Routing Protocols

Introduction:-

An ad-hoc wireless network consists of set of mobile nodes that are connected by wireless links. The network topology in such a network may keep changing randomly. Routing protocols are used to find the path from source to destination. Finding a path in wireless Network is difficult because of following reasons

- Highly dynamic topology
- No infrastructure for centralized administration
- Bandwidth constrained
- Energy constrained

Hence a variety of routing protocols for adhoc wireless network has been proposed

Issues in Designing A Routing Protocol for Ad-hoc wireless Networks:

The major challenges that a routing protocol designed for ad-hoc wireless networks faces are mobility of nodes, resources Constraints, Error-prone channel state and hidden and exposed node problems.

Mobility:

The network topology in an adhoc wireless less Network is highly dynamic due to movement of nodes hence, an ongoing session suffers frequent path breaks.

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Disruption occurs due to the movement of intermediate nodes for end nodes in the path. Mobility of nodes results in frequently changing Network topology. Routing protocols must be able to perform efficient and effective mobility management.

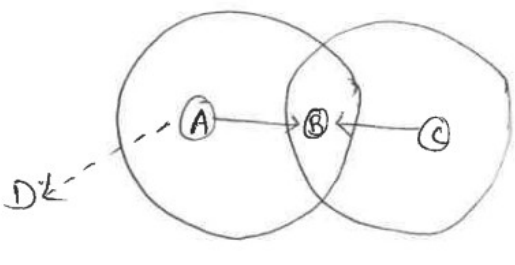
Bandwidth Constraint:-

In a wireless network, the radio band is limited, and hence the available bandwidth is also limited. This requires that the routing protocols use the bandwidth optimally by keeping the overhead as low as possible. The limited bandwidth availability also imposes a constraint on routing protocols in maintaining the topological information.

Broad cast Nature of radio Channel:-

This broad cast Nature of radio channel poses a unique challenge in adhoc wireless networks. The wireless links have time varying characteristics in terms of link capacity and link-error probability This requires that the routing protocols interact with the MAC layer to find alternate routes through better-quality links. Also, transmission in ad-hoc wireless networks result in collision of data and control packets. Therefore, it is required that adhoc wireless network routing protocols in find & maintaining the paths with less congestion.

Hidden and exposted node problem:



The hidden node problem refers to the collision of packets at the receiving node due to the simultaneous transmission of those node that are not

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not within the direct transmission range of the receiver, but are with in the transmission range of the receiver. collision occur when both nodes transmit packet at the same time without knowing about the transmission of each other.

The exposed terminal problem refers to the inability of node which is blocked due to transmission by a nearby transmitting node to transmit to another node.

Resource Constraints:

Two essential and limited resources are battery life and processing power. Devices used in wireless networks require portabi and hence they also have size and weight constraints along with the restrictions on the power source. Increase the battery power and proces ability makes the node bulky and less portable. Thus, routing proto design must optimally manage these resources.

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Characteristics of Routing Protocols

A routing protocols should have the following characteristics.

1. It must be fully distributed in nature. Distributed routing is more fault-tolerant than centralized routing, which involves the risk of single point failure.

2. It must adaptive to frequent topology changes caused by the mobility of nodes.

3. Route computation and maintenance must involve a minimum no. of nodes. Each node in the network must have quick access

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to routes. (Min connection setup time is desired).

4. It must be localized, as global state maintenance involves a huge state propagation control overhead.

5. It must be loop-free and free from stale routes.

6. The no. of packet collisions must be kept to a minimum by limiting the number of broadcasts made by each node. The transmission should be reliable to reduce message loss and to prevent the occurrence of stale routes.

7. It must optimally use scarce resource such as bandwidth, computing power, memory, and battery power.

8. Every node in the nlw should try to store information regarding the stable local topology only. Changes in remote parts of the network must not cause updates in the topology information maintained by the node.

9. It should be able to provide a certain level of quality of Service (QoS) as demanded by the applications.

10. It also offer support for time-sensitive traffic.

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Classification of Routing Protocols:-

The routing protocols for ad hoc wireless networks can be broadly classified into four categories based on

1) Routing information update Mechanism

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2) Use of temporal information for routing

3) Routing Topology

4) Utilization of specific resources.

Based on the routing information Update Mechanism:-

The three major categories based on the routing information update Mechanism are,

1 Proactive or table-driven routing protocols:

In this method, every node maintains the network topology information in the form of routing tables by periodically exchanging routing information. Routing informations are generally flooded in the whole network. Whenever a node requires a path to destination, it runs an appropriate path-finding algorithm on the topology information it maintains.

2. Reactive or on-demand routing protocols:

Protocols that fall under this category do not maintain the network topology information. They obtain the necessary path when it is required, by using a connection establishment process. Hence these protocols do not exchange routing information periodically.

3. Hybrid routing protocols:

Protocols belonging to this category combine the best features of the above two categories.

Nodes within routing zone – A table driven approach is used

Nodes beyond routing zone – An on-demand approach is used

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Based on the use of temporal information for routing:

The protocols that fall under this category can be further classified into two types

1. Routing Protocols that use past temporal information:

Use information about the past status of the links or the status of the links at the time of routing to make routing decisions.

2. Routing Protocols that use future temporal information:

These protocols use information about the expected future status of the wireless links to make approximate routing decisions.

The future status information also includes information regarding the lifetime of wireless links, node prediction of location and prediction of link availability.

Based on Routing Topology:

1. Flat topology routing protocols:

These protocols use of a flat addressing scheme similar to the one used in IEEE 802.3 LANs. It assumes the presence of a globally unique addressing mechanism for nodes in an adhoc wireless network.

2. Hierarchical topology routing protocols:

These protocols make use of a logical hierarchical in

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the network and an associated addressing scheme. The hierarchy could be based on geographical information or it could be based on hop distance.

Based on the utilization of specific Resources:

1. Power-aware routing:

These protocols aims at minimizing the consumption of a very important resource in the ad-hoc wireless networks: the battery power. The routing decisions are based on minimizing the power consumption either locally or globally in the network.

2. Geographical information assisted routing:

Protocols belonging to this category improve the performance of routing and reduce the control overhead by effectively utilizing the geographical information available.

Pro-Active Routing Protocol: (or) TABLE DRIVEN ROUTING PROTOCOLS

These protocols are extensions of the wired network routing protocols. They maintain the global topology information in the form of tables at every node. Tables are updated frequently in order to maintain consistent and accurate network state information.

Examples:

1. Destination Sequenced distance Vector routing protocol (DSDV)
2. Wireless routing protocol (WRP)
3. Source-tree adaptive routing protocol (STAR)
4. Cluster-head gateway switch routing Protocol (CGSR)

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Destination Sequenced distance-vector routing protocol:

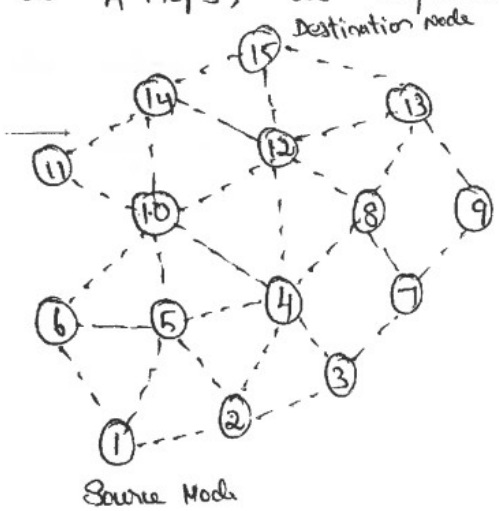
- It is an enhanced version of the distributed Bellman Ford algorithm where each node maintains a table that contains the shortest distance and the first node on the shortest path to every other node in the network.
- It incorporates table updates with increasing sequence number tags to prevent loops, to counter the count to infinity problem, and for faster convergence.
- As it is a table driven routing protocol, routes to all destinations are readily available at every node at all times.
- The tables are exchanged between neighbors at regular intervals to keep an up-to-date view of the network topology.
- The table updates are of two types:
  - → Incremental updates: Takes a single network data packet unit (NDPU). These are used when a node does not observe significant changes in the local topology. (No change).
  - → Full dumps: Takes multiple NDPUs. It is done either when the local topology changes significantly or when an incremental update requires more than a single NDPU.
- Table updates are initiated by a destination with a new sequence number which is always greater than the previous one.

Consider the example as shown in figure (a). Here node 1 is a source node and node 15 is the destination. As all the nodes maintain global topology information, the route is already available as shown in figure (b)

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Here the routing table node 1 indicates that the shortest route to the destination node is available through node 5 and the distance to it is 4 hops, as depicted in figure (b)



a) Topology Graph of the Network

Dest	Next node	Dist	seq.no
2	2	1	22
3	2	2	26
4	5	2	32
5	5	1	134
6	6	1	144
7	2	3	162
8	5	3	170
9	2	4	186
10	6	2	142
11	6	3	176
12	5	3	190
13	5	4	198
14	6	3	214
15	5	4	256

b) Routing Table for node 1

The reconfiguration of a path used by an on-going data transfer session is handled by the protocol in the following way.

When the link of the node breaks, then paths that are passing through that link are assigned to infinity (∞) and all its neighbors are informed about the changes in the routing table. And also sequence number of that node is assigned with a new number greater than the previous one. This information also broadcasted to entire network. Figure shows the case when node 11 moves from its current position.

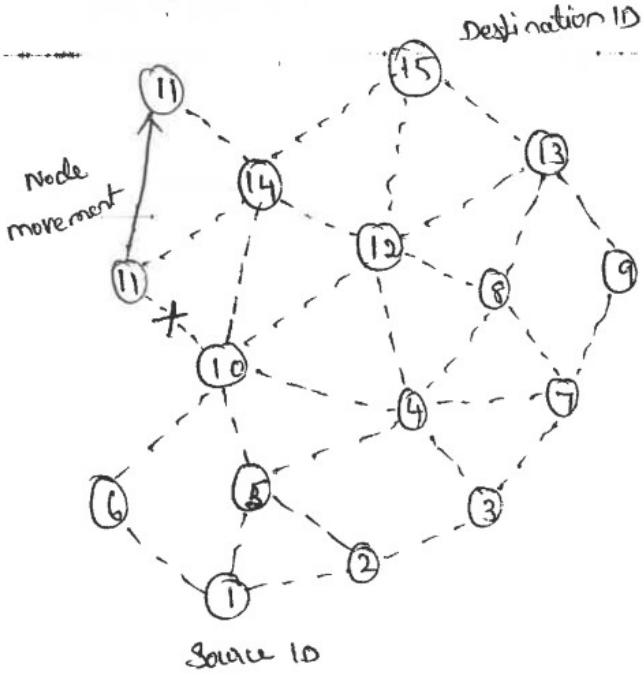
Advantages

- Less delay involved in the route setup process.
- Mechanism of incremental update with sequence number tags makes the existing wired network protocols adaptable to adhoc wireless Networks.
- The updates are propagated throughout the nlw in order to

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maintain an up to date view of the Nlw topology at all nodes.



