Chapter 7: Routing Protocols for Ad Hoc Wireless Networks

Jang-Ping Sheu

Introduction

- Routing protocols used in wired networks cannot be directly applied to ad hoc wireless networks
  - Highly dynamic topology
  - No infrastructure for centralized administration
  - Bandwidth constrained
  - Energy constrained
- For the above reasons, we need to design new routing protocols for ad hoc networks

Issues in Designing a Routing Protocol

- Mobility:
  - Ad hoc is highly dynamic due to the movement of nodes
  - Node movement causes frequent path breaks
  - The path repair in wired network has slow convergence
- Bandwidth Constraint:
  - Wireless has less bandwidth due to the limited radio band: Less data rate and difficult to maintain topology information
  - Frequent change of topology causes more overhead of topology maintenance
  - Target: Bandwidth optimization and design topology update mechanism with less overhead

Issues in Designing a Routing Protocol

- Error-prone shared broadcast radio channel:
  - Wireless links have time varying characteristics in terms of link capacity and link-error probability
  - Target: Interact with MAC layer to find better-quality link
  - Hidden terminal problem causes packet collision
  - Target: Find routes through better quality links and find path with less congestion
- Hidden and exposed terminal problems
  - RTS-CTS control packet cannot ensure collision free, see Fig. 7.2
- Resource Constraints:
  - Limited battery life and limited processing power
  - Target: optimally manage these resources

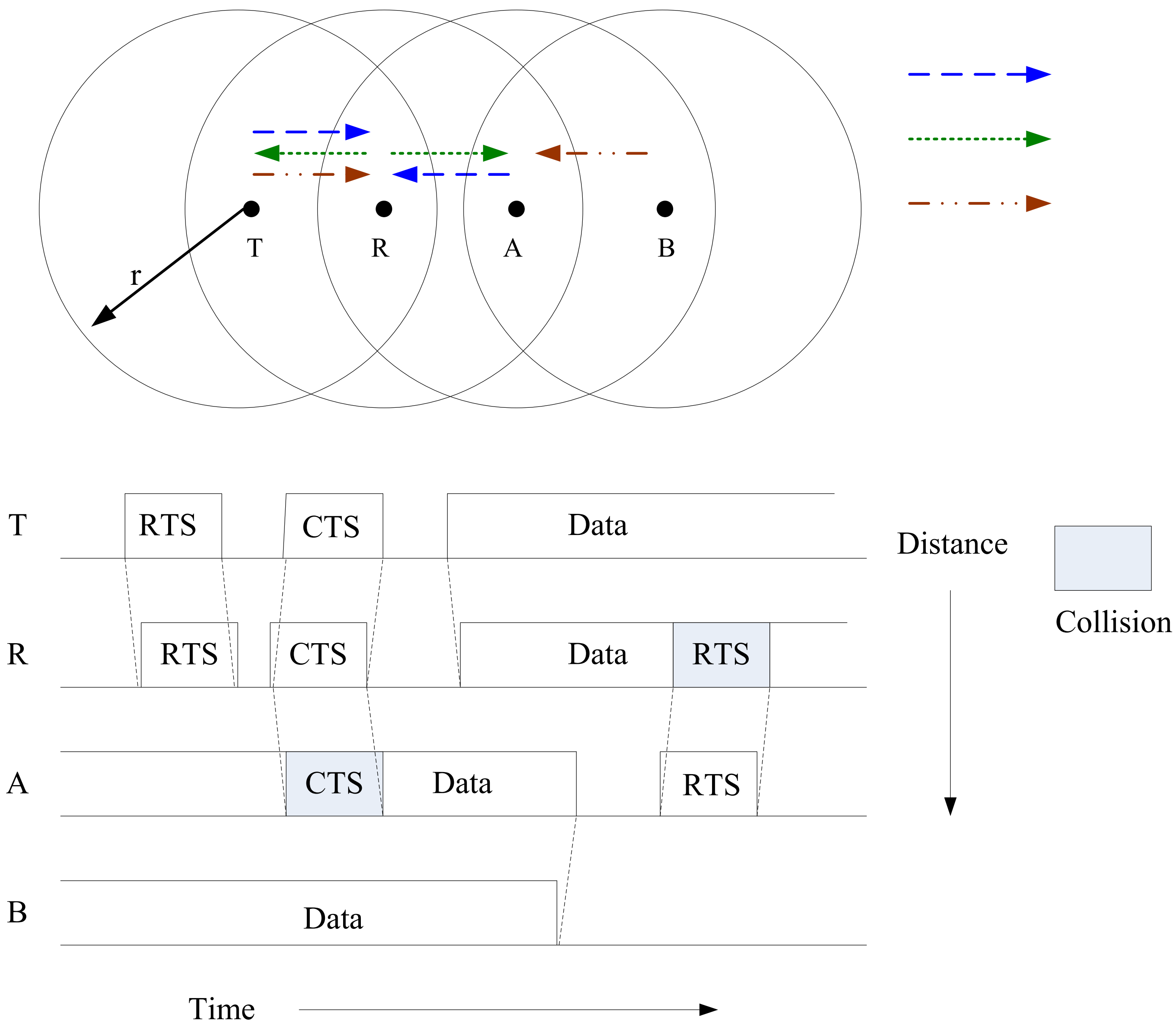


Figure 7.2. Hidden terminal problem with RTS-CTS-Data-ACK scheme.

Characteristics of an Ideal Routing Protocol for Ad Hoc

- Fully distributed
- Adaptive to frequent topology changes
- Minimum connection setup time is desired
- Localized
  - global maintenance involves a huge state propagation control overhead
- Loop free and free from stale routes
- Packet collision must seldom happen

Characteristics of an Ideal Routing Protocol for Ad Hoc (cont.)

- Converge to optimal route quickly
- Optimally use scarce resource
  - Bandwidth, computing power, memory, and battery
- Remote parts of the network must not cause updates in the topology information maintained by this node
- Provide quality of service and support for time-sensitive traffic

Classifications of Routing Protocols

- Routing protocol can be broadly classified into four categories :
  - Routing information update mechanism
  - Use of temporal information for routing
  - Routing topology
  - Utilization of specific resource
- These classification is not mutually exclusive

Based on the Routing Information Update Mechanism

- Proactive or table-driven routing protocols
  - Maintain routing information in the routing table
  - Routing information is flooded in the whole network
  - Runs path-finding algorithm with the routing table
- Reactive or on-demand routing protocols
  - Obtain the necessary path while required
- Hybrid routing protocols
  - In the zone of given node : use table-driven
  - Out of the zone of given node : use on-demand

Based on the Use of Temporal Information for Routing

- Using past temporal information
  - Past status of the links or
  - the status of links at the time of routing to make routing decision
- Using future temporal information
  - Expected future status of the links to make decision
  - Node lifetime is also included
    - Ex: remaining battery charge, prediction of location, and link availability

Based on the Routing Topology

- Flat topology routing protocols
  - Flat addressing scheme similar to IEEE 802.3 LANs
  - Globally unique addressing mechanism for nodes
- Hierarchical topology routing protocols
  - Logical hierarchy
  - Associated addressing scheme
  - May based on geographical information or hop distance

Based on the Utilization of Specific Resource

- Power-aware routing
  - Minimize consumption of resource
    - Ex: Battery power
- Geographical information assisted routing
  - Improve the routing performance
  - Reduce control overhead

Classifications of Routing Protocol:

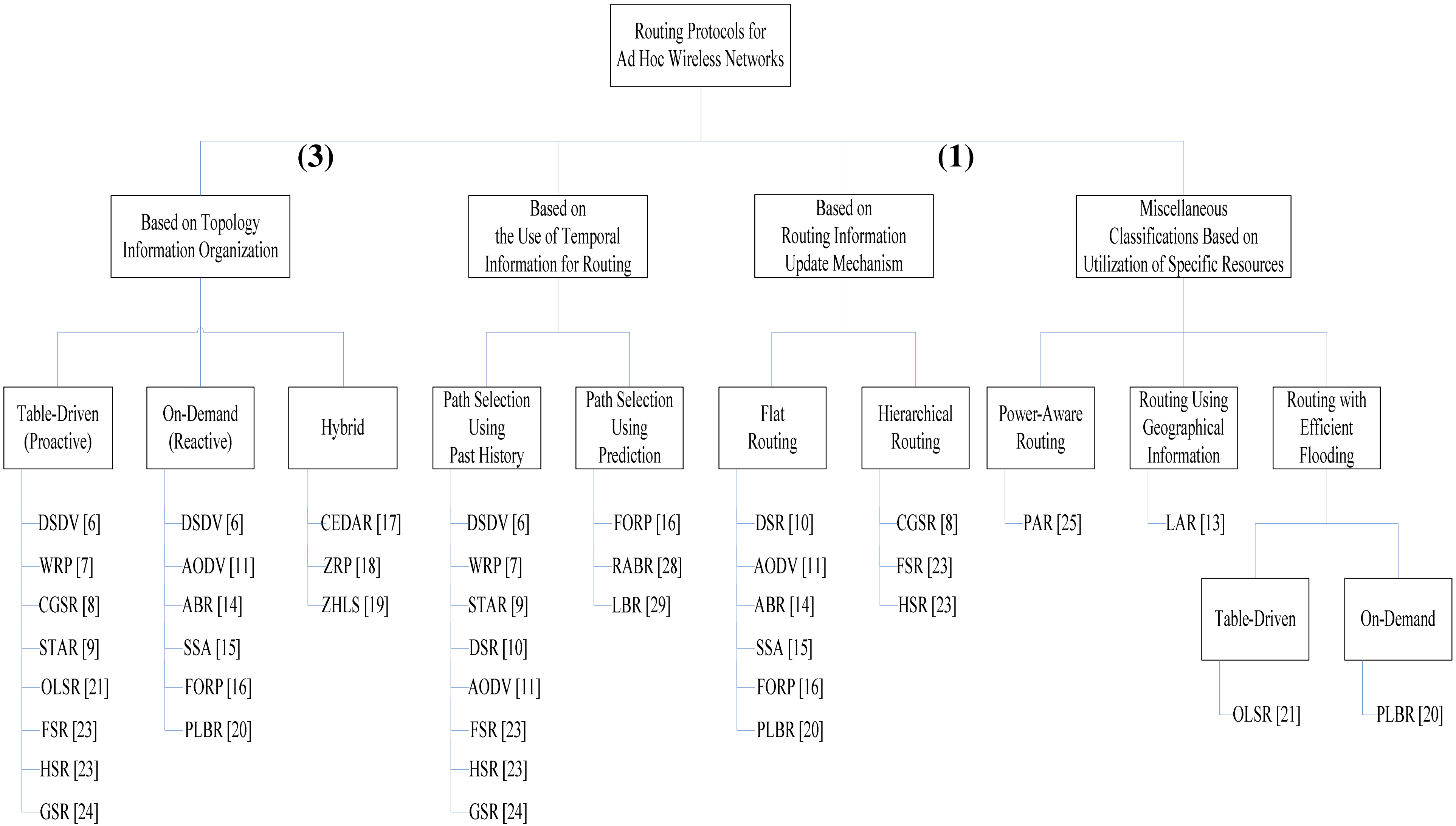


Figure 7.4. Classifications of routing protocols.

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols

Table-Driven Routing Protocols

- We introduce these routing protocols:
  - Destination Sequenced Distance-Vector Routing Protocol (DSDV)
  - Wireless Routing Protocol (WRP)
  - Cluster-Head Gateway Switch Routing Protocol (CGSR)
  - Source-Tree Adaptive Routing Protocol (STAR)

Destination Sequenced Distance-Vector Routing Protocol (DSDV)

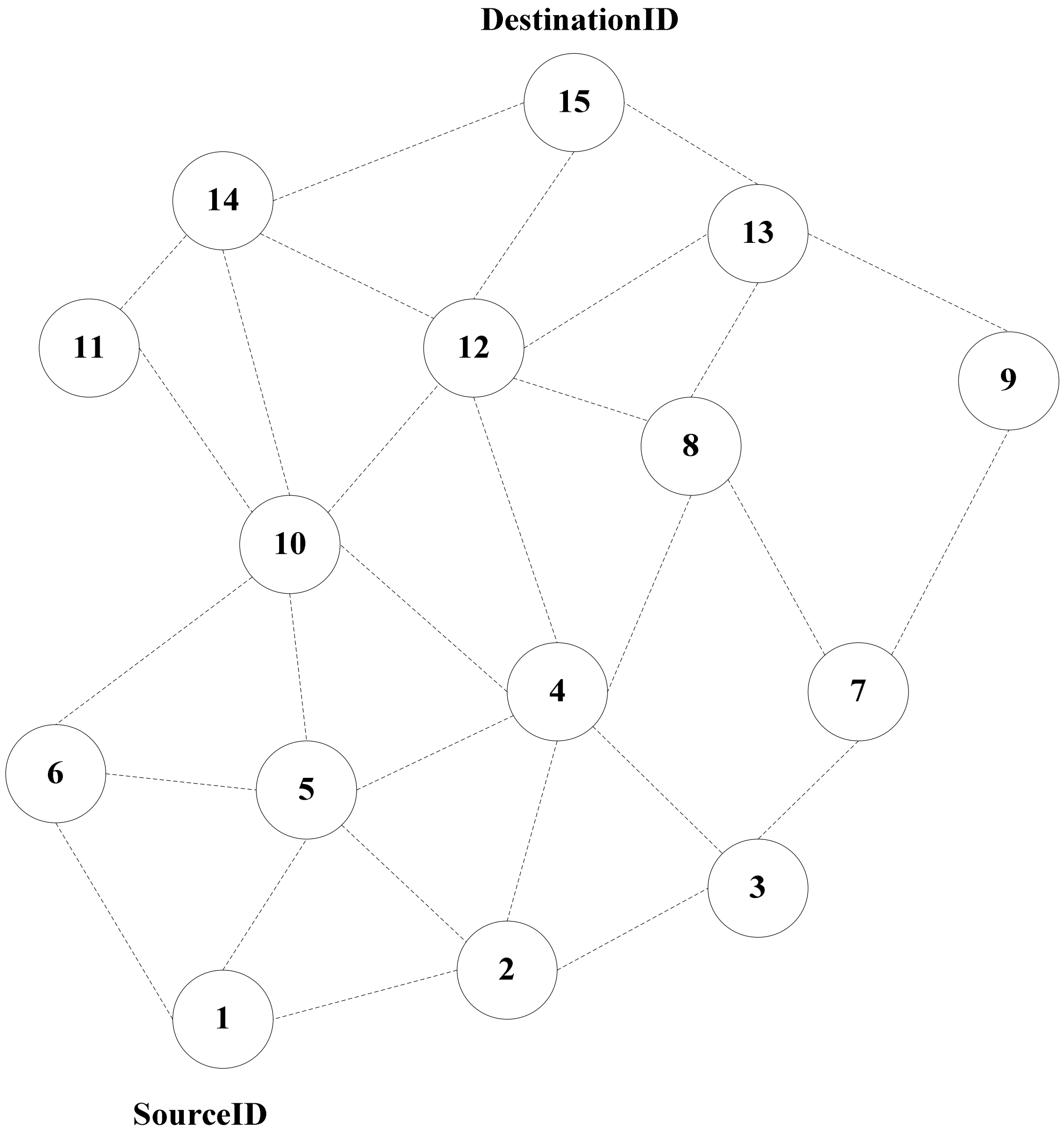
- Enhanced from distributed Bellman-Ford algorithm
- Obtain a table that contains shortest path from this node to every node
- Incorporate table updates with increasing sequence number tags
  - Prevent loops
  - Counter the count-to-infinity problem
  - Faster convergence

DSDV (Cont.)

