# Routing protocols for ad hoc networks

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**OUTLINE:**

- Introduction
- Classification
- Proactive routing protocols
- Reactive routing protocols
- Hybrid routing protocols
- Hierarchial routing protocols
- Power-aware routing protocols

# 1. Introduction

**What we have in ad hoc environment:**

- dynamically changing topology;
- absence of fixed infrastructure and centralized administration;
- bandwidth constrained wireless links;
- energy-constrained nodes.

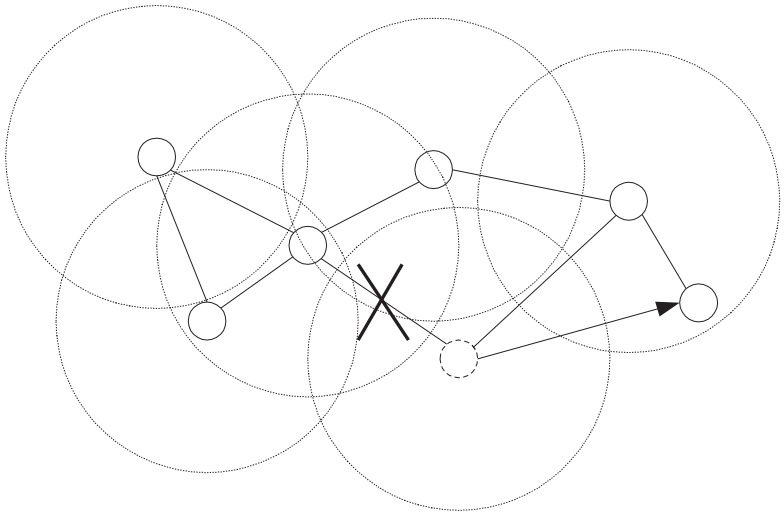


Figure 1: Link loss is one of the biggest problem for routing.

## 1.1. Challenges of routing protocols in ad hoc networks

**The following are the main challenges:**

- Movement of nodes:
  - Path breaks;
  - Partitioning of a network;
  - Inability to use protocols developed for fixed network.
- Bandwidth is a scarce resource;
  - Inability to have full information about topology;
  - Control overhead must be minimized.
- Shared broadcast radio channel:
  - Nodes compete for sending packets;
  - Collisions.
- Erroneous transmission medium:
  - Loss of routing packets.

## 1.2. Design goals

**Goals that must be met:**

- must be scalable;
- must be fully distributed, no central coordination;
- must be adaptive to topology changes caused by movement of nodes;
- route computation and maintenance must involve a minimum number of nodes;
- must be localized, global exchange involves a huge overhead;
- must be loop-free;
- must effectively avoid stale routes;
- must converge to optimal routes very fast;
- must optimally use the scare resources: bandwidth, battery power, memory, computing;
- should provide QoS guarantees to support time-sensitive traffic.

# 2. Classification of routing protocols

**Routing protocols for ad-hoc wireless networks can be classified based on:**

- routing information update mechanism;
- usage of temporal information (e.g. cached routes);
- usage of topology information;
- usage of specific resources (e.g. GPS).

**Based on routing information update mechanism**

- Proactive (table-driven) routing protocols;
- Reactive (on-demand) routing protocols;
- Hybrid protocols.

**Based on usage of temporal information**

- Based on past temporal information;
- Based on future temporal information.

**Based on the routing topology**

- Flat topology routing protocols:
- Hierarchial topology routing protocols:

**Routing based on utilization of specific resources:**

- Power-aware routing;
- Geographical information assisted routing.

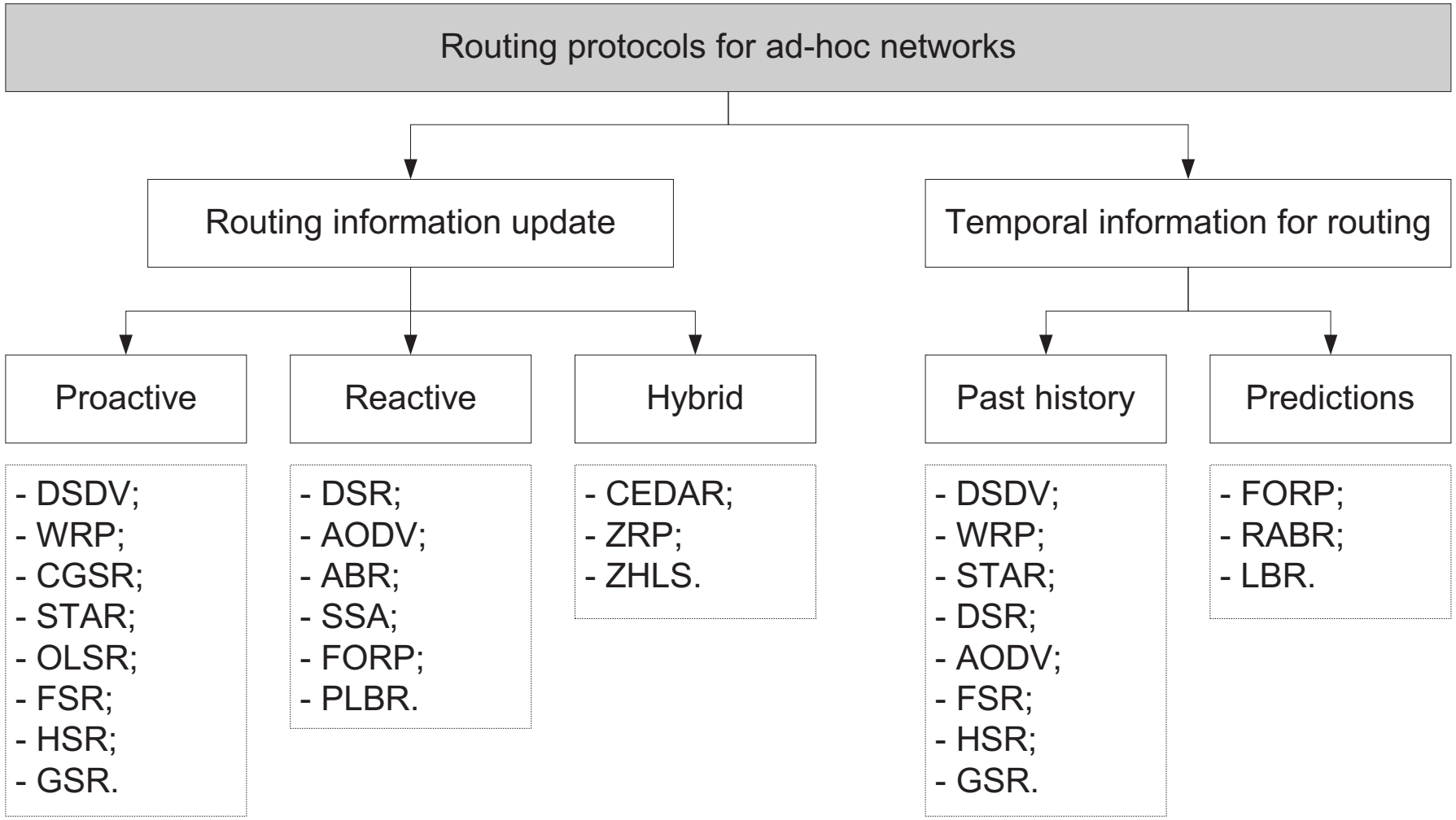



Figure 2: Classification of routing protocols, part I.

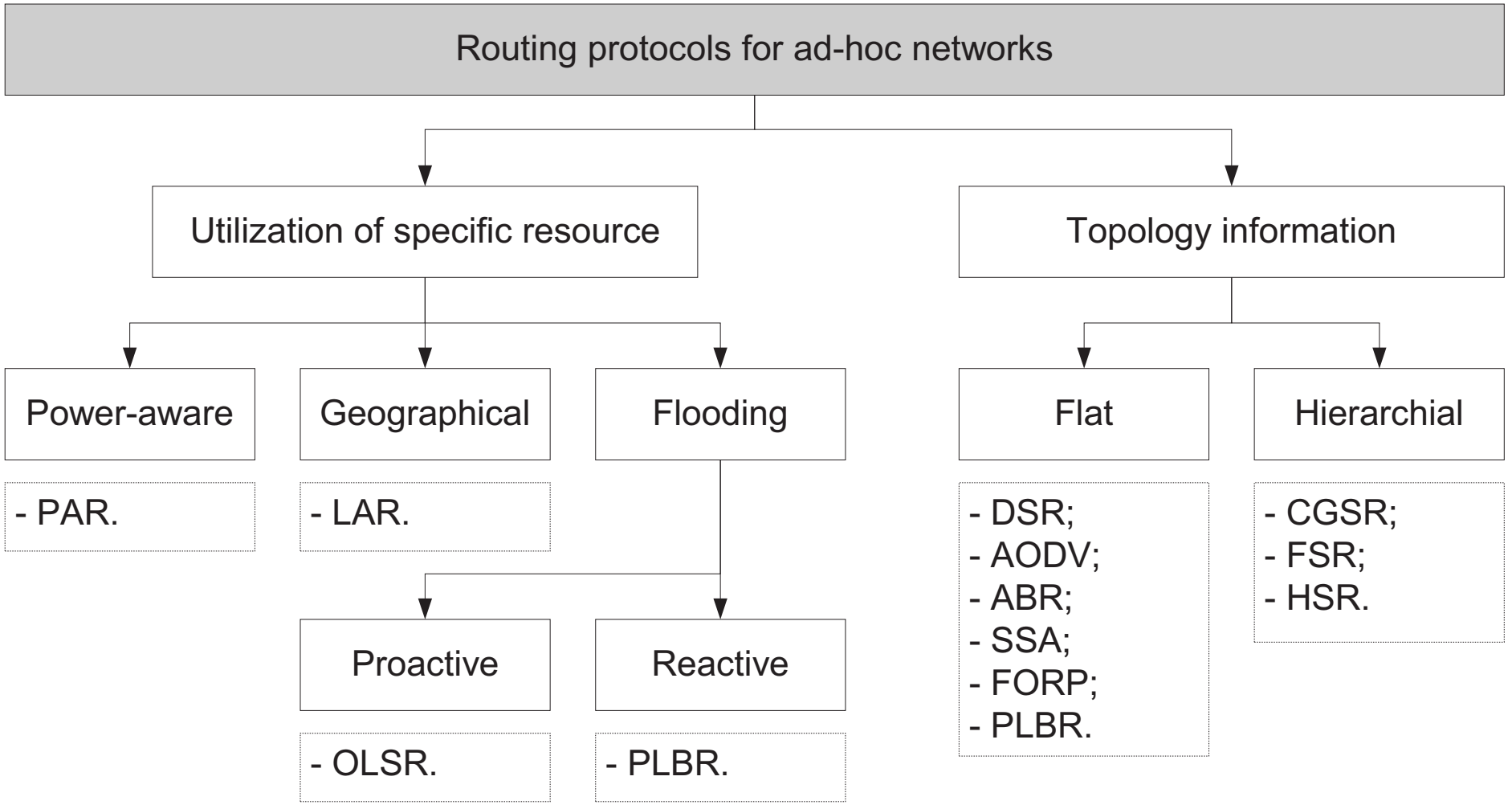



Figure 3: Classification of routing protocols, part II.

# 3. Proactive routing protocols

These are table-driven protocols.

**We consider:**

- destination sequenced distance vector routing protocol (DSDV);
- wireless routing protocol (WRP);
- cluster head gateway routing protocol (CGCR).
- source-tree adaptive routing protocol (STAR);

**Common advantages and shortcoming of these protocols:**

- +: low delay of route setup process: all routes are immediately available;
- −: high bandwidth requirements: updates due to link loss leads to high control overhead;
- −: low scalability: control overhead is proportional to the number of nodes;
- −: high storage requirements: whole table must be in memory.