Dest	Next node	Dist	Seq. No
2	2	1	22
3	2	2	26
4	5	2	32
5	5	1	134
6	6	1	144
7	2	3	162
8	5	3	170
9	2	4	186
10	6	2	142
11	5	4	180
12	5	3	190
13	5	4	198
14	6	3	214
15	5	4	256

Figure: Route maintenance in DSDV

Dis Advantages:

- The updates due to broken links lead to a heavy control overhea during high mobility.
- Even small network with high mobility or a large network with low mobility can completely choke the available bandwidth.
- Suffers from excessive control overhead.
- Delay occur in obtaining the information regarding specific node.

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Wireless Routing Protocol (WRP):-

WRP is similar to DSDV. The node present in WRP also contain a route to all destination node in the network topology. But the difference is that WRP has a unique table maintenance and update Mechanism. while DSDV maintains only one topology table, WRP uses a set of tables to maintain more accurate informatio

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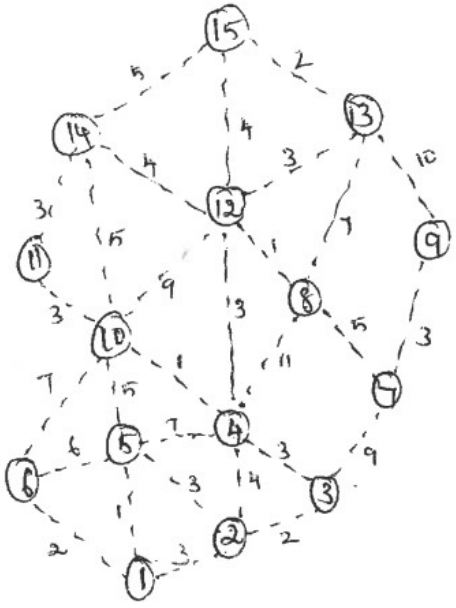
The tables that are maintained by a node are:

i) Distance Table (DT): Contains the network view of the neighbors of a node. It contains a matrix where each element contains the distance and the penultimate (next-to-last) node reported by the neighbor for a particular destination.

2) Routing Table (RT): contains the up-to-date view of the network for all known destinations. It keeps the shortest distance, the predecessor / penultimate node, the successor node and a flag indicating path the status of the paths. The path status may be a simplest (correct) path or loop (error), or destination node not marked (null).

3) Link cost table (LCT): contains the cost of relaying messages through each link. The cost of broken link is ∞. It also contains the number of update periods passed since the last successful update was received from i

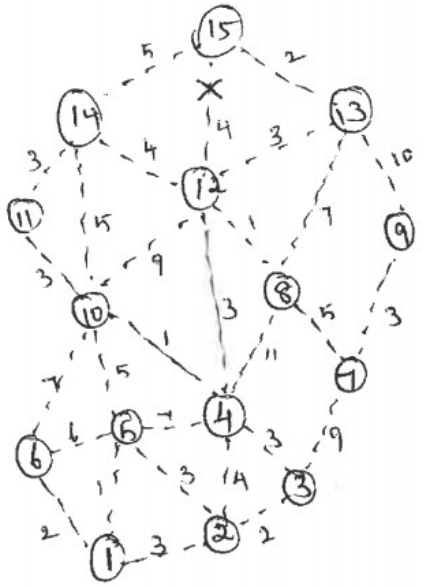
4) Message retransmission list (MRL): contains an entry for every update message that is to be retransmitted and maintains a counter for each entry.



Node	Next node	Pred.	cost
15	15	15	0
14	15	14	5
13	15	13	2
12	15	12	4
11	14	14	8
10	4	12	8
9	13	13	12
8	12	12	5
7	8	12	10
6	10	12	20
5	4	12	14
4	12	12	7
3	4	12	10
2	4	12	11
1	2	12	14

Routing entry at each node for destination ID 15

Fig: Route establishment in WRP



Node	Next node	Pred.	cost
15	15	15	0
14	15	14	5
13	15	13	2
12	13	13	5
11	14	14	8
10	4	13	9
9	13	13	12
8	12	13	6
7	8	13	11
6	10	13	16
5	10	13	14
4	12	13	8
3	4	13	11
2	4	13	12
1	2	13	15

Fig: Route maintenance in WRP

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Consider the example shown in figure (a), where the source of the route is node 1 and destination is node 15. As WRP proactively maintains the route to all destinations, the route to any destination node is readily available at the source node.

From the routing table shown, the route from node 1 to node 15 has the next node as node 2. The predecessor node of 15 corresponding to this route is route 12. The predecessor information helps WRP to converge quickly during link breaks.

When a node detects a link break, it sends an update message to its neighbors with the link cost of the broken link sent to ∞. After receiving the update message; all affected nodes update their minimum distance to the corresponding nodes. The node that initiated the update message then finds alternative route, if available from its DT. figure(b) shows route maintenance in WRP.

Advantages:

- WRP has the same advantages as that of DSDV
- It has faster convergence and involves fewer table updates.

Disadvantages:

- The complexity of maintenance of multiple tables demands a larger memory and greater processing power from nodes in the adhoc wireless Network.
- It is not suitable for highly dynamic and also for very large adhoc wireless Networks.

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Cluster-Head Gateway Switch Routing Protocol (CGSR):

- Uses a hierarchical network topology.
- CGSR organizes nodes into clusters, with co-ordination among the members of each cluster, one node named cluster-head.
- This cluster-head is elected dynamically by employing a least cluster change (LCC) algorithm.
- According to this algorithm, a node ceases to be a cluster-head only if it comes under the range of another cluster-head, where the tie is broken either using the Lowest ID or highest connectivity algorithm
- Clustering provides a mechanism to allocate bandwidth, which is a limited resource, among different clusters, thereby improving reuse.
- Different cluster-heads could operate on different spreading codes on a CDMA system.
- Inside a cluster, the cluster-head can co-ordinate the channel access based on a token-based polling protocol. All members nodes of a cluster can be reached by the cluster-head within a single hop, thereby enabling the cluster-head to provide improved coordination among nodes that fall under its cluster.
- A token-based scheduling is used within a cluster for sharing the bandwidth among the members of the cluster.
- CGSR assumes that all communication passes through the cluster-head. Communication between 2 clusters takes place through the common member nodes that are members of both the cluster are called gateways
- A gateway is expected to be able to listen to multiple spreading codes that are currently in operation in the clusters in which the node exists as a member.

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• Gateways that are capable of simultaneously communicating over two interfaces can avoid gateway conflicts. [gateway conflicts is said to occur when a cluster-head issues a token to a gateway over spreading code while gateway is tuned to another code].

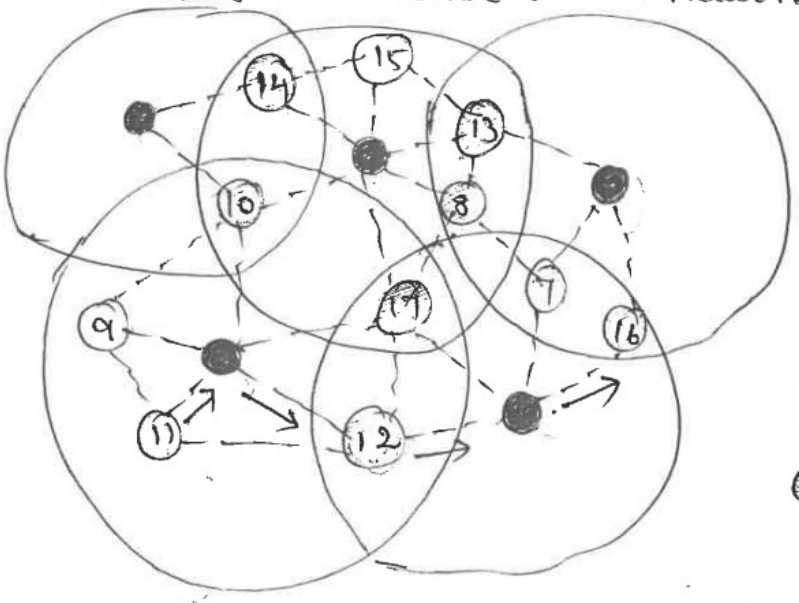
• The performance of routing is influenced by token scheduling and code scheduling that are handled at cluster-heads and gateways, respectively.

• The routing protocol used in CGSR is an extension of DSDV. Every member node maintains a routing table containing the destination cluster head for every node in the network. In addition to the cluster member table, each node maintains a routing table which keeps the list of next hop nodes for reaching every destination cluster.

• The cluster (hierarchical) routing protocol is used here.

• As per this protocol, when a node want to transmit packet, first it gets the token from its cluster-head. It contains the destination cluster-head, next hop node from the cluster member table and the routing table respectively.

Figure shows the cluster head, cluster gateways and normal cluster member nodes in an ad hoc wireless network.



A path between node 11 and node 16 would follow 11 - 6 - 12 - 5 - 16.

○ Cluster member node

● Cluster head

◉ Cluster gateway.

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Advantages:

... CGSR is a hierarchical routing scheme which enables partial coordination between nodes by electing cluster-heads.

- Better Bandwidth utilization is possible.
- Easy to implement priority scheduling schemes with token scheduling and gateway code scheduling.

Disadvantages:

- Increase in path length and instability in the system at high mobility when the rate of change of cluster-head is high.
- In order to avoid gateway conflicts, more resources are required.
- The power consumption at the cluster-head node is also a matter of concern.
- Lead to Frequent changes in the cluster-head, which may result in multiple path breaks.