- Exchange table between neighbors at regular time interval
- Two types of table updates
  - Incremental update
    - Takes a single network data packet unit (NDPU)
      - When no significant change in the local topology
  - Full dumps update
    - Takes multiple NDPUs:
      - When local topology changes significantly
      - Or incremental updates require more than a NDPU

DSDV (Cont.)

- Table updates are initiated by the destination with the new sequence number which is always greater than the previous one
- Single link break cause propagation of table update information to the whole network
  - With odd sequence
- The changed node informs neighbors about new shortest path while receiving the table update message
  - With even sequence

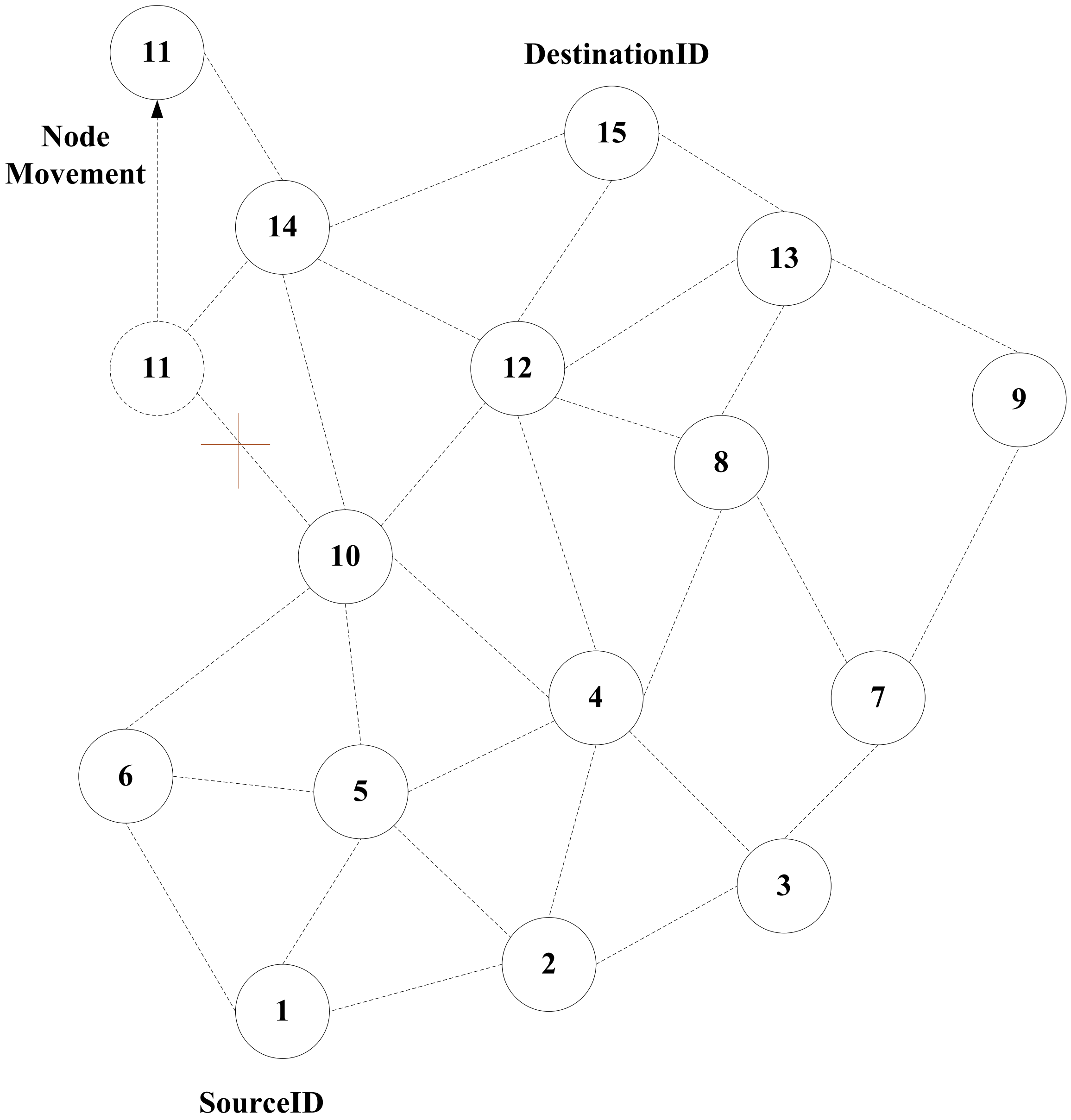


(a) Topology graph of the network

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



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	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

DSDV (Cont.)

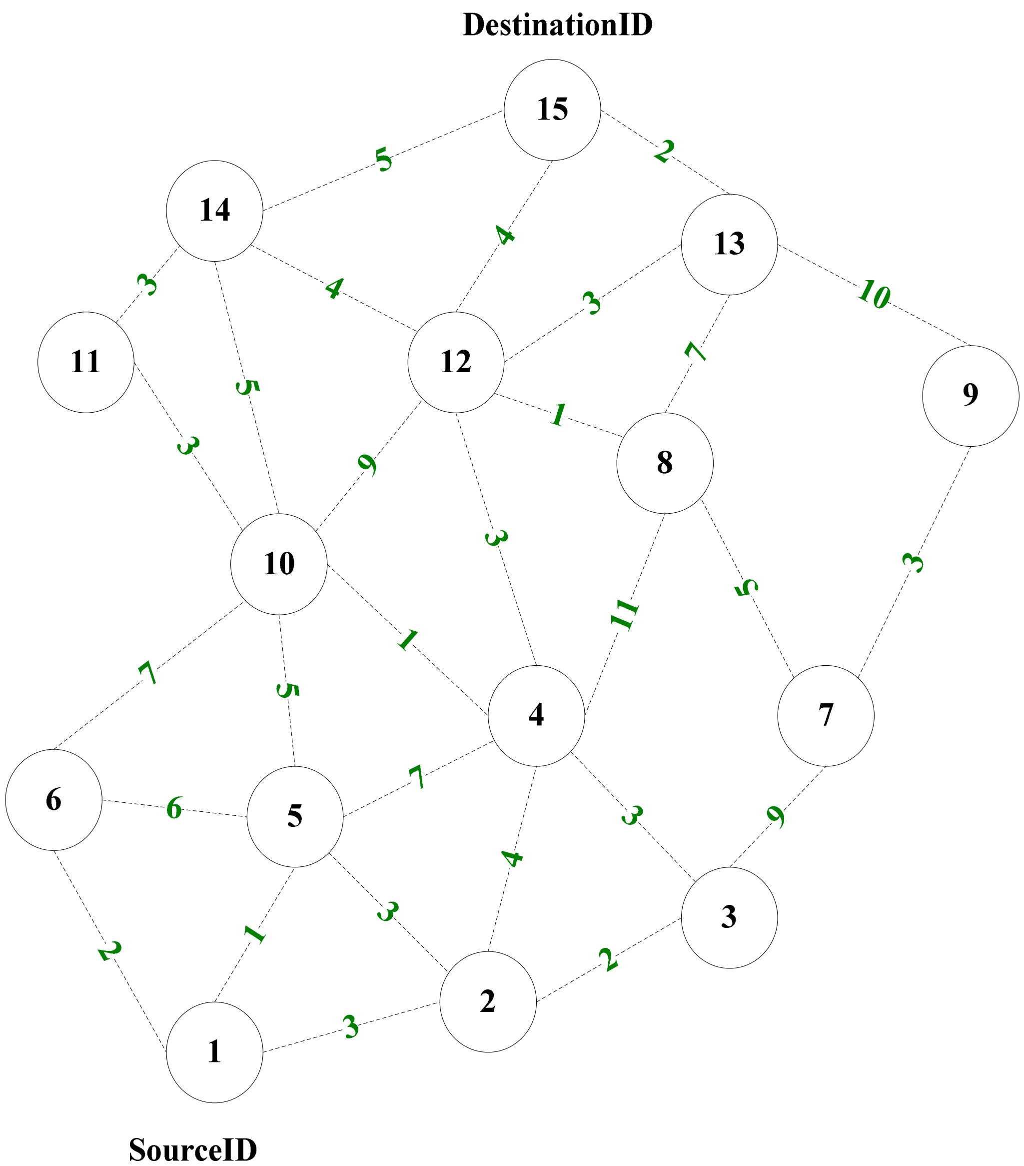
- Advantages:
  - Route setup process is very fast
  - Make the existing wired network protocol apply to ad hoc network with fewer modifications
- Disadvantages:
  - Excessive control overhead during high mobility
  - Node must wait for a table update message initiated by the destination node
    - Cause stale routing information at nodes

Wireless Routing Protocol (WRP)

- Similar to DSDV, but it uses multiple tables for routing processes
- Differs from table maintenance and in the update procedure
  - Uses a set of tables to maintain more accurate information instead of single topology information
  - Not only updates distance for transmitted neighbor but also checks the other neighbors' distance

Wireless Routing Protocol (WRP)

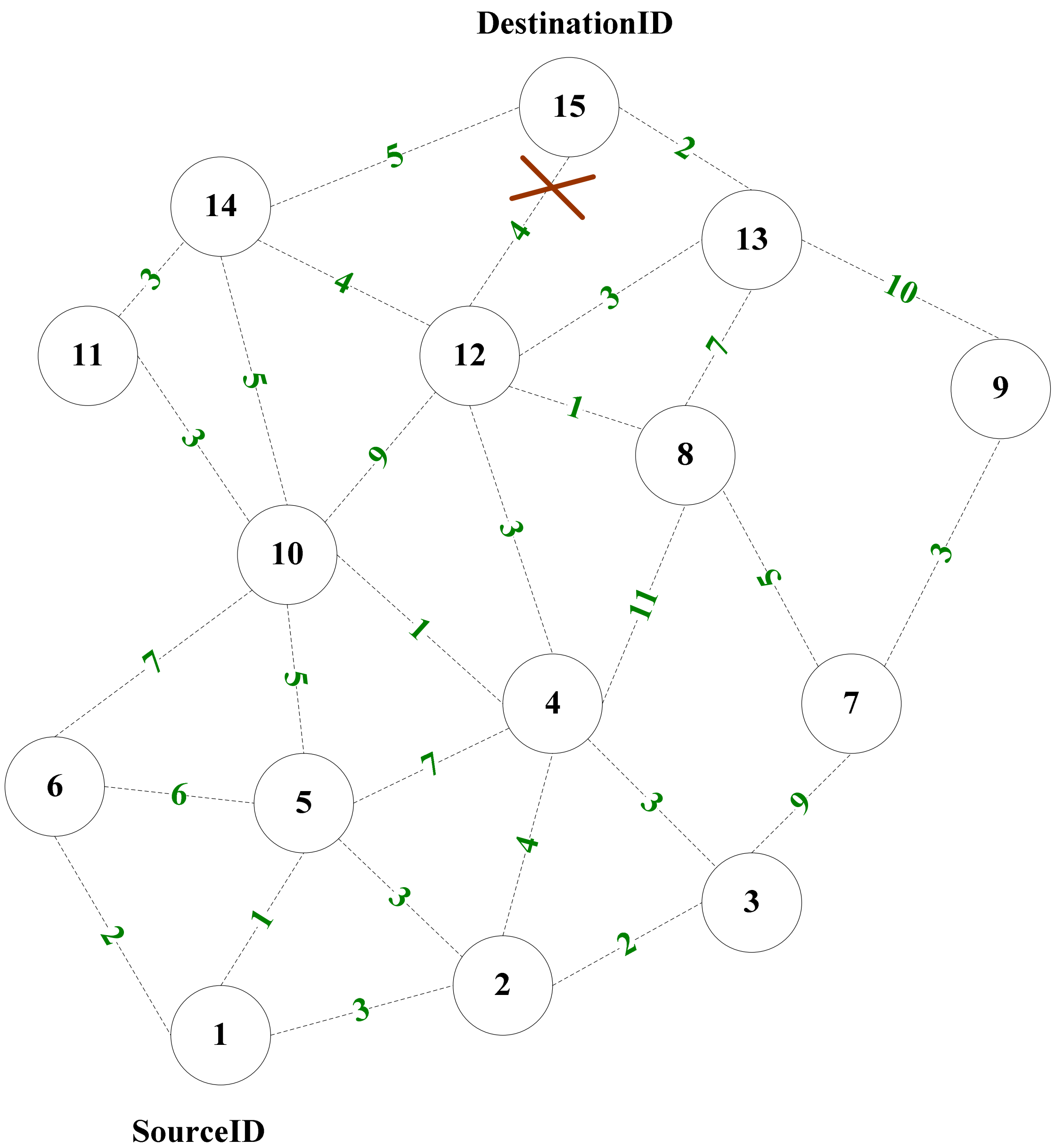
- Distance table
  - Contains distance and predecessor node for a destination
- Routing table
  - Contains shortest distance, predecessor node, successor node, and status of the path
- Link cost table
  - Cost of relaying messages through each link
  - Number of update periods passed since the last successful update was received (for detecting link breaks)
- Message retransmission table
  - Update message that is to be retransmitted with a counter
    - Counter decremented after every update message retransmission



Routing Entry at Each Node for DestinationID 15

Node	NextNode	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	15
5	10	12	13
4	12	12	10
3	4	12	7
2	4	12	11
1	2	12	14

Figure 7.7. Route establishment in WRP.



**Routing Entry at Each Node
for DestinationID 15**

Node	NextNode	Pred	Cost
15	15	15	0
14	15	14	5
13	15	13	2
12	15	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

Figure 7.8. Route maintenance in WRP.