## 3.1. Destination sequenced distance vector routing protocol (DSDV)

**Modification of the Bellman-Ford algorithm where each node maintains:**

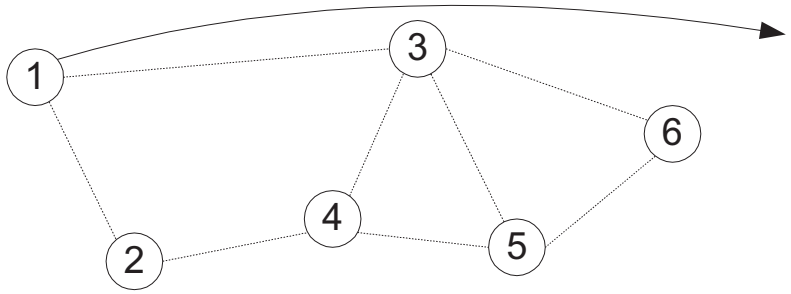
- the shortest path to destination;
- the first node on this shortest path.

**This protocol is characterized by the following:**

- routes to destination are readily available at each node in the routing table (RT);
- RTs are exchanged between neighbors at regular intervals;
- RTs are also exchanged when significant changes in local topology are observed by a node.

**RT updates can be of two types:**

- incremental updates:
  - take place when a node does not observe significant changes in a local topology;
- full dumps:
  - take place when significant changes of local topology are observed;



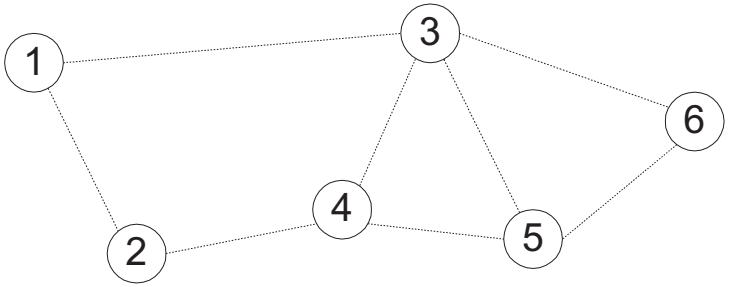

| Dest | Next | Dist |
|---|---|---|
| 6 | 3 | 2 |
| 5 | 3 | 2 |
| 4 | 2 | 2 |

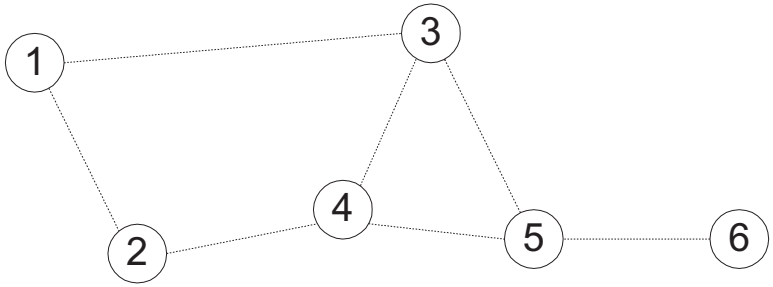
Figure 4: Example of routing table in DSDV.

**The reconfiguration of path (used for ongoing data transfer) is done as follows:**

- the end node of the broken link sends a table update message with:
  - broken link's weight assigned to infinity;
  - sequence number greater than the stored sequence number for that destination.
- each node re-sends this message to its neighbors to propagate the broken link to the network;
- even sequence number is generated by end node, odd – by all other nodes.

**Note:** single link break leads to the propagation of RT updates through the whole network!




| Dest | Next | Dist |
|---|---|---|
| **6** | **3** | **3** |
| 5 | 3 | 2 |
| 4 | 2 | 2 |

Figure 5: Route update in DSDV.

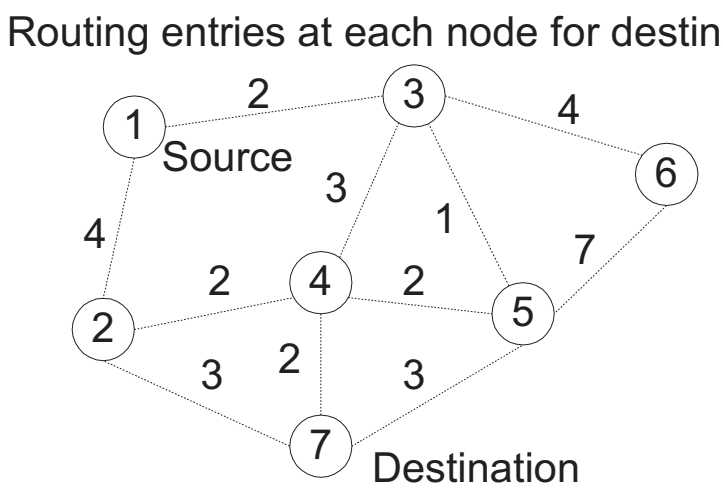
**Route maintenance in DSDV is performed as follows:**

- when a neighbor node perceives a link break (node 3):
  - it sets all routes through broken link to $\infty$;
  - broadcasts its routing table.
- node 5 receives update message, it informs neighbors about the shortest distance to node 6;
- this information is propagated through the network and all node updates their RTs;
- node 1 may now sends their packets through route $1-3-5-6$ instead of $1-3-6$.

## 3.2. Wireless routing protocol (WRP)

**Each node maintains the following:**

- Distance table (DT) containing network view of the neighbors of the node:
  - distance and predecessor node for all destinations as seen by each neighbor.
- Routing table (RT) containing view of the network for all known destinations including:
  - the shortest distance to destinations;
  - the predecessor node;
  - the successor node;
  - flag indicating the status of the path (correct, loop, null).
- Link cost table (LCT) containing cost-related information including:
  - number of hops to reach destination (cost of the broken link is $\infty$);
  - number of update periods passed from the last successful update of the link.
- Message retransmission list (MRL) containing counter for each entry:
  - the counter is decremented after every retransmission of the update message.




| Dest | Next | Pred | Cost |
|---|---|---|---|
| 7 | 7 | 7 | 0 |
| 6 | 3 | 5 | 8 |
| 5 | 7 | 5 | 3 |
| 4 | 7 | 4 | 2 |
| 3 | 5 | 5 | 4 |
| 2 | 7 | 2 | 3 |
| 1 | 3 | 5 | 6 |

Figure 6: Routing table in WRP.

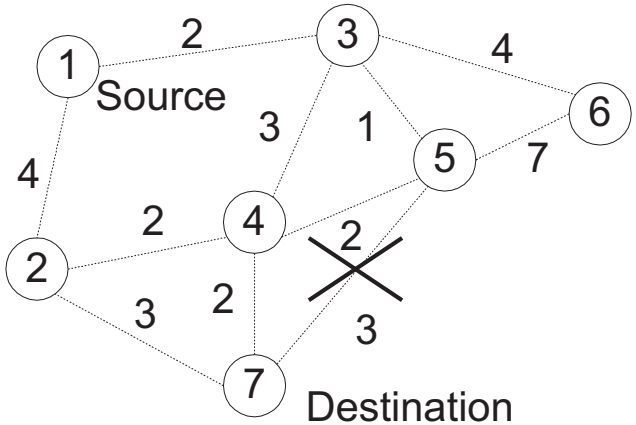
**Break: detected by number of update periods missed since successful transmission:**

- each update message contains a list of updates;
- a node marks each node in RT that has to acknowledge update message it transmitted;
- once the counter of MRL reaches zero:
  - entries in update message for which no acknowledgement received are to be retransmitted;
  - update message is deleted.

**When a node detects a link break:**

- it sends an update message to its neighbors with link cost set to $\infty$;
- all affected node update their routes when they receive update message;
- the node that initiated the update message finds an alternative route from its DT;
- it updates its RT and sends update message to its neighbors;
- nodes update its RTs if this received route is better than they have, otherwise they discard it.

| Dest | Next | Pred | Cost |
|---|---|---|---|
| 7 | 7 | 7 | 0 |
| 6 | 3 | 5 | 8 |
| 5 | 7 | 5 | 3 |
| 4 | 7 | 4 | 2 |
| 3 | 5 | 5 | 4 |
| 2 | 7 | 2 | 3 |
| 1 | 3 | 5 | 6 |




| Dest | Next | Pred | Cost |
|---|---|---|---|
| 7 | 7 | 7 | 0 |
| **6** | **3** | **4** | **9** |
| **5** | **4** | **4** | **4** |
| 4 | 7 | 4 | 2 |
| **3** | **4** | **4** | **5** |
| 2 | 7 | 2 | 3 |
| **1** | **2** | **2** | **7** |

Figure 7: Route maintenance in WRP.

## 3.3. Cluster head gateway switch routing protocol (GGSR)

**It is characterized by the following:**

- nodes are organized into clusters, each having an elected cluster-head;
- cluster head provides a coordination within its transmission range (single hop);
- token-based scheduling is used within a cluster for sharing bandwidth between nodes;
- all communications pass through the cluster head;
- communication between cluster is done using the common nodes (gateways with two interfaces).

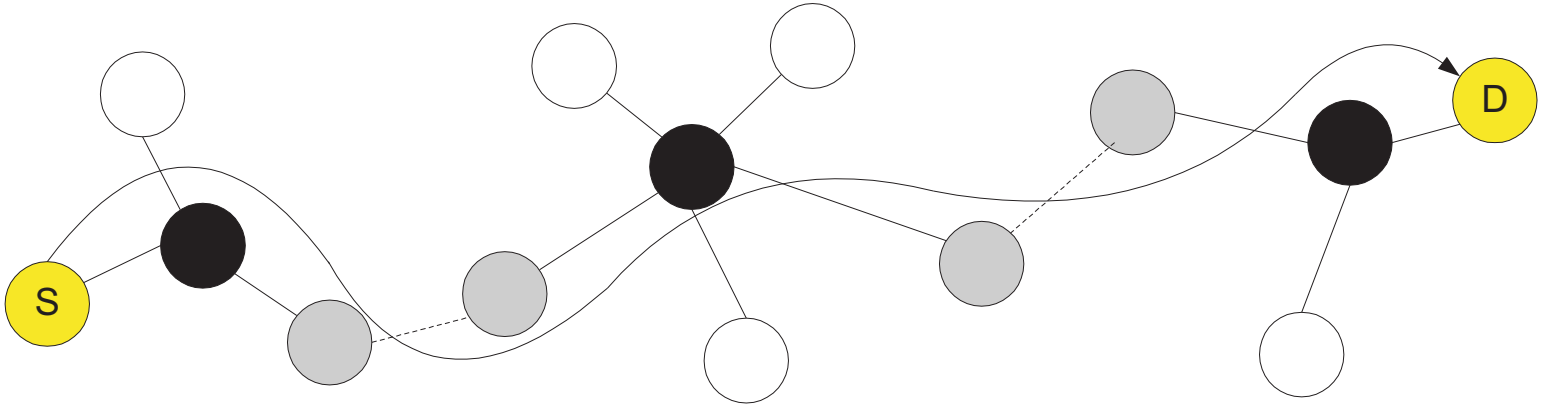



Figure 8: Abstract representation of routing in GGSR.

**Two tables are used in CGSR:**

- Cluster member table containing the destination cluster head for every node;
- Routing table containing the next-hop node for every destination cluster.

**The protocol operates as follows:**

- a node obtains a token from its cluster head;
- if this node has a packet to transmit, it determines the destination cluster head and next-hop;
- routed packet goes as follows:
  - $a - H_1 - G_1 - H_2 - G_2 - \cdots - H_i - G_i - \cdots - G_n - H_n - b$: where
  - $G_i$ is the gateway $i$;
  - $H_i$ is the cluster head $i$.

**Route reconfiguration happens when:**

- there is a change in cluster heads;
- stale entries are in cluster member table or routing table.

