Chapter 13

Ad Hoc Networks

Outline

- Introduction
- Characteristics of MANETs
- Applications
- Routing
- Table-driven Routing Protocols
- Source-initiated On-demand Routing
- Hybrid Protocols
- Vehicular Area Network (VANET)
- Security Issues in Mobile Ad hoc Networks (MANETs)
- Network Simulators
- Summary

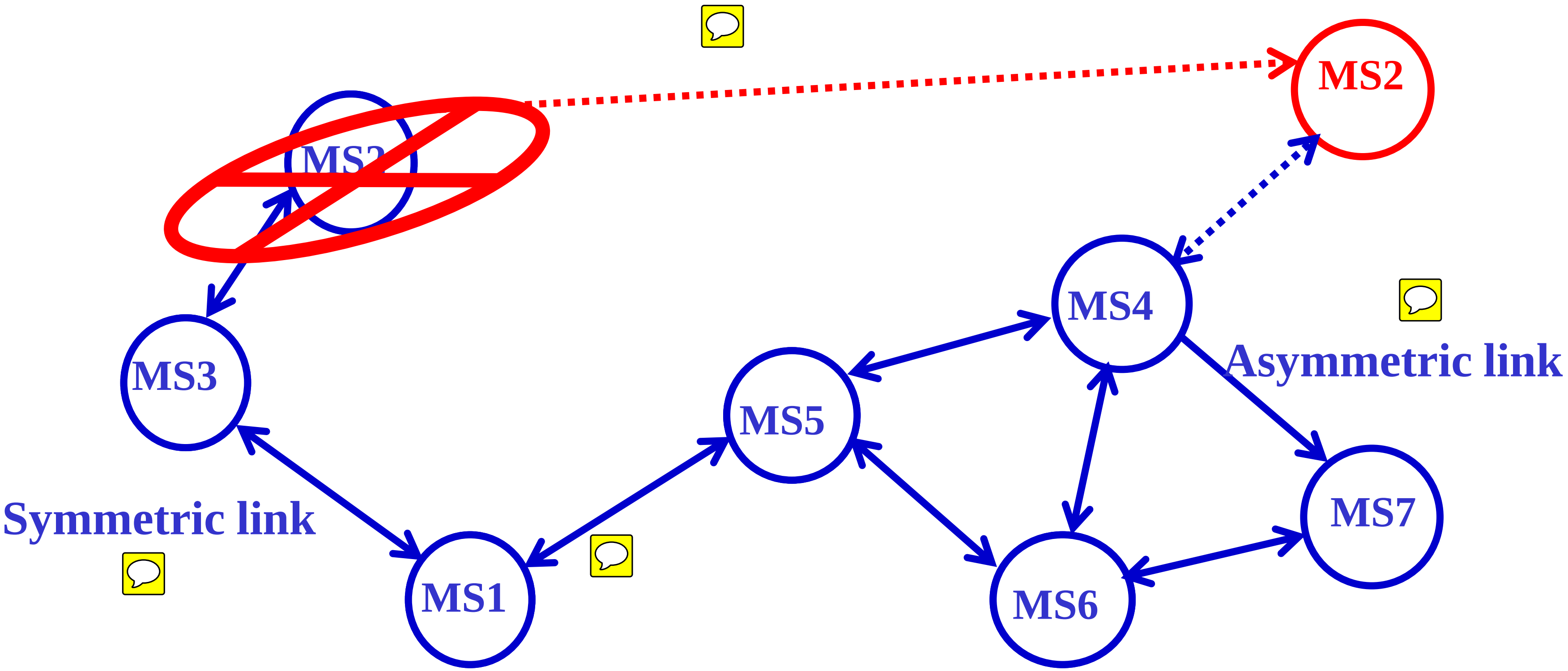
Introduction

- A Mobile Ad hoc Network (MANET) is an autonomous system of nodes (MSs) (also serving as routers) connected by wireless links
- No infrastructure exists in a MANET
- The network's wireless topology may change dynamically in an unpredictable manner since nodes are free to move and each node has limited transmitting power
- Information is transmitted in a store-and forward manner (peer-to-peer) using multi hop routing

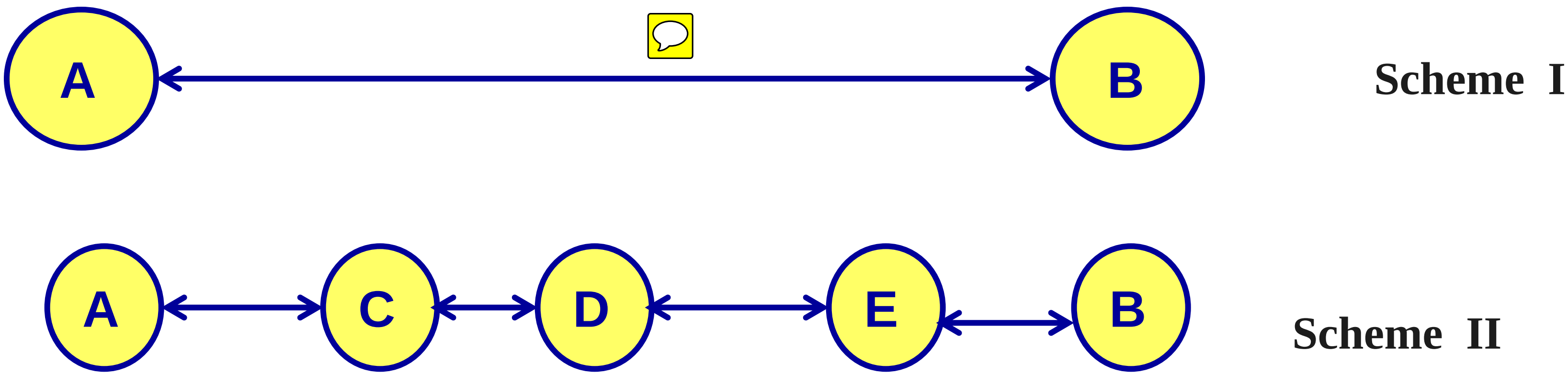
Introduction (Cont'd)

- Each node is equipped with a wireless transmitter and receiver with an appropriate antenna
- We assume that it is not possible to have all nodes within each other's radio range
- When the nodes are close-by, i.e., within radio range, there are no routing issues to be addressed
- At a given point in time, wireless connectivity in the form of a random multi-hop graph exists between the nodes

A Mobile Ad Hoc Network (MANET)



Direct Transmission versus Multi-hop



- **Energy Consumption**
- **Time delay**

Characteristics	Scheme I	Scheme II
# Store and Forward	1	4
# Transmissions	1	4
# Receptions	1	4

Characteristics of MANETs

- ***Dynamic topologies*: Network topology may change dynamically as the nodes are free to move**
- ***Bandwidth-constrained, variable capacity links*: Realized throughput of wireless communication is less than the radio's maximum transmission rate Collision occurs frequently**
- ***Energy-constrained operation*: Some nodes in the ad hoc network may rely on batteries or other exhaustible means for their energy**
- ***Limited physical security*: More prone to physical security threats than fixed cable networks**

Applications

- ***Defense applications:*** **On-the-fly communication set up for soldiers on the ground, fighter planes in the air, etc.**
- ***Crisis-management applications*****: Natural disasters, where the entire communication infrastructure is in disarray**
- ***Tele-medicine*****: Paramedic assisting a victim at a remote location can access medical records, can get video conference assistance from a surgeon for an emergency intervention**
- ***Tele-Geoprocessing applications*****: Combines geographical information system, GPS and high capacity MS, Queries dependent of location information of the users, and environmental monitoring using sensors**
- ***Vehicular Area Network*****: in providing emergency services and other information in both urban and rural setup**
- ***Virtual navigation*****: A remote database contains geographical representation of streets, buildings, and characteristics of large metropolis and blocks of this data is transmitted in rapid sequence to a vehicle to visualize needed environment ahead of time**
- ***Education via the internet:*** **Educational opportunities on Internet to K-12 students and other interested individuals. Possible to have last-mile wireless Internet access**

Routing in MANETS - Goals

- Provide the maximum possible reliability - use alternative routes if an intermediate node fails
- Route network traffic through the path with least cost metric
- Give the nodes the best possible response time and throughput

