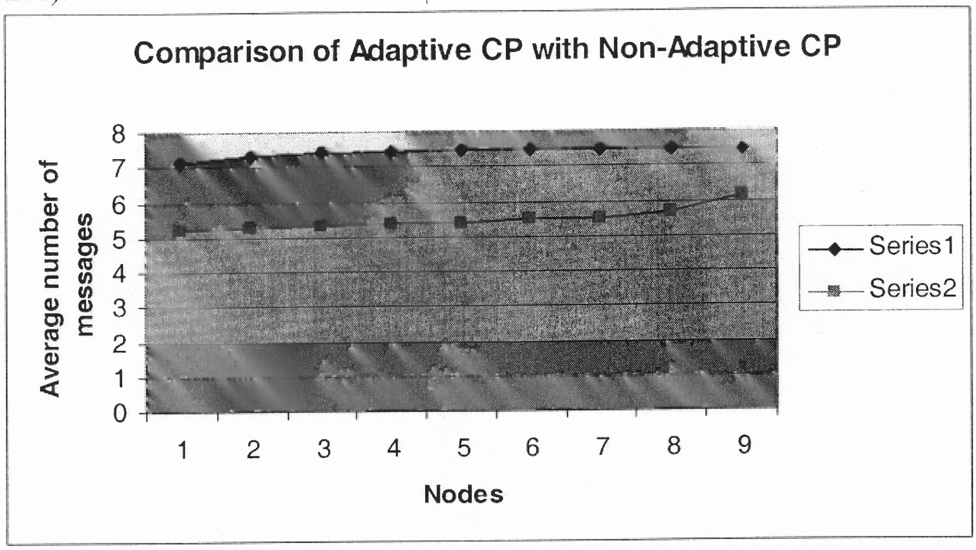

Figure 3.5 Comparison of adaptive constant power (series 1) with non adaptive constant power (series 2) R=8, Ch=10.

Case 4: N=(20,30,40,50,60,70,80,90,100), MTR=20, Ch=20, IR=0(Non Adaptive), IR=3 (Adaptive).

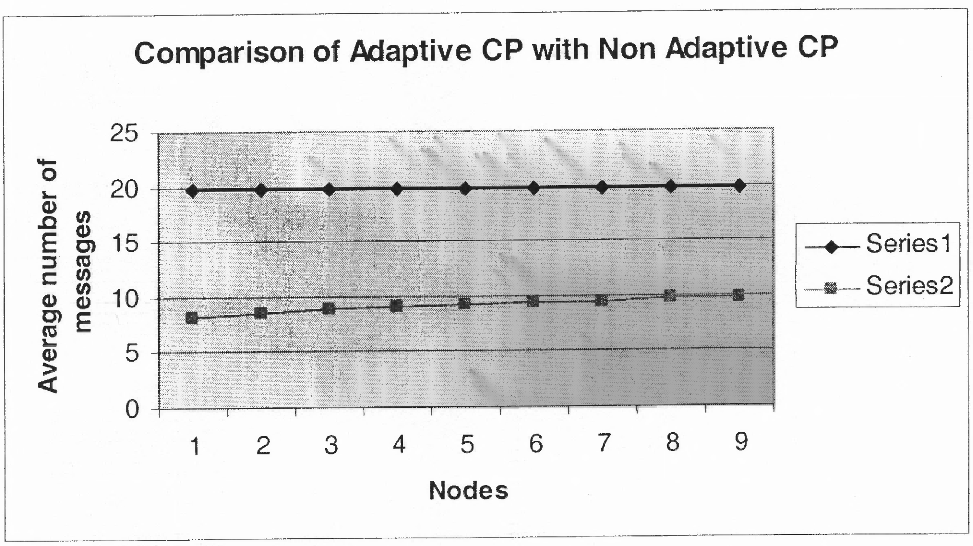

Figure 3.6 Comparison of adaptive constant power (series 1) with non adaptive constant power (series 2) R=20, Ch=20.

3.5.2 Comparison of Adaptive Variable Power with Variable Power

Figure 3.7 to 3.10 are used to demonstrate the advantage of having adaptive nature.

Case 1: N=(20,30,40,50,60,70,80,90,100),TR α dist(N_i,N_j), MTR=5, Ch=5, IR=0(Non Adaptive), IR=3(Adaptive).