Source-Tree Adaptive Routing Protocol (STAR):

→ It is a Least overhead routing Approach (LORA) Protocol.
→ This protocol attempts to provide feasible paths that are not guaranteed to be optimal.
→ Involves much less control overhead.
→ In STAR protocol, every node broadcasts its source tree information
→ The source tree of a node broadcasts its source tree information

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- The source tree of a node consists of the wireless links used by the node.
- Every node builds a partial graph of the topology.
- During initialization, a node sends an update message to its neighbors.
- Each node will have a path to every destination node.
- The path would be sub-optimal.
- The data packet contains information about the path to be transversed in order to prevent the possibility of routing loop formation
- In the presence of reliable broadcast mechanism, STAR assumes implicit route maintenance.
- In addition to path breaks, the intermediate nodes are responsible for handling the routing loops.
- The route repair packet contains the complete source tree of node k and the traversed path of the packet.
- When an intermediate node receives a route repair update message, it removes itself from the top of the route repair path and reliably sends it to the head of the route repair path.

Advantages:

- Very Low communication overhead
- Reduces the Average control overhead.

ON-DEMAND ROUTING PROTOCOLS: (Reactive Protocol):

On demand routing protocols execute the path-finding process and exchange routing information only when path is required by a node to communicate with a destination.

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1) Dynamic Source Routing Protocol (DSR):

- Dynamic Source routing protocol is an on-demand protocol designed to restrict the bandwidth consumed by control packets in adhoc wireless networks by eliminating the periodic table update message.
- It is beacon-less and hence does not require periodic hello packet (beacon) transmission, which are used by a node to inform its neighbors of its presence.
- Basic approach of the protocol, to establish a route by flooding Route-Request packets in the network.
- Destination node responds by sending a Route-Reply packet back to the source.
- Each Route Request carries a sequence number generated by the source node and it has path traversed. (Pass over path).
- A node, upon receiving a Route Request packet, checks the sequence number on the packet before forwarding it.
- The packet is forwarded only if it is not a duplicate Route Request.
- The sequence number on the packet is used to prevent loop formations and avoid multiple transmission.
- Thus, all node except the destination forward a Route Reque packet during the route construction phase.
- In figure, source node 1 initiates a Route Request packet to Obtain a path for destination node 15

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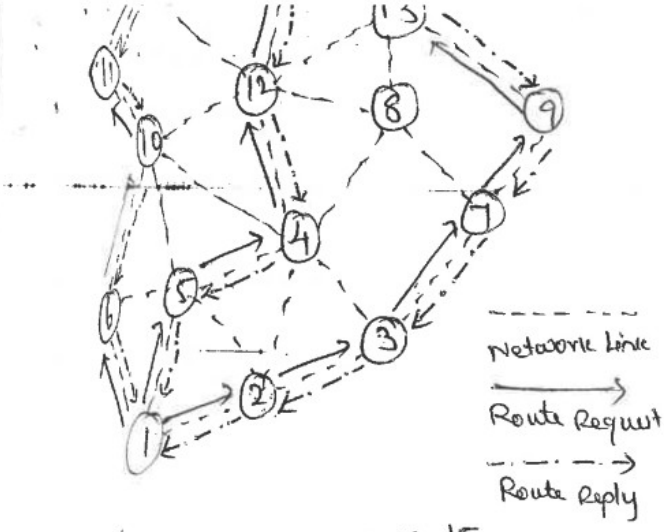
- This protocol uses a route cache that stores all possible information extracted from the source route contained in data packets.
- This cache information is used by the intermediate nodes to reply to the source when they receive a route Request packet and if they have a route to the corresponding destination.
- During Network partitions, the affected nodes initiates Route-Request packets.
- DSR also allows piggy-backing of a data packet on the Route Request so that a data packet can be sent along with the Route Request.
- If optimization is not allowed in DSR, the route construction phase redundant. For example, after receiving the Route Request packet from node 1, all its neighboring nodes, ie 2, 5, 6 forward it. Node 4 Receives the Route Request from both 2 and 5. Node 4 forwards the first Route Request and discard the other redundant / duplicate packets.
- As part of optimization, If the intermediate nodes have route to reach destinate, then it also sends the Route Reply to the source node.
- The source node selects the latest and best route and uses that for sending data packets.

Example: If the intermediate node 10 has route to the destination via node 14, it also sends the Route Reply to source node.

- Each data packet carries the complete path to its destination.
- If link breaks, source node again initiates the route discovery process.

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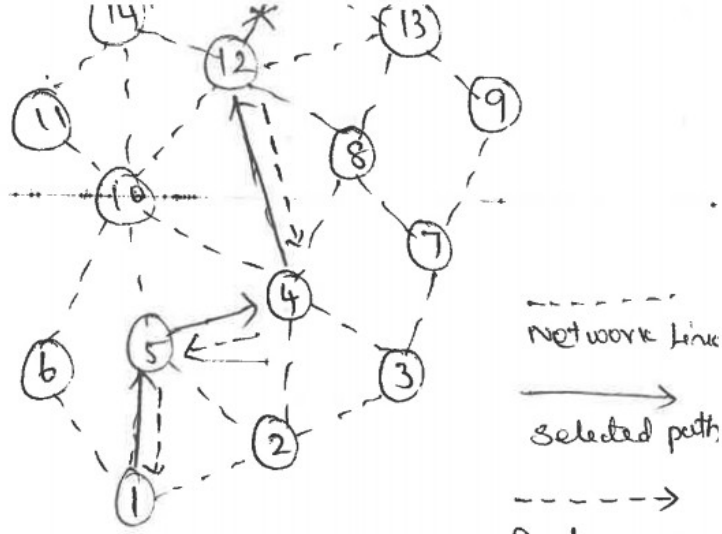


path 1: 1-2-3-7-9-13-15

path 2: 1-5-4-12-15

path 3: 1-6-10-11-14-15

fig: Route Establishment



Selected Route : 1-5-4-12-15

fig: Route maintenance in DSR

Advantages:

- uses a reactive approach which eliminates the need to periodically flood the network with table update messages.
- Route is established only when required.
- Reduce control overhead.

Disadvantage:

- Connection setup delay is higher
- performance degrades rapidly with increasing mobility
- Routing overhead is more which is directly proportional to path length.

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2) Ad-Hoc On Demand Distance-Vector Routing Protocol: (AODV)

→ Ad-hoc on demand distance vector routing Protocol uses an on-demand approach for finding routes, that is, a route is

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established only when it is required by a source node for transmitting data packets.

→ Every node has to be identified by its (destination) sequence number.

→ The major difference between DSR and AODV

→ DSR uses source routing in which a data packet carries the complete path to traversed.

→ AODV stores the next-hop information corresponding to each flow for data packet transmission.

→ In an on-demand routing Protocol, the source node floods RouteRequest packet in the network when the routes to is not available for the desired destination.

→ Uses Destination Sequence number (DestSeqNum) to determine an up-to-date path to destination.

→ A RouteRequest carries the source identifier (SrcID), the destination Identifier (DestID), the source Sequence number (SrcSeqnum), the destination Sequence number (DestSeqNum), the broadcast identifier (BcastID) and (TTL) Time to live field.

→ DestSeqNum indicates the freshness of the route that is accepted by source

→ When an Intermediate node receives a RouteRequest, it either forwards it (or) prepares a RouteReply if it has a valid route to destination.

→ The validity of the intermediate node is determined by comparing the sequence numbers.

→ If a RouteRequest is received multiple times, then duplicate copies are discarded.

→ Either intermediate nodes (or) Destination node are allowed to send RouteReply packets to source.

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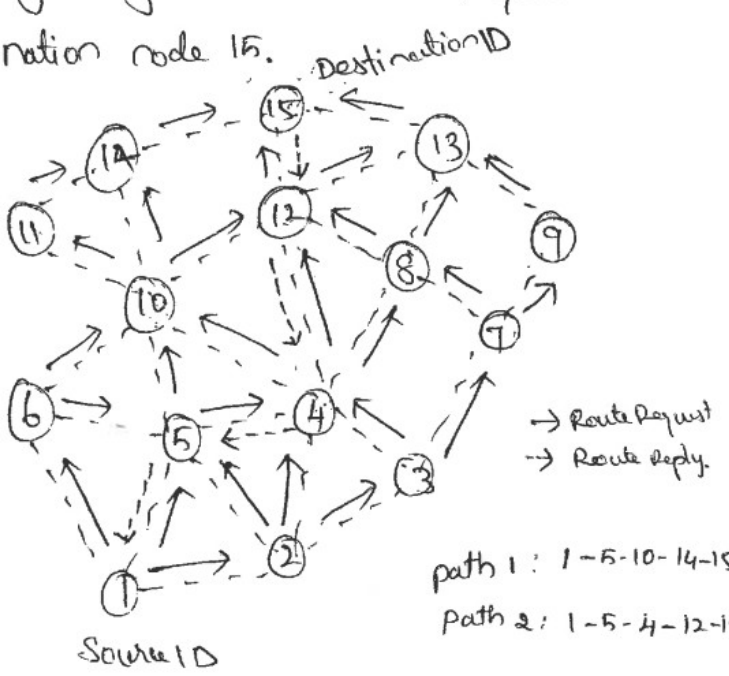
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→ Every intermediate node while forwarding a Route Request, enters the previous node address and its Bcast ID.

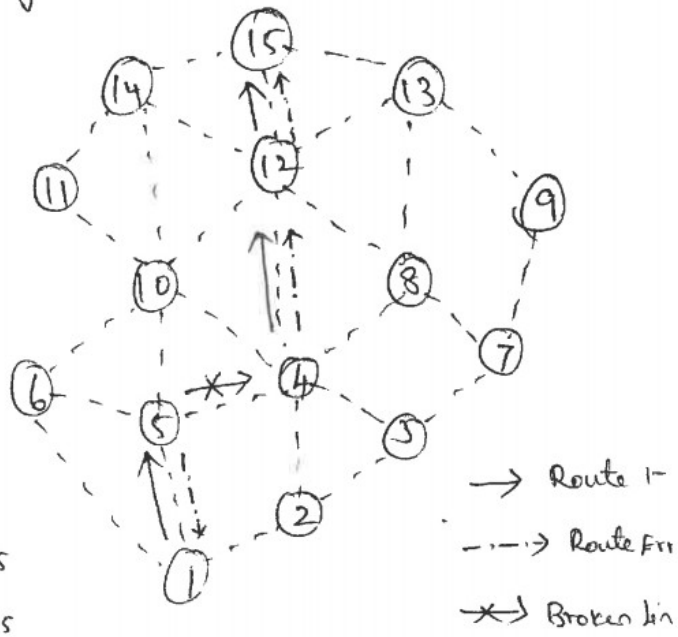
→ A Timer is used to delete this entry in the case a Route Reply is not received before the timer expires.