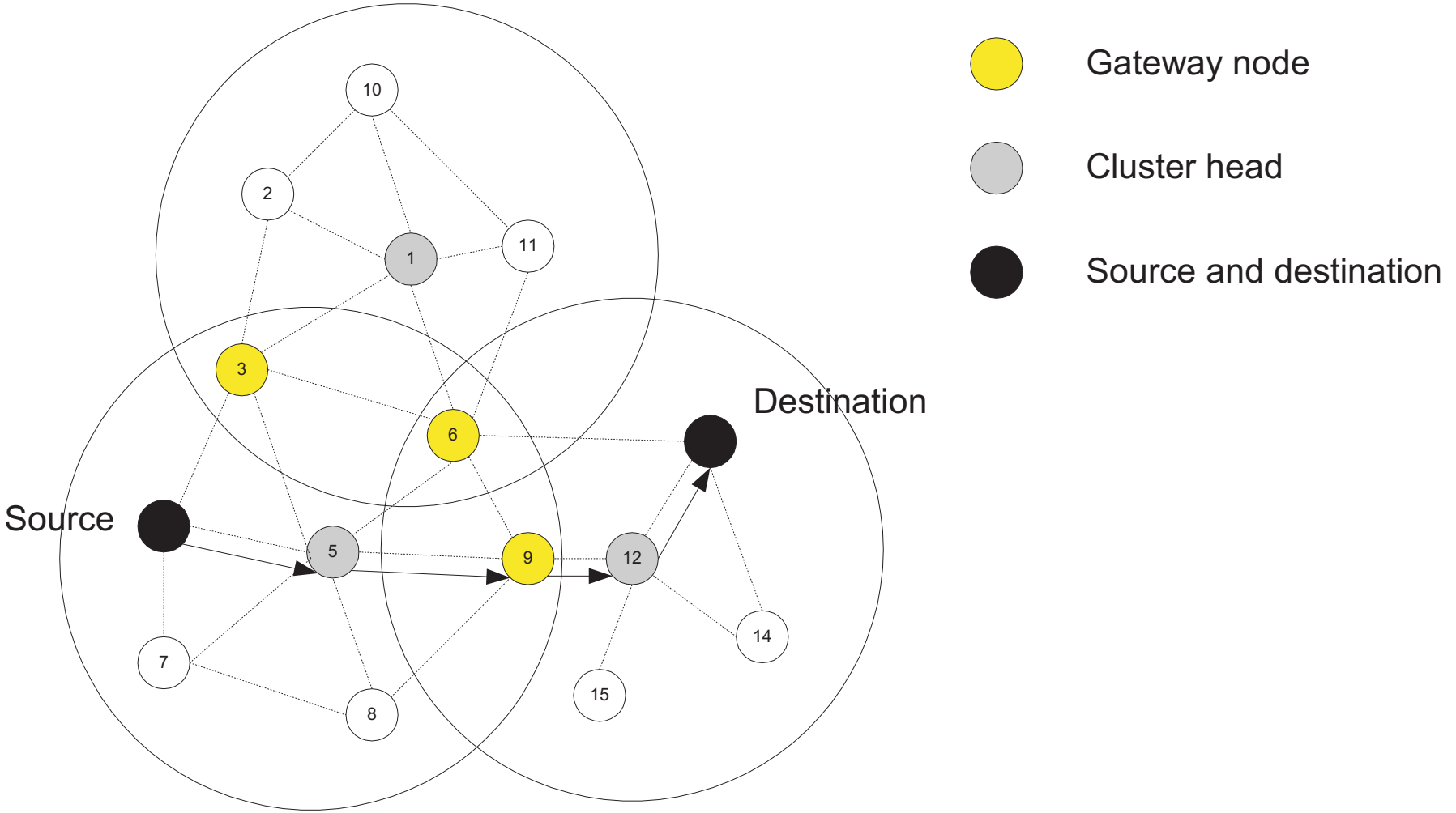



Figure 9: Route path in CGSR.

## 3.4. Source-tree adaptive routing protocol (STAR)

**There are two protocols with different aims:**

- Least overhead routing approach (LORA):
  - minimize control overhead irrespective of optimality;
- Optimum routing approach (ORA):
  - provide optimal routes irrespective of the control overhead;

**The STAR protocol operates as follows:**

- each node is required to:
  - send an update message to its neighbors during initialization;
  - send update messages about new destinations, chances of routing loops, costs of paths.
- every node broadcasts its **source-tree** information:
  - wireless links used by the node in its preferred path to destinations.
- every node builds its partial graph of topology based on:
  - its adjacent links with neighbors, source-tree broadcasts by neighbors.

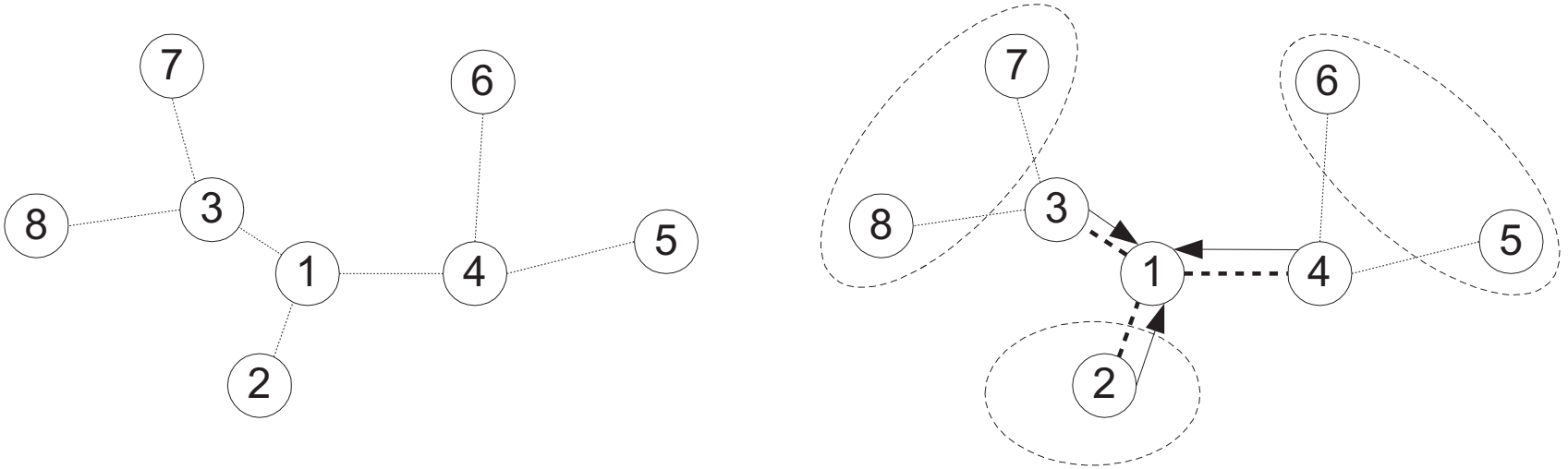



Figure 10: Local topology construction.

**The following method is used to find paths:**

- if a node 1 wishes to send data to node $N$ and does not have path in its source tree:
  - it sends update message to all neighbors and indicates that there is no path to $N$;
  - neighbor that have the path, responses with update messages;
  - node 1 updates its source tree and may begin transmission.

# 4. Reactive routing protocols

These protocols find paths to destination only when needed (on-demand) to transmit a packet.

**We consider:**

- Dynamic source routing protocol (DSR);
- Ad hoc on-demand distance vector routing protocol (AODV);
- Location aided routing (LAR);
- Associativity-based routing (ABR);
- Signal stability-based adaptive routing protocol (SSA);

**These protocols have the following advantages and shortcomings:**

- −: high delay of route setup process: routes are established on-demand;
- +: small control overhead: no route updates;
- −: low scalability: no route updates;
- −: low storage requirements: only needed routes are in cache.

## 4.1. Dynamic source routing protocol

This is a source-based routing protocol.

**The difference between DSR and other on-demand routing protocols is:**

- on-demand protocols periodically exchange the so-called **beacon** (hello) packets:
  - hello packets are used to inform neighbors about existence of the node.
- DSR does not use hello packets.

**The basic approach of this protocol is as follows:**

- during route contraction DSR floods a RouteRequest packets in the network;
- intermediate nodes forward RouteRequest if it is not redundant;
- destination node replies with RouteReply;
- the RouteReply packet contains the path traversed by RouteRequest packet;
- the receiver responds only if this is a first RouteRequest (not duplicate).

**The DSR protocol uses the sequence numbers:**

- RouteRequest packet carries the path traversed and the sequence number;
- the sequence numbers are used to prevent loop formation and nodes check it.

**The DSR also uses route cache in each node:**

- if node has a route in the cache, this route is used.

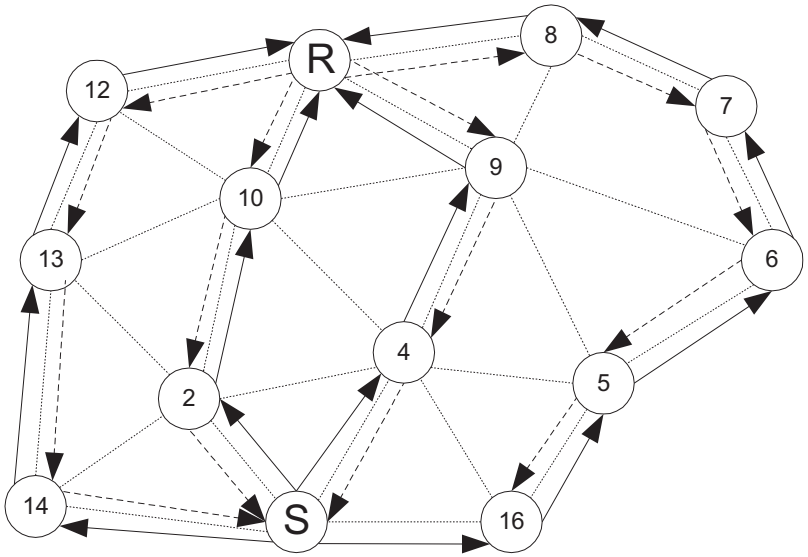



Figure 11: Route establishment in DSR.

**Refinements of DSR:**

- to avoid over-flooding the network, exponential back-off is used between RouteRequest sending;
- intermediate node is allowed to reply with RouteReply if it has a route to destination in cache:
- if the link is broken the RouteError is sent to the sender by node adjacent to a broken link.

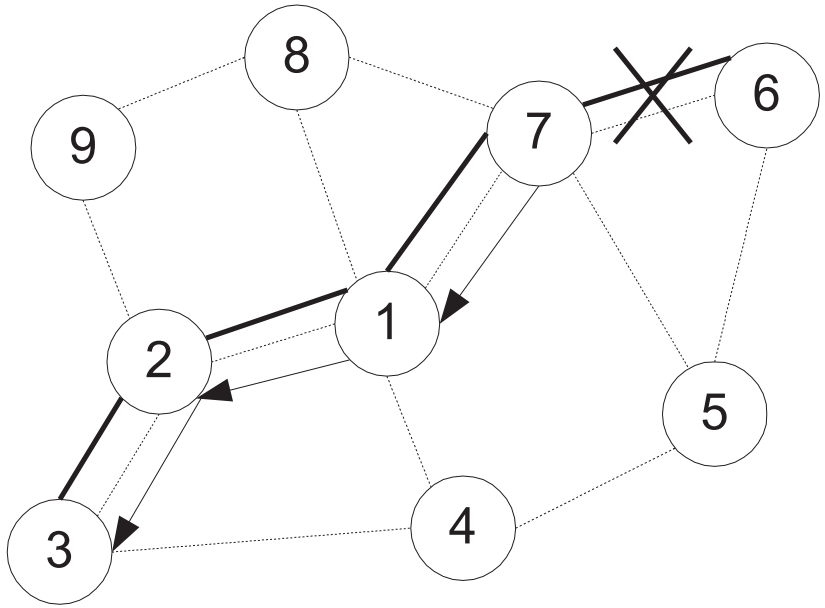



Figure 12: Route failure notification in DSR.

## 4.2. Ad hoc on-demand distance vector routing protocol

**The major differences between AODV and DSR are as follows:**

- in DSR a data packet carries the complete path to be traversed;
- in AODV nodes store the next hop information (hop-by-hop routing) for each data flow.

**The RouteRequest packet in AODV carries the following information:**

- the source identifier (SrcID): this identifies the source;
- the destination identifier (DestID): this identifies the destination to which the route is required;
- the source sequence number (SrcSeqNum);
- the destination sequence number (DestSeqNum): indicates the freshness of the route.
- the broadcast identifier (BcastID): is used to discard multiple copies of the same RouteRequest.
- the time to live (TTL): this is used to not allow loops.