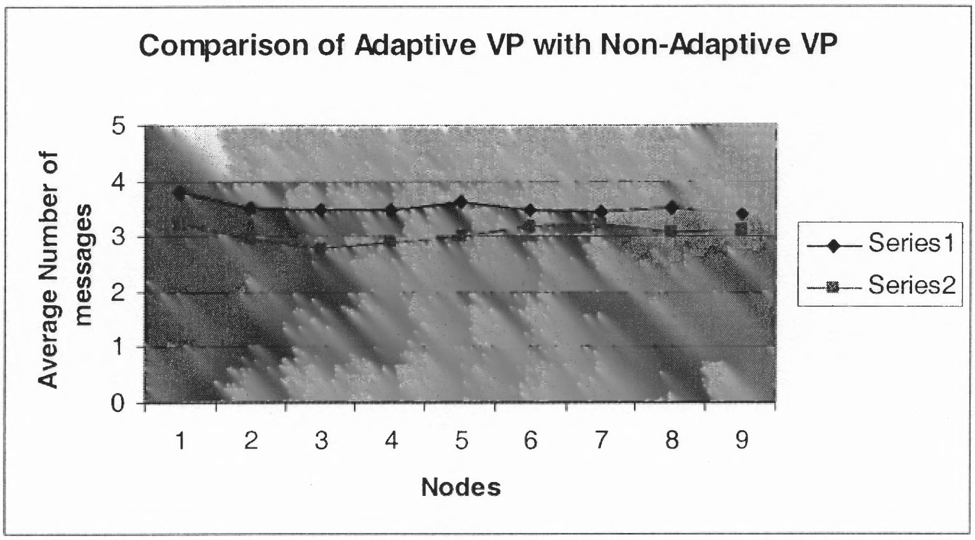

Figure 3.7 Comparison of adaptive variable power (series 1) with non adaptive variable power (series 2) R=5, Ch=5.

Case 2: N=(20,30,40,50,60,70,80,90,100), TR α dist(N_i,N_j), MTR=5, Ch=10, IR=0(Non Adaptive), IR=3(Adaptive).

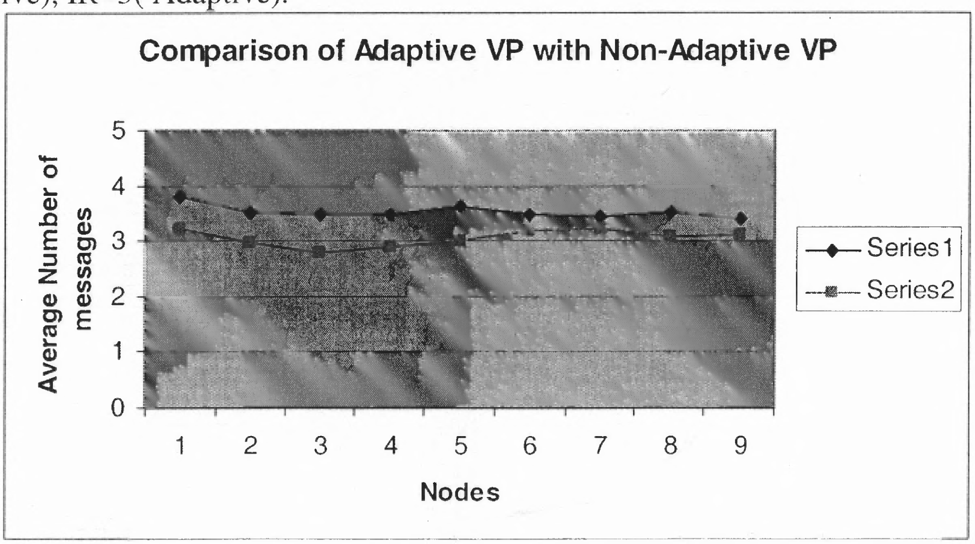

Figure 3.8 Comparison of adaptive variable power (series 1) with non adaptive variable power (series 2) R=5, Ch=10.

Case 3: N=(20,30,40,50,60,70,80,90,100), TR α dist(N_i,N_j), MTR=8, Ch=10, IR=0(Non Adaptive), IR=3(Adaptive).