Need for Routing

- Route computation must be distributed. Centralized routing in a dynamic network is usually very expensive
- Routing computation should not involve the maintenance of a global state
- Fewer nodes must be involved in route computation
- Each node must care about the routes to its destination and must not be involved in frequent topology updates
- Stale routes must be either avoided or detected
- Broadcasts should be avoided (highly unreliable)
- If topology stabilizes, routes must converge to optimal routes
- It is desirable to have a backup route when the primary route has become stale

Routing Classification

The existing routing protocols can be classified as:

- **Proactive**: when a packet needs to be forwarded, the route is already known
- **Reactive**: Determine a route only when there is data to send

Routing protocols may also be categorized as:

- Table Driven protocols
- Source Initiated (on demand) protocols
- Hybrid protocols

Table Driven Routing Protocols

- **Each node maintains routing information to all other nodes in the network**
- **When the topology changes, updates are propagated throughout the network**
- **Examples are:**
  - ***Destination Sequenced Distance Vector routing (DSDV)***
  - ***Cluster-head Gateway Switch routing (CGSR).***
  - ***Wireless Routing Protocol (WRP)***

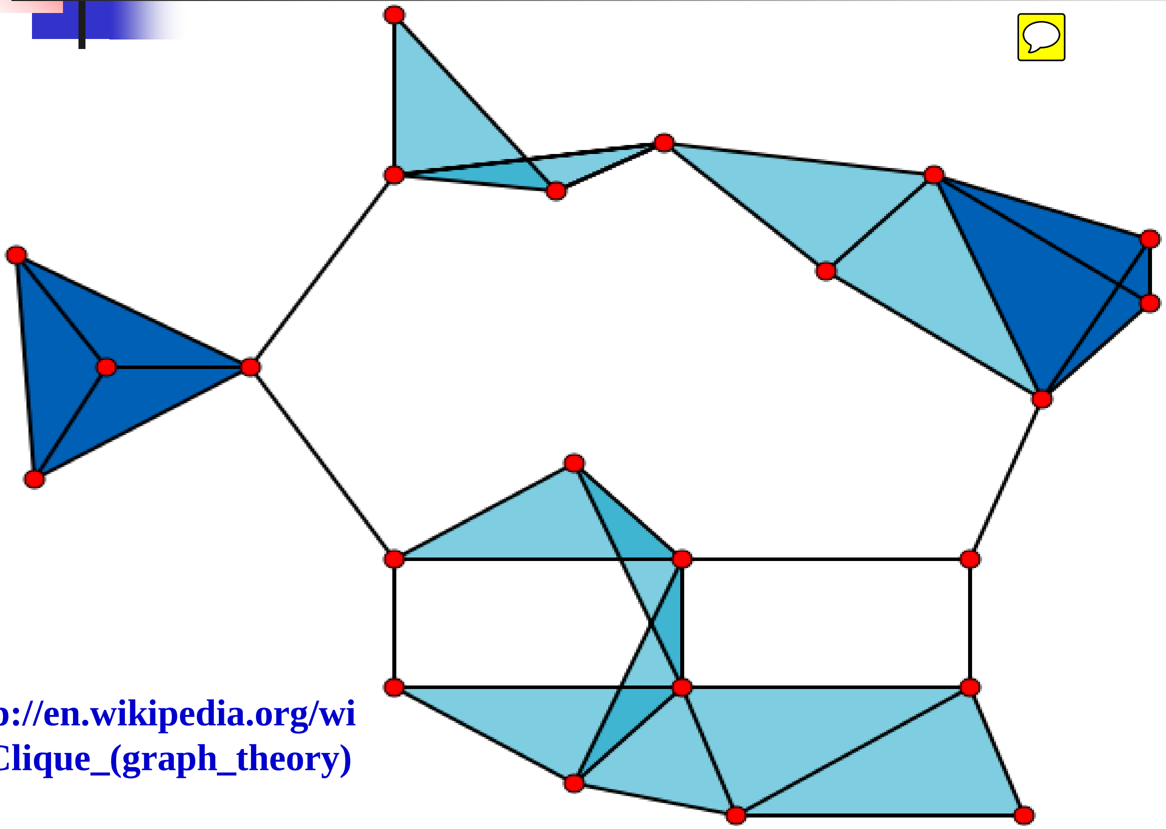
Destination Sequenced Distance Vector Routing (DSDV)

- Based on the Bellman-Ford algorithm
- Each mobile node maintains a routing table in terms of number of hops to each destination
- Routing table updates are periodically transmitted
- Each entry in the table is marked by a sequence number which helps to distinguish stale routes from new ones, and thereby avoiding loops
- A new route broadcast contains:
  - Destination address
  - Number of hops required to reach destination
  - Sequence number of information received about the destination
- To minimize the routing updates:
  - Either full dump carrying all available routing information
  - Smaller incremental packets containing the change in information since last full dump

Cluster-head Gateway Switch Routing (CGSR)

- CGSR is a clustered multi-hop mobile wireless network with several heuristic routing schemes
- A distributed cluster-head (CH) selection algorithm is used to elect a node as the cluster head
- It modifies DSDV by using a hierarchical CH to route traffic
- Gateway nodes serve as *bridge nodes* between two or more clusters
- A packet sent by a node is first routed to its CH and then the packet is routed from the CH to a gateway of another cluster and then to the CH and so on, until the destination cluster head is reached
- Frequent changes in the CH may affect the performance of the routing protocol

Cluster-head Gateway Switch Routing (CGSR)



- A graph with 23 1-vertex cliques (its vertices)
- 42 2-vertex cliques (its edges)
- 19 3-vertex cliques (the light and dark blue triangles)
- 2 4-vertex cliques (dark blue areas)
- The two dark blue 4-cliques are both maximum and maximal, and the clique number of the graph is 4

http://en.wikipedia.org/wiki/Clique_(graph_theory)

A clique in an undirected graph is a subset of its vertices such that every two vertices in the subset are connected by an edge

Destination Sequenced Distance Vector Routing (DSDV)

