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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT - I

ADHOC NETWORKS –INTRODUCTION AND ROUTING PROTOCOLS

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Chapter 7

ROUTING PROTOCOLS FOR AD HOC WIRELESS NETWORKS

7.1 INTRODUCTION

An ad hoc wireless network consists of a set of mobile nodes (hosts) that are connected by wireless links. The network topology (the physical connectivity of the communication network) in such a network may keep changing randomly. Routing protocols that find a path to be followed by data packets from a source node to a destination node used in traditional wired networks cannot be directly applied in ad hoc wireless networks due to their highly dynamic topology, absence of established infrastructure for centralized administration (*e.g.*, base stations or access points), bandwidth-constrained wireless links, and resource (energy)-constrained nodes. A variety of routing protocols for ad hoc wireless networks has been proposed in the recent past. This chapter first presents the issues involved in designing a routing protocol and then the different classifications of routing protocols for ad hoc wireless networks. It then discusses the working of several existing routing protocols with illustrations.

7.2 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, resource constraints, error-prone channel state, and hidden and exposed terminal problems. A detailed discussion on each of the following is given below.

7.2.1 Mobility

The network topology in an ad hoc wireless network is highly dynamic due to the movement of nodes, hence an on-going session suffers frequent path breaks. Disruption occurs either due to the movement of the intermediate nodes in the

path or due to the movement of end nodes. Such situations do not arise because of reliable links in wired networks where all the nodes are stationary. Even though the wired network protocols find alternate routes during path breaks, their convergence is very slow. Therefore, wired network routing protocols cannot be used in ad hoc wireless networks where the mobility of nodes results in frequently changing network topologies. Routing protocols for ad hoc wireless networks must be able to perform efficient and effective mobility management.

7.2.2 Bandwidth Constraint

Abundant bandwidth is available in wired networks due to the advent of fiber optics and due to the exploitation of wavelength division multiplexing (WDM) technologies. But in a wireless network, the radio band is limited, and hence the data rates it can offer are much less than what a wired network can offer. 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. Due to the frequent changes in topology, maintaining a consistent topological information at all the nodes involves more control overhead which, in turn, results in more bandwidth wastage. As efficient routing protocols in wired networks require the complete topology information, they may not be suitable for routing in the ad hoc wireless networking environment.

7.2.3 Error-Prone Shared Broadcast Radio Channel

The broadcast nature of the radio channel poses a unique challenge in ad hoc wireless networks. The wireless links have time-varying characteristics in terms of link capacity and link-error probability. This requires that the ad hoc wireless network routing protocol interacts with the MAC layer to find alternate routes through better-quality links. Also, transmissions in ad hoc wireless networks result in collisions of data and control packets. This is attributed to the hidden terminal problem [1]. Therefore, it is required that ad hoc wireless network routing protocols find paths with less congestion.

7.2.4 Hidden and Exposed Terminal Problems

The hidden terminal problem refers to the collision of packets at a receiving node due to the simultaneous transmission of those nodes that are not within the direct transmission range of the sender, but are within the transmission range of the receiver. Collision occurs when both nodes transmit packets at the same time without knowing about the transmission of each other. For example, consider Figure 7.1. Here, if both node A and node C transmit to node B at the same time, their packets collide at node B. This is due to the fact that both nodes A and C are hidden from each other, as they are not within the direct transmission range of each other and hence do not know about the presence of each other. Solutions for this problem include medium access collision avoidance (MACA) [2], medium ac-