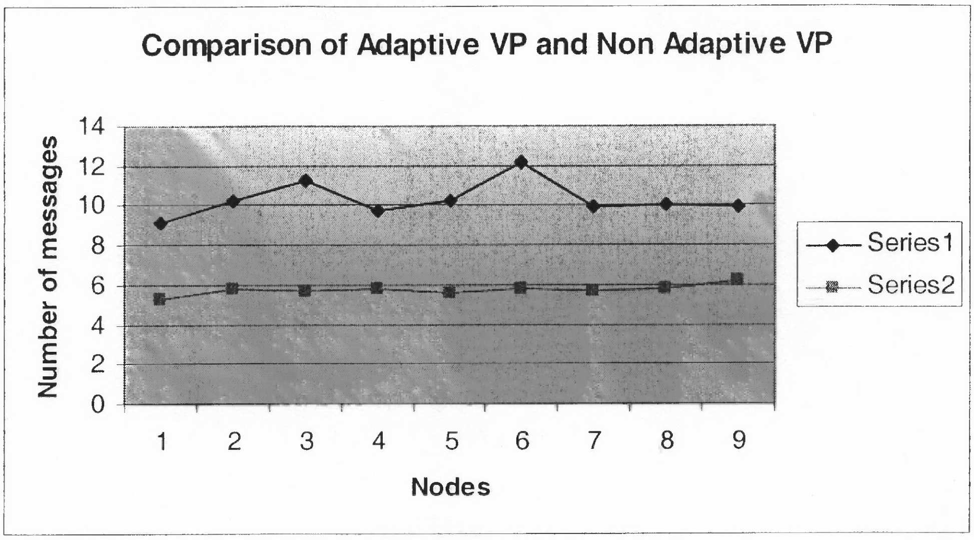

Figure 3.9 Comparison of adaptive variable power (series 1) with non adaptive variable power (series 2) R=8, Ch=10.

Case 4: N=(20,30,40,50,60,70,80,90,100), TR α dist(N_i,N_j), MTR=20, Ch=20, IR=0(Non Adaptive), IR=3(Adaptive).

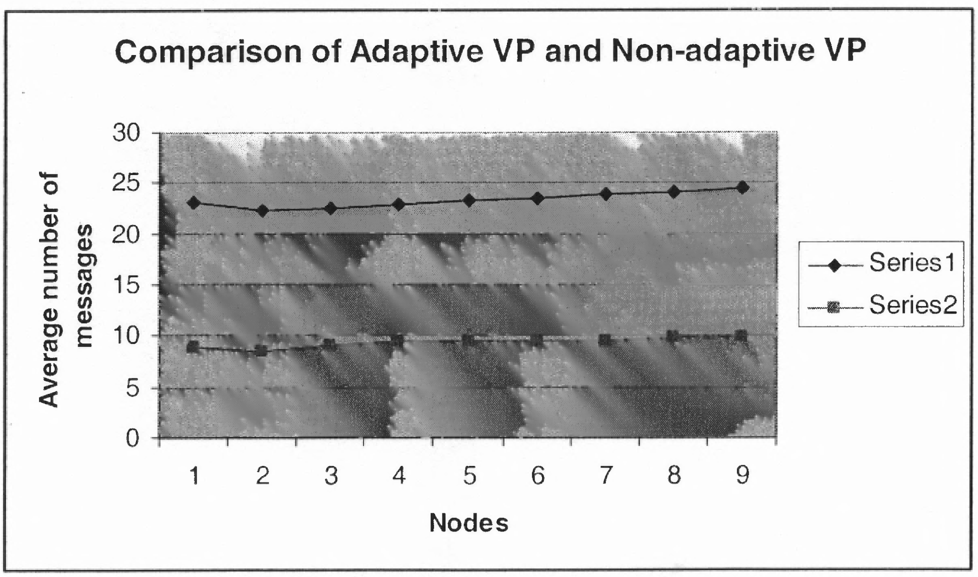

Figure 3.10 Comparison of adaptive variable power (series 1) with non adaptive variable power (series 2) R=20, Ch=20.

3.5.3 Comparison of Adaptive Variable Power with Shortest Path Algorithm

Figure 3.11 to 3.14 are used to demonstrate the advantage of having adaptive nature.

Case 1: N=(20,30,40,50,60,70,80,90,100), TR α dist(N_i,N_j), MTR=5, Ch=5, IR=3(Adaptive).

