# ROUTING PROTOCOLS FOR MANETs

## Introduction

The act of transferring data from source to destination in internetworking is called routing. It can also be defined as the process of selecting a particular path for the transfer of the data. This process is carried out by a device known as router. Routing usually occurs at the layer 3 (network layer) of the OSI reference model.

Parameters such as current load on path, delay, reliability, bandwidth of the path, etc. are used by the routing protocols to select the best path for the transfer of the packet. The optimal path from the source to the destination will be determined by the routing algorithm with the help of the above-mentioned metrics. The routing tables containing information about the route will be initialized and maintained by the routing algorithms.

Routing tables will be filled by the routing algorithms with different kinds of information like the destination IP, address of the next hop, etc. Upon receiving the packet, the router checks for the address of the destination and will check it with the next hop address. Multiple next hop addresses are allowed for a router by some routing algorithms. The best path will be chosen based on different parameters as mentioned in the paragraph above. The routing tables will be maintained throughout the journey of the packets with the help of communication between the routers. The network topology can be built by the analysis of the routing updates obtained from all the routers present in the network. Centralized routing and decentralized routing are two different routing models.

The routing model which uses a centralized database to perform routing is called a centralized routing model. In this model, the routing table is maintained by a single node which should be approached when the nodes present in the network need to decide the next step in the process of routing. The developed routing tables will be transmitted to all the nodes in the network. These tables will be used until there is a change in the network and the network routing manager develops new tables. A global view of the network will be possessed by this centralized database. Global state information is used by the centralized model. Centralized routing is used by star networks and also in mesh networks.

The main advantage of a centralized routing model is simplicity. Resources are saved in this model as the routing tables are developed by a single computer and these tables are simply used by the others. There are also many disadvantages in using a centralized routing model. A computer might be overloaded with many data packets and this change in the network condition is not reflected by this model. In the case of changing routing tables, there is a wastage of network capacity during the transmission of the new routing tables to all the computers in the network.

In a distributed routing model, each node will have its own routing table. This model is very much suitable for a complete opaque network because the impairment constraints will have no role in the process of routing in such a domain. Distributed routing systems are useful in the case of a packet transfer failure by rapid restoration and the path recovery will be done by on-demand computation. With the current distributed routing procedure of the internet, the distributed routing model is very much consistent. This model is considered to be self-adjusting. They can easily adapt to the network changes. This model is mostly used by the mobile networks and also many other wireless networks.

The mobile networks which are wireless do not have a particular infrastructure. These networks are also called as ad-hoc networks. In this network, every node behaves like a router and help in forwarding the traffic. Fixed routers are not used in this network. The main purpose of building the ad-hoc networks was for the military applications. It has slowly gained popularity and is now being used in the science industry as well. Some of the applications of the ad-hoc networks are virtual classrooms, exhibitions, conferences, deployment of sensors, rescue operations and emergency search. These networks are used in the cases where it is expensive or difficult to build the infrastructure. Lack of infrastructure is the reason for the easy deployment of the ad-hoc networks.

The mobile ad-hoc networks otherwise known as the MANETs are evolving these days. Rapid changes in their structure are taking place. Thousands of nodes are connected in these types of networks which have a large span. The topology of the MANETs changes very frequently because of the high mobility of the nodes. The connection of the nodes is done in an arbitrary fashion. In this type of network, the radio coverage as well as the transmission power of the nodes is very small and limited. The number of the surrounding nodes will be restricted because of the less transmission power. With the movement of the nodes, the topology keeps changing rapidly. Low bandwidths characterize the ad-hoc networks. Routing becomes difficult because of the mobility of the nodes and the instability of the link. Many scientists have come up with various protocols for this ad-hoc network. These proposed protocols are divided into two classes' namely proactive routing protocols and reactive routing protocols as shown in figure 1. The routing protocols of MANETs are expected to satisfy certain principles are listed below:

- Consumption of minimum amount of energy.
- Should be flexible to the heavy traffic loads.
- Should be tolerant to sudden network failures.

Hosts and routers are used to form the wireless networks just like the wired networks. In the case of wireless networks, the hosts will act as source/destination whereas the packets will be forwarded by the routers in the network. The way of communication between the components present in the network is the main difference between the wireless and the wired networks. Data will be transferred through physical cables in the case of wired networks. The network components in the wireless network can communicate either through wires or wireless. The routers and the hosts in the wireless networks will have the freedom to move around because they need not necessarily use physical cables. This is considered to be one of the benefits of using wireless networks.

Wireless channels are used in wireless networks for the network components to communicate with each other. Wireless networks make use of ranges of radio frequency spectrum. Strength of the signal goes down when the speed of the signals increases in a wireless medium. The reception of the signal becomes almost zero after the signal has traveled some distance. This range until where the signal loses reception is considered as the radio range of that particular signal. In simple words, it can be said that the receivers can receive strong signals if they are present in the radio range of that signal.

Fixed wireless networks will be formed by the fixed routers and fixed hosts which make use of the wireless channels for communication purposes. The communication between the fixed access points and the mobile hosts is through a wireless channel. A mobile network will be formed with fixed access points in which the fixed access points will behave like routers.

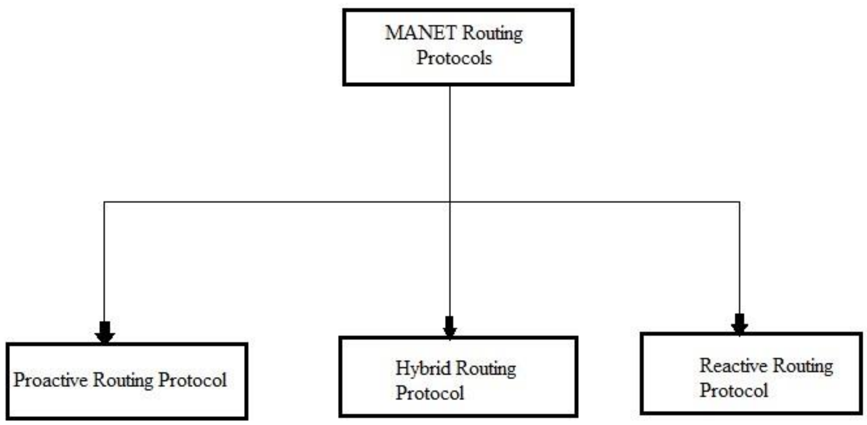


Figure 1: Classification of MANET Routing Protocols

The nodes in an ad hoc network are not aware of the topology of the network initially. They eventually have to discover the topology. During the process of discovery, every node will learn about its neighbor nodes and also the distance between them. This way, it also lets the other nodes know about its existence in the network. For efficient routing, routing tables are initialized and maintained by the routers using routing protocols and these tables are stored in its memory. The routers make use of the routing protocols to decide the path of the packet from the source node to the destination.

## Classification of MANET routing protocols

There are three types of routing protocols for ad-hoc networks. They are Proactive routing protocols, Reactive routing protocols and Hybrid routing protocols. The main function of these routing protocols is to detect the paths between the source and the destination and suggest them to the source node.

Proactive Routing Protocol otherwise known as table driven routing protocol keeps the record of the latest topology of the network. In this type of protocol, every node present in the network, will maintain more than one table related to the topology of the network. The tables will be updated on a regular basis so that every node of the network will have the updated information. The information related to topology will be exchanged between the nodes for them to be updated about the topology as a result of which the network will have a high overhead. The nodes can also request for routes any time. Some of the examples of this kind of routing protocol are Optimized link state routing; Destination sequenced distance vector, fisheye state routing and Distance vector.

In Reactive routing protocol, each node will not have information about the other nodes. When a packet has to be forwarded, the node will get in touch with the destination and get the information related to that route only. Every time a new packet has to be forwarded; route search will be done for that particular destination. In simple words, the routes will be discovered only on demand. In such a case, the overhead of the network will be less but the time taken to get the route information will be more when compared to Proactive Routing Protocols. The active routes can be broken with the frequent changes in the topology of the network. These routes will be stored only for a certain time period in cache. They can be used again if a packet has to be forwarded to the same destination. Some of the examples of Reactive Routing Protocols are Temporally Ordered Routing Algorithm, Location Aided Routing, Dynamic Source Routing, and Ad-hoc On-Demand Distance Vector Routing.

It is a combination of the best properties of proactive routing as well as reactive routing. Hence, this routing protocol is called a hybrid proactive – reactive routing protocol. The majority of the traffic will be sent to the nodes that are available nearby in ad-hoc networks. The Zone Routing Protocol will reduce the scope of the proactive routing by minimizing it to a zone where each node will be the center. Routing information will be maintained easily for a limited zone.

