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INSTITUTE OF SCIENCE AND TECHNOLOGY

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SITA1501
Wireless Sensor Network and Architecture

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Unit II

ROUTING PROTOCOLS FOR AD HOC WIRELESS NETWORKS 9 Hrs.

- **Designing issues**
- **Classification of routing protocols**
  - Table driven routing protocols
  - On demand routing protocol,
  - Hybrid routing protocol
  - Hierarchical routing protocols.
  - Multicast routing in Ad Hoc wireless networks:
    - **Operations and classification of multicast routing protocols**
    - **Tree based multicast routing protocol**
    - **Mesh based multicast routing protocol**

Basic Terminologies

- **Mobile Ad-hoc Network (MANET) :**

  a self-configuring ad-hoc network of many autonomous nodes, which are often mobile devices

- **Routing :**

is a process which discovers the best available path from source to target node also maintains the route

- **Quality of services parameters:**
  - Packet Delivery Ratio,
  - Routing overhead
  - Average end-to-end Delay
  - Jitter and Packet Loss

Design Issues

1. Mobility
2. Bandwidth constraint
3. Error Prone Shared Broadcast Radio Channel
4. Hidden and Exposed Terminal Problems
5. Resource constraints

Design Issues

1. Mobility
    - Highly dynamic
    - Frequent path breaks
    - Frequent topology changes

Design Issues

2. Bandwidth constraint

- Radio band is limited, hence the data rates are smaller when compared with the wired network
- So, bandwidth has to be used carefully to avoid overheads
- Topology changes incur more control overhead in turn consumes more bandwidth

Design Issues

3. Shared Broadcast Radio Channel

- Wireless links have time varying characteristics
- The routing protocols interacts with the MAC layer for finding the routes or alternate routes
- So, collision of data and control packets

Design Issues

4. Hidden and Exposed Terminal Problems

Hidden Terminal Problem

- Assuming B is the intermediate node between A and C
- A and C are sending data to B. A is hidden to C and C is hidden to A. But both are visible to B.
- Since A and C are hidden terminals, the packets sent by both the nodes at the same time causes collision at node B.
- This can be avoided by using RTS-CTS messages and also using RTS- CTS- Data-ACK.

Exposed Terminal Problem

- Node arrangement is A<-->B<-->C<-->D
- B is sending to A and at the same time C wants to send to D, but it cannot, because of inability of use of radio spectrum.
- when B-> A and C->D to happen simultaneously, then the transmitting frequency of C to be different from the receiving frequency.

Design Issues

5. Resource constraints

- Battery Life
- Processing Power
- Size and Weight

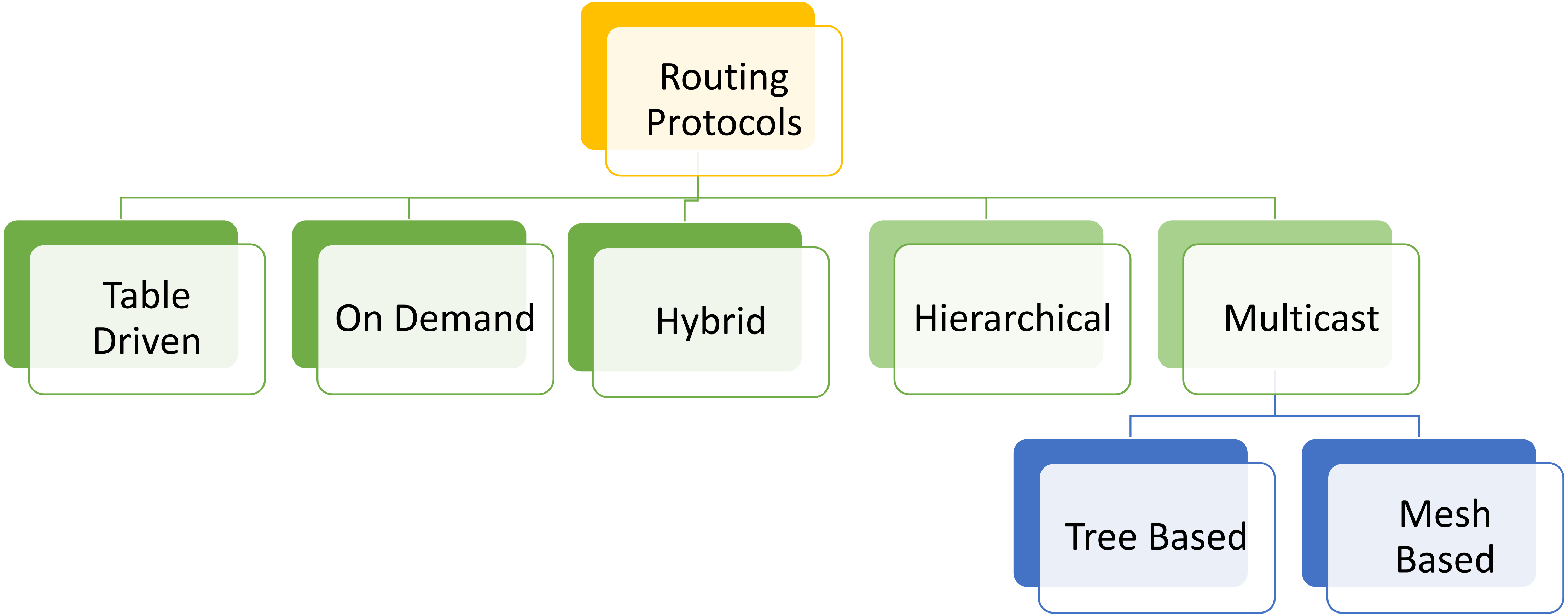
Ideal Characteristics

- Fully distributed (it is more fault tolerant than centralized)
- Adaptive to frequent topology changes
- Route computation and maintenance must involve minimum number of nodes
- Localized, loop free and free from stale routes
- Number of broadcasts to be limited to avoid packet collisions
- Must converge to optimal route in case of path break or path failure
- Scarce use of battery, bandwidth, computing power, memory, etc.
- Store information locally within the nodes (to store only the stable local route, rather than the remote unstable route)
- Should support some Quality of service and also to support time sensitive traffic

Routing Protocols

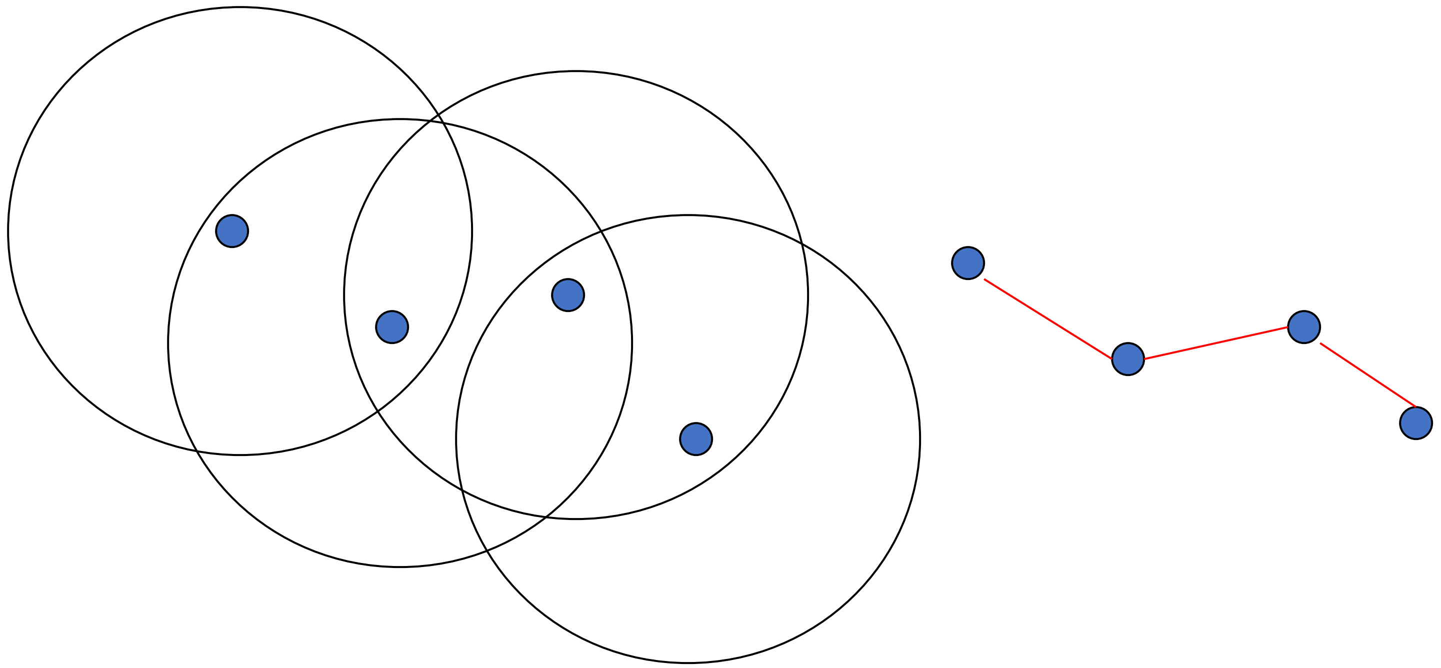
- A routed protocol is **used to deliver application traffic**
- It provides appropriate addressing information in its **network layer** to allow a packet to be forwarded from one node to another
- Routing protocols need to adapt to changes in the network topology and maintain routing information, so that packets can be forwarded to their destinations
- 2 phases
    - Route discovery
    - Packet Delivery

Routing Protocols - Classification



Multi-Hop Wireless

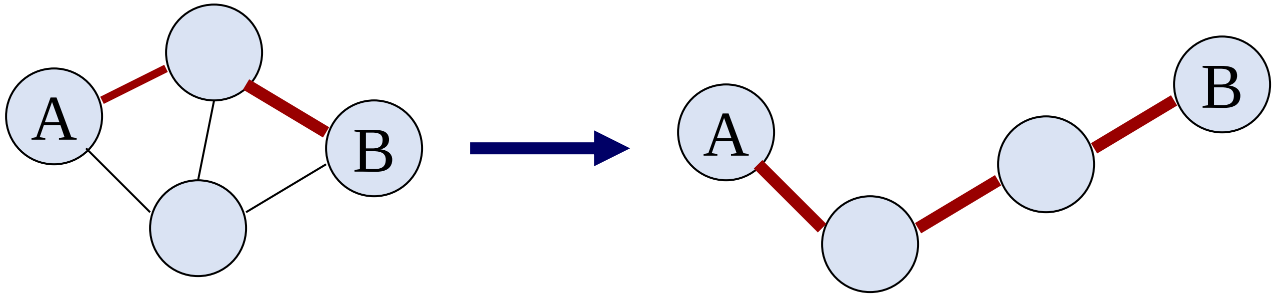
- Hop ??
- May need to traverse multiple links to reach destination



- Mobility causes route changes

Mobile Ad Hoc Networks (MANET)

- Host movement frequent
- Topology change frequent



- No cellular infrastructure. Multi-hop wireless links.
- Data must be routed via intermediate nodes.

Routing Protocols - Classification

- **Based on Routing Information Update Mechanism**

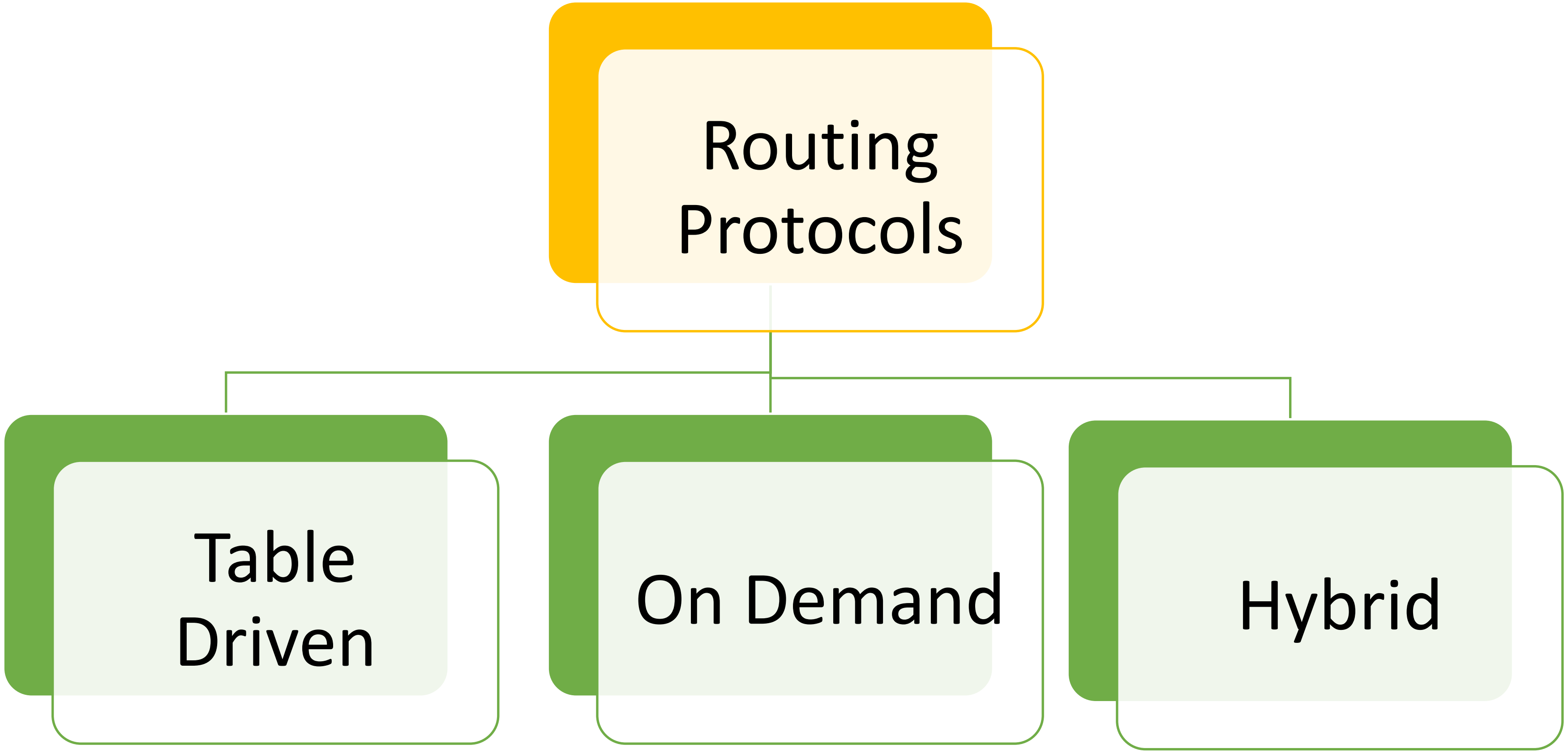
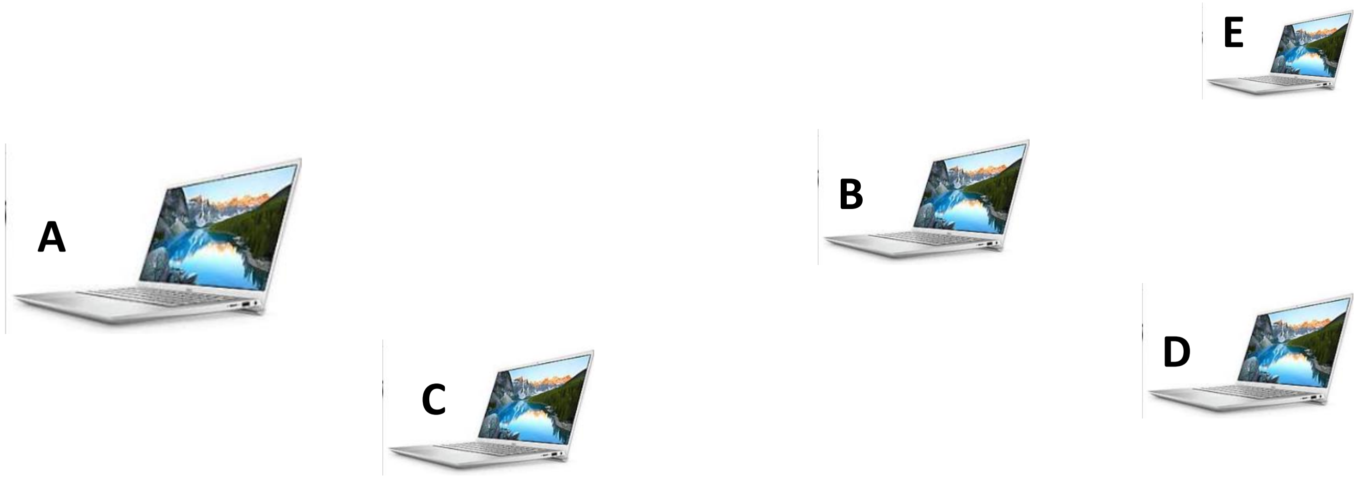


Table Driven Routing Protocols
(Proactive Routing Protocols)

- Each node maintains a routing table
- Traditional distributed shortest-path protocols
- Maintain routes between every host pair at all times
- Based on periodic updates; High routing overhead



Routing Table - Node A

Source	Destination	Route
A	B	A-C-B
A	C	A-C
A	D	A-C-B-D
A	E	A-C-B-E

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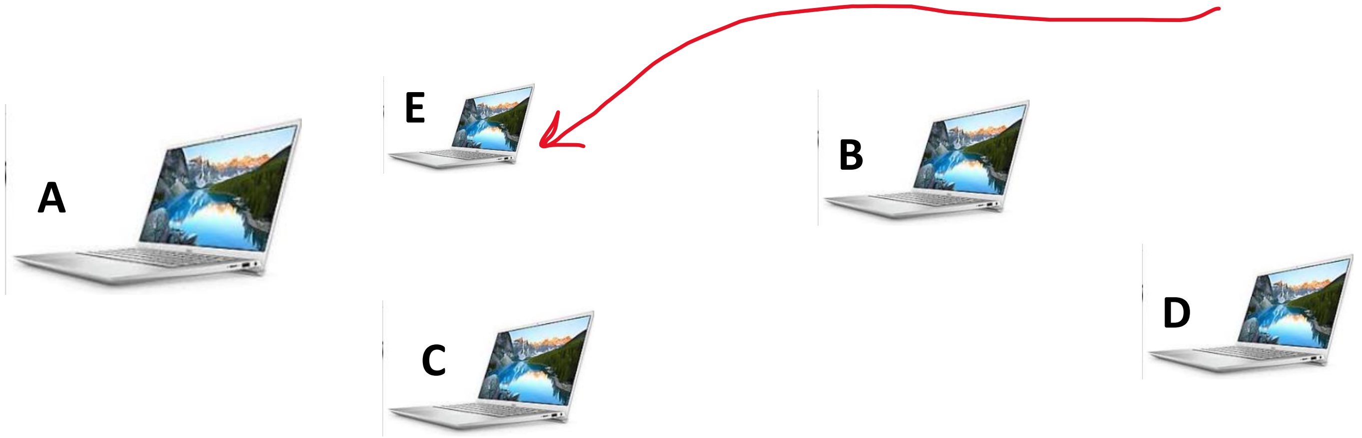

Routing Table - Node A

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A	D	A-E-B-D
A	E	A-E

Table Driven Routing Protocols (Proactive Routing Protocols)

Table Driven Protocols

- Destination Sequenced Distance Vector (DSDV)
- Optimized Link State Routing (OLSR)
- Fisheye State Routing (FSR)
- Global State Routing (GSR)
- Source Tree Adaptive Routing (STAR)
- Wireless Routing Protocol (WRP)

Table Driven Protocols

1. DSDV

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  - Destination Sequenced Distance Vector (DSDV)
  - Optimized Link State Routing (OLSR)
  - Fisheye State Routing (FSR)
  - Global State Routing (GSR)
  - Source Tree Adaptive Routing (STAR)
  - Wireless Routing Protocol (WRP)

Table Driven Protocols

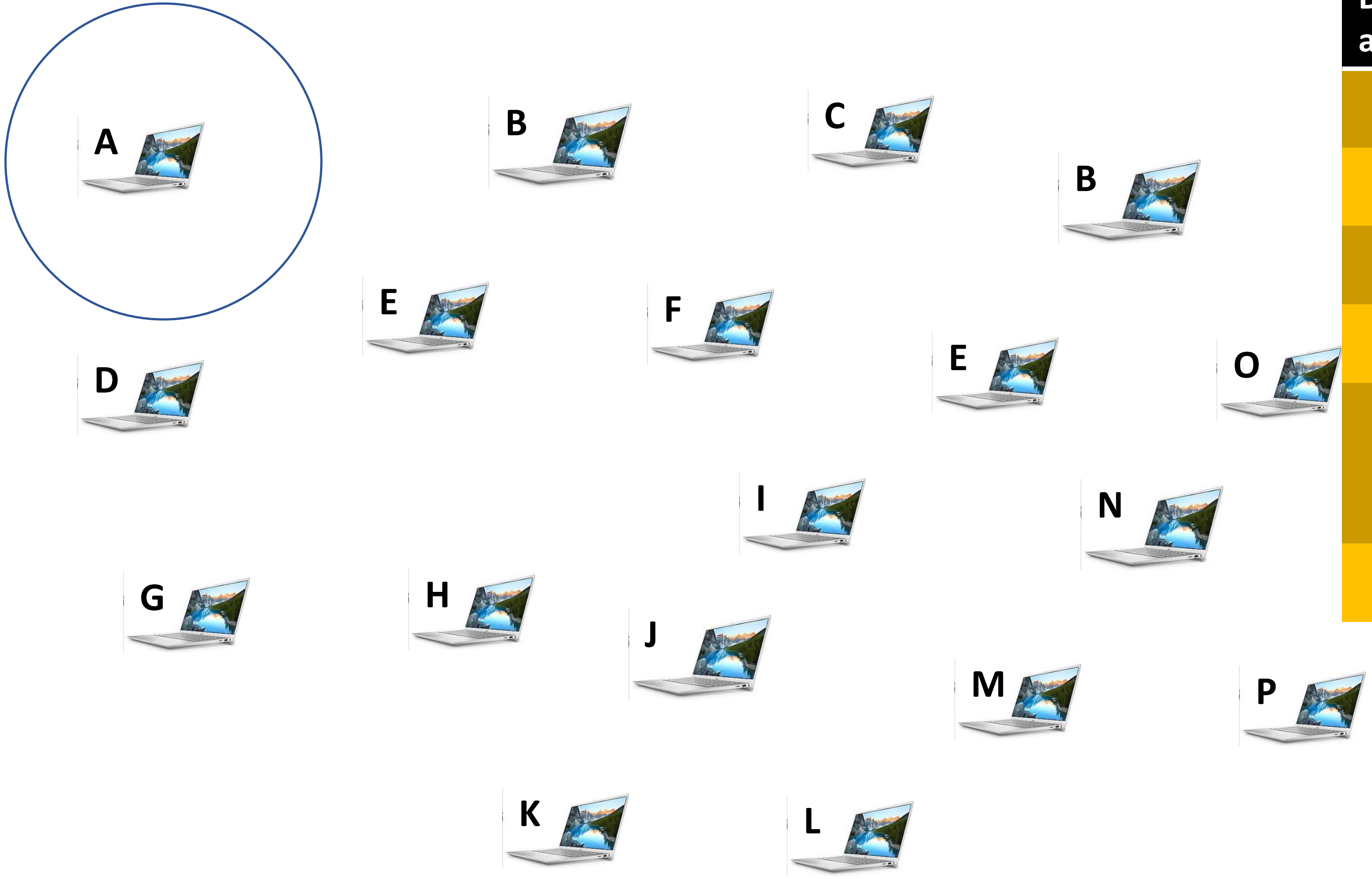
1. DSDV

Based on **Distributed Bellman-Ford algorithm**

- A proactive **hop-by-hop distance vector** routing protocol
- Requires each node to broadcast **routing updates** periodically
- Every node maintains a **routing table** for all possible destinations and the number of hops to each destination
- **Sequence numbers** enable the nodes to distinguish stale routes from new ones
- To alleviate large network **update traffic**, two possible types of update packets: full dumps or small increment packets
- The **route labeled** with the most recent sequence number is always used
- In the event that two updates have the **same sequence number**, the route with the **smaller metric** is used in order to optimize (shorten) the path