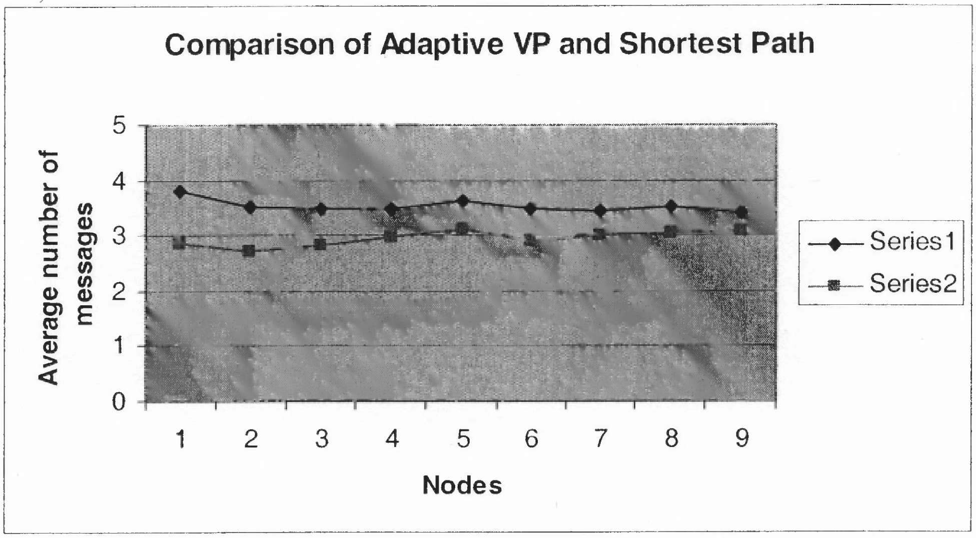

Figure 3.11 Comparison of adaptive variable power (series 1) with shortest path (series 2) R=5, Ch=5.

Case 2: N=(20,30,40,50,60,70,80,90,100), TR α dist (N_iN_j), MTR=5, Ch=10, IR=3(Adaptive).

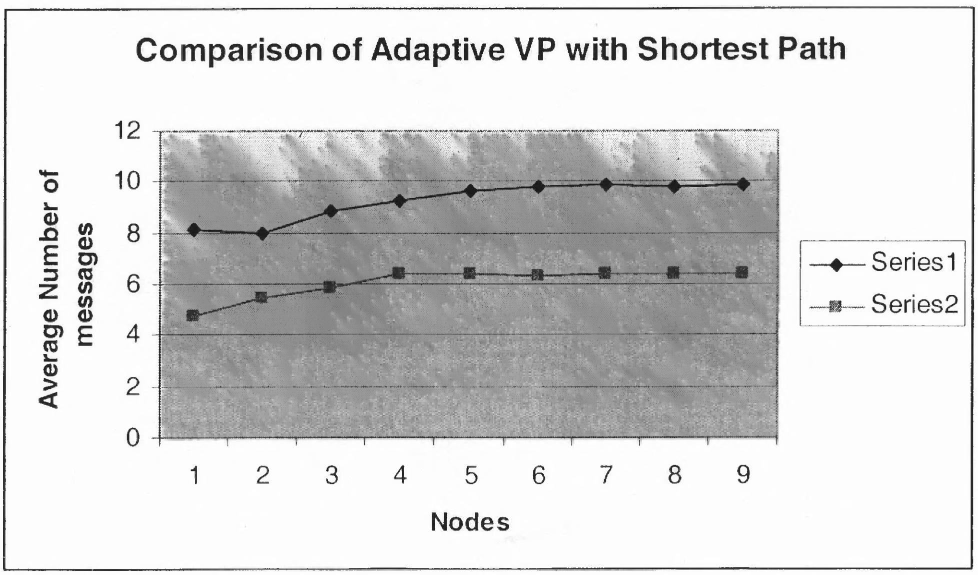

Figure 3.12 Comparison of adaptive variable power (series 1) with shortest path (series 1) R=5, Ch=10.

Case 3: N=(20,30,40,50,60,70,80,90,100), TR α dist (N_i,N_j), MTR=8, Ch=5, IR=3(Adaptive).