Proactive routing protocol, reactive routing protocol and hybrid routing protocols are used in detecting and providing the routes between the source and the destination. Proactive routing protocol keeps track of the latest topology of the network. Reactive routing protocol is different from proactive routing protocol and each node in reactive routing protocol will have information about the neighboring nodes. Zone routing protocol comes under hybrid routing protocol and this protocol is a combination of the proactive routing protocol and reactive routing protocol.

## Comparison of proactive and reactive routing protocols in mobile ad-hoc network using routing protocol property

The nodes present in the mobile ad-hoc networks can organize themselves in the ever-changing topology of the ad-hoc network. The major problem in the case of mobile ad-hoc networks is routing the data packets to the destination from the source node. The main principle or the working of the mobile ad-hoc networks is to provide the capabilities of communication in the areas where there is absolutely no infrastructure for communication or where there is limited infrastructure. There are many unique characteristics of mobile ad-hoc networks namely physical security that is limited, energy constrained operation, dynamic topologies and bandwidth constrained links. Mobile ad-hoc networks make use of multi hop routing infrastructure instead of the static network infrastructure. Network connectivity is provided with the use of these routing schemes. Finding stable routes decrease the route related overhead and finding the shortest routes are the main goals of these routing protocols.

Proactive routing protocol and reactive routing protocol are the two protocols suggested for mobile ad-hoc networks. Every node in the proactive routing protocol will have information about the routes of the networks and will be ready to deliver the data packets to the destination once they receive them. The destination node will use a sequence number to tag the entry of the route. Every station in the network will keep updating and broadcasting the routing table for every interval of time to maintain the stability. By broadcasting the packets, the number of hops to reach a particular node and the easily accessible stations will be known. A new sequence number will be stored when the data is broadcasted by a node. The address of the destination, new sequence number that has been generated and the number of hops that are required to reach a destination will all be stored in a node for every new route.

This protocol is best suited for the networks with limited number of nodes. This is because, the node should be updated with the latest topology information always in the case of proactive protocol and this can lead to overhead issues in the case of the networks with more nodes. More bandwidth will also be consumed in this case.

Overhead is less in the case of Reactive routing protocol. This is because the nodes will determine the routes as and when they are needed. In this protocol, the nodes will not keep a track of the changing topology of the network. The routes will be discovered on demand once the network is flooded with route requests. Ad-hoc on-demand vector routing and Dynamic Source routing are the best examples of these reactive routing protocols.

Below is a table in which the proactive routing protocol and the reactive routing protocols are compared in terms of protocol properties. DSDV stands for Destination Sequenced Distance Vector, DSR stands for Dynamic Source Routing and AODV stands for Ad-hoc On Demand Vector Routing.

| **S. No** | **Property of the protocol** | **DSDV** | **DSR** | **AODV** |
|---|---|---|---|---|
| 1. | Proactive/ Reactive | Proactive protocol | Reactive protocol | Reactive protocol |
| 2. | Source routing/ table driven | Table driven | Source routing | Both source routing and table driven |
| 3. | Routing Overhead | Medium | Low | High |
| 4. | Route Discovery | Periodically | Done on demand | Done on demand |
| 5. | Multiple routes | No | Yes | No |
| 6. | Size of the packet | Uniform | Non – Uniform | Uniform |

Table 1: Comparison of DSDV, DSR, AODV

The Ad-hoc on-Demand Vector Routing protocol is the best among the three protocols. This protocol tries to establish and maintain the connection by continuously exchanging the information. Reactive routing protocols perform better than the proactive routing protocols. The proactive routing protocols perform better than the reactive protocols in the case of less mobility and limited number of nodes. The reactive routing protocols are mostly based on the discovery of the routes and the maintenance of the routes.

## Zone routing protocol (ZRP)

Mobile ad-hoc networks should overcome the issues caused due to the frequent change in network infrastructure or network topology where both the proactive and reactive routing protocols are not efficient enough to overcome the issues. Zone Routing Protocol is a combination of proactive and reactive protocols where each node in the zone has an updated topological map.

Ad-hoc networks undergo frequent change in network due to the mobility of nodes in these networks. Nodes have a very low transmission power which further results in the topology change because of the node's instability. Also, the links between the nodes are not stable which further leads to the change in network topology.

Proactive routing protocol otherwise known as table driven routing protocol keeps the record of the latest topology of the network. In this type of protocol, every node present in the network, will maintain more than one table related to the topology of the network. The tables will be updated on a regular basis so that every node of the network will have the updated information. The information related to topology will be exchanged between the nodes for them to be updated about the topology as a result of which the network will have a high overhead. The nodes can also request for routes any time. Some of the examples of this kind of routing protocol are optimized link state routing; destination sequenced distance vector, fisheye state routing and distance vector.

The nodes will update the topology information by sending a message to the whole network to check for the changes in the topology of the network. Because of the high overhead, the throughput of the entire network will get affected. The whole routing information will be maintained by the nodes in tables. These tables will change with the change in the topology. There will be heavy traffic in the network because of this. The amount of bandwidth consumed by this routing protocol will be very high as it as to keep sending messages constantly to keep the nodes updated about the changes in the topology. Also, the nodes of this network will consume large amount of energy. As a result of the control messages, the memory consumption will also be high. In this case, most of the routing information that has been collected remains unused as these routes will stay only for a certain time period.

In reactive routing protocol, each node will not have information about the other nodes. When a packet has to be forwarded, the node will get in touch with the destination and get the information related to that route only. Every time a new packet has to be forwarded; route search will be done for that particular destination. In simple words, the routes will be discovered only on demand. In such a case, the overhead of the network will be less but the time taken to get the route information will be more when compared to proactive routing protocols. The active routes can be broken with the frequent changes in the topology of the network. These routes will be stored only for a certain time period in cache. They can be used again if a packet has to be forwarded to the same destination. Some of the examples of reactive routing protocols are temporally ordered routing algorithm, location aided routing, dynamic source routing, and ad hoc on-demand distance Vector routing.

Hybrid routing protocols is a combination of the best properties of proactive routing as well as reactive routing. The majority of the traffic will be sent to the nodes that are available nearby in ad-hoc networks. The zone routing protocol will reduce the scope of the proactive routing by minimizing it to a zone where each node will be the center. Routing information will be maintained easily for a limited zone. In this case, there will be a decrease in the wastage of the routing information. Reactive routing can be used to interact with the nodes that are far away. Querying of all the nodes in the network will not be needed when route requests come in as the routing information is stored in all the nodes using proactive routing. The view of the network of the zone routing protocol will be flat even though it uses zones. As overlapping of the zones take place, zone routing protocol is also called a flat protocol. As a result of this, the congestion taking place in the network can be minimized and the detection of the optimal routes can be done. Zone routing protocol is adaptive in nature. This is dependent on the users' behavior and also the present configuration of the network.

The limitations and drawbacks of proactive and reactive routing protocols were discussed in detail. Proactive routing protocols require high bandwidth to maintain the up-to-date network topology. Reactive routing protocol broadcast the packet to determine the path which is inefficient.

Proactive routing component in ZRP contains intra-zone routing protocol (IARP) that holds the route information for the nodes within the zone whereas Reactive routing component contains inter-zone routing protocol (IERP) access the information in IARP to answer the route quires and there exists a broadcast resolution protocol (BRP) to broadcasts the route request for the inter zone communication

The proactive routing protocol reduces the connection time whereas the reactive protocol reduces the amount of traffic utilized to determine the path. ZRP is a combination of proactive and reactive routing protocols. The control traffic depends on various factors like radius, node density, network size and velocity of node. ZRP can determine multiple routes to a destination that results in increased performance and guarantees a loop free path. ZRP is aimed for larger networks.

## Overview of routing protocols for MANETs

The growth in the industry of the mobile ad-hoc networks was rapid in the 1990s. There was a demand for a new set of protocols and strategies for efficient communication in the infrastructure less mobile networks. Because of the limited resource and mobility of the nodes in the wireless networks, the existing TCP/IP structure had to be modified and redefined for efficient functioning in MANETs. Routing was one topic which gained the attention of the researchers as it was a challenging task in MANETs. This led to the birth of many routing protocols for mobile ad-hoc networks.