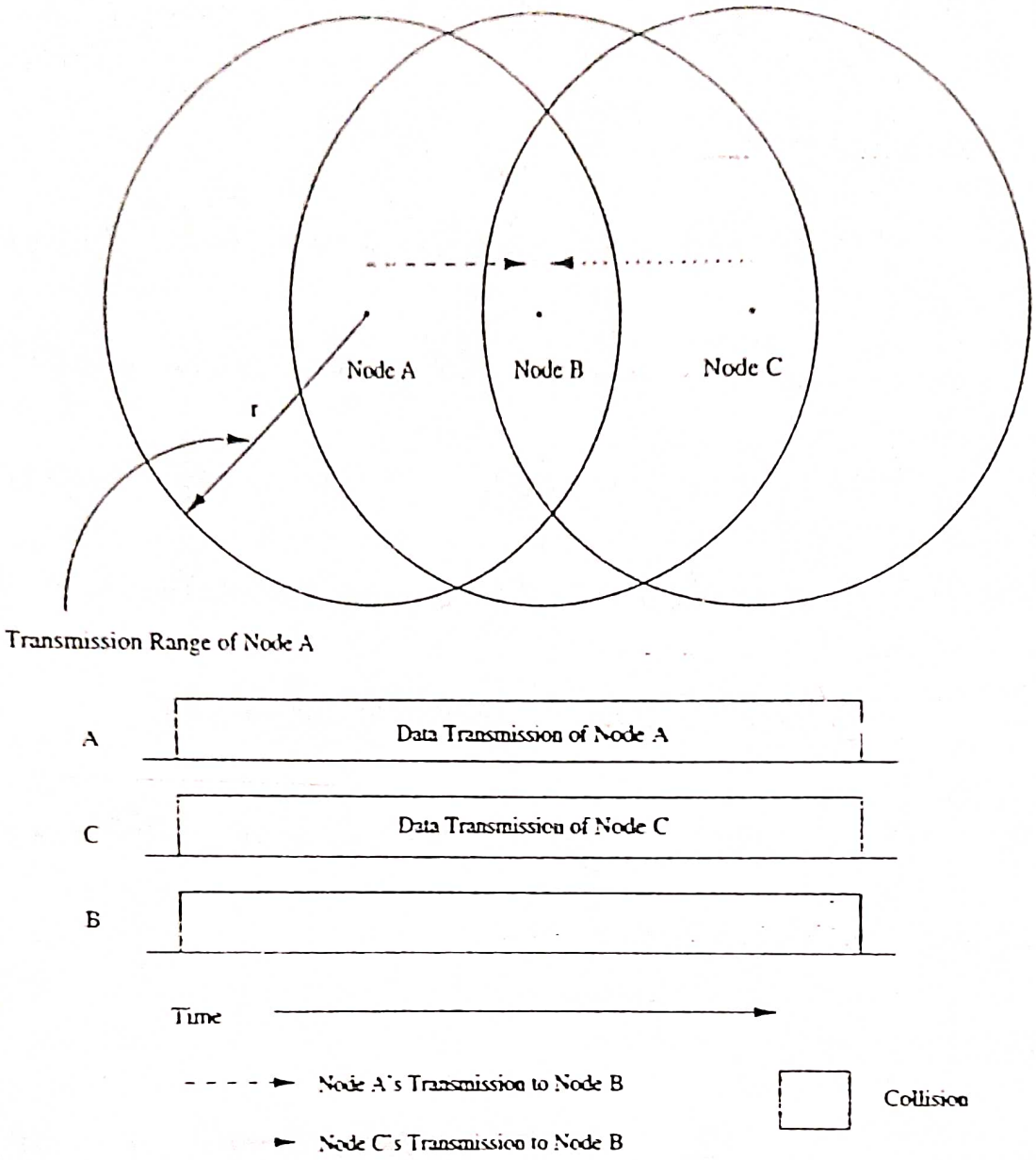


Figure 7.1. Hidden terminal problem.

cess collision avoidance for wireless (MACAW) [3], floor acquisition multiple access (FAMA) [4], and dual busy tone multiple access (DBTMA) [5]. MACA requires that a transmitting node first explicitly notifies all potential hidden nodes about the forthcoming transmission by means of a two-way handshake control protocol called the RTS-CTS protocol exchange. Note that this may not solve the problem completely, but it reduces the probability of collisions. To increase the efficiency, an improved version of the MACA protocol known as MACAW [3] has been proposed. This protocol requires that the receiver acknowledges each successful reception of a data packet. Hence, successful transmission is a four-way exchange mechanism, namely, RTS-CTS-Data-ACK. Even in the absence of bit errors and mobility, the RTS-CTS control packet exchange cannot ensure collision-free data transmission

that has no interference from hidden terminals. One very important assumption made is that every node in the capture area of the receiver (transmitter) receives the CTS (RTS) cleanly. Nodes that do not hear either of these clearly can disrupt the successful transmission of the Data or the ACK packet. One particularly troublesome situation occurs when node A, hidden from the transmitter T and within the capture area of the receiver R, does not hear the CTS properly because it is within the capture area of node B that is transmitting and that is hidden from both R and T, as illustrated in Figure 7.2. In this case, node A did not successfully receive the CTS originated by node R and hence assumes that there is no on-going transmission in the neighborhood. Since node A is hidden from node T, any attempt to originate its own RTS would result in collision of the on-going transmission between nodes T and R.

The exposed terminal problem refers to the inability of a node which is blocked due to transmission by a nearby transmitting node to transmit to another node. Consider the example in Figure 7.3. Here, if a transmission from node B to another node A is already in progress, node C cannot transmit to node D, as it concludes that its neighbor, node B, is in transmitting mode and hence should not interfere with