**The AODV protocol performs as follows:**

- when a node does not have a valid route to destination a RouteRequest is forwarded;
- when intermediate node receives a RouteRequest packet two cases are possible:
  - if it does not have a valid route to destination, the node forwards it;
  - if it has a valid route, the node prepares a RouteReply message:
- if the RouteRequest is received multiple times, the duplicate copies are discarded:
  - are determined comparing BcastID-SrcID pairs.
- when RouteRequest is forwarded, the address of previous node and its BcastID are stored;
  - are needed to forward packets to the source.
- if RouteReply is not received before a time expires, this entry is deleted;
- either destination node or intermediate node responses with valid route;
- when RouteRequest is forwarded back, the address of previous node and its BcastID are stored;
  - are needed to forward packets to the destination.

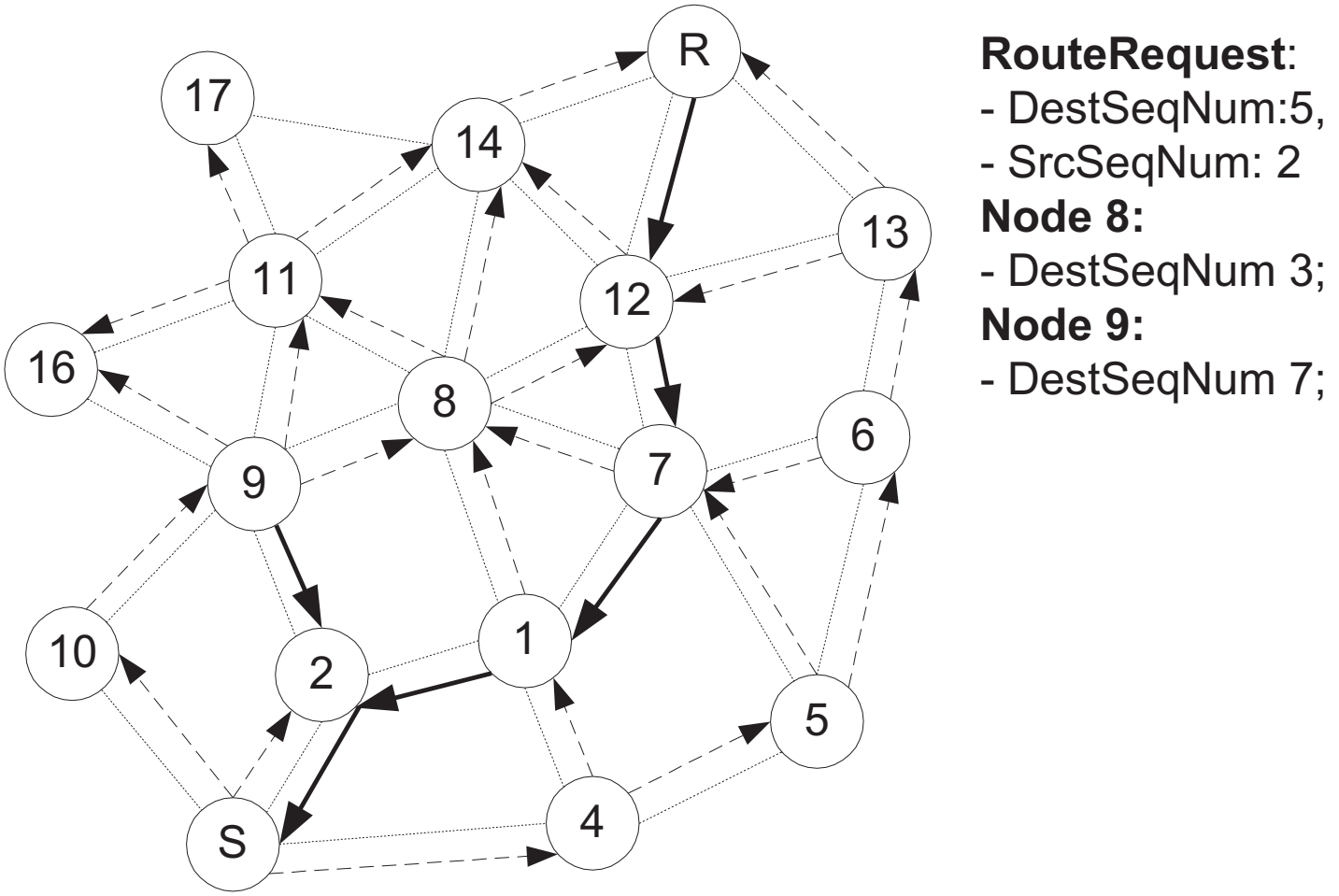



Figure 13: Route establishment in AODV.

**In case of the link break:**

- end-node are notified by unsolicited RouteReply with hop count set to $\infty$;
- end-node deletes entries and establishes a new path using new BcastID;
- link status is observed using the link-level beacons or link-level ACKs.

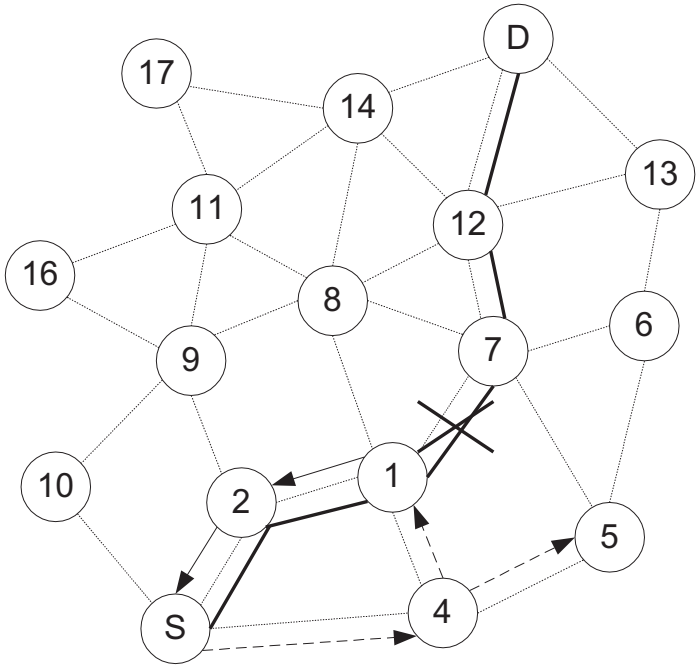



Figure 14: Route maintenance in AODV.

## 4.3. Location aided routing

**What are basics of LAR:**

- uses the location information (assumes the availability of GPS);
- reactive (on-demand) protocol.

**LAR designates two zones for selective forwarding of control packets:**

- **ExpectedZone**:
  This is a geographical zone in which the location of the terminal is predicted based on:
  - location of the terminal in the past;
  - mobility information of the terminal.

  There is no info about previous location of the terminal the whole network is the ExpectedZone.
- **RequestZone**:
  This is a geographical zone within which control packets are allowed to propagate:
  - this area is determined by the sender of the data packet;
  - control packets are forwarded by node within a RequestZone only;
  - if the node is not found using the first RequestZone, the size of RequestZone is increased.

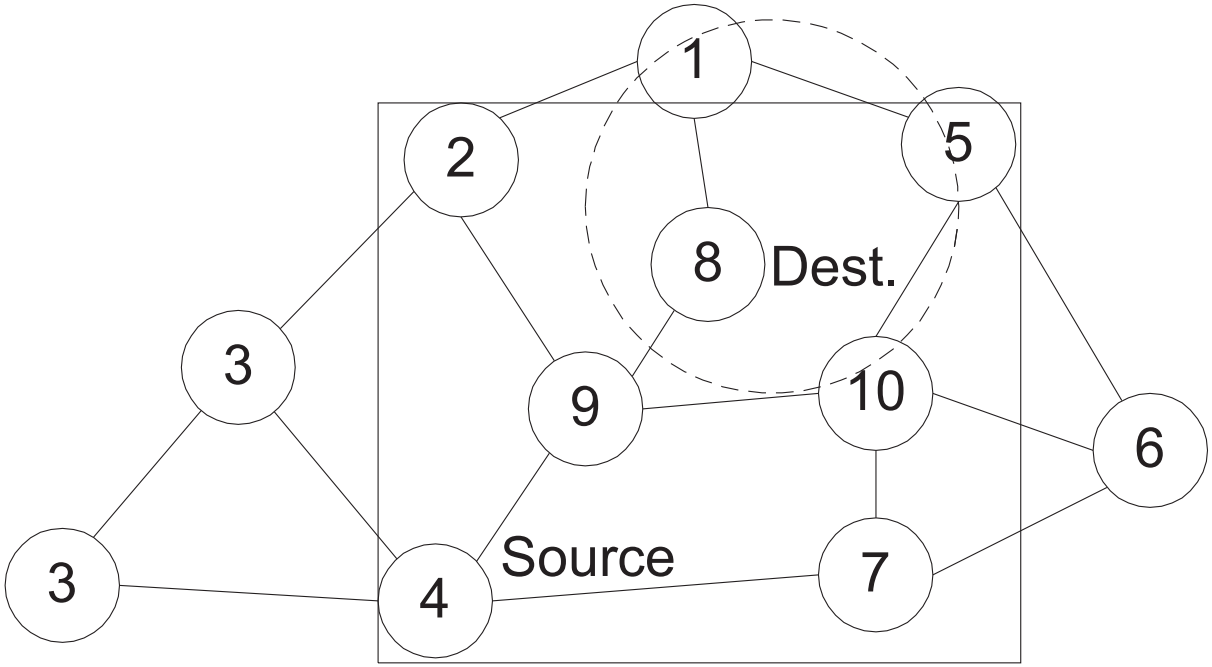



Figure 15: Example of ExpectedZone and RequestZone.

**Nodes decide whether to forward or discard packets based on two algorithms:**

- LAR type 1;
- LAR type 2.

**LAR type 1 algorithm works as follows:**

- the sender explicitly specifies the RequestZone in the RouteRequest packet;
- the RequestZone is the smallest rectangle that includes the source and the ExpectedZone;
- when the node is in ExpectedZone, the RequestZone is reduced to the ExpectedZone;
- if the ReouteRequest packet is received by the node within RequestZone, it forwards it.

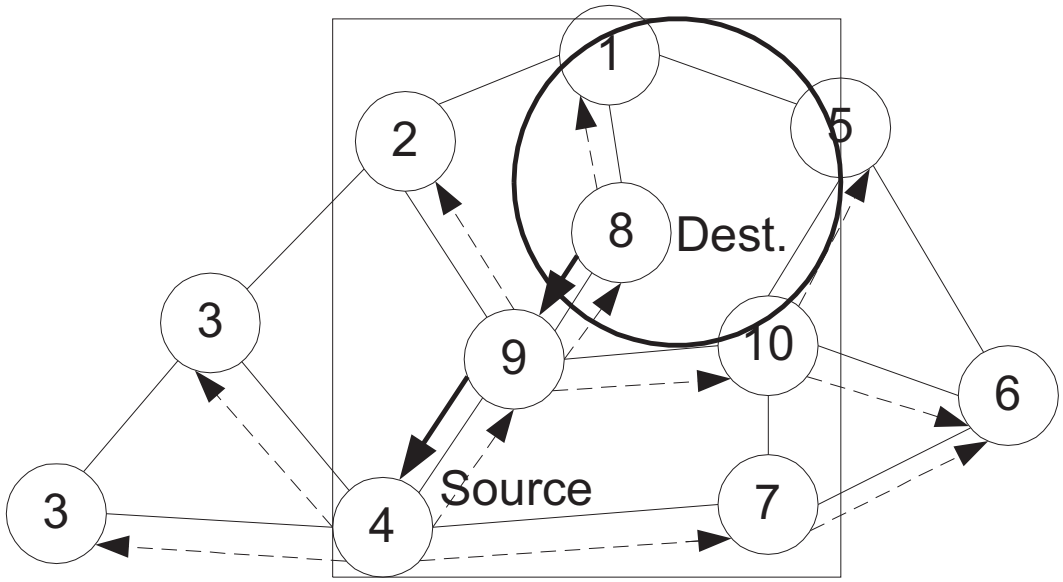



Figure 16: Routing procedure in LAR type 1.