Before the wireless networks came into light, two algorithms were used in the case of wired networks. They were called as the distance vector and link-state algorithms. In distance vector algorithm, shortest path between two source node and the destination node was calculated. Every node present in the network will have a set of distance costs to all the destination nodes. The tables are updated regularly. On the other hand, in link-state algorithm, a flooding strategy is employed to broadcast the link-state costs to the other nodes from the neighboring nodes. This is done to maintain the routing tables up-to-date regularly. The information of the link-state and the view of the network will be updated in this case and then the shortest path algorithm is applied to choose the best path to the destination.

However, both the link-state and the distance vector algorithms are not suitable in the big mobile ad-hoc networks. The reason for this is that large amount of bandwidth is wasted for continuous updating of the tables and many other factors. Many routing protocols have been developed to overcome the disadvantages of these link-state and distance vector protocols.

On the higher level, the routing protocols used for MANETs are classified into three types. They are:

- Proactive routing protocols
- Reactive routing protocols
- Hybrid routing protocols

The above groups of routing protocols have many more routing strategies under them.

The different types of proactive routing protocols are mentioned below.

- Destination-sequenced distance vector (DSDV)

This routing protocol is an extension to the Bellman Ford algorithm which aims at preventing the formation of loops. The path to the destination in this case is found using the shortest path algorithm. Periodic broadcasting of the update routing tables to all the nodes is done in this routing protocol to maintain consistency in the network. Because of the periodic broadcasting of the routing tables, the network overhead is large which is a disadvantage of this routing protocol. This protocol is used only in small networks and is not suitable for large networks with more than 200 nodes because a huge amount of bandwidth will be consumed for the periodic transmission of the update tables.

- Topology broadcast reverse path forwarding (TBRPF)

This routing protocol is based on link state algorithm. In this type of routing protocol, every node present in the network will find the path to all the destinations by calculating the source tree. These source trees are calculated using the modernized version of the very famous Dijkstra's algorithm. The network overhead will be minimized by all the nodes by broadcasting only partial source tree to all its neighbor nodes. This partial source tree will be further broadcasted among all the nodes in the network periodically. The changes in the topology of the network will be communicated using hello messages.

- Optimized link state routing (OLSR)

This routing protocol is also called as point to point routing protocol and is also based on the link state algorithm. Link state messages are exchanged periodically to maintain the consistency in the routing information throughout the network. Whenever there is a change in the topology of the network, this change will be broadcasted to only a few nodes which are responsible for rebroadcasting it. The nodes that do not receive the update information will just read the change and will not retransmit this change to the other nodes. This way the number of periodic transmissions reduces and the size of the control message will be minimized.

- Cluster-head gateway switch routing (CGSR)

In this type of routing protocol, all the nodes present in the network are divided into clusters. Each cluster has a cluster head which will maintain the information about the hierarchy of the cluster. This cluster head is also responsible for managing the other nodes present in that cluster. All the communications occurring within that cluster will be done through the cluster head. The routing overhead is low in this case as all the nodes in a cluster will maintain routing information only to the cluster head and not to all the other nodes.

- Multimedia support in mobile wireless networks (MMWN)

This routing protocol works something similar to the cluster-head gateway switch routing protocol. In this routing protocol, each cluster will have endpoints and switches. The nodes are grouped into clusters and each cluster will have a location manager. This node is responsible for finding and updating the location within that cluster. Hence, routing overhead will be reduced as location finding and updating is done by a single node from each cluster.

- Distance routing effect algorithm for mobility (DREAM)

Using a GPS, each node in the network will have an idea about its geographical coordinates. These coordinates are stored in the routing tables and are exchanged periodically between the nodes. The nodes which are stationary need not broadcast their tables in this process.

- Global state routing (GSR)

Link state algorithm is used by this routing protocol. A link state table is initiated and maintained by every node present in the network and this information will be broadcasted periodically to the neighbor nodes only. Hence, the count of the control messages is significantly reduced. Huge amount of bandwidth is consumed as the size of the update packets is huge and will grow with the increase in the size of the network.

- Wireless routing protocol (WRP)

In this type of routing protocol, every node will maintain four different routing tables. The memory overhead is affected by this and will increase with the increase in the size of the network. Hello messages are used to ensure the connection between two nodes. This is considered a disadvantage in this case because the nodes have to exchange the hello messages even when they are idle and are not participating in the transfer of a data packet.

The different types of reactive routing protocols are mentioned below.

- Ad-hoc on-demand distance vector (AODV)

Ad-hoc on-demand distance vector was proposed to minimize the broadcasts. The main objective of this protocol is to broadcast the update packets only when it is necessary. Ad-hoc on-demand distance vector protocol is an excellent choice in the battlefield communications, conferencing, emergency services, etc. The nodes which are not present on the active paths will neither actively transmit the update packets nor try to maintain their routing tables up-to-date in AODV. The nodes present in a mobile ad-hoc network using AODV protocol need not maintain the list of costs to each destination unless another node is trying to communicate with this node.

- Cluster-based routing protocol (CBRP)

This protocol divides the network into clusters which are disjoint or overlapped. Each cluster will have a head who maintains all the cluster membership information that helps the inter cluster routes. This protocol minimizes the RDP and utilizes the unidirectional link for both intra and inter cluster routing.

- Ant-colony-based routing algorithm (ARA)

This protocol is described based on the real behavior of ants. Ants search for food in a specific path and they come back home via the same path because ants on their path drop a chemical "pheromone" which they can smell. The more is the concentration, the shorter is the path. This way they know their return path. The same logic is applied to MANETS. This protocol doesn't require any routing tables or any route information to be transmitted to other nodes.

- Location-aided routing (LAR)

LAR is used to reduce the overhead of RDP by utilizing the node location. Location info can be known with help of GPS. LAR works in two ways, expected zone and request zone. In expected zone terminology, the sender initially identifies the location of destination. The destination after some time may be present at the different location. If the sender knows the destination node speed, then he can expect the destination to be in an expected zone. In request zone, the sender sends a route request to the node in the request zone only.

- Signal stability adaptive (SSA)

SSA selects only the routes that have a strong signal strength. So the shortest path may not be the best path to reach destination if the signal strength on this path is not strong. Therefore, nodes need to adapt the route based on the link stability between nodes.

- Associativity-based routing (ABR)

Associativity-based routing is initiated by the source like the other routing protocols. The route to the destination will be determined by this routing protocol using a query-reply mechanism. The path to the destination is not necessarily the shortest path but the life of the path is long. This protocol requires regular beaconing which is a huge disadvantage in this case. The nodes should be active throughout the beaconing process which results in the consumption of a lot of power. Multiple routes are not determined in this routing protocol which is also a disadvantage as there will be no alternate path ready in case of the failure of one path.

- Light-weight mobile routing (LMR)

This routing protocol determines the routes using flooding mechanism. Multiple routes are available for the desired destination. This acts as an advantage in case of a link failure. Alternate routes will be readily available and hence, route discovery process can be avoided in that case. The invalid routes are not discarded and so there will be an extra delay when this route will be chosen until the correct loop is determined.

- Temporally ordered routing algorithm (TORA)

This routing protocol is mainly based on the light-weight mobile routing protocol. The routing procedure is the same as in LMR protocol. The main advantage of this routing protocol is that it supports multicasting by using light-weight adaptive multicast algorithm. Temporary routes that may be invalid are produced by this routing protocol which can be a disadvantage.

Following are the different types of hybrid routing protocols.

- Zone routing protocol (ZRP)

In this type of routing protocol, each node has its own zone with radius defined in hops. Proactive routing protocol is used for routing within the zone. Whereas, routing outside the zone is carried out using reactive routing protocol. The advantages of both proactive and reactive routing protocols are combined for the working of this routing protocol. For networks with small routing zones, the zone routing protocol will act as a reactive protocol and for networks with large routing zones, this protocol acts as a proactive routing protocol.

- Distributed dynamic routing (DDR)

All the nodes in the network are divided into trees. Each tree is not controlled by a root node unlike the distributed spanning trees-based routing protocol. The neighbor nodes periodically beacon messages which help in the construction of the tree. All the trees are grouped into a forest and all these trees are connected to each other using gateway nodes. Routing is carried out in six phases which are electing the preferred neighbor, construction of a forest, inter tree clustering, naming of the zone and the partitioning of the zone.

- Distributed spanning trees-based routing protocol (DST)

In distributed spanning trees-based routing protocol, the nodes are divided into trees. Internal node and route nodes are the two kinds of nodes that are present in each tree. Each tree has a root node that is responsible for controlling the topology of the tree. Distributed spanning tree shuttling and hybrid tree flooding routing strategies are used to determine routes. Depending on the root node for the configuration of the tree is a disadvantage in this routing protocol.