Wireless Routing Protocol (WRP)

- Advantages:
  - Same as DSDV
  - Has faster convergence and fewer table updates
- Disadvantages:
  - Need large memory and greater computing power because of the multiple tables
  - At high mobility, the control overhead for updating table entries is almost the same as DSDV
    - Not suitable for highly dynamic and large ad hoc network

Cluster-Head Gateway Switch Routing Protocol (CGSR)

- Hierarchical topology based on cluster
- Cluster-head is elected by a Least Cluster Change (LCC) algorithm
- Clustering uses CDMA to allocate bandwidth between different clusters
  - Every cluster has its own spreading code
- Cluster-head coordinate channel access based on token-based polling protocol
- Cluster-head can reach all member nodes within a single hop

Cluster-Head Gateway Switch Routing Protocol (CGSR)

- Communication passes through the cluster-head
- Gateway: a member in more than one clusters
  - Listens to multiple spreading codes
  - Becomes a bridge between cluster
  - Gateways are capable of simultaneously communicating over two interfaces can avoid conflict
- Performance is influenced by:
  - Token scheduling for cluster-head
  - Code scheduling for gateway

Cluster-Head Gateway Switch Routing Protocol (CGSR)

- Routing in CGSR is an extension of DSDV
- Each node maintains a routing table containing
  - Destination cluster-head for every node
  - The list of next-hop nodes for reaching destination cluster
- Route reconfiguration is necessitated by two factor:
  - Cluster-head changes
  - Stale entries in the cluster member table and routing table

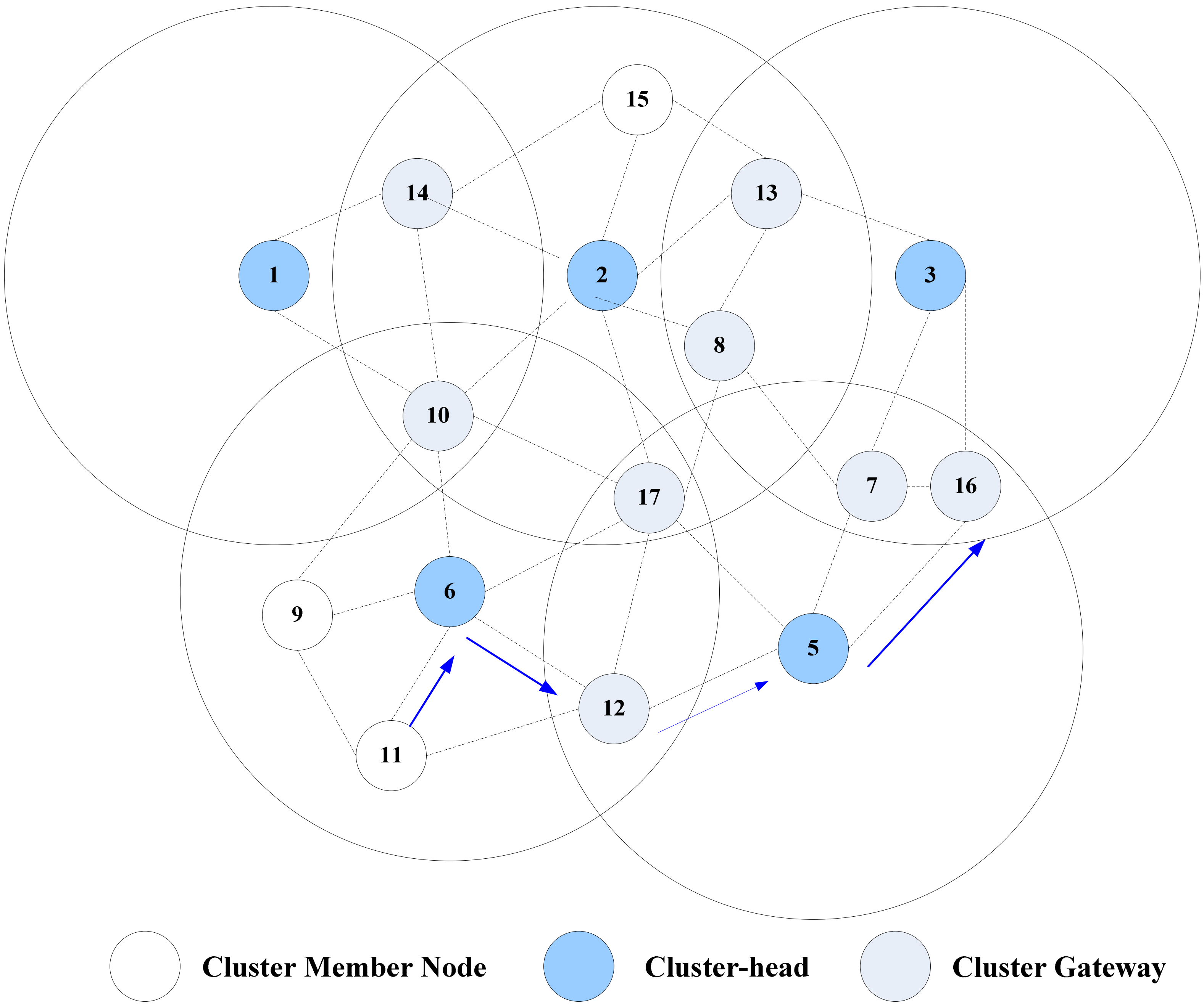


Figure 7.9. Route establishment in CGSR.

Cluster-Head Gateway Switch Routing Protocol (CGSR)

- Advantages:
  - Better bandwidth utilization
  - Easy to implement priority scheduling scheme
- Disadvantages:
  - Increase in path length
  - Instability when cluster-head are high mobility
  - Battery-draining rate at cluster-head is more than a normal node
    - Frequent changes in the cluster-head = multiple path break

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols
- Summery

On-demand Routing Protocol

- Unlike the table-driven routing protocols, on-demand routing protocols execute the path-finding process and exchange routing information **only when a path is required by a node to communicate with a destination**.

On-demand Routing Protocol

- Dynamic Source Routing Protocol (DSR)
- Ad Hoc On-demand Distance-Vector Routing Protocol (AODV)
- Temporally Ordered Algorithm (TORA)
- Location-Aided Routing (LAR)
- Associativity-Based Routing(ABR)
- Signal Stability-Based Adaptive Routing Protocol (SSA)
- Flow-Oriented Routing Protocol (FORP)

Dynamic Source Routing Protocol (DSR)

- Beacon-less: no *hello* packet
- Routing cache
- DSR contains two phases
  - Route Discovery (find a path)
    - Flooding RouteRequest with TTL from source
    - Response RouteReply by destination
  - If an forwarding node has a route to the destination in its route cache, it sends a RouteREply to the source
  - Route Maintenance (maintain a path)
    - RouteError

Routing Discovery

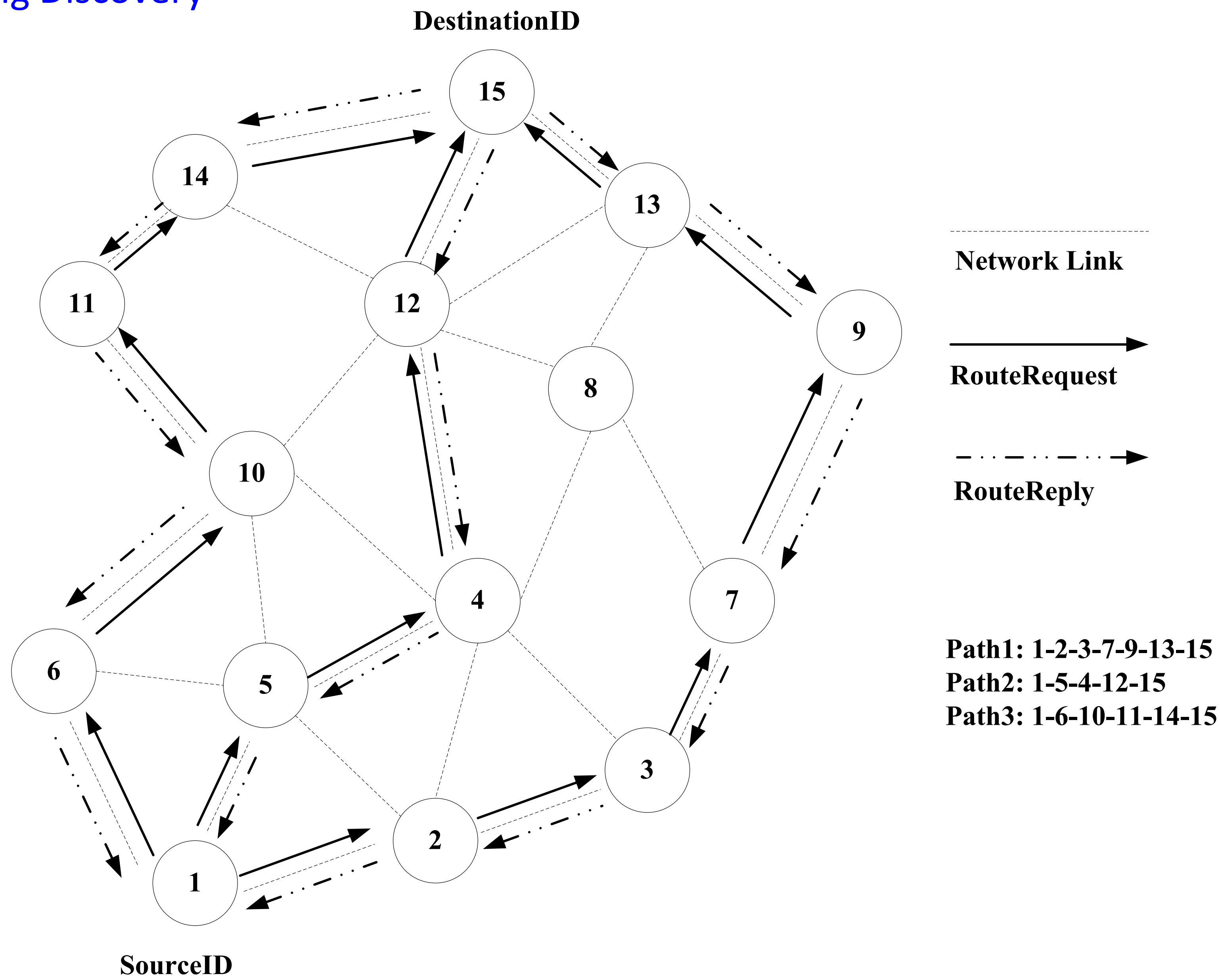


Figure 7.10. Route establishment in DSR.

Routing Maintain

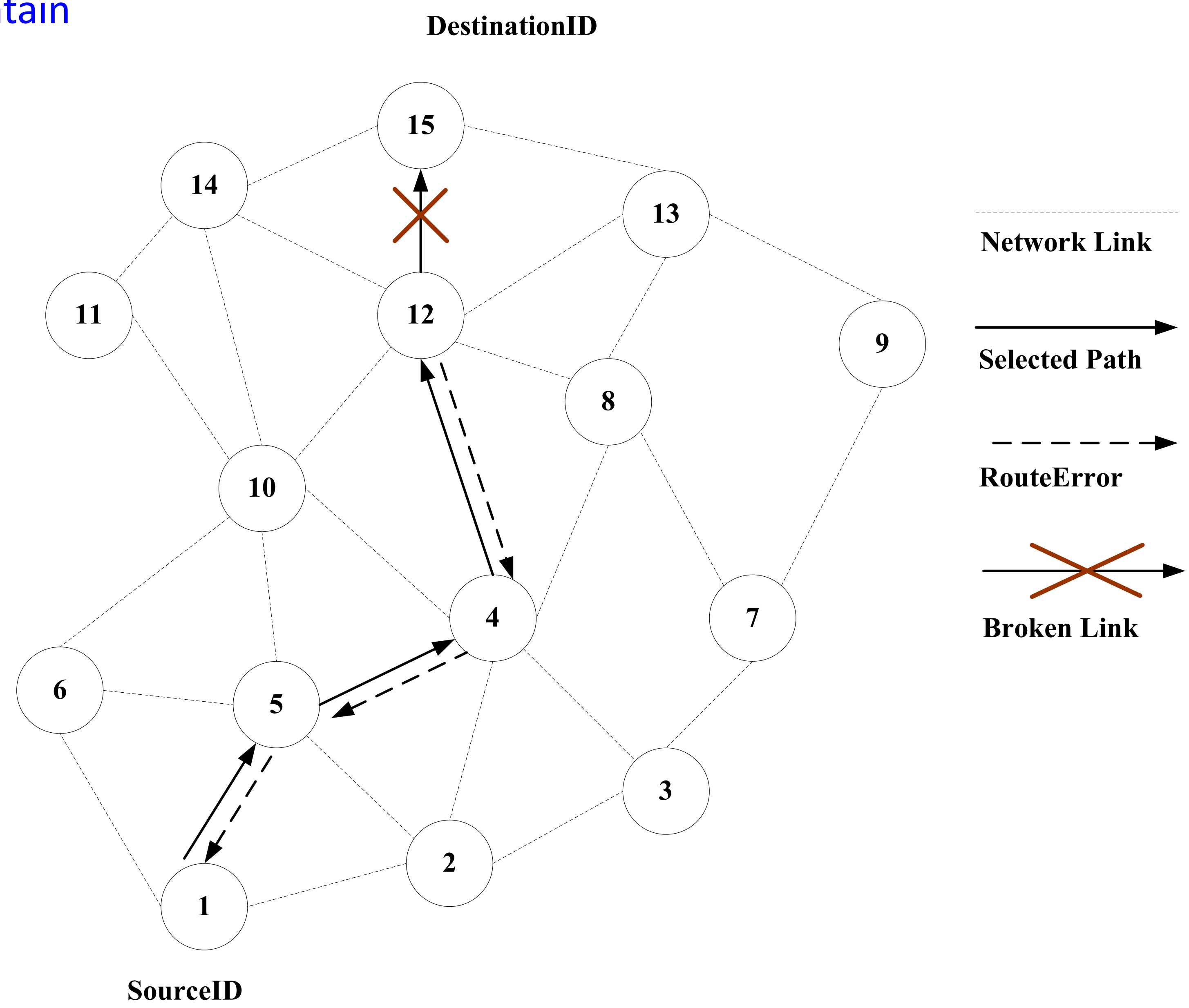


Figure 7.11. Route maintenance in DSR.

Dynamic Source Routing Protocol

- Advantage
  - No need to updating the routing tables
  - Intermediate nodes are able to utilize the Route Cache information efficiently to reduce the control overhead
  - There are no “hello” messages needed (beacon-less)
- Disadvantage
  - The Route Maintenance protocol does not locally repair a broken link
  - There is always a small time delay at the begin of a new connection

Ad Hoc On-demand Distance-Vector Routing Protocol (AODV)

- Every node has a routing table. When a node knows a route to the destination, it sends a route reply to the source node
- 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.
- Message types
  - Route Requests (RREQs)
  - Route Replies (RREPs)
  - Route Errors (RERRs).