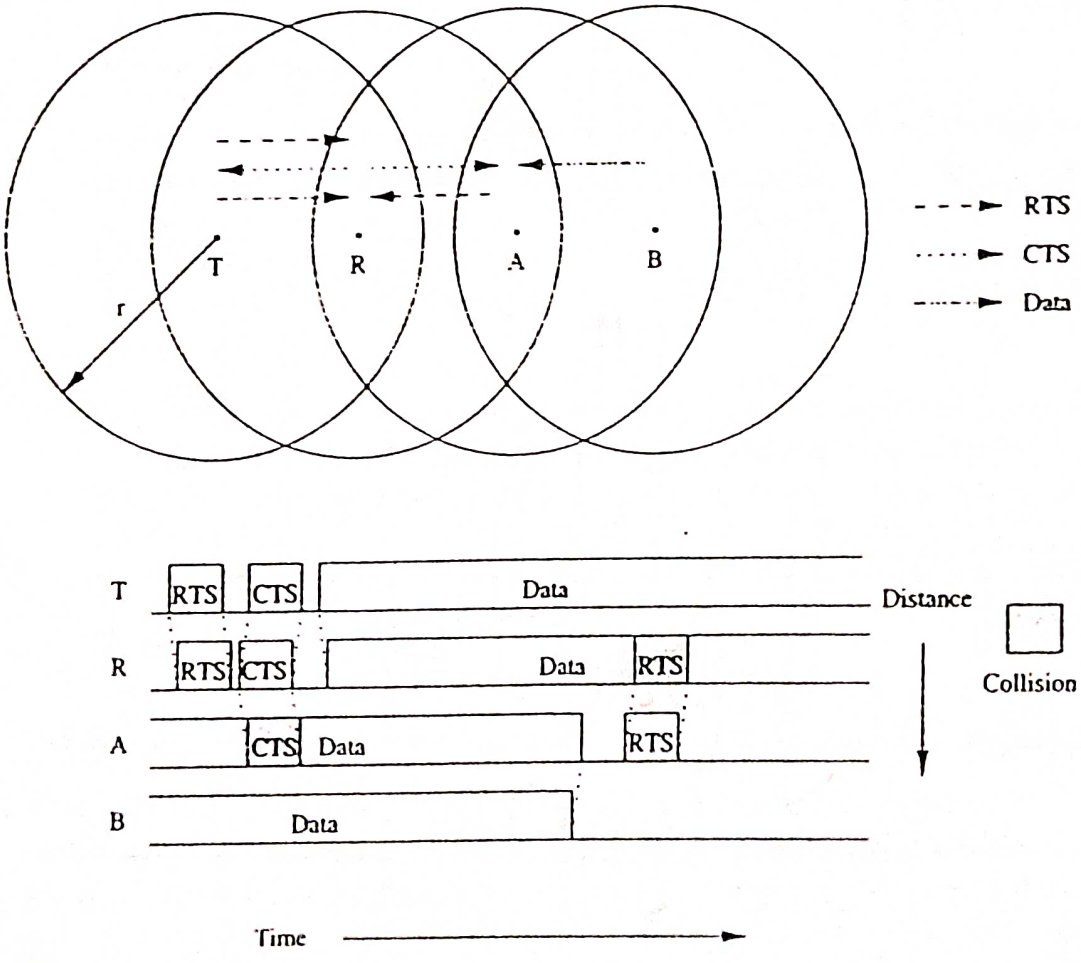


Figure 7.2. Hidden terminal problem with RTS-CTS-Data-ACK scheme.

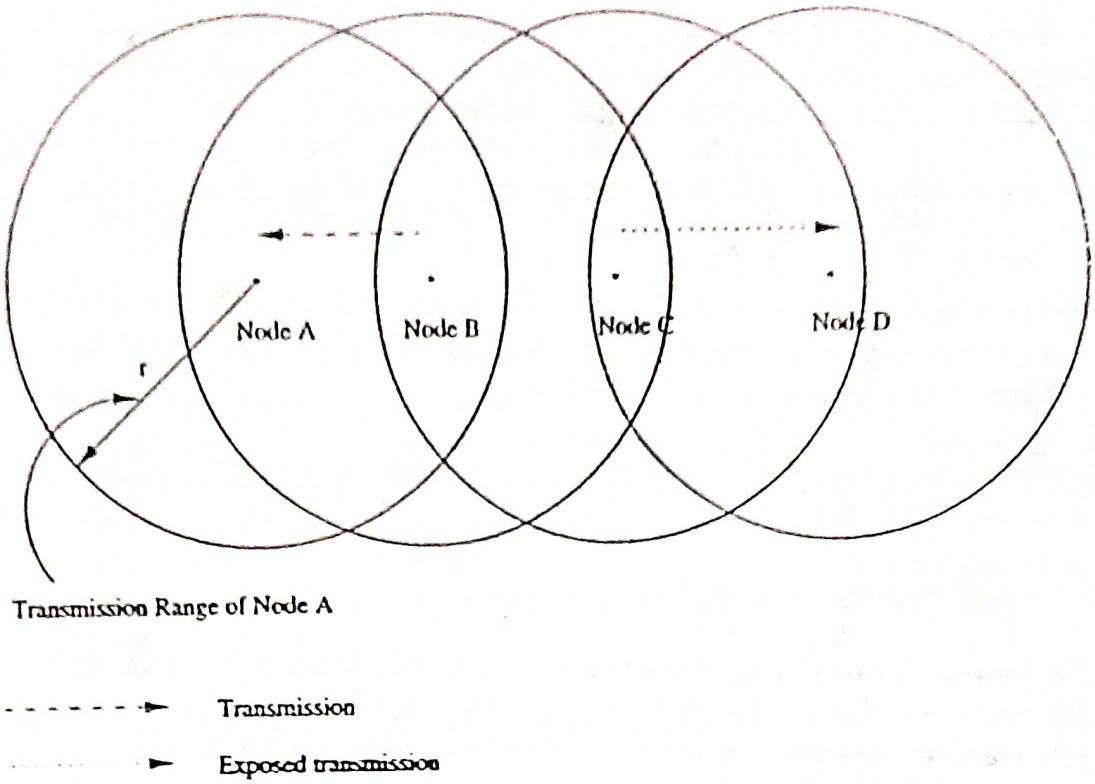


Figure 7.3. Exposed terminal problem.

the on-going transmission. Thus, reusability of the radio spectrum is affected. For node C to transmit simultaneously when node B is transmitting, the transmitting frequency of node C must be different from its receiving frequency.