→ When a node receives a Route Reply packet, it stores the information about previous node in order to forward data packets.

Consider the figure, source node 1 initiates a path-finding process by origination a Route Request to be flooded in the network for destination node 15.



a) Route establishment in AODV



b) Route Maintenance in AODV

→ Let Assume that if node 10 and node 3 has route to destination. When these two nodes receives Route Request packet, it check Dest seq Num. Suppose Dest seq Num for node 10 is 4 and node 3 is 1, then only node 10 is allowed to reply with Route Reply packet to source.

→ If Route Request Reaches destination through path 4-12-15 (or) any other path, it sends a Route Reply to the source.

→ All intermediate nodes updates their route tables with latest destination Sequence number.

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→ AODV does not repair a broken path locally.

→ When a link breaks, the end nodes are notified.

→ Source node re-establishes the route to the destination, when Route Error message received by the source, if required.

Advantages:

- Routes are established on demand and DestSeqNum are used to find latest route to the destination.
- Connection setup delay is less

Disadvantage:

- Intermediate nodes can lead to inconsistent routes if the source sequence number is very old.
- Multiple Route Reply packets to single Route Request packet can lead to heavy control overhead.
- Periodic beaconing leads to unnecessary bandwidth consumption.

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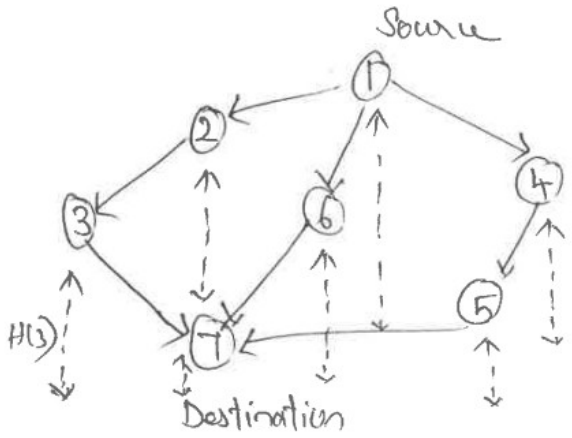
Temporally Ordered Routing Algorithm (TORA):

- Source-initiated on-demand routing Protocol.
- Uses a link reversal algorithm.
- Provides loop free multipath routes to the destination.
- Each node maintains its one-hop local topology information.
- Has the capability to detect partitions and limiting the control packets to a small region during the reconfiguration process initiated by a path break.

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• Figure shows the distance metric used in TORA which is nothing but the length of the path or the height from the destination. H(N) denotes the height of node N from the destination.



Edge of the DAG, Height of node I H(I)

• TORA has three main function: Establishing, maintaining and Erasing routes.

• The route establishment function is performed only when a node requires a path to the destination but does not have any direct link.

• This process establishment process using query / update mechanism which make destination-oriented direct acyclic graph (DAG).

• Consider the network topology, when node 1 has data packets to be sent to the destination node 7, a Query packet is originated by node 1 with the destination address included in it. This Query packet is forwarded by intermediate nodes 2, 3, 4, 5, 6 and reaches the destination 7.

• The Destination or any other intermediate node which has

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Path to destination can terminates the Query packets and replies with an update packet containing its distance from destination.

- Each node that receives this update packet sets its distance to a value higher than the distance of the sender of the update packet.
- Once the path to the destination is obtained, it is considered to exist as long as the path is available.
- When the intermediate node 5 discover that the route to the destination node is invalid, it changes its distance value and originates an update packet. The neighboring node 4 that receives the update packet reverses the link between 1 and 4 and forward the update packet to node 1. This result in change in graph (DAG).
- If source node has no other neighbor that has path to the destination, it initiates fresh Query / update procedure.
- Here clear messages are used to erase path to destination when partition occur.

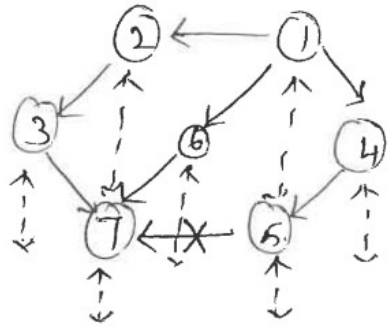
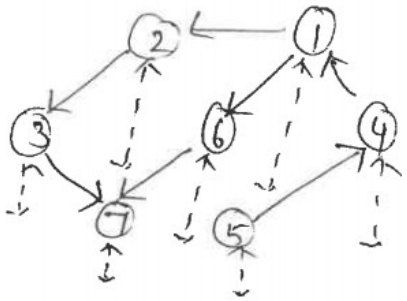


fig: Link breaue between 7 and 5



Node 4 & 5 reverse their Link in order to update path.

Advantages & Disadvantages:

→ TORA incurs less control overhead. (Advantage)

→ The local reconfiguration of paths results in non-optimal routes. (Disadvantage).

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Location - Aided Routing:

- It utilizes the location information for improving the efficiency of routing by reducing the control overhead.
- LAR assumes the availability of global positioning system (GPS) for obtaining the geographical position information nessary for routing.
- LAR designates two geographical regions for selective forwarding of control packets, namely, Expected Zone and Request zone.
- Expected Zone is the region in which the destination node is Expected to be present, given information regarding its location in the past and its mobility information.
- The Request Zone is a geographical region within which the path-finding control packets are permitted to be propagated.
- This area is determined by the sender of a data transfer session.
- The control packets used for path finding are forwarded by nodes which are present in the Request Zone and are discarded by nodes outside the zone.
- LAR uses flooding, but here flooding is restricted to a small geographical region.
- The node decide to forward or discard the control packets based on two algorithms, namely LAR1 and LAR2.
- In the LAR1 Algorithm figure 1, the source node explicitly specifies the RequestZone in the RouteRequest packet which is broadcast to its neighbors.
- These node verify their own geographical location to check whether they belong to the Expected Zone.

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- Finally, when the Route Request packet reaches the destination node, it originates a Route Reply that contain the current location and current time of the node.
- In LAR2 Algorithm (fig: 2) the source node includes the distance between itself and the destination node.
- When the intermediate node receives this Route Request packet it computes the distance to the node D. [Note: This distance should be less than previous one]
- A Route Request packet is forwarded only once and the distance between the forwarding node and D is updated in the Route Request packet for further relaying.

Example: Let consider the distance b/w source node 1 and destination node 8 is 3 hop distance. with in three hop, the Route Request has to reach the destination. otherwise that packet is discarded. Once the Route request reach the destination, it reply with Route Reply path back to source node.

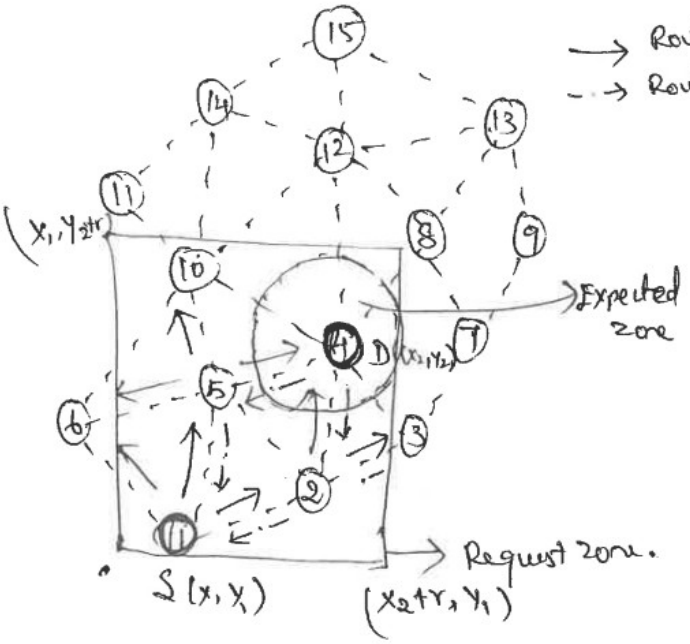


fig: 1 Request zone and Expected zone in LAR1

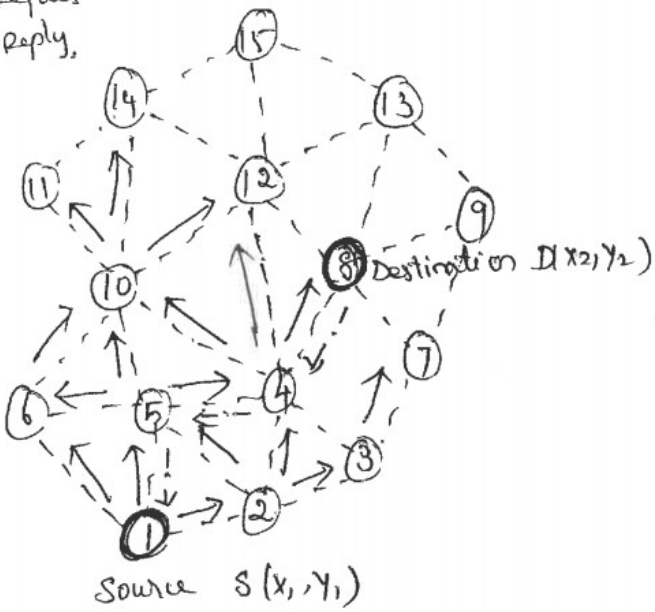


fig: 2 Route establishment in LAR2

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Advantage:

- LAR reduces the control overhead by limiting the search area for finding a path.
- Efficient use of geographical position information
- Reduced control overhead.
- Increased Utilization of bandwidth.

Disadvantage:

- Depends heavily on the availability of GPS infrastructure
- Hence, cannot be used in situations where there is no access to such information.