AODV

- RouteRequest packet carries:
  - SreID, DestID, DestSeqNum, BcastID, and TTL
  - DestSeqNum indicates the freshness of the route is accepted
  - An intermediate node receives a RouteRequest packet. It either forwards it or prepares a RouteReply if it has a valid route to the destination
- RouteReply packet:
  - A node receives RouteReply packet will record the information as the next hop toward the destination
- AODV does not repair a broken path locally

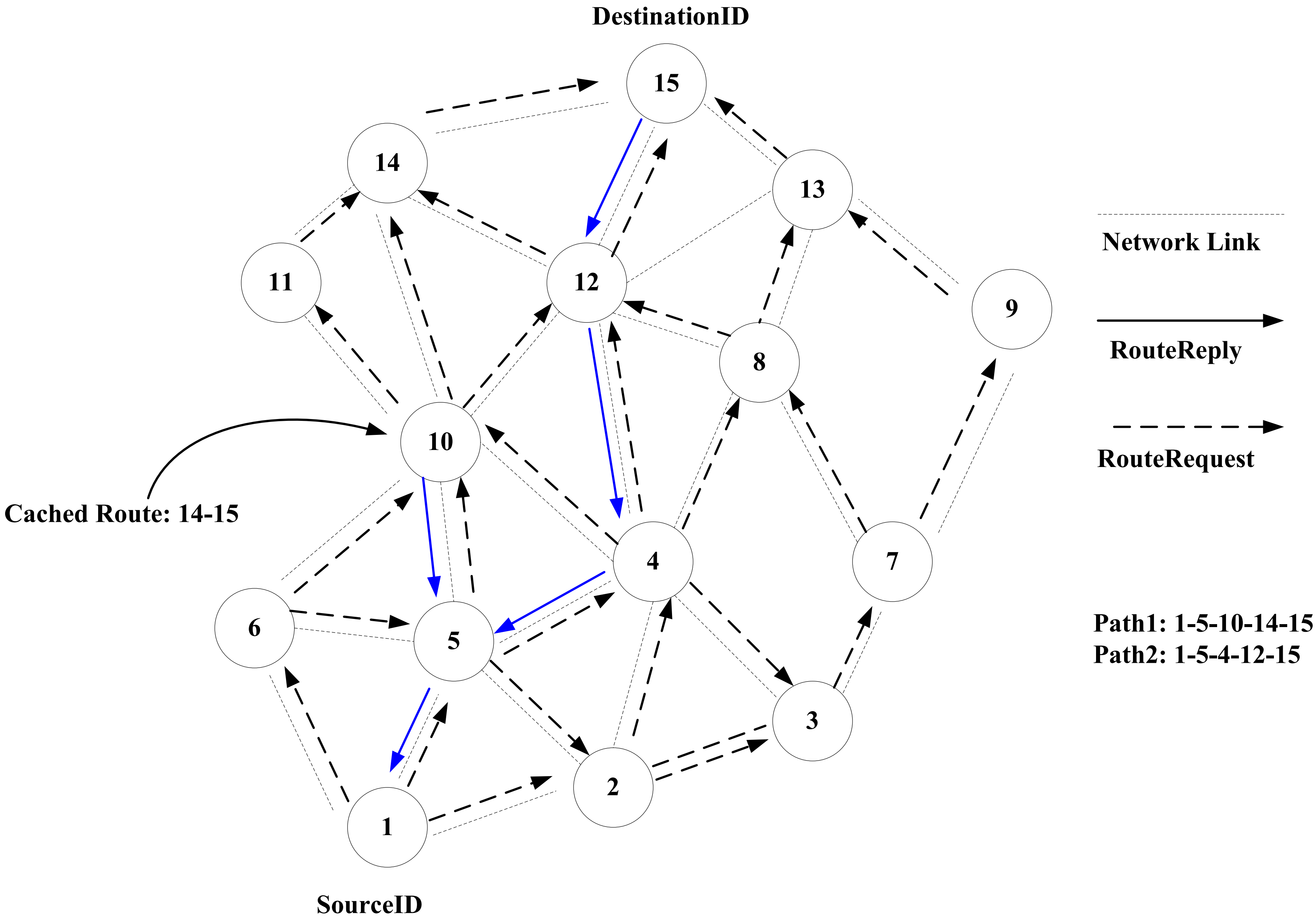


Figure 7.12. Route establishment in AODV.

Route Maintenance

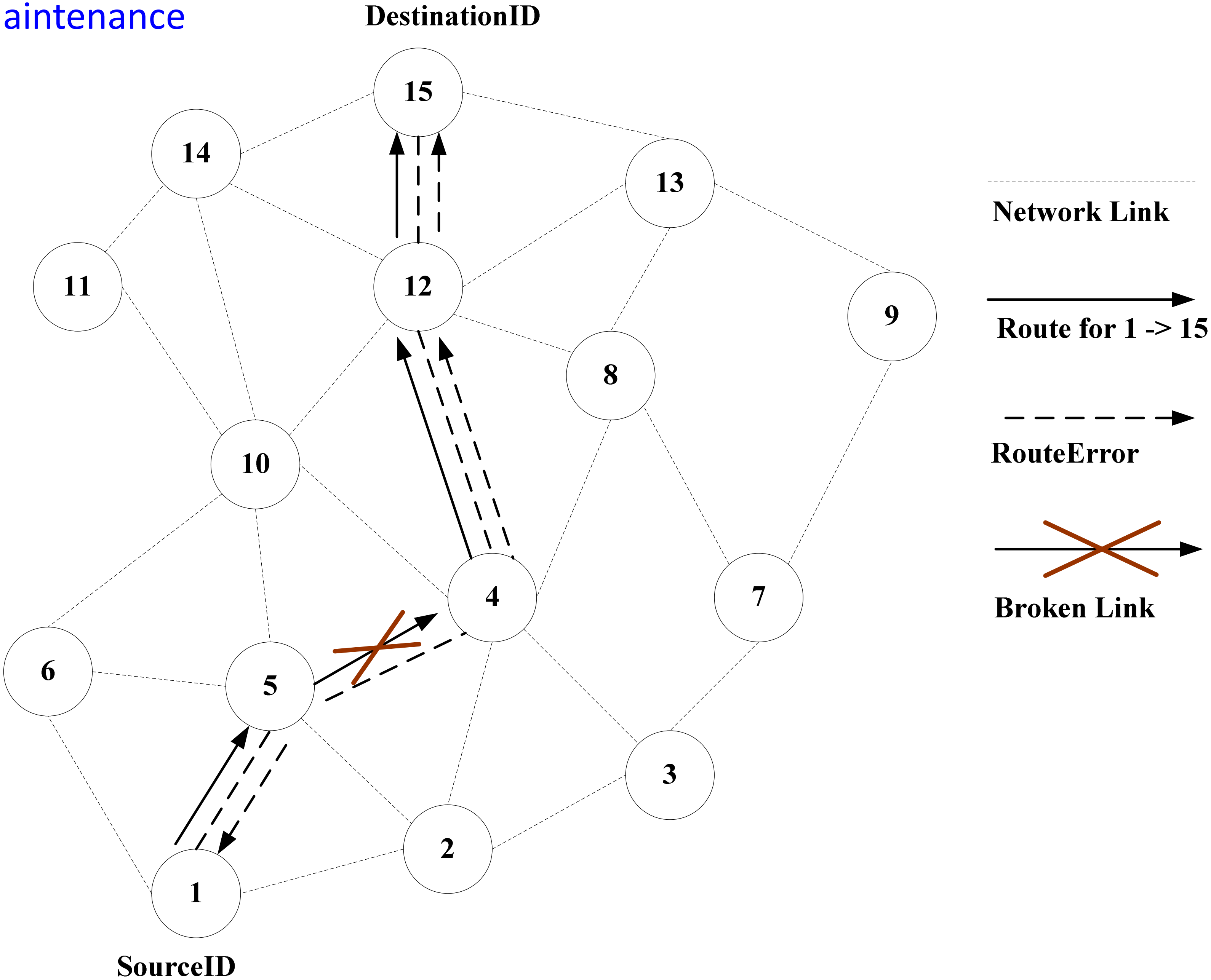


Figure 7.13. Route maintenance in AODV.

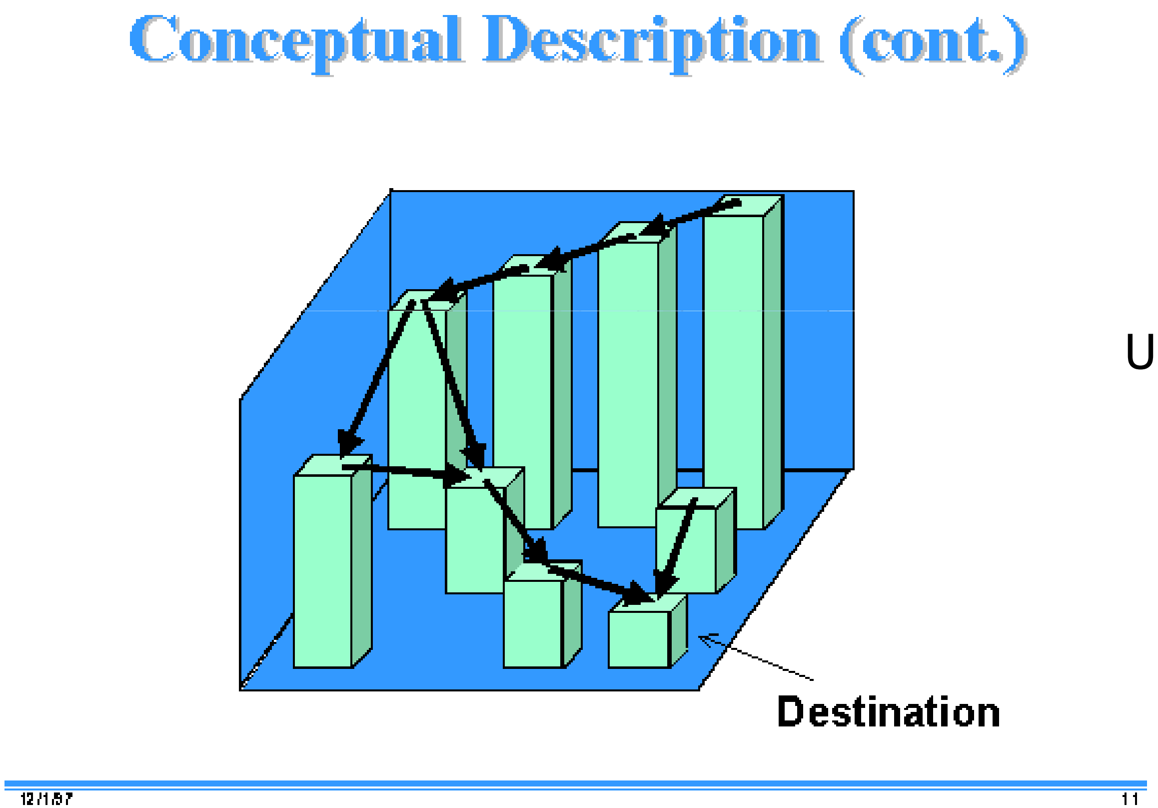
AODV

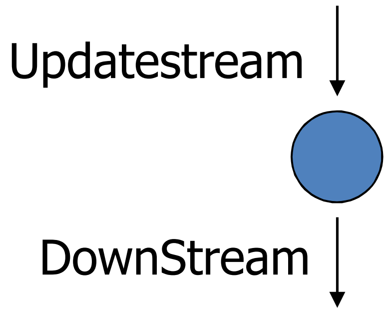
- Advantage
  - Establish on demand
  - Destination sequences are used to find the latest path to destination
  - The connection setup delay is less
- Disadvantage
  - Intermediate node can lead to inconsistent route
  - Beacon-base
  - Heavy control overhead

Temporally Ordered Algorithm (TORA)

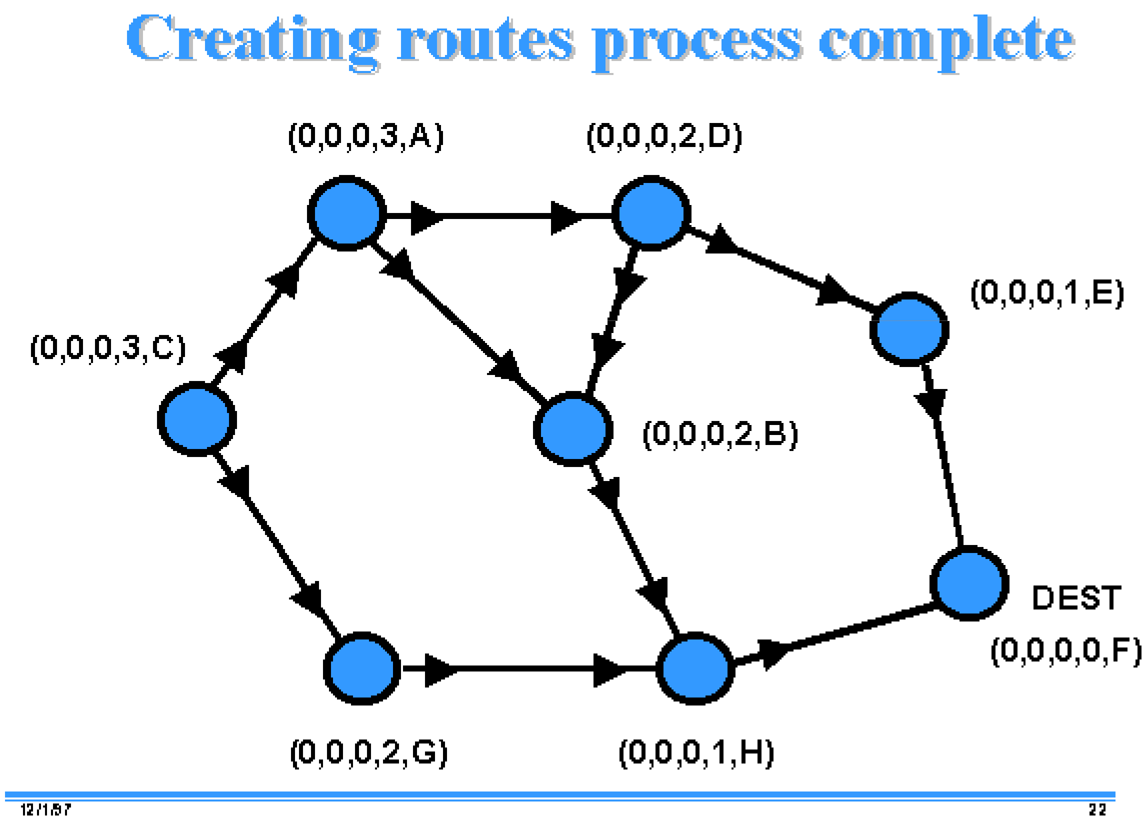
- A source-initiated on-demand routing protocol which uses a link reversal routing algorithms
- Provide loop-free multipath routes
- Beacon-base
- Three main functions
  - Route Establishing: when a node requires a path to a destination but does not have any directed link
    - Query packet
  - Route Maintenance: Update packet
  - Route Erasing: CLR packet

Link reversal routing algorithms



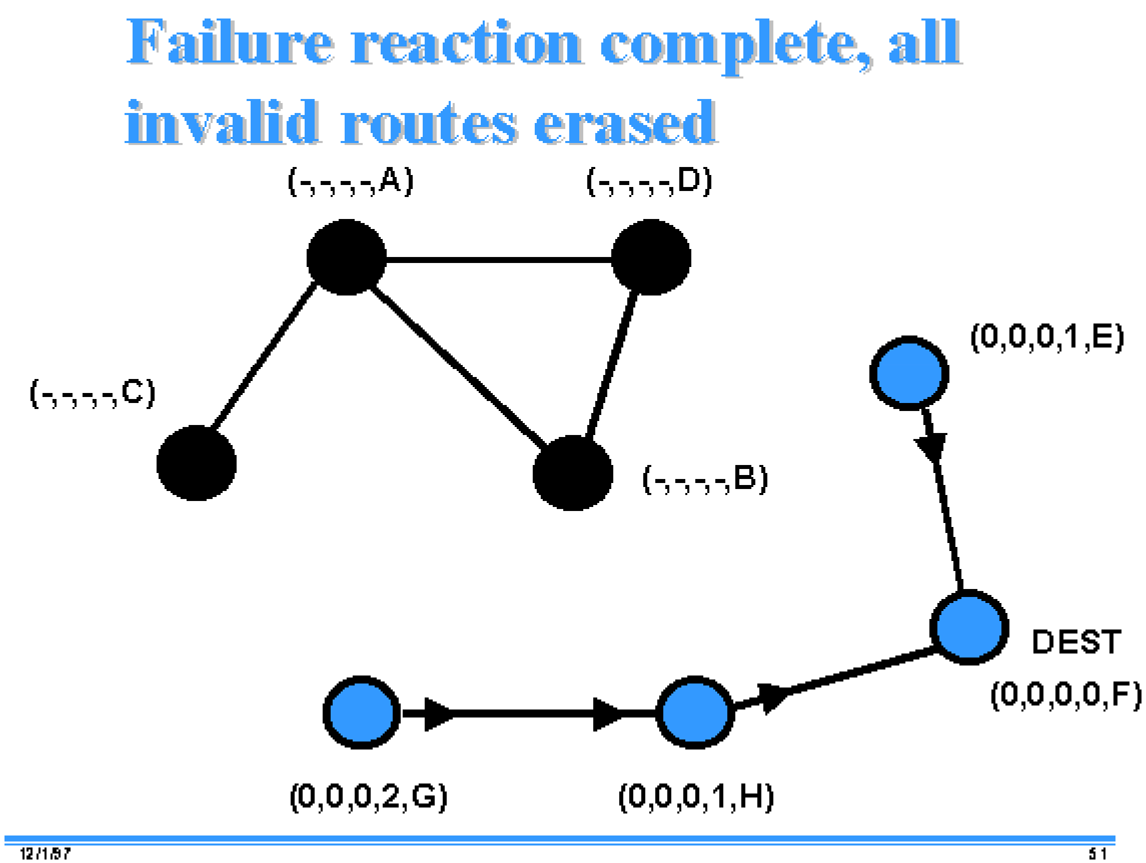


Route Establishing



(logical time,NodeID',Height',Height,NodeID)

Route Maintenance



(logical time,NodeID',Height',Height,NodeID)

TORA

- Advantage
  - Less control overhead

- Disadvantage
  - The local reconfiguration of paths result in no optimal routes.