Table Driven Protocols

1. DSDV

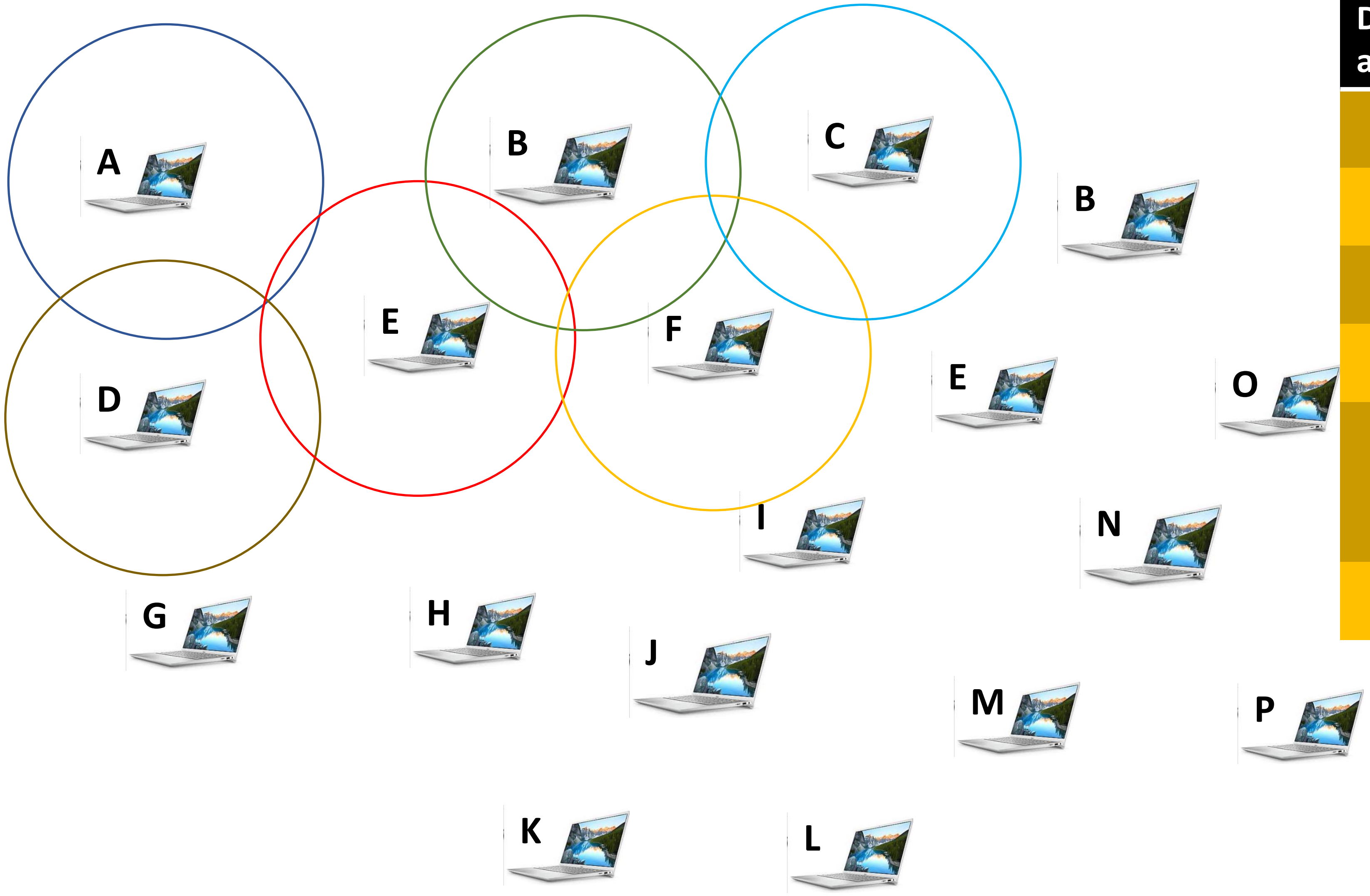


Routing Table - Node A

Destination	Next hop	No. of Hops	Sequence No.	Route
B	E	2	S128-B	A-E-B
C	E	3	S234-C	A-E-B-C
D	D	1	S562-D	A-D
E	E	1	S128-E	A-E
.	.			
.	.			
.	.			
P	E			

Table Driven Protocols

1. DSDV

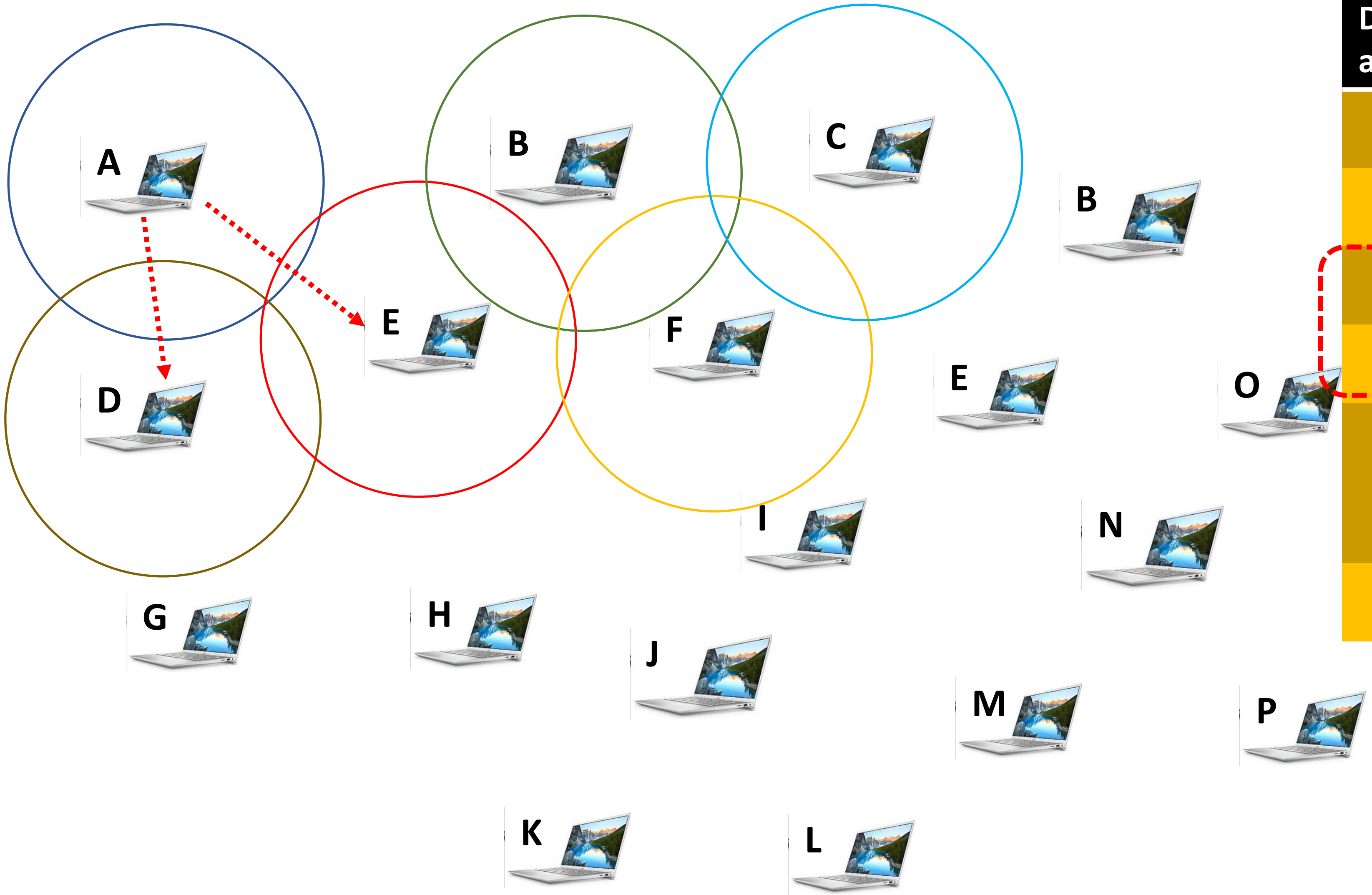


Routing Table - Node A

Destination	Next hop	No. of Hops	Sequence No.	Route
B	E	2	S128-B	A-E-B
C	E	3	S234-C	A-E-B-C
D	D	1	S562-D	A-D
E	E	1	S128-E	A-E
. . .	. . .			
P	E			

Table Driven Protocols

1. DSDV



Routing Table - Node A

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B	E	2	S128-B	A-E-B
C	E	3	S234-C	A-E-B-C
D	D	1	S562-D	A-D
E	E	1	S128-E	A-E
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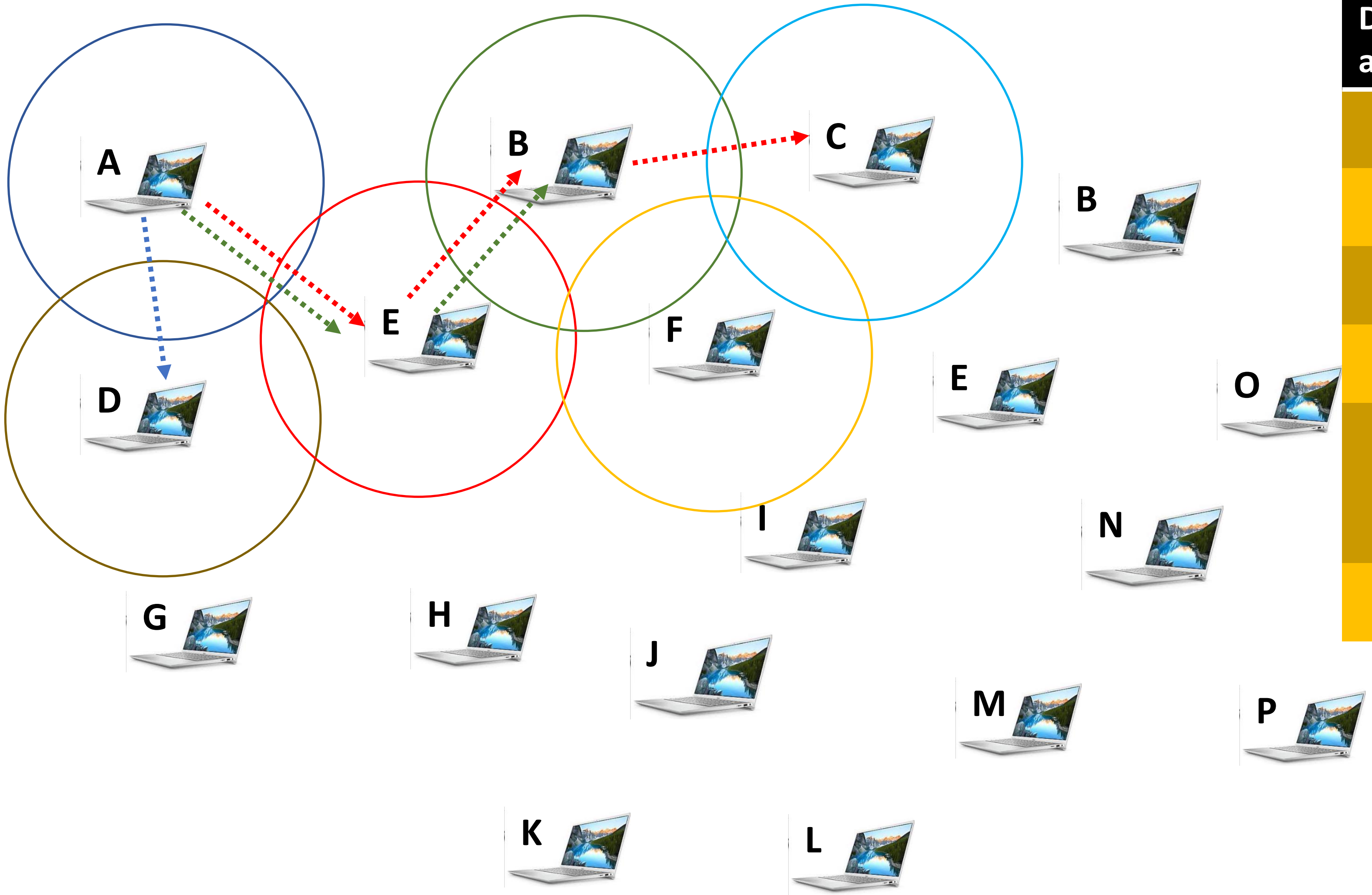
.	.			
.	.			
P	E			

Table Driven Protocols

1. DSDV

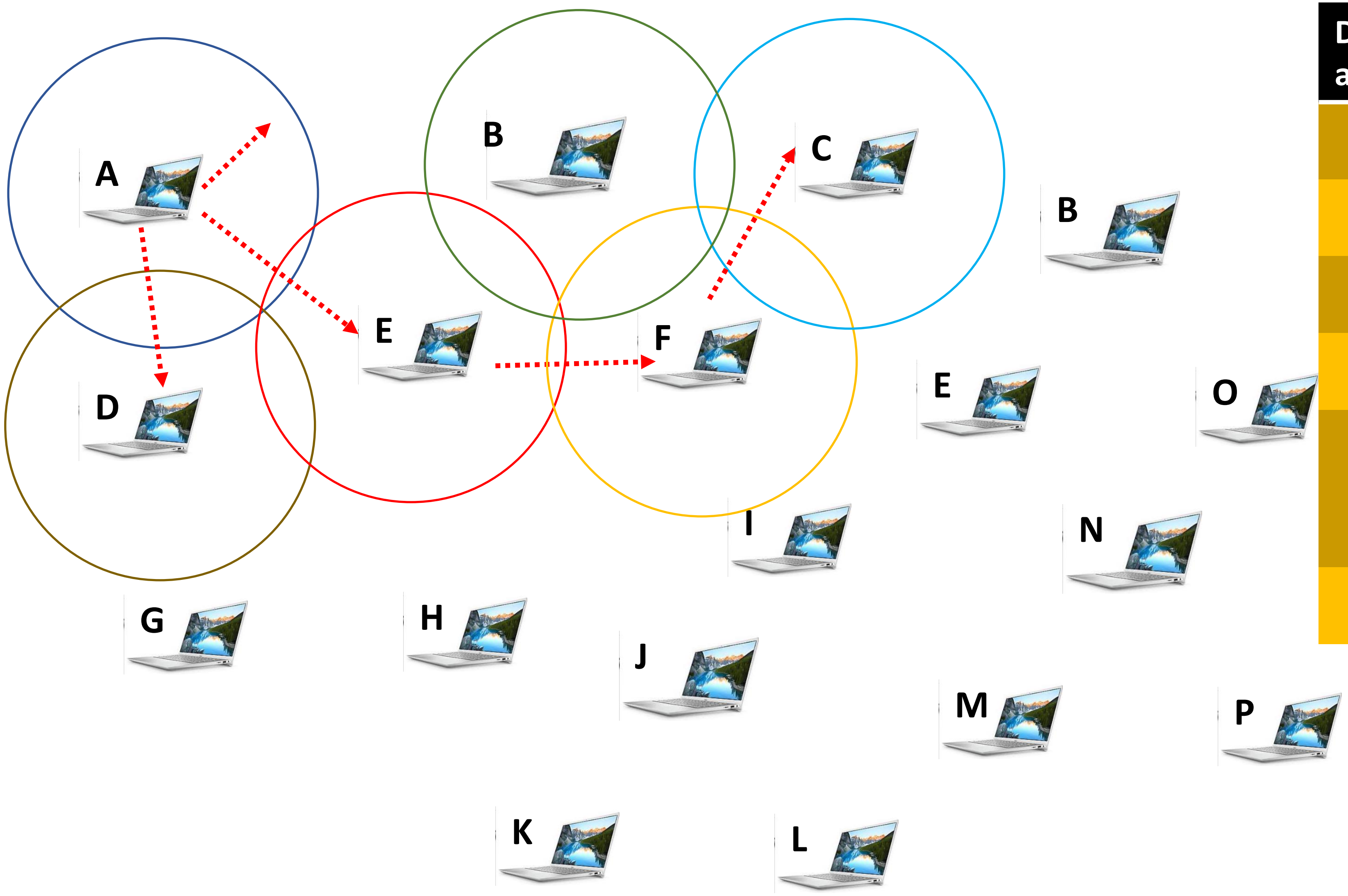


Routing Table - Node A

Destination	Next hop	No. of Hops	Sequence No.	Route
B	E	2	S128-B	A-E-B
C	E	3	S234-C	A-E-B-C
D	D	1	S562-D	A-D
E	E	1	S128-E	A-E
.	.			
.	.			
.	.			
P	E			

Table Driven Protocols

1. DSDV



Routing Table - Node A

Destination	Next hop	No. of Hops	Sequence No.	Route
B	B	1	S156-B	A-B
C	E	3	S256-C	A-E-F-C
D	D	1	S562-D	A-D
E	E	1	S128-E	A-E
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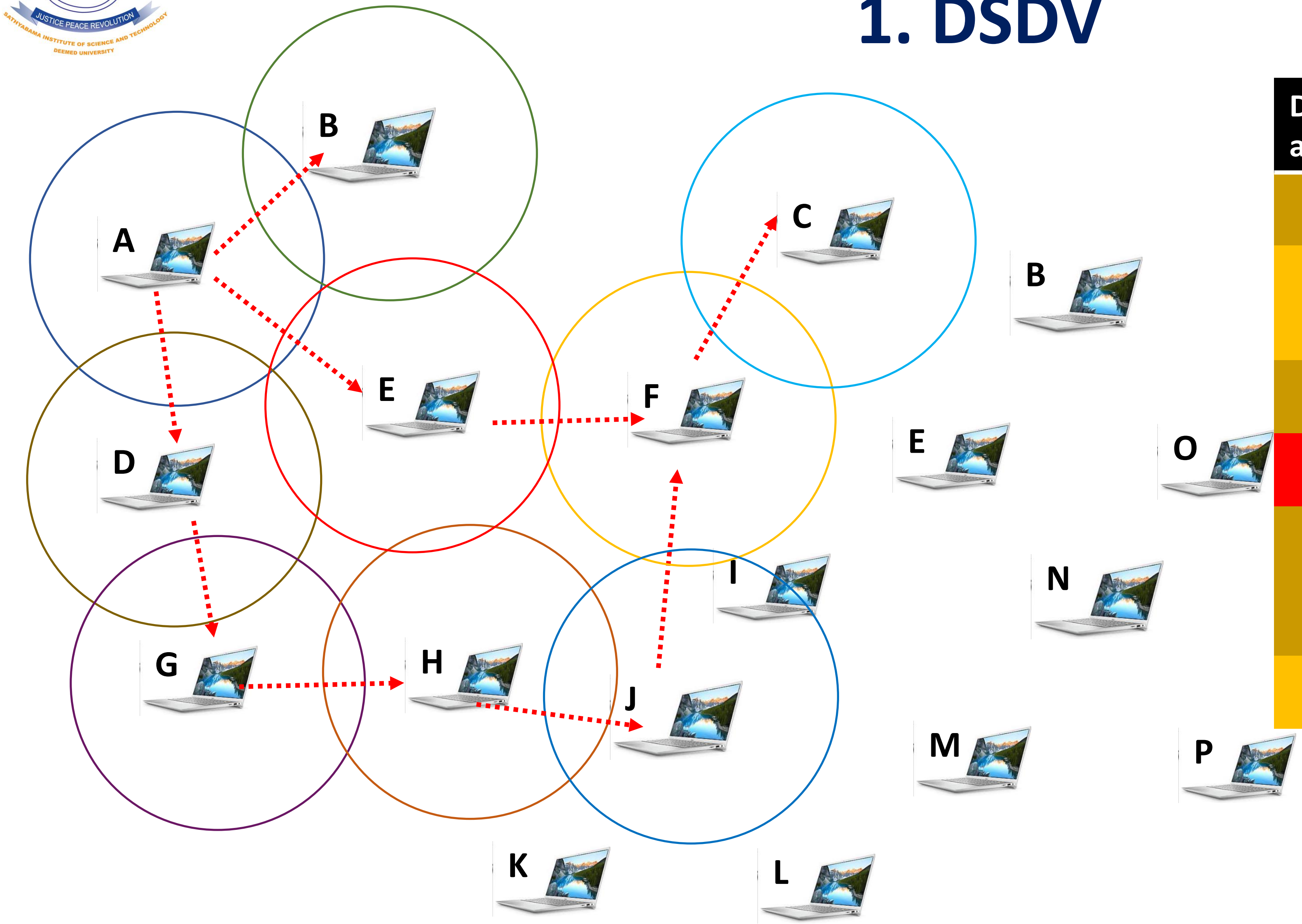
P	E			

Table Driven Protocols

1. DSDV



Routing Table - Node A

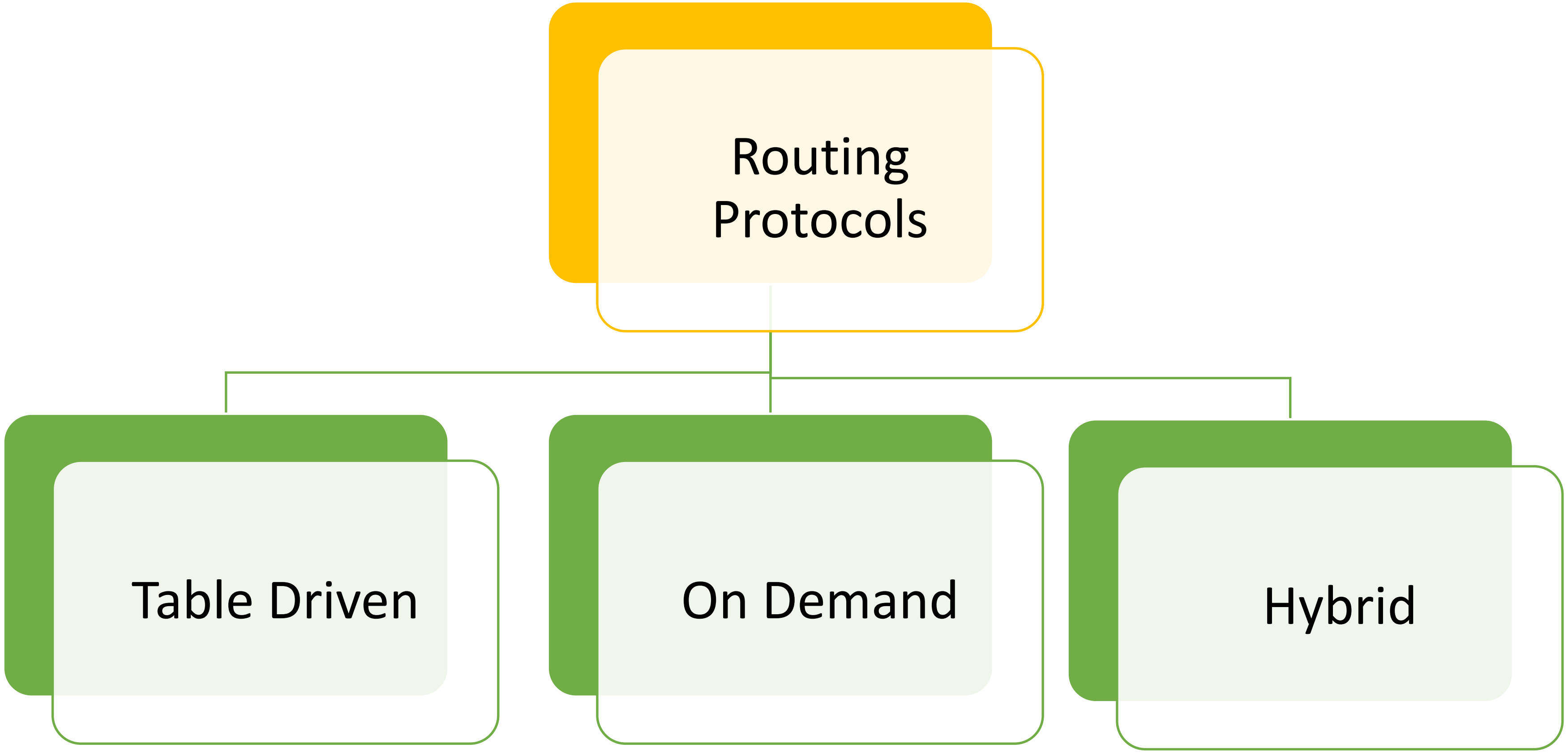
Destination	Next hop	No. of Hops	Sequence No.	Route
B	B	1	S156-B	A-B
C	D	6	S574-C	A-D-G-H-J-F-C
D	D	1	S562-D	A-D
E				
.	.			
.	.			
.	.			
P	E			

Table Driven Protocols
1. DSDV

- Advantages:
  - Routes available to all destinations
    - Less latency in route setup
  - Loop-free paths are guaranteed in DSDV
- Disadvantages:
  - Updates are propagated throughout the network
    - Updates due to broken link (due to mobility) can lead to heavy control traffic
    - Even a small network with high mobility or large network with less mobility can choke the network

Routing Protocols - Classification

- **Based on Routing Information Update Mechanism**



On Demand Routing Protocols
(Reactive Routing Protocols)

- Determine route if and when needed
- Source node initiates route discovery

- ➢ Lower overhead since routes are determined on demand
- ➢ Significant delay in route determination
- ➢ Employ flooding (global search)
- ➢ Control traffic may be burst

On-demand Routing Protocols

On-demand Protocols

- Dynamic Source Routing (DSR)
- Adhoc On-demand Distance Vector (AODV)
- Temporally Ordered Routing Algorithm (TORA)
- Associativity Based Routing (ABR)
- Gathering based Routing Protocol (GRP)
- Labelled Distance Routing (LDR)

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

- 2 phases
  1. Route discovery
  2. Route Maintenance
- When node **S** wants to send a packet to node **D**, but does not know a route to D, node S initiates a route discovery