7.2.5 Resource Constraints

Two essential and limited resources that form the major constraint for the nodes in an ad hoc wireless network are battery life and processing power. Devices used in ad hoc wireless networks in most cases require portability, and hence they also have size and weight constraints along with the restrictions on the power source. Increasing the battery power and processing ability makes the nodes bulky and less portable. Thus ad hoc wireless network routing protocols must optimally manage these resources.

7.2.6 Characteristics of an Ideal Routing Protocol for Ad Hoc Wireless Networks

Due to the issues in an ad hoc wireless network environment discussed so far, wired network routing protocols cannot be used in ad hoc wireless networks. Hence ad hoc wireless networks require specialized routing protocols that address the challenges described above. A routing protocol for ad hoc wireless networks should have the following characteristics:

1. It must be fully distributed, as centralized routing involves high control overhead and hence is not scalable. Distributed routing is more fault-tolerant than centralized routing, which involves the risk of single point of failure.

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

3. Route computation and maintenance must involve a minimum number of nodes. Each node in the network must have quick access to routes, that is, minimum 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 number of packet collisions must be kept to a minimum by limiting the number of broadcasts made by each node. The transmissions should be reliable to reduce message loss and to prevent the occurrence of stale routes.

7. It must converge to optimal routes once the network topology becomes stable. The convergence must be quick.

8. It must optimally use scarce resources such as bandwidth, computing power, memory, and battery power.

9. Every node in the network should try to store information regarding the stable local topology only. Frequent changes in local topology, and changes in the topology of parts of the network with which the node does not have any traffic correspondence, must not in any way affect the node, that is, changes in remote parts of the network must not cause updates in the topology information maintained by the node.

10. It should be able to provide a certain level of quality of service (QoS) as demanded by the applications, and should also offer support for time-sensitive traffic.

7.3 CLASSIFICATIONS OF ROUTING PROTOCOLS

Routing protocols for ad hoc wireless networks can be classified into several types based on different criteria. A classification tree is shown in Figure 7.4. Some of the classifications, their properties, and the basis of classifications are discussed below. The classification is not mutually exclusive and some protocols fall in more than one class. The deviation from the traditional routing metrics and path-finding processes that are employed in wired networks makes it worth further exploration

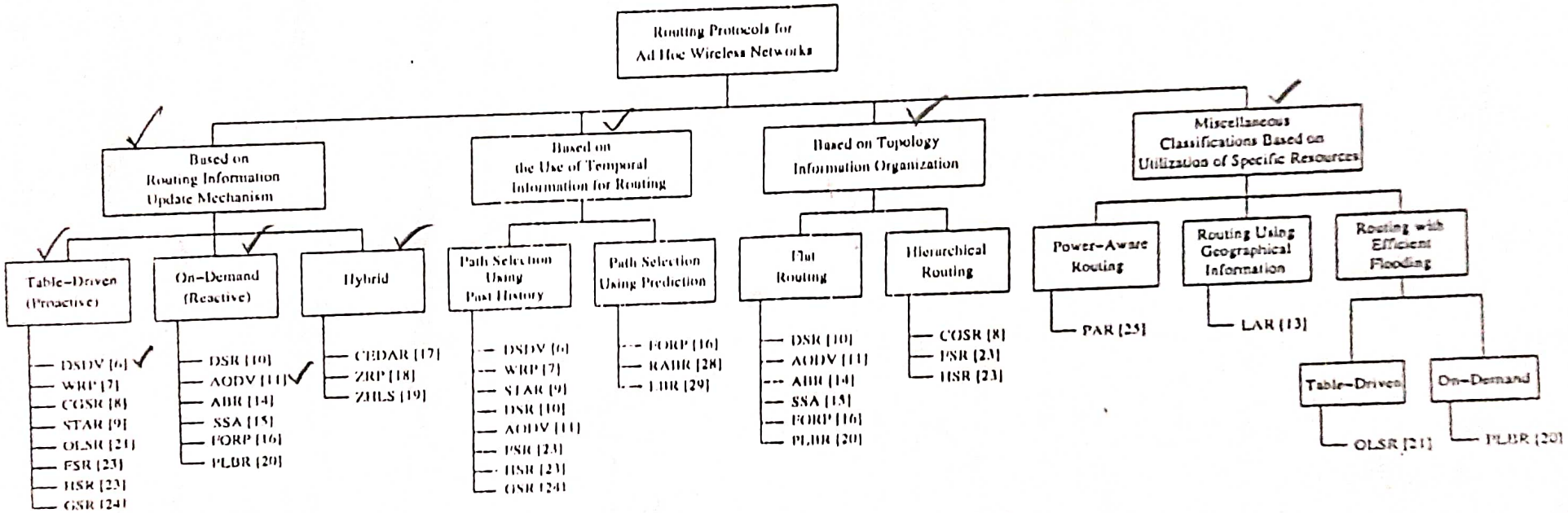


Figure 7.4. Classifications of routing protocols.