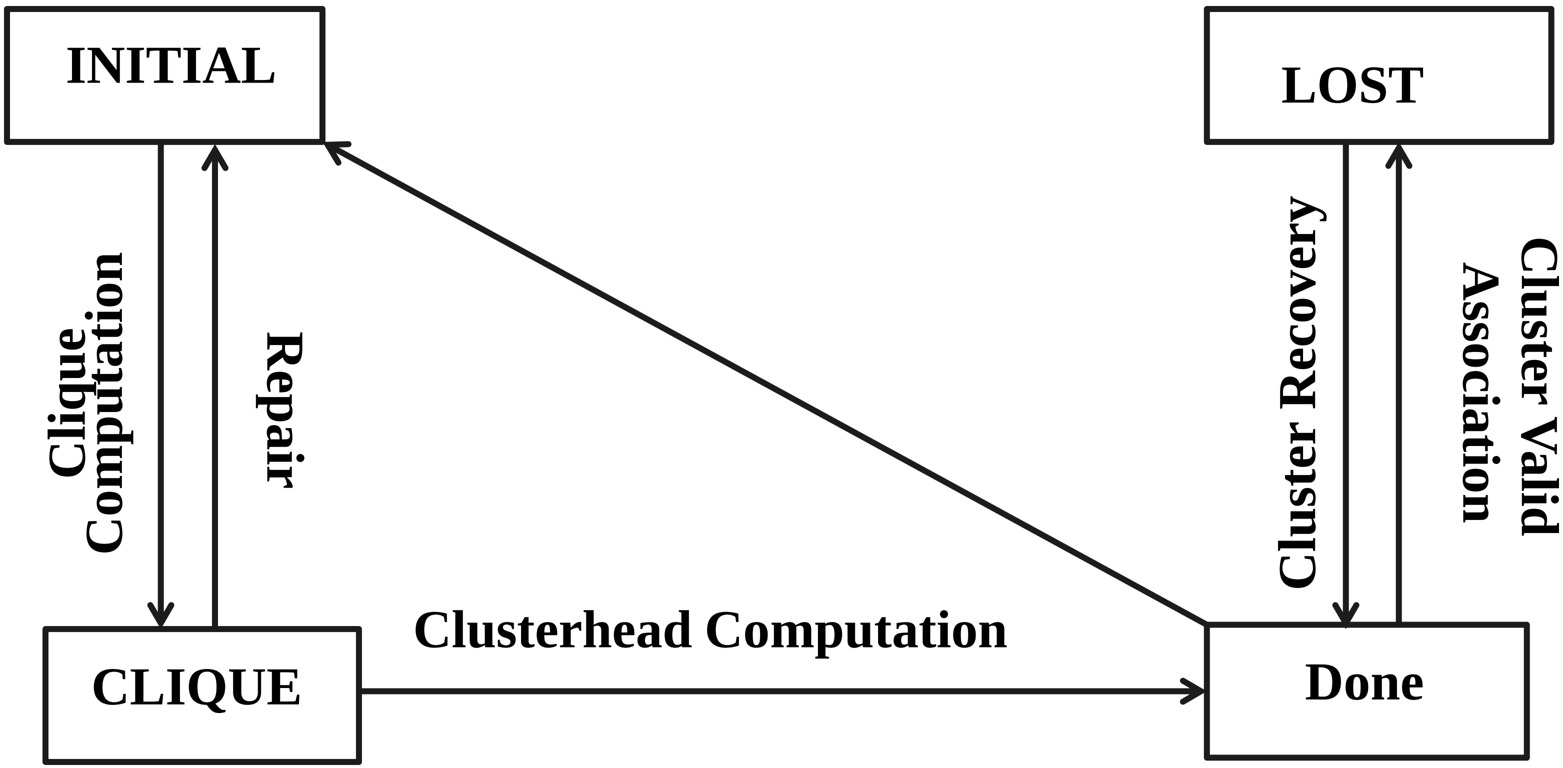
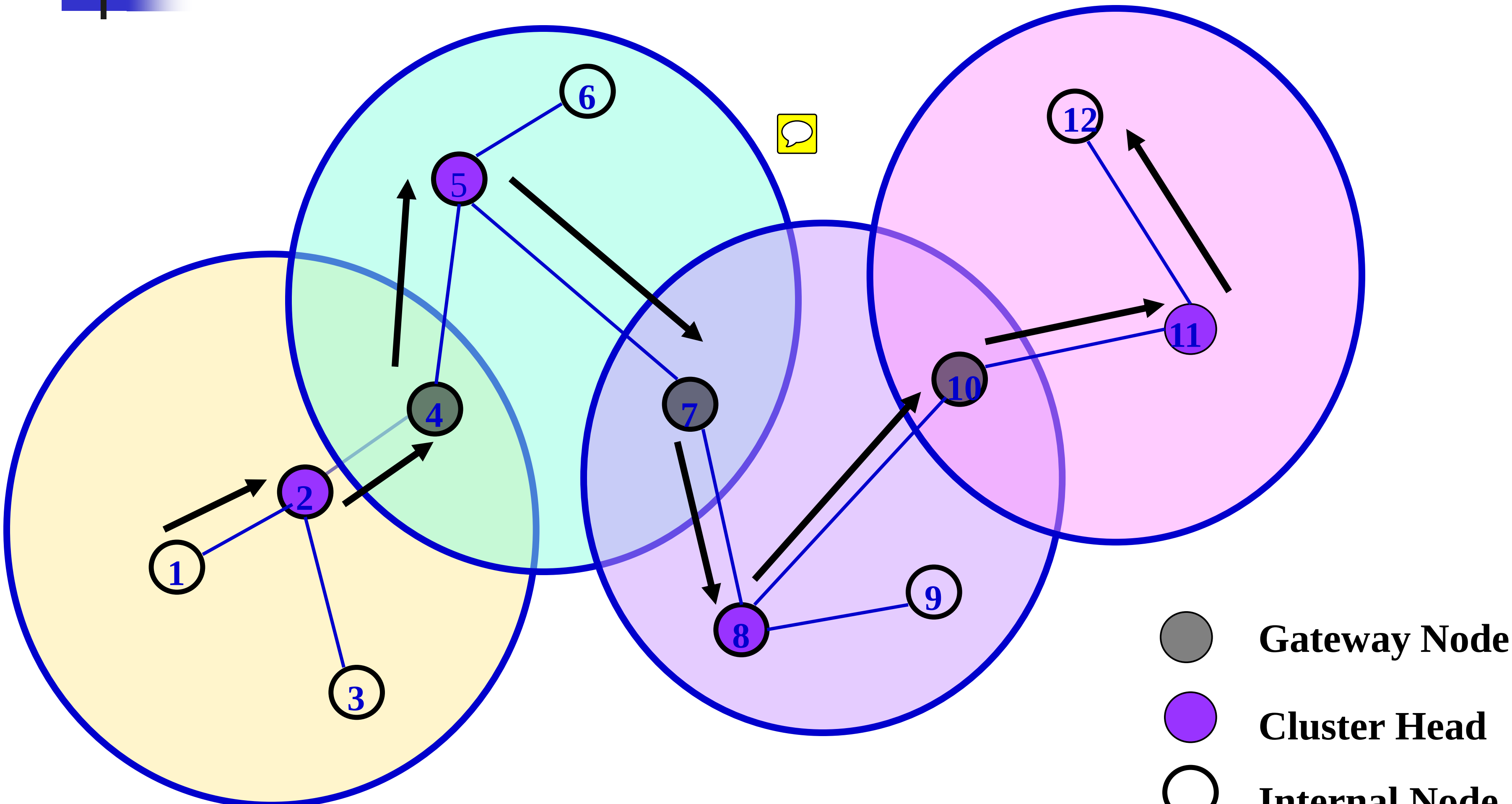


Figure 13.13 Cluster Head Selection in a MANET

CGSR (Cont'd)



Routing in CGSR from node 1 to node 12

The Wireless Routing Protocol (WRP)

- Each node maintains 4 tables:
  - -- Distance table
  - -- Routing table
  - -- Link cost table
  - -- Message Retransmission List table (MRL)
- MRL contains:
  - -- Sequence number of the update message,
  - -- A retransmission counter and
  - -- A list of updates sent in the update message
- Nodes discover each other through hello messages
- Nodes inform link changes through updates

Source-Initiated On-Demand Routing

Reactive protocol:

- Ad hoc On-Demand Distance Vector (AODV)
- Dynamic Source Routing (DSR)
- Temporary Ordered Routing Algorithm (TORA)
- Associativity Based Routing (ABR)
- Signal Stability Routing (SSR)

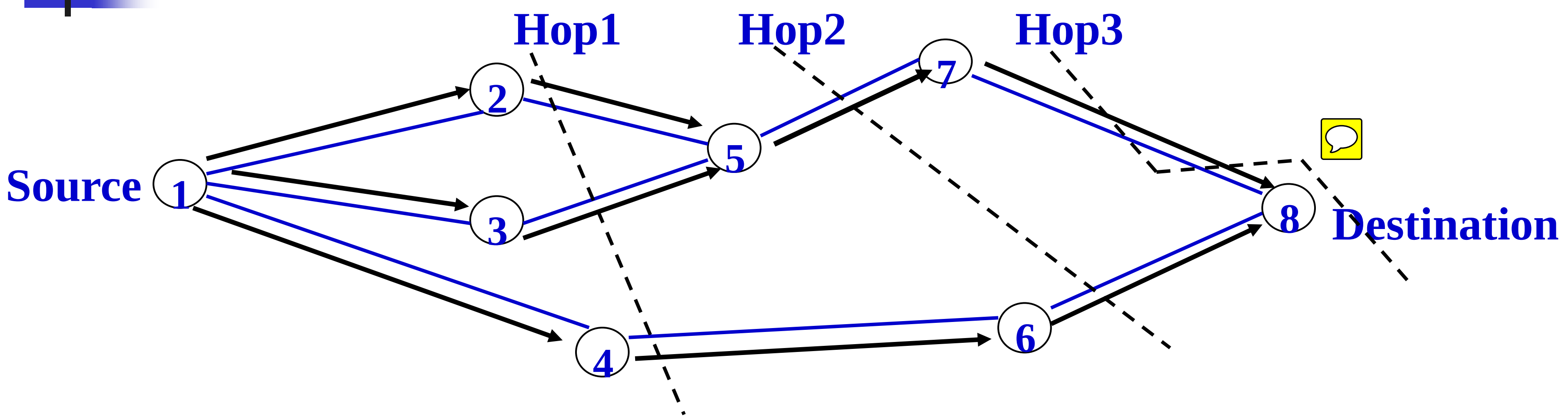
Ad hoc On-Demand Distance Vector Routing (AODV)