**LAR type 2 algorithm operates as follows:**

- the sender includes the distance to the source in the RouteRequest packet;
- intermediate nodes compute the distance to the destination:
  - if this distance is less than the distance between source and destination packet is forwarded;
  - otherwise the packet is discarded.
- distance in the packet is updated at every node with lower distance to destination.

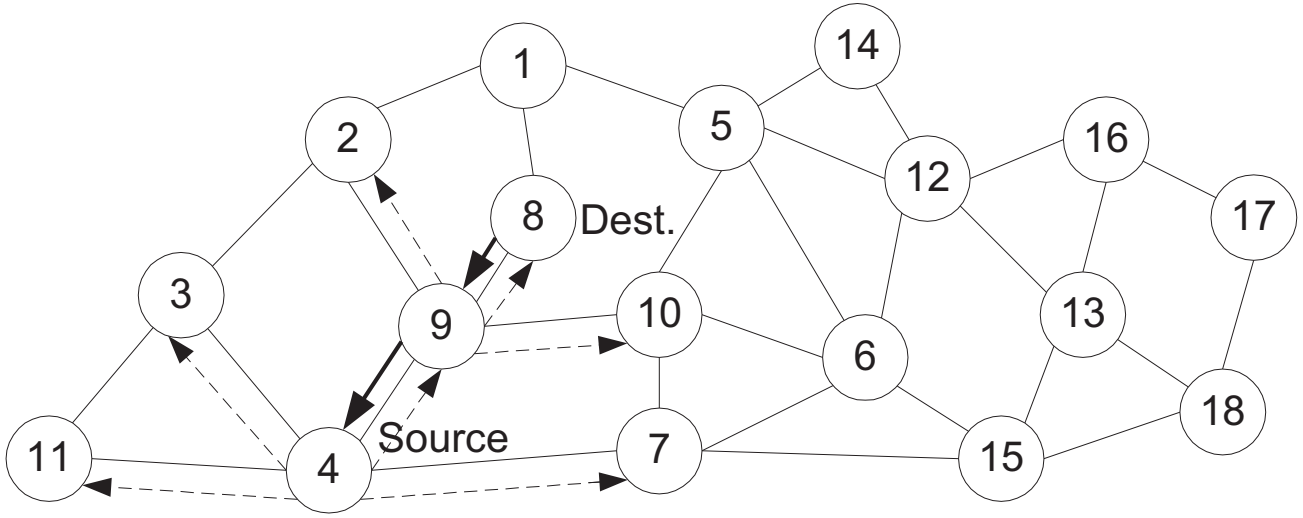



Figure 17: Routing procedure in LAR type 2.

## 4.4. Associativity-based routing

**It is characterized by the following:**

- on-demand beacon-based protocol;
- routes are selected based on temporal stability of wireless links:
- to determine temporal stability, each node maintains the count of its neighbors' beacons.

**The protocol operates as follows:**

- source node floods the RouteRequest packet, all intermediate nodes forward this packet;
- RouteRequest packet carries the following:
  - the path it has traversed;
  - the beacon count for corresponding node in the path.
- when the first RouteRequest reaches the destination, the destination:
  - waits for RouteSelect time to receive multiple copies of RouteRequest;
  - selects the path that has the maximum number of stable links;
  - replies to the source with RouteReply packet.

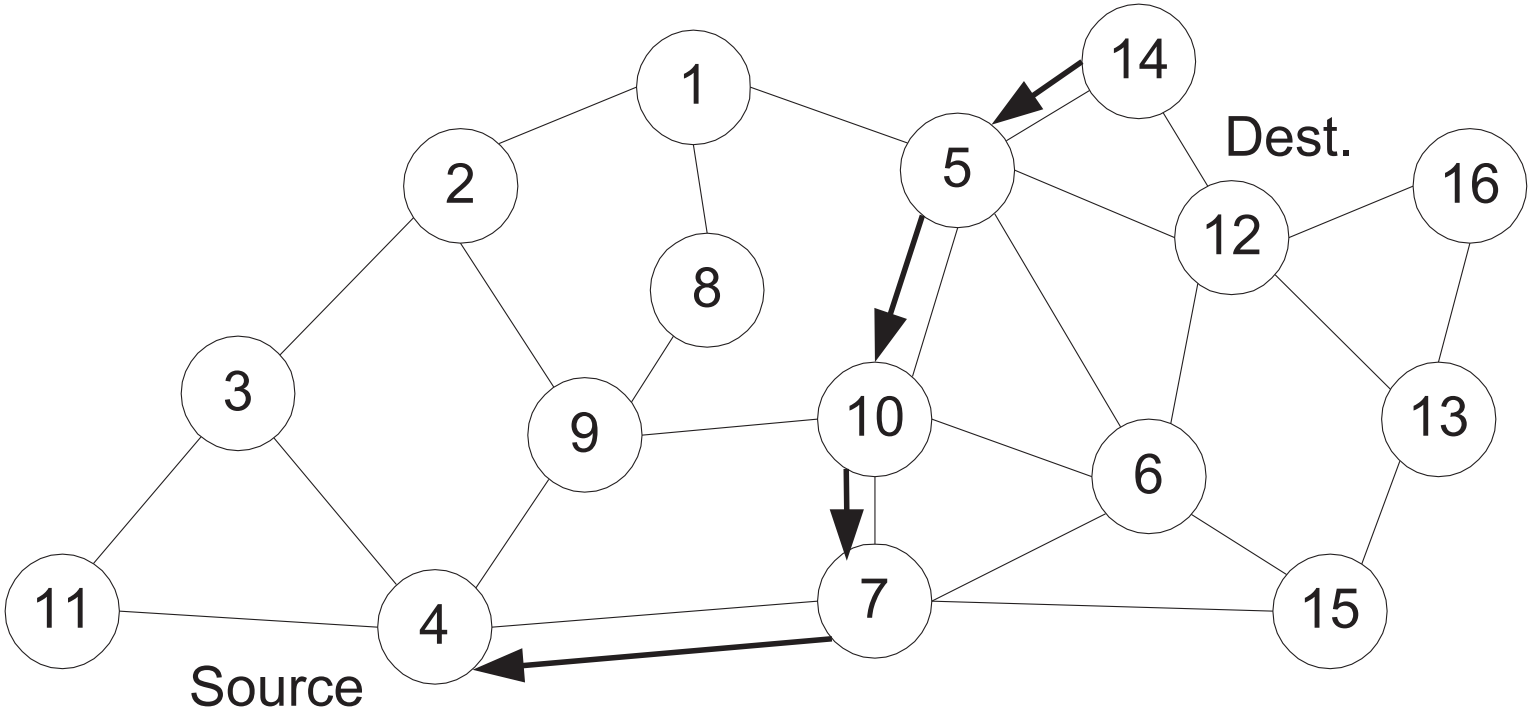



Figure 18: Routing in ABR.

**If the link break occurs:**

- the node closer to the source initiates a local link repair as follows:
  - broadcasts locally route repair packet (local query (LQ)) with limited TTL (e.g., 3);
- if this node fails to repair, then the next node closer to destination initiates a route repair;
- if nodes constituting a half of pass of the route fail to repair, the source is informed.

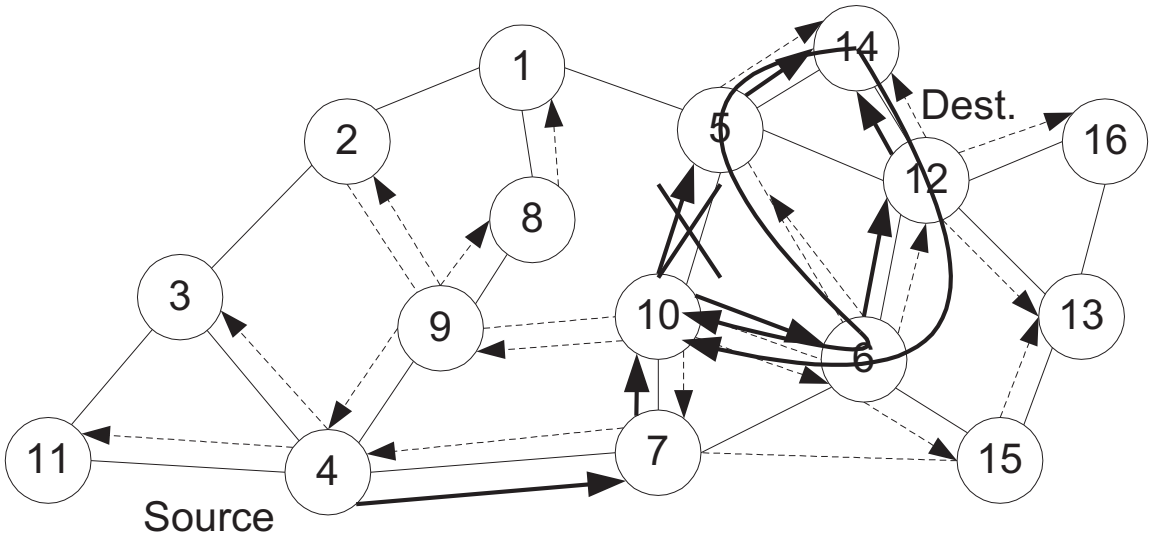



Figure 19: Local route repair in ABR.

## 4.5. Signal stability-based adaptive routing protocol

**This protocol is characterized by the following:**

- on-demand beacon-based protocol;
- routes are selected based on temporal stability of wireless links:
- based on temporal stability, each links is classified to:
  - stable
  - unstable
- to determine temporal stability, each node measures the signal strength of beacons.

**The whole protocols consist of the following two parts:**

- dynamic routing protocol (DRP):
  - DRP maintains the routing table interacting with DRPs on other hosts.
- forwarding protocol (FP):
  - is responsible for forwarding of packets to destination.

**In each node the signal stability table is maintained containing:**

- beacon count and signal strength of these beacons;
  - if the signal strength is strong for past few beacons the link is stable;
  - if the signal strength is weak for past few beacons the link is unstable.

**The protocol operates as follows:**

- if no route in cache, the node floods the RouteRequest packet;
- RouteRequest packet carries the path it has traversed;
- if the intermediate node receives the RouteRequest via stable link it forwards it;
- if the intermediate node receives the RouteRequest via unstable link it drops it;
- when the first RouteRequest reaches the destination, the destination:
  - waits for RouteSelect time to receive multiple copies of RouteRequest;
  - selects the path that is most stable;
    - if two or more paths are equal in stability, the shortest path is selected;
    - if two or more shortest paths are available, random path among them is selected.
  - replies to the source with RouteReply packet.