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

- Routing information update mechanism
- Use of temporal information for routing
- Routing topology
- Utilization of specific resources

7.3.1 Based on the Routing Information Update Mechanism

Ad hoc wireless network routing protocols can be classified into three major categories based on the routing information update mechanism. They are:

1. **Proactive or table-driven routing protocols:** In table-driven routing protocols, every node maintains the network topology information in the form of routing tables by periodically exchanging routing information. Routing information is generally flooded in the whole network. Whenever a node requires a path to a destination, it runs an appropriate path-finding algorithm on the topology information it maintains. Table-driven routing protocols are further explored in Section 7.4.

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. Some of the existing routing protocols that belong to this category are discussed in Section 7.5.

3. **Hybrid routing protocols:** Protocols belonging to this category combine the best features of the above two categories. Nodes within a certain distance from the node concerned, or within a particular geographical region, are said to be within the routing zone of the given node. For routing within this zone, a table-driven approach is used. For nodes that are located beyond this zone, an on-demand approach is used. Section 7.6 describes the protocols belonging to this category in detail.

7.3.2 Based on the Use of Temporal Information for Routing

This classification of routing protocols is based on the use of temporal information used for routing. Since ad hoc wireless networks are highly dynamic and path breaks are much more frequent than in wired networks, the use of temporal information regarding the lifetime of the wireless links and the lifetime of the paths selected assumes significance. The protocols that fall under this category can be further classified into two types:

1. **Routing protocols using past temporal information:** These routing protocols use information about the past status of the links or the status of links at the time of routing to make routing decisions. For example, the routing metric based on the availability of wireless links (which is the current/present information here) along with a shortest path-finding algorithm, provides a path that may be efficient and stable at the time of path-finding. The topological changes may immediately break the path, making the path undergo a resource-wise expensive path reconfiguration process.

2. **Routing protocols that use future temporal information:** Protocols belonging to this category use information about the expected future status of the wireless links to make approximate routing decisions. Apart from the lifetime of wireless links, the future status information also includes information regarding the lifetime of the node (which is based on the remaining battery charge and discharge rate of the non-replenishable resources), prediction of location, and prediction of link availability.

7.3.3 Based on the Routing Topology

Routing topology being used in the Internet is hierarchical in order to reduce the state information maintained at the core routers. Ad hoc wireless networks, due to their relatively smaller number of nodes, can make use of either a flat topology or a hierarchical topology for routing.

1. **Flat topology routing protocols:** Protocols that fall under this category make use of a flat addressing scheme similar to the one used in IEEE 802.3 LANs. It assumes the presence of a globally unique (or at least unique to the connected part of the network) addressing mechanism for nodes in an ad hoc wireless network.

2. **Hierarchical topology routing protocols:** Protocols belonging to this category make use of a logical hierarchy in the network and an associated addressing scheme. The hierarchy could be based on geographical information or it could be based on hop distance.

7.3.4 Based on the Utilization of Specific Resources

1. **Power-aware routing:** This category of routing 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.

The following section further explores the above classifications and discusses specific routing protocols belonging to each category in detail.

7.4 TABLE-DRIVEN ROUTING PROTOCOLS

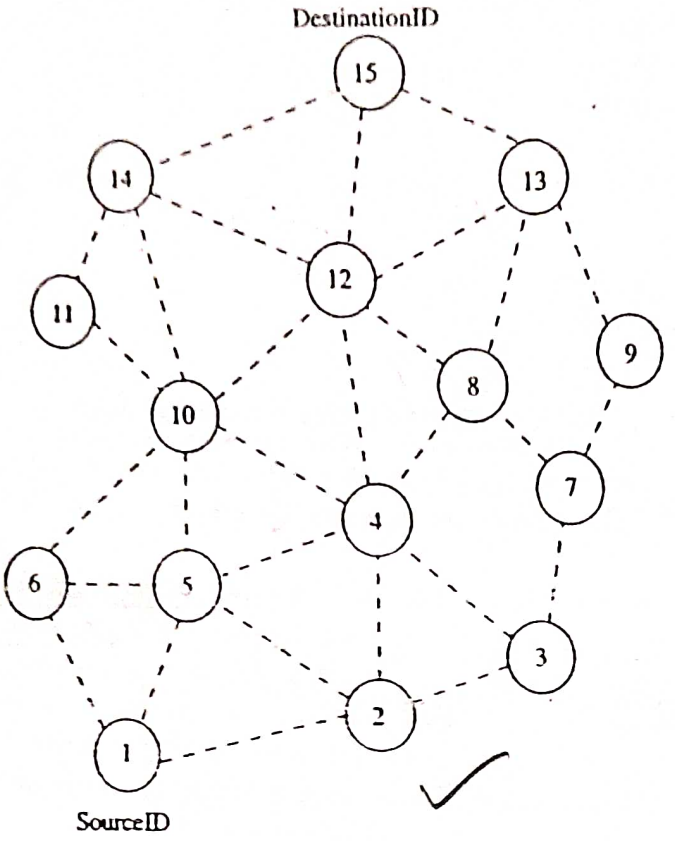
These protocols are extensions of the wired network routing protocols. They maintain the global topology information in the form of tables at every node. These tables are updated frequently in order to maintain consistent and accurate network state information. The destination sequenced distance-vector routing protocol (DSDV), wireless routing protocol (WRP), source-tree adaptive routing protocol (STAR), and cluster-head gateway switch routing protocol (CGSR) are some examples for the protocols that belong to this category.