- AODV is an improvement over DSDV, which minimizes the number of required broadcasts by creating routes on demand
- Nodes that are not in a selected path do not maintain routing information or participate in routing table exchanges
- A source node initiates a path discovery process to locate the other intermediate nodes (and the destination), by broadcasting a Route Request (RREQ) packet to its neighbors

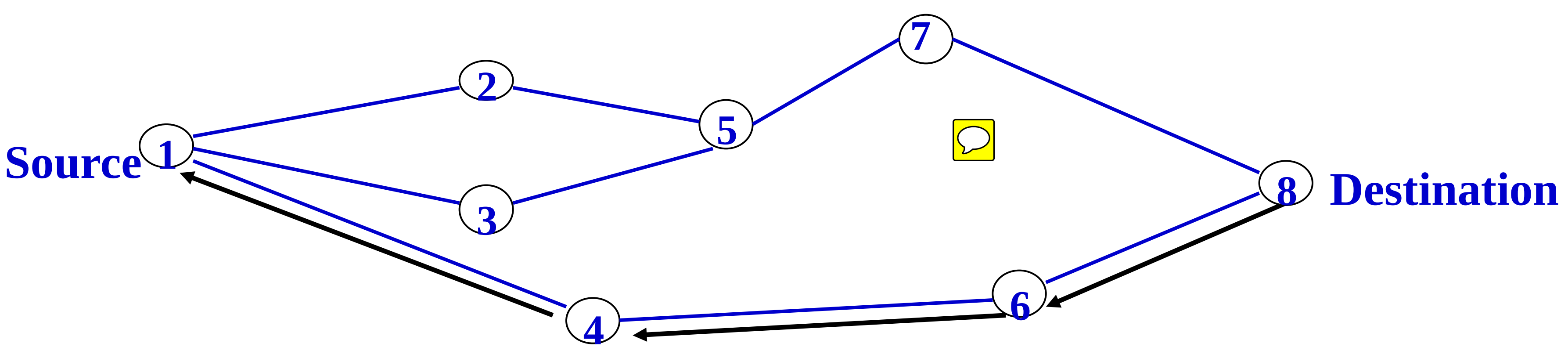
AODV ctd..

- Initiator node includes the following in the RREQ packet:
  --- Its own sequence number
  --- The broadcast ID
  --- The most recent sequence number the initiator has for the destination
- Intermediate nodes reply only if they have a route to the destination with a sequence number greater than or at least equal to that contained in RREQ
- To optimize, intermediate nodes record the address of the neighbor from which first copy received
- All subsequent copies discarded
- Once RREQ reaches destination or intermediate node with fresh enough route to the destination, it sends a route-reply message
- If nodes along the route move, their upstream neighbors propagate a link failure notification, until it reaches the source

Route Discovery in AODV Protocol



(a) Propagation of Route Request (RREQ) Packet



(b) Path Taken by the Route Reply (RREP) Packet

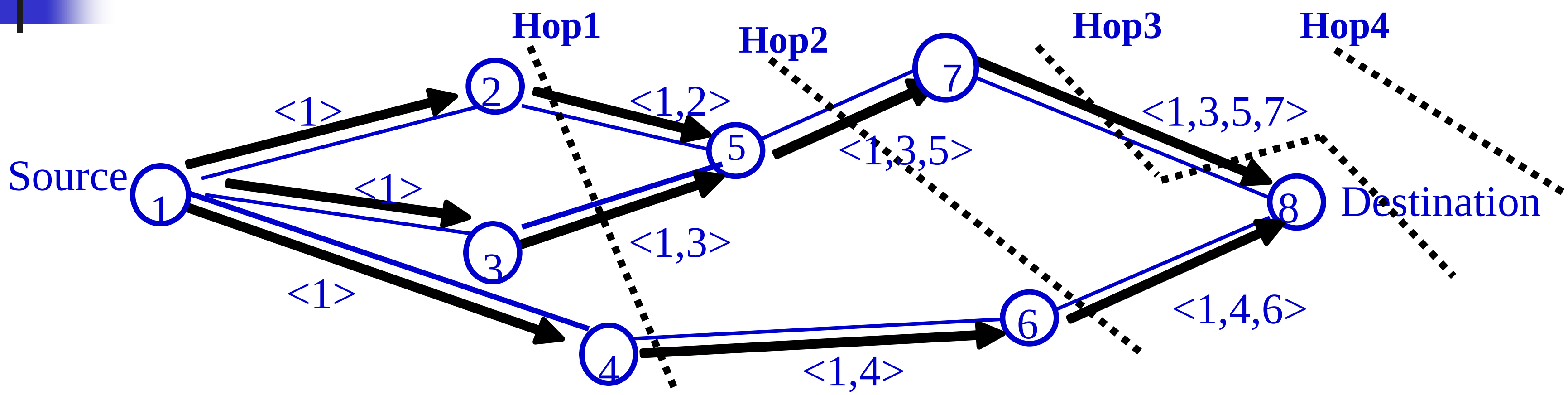
Dynamic Source Routing

- This is an on-demand routing protocol
- The protocol consists of two major phases: Route Discovery, Route Maintenance
- When a mobile node has a packet to send to some destination, it first consults its route cache to check whether it has a route to that destination
- If it is an un-expired route, it will use this route
- If the node does not have a route, it initiates route discovery by broadcasting a Route Request packet
- This Route Request contains the address of the destination, along with the source address

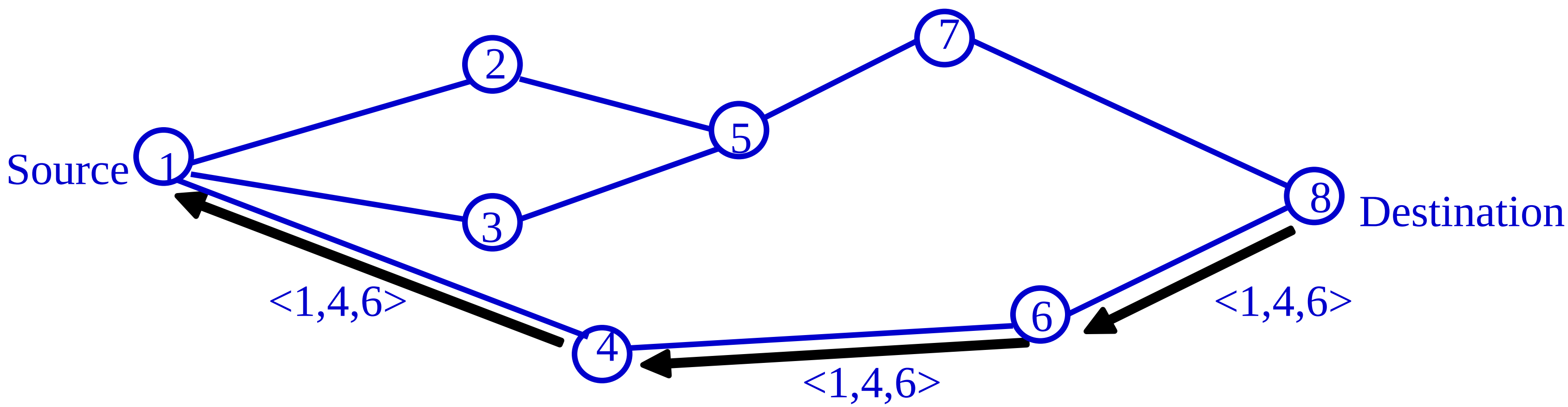
Dynamic Source Request (Cont'd)

- Each node receiving the packet checks to see whether it has a route to the destination. If it does not, it adds its own address to the route record of the packet and forwards it
- A route reply is generated when the request reaches either the destination itself or an intermediate node that contains in its route cache an un-expired route to that destination
- If the node generating the route reply is the destination, it places the route record contained in the route request into the route reply
- A reply packet is sent to the initiator
- Is links are symmetric, reverse path can be taken
- Otherwise, responding node initiates its own route discovery process
- Route maintenance carried by route-error packets and acknowledgements

Creation of Route Record in DSR



(a) Building Record Route During Route Discovery



(b) Propagation of Route Reply with the Route Record

Temporarily Ordered Routing Algorithm (TORA)

- TORA is a highly adaptive loop-free distributed routing algorithm based on the concept of link reversal
- TORA minimizes reaction due to topological changes
- Algorithm tries to localize messages in the neighborhood of changes
- TORA exhibits multipath routing capability
- Can be compared with water flowing downhill towards a sink node
- The height metric is used to model the routing state of the network
- Nodes maintain routing information to one-hop neighbors