S – source node D- Destination node

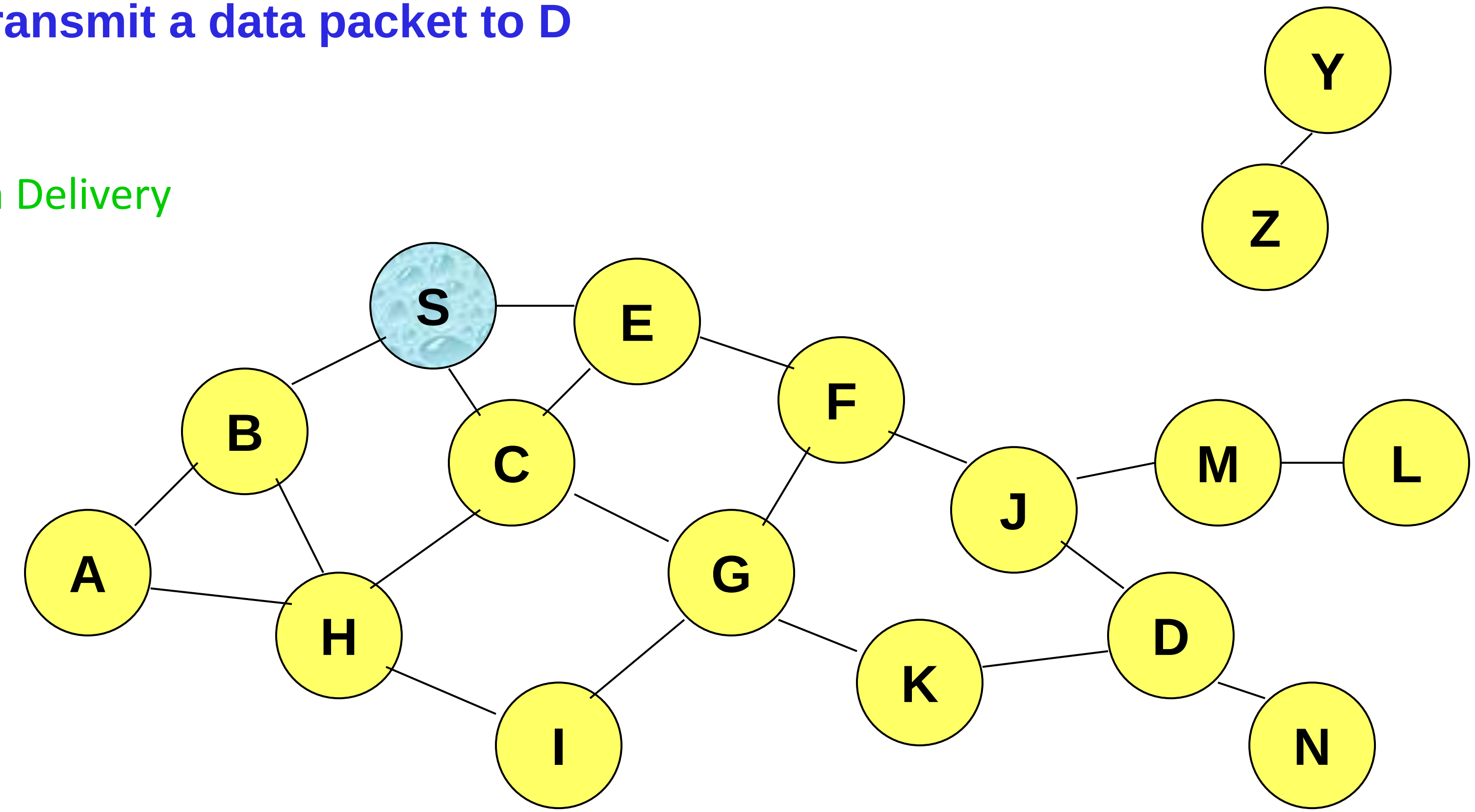
- Source node S floods Route Request (RREQ)
- Each node *appends own identifier* when forwarding RREQ

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

S likes to transmit a data packet to D

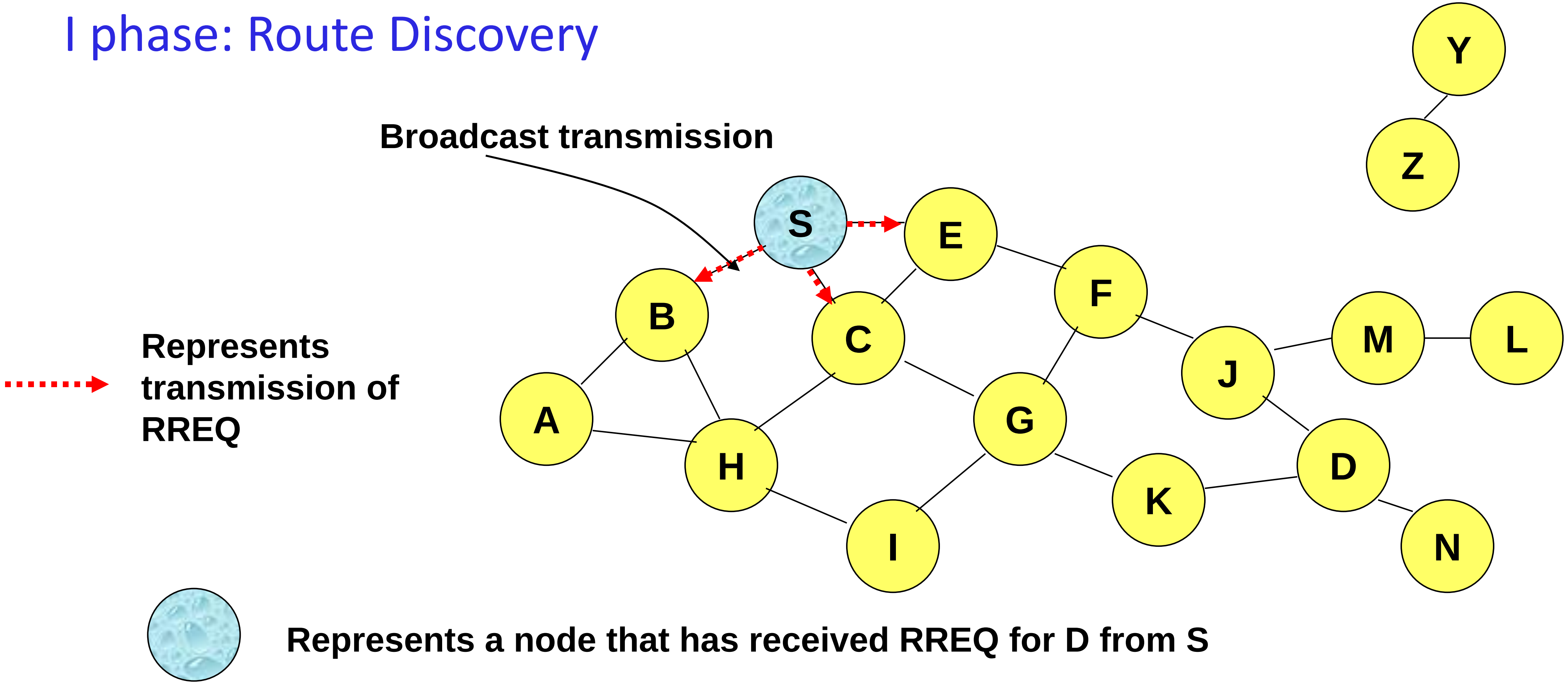
1. Route discovery
2. Route Maintenance – Data Delivery



On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

I phase: Route Discovery

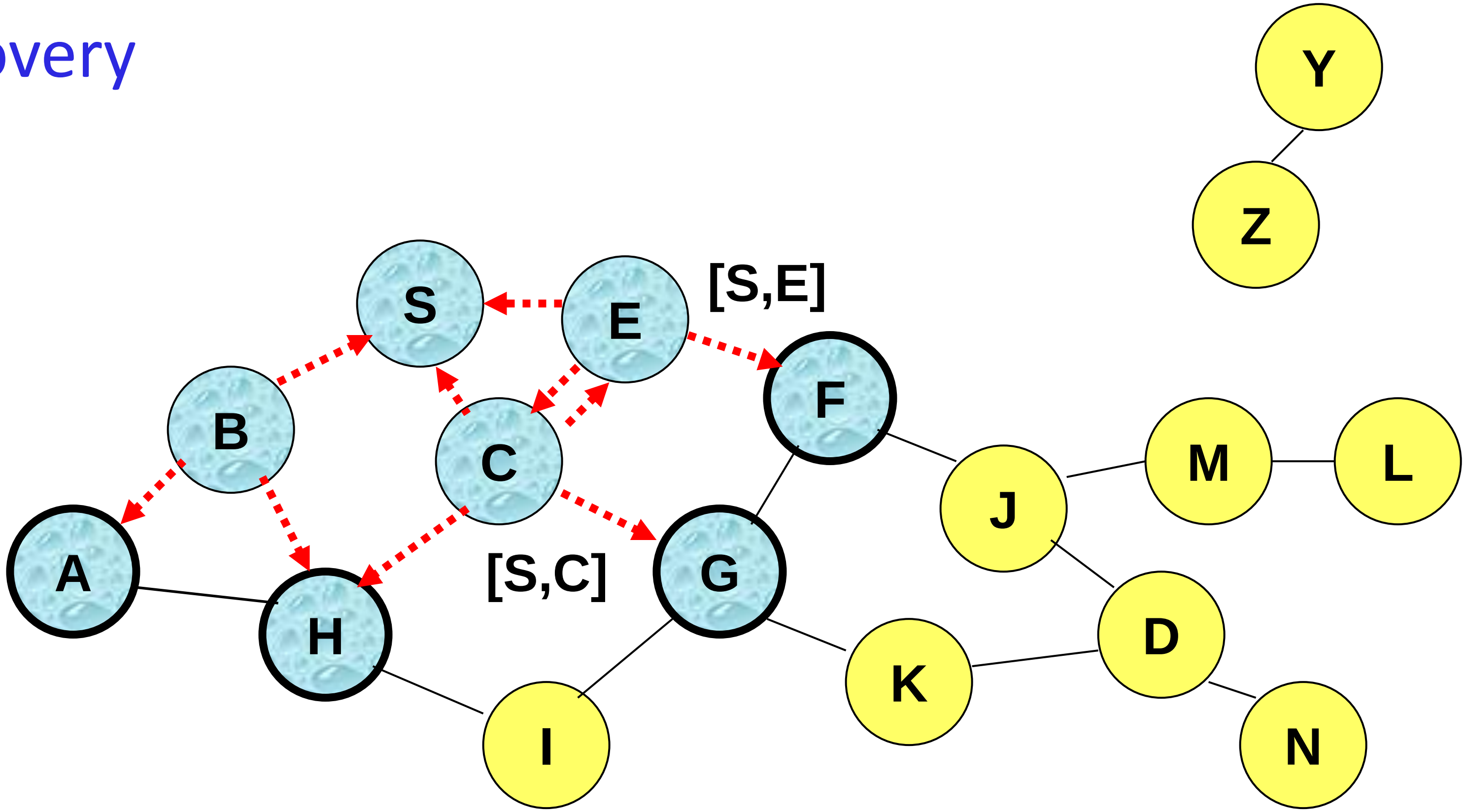


On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

I phase: Route Discovery

[X,Y] Represents list of identifiers appended to RREQ

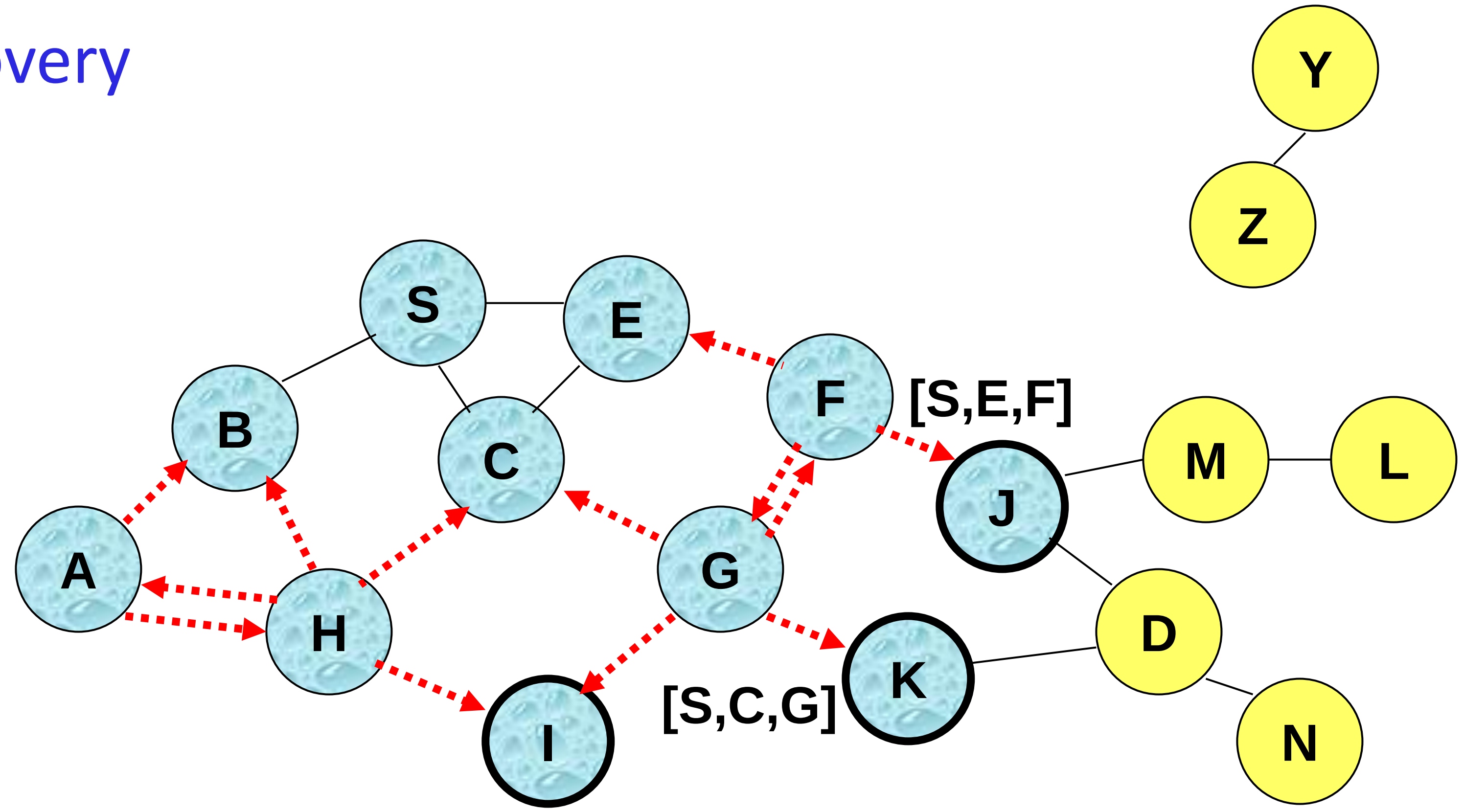


- **Node H receives packet RREQ from two neighbors:** **potential for collision**

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

I phase: Route Discovery



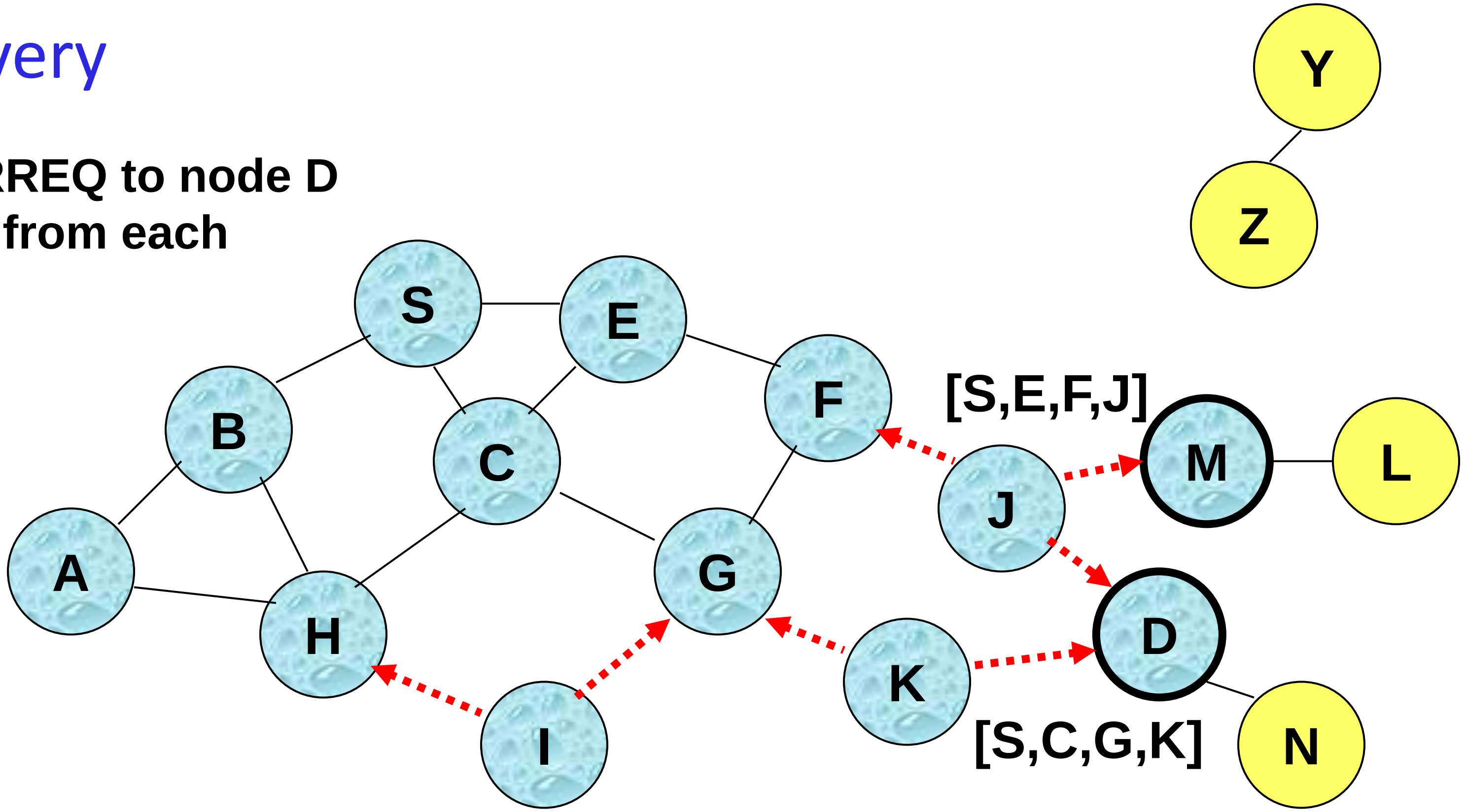
- **Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once**

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

I phase: Route Discovery

- **Nodes J and K both broadcast RREQ to node D**
- **Since nodes J and K are hidden from each other, their transmissions may collide**

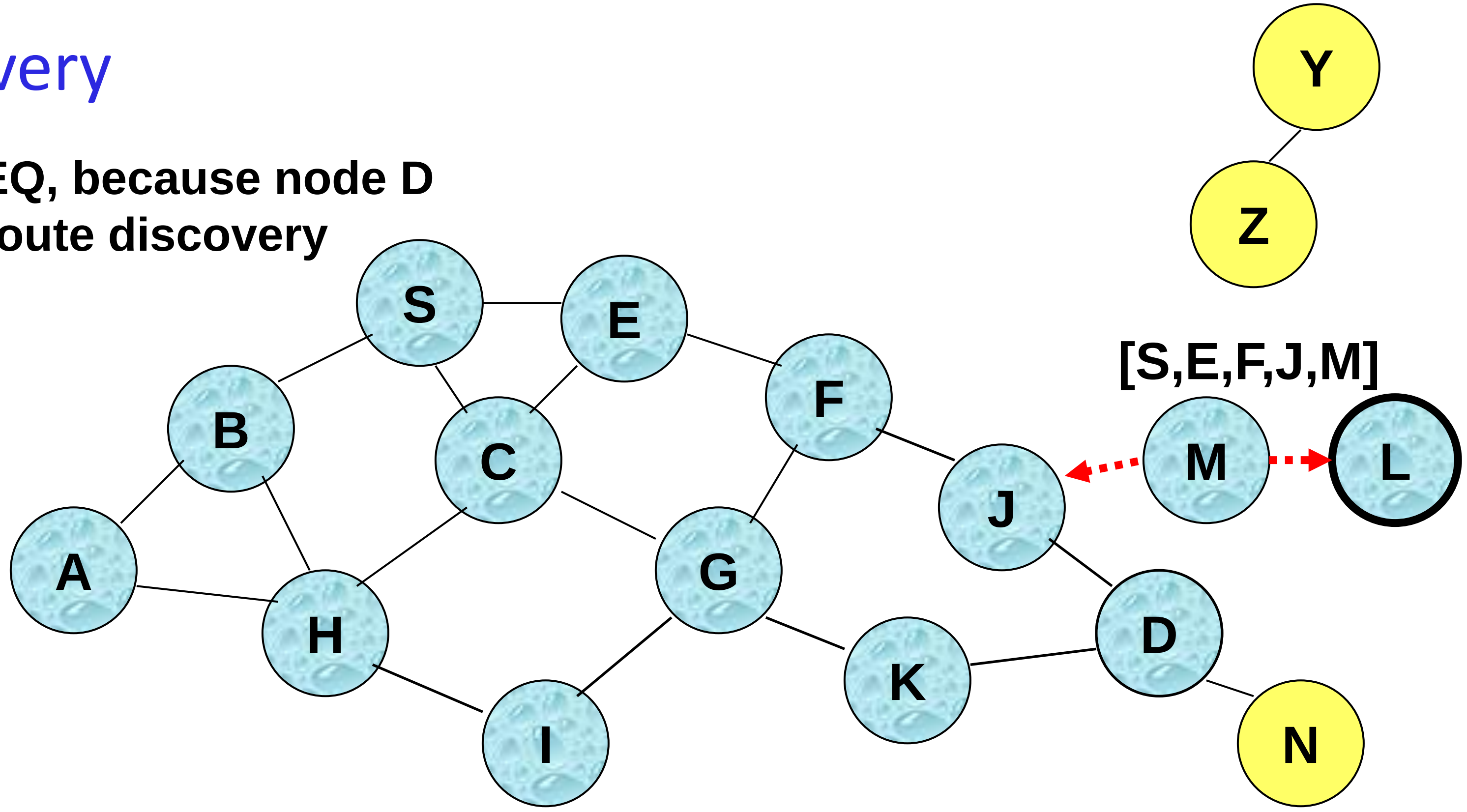


On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

I phase: Route Discovery

- **Node D does not forward RREQ, because node D is the intended target of the route discovery**



On-demand Routing Protocols

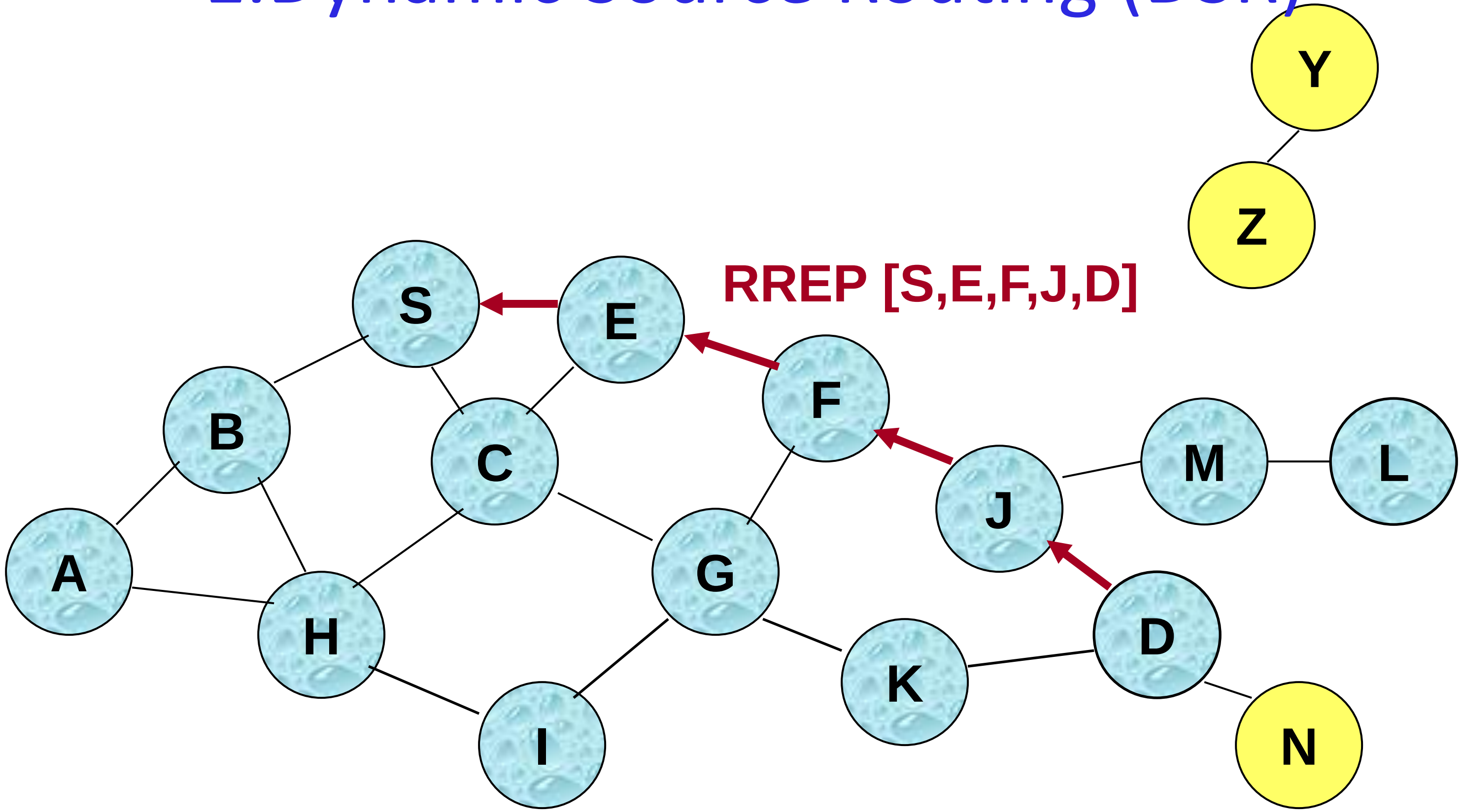
1.Dynamic Source Routing (DSR)