7.4.1 Destination Sequenced Distance-Vector Routing Protocol

The destination sequenced distance-vector routing protocol (DSDV) [6] is one of the first protocols proposed for ad hoc wireless networks. 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 tables are also forwarded if a node observes a significant change in local topology. The table updates are of two types: incremental updates and full dumps. An incremental update takes a single network data packet unit (NDPU), while a full dump may take multiple NDPUs. Incremental updates are used when a node does not observe significant changes in the local topology. A full dump 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. Upon receiving an updated table, a node either updates its tables based on the received information or holds it for some time to select the best metric (which may be the lowest number of hops) received from multiple versions of the same update table from different neighboring nodes. Based on the sequence number of the table update, it may forward or reject the table. Consider the example as shown in Figure 7.5 (a). Here node 1 is the 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 7.5 (b). Here the routing table of node 1 indicates that the shortest route to the destination node (node 15) is available through node 5 and the distance to it is 4 hops, as depicted in Figure 7.5 (b).

The reconfiguration of a path used by an on-going data transfer session is handled by the protocol in the following way. The end node of the broken link initiates a table update message with the broken link's weight assigned to infinity (∞) and with a sequence number greater than the stored sequence number for that destination. Each node, upon receiving an update with weight ∞, quickly disseminates it to its neighbors in order to propagate the broken-link information to the whole net-



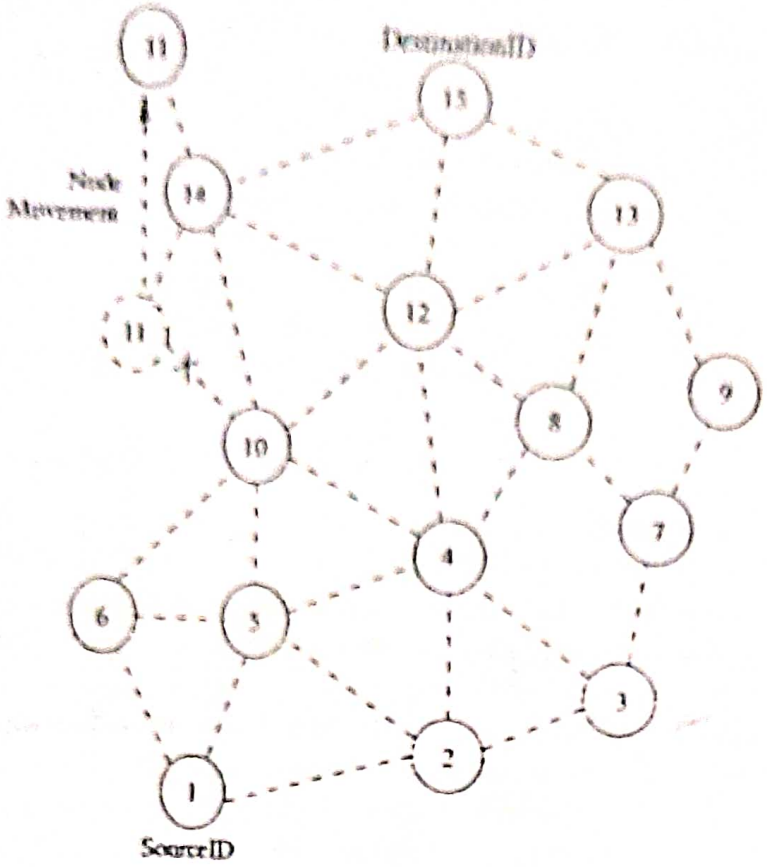
(a) Topology graph of the network

Dest	NextNode	Dist	SeqNo
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

Figure 7.5. Route establishment in DSDV.

work. Thus a single link break leads to the propagation of table update information to the whole network. A node always assigns an odd sequence number to the link break update to differentiate it from the even sequence number generated by the destination. Consider the case when node 11 moves from its current position, as shown in Figure 7.6. When a neighbor node perceives the link break, it sets all the paths passing through the broken link with distance as ∞. For example, when node 10 knows about the link break, it sets the path to node 11 as ∞ and broadcasts its routing table to its neighbors. Those neighbors detecting significant changes in their routing tables rebroadcast it to their neighbors. In this way, the broken link information propagates throughout the network. Node 1 also sets the distance to node 11 as ∞. When node 14 receives a table update message from node 11, it informs the neighbors about the shortest distance to node 11. This information is also propagated throughout the network. All nodes receiving the new update message with the higher sequence number set the new distance to node 11 in their corresponding tables. The updated table at node 1 is shown in Figure 7.6, where the current distance from node 1 to node 11 has increased from three to four hops.