TORA (Cont'd)

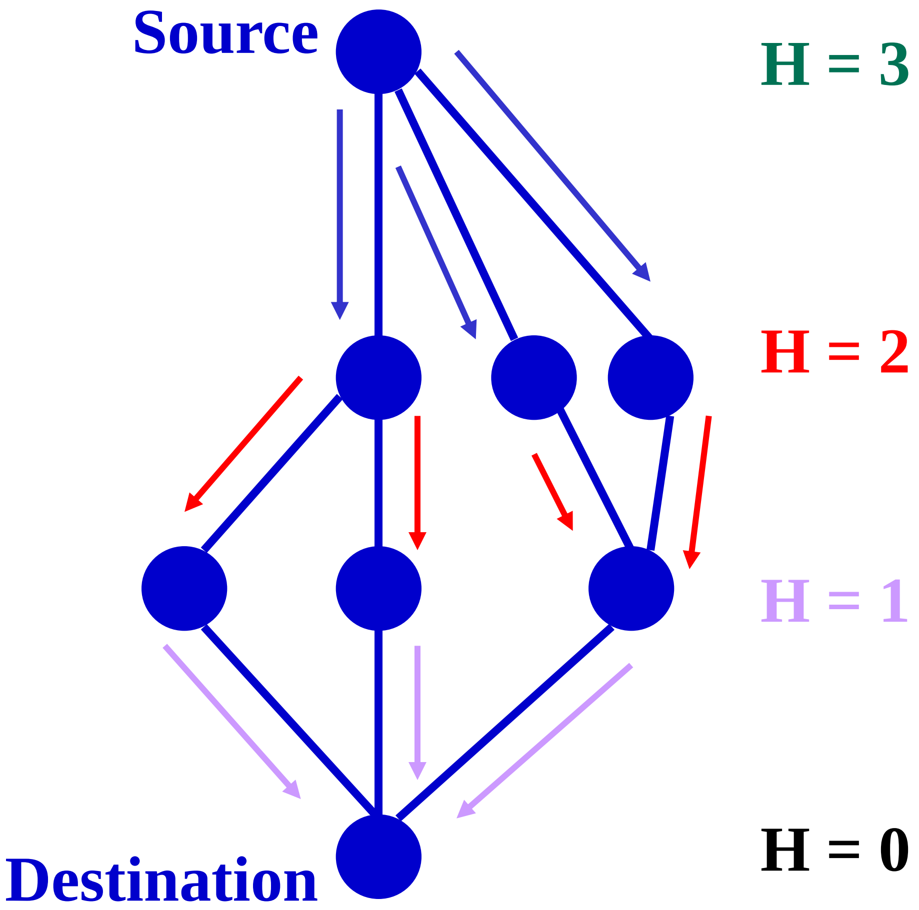
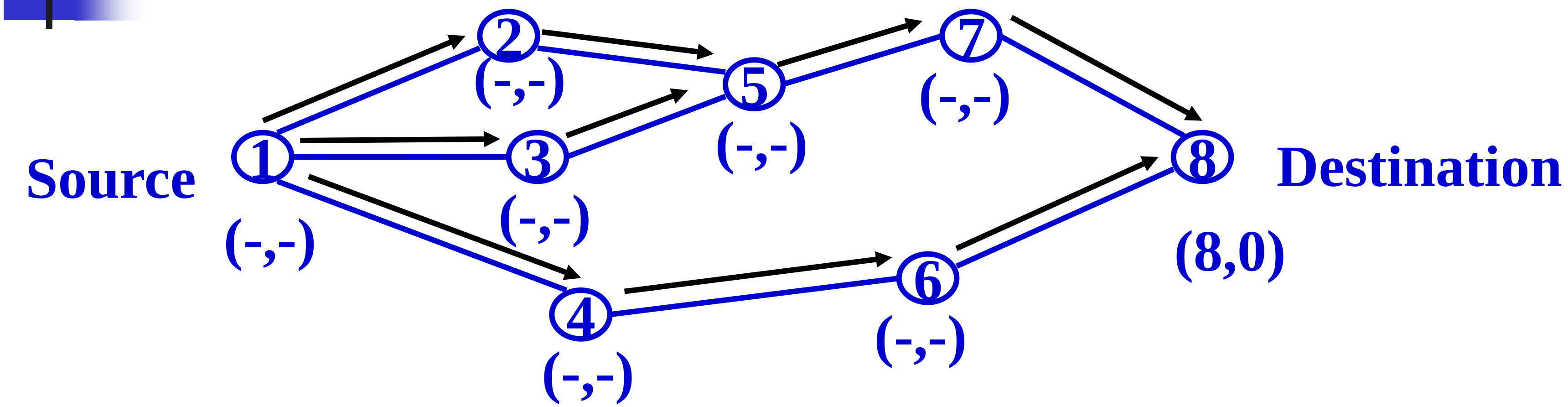


Illustration of Tora height metric

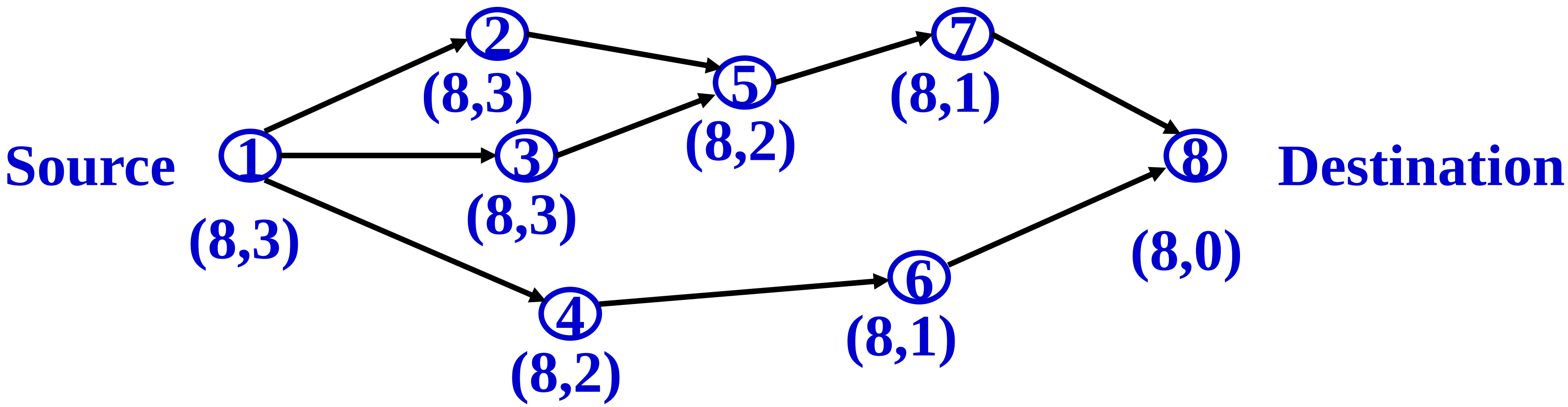
TORA (Cont'd)

- The protocol performs three basic functions:
  --- Route creation
  --- Route maintenance
  --- Route erasure
- A separate directed acyclic graph (DAG) is maintained by each node to every destination
- Route query propagates through the network till it reaches the destination or an intermediate node containing route to destination
- This node responds with update and sets its height to a value greater than its neighbors
- When a route to a destination is no longer valid, it adjusts its height
- When a node senses a network partition, it sends CLEAR packet to remove invalid routes
- Nodes periodically send BEACON signals to sense the link status and maintain neighbor list

TORA (Cont'd)



Propagation of the query message



Node's height updated as a result of the update message

TORA (Cont’d)

- The height metric in TORA depends on logical time of a link failure
- The algorithm assumes all nodes to be synchronized.
- TORA has 5-tuple metric:
  --- Logical time of link failure
  --- Unique ID of the node that defined the new
  reference level
  --- A reflection indicator bit
  --- A propagation ordering parameter
  --- Unique ID of the node
- The first three elements together describe the
  reference level
- Oscillation can occur using TORA, similar to count-to-infinity problem
- TORA is partially reactive and partially proactive

Associativity Based Routing (ABR)

- The objective is to discover longer-lived routes
- In ABR a route is selected based on the degree of stability associated with mobile nodes
- The three phases of ABR are:

  --- Route discovery

  --- Route reconstruction

  --- Route deletion
- The route discovery is accomplished by a Broadcast Query- Reply (BQ-REPLY) cycle
- Each node generates a beacon to signify its existence
- When received by neighboring nodes, the beacon causes their associativity tables to be updated
- Association stability is defined by connection stability of one node with respect to another node over time and space
- A Route Notification is used to erase entries with downstream nodes
- If a route is no longer needed, a route delete message is broadcasted so that all the nodes along the route update their routing tables

Signal Stability Routing (SSR)

- SSR is another on-demand routing protocol
- It selects a route based on the signal strength between nodes and a node's location stability
- Dynamic routing protocol maintains signal stability table and the routing table
- All transmissions are processed by static routing protocol
- The packet is passed up the stack if it is intended receiver
- Otherwise, it looks up in the routing table and forwards the packet
- This route selection criteria has the effect of choosing routes that have a better link connectivity

Hybrid protocols

- **Zone Routing Protocol (ZRP):**
  - Hybrid of reactive and proactive protocols.
  - Limits the scope of proactive search to the node's local neighborhood
  - Nodes local neighborhood is defined as a routing zone with a given distance
  - The node need to identify all its neighbors which are one hop away
  - MAC-level neighbor discovery protocol used
  - Interzone routing protocol employs query-response mechanism on demand basis

- **Fisheye State Routing (FSR):**
  - Uses a multi-level fisheye scopes to reduce routing update overhead in large networks
  - It helps to make a routing protocol scalable by gathering data on the topology, which may be needed soon

Hybrid protocols

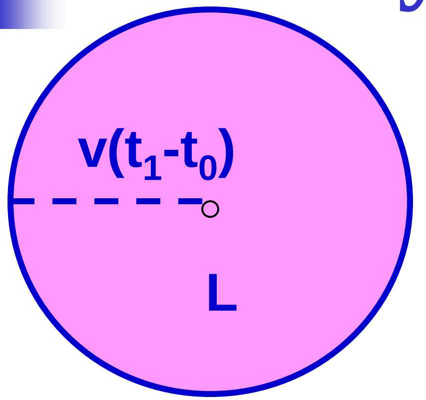
Landmark Routing (LANMAR):

- Combines the features of FSR and landmark routing
- Uses a landmark to keep track of each set of nodes that move together
- The nodes exchange the link-state information only with their neighbors
- A modified version of FSR used for routing by maintaining routing table within the scope and landmark nodes
- Nodes periodically exchange topological information with their immediate neighbors

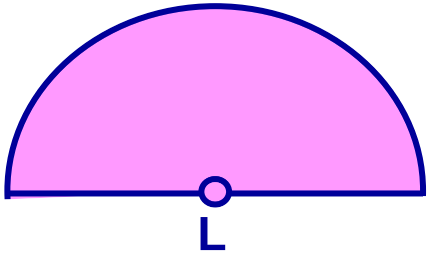
Location-Aided Routing (LAR):

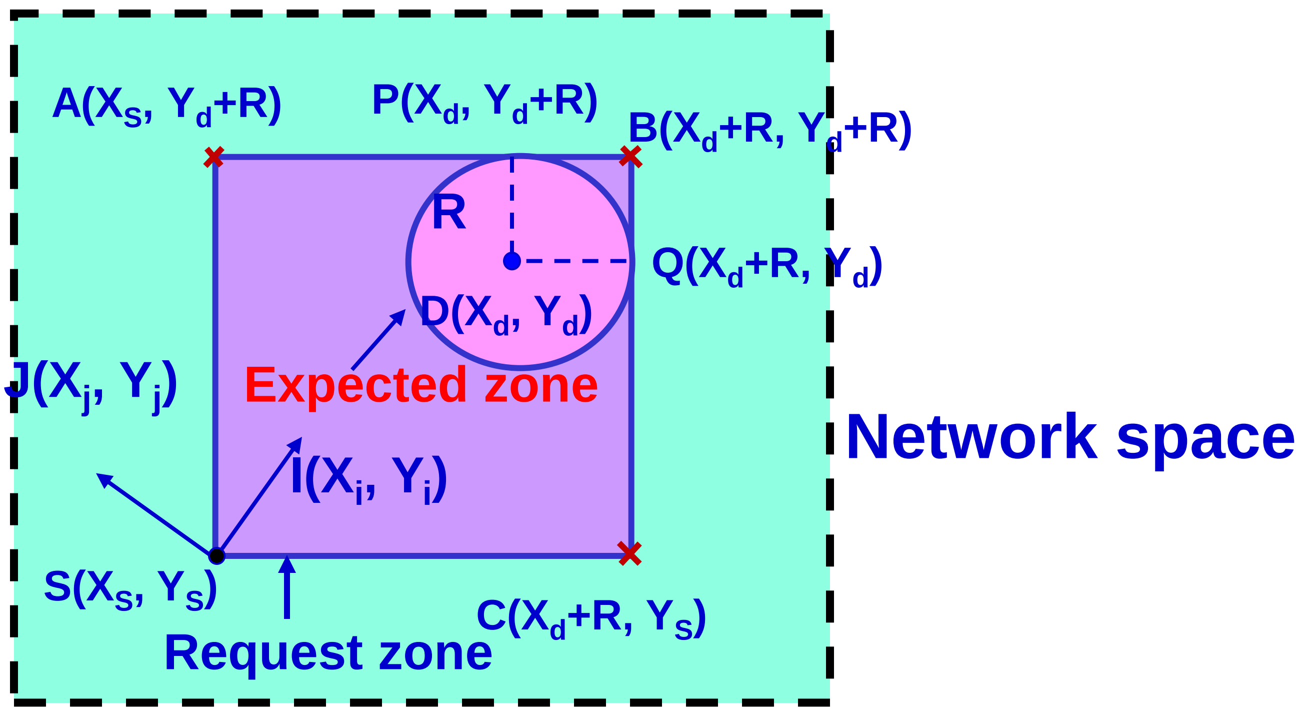
- It exploits location information to limit the scope of routing
- LAR limits the search based on the expected location of the destination node, given location of destination at given time, try to speculate expected zone at current time, using average velocity
- Expected zone provides a request zone

Hybrid protocols: LAR



Expected zones





Hybrid protocols (Cont'd)

Distance Routing Effect Algorithm for Mobility (DREAM):

- Each node can optimize the frequency at which it sends updates to the networks and correspondingly reduce the bandwidth and energy used
- It is based on the distance effect and a node's mobility rate

Relative Distance Micro-discovery Ad Hoc Routing (RDMAR):

- This is based on the calculated relative distance between two terminals
- The query flood is localized to a limited region centered at the source node

Power Aware Routing:

- Power-aware metrics are used for determining routes
- It reduces the cost, ensures that the mean time to node failure is increased, without any further delay in packet delivery

Protocol Characteristics (1/2)

Routing Protocol	Route Acquisition	Flood for Route Discovery	Delay for Route Discovery	Multipath Capability	Effect of Route Failure
DSDV	Computed a priori	No	No	No	Updates the routing tables of all nodes
WRP	Computed a priori	No	No	No	Ultimately, updates the routing tables of all nodes by exchanging MRL between neighbors
DSR	On-demand, only when needed	Yes. Aggressive use of caching may reduce flood	Yes	Not explicitly. The technique of salvaging may quickly restore a route	Route error propagated up to the source to erase invalid path
AODV	On-demand, only when needed	Yes. Controlled use of cache to reduce flood	Yes	No, although recent research indicate viability	Route error propagated up to the source to erase invalid path

Protocol Characteristics (2/2)

Routing Protocol	Route Acquisition	Flood for Route Discovery	Delay for Route Discovery	Multipath Capability	Effect of Route Failure
AODV	On-demand, only when needed	Yes. Controlled use of cache to reduce flood	Yes	No, although recent research indicate viability	Route error propagated up to the source to erase invalid path
TORA	On-demand, only when needed	Basically one for initial route discovery	Yes. Once the DAG is constructed, multiple paths are found	Yes	Error is recovered locally
ZRP	Hybrid	Only outside a source's zone	Only if the destination is outside the source's zone	No	Hybrid of updating nodes' tables within a zone and propagating route error to the source
LAR	On-demand, only when needed	Reduced by using location information	Yes	No	Route error propagated up to the source