Location-Aided Routing (LAR)

- With the availability of GPS, the mobile hosts knows their physical locations
- Expected Zone: the destination node is expected to be presented
- Request Zone: the path-finding control packets are permitted to be propagated
- LAR1: the source node specifies the request-zone in the *RouteRequest* packet
- LAR2: source node includes the distance between itself and the destination node

Expected Zone & Request Zone

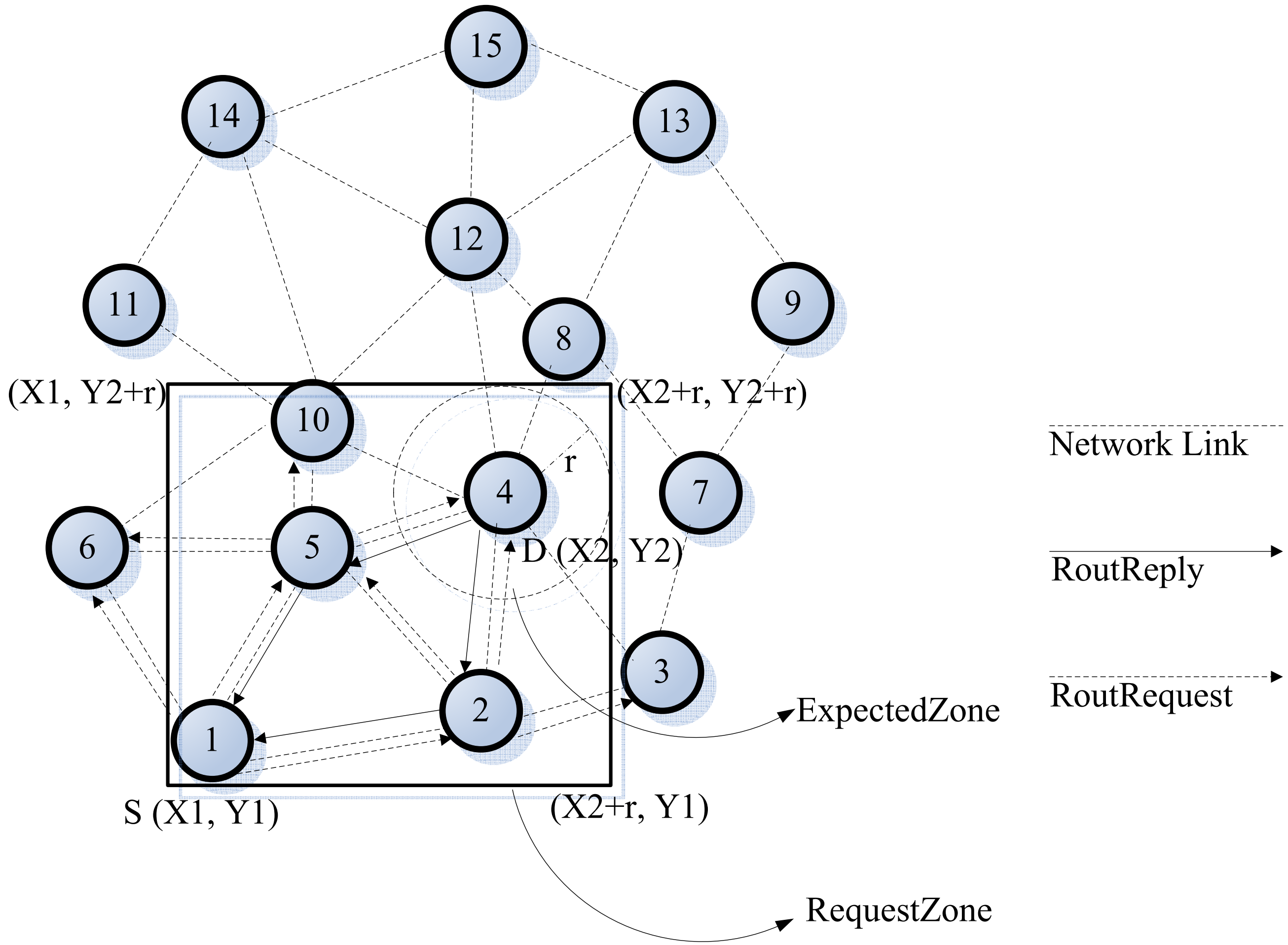
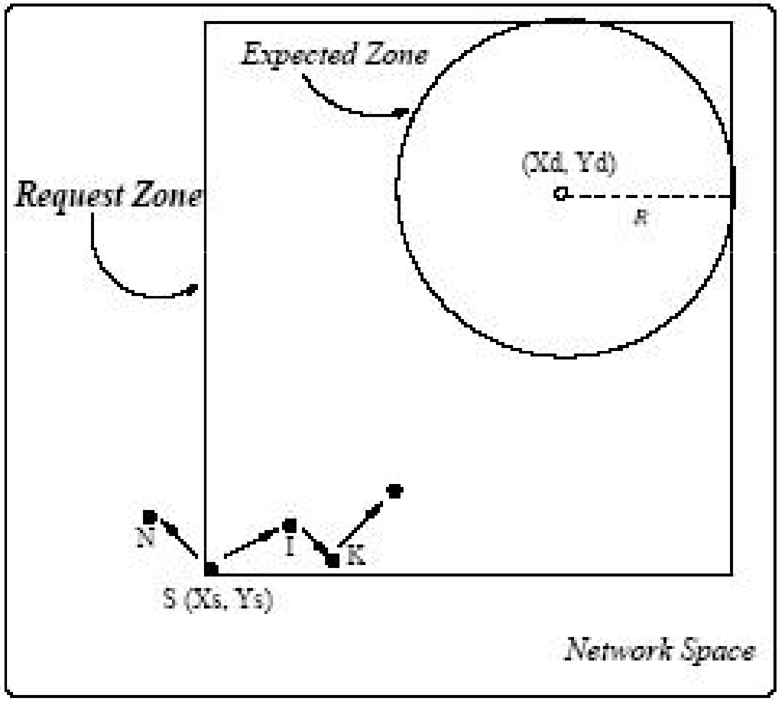
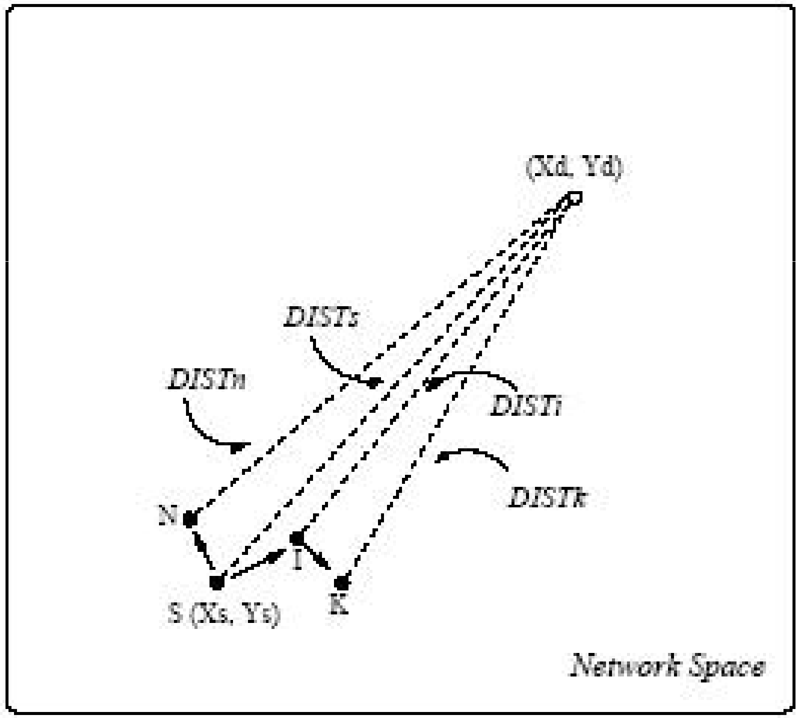


Figure 7.16. *RequestZone* and *ExpectedZone* in LAR1.

LAR Scheme



(a) LAR scheme 1



(b) LAR scheme 2

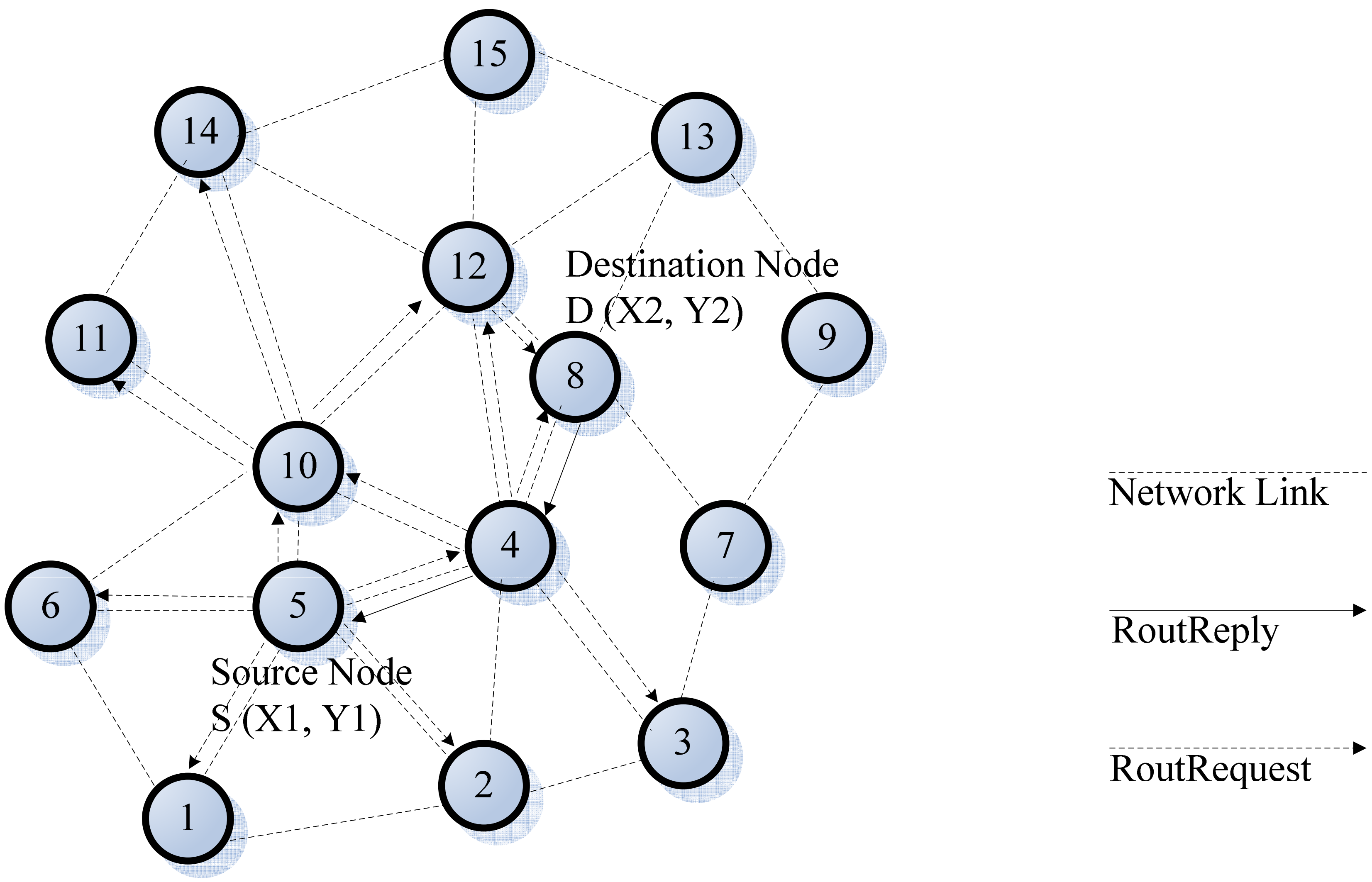


Figure 7.17. Route establishment in LAR2.