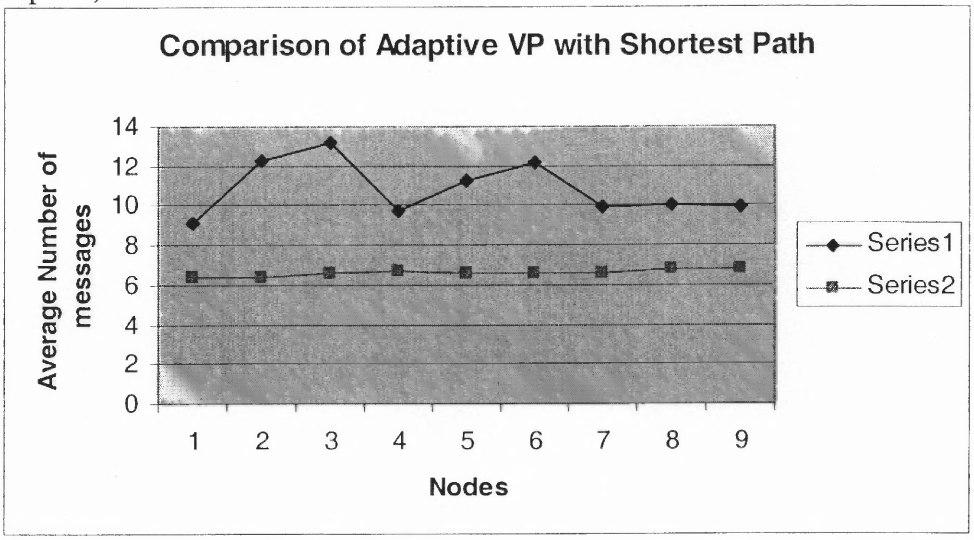

Figure 3.13 Comparison of adaptive variable power (series 1) with shortest path (series 2) R=8, Ch=10.

Case 4: N=(20,30,40,50,60,70,80,90,100), TR α dist (N_i,N_j), MTR=20, Ch=20, IR=3(Adaptive).

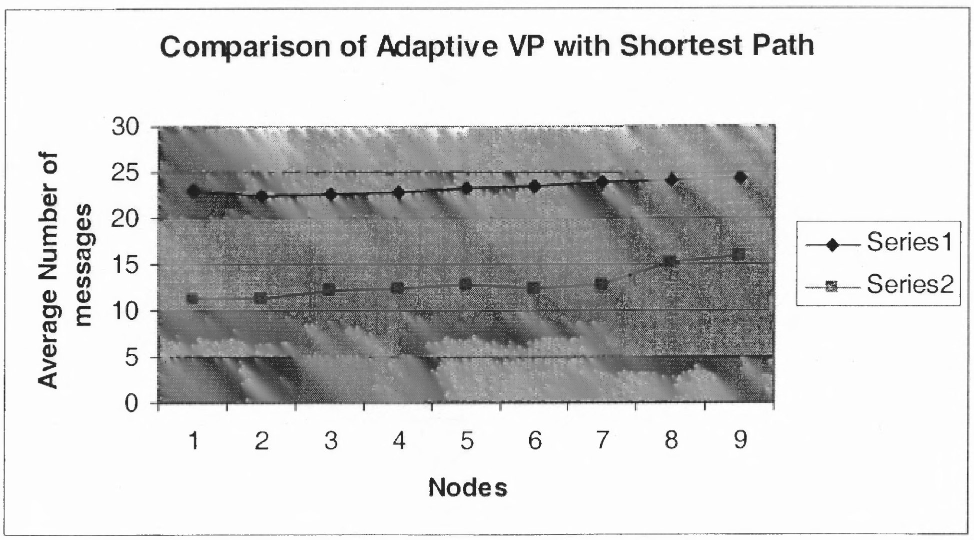

Figure 3.14 Comparison of adaptive variable power (series 1) with shortest path (series 2) R=20, Ch=20.

3.6 Conclusion

Thus, it is found that adaptive routing strategy reduces the interference of nodes with other nodes in the network when multiple numbers of messages are handled in the system. It is found that the numbers of messages that can be handled are more when the system is adaptive. Amongst the proposed and existing routing strategies we found that adaptive routing in which it is possible to change the transmitting power of the nodes allows maximum number of messages to be handled with the system.

It is easy to show that when the transmission range is increased then the overall connectivity within the network increases, as more nodes are neighbors to each other and hence can communicate. It is also easy to note that with increase in the number of nodes the number of message, which can co-exist in the network, is higher but if transmission range and number of channels is kept constant then the overall blocking remains unchanged.

When there is increase the number of channels available at each node, then a higher number of messages can be handled per node, but since the number of available channels in a network is limited thus, increasing is the number of channels for reducing blocking is not a possible but expensive solution.

After studying the affect of varying all parameters in the network, it can be concluded the suggested adaptive routing technique is better than the conventional routing techniques.

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