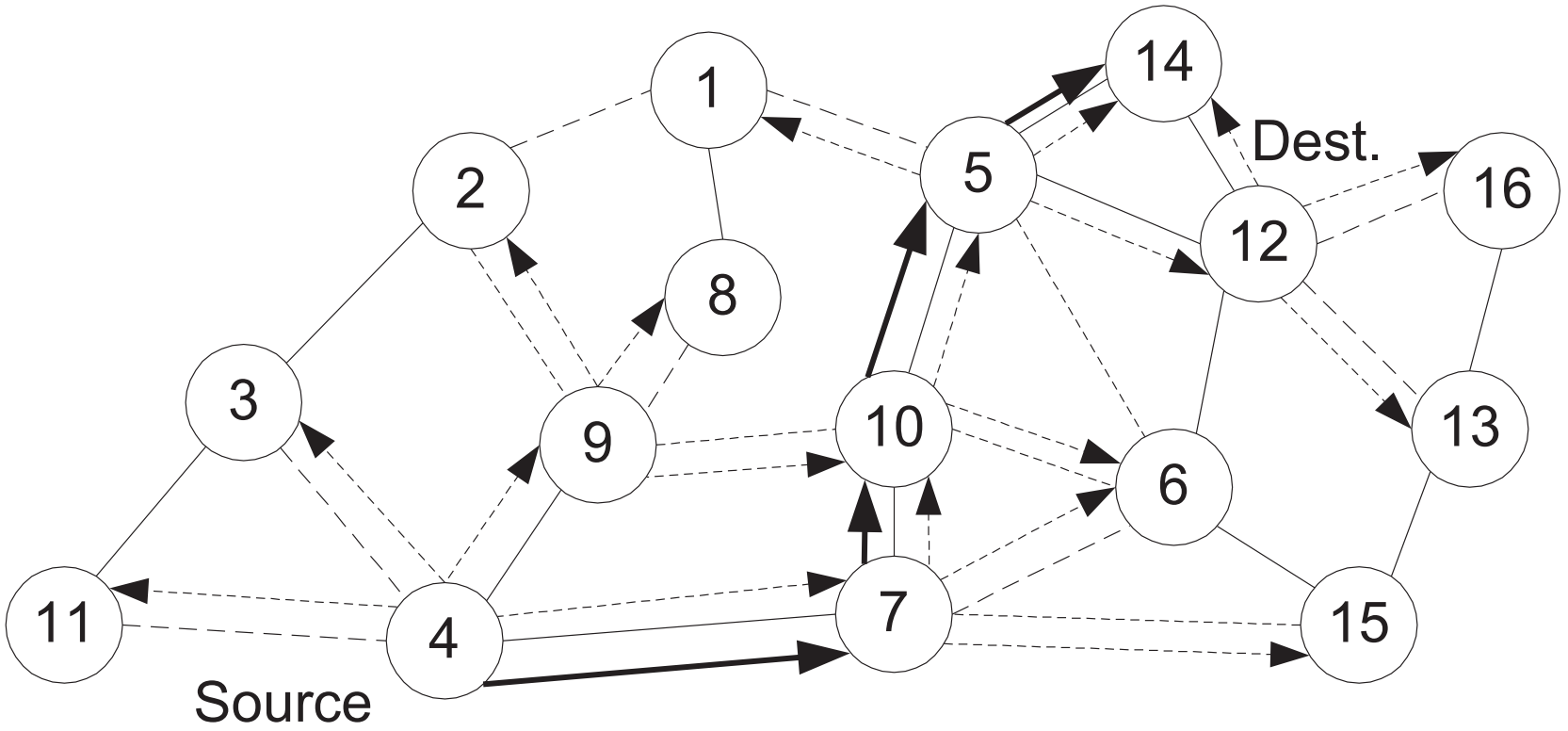



Figure 20: Routing in SSA.

**In case of the link break:**

- end-nodes are informed and they try to establish new stable route;
- of no stable routes are available, the restriction of stable links is removed.

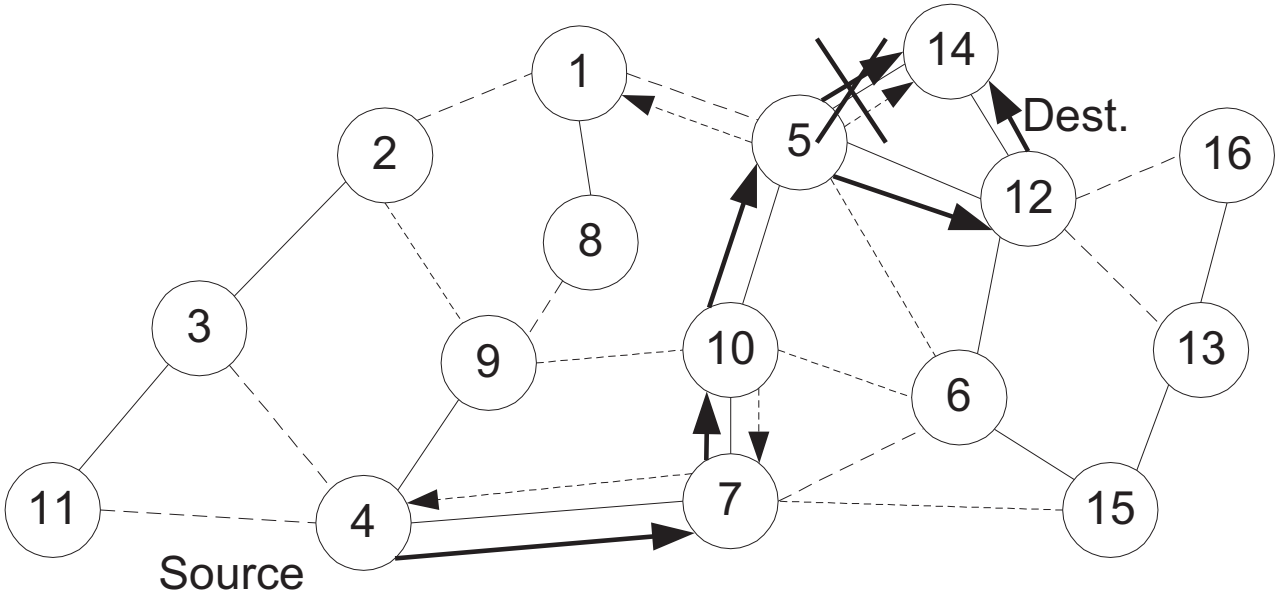



Figure 21: Route repair in SSA.

## 4.6. Flow-oriented routing protocol

**Aim is on supporting real-time traffic using a predictive multi-hop-handoff feature:**

- Classic protocols (e.g., DSR, AODV etc.):
  - route repair is initiated when intermediate node detects the link breaks;
  - it causes delay, losses: low QoS is provided in result.
- FORP uses the predictive mechanism to estimate link expiration time (LET):
  - it is based on location, mobility and transmission range of nodes involved in forwarding;
  - the minimum of LET determines the route expiration time (RET);
  - it is assumed that GPS is used to make prediction of LET.

**New shortcomings:**

- −: devises are expensive;
- −: can only operate at the open air (due to GPS).

**The protocol operates as follows:**

- if no route in cache, the destination floods the Flow-REQ packet carrying:
  - information regarding the source and destination nodes;
  - flow identification number (sequence number) that is unique for every session.
- when neighbor receives the Flow-REQ packet:
  - to avoid looping checks if the sequence number if higher than that previously used;
  - if so, this node appends LET and its address in the packet, and forwards it;
  - if not, the packet is discarded.
- when the destination receives the packet:
  - the packet has a path it has traversed and LET associated with each wireless link;
  - if RET is acceptable, it originates the Flow-SETUP packet.
- when the source receives Flow-SETUP packet, it begins the transmission of packets.

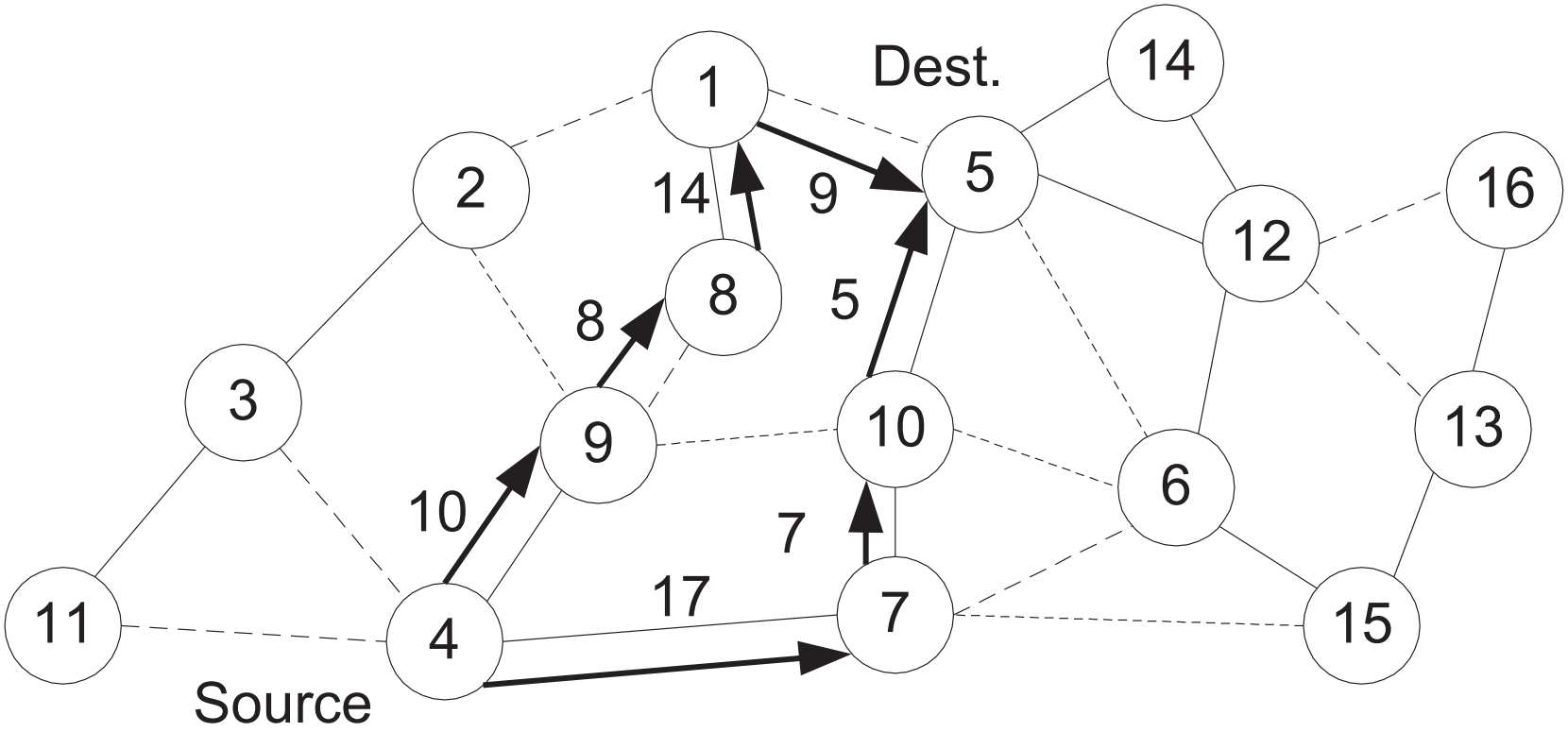



Figure 22: Route establishment in FORP.

**The LET of the link is estimated as follows:**

$$LET_{AB} = \frac{-(pq+rs)+(p^2+r^2)T_X^2-(ps-qr)2}{p^2+q^2},$$
$$p = V_A\cos T_A - V_B\cos T_B, \qquad q = X_A - X_B$$
$$r = V_A\sin T_A - V_B\sin T_B, \qquad s = Y_A - Y_B, \tag{1}$$

- A and B are nodes with transmission range $T_X$;
- $V_A$ and $V_B$ are velocities of nodes;
- $T_A$ and $T_B$ are angles as shown below:

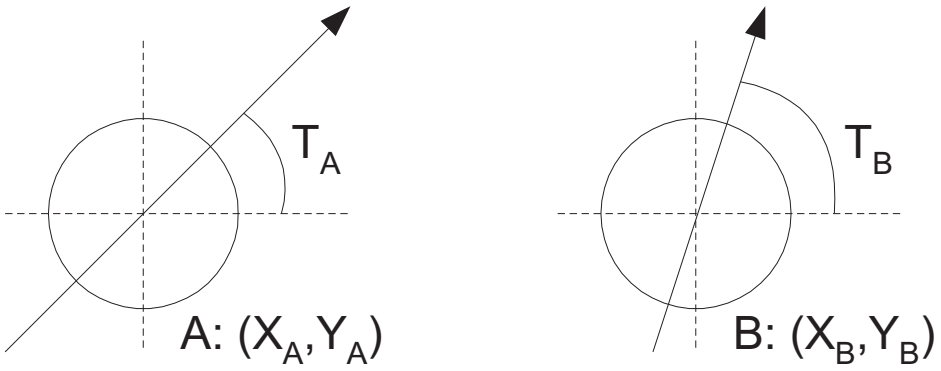



Figure 23: Motion angles in FORM.

**FORP uses proactive route maintenance using available RET:**

- when the destination determines that the break is about to occur it sends Flow-HANDOFF;
- Flow-HANDOFF propagates in the network similarly to Flow-REQ;
- when many Flow-HANDOFF are received at the source new path with highest RET is chosen.