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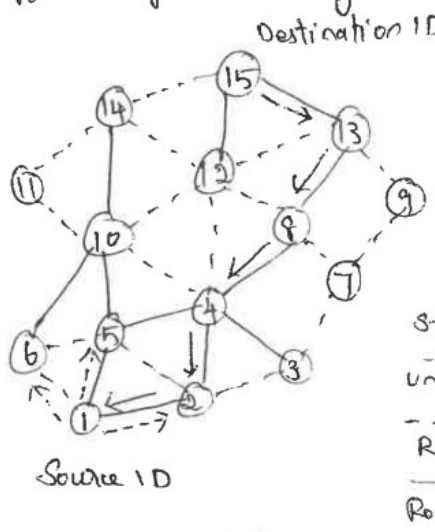
Associativity – Based Routing (ABR):

- It is a distributed routing protocol that selects routes based on the stability of the wireless links.
- It is a beacon-based on-demand routing protocol.
- A link is classified as stable or unstable based on its temporal stability. The temporal stability is determined by counting the periodic beacons that a node receives from its neighbors.
- Each node maintains the count of its neighbor's beacons and classifies each link as stable or unstable.
- The link corresponding to a stable neighbor is termed as a stable link, while a link to an unstable neighbor is called an unstable link.
- A source node floods RouteRequest packets throughout the network. if, a route is not available in its route cache.

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- All intermediate nodes forward the RouteRequest packet.
- A RouteRequest packet carries the path it has traversed and the beacon count for the corresponding nodes in the path.
- When the first RouteRequest reaches the destination, the destination waits for a time period T to receive multiple RouteRequest through different path.
- If two path have the same proportion of stable links, the shorter of them is selected. If more than one path is available, then a random path among them is selected as the path between source & destination.



Selected path = 1-2-4-8-13-15

fig: Route Establishment in ABR

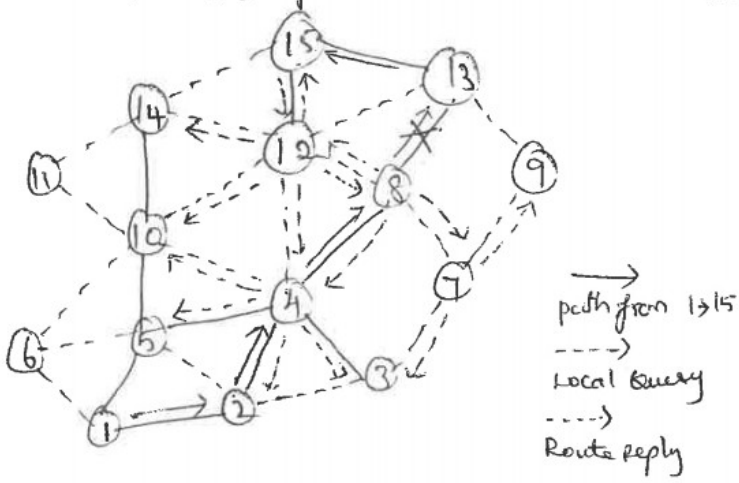


fig: Route Maintenance in ABR

- In figure, Soure node initiates the RouteRequest to the flooded for finding a route to the destination.
- Solid line represent stable links and Dotted line represent unstable links
- ABR forward RouteRequest packet to all node in the network.
- It uses stability information only during the route selection process at the destination node.
- ABR gives more priority to stable routes than to shorter routes. So, The selected path is 1-2-4-8-13-15.
- If a link break occurs at an intermediate node, the node

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The node closer to the source, which detects the break, initiate (Query) local route repair process.

- In this process the Node locally broadcast a local query (= packet with a limited time to live as shown in figure. [Here the TTL value is 2.]
- This way a broken link is bypassed locally without flooding a new Route Request packet in the whole network.
- Consider the figure, The path between 8 and 13 is broken. So node 8 initiates a local Query packet and broadcast in order to locally repair the broken path.
- The broken path is repaired locally by bypassing the path segment 8-13-15 through segment 8-12-15.

Advantages:

- stable routes have a higher preference compare to shorter routes
- They result in fewer path breaks which, in turn, reduces the extent of flooding due to reconfiguration of path in the network.

Disadvantage:

- Chosen path may be longer than the shortest path between the source and destination because of the preference given to stable paths
- Repetitive LQ broadcast may result in high delays during route repairs.

Signal Stability - Based Adaptive Routing Protocol (SSA):

- Uses Signal stability as the prime factor for finding path.
- This protocol is beacon-based, in which signal strength of the beacon is measured for determining link stability.

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- The signal strength is used to classify a link as stable or unstable.
- This protocol consist of two part : Forwarding protocol (FP) and dynamic routing Protocol (DRP).
- These protocols use an extended radio interface that measures the signal strength from beacons.
- DRP maintains the routing table by interacting with the DRP processes on other hosts.
- FP performs the actual routing to forward a packet on its way to the destination.
- every node maintains a table that contains the beacon count and the signal strength of each of its neighbors.
- If a node receives strong beacons, then link is classified as strong/stable link, otherwise weak/unstable link.
- Every node maintains a table called the signal stability table (SST) which is based on the signal strength of its neighbor's beacons.
- This table is used by the nodes to forward the incoming Route Request over strong links for finding the most stable end to end path.
- A source node floods the Route Request packet throughout the network to find the path to destination.
- SSA protocol process a RouteRequest only if it is received over a strong link.
- A RouteRequest received through a weak link is dropped without being processed.
- The destination selects the first RouteReply Request packet received over strong links,
- The destination initiates a RouteReply packet to notify the selected

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route to the Source.

- In figure, Source node broadcasts a RouteRequest for finding the route to the destination.
- Solid lines represents the stable links and Dotted lines are unstable link
- SSA restricts intermediate node from forwarding a RouteRequest packet if the packet has been received over a weak link.
- When a link breaks, the end nodes of the broken link notify the corresponding end nodes of the path.
- A Source node, after receiving a route break notification packet, rebroadcast the RouteRequest to find another stable path to the destination
- Stale entries are removed only if data packets that use the stale route information fail to reach the next node.
- If no strong path is available when a link gets broken, then the new route is established by considering weak links also.
- This is done when multiple RouteRequest attempts fail to obtain path to the destination using only the stable links.

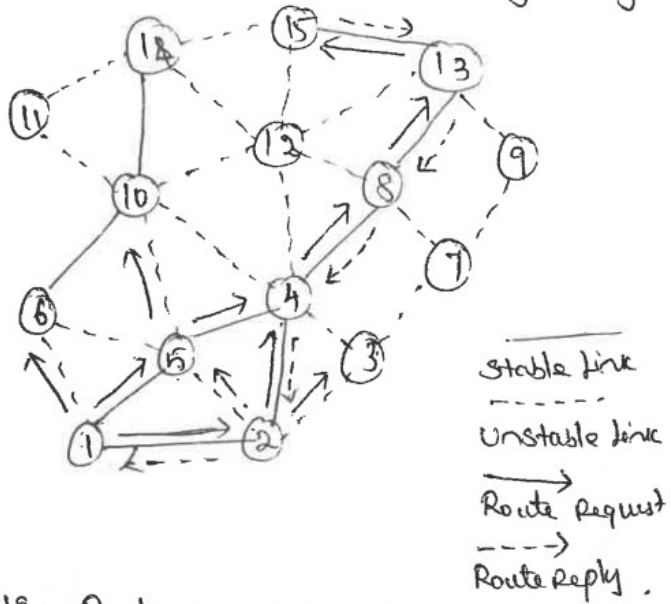


Fig: Route Establishment in SSA

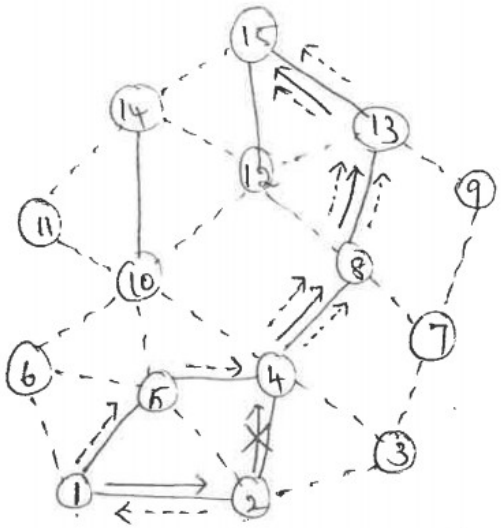


Fig: Route Maintainability in SSA.

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Advantages:

- Find more stable routes when compared to the shortest path route selection protocols.
- Accomodates temporal stability by using beacon counts to classify a link as stable or weak.

Dis Advantage:

- It puts a strong RouteRequest forwarding condition which results in RouteRequest failures.
- Multiple flooding of RouteRequest forwarding condition which results in & consumes significant amount of bandwidth.
- Increase the path setup time.
- Strong link criterion increases the path length.

Flow oriented Routing Protocol (FORP):

- It is a on-demand based Routing Protocol
- Employs a prediction-based multi-hop-hand off mechanism for supporting time-sensitive traffic in ad-hoc wireless networks
- this protocol has been proposed for IPV6-based ad-hoc wireless networks where quality of service needs to be provided.
- The multi-hop-handoff is aimed at alleviating the effects of path breaks on the real time packet flows.
- FORP utilizes the mobility and location information of nodes to estimate the link Expiration time (LET).
- LET is the approximate lifetime of a given wireless link.
- The minimum of the LET values of all wireless links on a path is termed as the route Expiry time (RET).

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- Every node is assumed to be able to predict the LET of each of its links with its neighbors.
- The LET between two nodes can be estimated using information such as current position of the nodes, Mobility of nodes with Direction.
- FORP requires the availability of GPS information in order to identify the location of nodes.
- When a sender node needs to set up a real-time flow to a particular destination, it checks its routing table for the availability of a route to that destination. If a route is available, then that is used to send packets to the destination.
- Otherwise, the sender broadcasts a flow-REQ packet carrying information regarding the source and destination nodes.
- The flow-REQ packet also carries a flow identification number/ sequence number which is unique for every session.
- A neighbor node, on receiving this packet, first checks if the sequence number of the received Flow-REQ is higher than the sequence number corresponding to previous packet.
- If the sequence number on the packet is less than that of the previous packet, then the packet is discarded.
- This is done to avoid looping of flow-REQ packets.
- Before forwarding a flow-REQ, the intermediate node appends its node address and LET of the last link packet had traversed onto the packet.
- Flow-REQ packet, when received at the destination node, contains the list of the nodes on the path it had traversed, along with the

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LET value of every wireless link on that path.