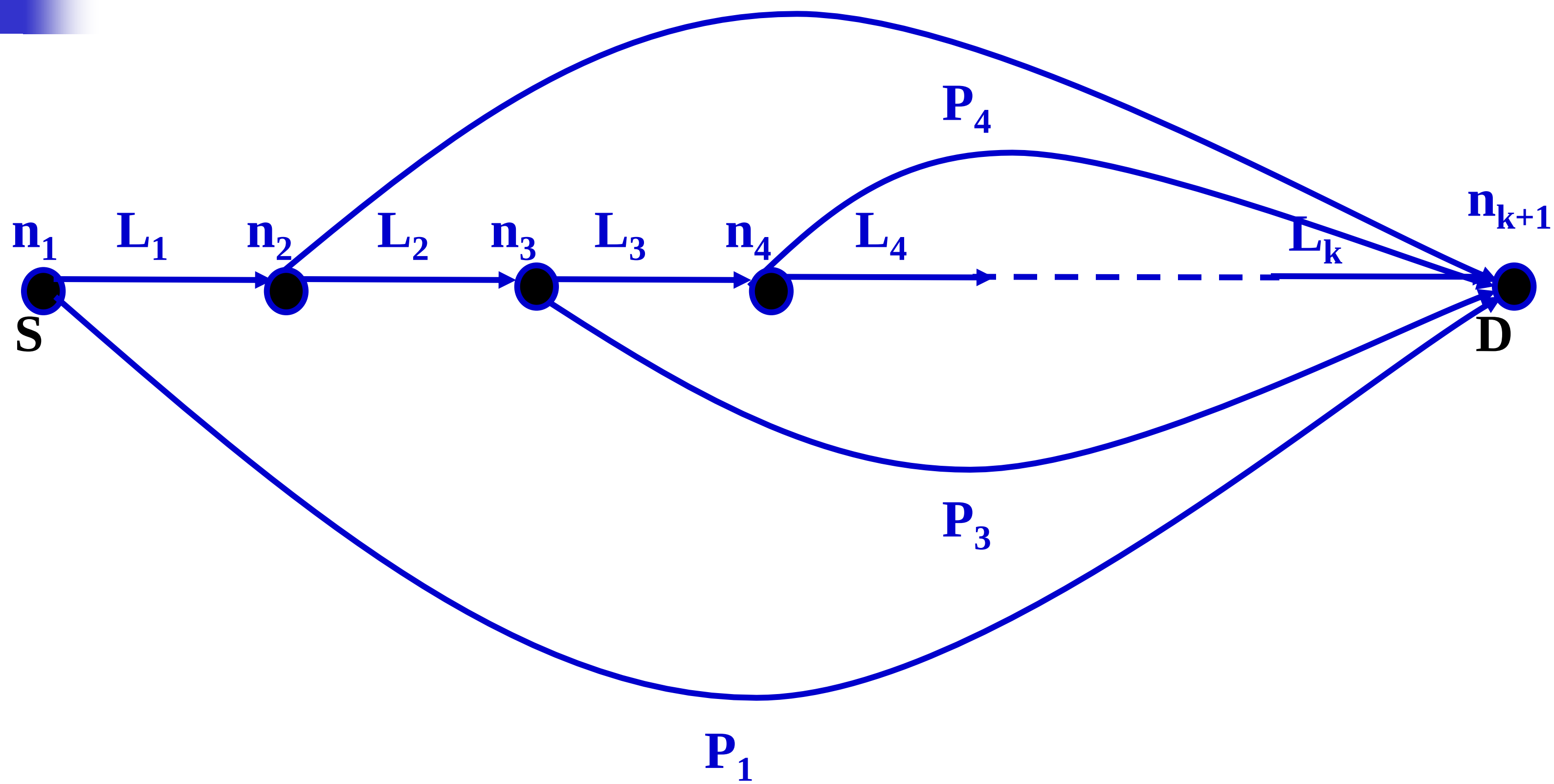
Multipath Routing

- Multipath provides redundant paths between source and destination
- Routes are disconnected frequently in ad hoc networks due to mobility or poor wireless link quality
- Multipath routing could lead to out-of-order delivery, re-sequencing of packets at the destination and increased collision
- Can aid in secured routing against denial of service
- Various unipath protocols can discover multiple paths

On-Demand Multipath Routing

- Extension of DSR protocol
- Route discovery by flooding the network query: two possible extensions
- First extension: destination responds to a set of query packets- source has multiple routes
- Second extension: destination replies to all intermediate nodes along primary paths- giving alternate disjoint routes to all those nodes

Multipath Routing



Route construction and maintenance in On Demand Multipath Routing Protocol

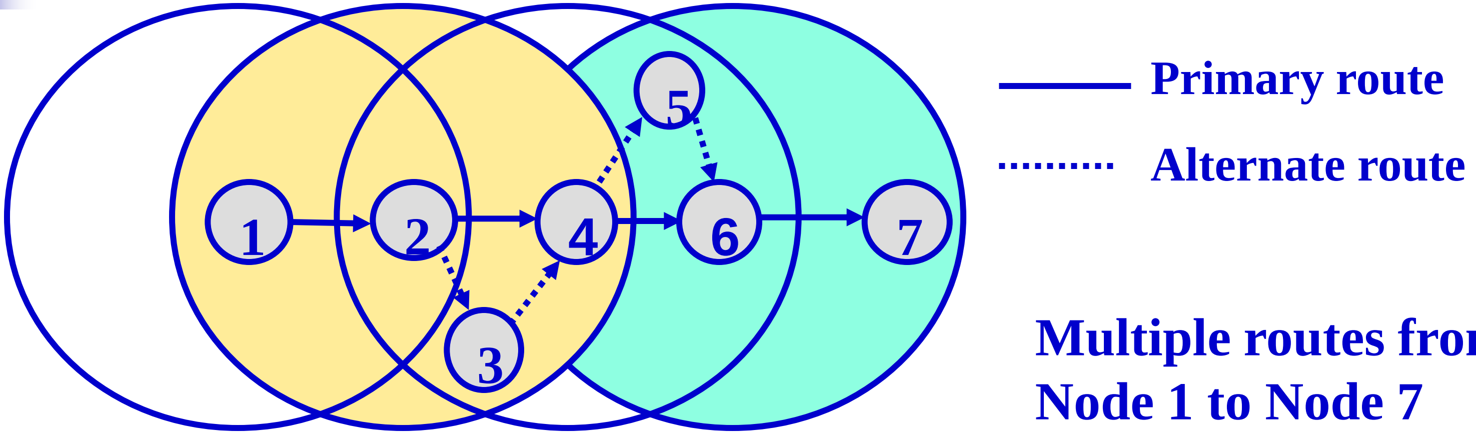
Multipath Routing ctd…

Ad Hoc On-Demand Distance Vector-Backup Routing

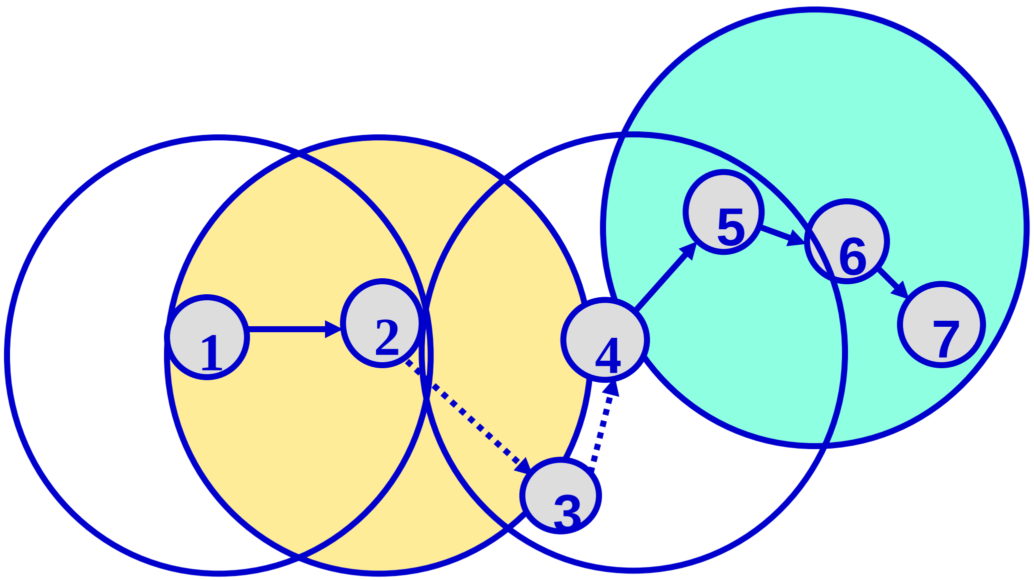
- AODV-BR constructs routes on demand
- Uses alternate path if primary path disrupted
- Utilizes mesh arrangement to provide alternate paths
- Two phases: Route Construction and Route Maintenance:
- Route construction: Source initiates route discovery by flooding:
  - Intermediate nodes stores previous hop and source node information upon receiving non-duplicate path request
  - Mesh construction and alternate paths established during route reply phase
  - Node chooses the best route among multiple route responses
  - When route response reaches the destination, primary route is established
- Route Maintenance and Mesh Routes
  - Primary path used unless failure
  - In case of route failure, one hop data broadcast is performed
  - Neighbors having entry to destination in alternate route table send unicast packet