Routing Table for Node 1

Dest	NextNode	Dist	SeqNo
2	2	1	32
3	2	2	28
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 7.6. Route maintenance in DSDV.

Advantages and Disadvantages

The availability of routes to all destinations at all times implies that much less delay is involved in the route setup process. The mechanism of incremental updates with sequence number tags makes the existing wired network protocols adaptable to ad hoc wireless networks. Hence, an existing wired network protocol can be applied to ad hoc wireless networks with many fewer modifications. The updates are propagated throughout the network in order to maintain an up-to-date view of the network topology at all the nodes. The updates due to broken links lead to a heavy control overhead during high mobility. Even a small network with high mobility or a large network with low mobility can completely choke the available bandwidth. Hence, this protocol suffers from excessive control overhead that is proportional to the number of nodes in the network and therefore is not scalable in ad hoc wireless networks, which have limited bandwidth and whose topologies are highly dynamic. Another disadvantage of DSDV is that in order to obtain information about a particular destination node, a node has to wait for a table

and best route, and uses that for sending data packets. Each data packet carries the complete path to its destination.

When an intermediate node in the path moves away, causing a wireless link to break, for example, the link between nodes 12 and 15 in Figure 7.11, a *RouteError* message is generated from the node adjacent to the broken link to inform the source node. The source node reinitiates the route establishment procedure. The cached entries at the intermediate nodes and the source node are removed when a *RouteError* packet is received. If a link breaks due to the movement of edge nodes (nodes 1 and 15), the source node again initiates the route discovery process.

Advantages and Disadvantages

This protocol uses a reactive approach which eliminates the need to periodically flood the network with table update messages which are required in a table-driven approach. In a reactive (on-demand) approach such as this, a route is established only when it is required and hence the need to find routes to all other nodes in the network as required by the table-driven approach is eliminated. The intermediate nodes also utilize the route cache information efficiently to reduce the control overhead. The disadvantage of this protocol is that the route maintenance mechanism does not locally repair a broken link. Stale route cache information could also result in inconsistencies during the route reconstruction phase. The connection setup delay is higher than in table-driven protocols. Even though the protocol performs well in static and low-mobility environments, the performance degrades rapidly with increasing mobility. Also, considerable routing overhead is involved due to the source-routing mechanism employed in DSR. This routing overhead is directly proportional to the path length.

7.5.2 Ad Hoc On-Demand Distance-Vector Routing Protocol

Ad hoc on-demand distance vector (AODV) [11] routing protocol uses an on-demand approach for finding routes, that is, a route is established only when it is required by a source node for transmitting data packets. It employs destination sequence numbers to identify the most recent path. The major difference between AODV and DSR stems out from the fact that DSR uses source routing in which a data packet carries the complete path to be traversed. However, in AODV, the source node and the intermediate nodes store the next-hop information corresponding to each flow for data packet transmission. In an on-demand routing protocol, the source node floods the *RouteRequest* packet in the network when a route is not available for the desired destination. It may obtain multiple routes to different destinations from a single *RouteRequest*. The major difference between AODV and other on-demand routing protocols is that it uses a destination sequence number (DestSeqNum) to determine an up-to-date path to the destination. A node updates its path information only if the DestSeqNum of the current packet received is greater than the last DestSeqNum stored at the node.

A *RouteRequest* carries the source identifier (SrcID), the destination identifier (DestID), the source sequence number (SrcSeqNum), the destination sequence num-

ber (DestSeqNum), the broadcast identifier (BcastID), and the time to live (TTL) field. DestSeqNum indicates the freshness of the route that is accepted by the source. When an intermediate node receives a *RouteRequest*, it either forwards it or prepares a *RouteReply* if it has a valid route to the destination. The validity of a route at the intermediate node is determined by comparing the sequence number at the intermediate node with the destination sequence number in the *RouteRequest* packet. If a *RouteRequest* is received multiple times, which is indicated by the BcastID-SrcID pair, the duplicate copies are discarded. All intermediate nodes having valid routes to the destination, or the destination node itself, are allowed to send *RouteReply* packets to the source. Every intermediate node, while forwarding a *RouteRequest*, enters the previous node address and its BcastID. A timer is used to delete this entry in case a *RouteReply* is not received before the timer expires. This helps in storing an active path at the intermediate node as AODV does not employ source routing of data packets. When a node receives a *RouteReply* packet, information about the previous node from which the packet was received is also stored in order to forward the data packet to this next node as the next hop toward the destination.