- Zone-based hierarchical link state (ZHLS)

In this case, the network is divided into zones that do not overlap. Each node maintains a zone Id and a node Id and these Ids are calculated using a global positioning system. This routing protocol does not affect the case where the network topology changes during the routing process because routing in this protocol needs only the zone Id and the node Id of the required destination.

# PROACTIVE ROUTING PROTOCOL

Proactive routing protocol otherwise known as table driven routing protocol keeps the record of the latest topology of the network. In this type of protocol, every node present in the network, will initiate and maintain more than one table related to the topology of the network. The tables will be updated on a regular basis so that every node of the network will have the updated information.

The information related to topology will be exchanged between the nodes for them to be updated about the topology as a result of which the network will have a high overhead. The nodes can also request for routes any time. Some of the examples of this kind of routing protocol are optimized link state routing; destination sequenced distance vector, fisheye state routing and distance vector.

The nodes will update the topology information by sending a message to the whole network to check for the changes in the topology of the network. Because of the high overhead, the throughput of the entire network will get affected. The whole routing information will be maintained by the nodes in tables. These tables will change with the change in the topology. There will be heavy traffic in the network because of this. The amount of bandwidth consumed by this routing protocol will be very high as it as to keep sending messages constantly to keep the nodes updated about the changes in the topology. Also, the nodes of this network will consume large amount of energy. As a result of the control messages, the memory consumption will also be high. In this case, most of the routing information that has been collected remains unused as these routes will stay only for a certain time period.

The approach of proactive routing protocols is similar to the routing protocols of the wired networks. The main function of the nodes is to constantly evaluate the already known routes and keep discovering the changes in the network. The packets from one node to other node will be forwarded efficiently without any delay because every node in the network knows the route to every other node. Since the route is already known, the nodes need not wait for other information to forward the packet. Each node will maintain the following information to forward a packet.

- The number of hops that packets should cross for it to reach the destination node.
- The fresh sequence number as generated by the destination node.
- The address of the destination.

This protocol will be much efficient in the networks with small number of nodes. For a large network, it will be difficult for each node to maintain the routing information of the plenty other nodes in that network.

## Destination-sequenced distance vector (DSDV) protocol

An instant network can be formed by a group of mobile nodes without any fixed topology. This instant network is nothing but an ad-hoc network. In this type of network, the nodes are free to join the network or move out of the network. When compared to a conventional network, the ad hoc network will not have a fixed infrastructure. But a conventional network is very much compatible with an ad-hoc network.

Destination-sequenced distance vector was developed by Bhagwat P and Perkins C in the year 1994. This routing protocol is used by the mobile ad-hoc networks and is based on the Bellman Ford algorithm which is used by the conventional networks to calculate the shortest path. The main aim of this protocol is to resolve the poor looping problem which exists in the Routing Information Protocol (RIP). This section will have a review of the DSDV protocol, advantages and disadvantages of the protocol.

Every node in the ad-hoc network will maintain a routing table that contains the information like the list of destination nodes, distance to the destination node, the next hop in the path and also a sequence number which will be generated by the destination node. The data packets are transmitted across the ad-hoc network using these routing tables. Because the topology in ad-hoc network is not consistent, these routing tables are updated periodically or with the change of topology, to maintain routing tables throughout the network. As soon as changes in the topology are detected, the routing information will be advertised with the means of broadcasting or multicasting packet to update the routing table. This update packet will be sent out to the directly connected nodes with a metric equal to one. This proves that the distance between the source node and the neighboring node is one metric or one hop.

The routing tables of the neighboring nodes will be updated by increasing their metric by one, once the update packet is received. The update packet will then be retransmitted to their neighbor nodes. This retransmission of the update packet will be done until all the nodes present in the mobile network receive it. This data will be kept for some time before another update packet is transmitted. When a node is waiting for an update packet for a particular destination and if multiple update packets are received, then the packet with the highest sequence number will be preferred. The sequence number helps in differentiating the old routes and the new routes. If the sequence number is the same for all the multiple update packets received by a node, then the packet which has the least metric will be chosen and the routing table of that node will be updated with this metric for the destination. This updated information will be transmitted throughout the ad-hoc network with that sequence number. The transmission of the update packet of a node whose route is ready to change will be delayed till the best route to the destination is found. Delaying of these unstable routes will result in damping fluctuations of the route tables which will in turn result in the reduced number of rebroadcasting the routes that have the same sequence number.

To maintain consistency with the ever-changing topology of the network, there will be a dynamic change in the elements of the routing table of every node. To reach to this level of consistency, the transmission or broadcast of the routing information should be fast and frequent and ensure that every node should be able to identify all the other nodes present in that ad-hoc network. Upon request, data packets should be relayed by each node using the updated routing tables. Let us understand the working of DSDV protocol with the example below.

Consider an ad-hoc network with three nodes – A, B and C as shown in figure 2.

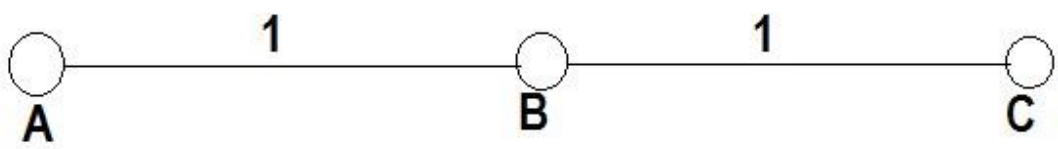


Figure 2: Example of Ad-Hoc Network

The routing tables of A, B and C will be as follows as table 2, 3 and 4.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 0 | A-500 |
| B | B | 1 | B-200 |
| C | ∞ | ∞ | C-100 |

Table 2: Routing Table of Node A

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 1 | A-500 |
| B | B | 0 | B-200 |
| C | C | 1 | C-100 |

Table 3: Routing Table of Node B

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | ∞ | ∞ | A-500 |
| B | B | 1 | B-200 |
| C | C | 0 | C-100 |

Table 4: Routing Table of Node C

In the above routing tables, it can be observed that node A cannot reach node C initially as it is not aware that node B can reach node C. Hence, the metric will be ∞. Same is the case when C tries to reach A. Node B will first broadcast its routing table to the neighboring nodes A and C by increasing the sequence number by 2. Nodes A and C will update their routing tables upon receiving this update packet from node B. Nodes A and C will first check for the sequence number of the update packet and if this sequence number is greater than the sequence number of the local table, the routing tables will be updated. The updated routing tables will look as below then.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 0 | A-500 |
| B | B | 1 | B-202 |
| C | B | 2 | C-100 |

Table 5: Updated Routing Table of Node A

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 1 | A-500 |
| B | B | 0 | B-202 |
| C | C | 1 | C-100 |

Table 6: Updated Routing Table of Node B

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | B | 2 | A-500 |
| B | B | 1 | B-202 |
| C | C | 0 | C-100 |

Table 7: Updated Routing Table of Node C

Upon receiving the update packet, node A will learn that C can be reached through B at a distance of 2. Hence, it can observe in table 5 that the entry for C has changed and the sequence number has been updated with the current number which was broadcasted by B. Similar update is done in the routing table of node C as it learns that A can be reached through B. This way, when there is a change in the topology, the update packets will be transmitted throughout the network with an increase in the sequence number by the destination. The receiving node will update its table by checking for the condition that the local sequence number is less than the sequence number of the update packet. Let’s say there is a change in the topology of the above network with the addition of a new node – node D beside node C. Please refer to figure 3 below.

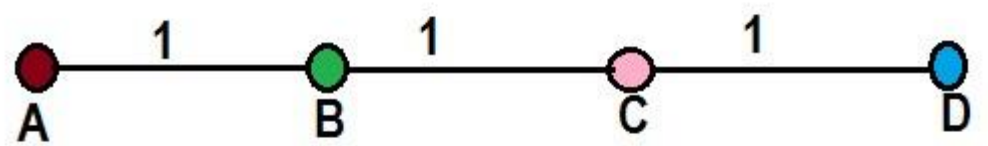


Figure 3: Addition of A New Node – Node D

In the above case, node D will broadcast its table with sequence number D-000 to node C and the routing table of node C will be updated as below.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | B | 2 | A-500 |
| B | B | 1 | B-202 |
| C | C | 0 | C-100 |
| D | D | 1 | D-000 |

Table 8: New Routing Table of Node C

Now, C will broadcast its updated table to its neighboring node B and the sequence number will change to C-102 while transmitting the update packet. Node B will update its routing table and will add an entry for node D. The updated routing table of node B will be as below.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 1 | A-500 |
| B | B | 0 | B-202 |
| C | C | 1 | C-102 |
| D | C | 2 | D-000 |

Table 9: New Routing Table of Node B

Furthermore, B will broadcast its table to its neighbor node A. Node A will update its table which resembles the table below.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 0 | A-500 |
| B | B | 1 | B-204 |
| C | B | 2 | C-102 |
| D | B | 3 | D-000 |

Table 10: New Routing Table of Node A

This is how the tables try to achieve consistency. This process keeps repeating periodically or whenever a change in the topology is detected.