Route Discovery in DSR

- Destination D on receiving the first RREQ, sends a Route Reply (RREP)
- RREP is sent on a route obtained by reversing the route appended to received RREQ
- RREP includes the route from S to D on which RREQ was received by node D

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)



Represents RREP control message

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

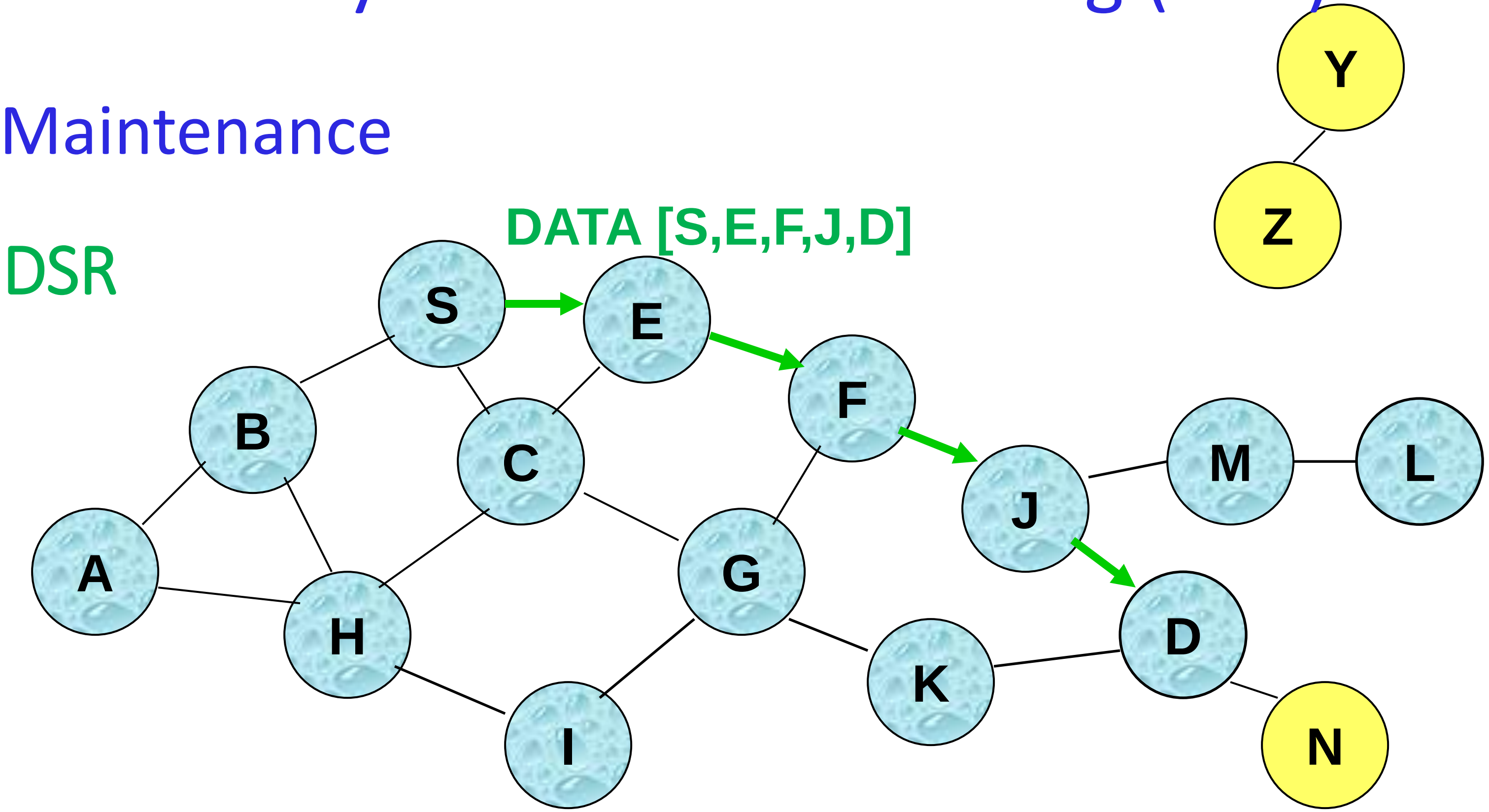
- Node S on receiving RREP, caches the route included in the RREP
- When node S sends a data packet to D, the entire route is included in the packet header
  - hence the name **source routing**
- Intermediate nodes use the source route included in a packet to determine to whom a packet should be forwarded

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

II phase: Route Maintenance

Data Delivery in DSR



Packet header size grows with route length

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

DSR Optimization: Route Caching

- Each node caches a new route it learns by *any means*
- When node S finds route [S,E,F,J,D] to node D, node S also learns route [S,E,F] to node F
- When node K receives Route Request [S,C,G] destined for node, node K learns route [K,G,C,S] to node S
- When node F forwards Route Reply RREP [S,E,F,J,D], node F learns route [F,J,D] to node D
- When node E forwards Data [S,E,F,J,D] it learns route [E,F,J,D] to node D
- A node may also learn a route when it overhears Data
- Problem: Stale caches may increase overheads

On-demand Routing Protocols

1.Dynamic Source Routing (DSR)

Advantages

- Routes maintained only between nodes who need to communicate
  - reduces overhead of route maintenance
- Route caching can further reduce route discovery overhead
- A single route discovery may yield many routes to the destination, due to intermediate nodes replying from local caches

On-demand Routing Protocols

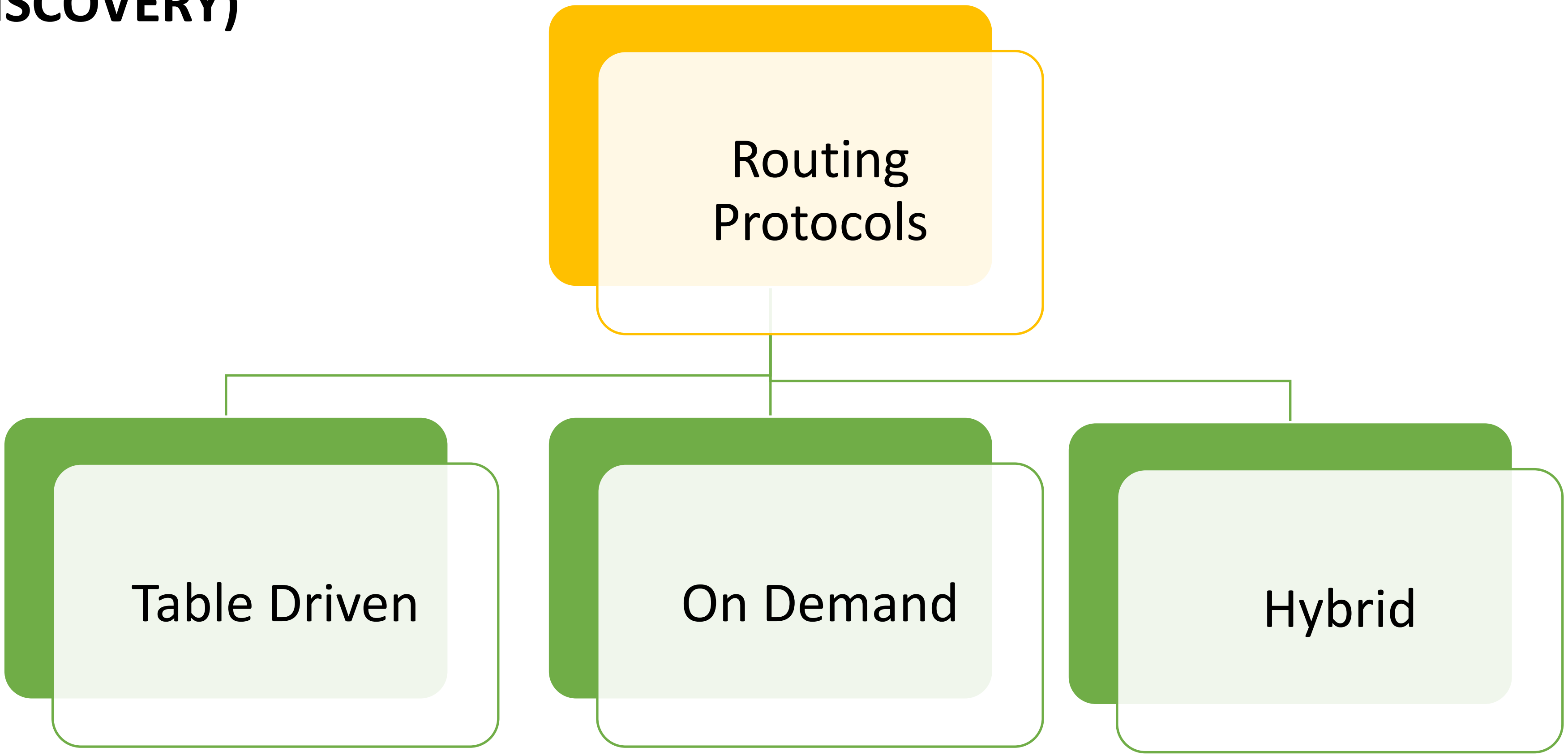
1.Dynamic Source Routing (DSR)

Disadvantages

- Packet header size grows with route length due to source routing
- Flood of route requests may potentially reach all nodes in the network
- Potential collisions between route requests propagated by neighboring nodes
    - insertion of random delays before forwarding RREQ
- Increased contention if too many route replies come back due to nodes replying using their local cache
    - Route Reply *Storm* problem
- Stale caches will lead to increased overhead

Routing Protocols - Classification

- **Based on Routing Information Update Mechanism (ROUTE DISCOVERY)**



Hybrid Routing Protocols

- 2 phases
- Hybrid Wireless Networking routing protocol that uses both proactive and reactive routing protocols when sending information over the network

Hybrid Routing Protocols

1. ZRP

- Hybrid Routing Protocols
  - Zone Routing Protocol (ZRP)
  - Distributed Spanning Tree (DST)
  - LANdMark Ad hoc Routing (LANMAR)
  - Distributed Dynamic Routing (DDR)
  - Link Reliability based Hybrid Routing (LRHR)
  - Fisheye Zone Routing Protocol (FZRP)

Hybrid Routing Protocols

1.Zone Routing Protocol (ZRP)

- ZRP combines proactive and reactive approaches
- All nodes within hop distance at most *d* from a node X are said to be in the routing zone of node X
- All nodes at hop distance exactly *d* are said to be peripheral nodes of node X's routing zone

- Intra-zone routing: Proactively maintain routes to all nodes within the source node's own zone.
- Inter-zone routing: Use an on-demand protocol (similar to DSR or AODV) to determine routes to outside zone.

Zone Routing Protocol, or **ZRP** is a hybrid Wireless Networking routing protocol that uses both proactive and reactive routing protocols when sending information over the network. ZRP was designed to speed up delivery and reduce processing overhead by selecting the most efficient type of protocol to use throughout the route.

Hybrid Routing Protocols

1.Zone Routing Protocol (ZRP)

- It basically combines the advantages of both, reactive and pro-active routing protocols. These protocols are adaptive in nature and adapts according to the zone and position of the source and destination mobile nodes.
- The whole network is divided into different zones and then the position of source and destination mobile node is observed.
- If the source and destination mobile nodes are present in the same zone, then proactive routing is used for the transmission of the data packets between them.
- And if the source and destination mobile nodes are present in different zones, then reactive routing is used for the transmission of the data packets between them.

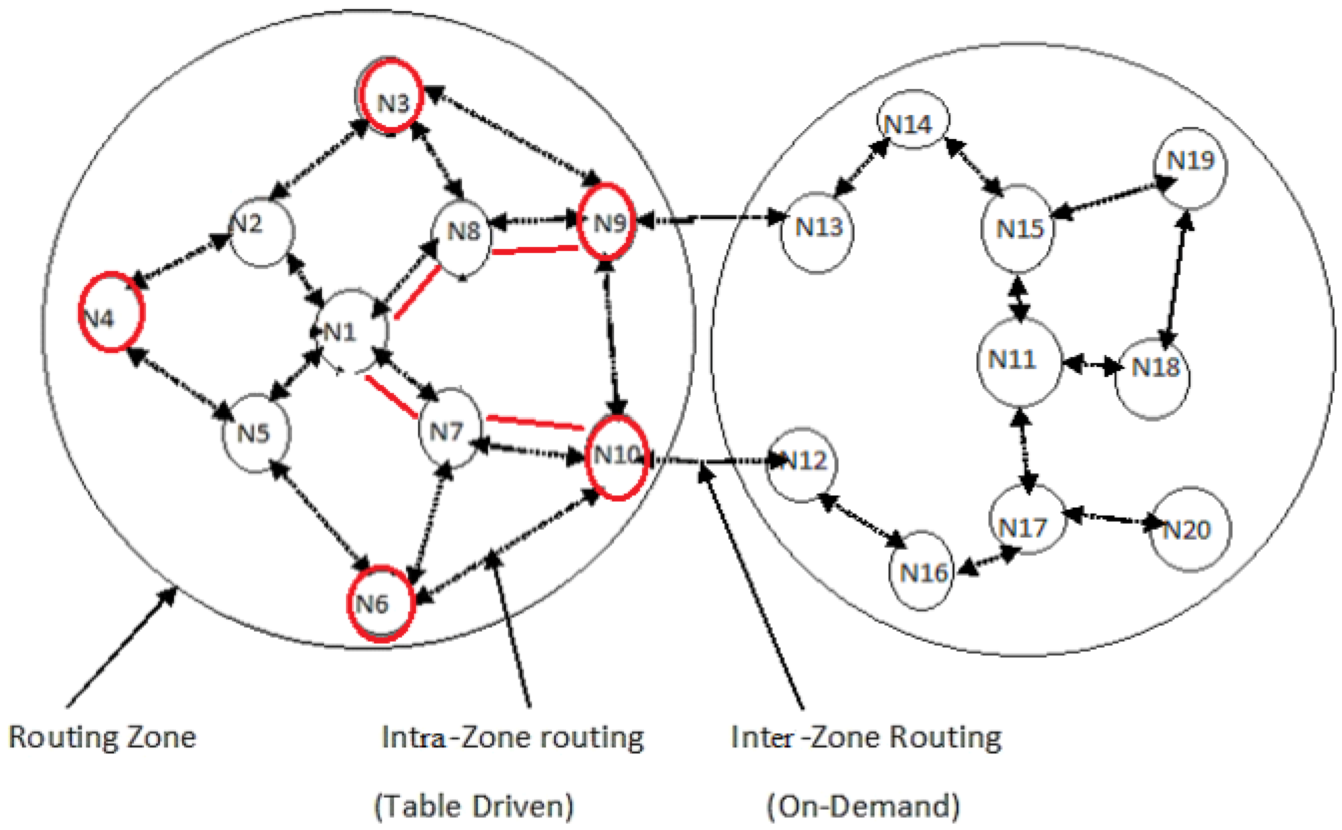
Hybrid Routing Protocols

1.Zone Routing Protocol (ZRP)

- HOW ZRP works?
- If a packet's destination is in the same zone as the origin, the proactive protocol using an already stored routing table is used to deliver the packet immediately.
- If the route extends outside the packet's originating zone, a reactive protocol takes over to check each successive zone in the route to see whether the destination is inside that zone.
- This reduces the processing overhead for those routes. Once a zone is confirmed as containing the destination node, the proactive protocol, or stored route-listing table, is used to deliver the packet.
- Thus ZRP reduces the control overhead for longer routes that would be necessary if using proactive routing protocols throughout the entire route, while eliminating the delays for routing within a zone that would be caused by the route-discovery processes of reactive routing protocols.

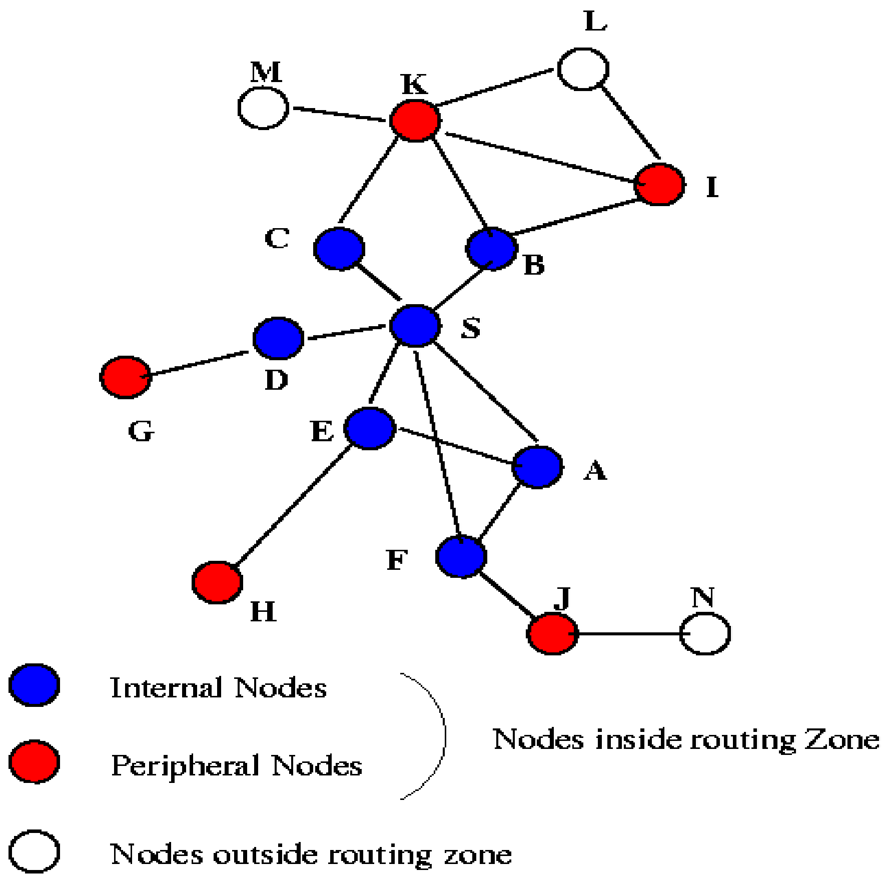
Hybrid Routing Protocols

1.Zone Routing Protocol (ZRP)



Hybrid Routing Protocols

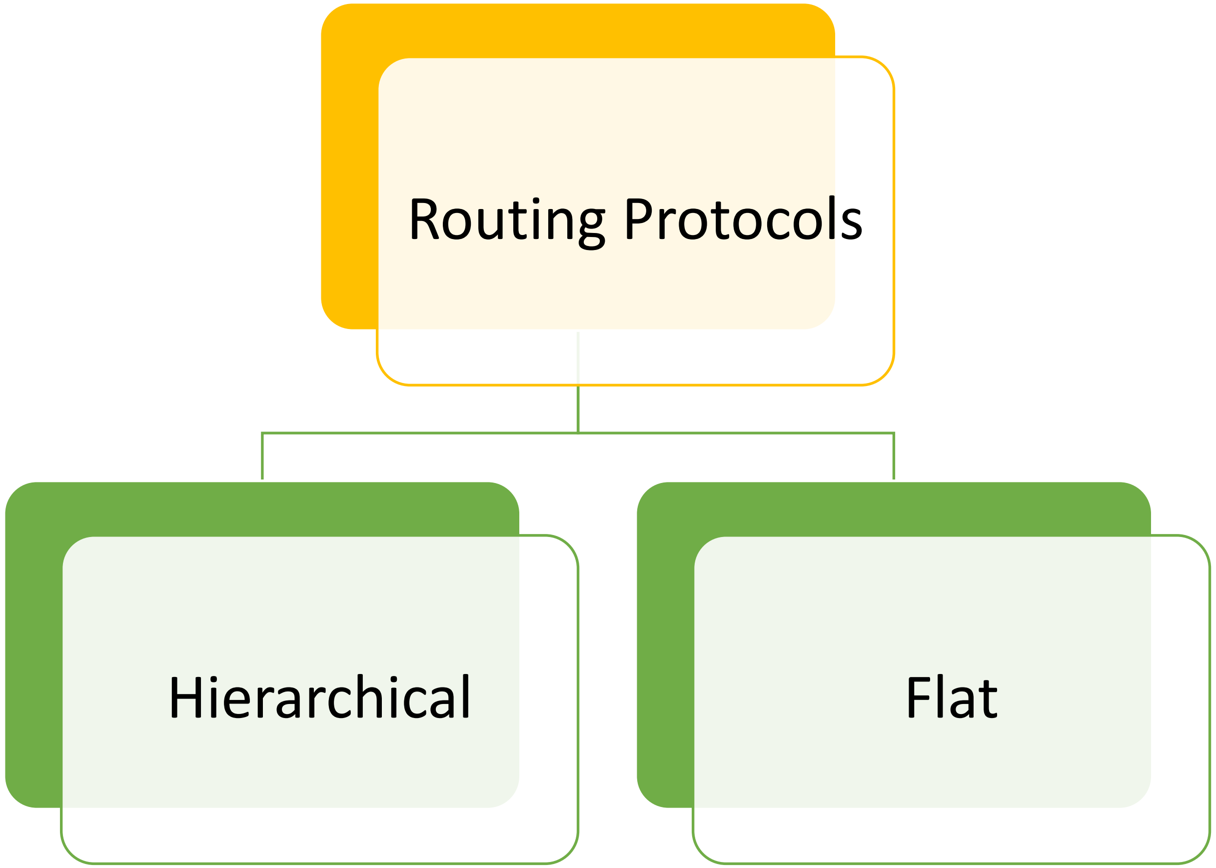
1.Zone Routing Protocol (ZRP)



Radius of routing zone = 2

Routing Protocols - Classification

- **Based on Network Architecture**

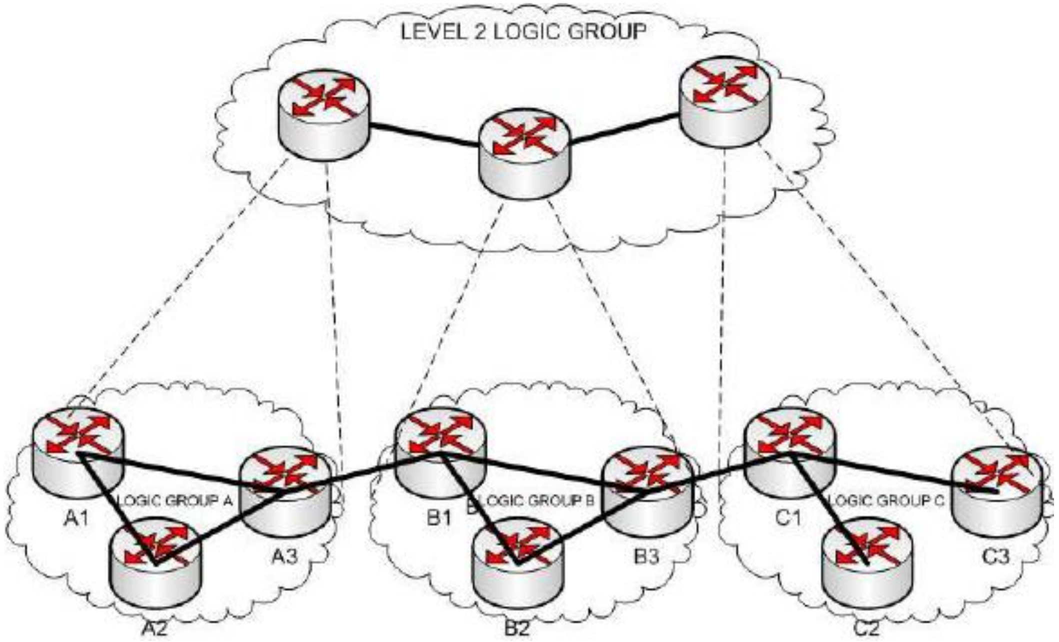


Hierarchical Routing

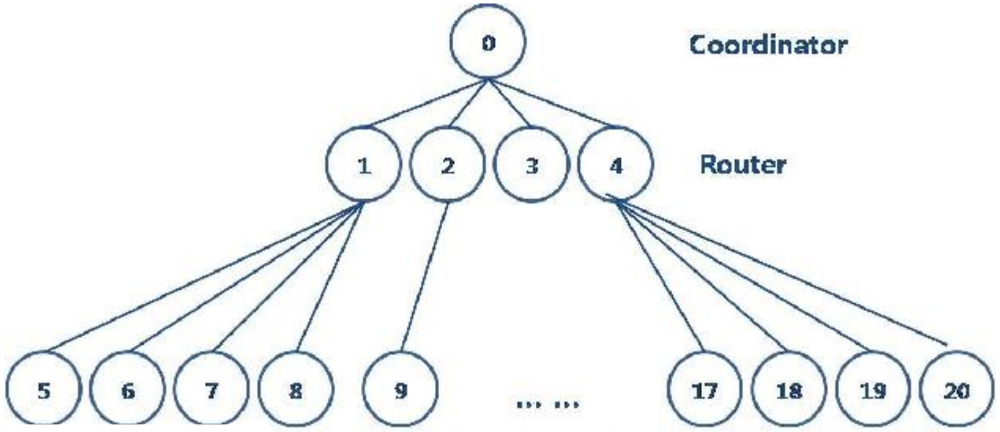
- Hierarchical routing protocols apply clustering techniques to build a hierarchy of nodes