Consider the example depicted in Figure 7.12. In this figure, source node 1 initiates a path-finding process by originating a *RouteRequest* to be flooded in the network for destination node 15, assuming that the *RouteRequest* contains the des-

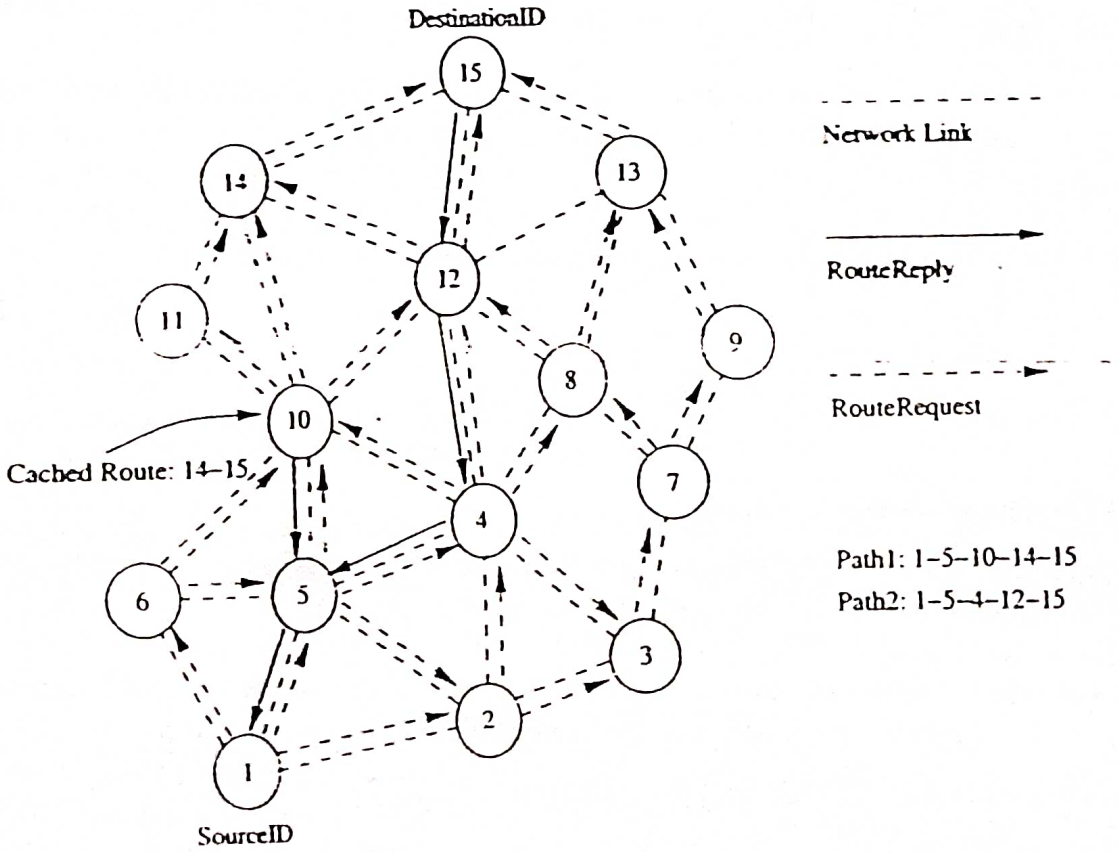


Figure 7.12. Route establishment in AODV.

If a node has a route then it will send route Replying.

tination sequence number as 3 and the source sequence number as 1. When nodes 2, 5, and 6 receive the *RouteRequest* packet, they check their routes to the destination. In case a route to the destination is not available, they further forward it to their neighbors. Here nodes 3, 4, and 10 are the neighbors of nodes 2, 5, and 6. This is with the assumption that intermediate nodes 3 and 10 already have routes to the destination node, that is, node 15 through paths 10-14-15 and 3-7-9-13-15, respectively. If the destination sequence number at intermediate node 10 is 4 and is 1 at intermediate node 3, then only node 10 is allowed to reply along the cached route to the source. This is because node 3 has an older route to node 15 compared to the route available at the source node (the destination sequence number at node 3 is 1, but the destination sequence number is 3 at the source node), while node 10 has a more recent route (the destination sequence number is 4) to the destination. If the *RouteRequest* reaches the destination (node 15) through path 4-12-15 or any other alternative route, the destination also sends a *RouteReply* to the source. In this case, multiple *RouteReply* packets reach the source. All the intermediate nodes receiving a *RouteReply* update their route tables with the latest destination sequence number. They also update the routing information if it leads to a shorter path between source and destination.

AODV does not repair a broken path locally. When a link breaks, which is determined by observing the periodical *beacons* or through link-level acknowledgments, the end nodes (*i.e.*, source and destination nodes) are notified. When a source node learns about the path break, it reestablishes the route to the destination if required by the higher layers. If a path break is detected at an intermediate node, the node informs the end nodes by sending an unsolicited *RouteReply* with the hop count set as ∞.

Consider the example illustrated in Figure 7.13. When a path breaks, for example, between nodes 4 and 5, both the nodes initiate *RouteError* messages to inform their end nodes about the link break. The end nodes delete the corresponding entries from their tables. The source node reinitiates the path-finding process with the new BcastID and the previous destination sequence number.

Advantages and Disadvantages

The main advantage of this protocol is that routes are established on demand and destination sequence numbers are used to find the latest route to the destination. The connection setup delay is less. One of the disadvantages of this protocol is that intermediate nodes can lead to inconsistent routes if the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence number, thereby having stale entries. Also multiple *RouteReply* packets in response to a single *RouteRequest* packet can lead to heavy control overhead. Another disadvantage of AODV is that the periodic *beaconing* leads to unnecessary bandwidth consumption.