Let us consider a situation where the link between node C and D is broken in the above network.

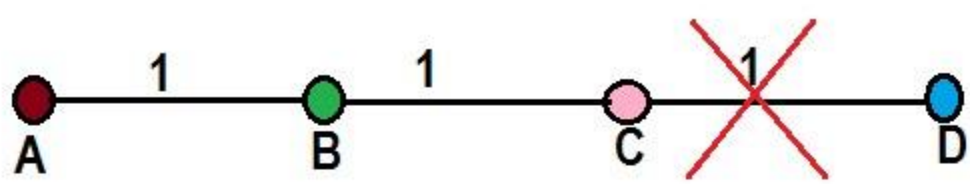


Figure 4: Broken Link Between C And D

As done in a proactive protocol, node C will learn about the broken link when it transmits a message to node D. C will update its table with the values for the broken link by increasing the sequence number by 1. Only in the case of a broken link, the source node will increase the sequence number and that too by 1 (odd number). The new routing table of C is as shown in table 11.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | B | 2 | A-500 |
| B | B | 1 | B-204 |
| C | C | 0 | C-102 |
| D | D | ∞ | D-001 |

Table 11: Routing Table of Node C After Detecting the Broken Link

Before node C tries to broadcast its updated table, if node B transmits its routing table, C will compare the sequence numbers. Since the sequence number of B will be less than C, node C will not update its table. In this way, routing loops are prevented. Now, node C tries to broadcast its new table to node B for it to update. Node B will update because the sequence number of the update packet is greater than the local sequence number. And then, node B will send its updated table to node A. The updated routing tables of B and A will look like below.

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 1 | A-500 |
| B | B | 0 | B-204 |
| C | C | 1 | C-102 |
| D | C | ∞ | D-001 |

Table 12: Routing Table of Node B After Detecting the Broken Link

| Destination | Next Hop | Metric | Sequence Number |
|---|---|---|---|
| A | A | 0 | A-500 |
| B | B | 1 | B-204 |
| C | B | 2 | C-102 |
| D | B | ∞ | D-001 |

Table 13: Routing Table of Node A After Detecting The Broken Link

This way there will be no routing looping problem which is the main reason why destination sequenced distance vector was developed.

**Advantages of proactive routing protocol**

- Less delay in transmitting data from source to destination as paths are readily available for all the destinations in the network.
- Usage of the sequence number ensures paths which are loop-free.
- This routing protocol is used for network with up to 100 nodes. The packet density ratio of this routing protocol reduces if the network size is more than 100 nodes.

**Disadvantages of proactive routing protocol**

- Performance of the mobile ad-hoc networks will be degraded because of the high overhead.
- With the regular updates of the routing information, bandwidth as well as battery power is wasted in the case where the mobile network is idle.
- DSDV is not suitable for large networks and is best suitable for just small networks with up to 200 nodes.
- This protocol is unstable until all the nodes have updated their routing tables when there is a change in the topology of the mobile ad-hoc network.

# REACTIVE ROUTING PROTOCOL

In reactive routing protocol, each node will not have information about the other nodes. When a packet has to be forwarded, the node will get in touch with the destination and get the information related to that route only. Every time a new packet has to be forwarded; route search will be done for that particular destination. In simple words, the routes will be discovered only on demand. In such a case, the overhead of the network will be less but the time taken to get the route information will be more when compared to proactive routing protocols.

The active routes can be broken with the frequent changes in the topology of the network. These routes will be stored only for a certain time period in cache. They can be used again if a packet has to be forwarded to the same destination. Some of the examples of reactive routing protocols are temporally ordered routing algorithm, location aided routing, dynamic source routing, and ad-hoc on-demand distance vector routing.

The major drawback of this routing protocol is the time taken for the route discovery. This will be very high in the cases where the distance from the node to the destination is very large. When compared to proactive routing protocols, the energy consumption and the generation of overhead is less.

To avoid heavy traffic, when the route is unknown to the source node, it checks with the neighboring node. If it does not get the required information about the route to the destination with the neighboring node, it spreads the check with the other nodes in the network. In this way, it is keeping minimal traffic in the network by making use of the route maintenance schemes. But, the whole network will also be flooded during the determination of the route in reactive routing protocol.

This routing protocol has no need for constant broadcasts. Reactive routing protocols are considered to be bandwidth efficient. Reactive routing protocols are popular when compared to proactive routing protocols because they consume low bandwidth. [5]

### Ad-hoc on-demand distance vector (AODV) protocol

Destination-sequenced distance vector protocol is used to form small ad-hoc networks with the cooperation of mobile nodes. The main drawback of this protocol is that it should wait till all the nodes update their tables before transmitting a packet from source to destination. The regular advertisement of the update packets lead to wastage of bandwidth, increase in overhead and delay. Before even transmitting the very first packet, the latency will be reduced because all the nodes in the network should maintain updated routing tables. With the usage of the on-demand routes in the ad-hoc networks, the above disadvantages can be overcome. There will be no delay and no wait is required for regular advertisements of the update packets in this case. Hence, ad hoc on demand distance vector was proposed to minimize the broadcasts. The main objective of this protocol is to broadcast the update packets only when it is necessary. Ad-hoc on-demand distance vector protocol is an excellent choice in the battlefield communications, conferencing, emergency services, etc.

The nodes which are not present on the active paths will neither actively transmit the update packets nor try to maintain their routing tables up-to-date in AODV. The nodes present in a mobile ad-hoc network using AODV protocol need not maintain the list of costs to each destination unless another node is trying to communicate with this node.

Broadcast route discovery mechanism is used by AODV. In this mechanism, a route request packet (RREQ) is sent to find a route to the destination. A route reply packet (RREP) is sent back to the source node by the destination upon receiving the RREQ. All the routes in AODV are maintained in the form of routing tables. The nodes that are present on the active paths will only maintain its routing tables. A timer is associated with these routing tables and if any table was not used recently, that entry will be removed from the table. Like DSDV, AODV also maintains destination sequence number in its routing tables to avoid the count-to-infinity problem.

In AODV protocol, sequence number and broadcast id are the two counters that are maintained by every node in the network. Broadcast id is a unique number which keep incrementing whenever a new route request packet is sent by the source node. The format of the route request packet is shown below,

< source address, source sequence number, broadcast id, destination address, destination sequence number, hop count >.

While transmitting the RREQ packet, if the source node is unaware of the destination, the destination sequence number will be empty. Hop count refers to the number of the hops required to send the data from source to the destination. Upon receiving the RREQ, the destination will send back a route reply packet to the source in the format as shown below,

< source address, destination address, destination sequence number, hop count, lifetime >.

Destination sequence number will be included by the destination node while sending the RREP packet. Lifetime mentions about the validity of this path information. The duplicate packets will be discarded by the intermediate nodes. If this intermediate node has a higher sequence number than the RREQ, then a route reply will be sent back to the source node by the intermediate node. If the sequence number of the intermediate node is less than the incoming packet, then this RREQ will be broadcasted further.

Let us consider an example to understand this protocol even better. Consider a mobile ad-hoc network with mobile nodes – A, B, C and D. This ad-hoc network is depicted in the picture below.

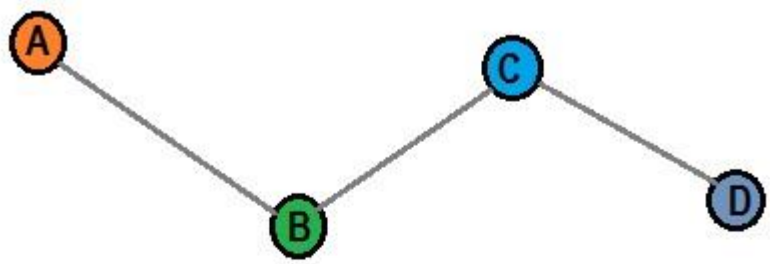


Figure 5: A Mobile Ad-Hoc Network With Four Nodes

In the above network, if node A wants to send a packet to node D, then the node A will start the route discovery process. In this process, A will transmit its route request packet to its neighbor node B. The route request packet of A will look like < A, 1, 1, D,  , 0 >. 'A' represents the source node address, 1 is the source sequence number, 1 is the broadcast id and 'D' is the destination node. Since the destination sequence number is not known at this point, its slot is left empty in the RREQ packet. Finally, the hop count value is 0 as the packet is yet to be broadcasted.