LAR

- Advantage
  - Reduce control overhead
  - Increase utilization bandwidth

- Disadvantage
  - Depend heavily on availability of GPS

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols
- Summery

Core Extraction Distributed Ad Hoc Routing Protocol (CEDAR)

- **CEDAR** is based on extracting *core nodes*, which together approximate the *minimum dominating set*
- **A dominating set** (DS) of a graph is defined as a set of nodes that 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 three hops
- **Core broadcast**: core nodes transmit any packet throughout the network in the unicast
  - Virtual link: the path between two core nodes
- QoS Path:
  - First phase: Finding a core path from the source node to the destination
  - Second phase: Finding a QoS feasible path over the core path

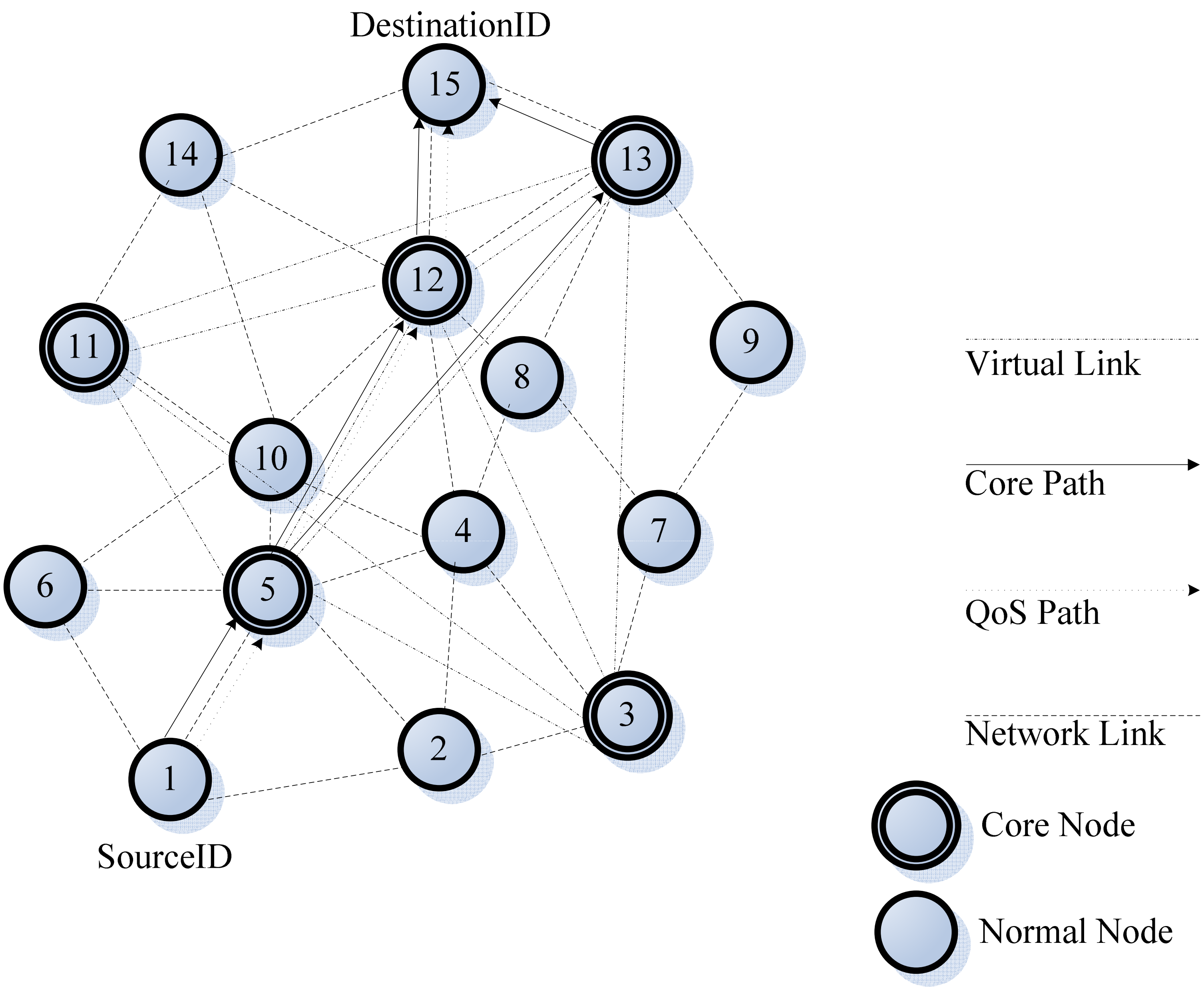


Figure 7.24. Route establishment in CEDAR.

CEDAR

- First phase
  - A node initiates a *RouteRequest* if the destination is not in the local topology table of its core node.
  - Source core node uses core broadcast to send *RouteRequest* to neighboring core nodes.
  - The recipient core node forwards the *RouteRequest* to its neighboring core nodes if the destination is not its core member.
  - A core node which has the destination as its core member replies to the source core.
- Second phase
  - *MidCore*: the farthest core node in the core path with required bandwidth found by the source core.
  - When the source finds a *MidCore*, *MidCore* becomes the new source core and finds another *MidCore* in the next iteration until a path to the destination with the required bandwidth is found.

CEDAR

- Broken path repair
  - When a link *u*-*v* on the path fails, node *u*
    - sends back a notification to the source node.
    - Starts re-computation of a route from s to destination
    - drops every subsequent packet that it receives until the recomputation gets completed.
  - The source node
    - stops transmitting immediately when it receives the notification.
    - starts reinitiating the route establishing from itself to the destination.

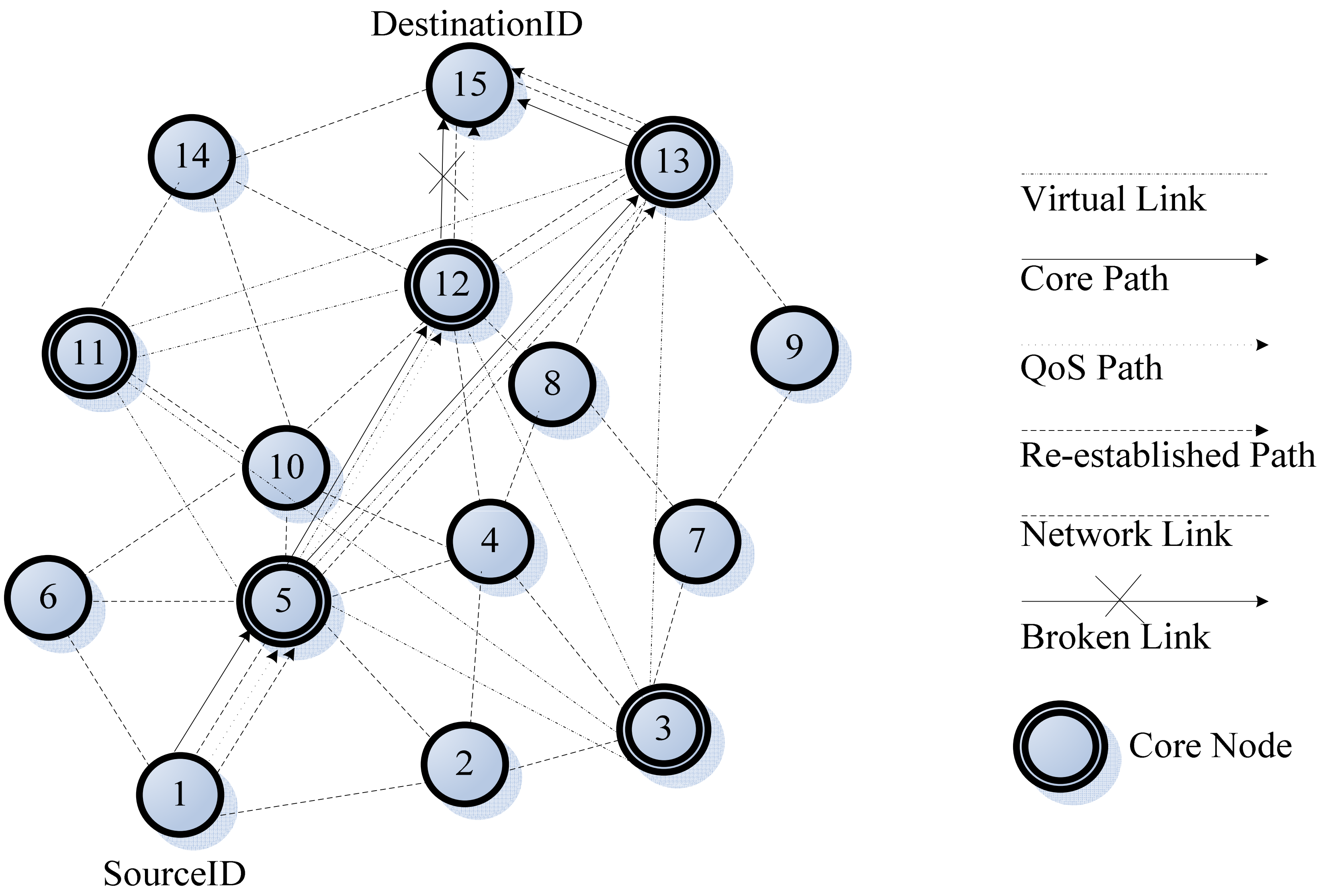


Figure 7.25. Route maintenance in CEDAR.

CEDAR

- Advantage
  - It performs both routing and QoS path computation very efficiently with the help of core nodes
- Disadvantage
  - The movement of the core nodes affects the performance of the protocol.
  - The update information of core nodes could cause a significant of control overhead.

Zone Routing Protocol (ZRP)

- Intra-zone routing protocol (Proactive routing)
  - It is only used in the routing zone.
  - It brakes all nodes in the routing zone into **interior nodes** and **peripheral nodes**.
  - Each node maintain routing path to all nodes in the routing zone by exchanging periodic route update packets.
- Inter-zone routing protocol (Reactive routing)

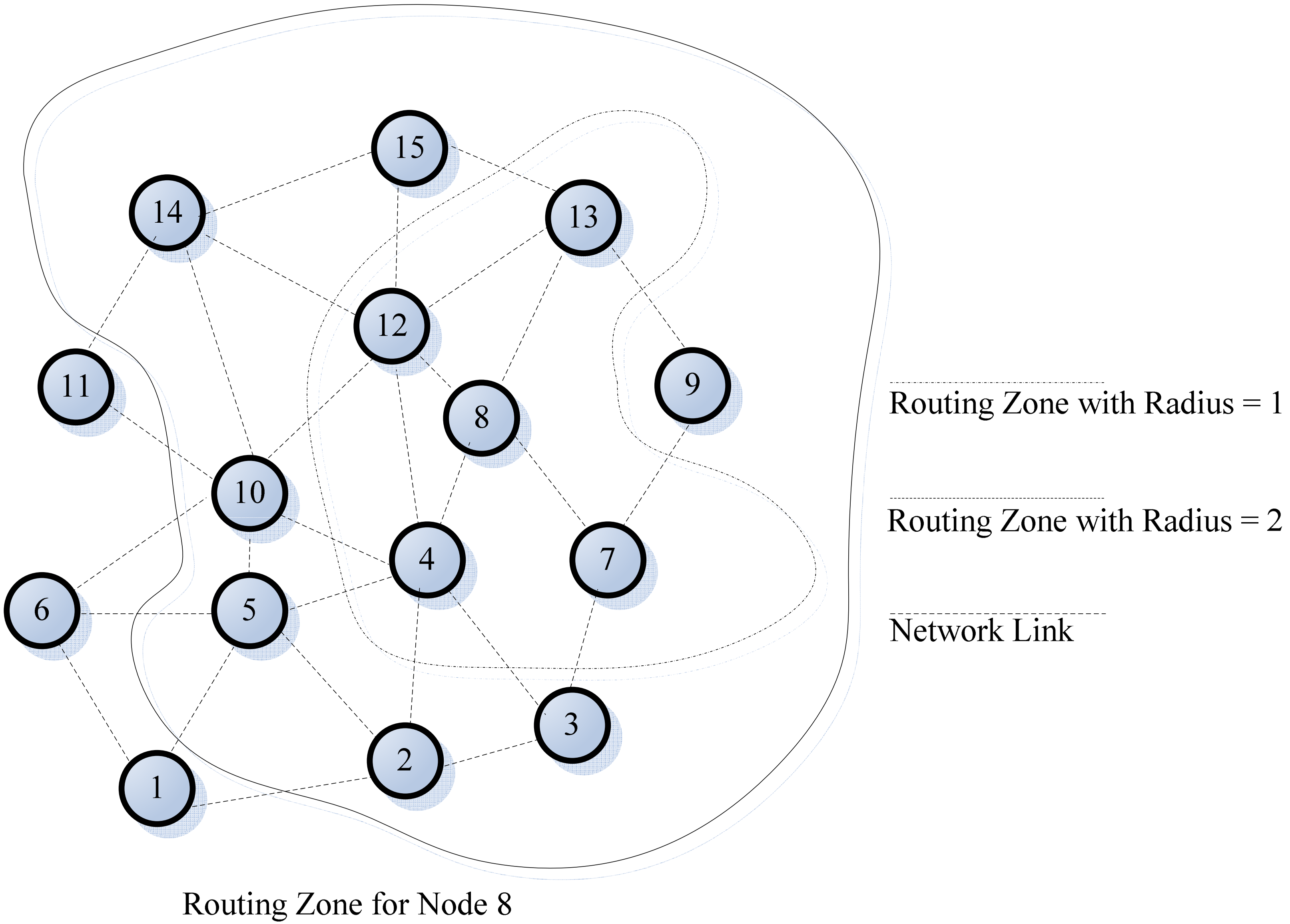


Figure 7.26. Routing Zone for node 8 in ZRP.

Zone Routing Protocol (ZRP)

- When a node *s* has packets to be sent to a node *d*
  - It checks whether node *d* is with in its zone.
  - If *d* isn't in the zone, *s* **broadcasts** (uses unicast routing) the *RouteRequest* to its peripheral nodes.
  - If any peripheral node finds *d* in its zone, it sends a *RouteReply* back to *s* indicating the path.
  - Otherwise, the peripheral node **rebroadcasts** the *RouteRequest* again.
- The query control must ensure that redundant or duplicate *RouteRequests* are not forwarded.
- The zone radius has significant impact on the performance.

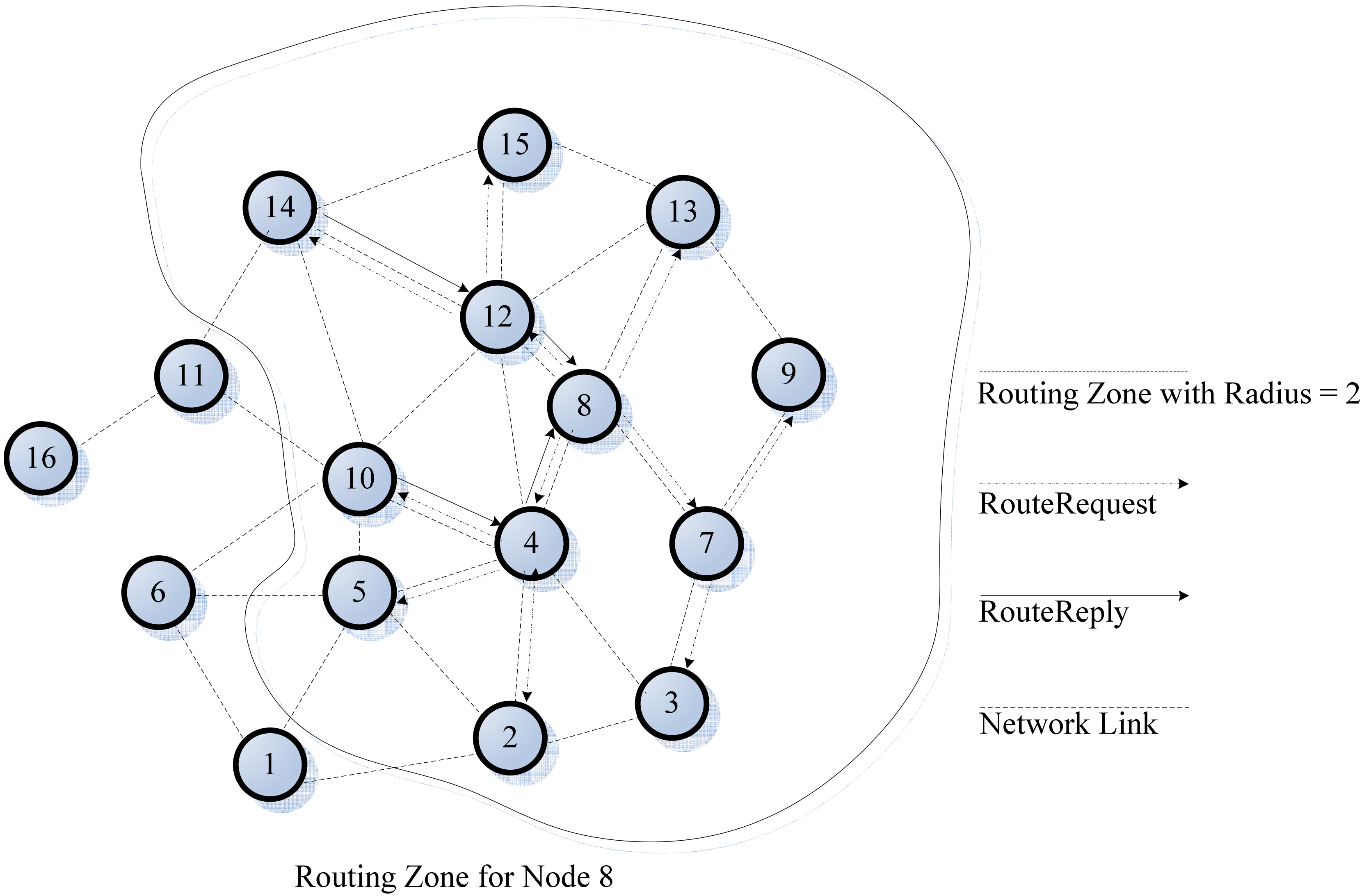


Figure 7.27. Path finding between node 8 and node 16.