- Nodes are organized into groups called **cluster**

- Each cluster consists of one or more clusters and gateways



- Hierarchical routing protocols are developed with an ability to address scalability issues in ad hoc network environment and to **minimize excessive overhead**
- This on the other side **increases the tediousness** of the routing techniques used by these protocols



Hierarchical routing structure

Hierarchical Routing Protocols

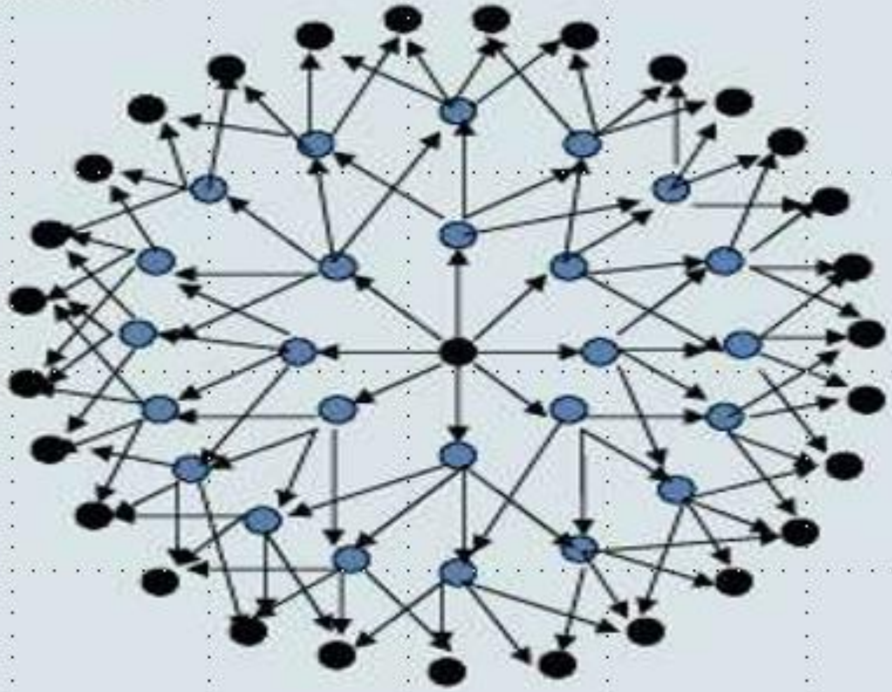
1. OLSR

Hierarchical Routing Protocols

- Optimized Link State Routing (OLSR)
- Hierarchical State Routing (HSR)
- Core-Extraction Distributed Ad hoc Routing (CEDAR)
- Hierarchical Landmark Routing (H-LANMAR))

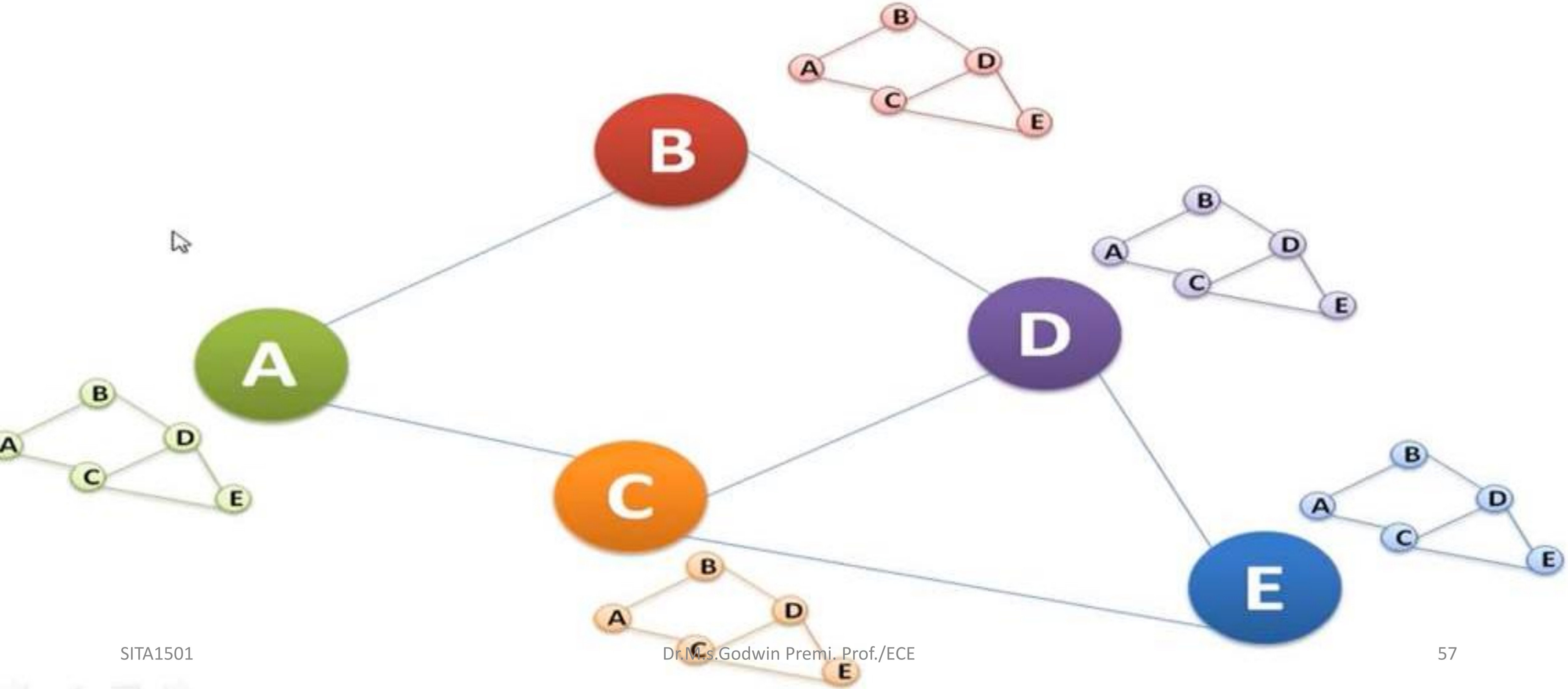
Link State Routing

- Each node periodically floods status of its links
- Each node re-broadcasts link state information received from its neighbour
- Each node keeps track of link state information received from other nodes
- Each node uses above information to determine next hope to each destination

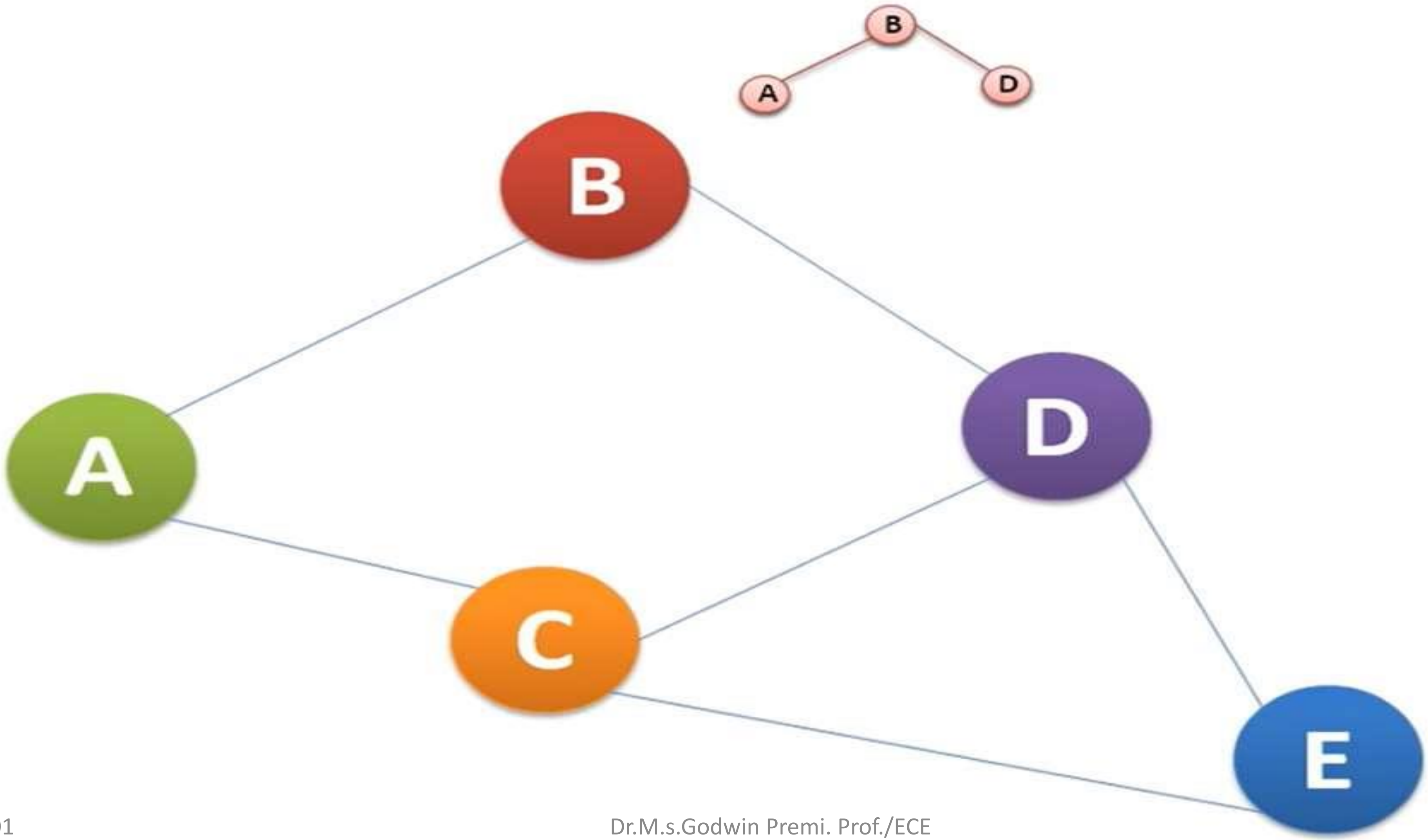


24 retransmissions to diffuse a message up to 3 hops

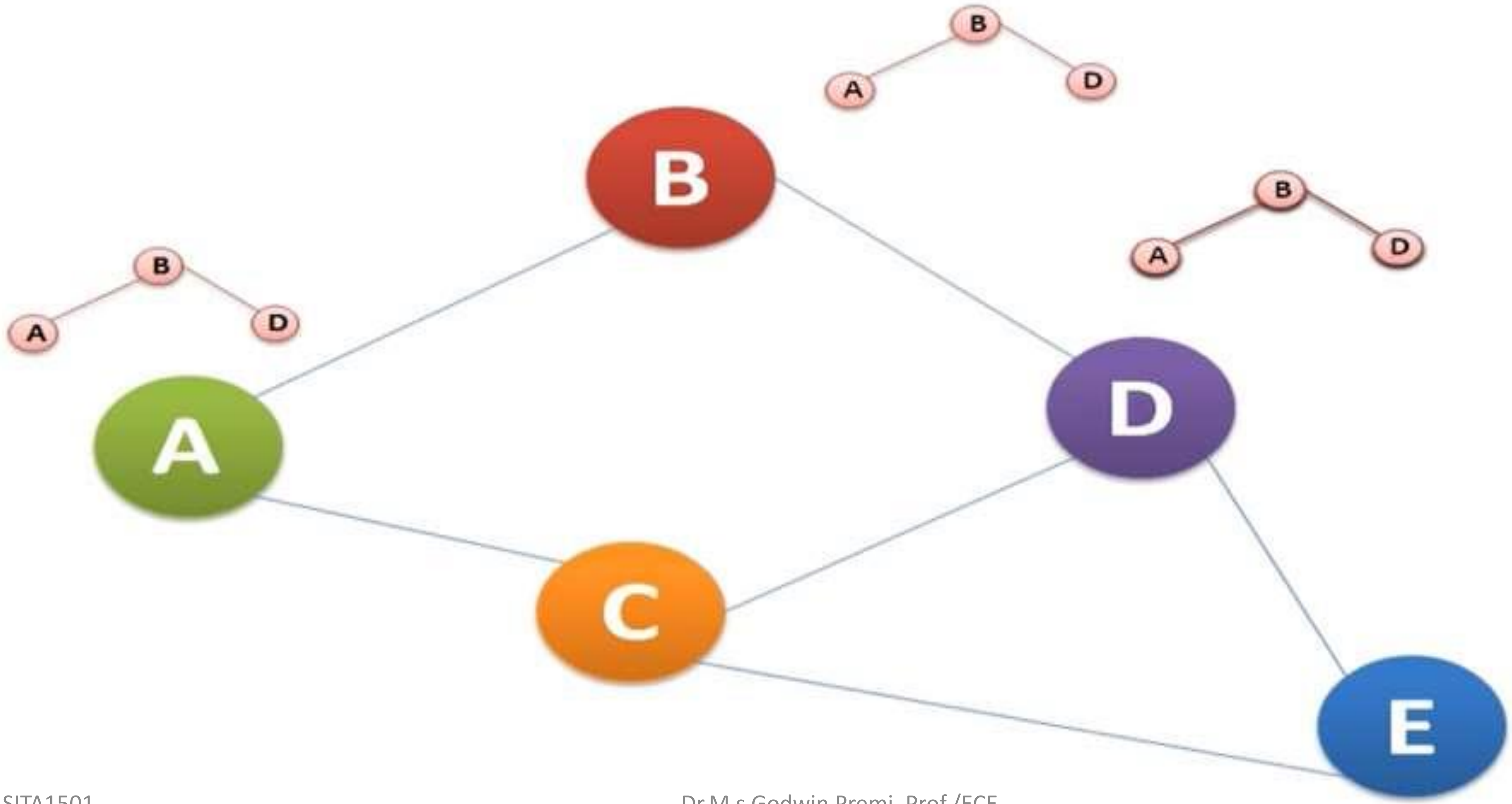
Link State Routing



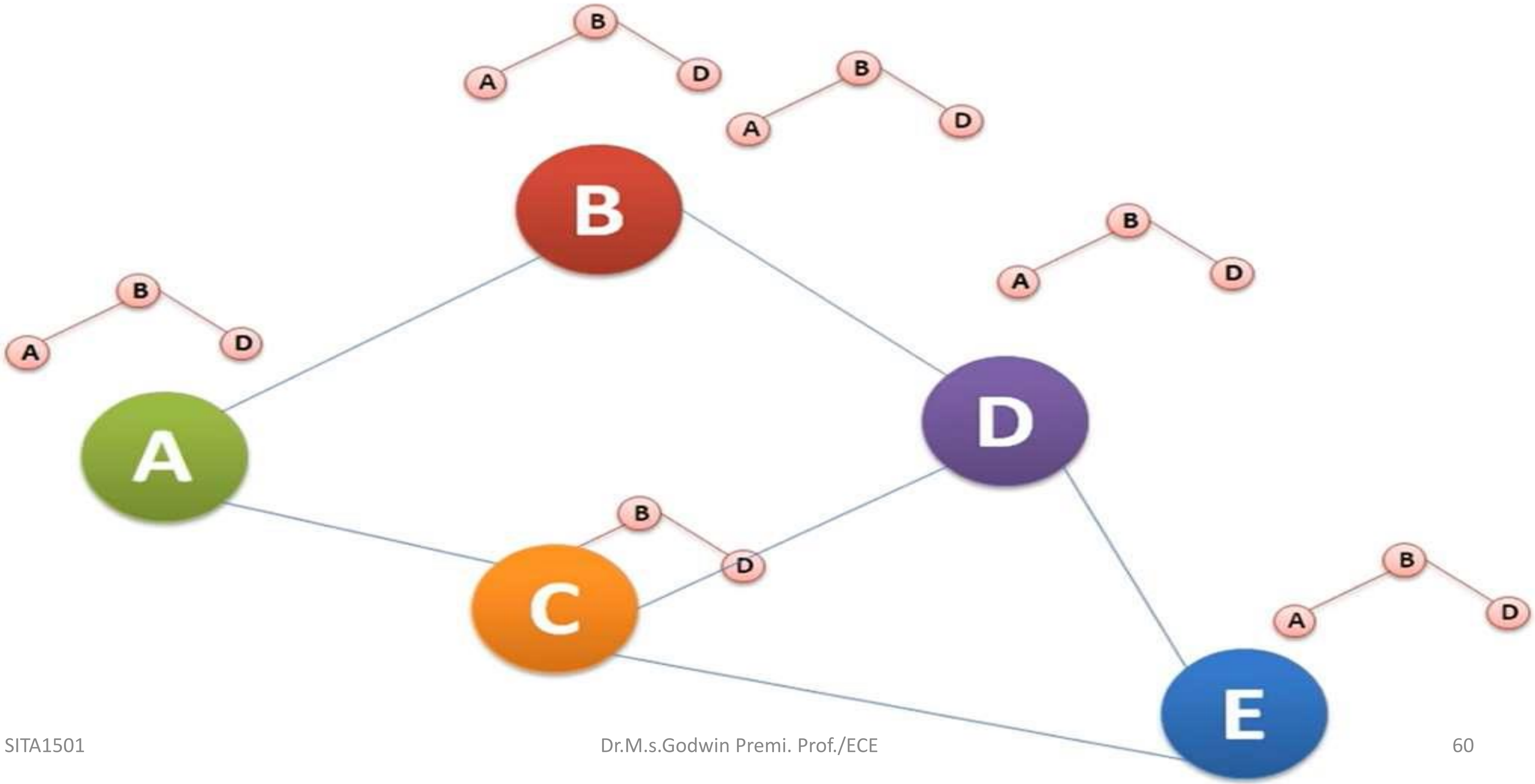
Link State Routing



Link State Routing

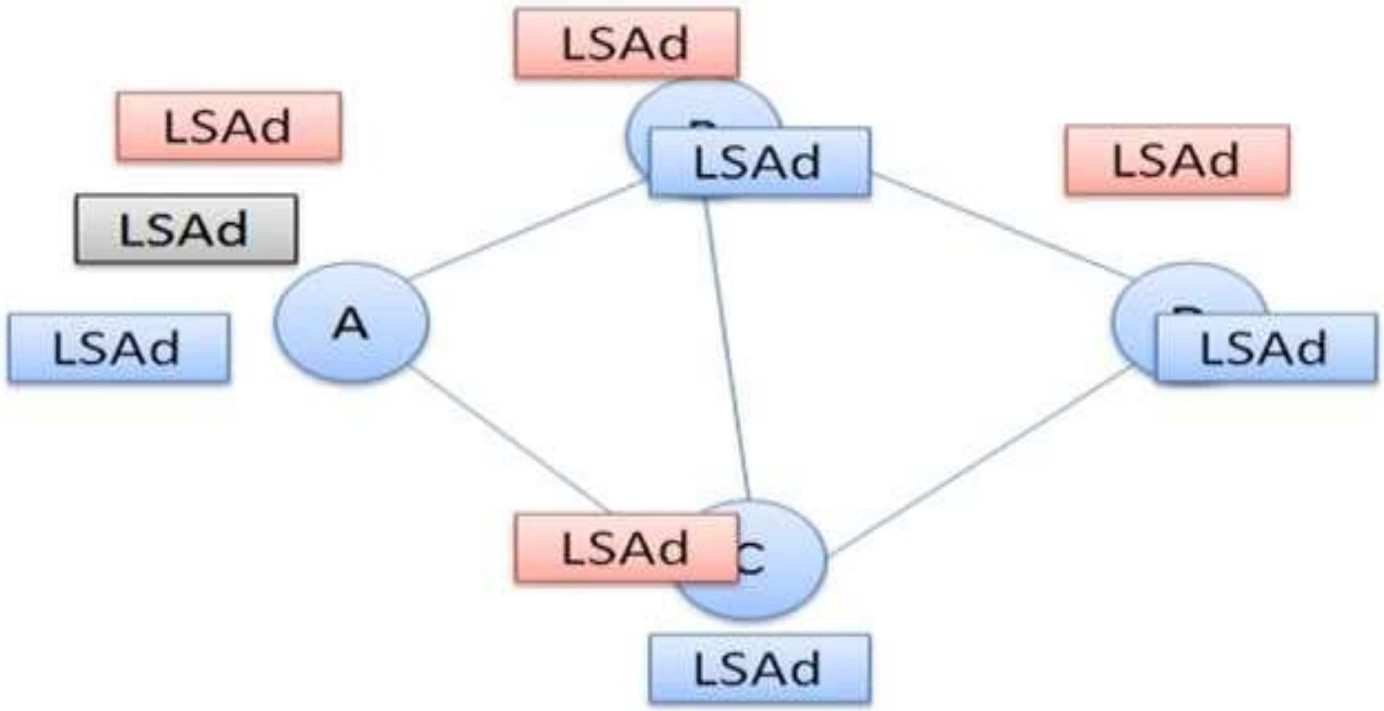


Link State Routing



Link State Routing- Problem

In Link State routing protocol LS advertisements are flooded. Flooding cause reception of multiple copies of same LS advertisement. In mobile adhoc network devices are mobile and battery powered. Flooding cause high battery consumption.



Link State Routing

The **Optimized Link State Routing Protocol (OLSR)** is an IP routing protocol optimized for mobile ad hoc networks, which can also be used on other wireless ad hoc networks.

>This protocol optimizes the pure forwarding mechanism called multipoint relaying.
>This protocol optimizes the pure link state routing protocol.

OPTIMIZATIONS ARE DONE IN TWO WAYS

>By reducing the size of the control packets.
>By reducing the number of links that are used for forwarding the link state packets.

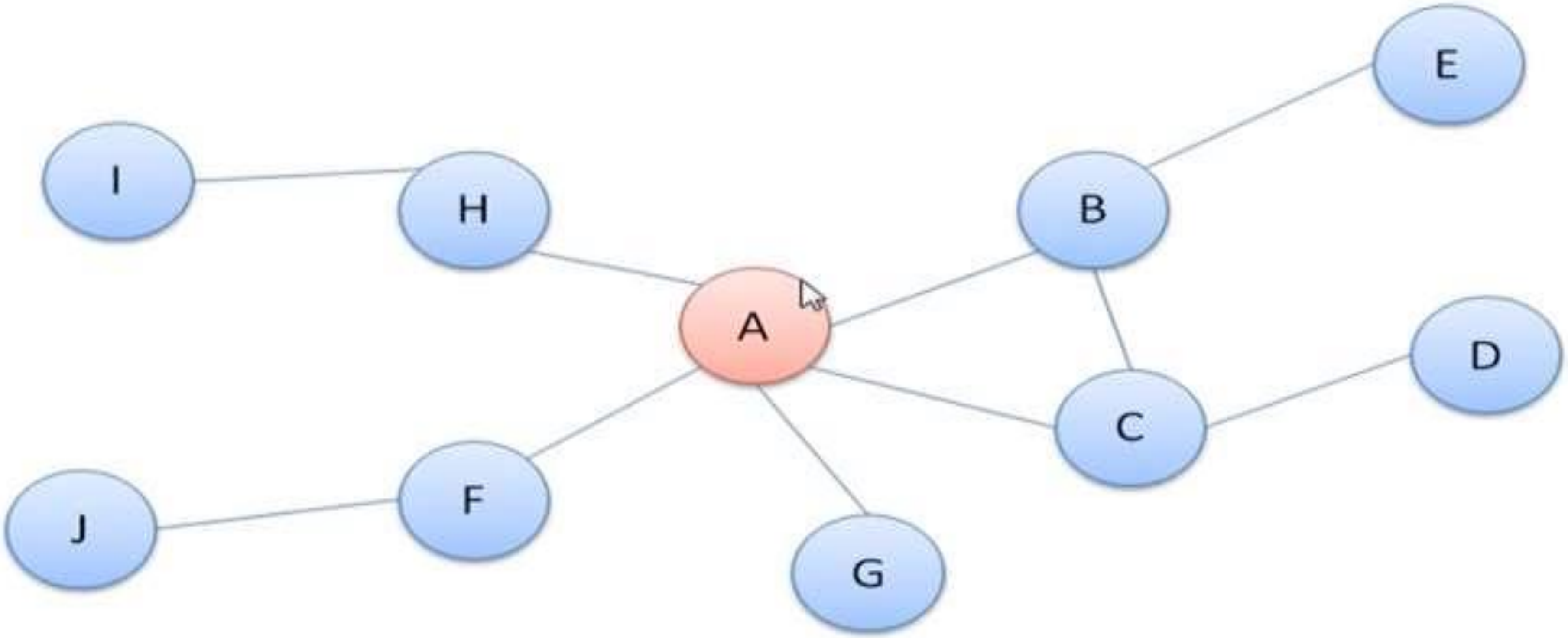
Optimized Link State Routing (OLSR)

- Avoid unnecessary transmission of LS packets.
- Each node decide which of it's neighbors can flood LS packet. These nodes known as MPR(Multi Point Relay).
- Only MPR can retransmit, other node don't transmit.