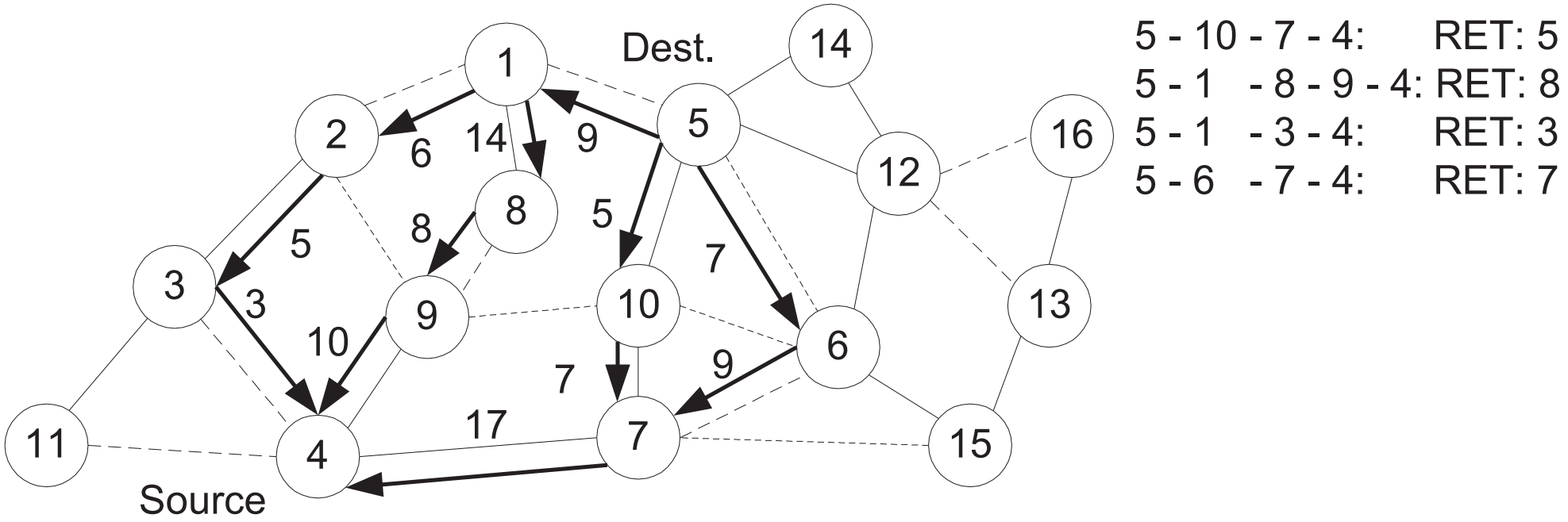



Figure 24: Route repair in FORP.

# 5. Hybrid routing protocols

These protocols maintain topology information up to $m$ hops in tables.

**We consider:**

- Zone routing protocol (ZRP);
- Zone-based hierarchial link state routing protocol (ZHLS);

**What are inherent shortcomings and advantages:**

- +: fast link establishment;
- +: less overhead as compared to table-driven and reactive protocols.
- −: high storage and processing requirements as compared to reactive protocols.

**Note:** a compromise between proactive and reactive protocols.

## 5.1. Zone routing protocol (ZRP)

**This protocols uses a combination of proactive and reactive routing protocols:**

- **proactive:** in the neighborhood of $r$ hops: Intra-zone routing protocol (IARP);
- **reactive:** outside this zone: Inter-zone routing protocol (IERP).

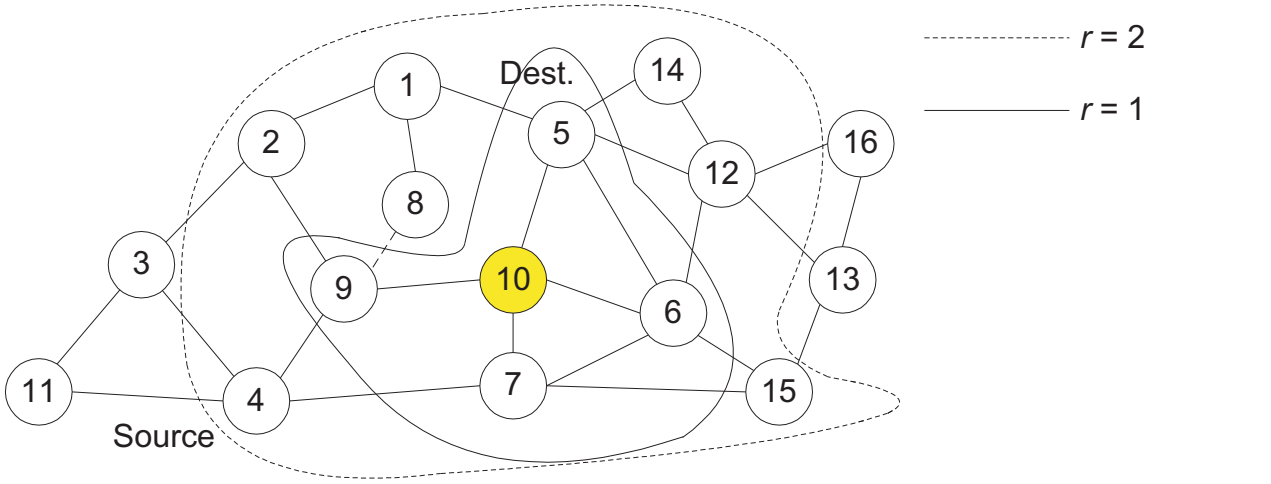



Figure 25: Zones in ZRP for node 10.

**The protocol operates as follows:**

- if the destination is within the zone, the source sends packets directly;
- if not, the destination sends RouteRequest to peripheral nodes;
- if any peripheral node, has the destination in its zone it replies with RouteReply;
- if not, peripheral nodes sends RouteRequest to their peripheral nodes and so on;
- if multiple RouteReply are received the best is chosen based on some metric.

**If the broken link is detected:**

- intermediate node repairs the link locally bypassing it (proactive routing!!!);
- end nodes are informed;
- sub-optimal pass but very quick procedure;
- after several local reconfiguration, the source initiates global pass finding to find optimal.

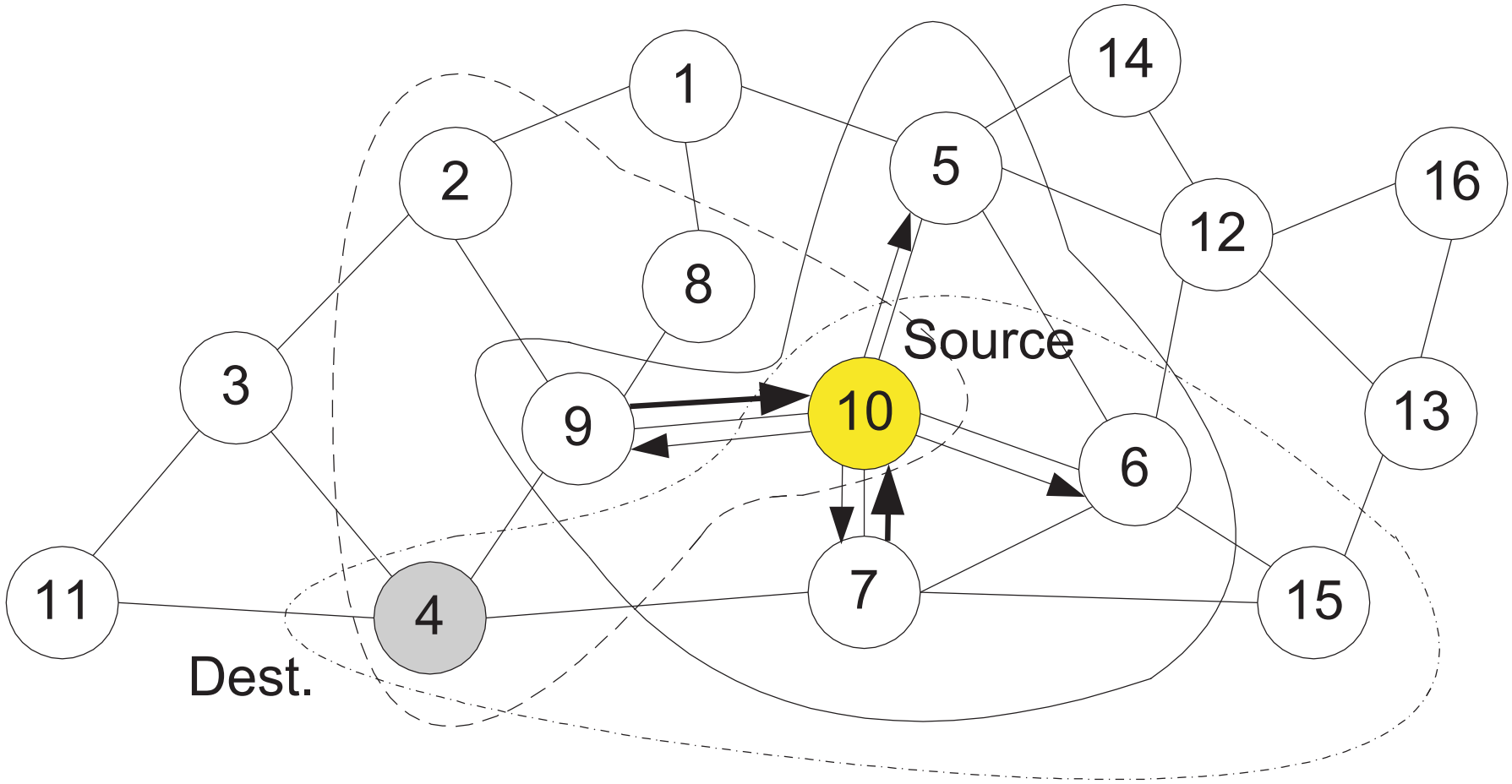



Figure 26: Routing in ZRP with $r = 1$.

## 5.2. Zone-based hierarchial link state routing protocol

**ZHLS is characterized by the following:**

- use of geographical location of nodes to determine the non-overlapping zones;
- hierarchial addressing with zone ID and node ID is used;
- each node requires the location information based on which its zone is obtained;
- topology information is maintained in every node inside this zone;
- for regions outside the zone, zone connectivity information is maintained;

**The ZHLS uses:**

- **proactive routing** is used inside zone;
- **reactive routing** is used outside zone;

**Note:** ZHLS requires GPS or similar service to identify itself with a certain sone.

**Zones:** coverage of the single node, application scenario, mobility of nodes, network size.

**The protocol operates as follows:**

- each node builds a one-hop node-level topology;
- this one-hop topology is propagated to other nodes in its zone using packet containing:
  - IDs of all zones in the zone, node ID, and zone IDs of all other nodes.
- nodes that receive responses from nodes belonging to other zones are **gateway nodes**;
- all traffic between zones is transmitted via gateway nodes;
- once node-level topology is built, nodes obtain zone-level topology sending packets via gates;
- if the destination is in the zone, packets are forwarded directly;
- if no, the source sends location request packet to every zone via gateways;
- every gateway node checks for destination in its routing table and replies with ReouteReply.