ZRP

- Advantage
  - ZRP reduces the control overhead employed in on-demand approach and the periodic flooding of routing information in table-driven.
- Disadvantage
  - In the absence of a query control, ZRP tends to produce higher control overhead.
  - The decision on the zone radius has a significant impact on the performance of the protocol

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.
- **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 nodes receive link responses form nodes belonging to other zones.
  - Every nodes in a zone is aware of the neighboring zones and their corresponding Gateway nodes.

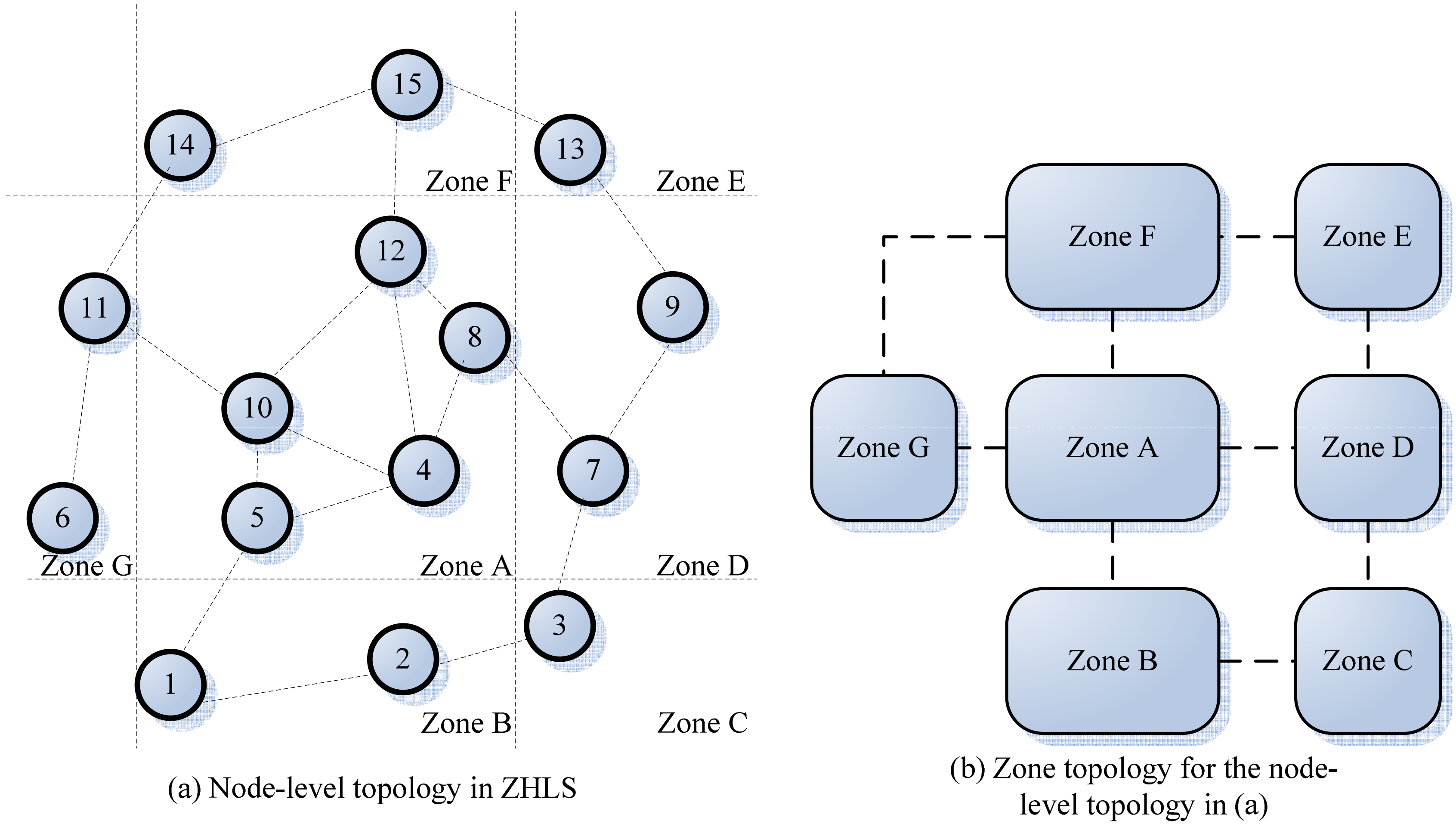


Figure 7.28. Zone-based hierarchical link state routing protocol.

Zone-Based Hierarchical Link State Routing Protocol (ZHLS)

- 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.

Source 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

Zone-Based Hierarchical Link State Routing Protocol (ZHLS)

- When a source node ***Src*** has packets to be sent to a node ***Dest***
  - If ***Dest*** is in the same zone, the packets are delivered by the intra-zone routing table.
  - If ***Dest*** is not in the zone, ***Src*** generates a location request packet 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 ***Src***.
- 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.

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols
- Summery

Routing Protocol With Efficient Flooding Mechanisms

- Existing routing protocols employ efficient flooding mechanisms to counter the requirement of flooding.
  - Preferred link-based routing (PLBR): On demand
  - Optimized link state routing (OLSR): Table-driven
- These protocols require a minimum number of retransmissions in order to flood the entire network.

Preferred Link-Based Routing Protocol (PLBR)

- *Neighbor List* (*NL*)
- *Preferred List* (*PL*): a subset of *NL*
  - Only the neighbors in *PL* forward the *RouteRequest* further.
- *Neighbor's Neighbor Table* (*NNT*)
- *RouteRequest*:
  - Contains *SrcID, DestID, SeqNum, TP(Traversed Path), TTL, NoDelay*
- Three phases
  - Route establishment
  - Route selection
  - Route maintenance

Preferred Link-Based Routing Protocol (PLBR)

- Route establishment
  - If ***Dest*** is in ***Src***'s *NNT*, the route is established directly.
  - Otherwise, ***Src*** transmits *RouteRequest*. And the *RouteRequest* is forwarded only
    - The node ID is in the *PL* (K entries) of received *RouteRequest*.
    - The *RouteRequest* must not have been forwarded by the node.
    - *TTL* is greater than zero.
  - Before forwarding, the node updates the *PL* of *RouteRequest* by its preference list table (*PLT*).
  - If ***Dest*** is in node's *NNT*, the node forwards *RouteRequest* as a unicast packet to the neighbor.

Preferred Link-Based Routing Protocol (PLBR)

- Route selection for *Dest*
  - Waiting *RouteSelectWait* period
  - The path has $Max(W^{i}_{min})$ is selected, where i is the number of *RouteRequest*.
  - If *NoDelay* is set, the *TP* of the first *RouteRequest* reaching the *Dest* is selected as the route.
- Route Maintenance
  - Bypassing the down link node form the broken path with the information in *NNT*.

Preferred Link-Based Routing Protocol (PLBR)

- Preferred Links Computation
  - Neighbor Degree-Based Preferred Link Algorithm (NDPL)
    - As higher degree neighbors cover more nodes, only a few of them are required to cover all the nodes of the NNT.
    - This reduces the number of broadcasts.
  - Weight-Based Preferred Link Algorithm (WBPL)
    - The notion of stability is based on the weight given to links.

Neighbor Degree-Based Preferred Link Algorithm (NPDL)

- *N*(*i*): neighbor of node *i* and itself. *INL*: a set of NB reachable by transmitting the *RouteRequest* packet. *EXL*: a set of NB unreachable by transmitting the *RouteRequest* packet. *TP*: the list of nodes the packet has traversed so far
  A. Node *d* adds *N*(*i*) to include list (*INL*).
     - A node *i* of *TP* is a neighbor of node *d*.
     - A node *i* of OLD_{PL} is a neighbor of node *d, and i* < *d*.
     - A node *i* is a neighbor of node *d* and has a neighbor *n* in *TP*.
     - A node *i* is a neighbor of node *d* and has a neighbor *n* in $OLD_{PL\backslash}$ and *n* < *d*
  B. If neighbor *i* of node *d* is not in *INL*, puts *i* in *PLT* and marks neighbors of *i* as reachable. If neighbor *i* is in *INL*, marks the neighbors of *i* as unreachable by adding them to exclude list (*EXL*).

Neighbor Degree-Based Preferred Link Algorithm (NPDL)

C. If neighbor *i* of node *d* has neighbor *n* in *EXL*, put *i* in *PLT*. Mark all neighbors of *i* as reachable and delete them from *EXL*.
   - After this step, all the nodes in NNT_d are reachable.

D. Reduction steps
   - Removing each neighbor *i* from *PLT* if *N*(*i*) is covered by remaining neighbors of *PLT*.
   - Removing neighbor *i* from *PLT* whose *N*(*i*) is covered by node *d* itself.

Weight-Based Preferred Link Algorithm (WBPL)

- WBPL
  - $W_i = WT^i_{time} + WT^i_{spatial}$
  - $WT^i_{time} = 1$ if $BCnt_i > TH_{bcon}$
    $= BCnt_i / TH_{bcon}$ otherwise
  - $WT^i_{spatial} = \dfrac{R - D_{Est}}{R}$
  - The neighbors are put into the *PLT* if they are in a non-increasing order of their weights.
  - If a link is overloaded, delete the associated neighbor from *PLT*.

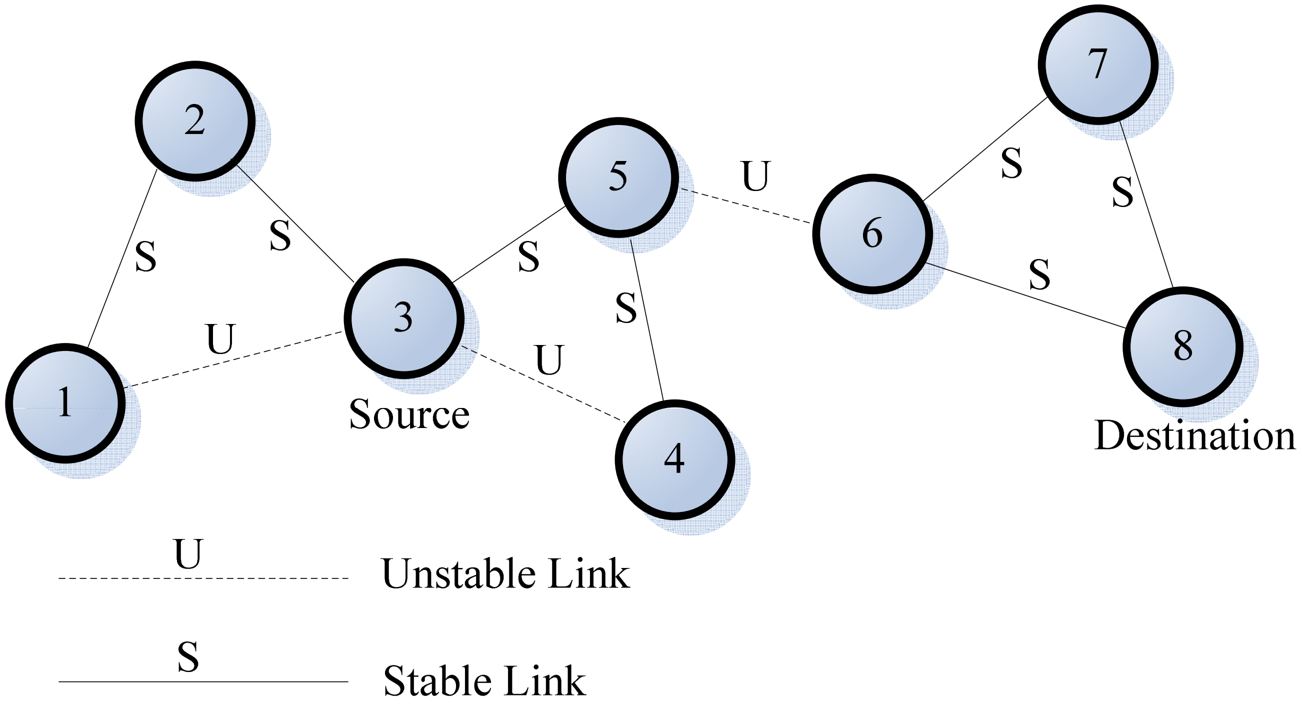
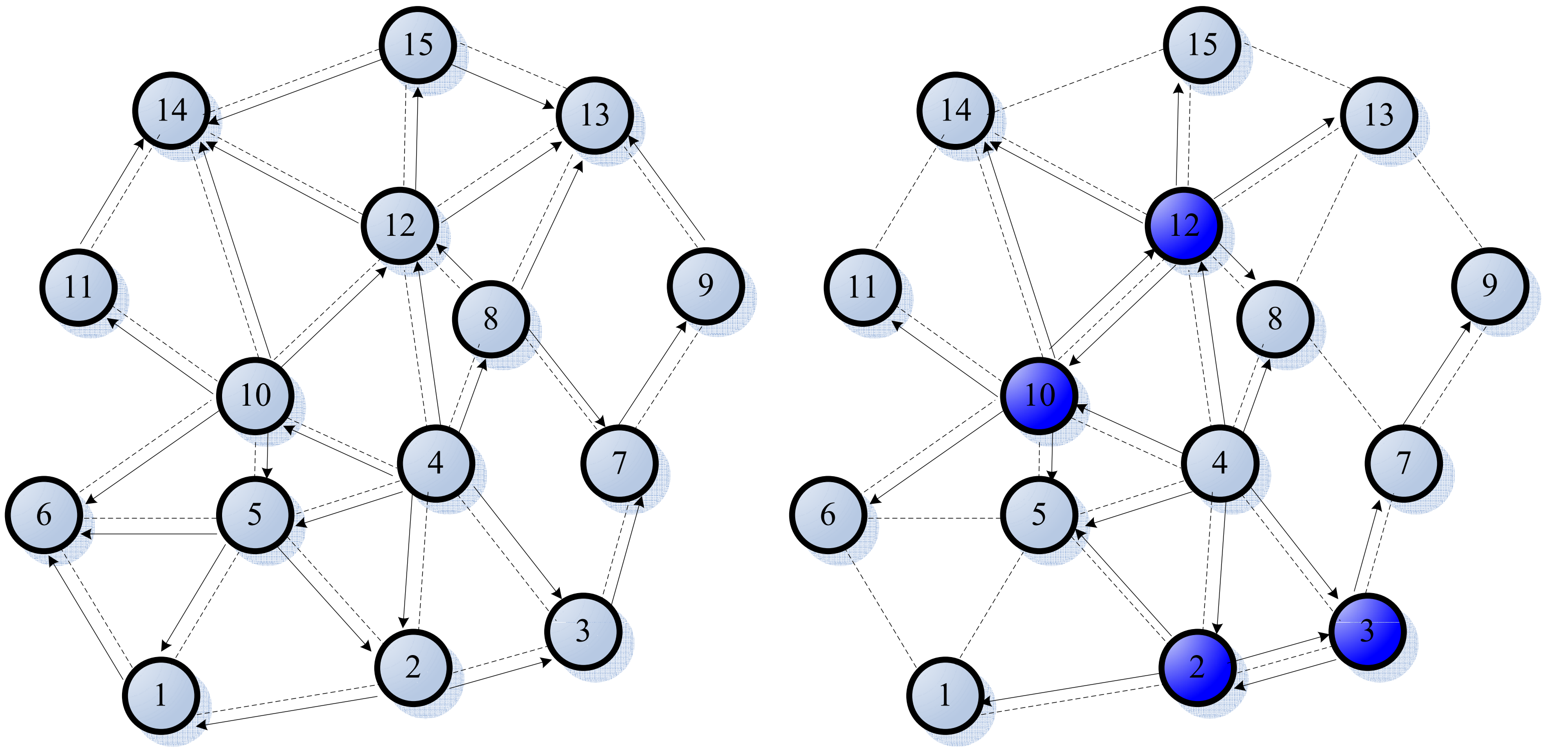


Figure 7.29. Example network. *Reproduced with permission from [20], © Korean Institute of Communication Sciences, 2002.*

Optimized Link State Routing (OLSR)

- Multipoint relays:
  - ***MPRset***:
    - *MPRset* processes and forwards every link state packet that node *P* originates.
    - The member of *MPRset* is selected in the manner that every node in the node's two-hop neighborhood has bidirectional link with the node.
  - ***MPR selectors***:
    - A node only forwards the packet received from its *MPRselector set*.
  - ***Hello message***:
    - The list of neighbor with which the node has bidirectional links.
    - The list of neighbor whose transmissions were received in the recent past but with whom bidirectional links have not yet been confirmed.