• The LET of the Link can be estimated given the information about the location, velocity and transmission range of the nodes concerned

• The LET of the wireless link between two nodes a and b with transmission range T_x with moving velocity V_a and V_b at angle T_a and T_b. Then,

$$LET_{ab} = \frac{-(pq+rs) + (p^2+r^2)T_x^2 - (ps-qr)^2}{p^2+q^2}$$

where

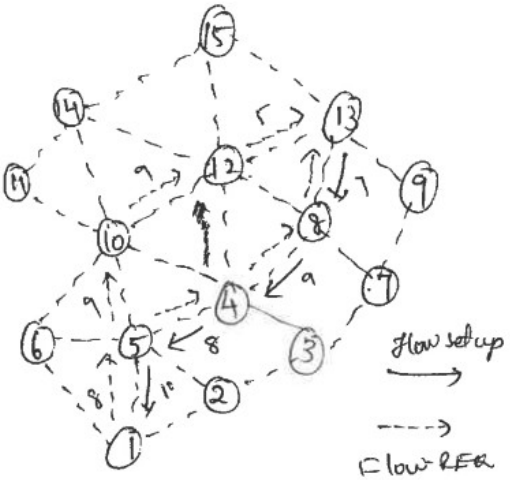
$$p = V_a \cos T_a - V_b \cos T_b$$

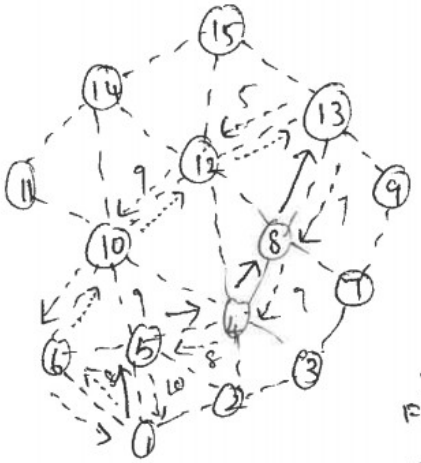
$$q = X_a - X_b$$

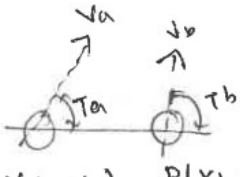
$$r = V_a \sin T_a - V_b \sin T_b$$

$$s = Y_a - Y_b.$$

• FORP assumes all the nodes in the network to be synchronized to a common time by means of GPS information







Calculation of LET

path A : 1-5-10-12-13

path B : 1-5-4-8-13.

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Advantage:

- Use of LET and RET estimates reduces path breaks.
- Reduces the reduction in packet delivery
- Reduces number of out of order packet

Disadvantage:

- Requirements of time synchronization increases the control overhead
- Dependency on GPS infrastructure affects the operability of the protocol whenever it is not available.

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HYBRID ROUTING PROTOCOLS:

Here, each node maintains the network topology information up to m hops.

Core Extraction Distributed Ad-hoc Routing Protocol (CEDAR):

- CEDAR integrates routing and support for QoS.
- It is based on Extracting core nodes (also called as Dominator nodes) in the network.
- Core nodes together approximate the minimum Dominating set (DS)
- A dominating set (DS) of a graph is defined as a set of nodes the every node in the graph is either in the DS or is a neighbor of some node in the DS.
- There exists at least one core node within every three hop
- The nodes that choose a core node as their dominating node are called core member nodes of the core node concerned.

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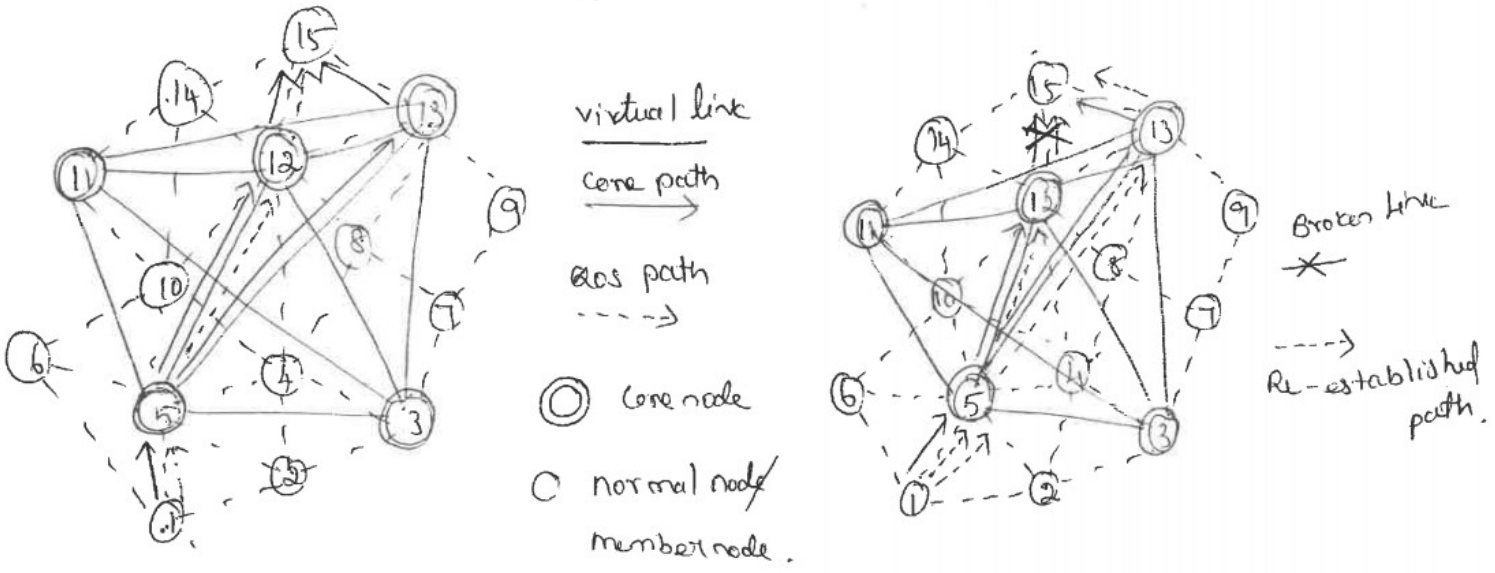
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- CEDAR employs a distributed Algorithm to select core nodes.
- The selection of core nodes represents the core extraction phase.
- CEDAR uses the core broadcast mechanism to transmit any packet throughout the network in the unicast.
- The path between two core nodes is termed as virtual link.
- Route Establishment in CEDAR:

It is carried out in two phase.

→ First phase: Finding a core path from the source node to the destination

→ Second phase: Finding a QoS feasible path over the core path



First phase

- A node initiates a Route Request if the destination is not in the local topology table of its core node, otherwise the path is immediately established.
- Source Core node broadcast to send Route Request to neighboring core nodes.
- The recipient core node forwards the Route Request to its neighboring Core nodes if the destination is not its core member.

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- A core node which has the destination as its core member replies to the source core.

Second phase:

- Once the core path is established, a path with the requested QoS support is then chosen.

Route Maintenance in CEDAR:

- CEDAR attempts to repair a broken route locally when a path break occurs
- A node after which the break occurred:
  - → Sends a notification of failure
  - → Begin to find a new path from it to the destination
  - → Rejects every received packet till the moment it finds the new path to the destination
- Meanwhile, as the source receives the notification message.
  - → It stops to transmit
  - → Tries to find a new route to distination
  - → If new route is found by either of these two nodes, a new path from the source to the destination is established.

Advantages:

- Utilization of core nodes reduces traffic overhead.
- Core broadcasts provide a reliable mechanism for establishing path with QoS support.

DisAdvantage:

- Since route establishment is carried out at core nodes, the movement of core nodes adversely affects the performance of the proto

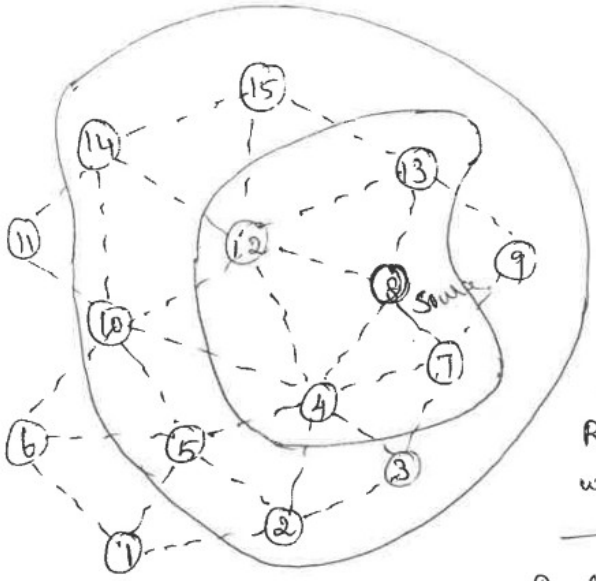
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- Core node update information causes control overhead.

Zone Routing Protocol: [ZRP]

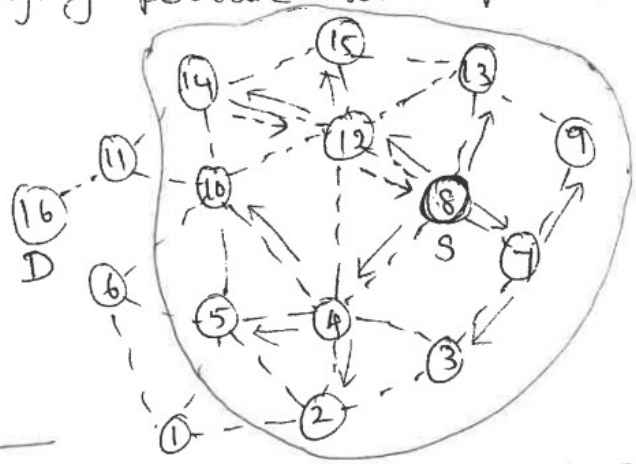
- ZRP effectively combines the best features of both proactive and reactive protocols.
- It uses a proactive protocol within a limited zone. and it uses a Reactive routing scheme for nodes beyond this zone,
- An Intra-zone routing protocol is used in the zone where a particular node employs proactive routing.
- An Inter-zone routing protocol is used beyond the zone where a particular node employs Reactive routing.
- In proactive scheme, each node maintain routing path to all node in the routing zone by exchanging periodic route update packets.