Once the RREQ packet is built, it is sent from A to B as B is the only neighbor in this scenario. Since, node B is also not aware of the path to node D, the RREQ packet received from A will be broadcasted further to node C by B after updating the RREQ. The routing table of node B will look like table 14.

| Destination | Next Hop | Hop count | Sequence Number |
|---|---|---|---|
| A | A | 1 | 1 |

Table 14: Routing Table of Node B After Receiving The RREQ Packet From A

The hop count in the above table will be 1 as it will be incremented by node B. This means that B knows that A is reachable at a distance of 1. After increasing the hop count, the RREQ packet is further broadcasted to C by B. The route request packet at this stage looks like < A, 1, 1, D,  , 1>. Upon receiving this request packet, node C will update its routing table which looks like below.

| Destination | Next Hop | Hop count | Sequence Number |
|---|---|---|---|
| A | B | 2 | 1 |

Table 15: Routing Table of Node C After Receiving The RREQ Packet From B

The hop count is 2 in the above table as it takes two hops from node A to node C via node B which also means that node A can be reached by node C at a distance of 2 through C. D will broadcast the updated RREQ to node D and this updated packet looks like < A, 1, 1, D, , 2 >.
Node D will now create an entry in its routing table after receiving the RREQ packet from C. The routing table of node D looks like table 16.

| Destination | Next Hop | Hop count | Sequence Number |
|---|---|---|---|
| A | C | 3 | 1 |

Table 16: Routing Table of Node D After Receiving The RREQ Packet From C

Now, D will prepare a route reply packet with the source node, destination node, destination sequence number and the hop count values like < D, A, 100, 0 >. This route reply will be sent to its neighbor node that is C. Node C will create a new entry in its routing table with this received information. The update routing table will look like

| Destination | Next Hop | Hop count | Sequence Number |
|---|---|---|---|
| A | B | 2 | 1 |
| D | D | 1 | 100 |

Table 17: Updated Routing Table of Node C After Receiving the RREP Packet From D
Node C will broadcast the route reply packet to node B and B will further broadcast it to node A by increasing the hop count at each stage. The updated routing tables of A and B are as below. The broadcasted RREP packet from C to B will look like < D, A, 100, 1 > and from B to A, it will look like < A, A, 100, 2 >.

| Destination | Next Hop | Hop count | Sequence Number |
|---|---|---|---|
| A | A | 1 | 1 |
| D | C | 2 | 100 |

Table 18: Updated Routing Table of Node B After Receiving The RREP Packet From C

| Destination | Next Hop | Hop count | Sequence Number |
|---|---|---|---|
| D | B | 3 | 100 |

Table 19: Routing Table of Node A After Receiving The RREP Packet From B

This way, the routing tables of all the nodes from A to D are updated. When the nodes in this network want to send another packet, they consult their routing tables and then make a decision about the path as they now have all the required routing information. In the case where the intermediate node receives multiple RREQs, it will retransmit just the first received RREQ and will discard all the redundant RREQ packets. The destination will send multiple RREPs in the case where it has received multiple RREQs.

If a link to the destination or an intermediate node break, a route error (RERR) message is generated. This RERR message is sent to all the neighbor nodes in the active line to update their routing table with distance as ∞ to that particular node which moved out of the network. The sequence number will be incremented by the source node in this case. When this RERR message is received by the source node, the route discovery mechanism will be reinitiated when a packet should be transmitted between two nodes in that network.

**Advantages of reactive routing protocol**

- In this type of routing protocols, only the necessary routes are stored in the routing tables.
- Minimized need for broadcasting.
- Duplications and memory requirements will be reduced.
- When there is a broken link in the active routes of the network, there will be a quick response.
- Usage of destination sequence number helps in preventing the route looping problem.
- Bandwidth is not wasted in this case as there is no periodic advertisement of routes.
- Less delay for connection setup.

- This routing protocol is used for networks with at least 100 nodes or more. [27]

**Disadvantages of reactive routing protocol**

- If the intermediate nodes have a very old, it can lead to routes that are inconsistent.
- There are chances of a large control overhead when a node receives multiple RREQ packets in reply to only one RREQ packet.

## HYBRID ROUTING PROTOCOL

Hybrid Routing Protocol is a combination of the best properties of proactive routing as well as reactive routing. Hence, this routing protocol is called a hybrid proactive – reactive routing protocol. In hybrid routing protocol, the whole network is divided into zones. Each node present in the network is the center of its own zone. Nodes in a zone are two types as shown in figure 6: a) interior nodes and b) peripheral nodes. The node is called as an interior node if its distance from the source node is less than the radius of the zone and, the node is called as a peripheral node if its distance from the central node is same as the radius of the zone. As overlapping of the zones take place, zone routing protocol is also called a flat protocol. As a result of this, the congestion taking place in the network can be minimized and the detection of the optimal routes can be done.

There will be no delay in delivering a packet if the source and the destination are present in the same zone. This is because the routing tables of all the nodes will have a record of all the destinations present in that zone with the use of proactive routing protocol. If the source and the destination are present in two different zones, there will be a delay in delivering the packet as reactive routing protocol is employed and the routes are searched only on-demand.

The majority of the traffic will be sent to the nodes that are available nearby in ad-hoc networks. The zone routing protocol will reduce the scope of the proactive routing by minimizing it to a zone where each node will be the center. Routing information will be maintained easily for a limited zone. In this case, there will be a decrease in the wastage of the routing information. Reactive routing can be used to interact with the nodes that are far away. Hence, proactive routing protocol is used by the nodes present in a zone and reactive routing protocol is used by the nodes which are present outside the zone. Querying of all the nodes in the network will not be needed when route requests come in as the routing information is stored in all the nodes using proactive routing.

Zone routing protocol is adaptive in nature. This is dependent on the users' behavior and also the present configuration of the network. [4]

## Zone routing protocol

Zone Routing Protocol (ZRP) is a hybrid wireless protocol used effectively to reduce the packet overhead and speed up the delivery process. ZRP divides the whole networks into small areas called Zones. In ZRP, zone is defined as an area in which set of nodes resides. The radius of the routing zone is represented using ρ and the units of this radius are hops.

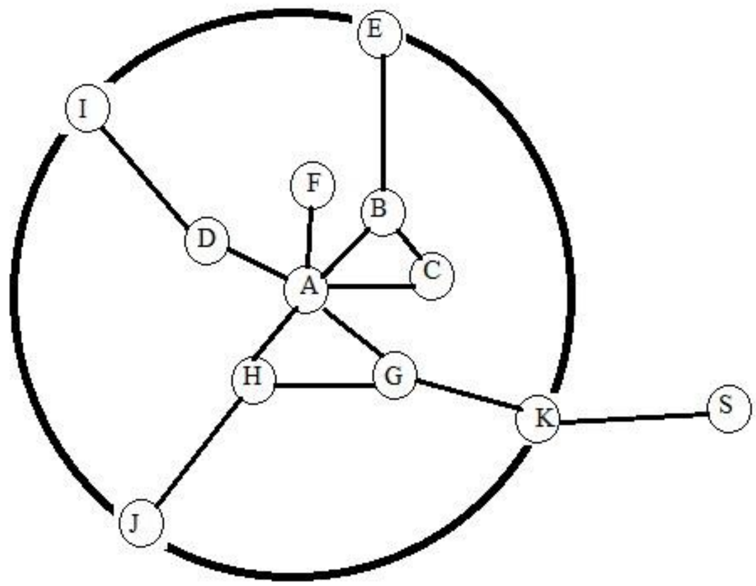


Figure 6: A Zone In ZRP

In Figure 6, considering 'A' as a central (source) node, 'B', 'C', 'D', 'F', 'G' and 'H' can be called as interior nodes whereas 'E', 'I', 'J' and 'K' can be called as peripheral nodes. Node 'S' is out of zone and can be reached via inter-zone routing protocol discussed in later sections.