OLSR - Terminology

Neighbor Node

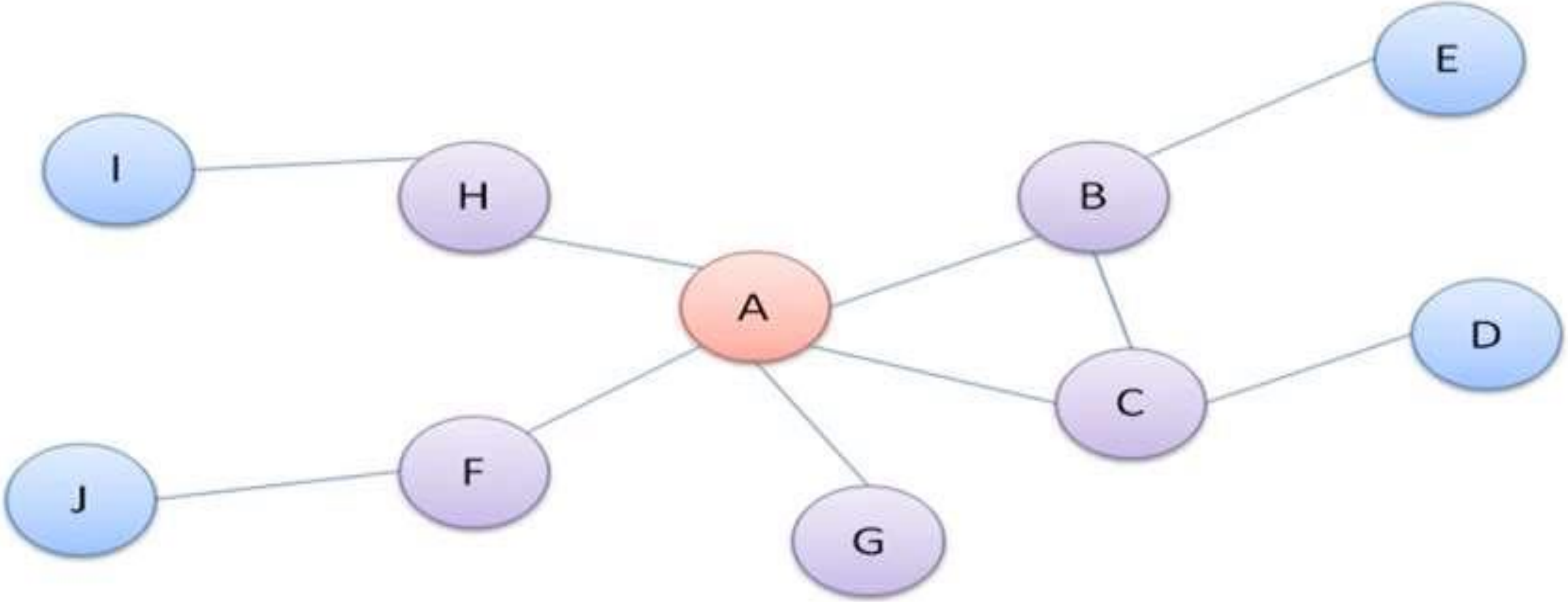
Node A is neighbor node of B if B can hear A



OLSR - Terminology

2 Hop Neighbor

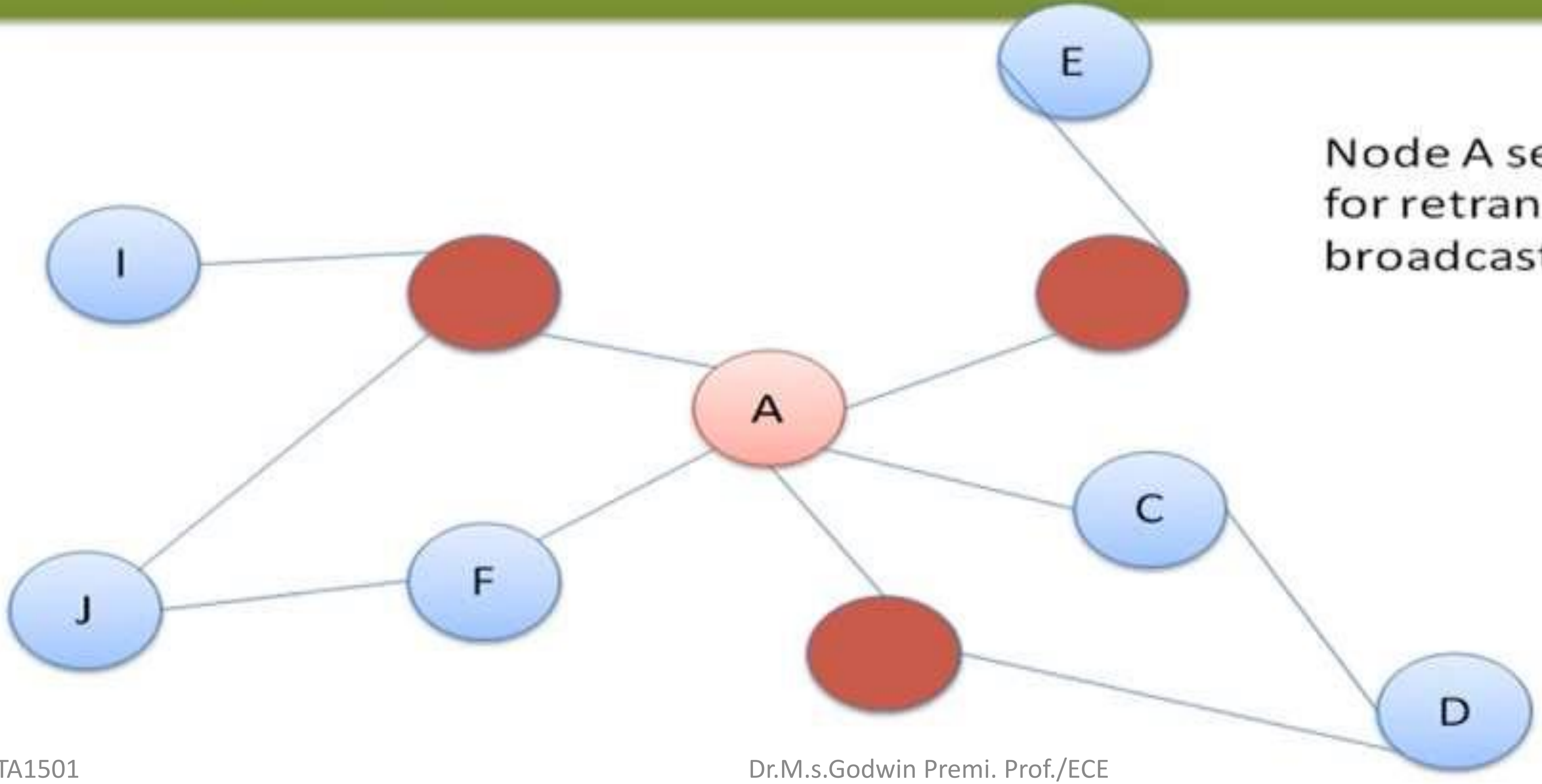
Node which can be heard by neighbor.



OLSR - Terminology

Multi Point Relay

Node which is selected by it's 1 hop neighbor to retransmit all broadcast message received by it.

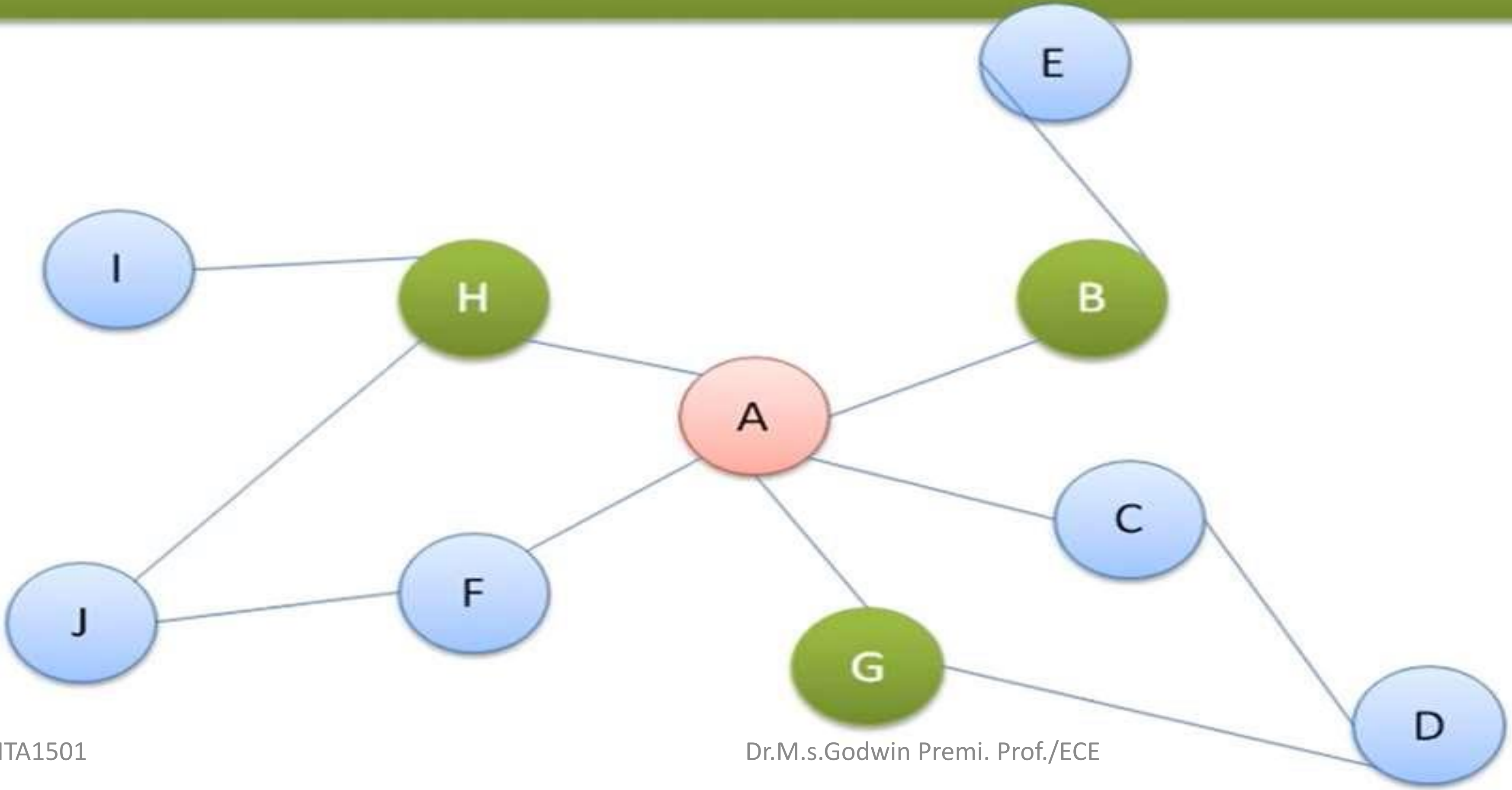


Node A select H, G and B for retransmitting broadcast message.

OLSR - Terminology

Multi Point Relay(MPR) Selector

Node which has selected it's 1-hop neighbor as MPR.



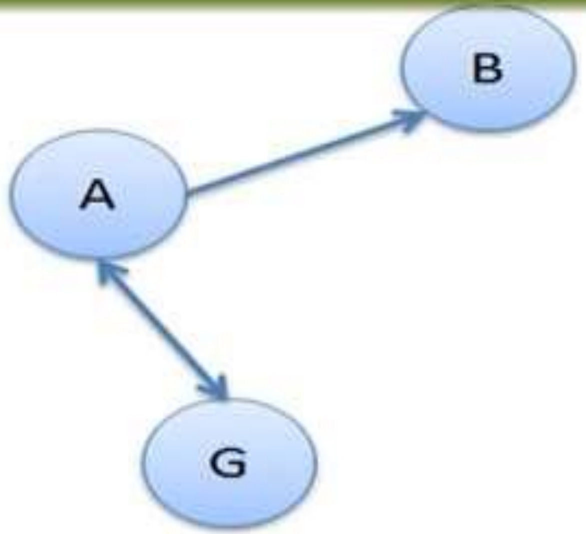
OLSR - Terminology

Symmetric Link

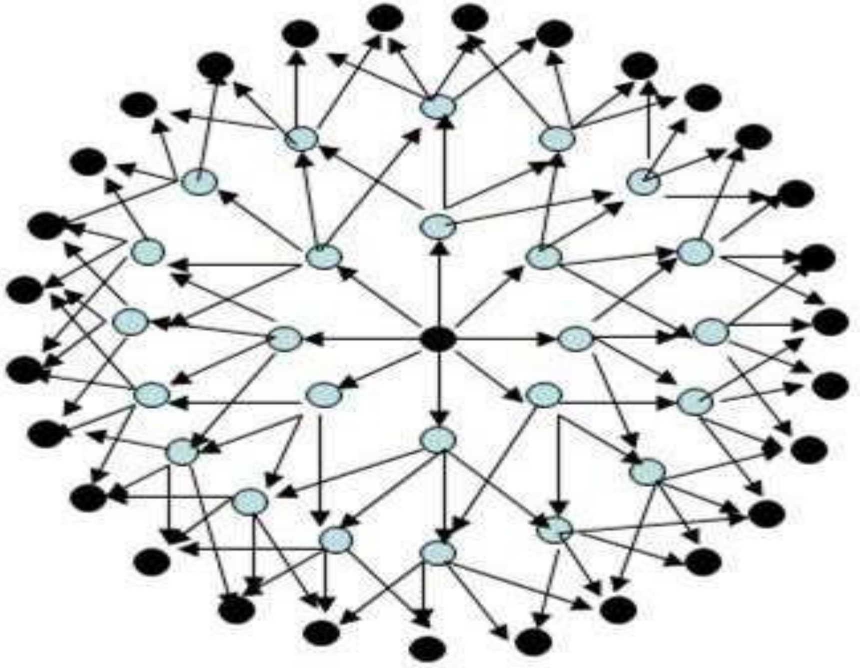
Bidirectional link

Asymmetric Link

Unidirectional link

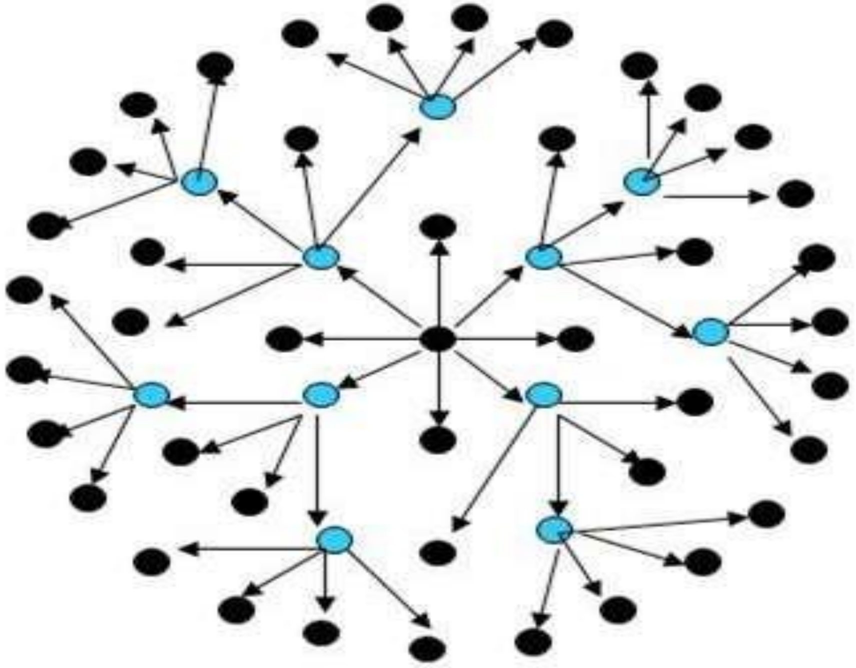


Flooding LSR vs. OLSR



24 retransmissions to diffuse a message up to 3 hops

Retransmission node



11 retransmission to diffuse a message up to 3 hops

Retransmission node

38

OLSR – Type of Packets

- Hello Packets
- Topology Control Packets
- MID Packets

Hello Packet

Each node periodically broadcasts its HELLO messages:

- Containing the information about its neighbors and their link status
- Hello messages are received by all one-hop neighbors

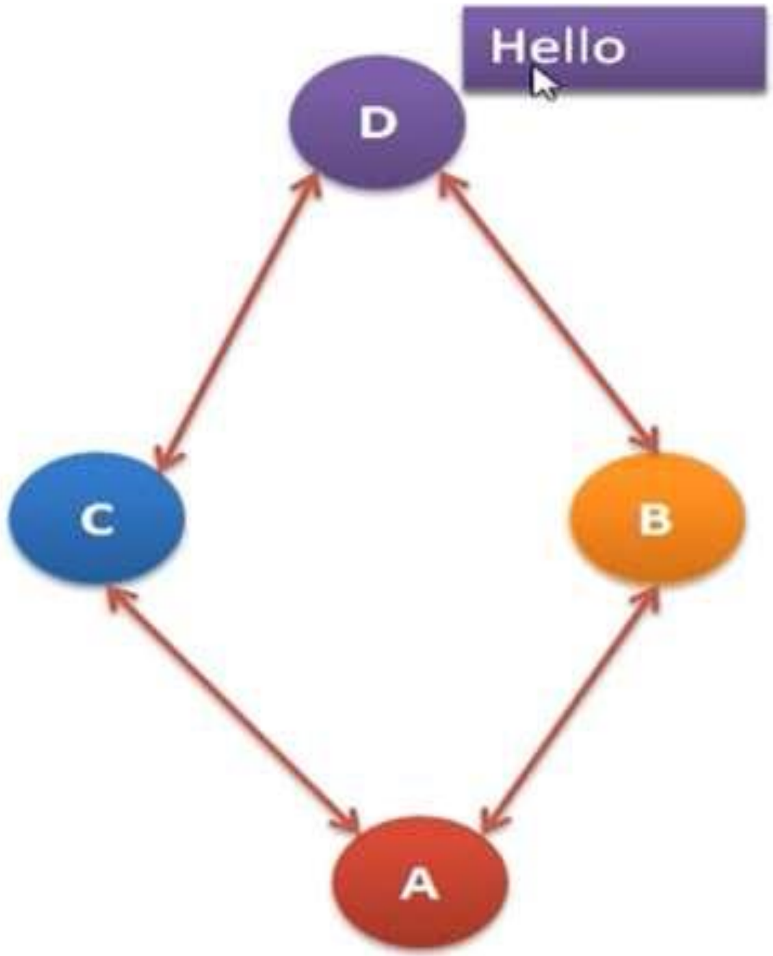
HELLO message contains:

- List of addresses of the neighbors to which there exists a valid bi-directional link
- List of addresses of the neighbors which are heard by node(a HELLO has been received)
  - But link is not yet validated as bi-directional

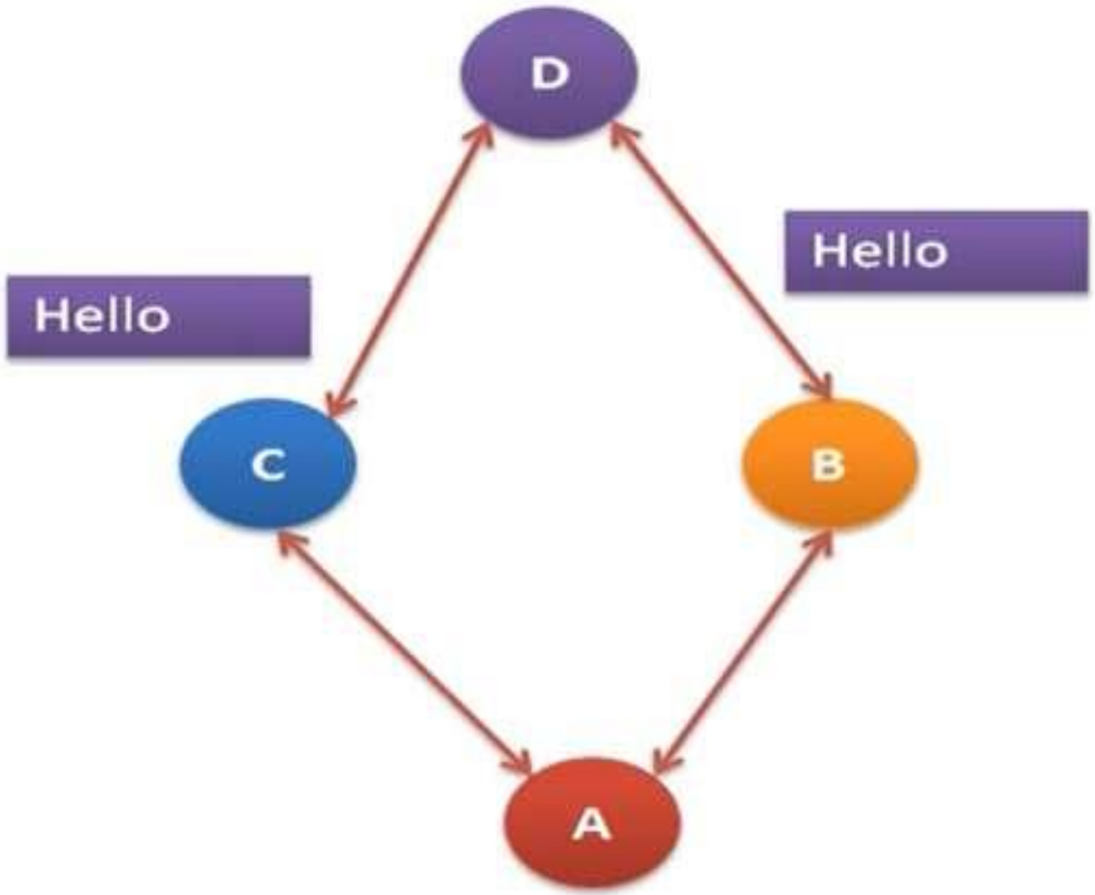
On the reception of HELLO message:

- Each node constructs its MPR Selector table

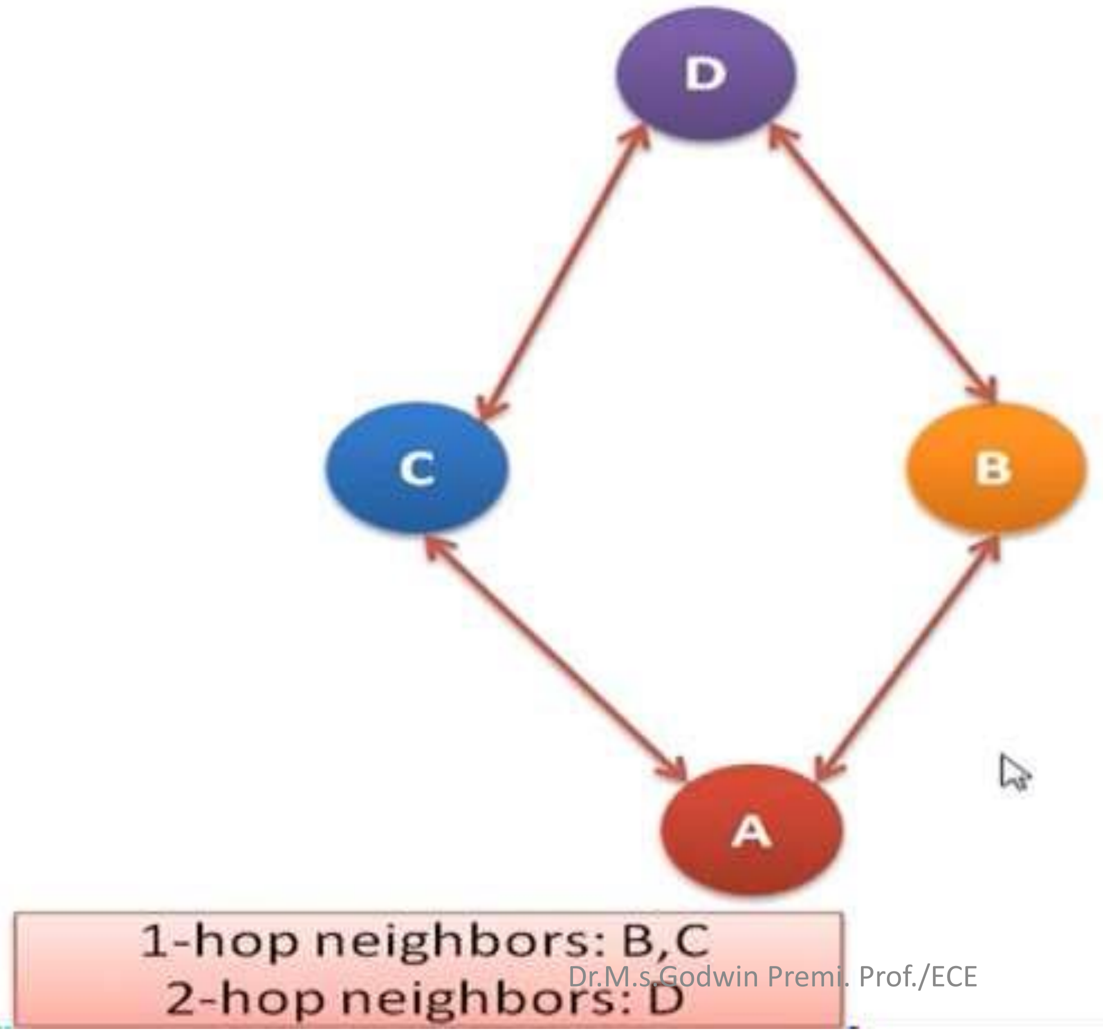
Hello Packet



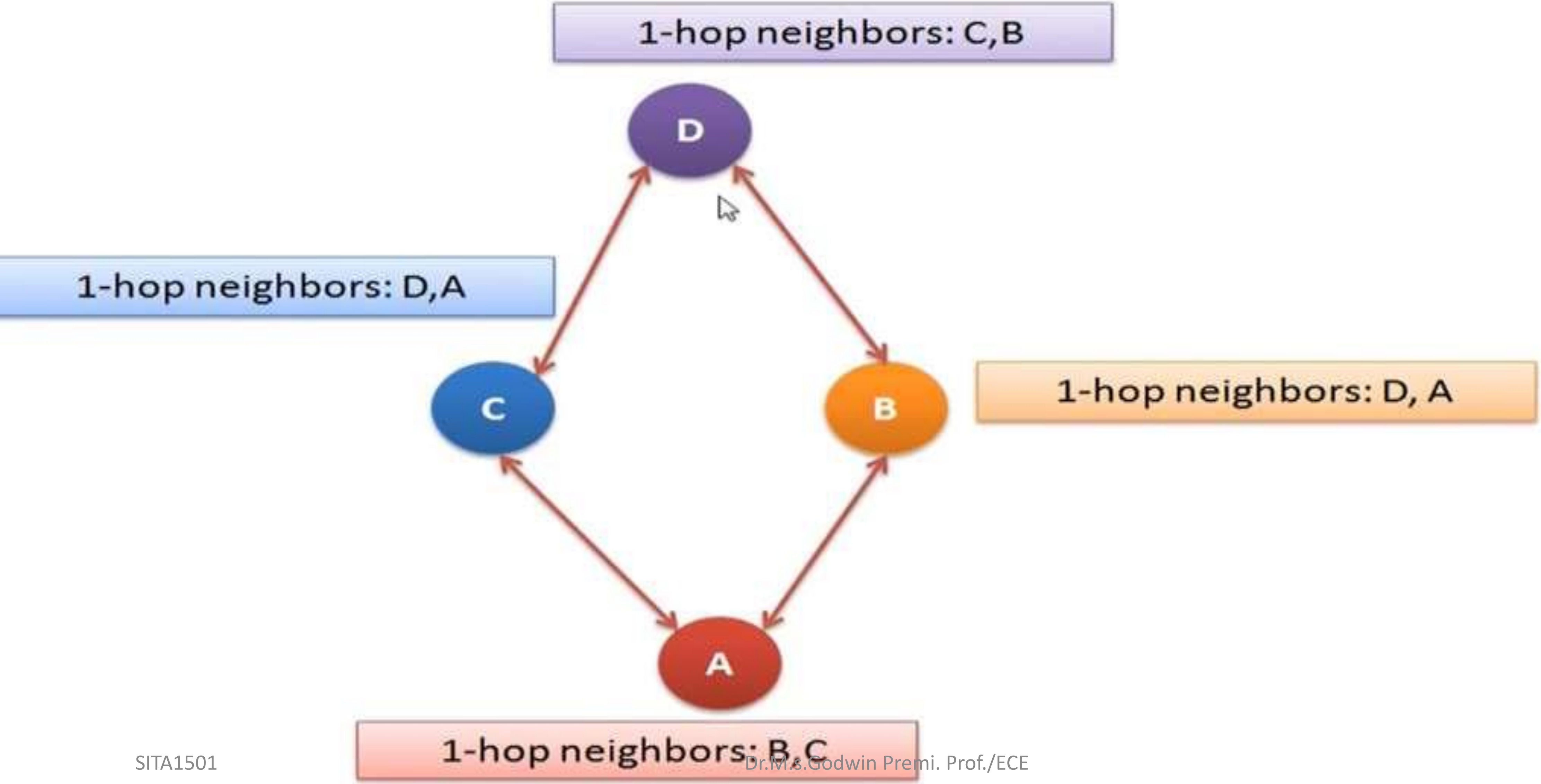
Hello Packet



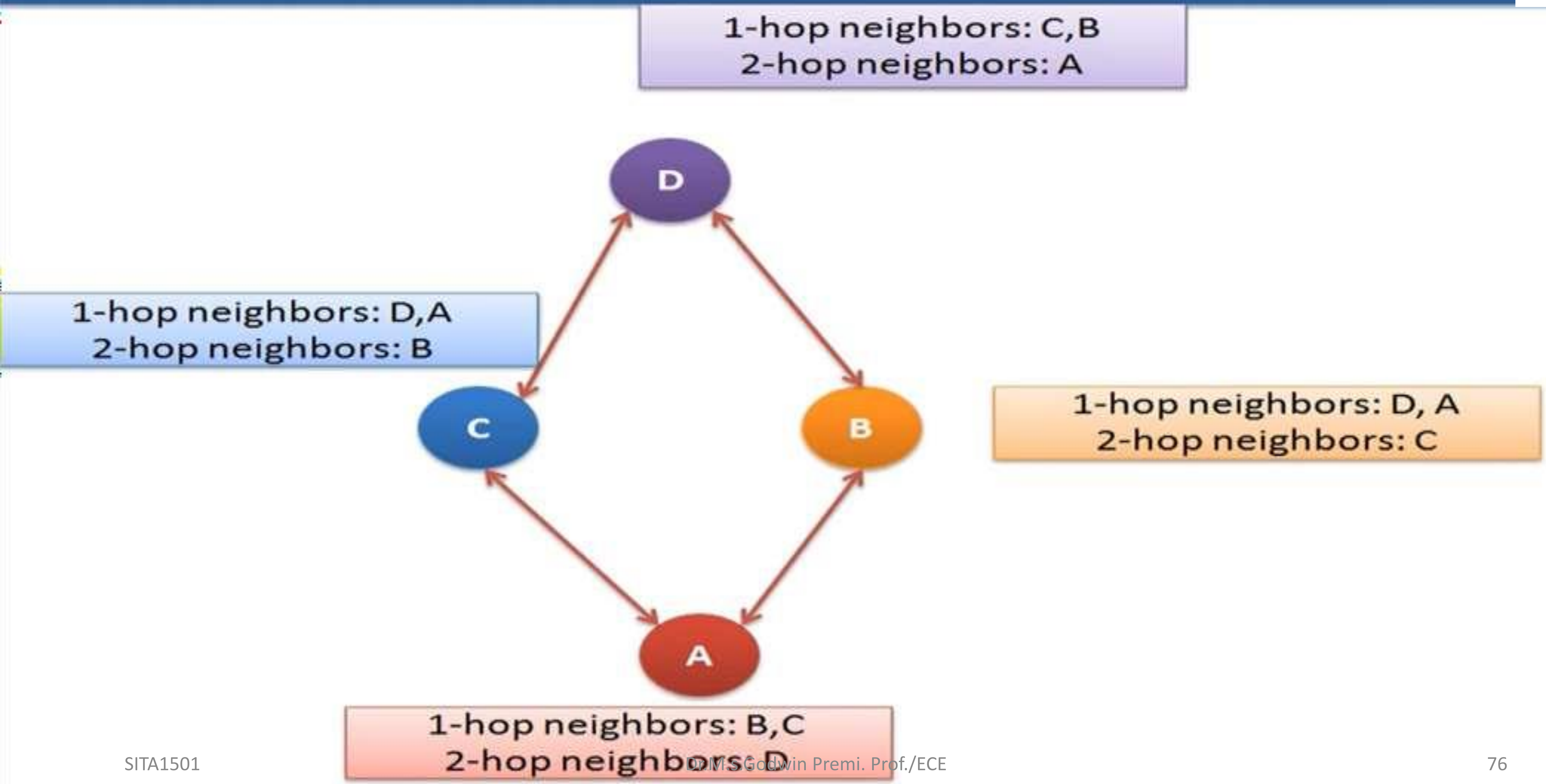
MPR Selection Algorithm



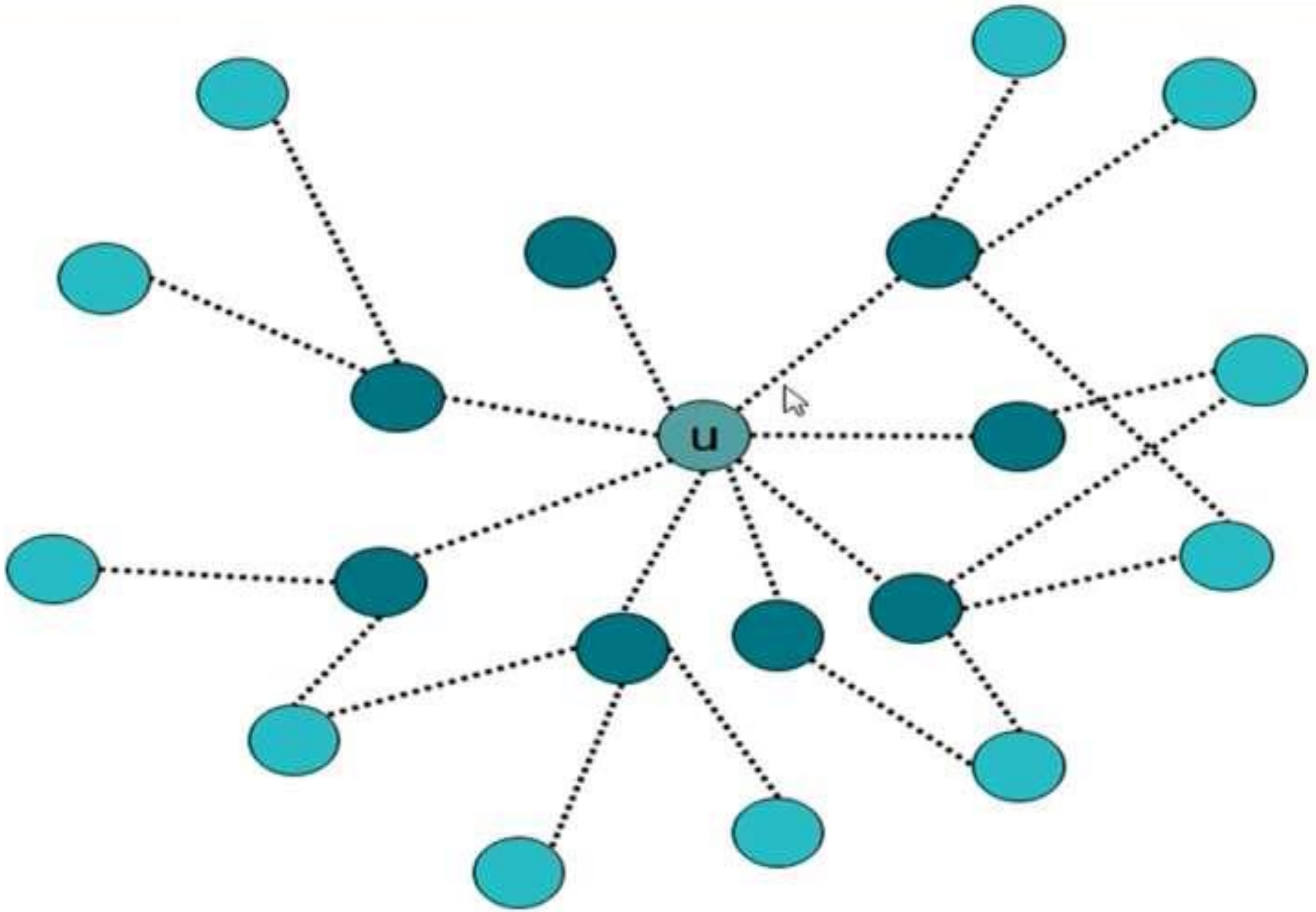
Hello Packet



Hello Packet



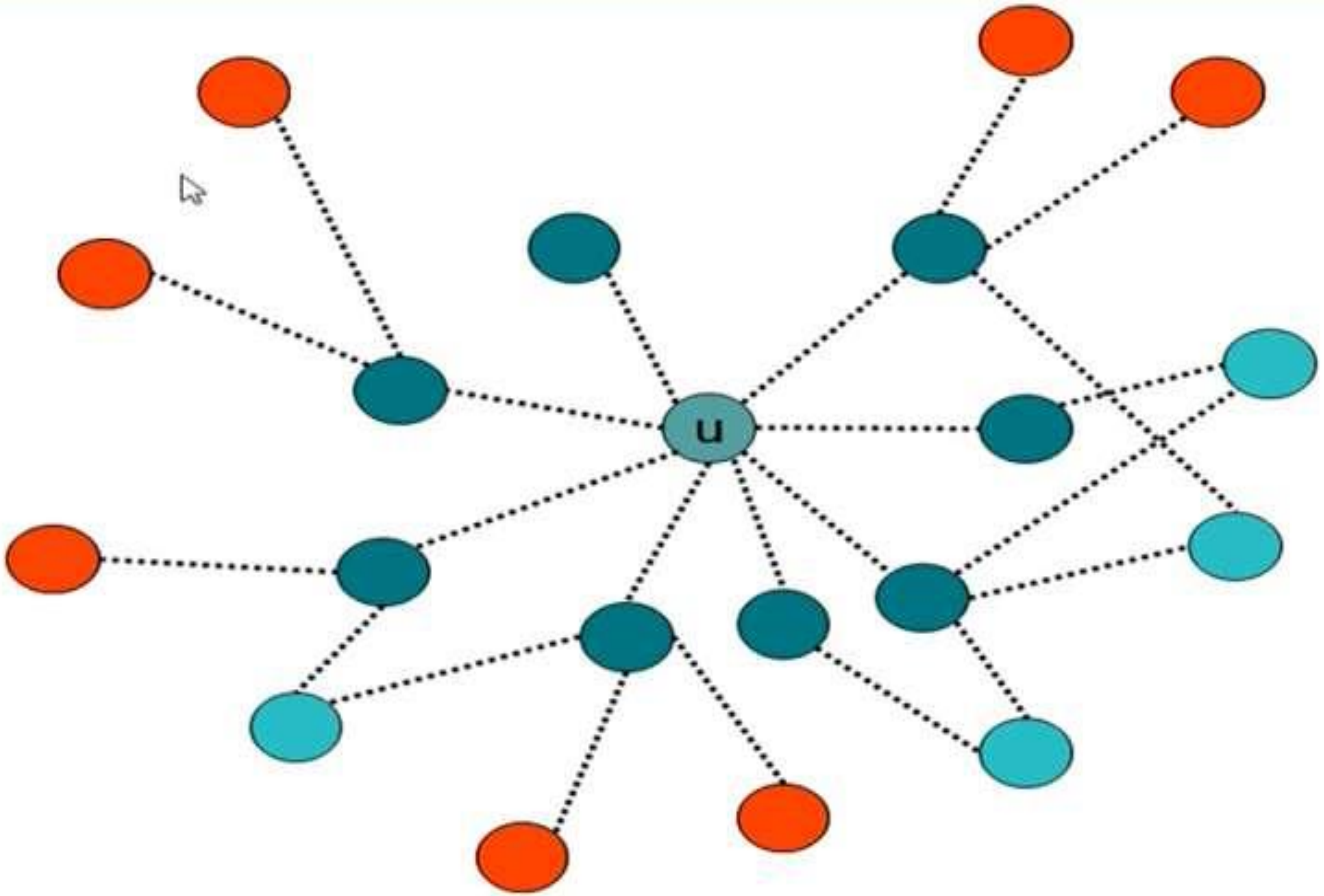
MPR Selection Algorithm



- **First step:** Select nodes in N1(u) which cover "isolated points" of N2(u).

N1(u): 1-hop neighborhood of u. N2(u): 2-hop neighborhood of u.

MPR Selection Algorithm



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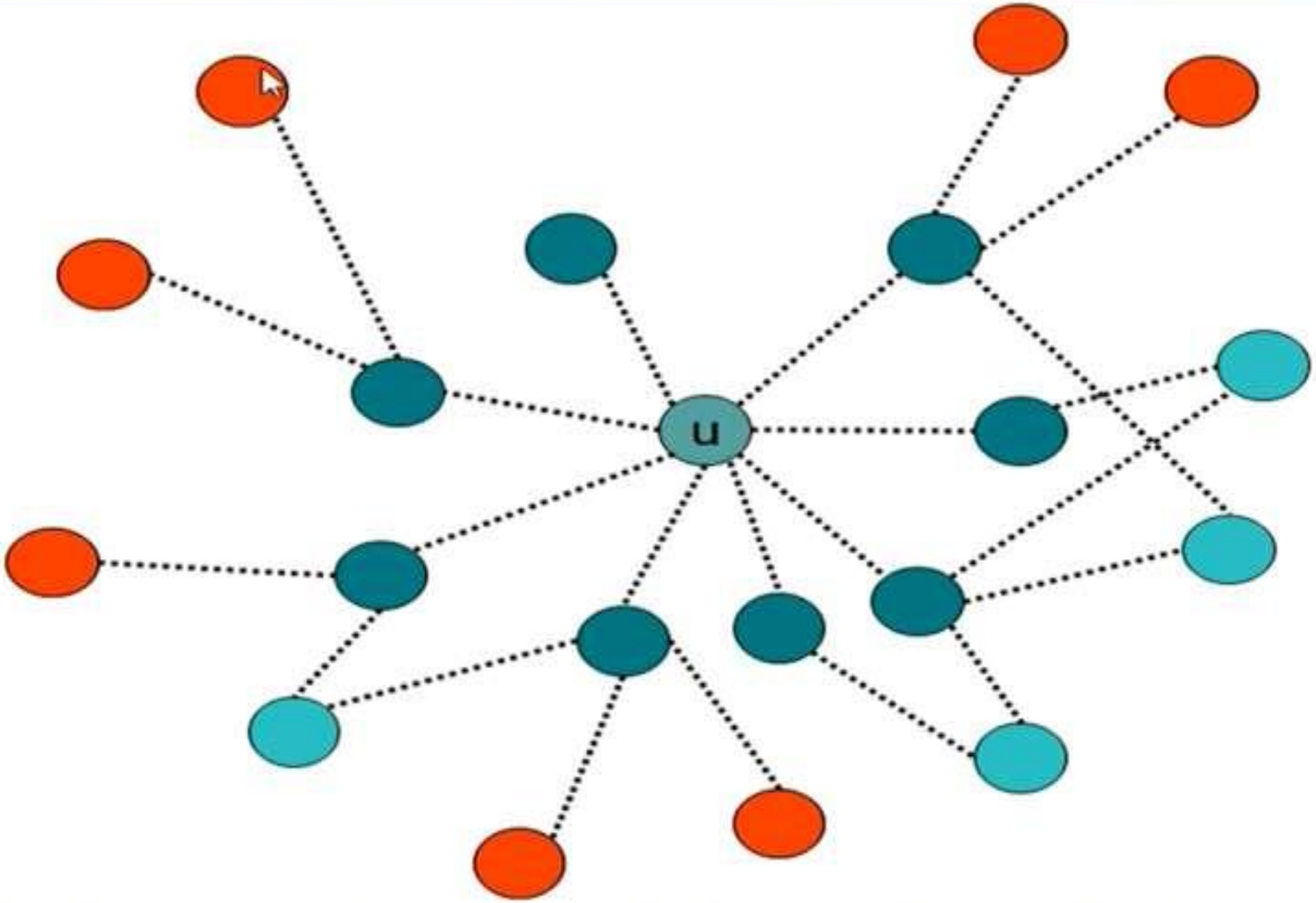
MPR Selection Algorithm



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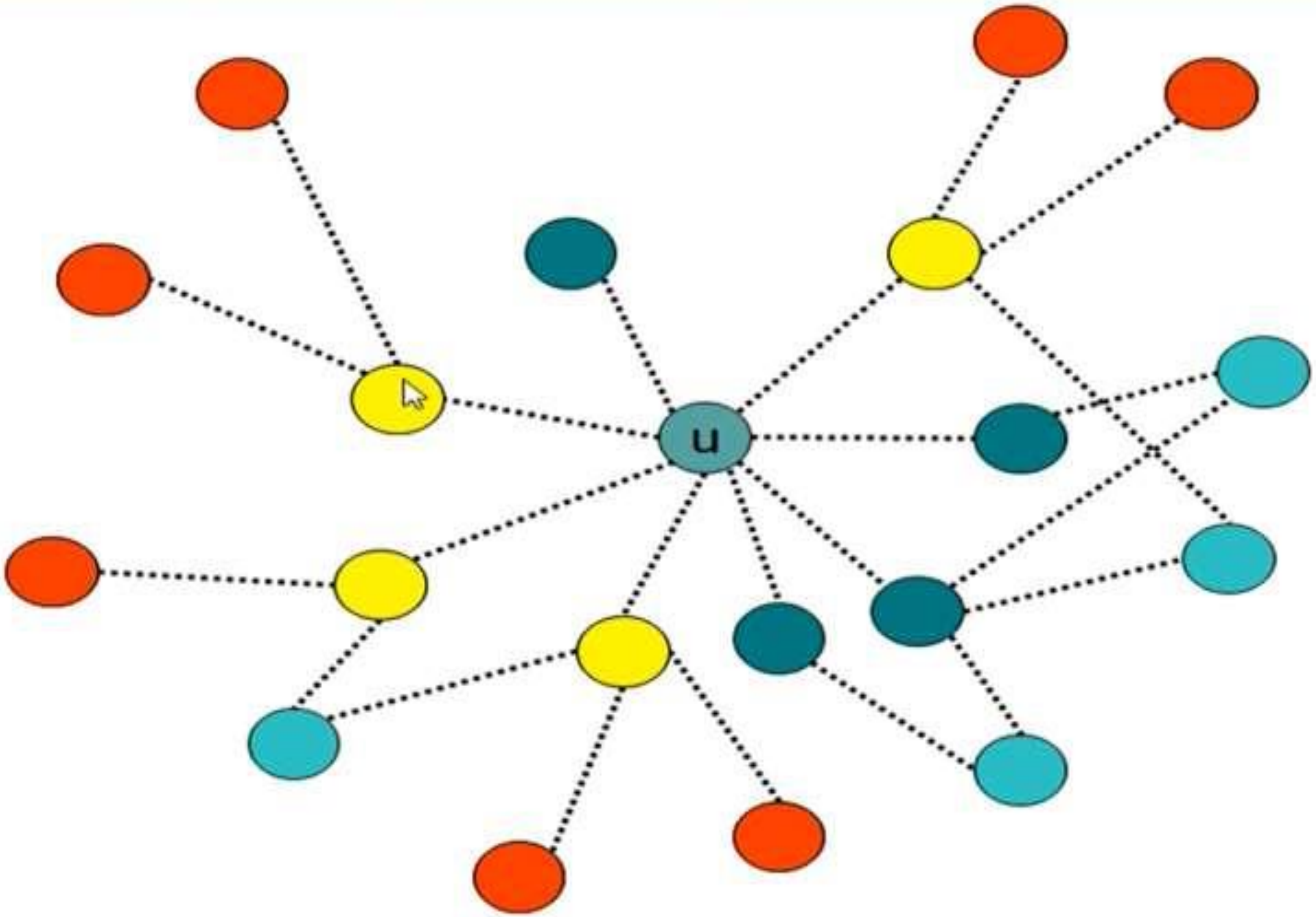
MPR Selection Algorithm