Node 4 selects MPRset <2, 3, 10, 12>

Network Link

Node belonging to MPRset of Node 4

Broadcast packets forwarded by members of MPRset

(a) Flooding the network takes as many transmissions as the number of nodes

(b) Flooding the entire network with six transmissions using MPR scheme

Figure 7.30. An example selection of MPRset in OLSR.

Optimized Link State Routing (OLSR)

- Topology Control (TC) packet
  - is periodically originated
  - contains *MPRselector* of every node
  - Floods throughout the network with *multipoint relaying* mechanism.
- Selection of the optimal MPRset is NP-complete.
  - ① $MPR(x) \leftarrow \Phi$
  - ② $MPR(x) \leftarrow$ {Those nodes that belong to $N_1(x)$ and which are the only neighbors of nodes in $N_2(x)$ }
  - ③ While there exists some node in $N_2(x)$ which is not covered by $MPR(x)$
    - ① Each node in $N_1(x)$,which is not in $MPR(x)$,compute the max number of nodes that it covers among the uncovered nodes in $N_2(x)$.
    - ② Add to $MPR(x)$ the node belonging to $N_1(x)$, for which this number is max.

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols
- Summery

Hierarchical Routing Protocols

- Using routing hierarchy.
- Reducing the size of routing table.
- Having better scalability.

Hierarchical State Routing Protocol (HSR)

- HSR operates by classifying different levels of clusters.
- Elected leaders at every level from the members at the immediate higher level.
- The physical clustering is done among the nodes that are reachable in a single wireless hop.
- Nodes are classified as
  - Cluster leaders
  - Gateway nodes：belonging to multiple clusters
  - Normal member nodes

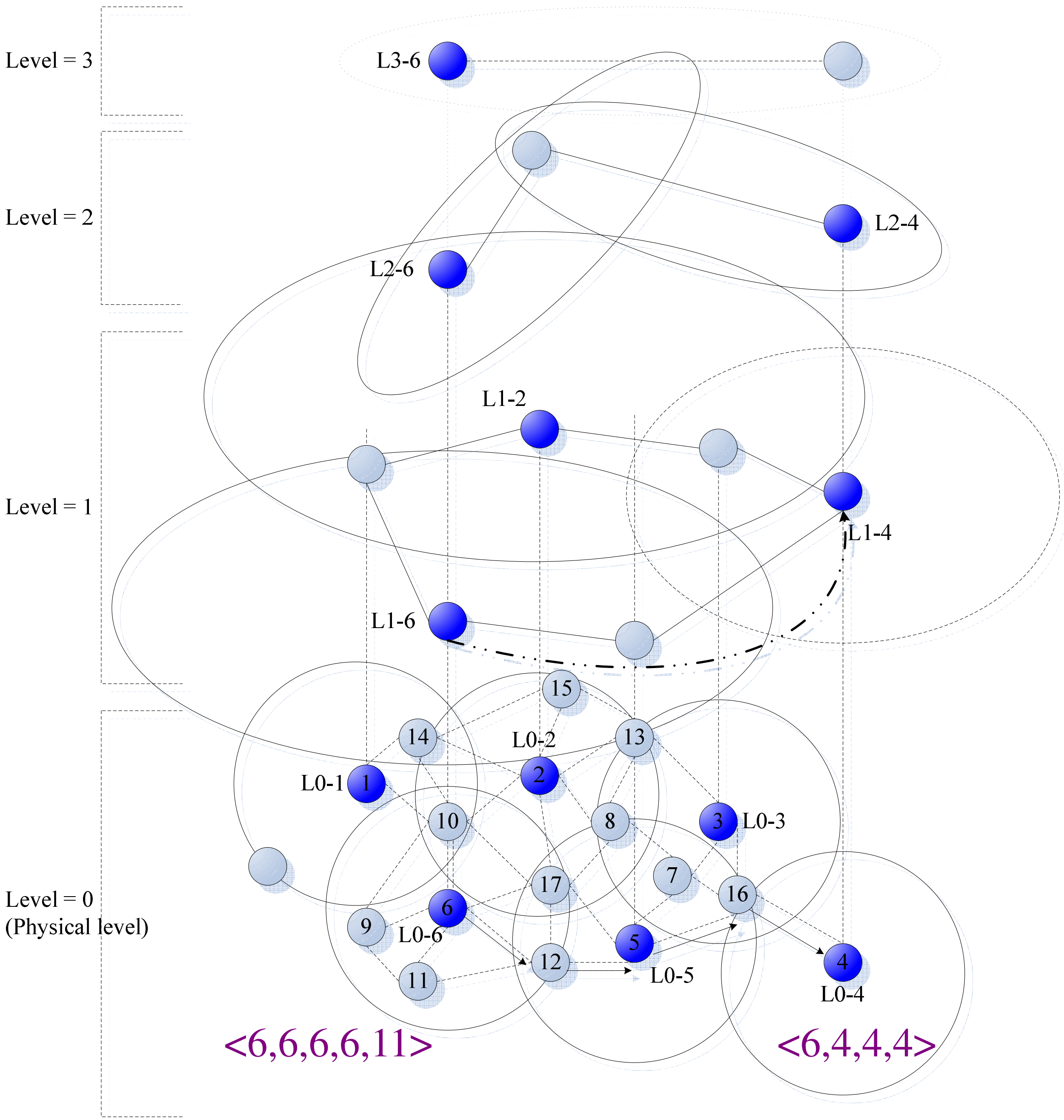


Figure 7.31. Example of HSR multi-level clustering.

Hierarchical State Routing Protocol (HSR)

- Cluster leaders must be responsible for
  - slot/frequency/code allocation
  - call admission control
  - scheduling of packet transmissions
  - exchange of routing information
  - handling route breaks
- Every node maintains information about neighbors and link states to each of them.
- This information is broadcast within the cluster at regular intervals.
- The clustering is done recursively to the higher levels
  - At any level, the cluster leaders exchange topology information with its peers.
  - After obtaining information from its peers, it floods the information to the lower levels.

Hierarchical State Routing Protocol (HSR)

- Hierarchical addressing can help in operation with reducing routing information exchanges.
- The storage required is $O(n \times m)$ compared to $O(n^m)$ that is required for a flat topology link state routing protocol.
  - n is the average number of nodes in a cluster.
  - m is the number of levels.
- In military applications of ad hoc networks, the hierarchy of routing assumes significance where devices with higher capabilities of communication can act as the cluster leaders.

Fisheye State Routing Protocol (FSR)

- **FSR** uses the *fisheye* technique to reduce routing overhead and graphical data.
- **FSR** maintains the topology of the network at every node and computes the shortest paths.
  - Periodically, every node exchanges topology information with sequence numbers only with its neighbors.
  - The accuracy decreases with an increase in the distance from the center of the focal point.
- ***Scope***: the set of nodes that can be reached in a specific numbers of hops.

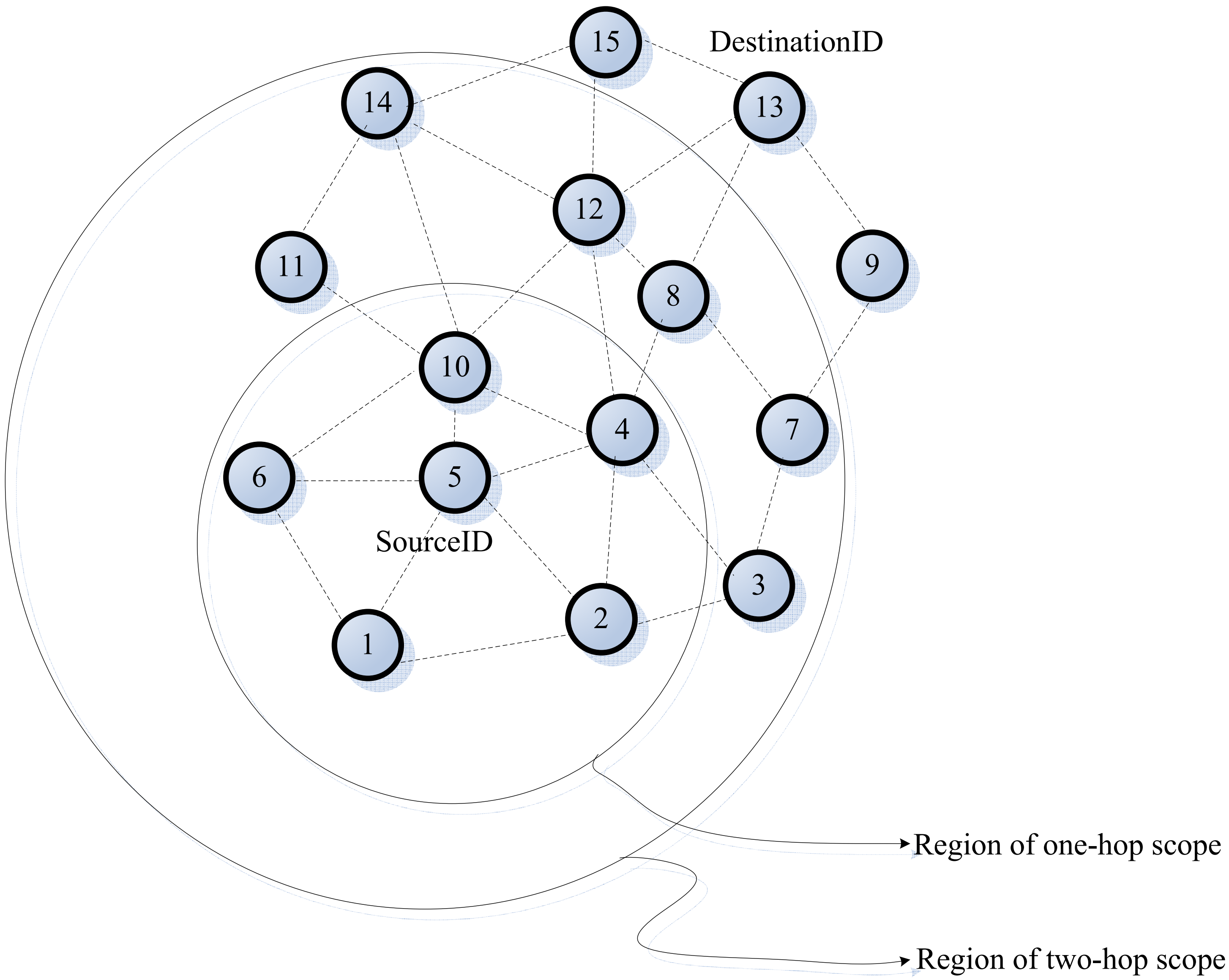


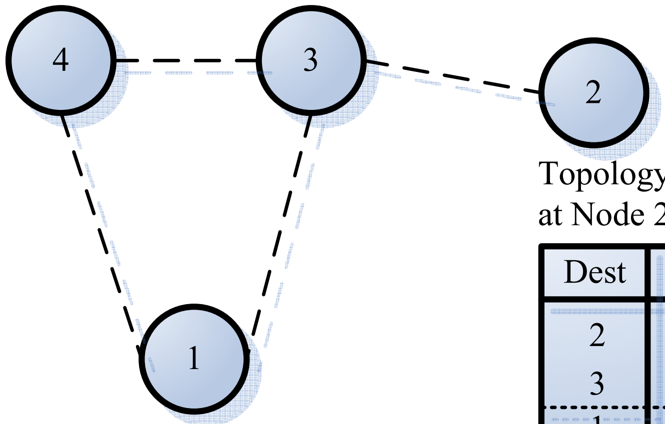
Figure 7.32. Fisheye state routing.

Topology Information at Node 3

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

Topology Information at Node 4

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



Topology Information at Node 2

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

Topology Information at Node 1

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

Figure 7.33. An illustration of routing tables in FSR.

Fisheye State Routing Protocol (FSR)

- The frequency of exchanges decrease with an increase in scope.
- The path information for far-away nodes may be inaccurate.
- FSR is suitable for large and highly mobile ad hoc wireless networks.
- The number of hops with each scope level has significant influence on the performance.

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols
- Summery

Power-Aware Routing Protocols

- In ad hoc networks, the routers are also equally power-constrained just as the nodes are.
- The use of routing metrics that consider the capabilities of the power source of nodes contributes to efficient utilization of energy and increases the lifetime of the networks.

Power-Aware Routing Metrics

- Minimal Energy Consumption per Packet
  - Minimize the power consumed by a packet in traversing from the source node to the destination node
- Maximize Network Connectivity
  - Balance the routing load among the *cut-set*
- Minimum Variance in Node Power Levels
  - Distribute the load among all nodes in the network
  - Remain uniform power consumption pattern across all nodes
- Minimum Cost per Packet
  - Maximize the life of every node in the network
- Minimize Maximum Node Cost
  - Minimize the maximum cost per node for a packet after routing a number of packets or after a specific period

- Table-Driven Routing Protocols
- On-Demand Routing Protocols
- Hybrid Routing Protocols
- Routing Protocol With Efficient Flooding Mechanisms
- Hierarchical Routing Protocols
- Power-Aware Routing Protocols
- Summery

Summary

- The major challenges of an ad hoc wireless routing protocol
  - The mobility of nodes
  - Rapid changes in topology
  - Limited bandwidth
  - Hidden and exposed terminal problems
  - Limited battery power
  - Time-varying channel properties
  - Location-dependent contention

Exercises

- 4, 6, 7(for DSR), 8, 11, 12