Routing zone with Radius 1

Route Request with Radius 2

Fig: Routing zone for node 8 in ZRP.



Routing zone for node 8.

→ Route Request

--> Route Reply.

fig: path finding between node 8 and node 16

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Route Establishment :

- when a node s (node-8) has packet to be sent to a destination node d (node-16), it checks whether node d is within its zone.
- If the destination belongs to its own zone, then it delivers the packets directly.
- Otherwise, node s broadcasts the RouteRequest to its peripheral nodes (In fig. node 8 broadcasts RouteRequest to node 2, 3, 5, 7, 9, 10, 13, 14 and 15)
- If any peripheral node finds node-d to be located within its routing zone, it sends a routereply back to node 8 indicating the path; otherwise, the node rebroadcast the RouteRequest packet to the peripheral nodes.
- This process continues until node d is located.
- During RouteRequest propagation, every node that forwards the RouteRequest appends its address to it.
- This information is used for delivering RouteReply packet back to the source.
- The critoria for selecting the best path may be the shortest path, least delay path etc.
- When an intermediate node in an active path detects a broken link in the path, it performs a local path reconfiguration in which the broken link is bypassed by means of a short alternate path connecting the ends of the broken link.
- A path update message is then sent to the sender node.
- This result in sub-optimal path between two end points.

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Advantage:

Reduce control overhead by combining the best features of proactive and Reactive protocols.

Dis Advantage:

Control overhead may increase due to the Large overlapping of node routing zones.

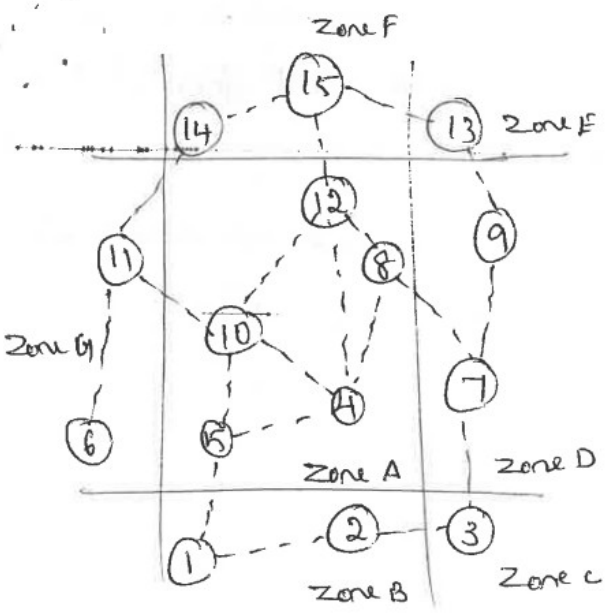
Routing Protocols with efficient flooding Mechanisms:-

Zone Based Hierarchical Link State Routing Protocol (ZHLS):

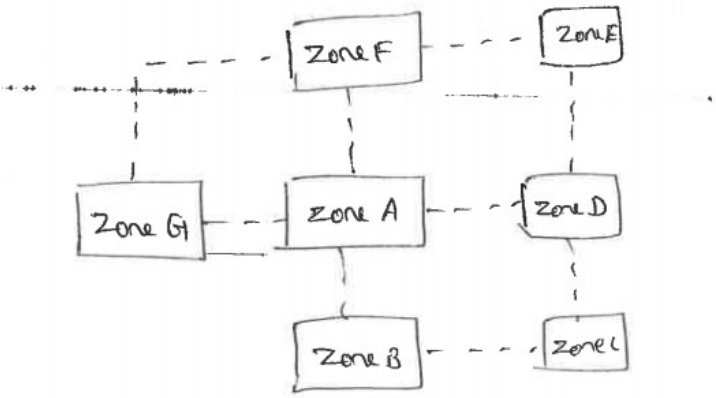
- Each node requires its location information (with GPS), node ID, zone ID and topology inside the zone
- Similar to ZRP, ZHLS also employs a proactive approach inside the geographical zone and a Reactive approach beyond the zone.
- Intra-zone:
  - → The routing table is updated by executing the shortest path algorithm.
  - → The node-Level topology is obtained by using the intra-zone clustering Mechanism.
- Gateway node:
  - → The node receive link responses from nodes belonging to other zone.
  - → Every node in a zone is aware of the neighboring zones and their corresponding Gateway nodes.

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a) Node Level topology in ZHLS



b) Zone topology for the node Level topology in (a)

- Inter-Zone:

– By using zone link state packets, a node can build the zone topology.

– The zone routing table is formed by executing the shortest path algorithm.

Soure Zone	Zone Link state packet
A	B, D, F, G
B	C, A
C	B, D
D	A, C, E
E	A, D, F
F	A, E, G
G	A, F

- When a source node (Src) has packet to be sent to a destination node (Dest),

→ If Destination is in the same zone, the packets are delivered by the intra-zone routing table directly.

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- If Dest. is not in the zone, source generates a location request packet verifies its routing table for Dest. and forward it to every other zone.
- The gateway nodes receiving the location request packet verifies its routing table for Dest. The gateway node which finds Dest in its zone send a location response packet containing the zone information to the soure
- ZHLS reduces the storage requirements and the communication overhead.
- But the creation of zone-level topology incurs the additional overhead. And the paths are not optimal.

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ROUTING PROTOCOLS WITH EFFICIENT FLOODING MECHANISMS:

- Many Protocols flood the network with RouteRequest packets in order to obtain a path to the destination.
- Flooding of control packets results in:
  - Wastage of bandwidth
  - Increase in number of collisions.
- Protocols with efficient flooding mechanisms
  - Preferred link-based routing (PLBR) Protocol.
  - Optimized link state routing (OLSR) Protocol.

Preferred Link Based Routing (PLBR) Protocols:

- The PLBR is a reactive routing protocol which applies particular mechanism to avoid just flooding the network with RouteRequest packets.
- It provides a mechanism where not all the nodes are allowed to forward the received RouteRequest packet. Hence, it

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reduces the control overhead.

- Here every node maintains a table with its neighbors (1
and the neighbor's neighbors (NNT).

- A node selects a subset of nodes from its Neighbors List. This subset is called preferred list (PL). It is based on link or node characteristics.

- All neighbors receive RouteRequest packet because of the broadcast radio channel but only nodes presents in PL forward them further. other will discard it.

- PL is always a subset of PLT where PLT is preferred list table maintained by every node and which contains all neighbors node in order of preference.

PLBR consist of three phases:

Route Establishment, route selection and route Maintenance.

During the first phase of route establishment, the source node s is trying to establish a route to the destination node d. If the node d is in source's NNT, the route is established directly and the information is forwarded to the destination. If it is not, source initiates a Route-Request packet which contains:

- Source node's address: Source ID
- Destination node's address: Destination ID
- Unique Sequence number: avoid duplicate RouteRequest packets.
- Traversed path: TP, which indicates the nodes that have been visited so far by the packet.
- Preferred list: PL, is the list of nodes determined by the sender node as eligible to forward the RouteRequest packet
- Time to live (TTL) field: Duration of packet existence in the network.

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- The RouteRequest packet is always broadcast to all node's neighbors.
- However, not all these nodes are considered to be eligible to forward the packet further, only node which in PLT can forward packets.
- It not to have forwarded the same packet again and the TTL value must be greater than zero.
- If the node satisfies all these requirements, it can forward the packet to all its neighbor nodes.
- Before broadcasting the packet however, the node checks whether the destination node is in its NT(r)-NTT. If it is, it unicasts the packet directly to the neighbor in its NT. otherwise, the packet will be broadcasted with new PL and new parameter.
- Every time, before forwarding the RouteRequest Packet, the node that receives the RouteRequest packet updates its PLT in the PL field of the packet.

Route Selection:

- As soon as the destination node is detected, the route selection Procedure is followed.
- When multiple RouteRequest packet reaches the destination, The selection of best route can be the shortest path, or the least delay path or the most stable path.
- After receiving the first RouteRequest packet, the destination node starts a timer which indicates for how long it will be receiving RouteRequest packets from the network. After timer expired, no more RouteRequest packets are received by the destination node and the route selection phase can start.

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- Finally in order to deal with the link breaks, PLBR uses a particular mechanism to achieve optimal route maintenance.
- PLBR uses a quick route repair mechanism to bypass the broken link using information about the next two hops from NNT.

Algorithms for preferred link computation:

Every time the node receives RouteRequest packet, it has to determine its own preferred list of eligible nodes and to replace the the received with the new one. Two different algorithms have been proposed for the selection of eligible nodes.

1. Neighbor-Degree-Based preferred link Algorithm (NDPL)
2. Weigh Based preferred link Algorithm (WBPL).

Neighbor Degree-based Preferred Link Algorithm is based on neighbor node's degree. Degree of a node is the number of its neighbor. The Algorithm is executed for one node and takes under consideration parameters that have to do with the degree of its neighbor nodes.

After the execution of the Algorithm, two lists are created: INL and EXL. INL - Include List contains a set of neighbors which are considered as reachable for forwarding the Route Request packet.

EXL is the Exclude List which contain the set of neighbor nodes which are considered as unreachable.

On the other hand, Weight-based preferred link algorithm is based on the weight given to a node, which in turn is based on its neighbor's temporal and spatial stability.

Temporal stability has to do with a particular time period in which it is communicating with its neighbors.

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- which while spatial stability has to do with the distance estimation from the strength of the signal received from its neighbor
- In both algorithms a preferred list table PLT is created with nodes being set in order of preference.
- After this step, a node can choose k first nodes from PLT and to create its preferred list (PL).

The efficient flooding mechanism used in both PLBR and WBPL reduces the routing control overhead and provides better solution than the other reactive protocol.