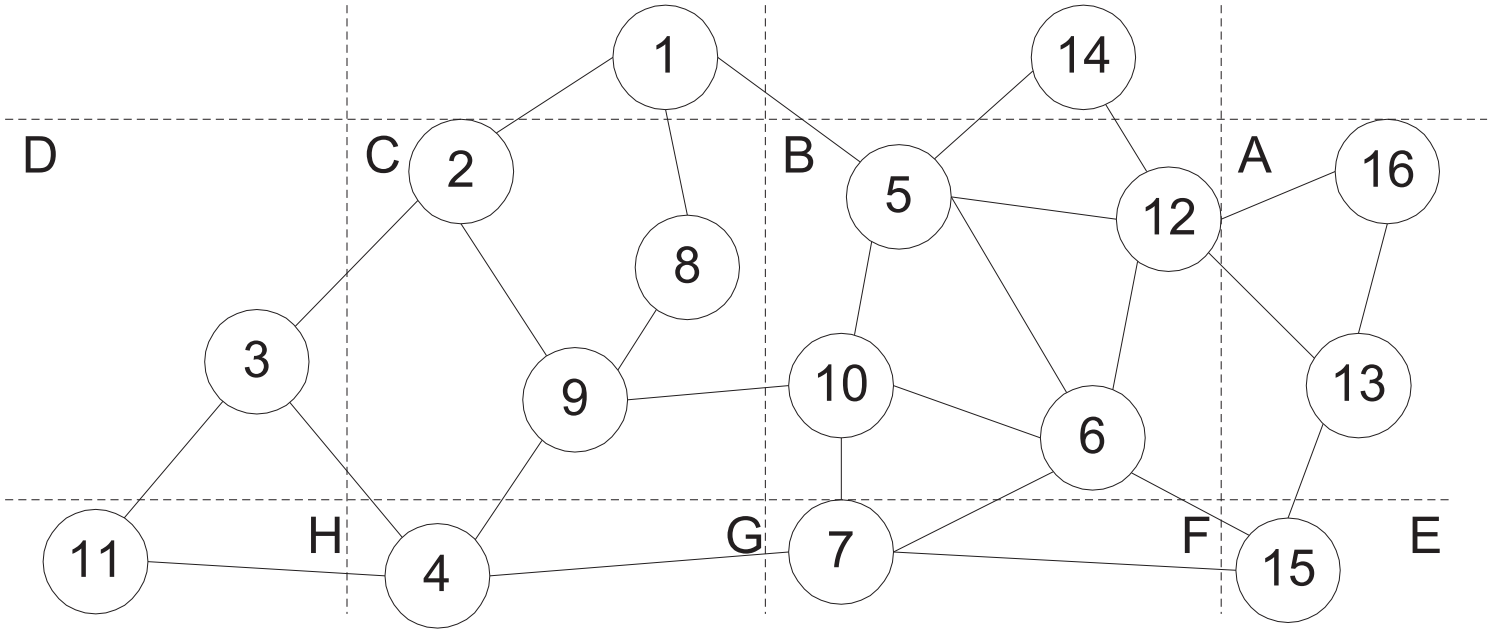



Figure 27: ZHLS zones.

**The repair of broken links is as follows:**

- source is notified about the link failures;
- if there are multiple gateways with the required zone, packet if forwarded via one of those;
- if no multiple gateways, packets are forwarded to other zones and then to the required zone.

# 6. Hierarchial routing protocols

These protocols introduce hierarchy in the network to achieve the following benefits:

- reduction in the size of routing tables;
- better scalability.

## 6.1. Hierarchial state routing protocol

**HSR is characterized by the following:**

- HSR uses multi-clustering to enhance resource allocation and management;
- HSR defines different levels of clusters;
- at every level leader is elected;
- the first level is made of single-hop clusters (physical clustering);
- the next level is comprised of leaders of clusters.

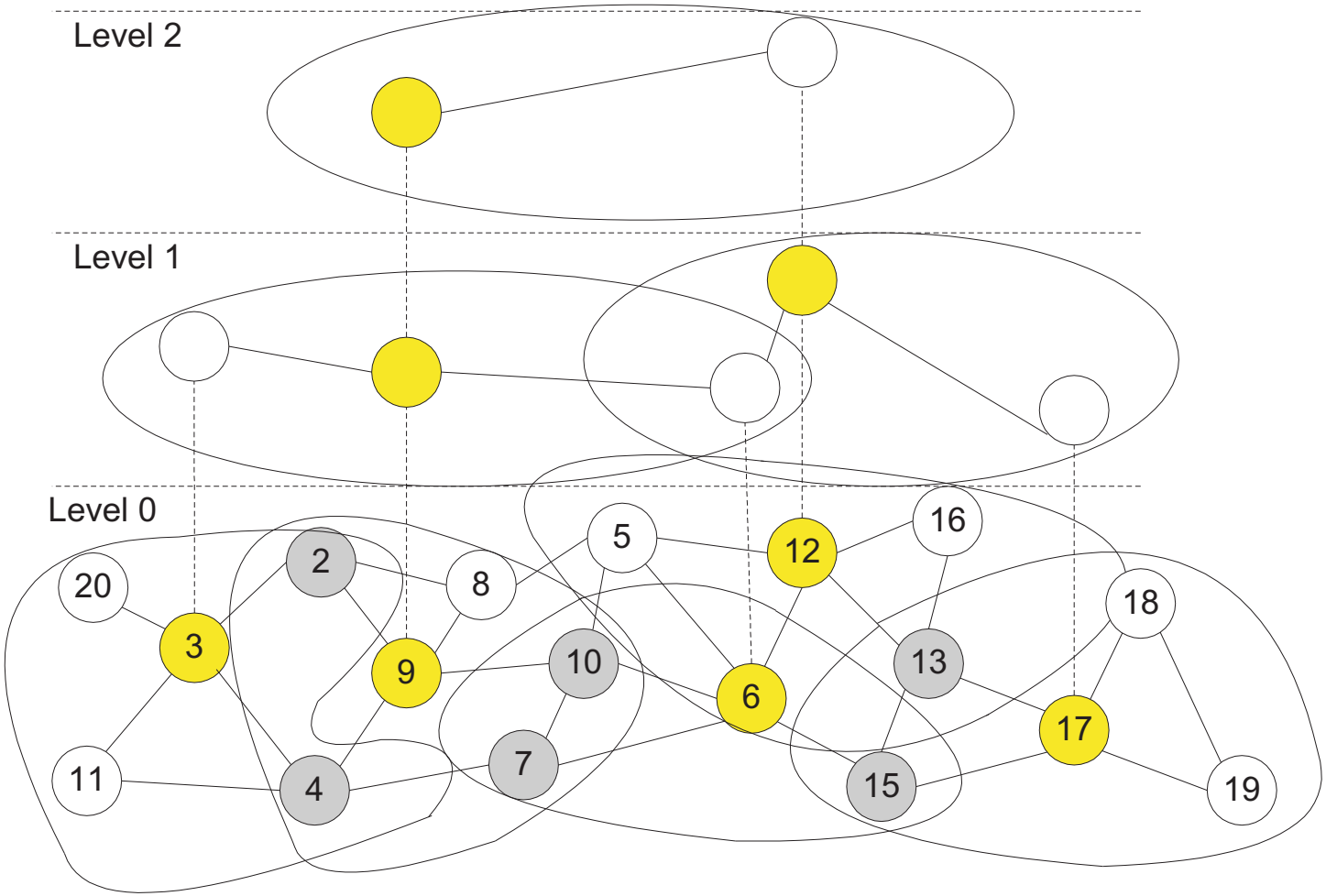



Figure 28: Topology example in HSR.

**At the physical layer nodes are classified into:**

- **cluster heads;** belong to a single cluster and elected as a cluster head;
- **gateway nodes;** belong to two or more clusters;
- **normal nodes**: belong to a single cluster.

**Cluster heads at level 0 (physical level) could be responsible for:**

- slot/frequency/code allocation to utilize spectrum more efficiently;
- call admission control from normal member nodes;
- scheduling of packets for transmission;
- exchange of routing information;
- handling route breaks.

**Gateway nodes are responsible for:**

- forwarding of packets between different clusters (cluster heads).

**The following routing responsibilities are assigned to nodes in HSR:**

- every node maintains information about the status of links with its neighbors:
  - this information is broadcasted within the cluster at regular intervals.
- cluster heads exchange the topology and link state information at any level:
  - this is done via multiple hops using the gateway nodes.
- the path between two cluster head involves multiple links is called the virtual link:
  - this is: head - gateway - head - gateway etc.
- every node knows the exact hierarchial topology information:
  - after obtaining the information the cluster head floods it to lower level.
- to route packets hierarchial addressing is used consisting of;
  - **hierarchial ID (HID):** sequence of cluster headers' IDs from higher level;
  - **node ID**: similar to unique MAC address.

  Address of node 12: (9,12,12).
- From 12 to 3: 12 - 9 - 3 over multiple links.

## 6.2. Fisheye state routing protocol

**Generalization of the GSR protocol where the following property is introduced:**

- accurate information about nodes in local topology;
- not so accurate information about node that are far away.

**Why is it needed:**

- complexity proactive routing: size of the network, mobility of node;
- reactive routing: + number of connections.

**What is the basis:**

- a node exchanges the routing information only with neighbors at periodic intervals:
  - trade-off between link-state (topology exchanges) and distance vector (link-level info).
- the complete topology information is maintained at each nodes;
- different update frequencies for different scopes one-hop/two-hop/... scopes:
  - one-hop – highest freq., two-hop less freq. etc.: decrease of the message size.

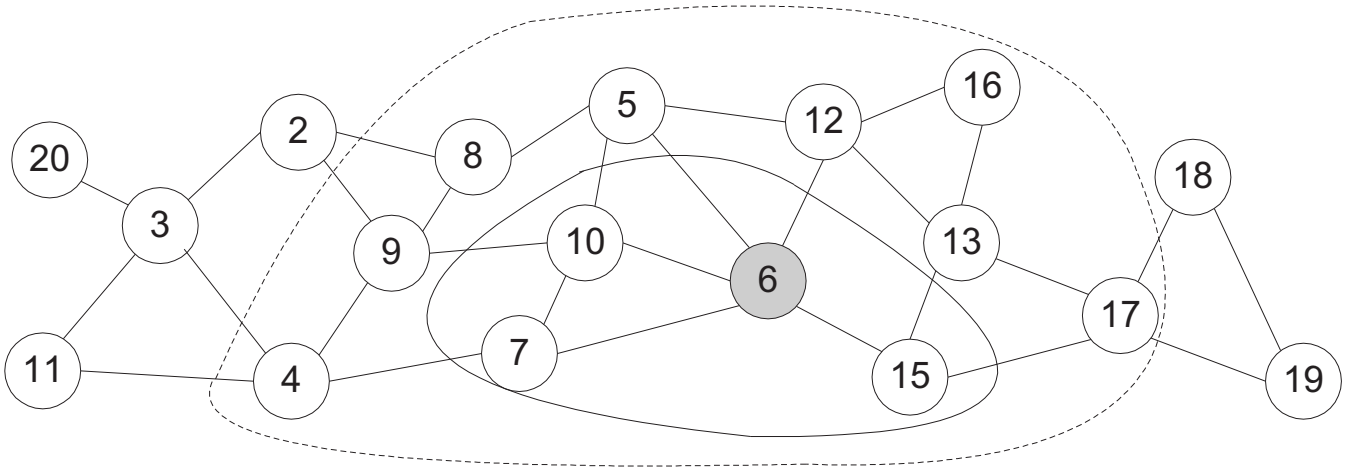
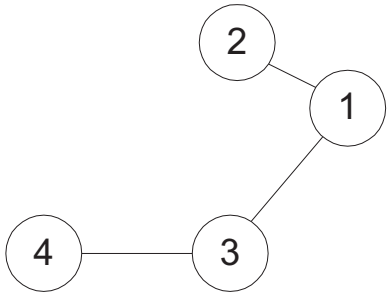



Figure 29: One-hop and two-hop scopes of the node.




| Dest. | Neigh. | Hops |
|---|---|---|
| 1 | 2,3 | 0 |
| 2 | 1 | 1 |
| 3 | 1,4 | 1 |
| 4 | 3 | 2 |

one-hop neighbors

two-hop neighbors

Figure 30: Example of topology information in FSR.

# 7. Power-aware routing protocols

**The following metrics can be taken into account on route selection procedure:**

- **Minimal energy consumption per a packet:**
  This metric involves a number of nodes from source to destination.
  - +: uniform consumption of power throughout the network;
- **Maximize the network connectivity:**
  To balance the load between the cut-sets (those nodes removal of which causes partitions).
  - −: difficult to achieve due to variable traffic origination.
- **Minimum variance in node power levels:**
  To distribute load such that power consumption pattern remains uniform across nodes.
  - +: nearly optimal performance is achieved by routing a packet to least loaded next-hop.
- **Minimum cost per a packet:**
  Cost as a function of the battery charge (less energy – more cost) and use it as a metric.
  - +: easy to compute (battery discharge patterns are available);
  - +: this metric handles congestions in the network.