A packet from source 'A' to destination 'E' can be sent in two ways i.e. A-B-E with length 2 or A-C-B-E with length 3. With the adjustment of the nodes' transmission power, the regulation of the nodes present in the routing zone will take place [8]. By reducing the power, the count of the nodes will reduce. Adequate redundancy and reachability will be achieved if there is sufficient number of nodes in the neighborhood.

Every node will have a specified routing zone separately and there will be overlapping of the zones belonging to the neighborhood nodes. The ZRP is itself classified into three types: a) intra zone routing protocol, b) inter zone routing protocol and c) bordercast resolution protocol.

When a node has to communicate with another node that is present inside its zone, it makes use of the Intra Zone Routing Protocol (IARP). The main aim of this protocol is to support the links that are unidirectional and not symmetric. There may be cases where a node P can send data to another node Q but the reverse case that is node Q to node P cannot be reached. This can happen either because of low transmission power or interference.

Routing zone radius is used to define the scope of the intra zone routing protocol. This protocol avoids the route discovery process as the routes are available immediately. An inefficient query broadcasting is used when a global route discovery is needed. This inefficient query broadcasting replaces the efficient query bordercasting by directing the route to border of the zone.

Communication between two nodes that are present in different zones make use of inter zone routing protocol (IERP). IERP is reactive routing protocol and in this case, the routes will be discovered only when there is a demand for it. Bordercast resolution protocol is used to minimize the delay that occurs in discovering the route by the IERP.

The IERP submits a query to only one node present in the border of the zone but is not sent to the local nodes because the local (interior) nodes carry route information within a zone. A query will not be sent back to the origin node from the border node. Inter zone routing protocol will suggest better routes and also helps in the maintenance of the routes.

Figure 7 shows the architecture of zone routing protocol.

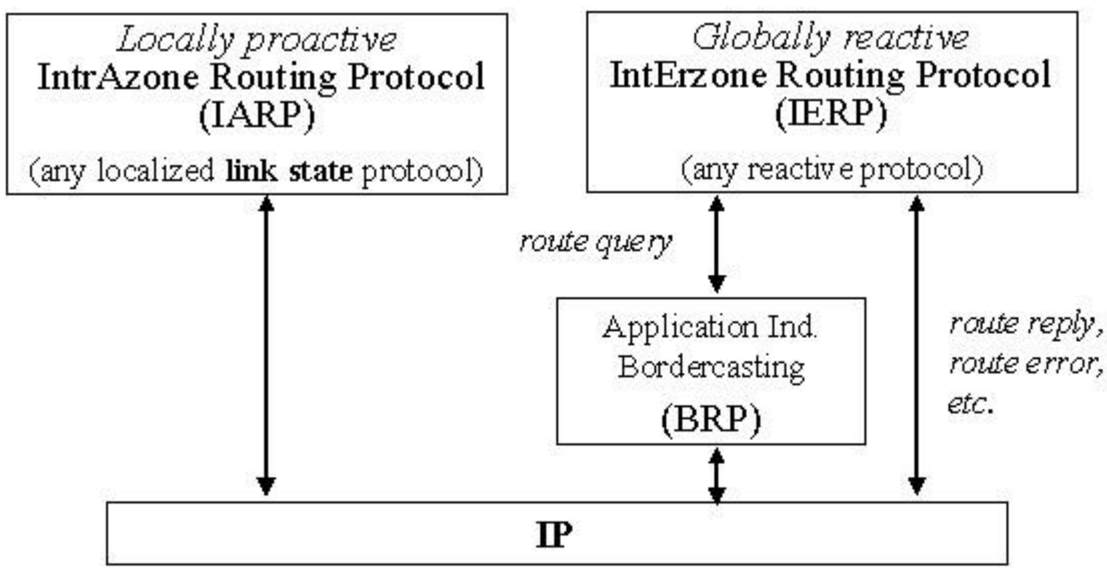


Figure 7: Zone Routing Protocol Architecture [4]

Every node will store the topology of the zone. Traffic can be reduced by knowing the topology of the zone present in every node. Bordercasting is used by zone routing protocol in place of packets' broadcasting. This makes use of the information regarding the topology of the zones that will be given by the intra zone routing protocol which will help in directing the quest. This query request will be sent to the border.

Bordercast resolution protocol will provide the service of delivering the bordercast packets. Bordercast trees will be built by the bordercast resolution protocol with the help of the extended routing zones. These trees are constructed for the query packets. Source routing will be used as an alternative by the BRP. [4] The MAC layer provides the neighbor discovery protocol which is used in the detection of link failures and also finding new neighbor nodes. HELLO messages will be transmitted by the NDP at regular time intervals. The neighbor table will get updated once it receives the HELLO message. Deletion of the neighbor nodes will take place if they don't receive this message in a particular time. Intra zone routing protocol will provide the functionality if the MAC layer does not consist of the neighbor discovery protocol (NDP).

The neighbor discovery protocol will trigger the updates related to routes. The intra zone routing protocol will be notified by the NDP that the neighbor table has been updated. The route queries will be responded by the intra zone routing protocol with the help of the routing tables of the intra zone routing protocol. The intra zone routing protocol will forward the queries with bordercast resolution protocol. The route queries will be guided by the bordercast resolution protocol away from the source of the query with the use of the routing tables of the intra zone routing protocol. [7]

In ZRP, if a source wants to send a packet to a destination, then it needs to discover the best route to send that packet to a destination. The process of route discovery in ZRP is explained below [16].

- First, the source node will check for the destination if it is present within that zone. If the destination is found within the same zone, there will be no route discovery process done further.

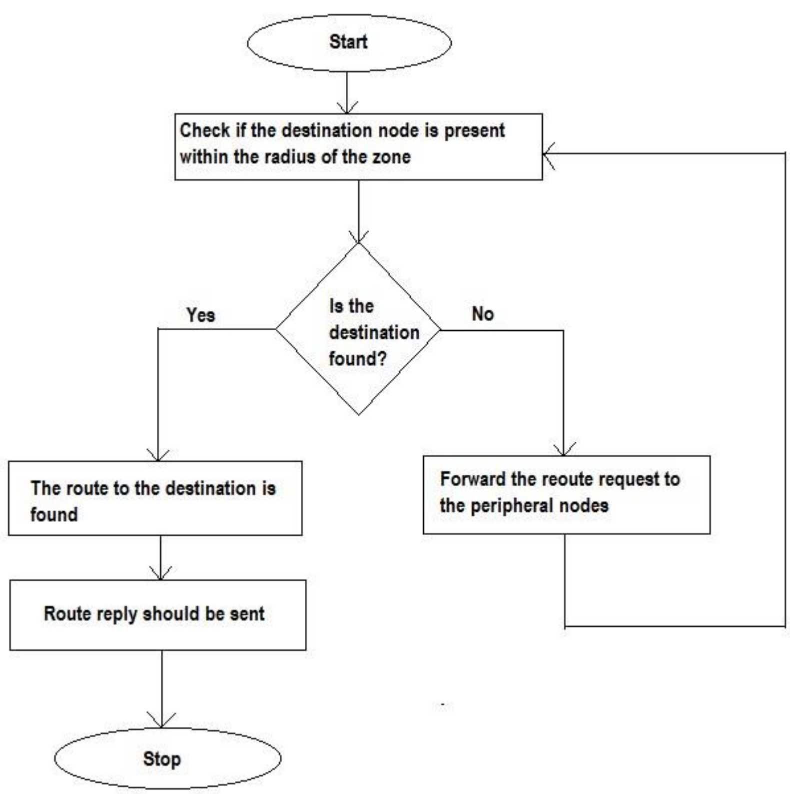

Figure 8: Route Discovery Process Explained Using A Flowchart [9]

- If the source node does not find the destination node within its zone, the route request will be bordercasted further to the peripheral nodes.
- On receiving the route request, the peripheral nodes check for the destination node within their zones. If the destination happens to be present in their zone, the source node will receive the route reply from the destination with the route information.
- If the peripheral nodes do not find the destination node within their zone, the route discovery process continues until the destination is found.

Let us consider the network in figure 9. Node A wants to send a packet to node T. In the above figure, let's say the radius of the zone is ρ = 2. Node A first checks its routing table to determine whether node T is within its routing zone. These routing tables will be provided by the intra zone routing protocol.

Since, node T is outside the zone, a routing request will be raised by node A using intra zone routing protocol. This route request will be sent to the peripheral nodes (Nodes C, F and J). Each of these peripheral nodes searches for the node T using their routing tables.