A node on primary path detects a route failure, sends a route error packet to source

Multipath Routing: AODV-BR



Multiple routes from Node 1 to Node 7



Alternate route used when primary disconnects

Multipath Routing ctd…

Split Multipath Routing (SMR)

- SMR is an on-demand routing with maximul disjoint paths.
- Routes may be of unequal length
- Two phases: Route Construction and Route Maintenance

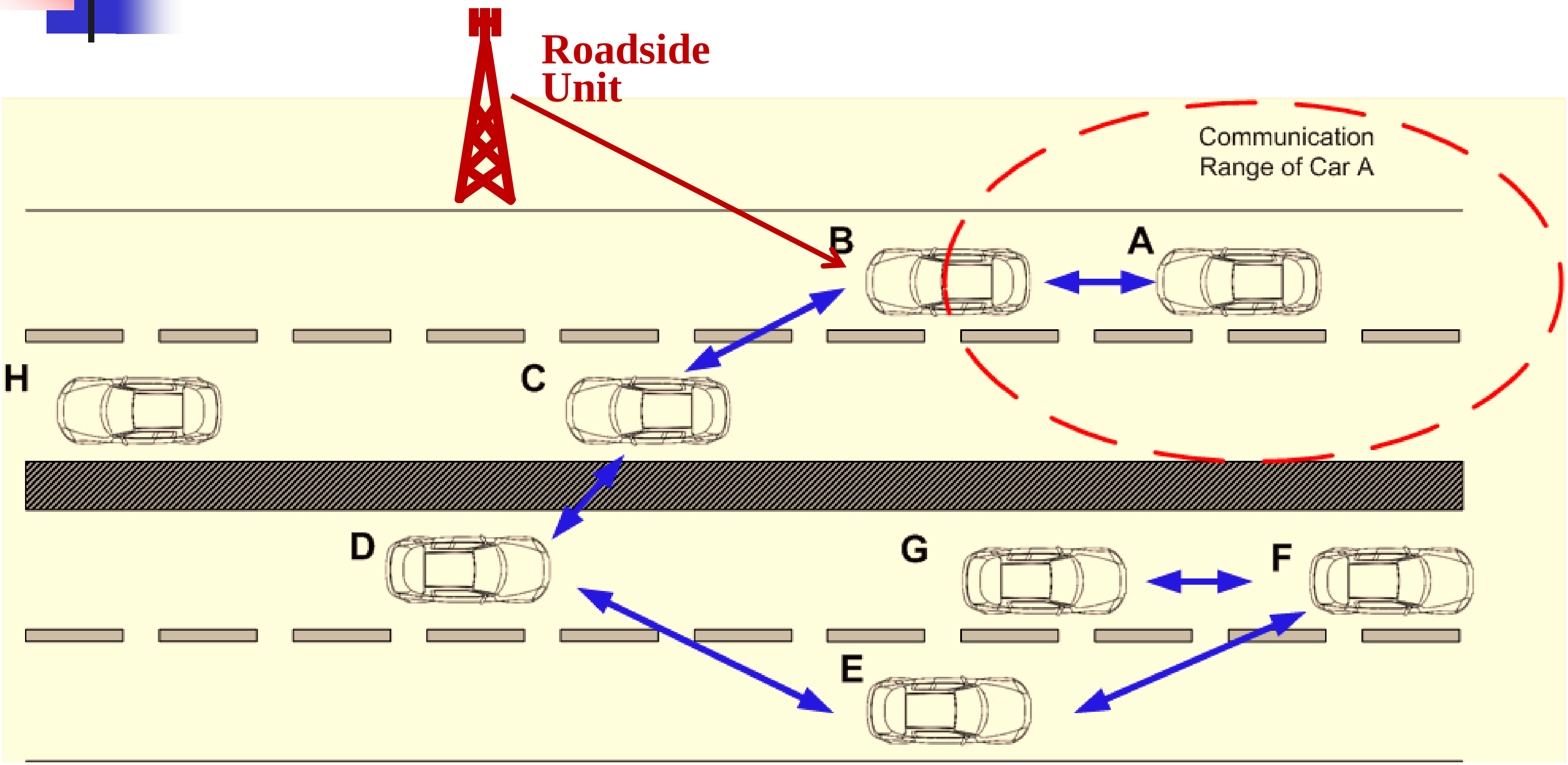
Caching and Multipath Routing Protocol (CHAMP)

- Every node maintains a route cache and route request cache
- Route cache contains forwarding information to every active destination
- Two phases: Route Construction and Data Forwarding
- Route construction: Source initiates route discovery by flooding
- Data forwarding: Data packets are identified by source identifier and a source-affixed sequence number

Neighbor-Table-Based Multipath Routing in Ad Hoc Networks

- This is a mixed multipath routing protocol which deals with regular topological changes
- Multiple paths need not be disjoint
- Three steps: Establishment of Neighbor Table and Route Cache, Route Discovery and Route Maintenance

Vehicular Area Network (VANET)



❑ **Basic objective is to find some relevant local information, such as close by gas stations, restaurants, grocery stores, and hospitals,**

❑**Primary motivation is to obtain knowledge of local amenities**

Vehicular Area Network (VANET)

- Hello beacon signals are sent to determine other vehicle in the vicinity
- Table is maintained and periodically updated in each vehicle
- Vehicle in an urban area move out relatively low speed of up to 56 km/hr while
- Speed varies from 56 km/hr to 90 km/hr in a rural region
- Freeway-based VANET could be for emergency services such as accident, traffic-jam, traffic detour, public safety, health conditions, etc.
- Early VANET used 802.11-based ISM band
- 75 MHz has been allocated in 5.850 - 5.925 GHz band
- Coverage distance is expected to be less than 30 m and data rates of 500 kbps
- FCC has allocated 7 new channels of in 902 - 928 MHz range to cover a distance of up to 1 km using OFDM
- It is relatively harder to avoid collision or to minimize interference
- Slotted ALOHA does not provide good performance
- Non-persistent or p-persistent CSMA is adopted

Vehicular Area Network (VANET)

Characteristic	Urban Area	Rural Area	Freeway-based
1. Connectivity	High	Sparse	Unpredictable
2. Application	Streaming media; emergency information; geographical information	Geographical information	Emergency use
3. Mobility	Low; slow changes in connectivity	Low medium	High-speed; rapid changes in link topology
4. Mobility pattern	Random road	Most likely fixed path	Fixed
5. Routing	Geographic	Geographic	Connectivity-aware Routing
6. Area of communication	Small region	Small area	Large space
7. Delay	Mostly acceptable	Acceptable	Not acceptable
8. Type of Information	Nearby grocery stores, restaurants, gas stations; and hospitals; rarely for emergency; safely for pedestrian or cyclists	Nearby amenities; notifying emergency of a vehicle	Congestion; detour; accident; traffic jam; emergency; road geometry warning; rail-road crossing; overweight vehicle
9. Volume of Information	Low to medium	Low: infrequent message	Large: frequent data
10. Data Delivery mode	Push	Push	Pull or Push
11. Security Requirements	Short term	Short term	Relatively long term

Network Simulators

- ns-2, ns-3
  - Utilizes discrete event-driven mechanism to simulate all kinds of activities in networks
  - Four schedulers available in ns-2: linked-list, heap, calendar queue, and real-time
  - Split-language programming
  - Open source
  - Visualization
  - Support of emulation
  - Support of mobility models
- OPENT Modeler
- QualNet
- Mininet
- OMNeT++