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Optimized Link State Routing Protocol: (OLSR)

- OLSR protocol is a proactive routing protocol and is based on the link state algorithm.
- This protocol optimizes the pure link state routing protocol.
- Optimizations are done in two ways
  - → By reducing the size of control packets
  - → By reducing the no. of links that are used for forwarding the link state packets.
- Its basic concept is the use of multipoint relaying technique to flood the network with control messages. (MPR).
- Each node in the network selects a set of its neighbors, is called Subset (or) MPRset (Multipoint Relay set).
- These MPRset nodes only can processes and forwards every link state packet.
- The neighbor node that do not belong to MPR-Set process

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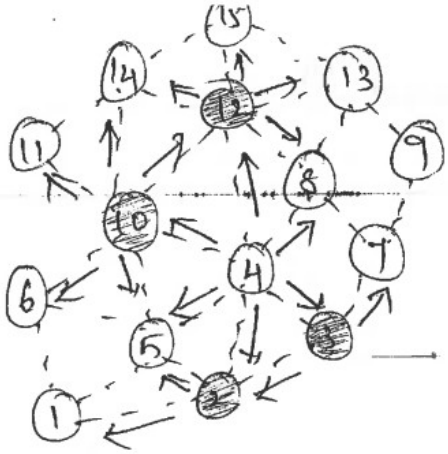
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the link state packet but not forward them.

- Similarly, each node maintains a subset of neighbors called MPR Selectors, which is nothing but the set of neighbors that have selected the node as a multipoint relay.
- In order to decide on the membership of the nodes in the MPR set, a node periodically sends Hello message that contain
  - → List of neighbors with which the node has bidirectional link.
  - → A list of neighbors whose transmission was received in the recent past but with whom bidirectional links have not yet been confirm
- The nodes that receives this Hello packet update their own two-hop topology Table.
- The selection of multipoint relays is also indicated in the Hello packet.
- The Data Structure called neighbor table is used to store the list of neighbors, the two-hop neighbors and the status of neighbor nodes.
- The neighbor node can be in one of the three possible link Status (ie) unidirectional, bidirectional and multipoint relay.
- Every node maintain a topology table about the network topology control in order to establish routes to destination nodes.
- That is why every node broadcasts topology control (TC) message which contain the MPR set of every node.
- Every node receives this, update its topology table with this info.
- So using this topology table node can reach every other node in the network.

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node H selects MPRset < 2, 3, 10, 12 >

node H in MPRselector.

Advantages:

- Reduces the routing overhead
- Reduces the no. of broadcast done
- Hence Low connection

Hierarchical Routing Protocols:

The use of routing hierarchy has several Advantages.

→ Reduction in size of routing tables

→ better Scalability.

Hierarchical State Routing Protocol: (HSR)

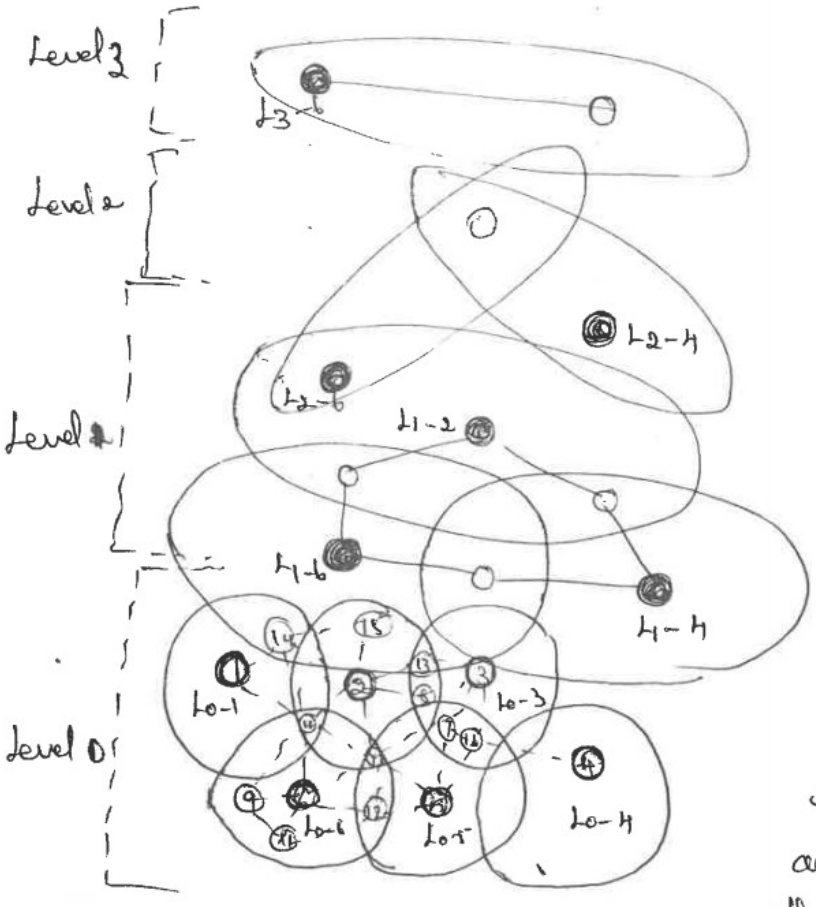
- HSR protocol is a distributed multi-level hierarchical routing protocol that employs clustering at different levels with efficient membership management at every level of clustering.
- The use of clustering enhances resource allocation and Management.
- For example, the allocation of different frequencies or spreading codes to different clusters can improve the overall spectrum reuse.
- HSR operates by classifying different levels of clusters.

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- Each cluster has its Leader.
- Clustering is organized in Levels:
  - The first Level is physical clustering. It is done among th nodes that are reachable in a single wireless hop.
  - The next higher level of physical clustering is done among t nodes that are elected as leaders of each of these first level cluste
  - In addition to the physical clustering, a logical clusteri scheme has been proposed in HSR. It is based on certain relations among the nodes rather than on their geographical position.

Figure illustrate the multilayer clustering defined by the HSR Protocol. At the lowest level (L=0), there are six cluster leaders (node 1, 2, 3, 4, 5, 6). Nodes are classified as cluster leaders, gateways, normal memb



- In figure, node 5 is a cluste head marked as L0-5. (ie) level is zero, node ID is 5.
- Similarly, each of the higher level cluster leaders is also marke with level ID and node ID ex: L2-6 means level 2, node ID=
- Every node maintains information about all its neighbors and the status of links to each of them

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- This information is broadcast within the cluster at regular intervals.
- The cluster Leaders exchanges the topology and link state routing information among its peers in the neighborhood clusters. The path b/w two Cluster-head virtual path.
- The hierachical addressing defined in HSR includes the hierarchical ID (HID) and node ID.
- The HID is a sequence of IDs of cluster Leaders of all levels starting from the highest level to the current node.
- Example: The hierachical address of node 11 in figure is 6-6-6-6-11. where 11 is node ID, remaining all HID.

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Fish-Eye state Routing Protocol: (FSR)

- FSR uses the fisheye technique to reduce the routing overhead.
- The basic principle behind this technique is the property of a fish's eye that can capture pixel information with greater accuracy near its eye's focal point. This accuracy is decreases with an increase in the distance from the center of the focal point.
- This property used in Routing Protocol.
- Each node maintain accurate information about near nodes in its local topology and not so accurate information about far away nodes. The accuracy of the network information decreasing with increasing distance.
- FSR maintain the topology of the network at every node, but not flood the entire network

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- Instead of flooding, a node exchange topology information only with its neighbors.

- FSR defines routing scope, which is the set of nodes that are reachable in a specific number of hops. The scope of a node at two hops is the set of nodes that can be reached in two hops. Figure shows the scope of node 5 with two hops and one hop.

- The routing overhead is significantly reduced by adopting different frequencies of updates for nodes belonging to different scopes.

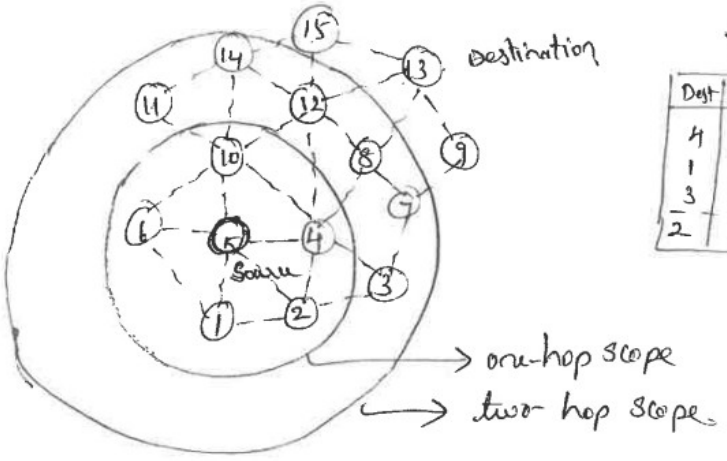
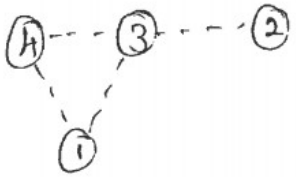


Fig1: Fisheye state routing

Topology table for node 4

Dest	neigh.	hop
4	1,3	0
1	4,3	1
3	4,1	1
2	3	0



Topology info. node - 2

Dest	neighbor	hops
2	3	0
3	1,2,4	1
1	3,4	2
4	1,3	2

Topology Info. of node 1

Dest	Neighbor	Hops
1	3,4	0
3	1,2,4	1
4	1,3	1
2	3	2

Fig2: Routing tables in FSR.

- The link state info for the nodes belongs to the smallest scope is exchanged at the highest frequency. Frequency of exchanges decreases with an increases in scope.

- This keeps the immediate neighborhood topology information maintained at a node more precise compared to the information about the nodes farther.

- The path information for a distant node may be inaccurate as there can be staleness in the information. But this is compensated by the fact that the route gets more and more accurate as the packet nears its destination.

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- figure 2 illustrate an example depicting the network topology information maintained at nodes in a network.

- The routing information for one hop distance nodes are exchanged more frequently than the routing information about nodes that are more than one hop away.

- The Information regarding nodes that are more than one hop away from the current node are listed below the dotted line in the topology table.

Advantage:

- Reduce bandwidth consumption
- Suitable for large and highly mobile adhoc wireless Networ

Disadvantage:

- very poor performance in small adhoc networks.

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Power - Aware Routing Protocols:

Power - aware Routing Metrics:

The limitation on the availability of power of operation is a significant bottle neck. Hence, the use of routing metrics contributes to the efficient utilization of energy and increases the lifetime of the network.

- Minimal energy consumption per packet

→ This metric aims at minimizing the power consumed by a packet in traversing from source node to the destination node.

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