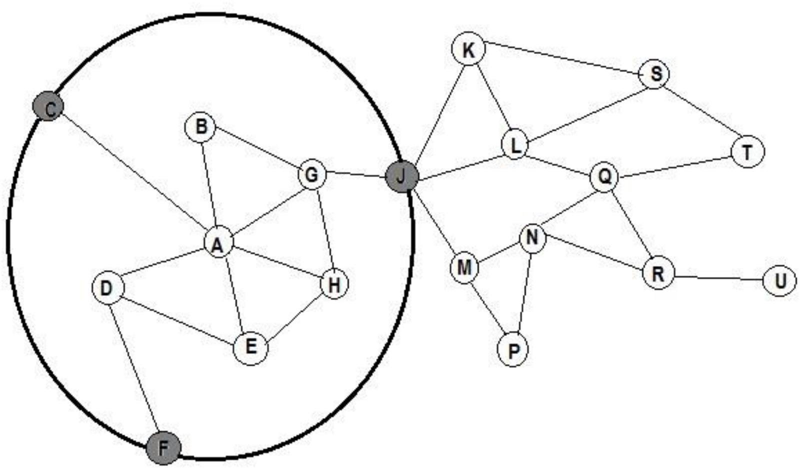


Figure 9: Route Zone Of Node 'A'

As shown in figure 10, node J fails to find the destination node within its routing zone. Hence, it repeats the discovery process and forwards the route request to its peripheral nodes (nodes K, P and Q). The request will not be sent back to node A because of query control mechanisms.

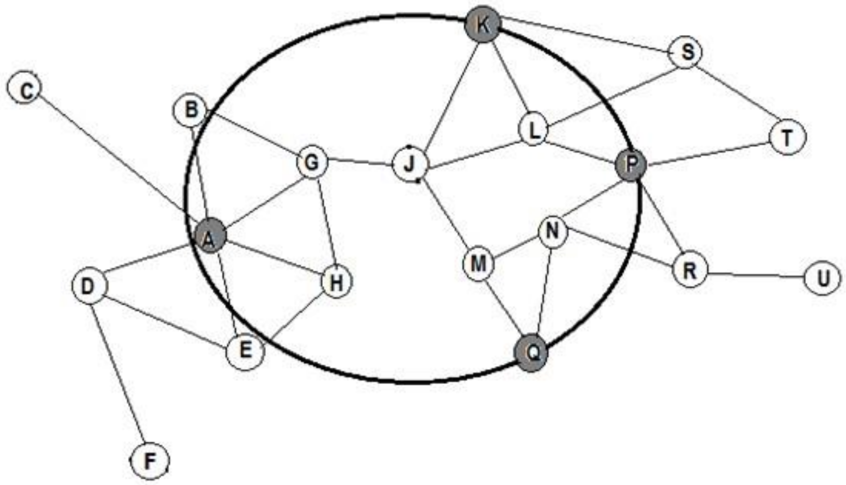


Figure 10: Route Zone Of Node ‘J’ [12]

Once the route request reaches node Q, it searches for the destination node i.e. node T in its routing tables and will succeed in finding it as node T belongs to the same zone as node Q as shown in figure 11.

Now, node Q will append the path to node T from itself in the route request packet. Node Q then sends a route reply back to node A (source node) with the route information of node T. If there are multiple paths available to reach the destination, multiple route replies will be sent back to the source node.

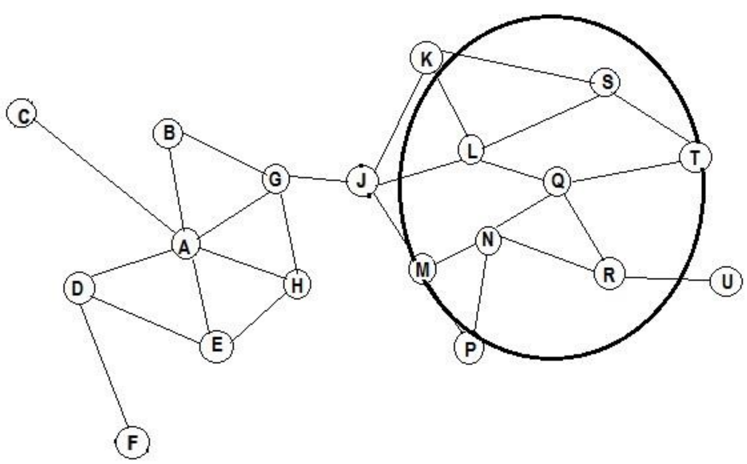

Figure 11: Route Zone Of Node 'Q'

The node which has the packet first checks with the Intra-zone Routing Protocol (IARP) to determine if the destination belongs to the same zone. In this particular case, the node will use the proactive routing protocol to transfer the packet. If the node determines that the destination is out of its zone, Reactive routing protocol will be used to move the packet.

If the packet has to be moved using reactive routing, this routing process will take place in two phases namely route request phase and route reply phase. Using bordercast resolution protocol (BRP), the source will initiate a route request to the neighboring nodes. If the destination is known by the node that receives the route request, a route reply will be sent back by the peripheral node to the source node. In case the destination is not known by the peripheral node, it sends the same route request to its neighboring node using the same BRP process in order to continue the process. The route request will be spread all over the network in this way. If a particular node receives more than one route request of the same kind, then it will discard them and consider them redundant. [15]

Any node which has route or the information about the destination will send a reply back. In the process where the request is passed on through the network, to send back a reply to the source node, the routing information should first be accumulated. The routing information will be recorded in two different ways.

- It can be saved as the next-hop address throughout the path. In this case, the routing information will be recorded as the next-hop address by the forwarding nodes. Since the size of the request and the reply will be small, transmission resources can be saved in this approach.
- Routing information can also be recorded in the route request packets. In this case, the source node details and the peripheral node details will be appended. Upon reaching the destination, the sequence in which the addresses are recorded will be reversed and copied onto the reply packet. This sequence will be used by the nodes to send the route reply back to the request initiating node/source.

After receiving the route reply packet, the source node will have complete routing information from the source to the destination. The nodes present between the source and the destination will also have the next-hop addresses recorded in their routing tables.

One-to-many transmission process is used by the bordercasting process [13]. In this process, a route request packet will be sent out by the bordercasting node to all of its neighboring nodes. This type of transmission is used to reduce the usage of resource and is implemented as multicast.

For the better performance of ZRP, radius of the zone plays an important role. Routing will be purely reactive when the radius of a zone is one hop. Bordercasting process will degenerate into flood searching. The routing will be reactive if the radius of a zone goes to infinity. Routing efficiency and increasing traffic maintenance are mainly affected by selection of radius.

**Advantages of hybrid routing protocols**

- Limited search cost.
- This routing protocol is suitable for networks with atleast1000 nodes or more.
- The delay is less for destinations with the zone.

**Disadvantages of hybrid routing protocols**

- There is a significant amount of delay for the destinations outside the zone.
- Large amount of resources is required for large sized zones.

## Proactive vs reactive vs hybrid routing protocols

| Parameters | Proactive routing protocol | Reactive routing protocol | Hybrid routing protocol |
|---|---|---|---|
| Routing scheme | Table driven routing | On-demand routing | Combination of proactive and reactive |
| Overhead | The routing overhead is high | The routing overhead is low | The routing overhead is medium |
| Scalability | Scalability level is low | This protocol is not suitable for large networks | This protocol is designed for networks with up to 1000 nodes |
| Traffic | High | Low | High inside the zone and low outside the zone |
| Latency | Latency is low | Latency is high because of flooding | Latency is low inside the zone and is high outside the zone |
| Delay | Low | High | Low inside the zone and high outside the zone |

Table 20: Comparison of Proactive, Reactive and Hybrid Routing Protocols Considering the characteristics of all the routing protocols mentioned in the previous chapters and also considering the performance parameters mentioned in table 20, we can draw some conclusions. These parameters are chosen because they are necessary to understand the stability and the condition of a network. To transfer a packet from a source to destination quickly, proactive routing protocol is preferred as there is less delay in using this routing protocol. This is because routing information to all the destinations in the network are readily available.

To transfer a packet of huge size, reactive routing protocol is preferred as the routing overhead is low for this protocol. For small sized networks with up to 100 nodes, proactive routing protocol is used for efficient routing. For networks of size more than 100 nodes, reactive routing protocol is the best. For large networks with at least 1000 nodes, hybrid routing protocol is best used. This way, each protocol is best suitable under different network conditions.