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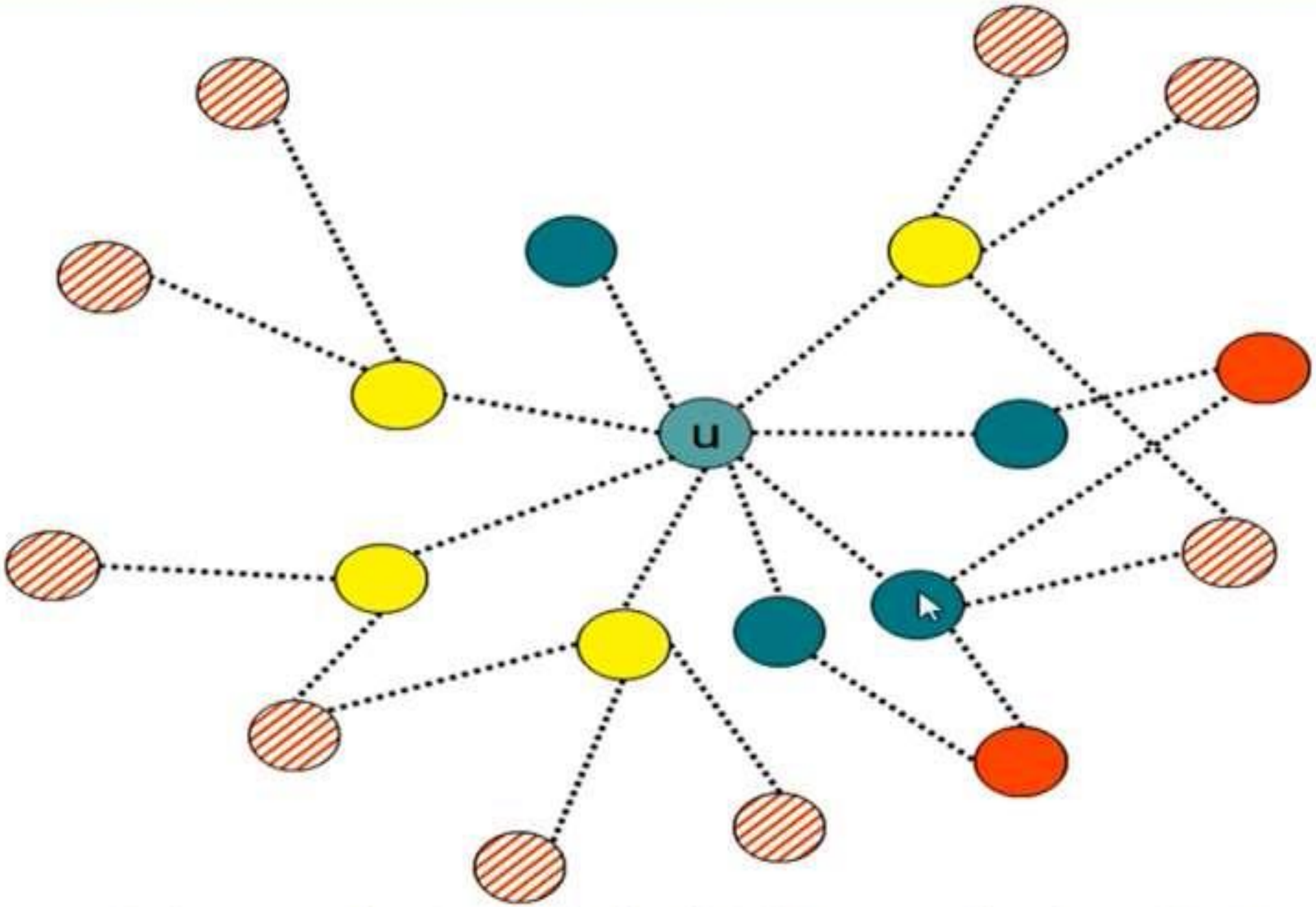
MPR Selection Algorithm



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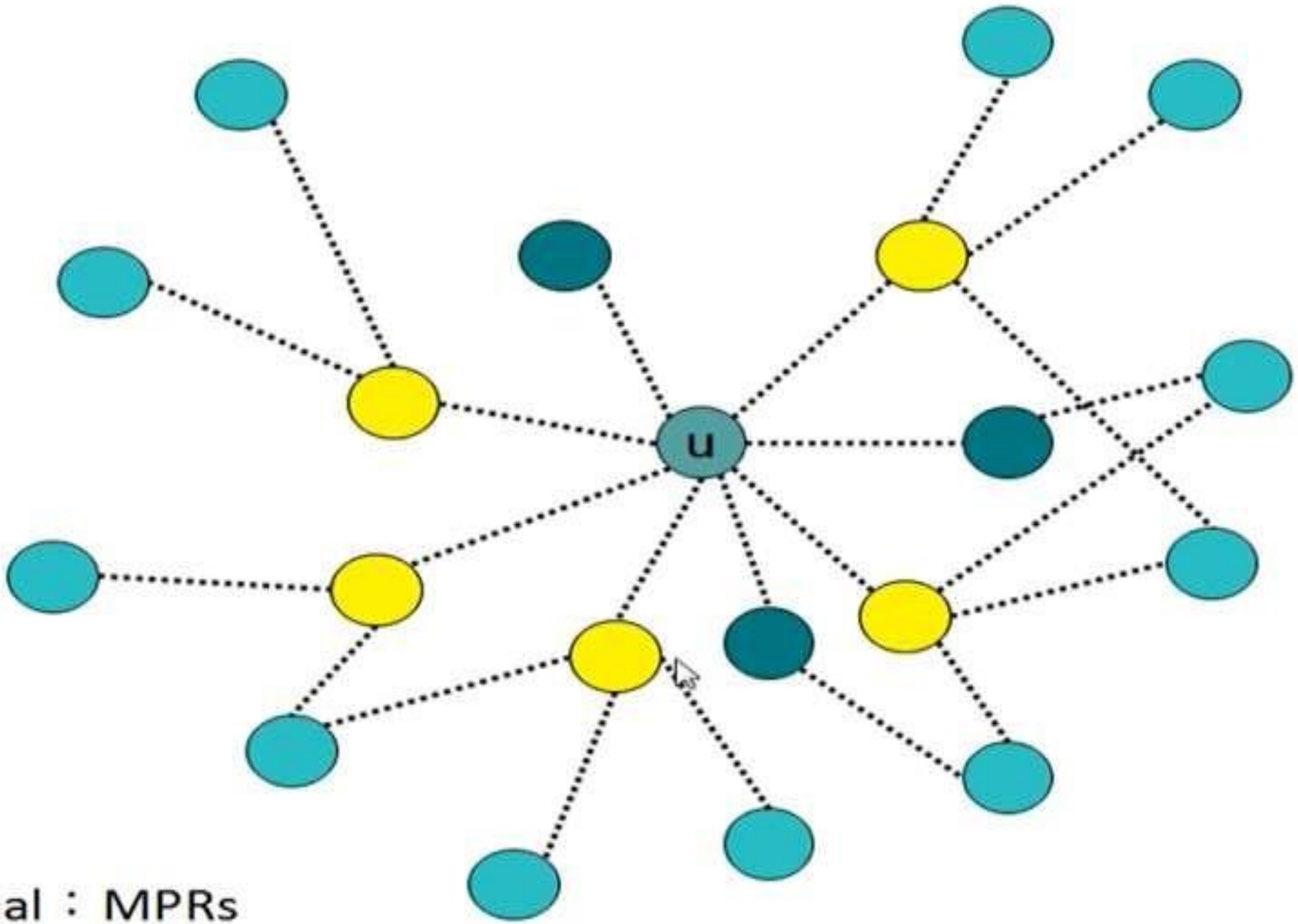
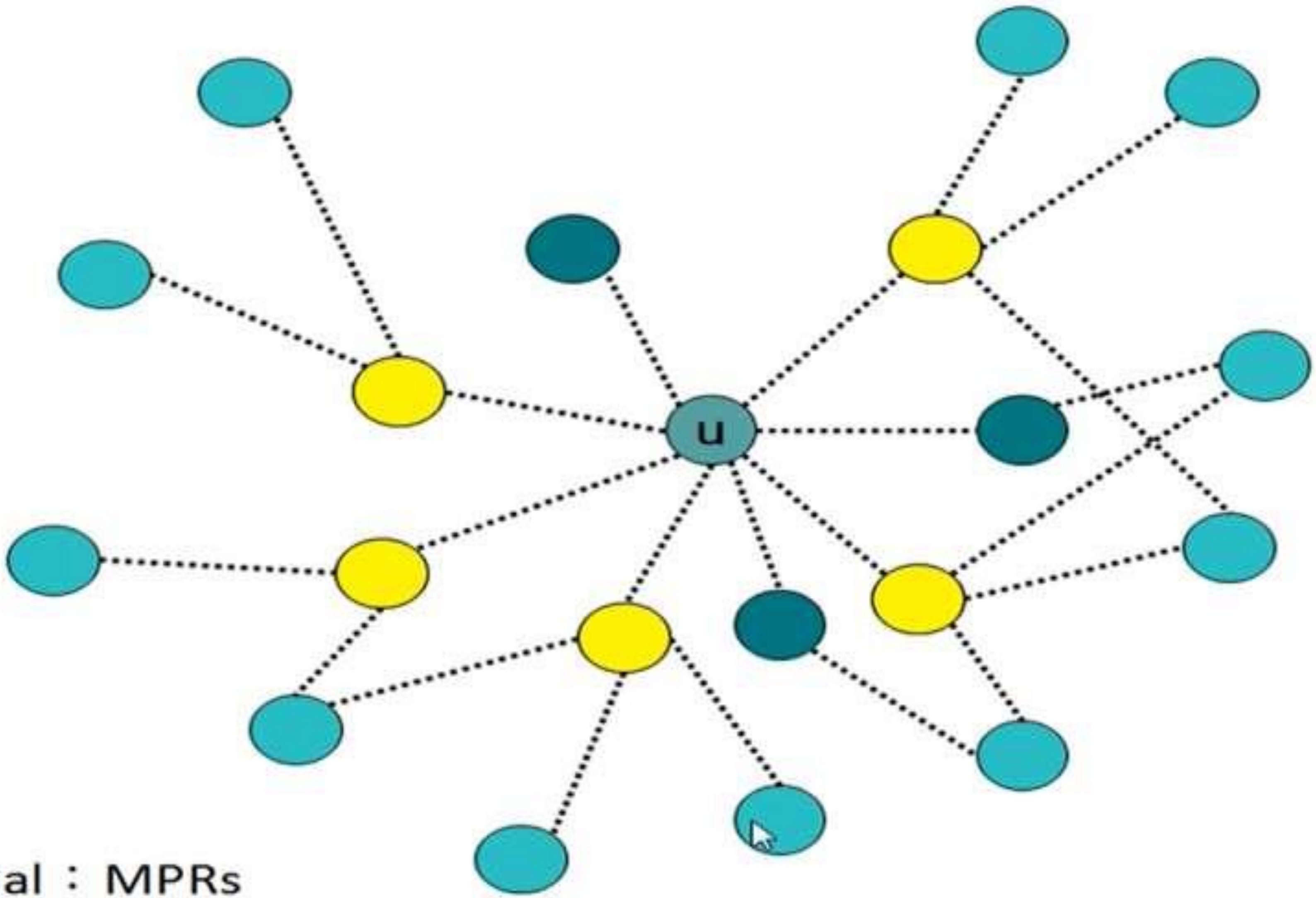
MPR Selection Algorithm



- Final : MPRs

MPR Selection Algorithm



- Final : MPRs

OLSR

- In this, each node N in the network selects a set of neighbor nodes as multipoint relays, MPR(N), that retransmit control packets from N- Neighbors not in MPR(N) process control packets from N, but they do not forward the packets.
- MPR(N) is selected such that all two-hops neighbors of N are covered by (one-hop neighbors) of MPR(N).

Adv. & Disadv.

Advantages of OLSR :

- OLSR has less average end-to-end delay therefore it is used for applications which needs minimum delay.
- The OLSR implementation is more user friendly and worked with fewer headaches than other protocols.
- It is also a flat routing protocol.
- It does not need a central administrative system to handle its routing process.
- It increases protocol's suitability for an ad hoc network with the rapid changes of the source and destination pairs.
- It does not require the link which is reliable in controlling messages, since the messages are sent periodically and the delivery does not have to be sequential.

Disadvantages of OLSR :

- It maintains routing table for all the possible routes.
- When the number of mobile hosts increases, then the overhead from the control messages also increases.
- It needs considerable time to re-discover a broken link.
- It requires more processing power than other protocols when discovering an alternate route.

Routing Protocols - Classification

- Routing Protocols
  - Table Driven
    1. DSDV
    2. OLSR
  - On Demand
    1. DSR
    2. AODV
  - Hybrid
    1. ZRP
    2. DST
  - Hierarchical
    1. OLSR
    2. HSR
  - Multicast
    - Tree Based
      1. AMRIS
      2. MAODV
    - Mesh Based
      1. ODMRP
      2. CAM

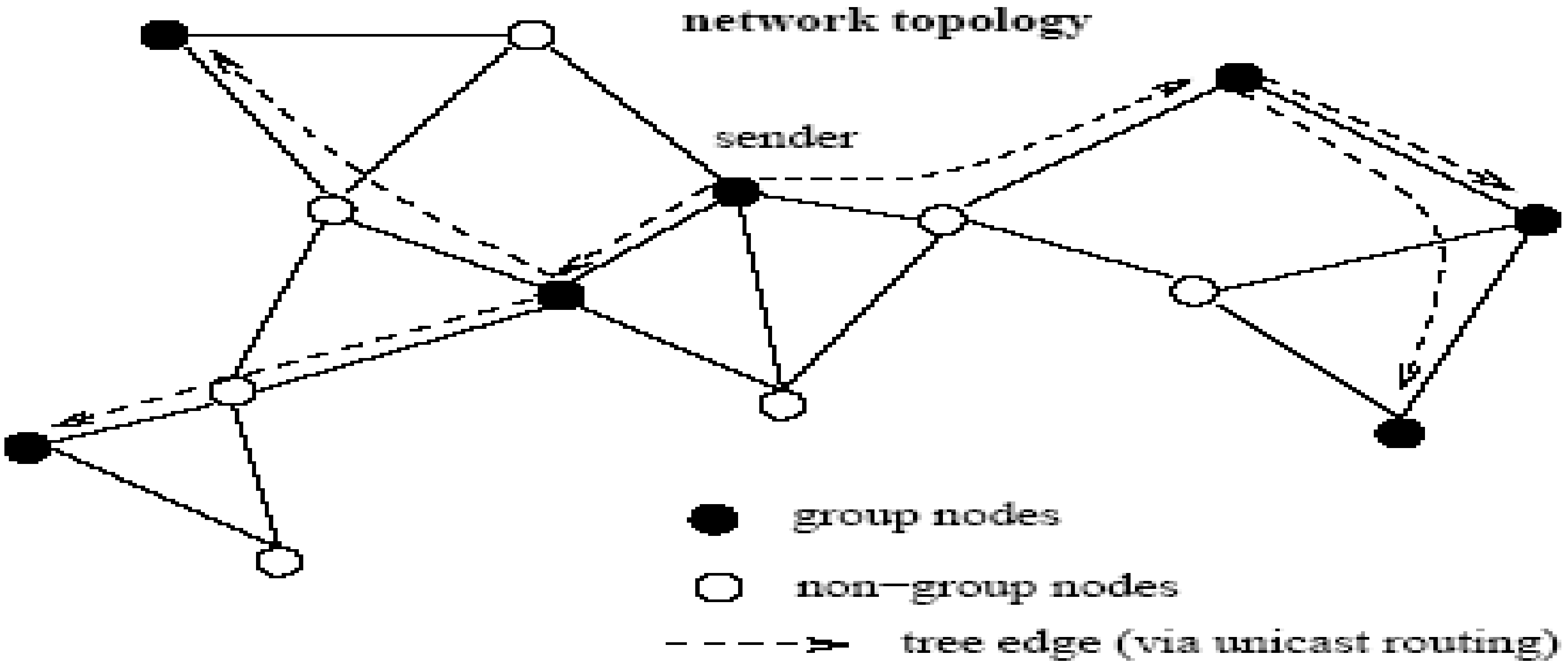
Expected advantages from Multicast Routing

- Providing efficient bandwidth
- Reducing communication cost
- Efficient delivery of data
- Supporting dynamic topology

Technical Constraints

- Minimizing network load
- Providing basic support for reliable transmission
- Designing optimal routes
- Providing robustness, efficiency, and adaptability

Multicasting v/s Broadcastng?



Multicasting

- Routing protocols offering efficient multicasting in wired networks may fail to keep up with node movements and frequent topological changes
- Broadcast protocols cannot be used either as multicasting requires a selected set of nodes to receive the message
- All multicast algorithms depend on the topology of the network
- Majority of applications requiring rapid deployment and dynamic reconfiguration, need multicasting such as military battlefields, emergency search and rescue sites, classrooms, and conventions
- Crucial to reduce the transmission overhead and power consumption
- Multicasting in a MANET faces challenges such as
  - *Dynamic Group Membership* and
  - *Update of Delivery Path* due to MH movement

Multicast Routing Protocols

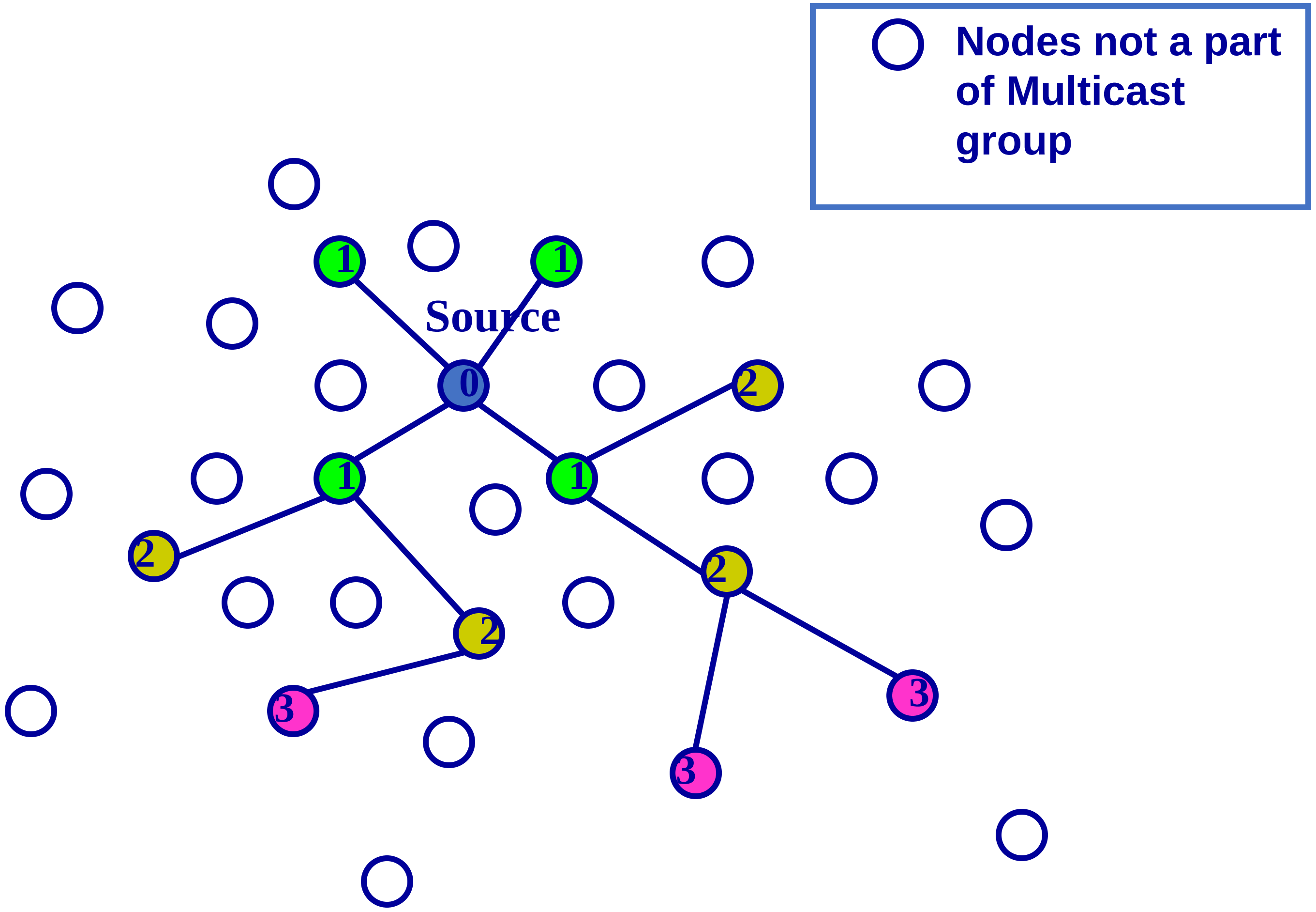
- Broadcast protocols cannot be used as multicasting requires a selected set of MHs to receive the message

- Protocols are classified into four categories based on how route to the members of the group is created:
  - Tree-Based Approaches
  - Meshed-Based Approaches
  - Stateless Multicast
  - Hybrid Approaches

Multicast Routing Protocols - Classification

- Multicast Routing Protocols
  - Based on Topology
    - Tree Based
    - Mesh Based
  - Based on Initialization of Multicast Session
    - Source Initiated
    - Receiver Initiated
  - Based on Topology Maintenance Mechanism
    - Soft State Approach
    - Hard State Approach
  - Hybrid Approaches

Illustration of Tree-Based Multicast



Tree-Based Approaches

- Extend tree-based approach to provide multicast in a MANET
- A packet traverses each hop and node in a tree at most once
- Very simple routing decisions at each node
- Tree structure built representing shortest paths amongst nodes, and a loop-free data distribution structure
- Even a link failure could mean reconfiguration of entire tree structure, could be a major drawback
- Consider either a shared tree or establish a separate tree per each source
  - For separate source trees, each router in multiple router groups must maintain a list of pertinent information for each group and such management per router is inefficient and not scalable
  - For shared trees, there is a potential that packets may not only not traverse shorter paths, but routed on paths with much longer distances

Tree-Based Approaches

- ***Ad hoc Multicast Routing Protocol Utilizing Increasing Id-Numbers***

  - ✓ AMRIS is an on-demand protocol, which constructs a shared multicast delivery tree to support multiple senders and receivers in a multicast session

  - ✓ AMRIS dynamically assigns an id-number to each node in each multicast session and a multicast delivery tree – rooted at a special node with Sid (Smallest-ID and is usually a source that initiates a multicast session) – is created and the id-number increases as the tree expands from the Sid

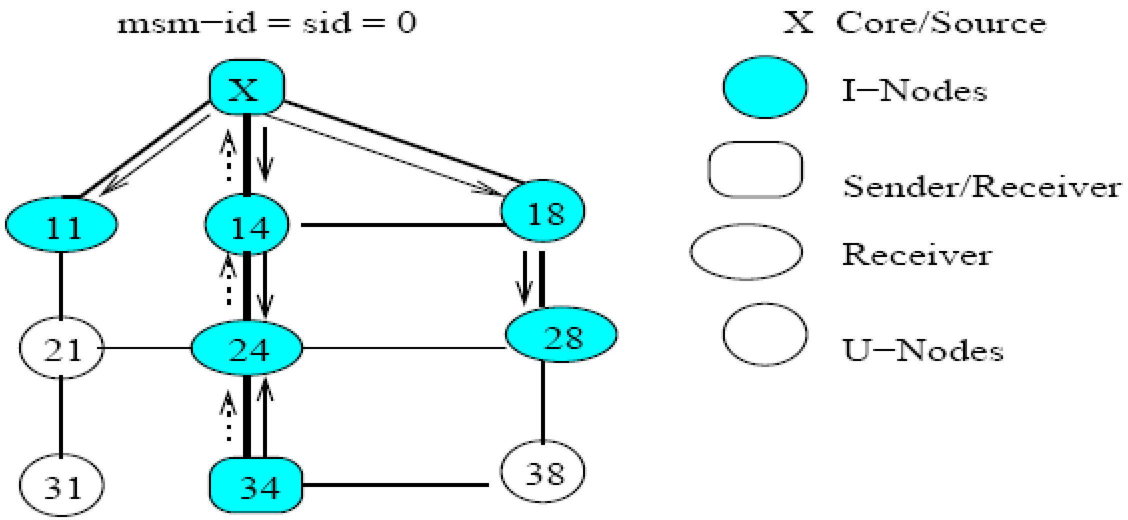
  - ✓ In case of multiple senders, a Sid is selected among the given set of senders
  - ✓ Once a Sid is identified, it sends a NEW-SESSION message to its neighbors
  - ✓ This message includes Sid's msm-id (multicast session member id) and the routing metrics

Tree-Based Approaches

- *Ad hoc Multicast Routing Protocol Utilizing Increasing Id-Numbers*
  - ✓ Nodes receiving the NEW-SESSION message generate their own msm-ids, which is larger than the msm-id of the sender
  - ✓ In case a node receives multiple NEW-SESSION messages from different nodes, it keeps the message with the best routing metrics and calculates its msm-ids
  - ✓ To join an ongoing session, a node checks the NEW-SESSION message, determines a parent with smallest msm-ids, and unicast a JOIN-REQ to its *potential parent node*
  - ✓ If parent node is already in the multicast delivery tree, it replies with a JOIN-ACK.
  - ✓ If a node is unable to find any potential parent node, it executes a branch reconstruction (BR) process to rejoin the tree

Tree-Based Approaches

- *Ad hoc Multicast Routing Protocol Utilizing Increasing Id-Numbers (AMRIS)*
  - **Packet forwarding example**



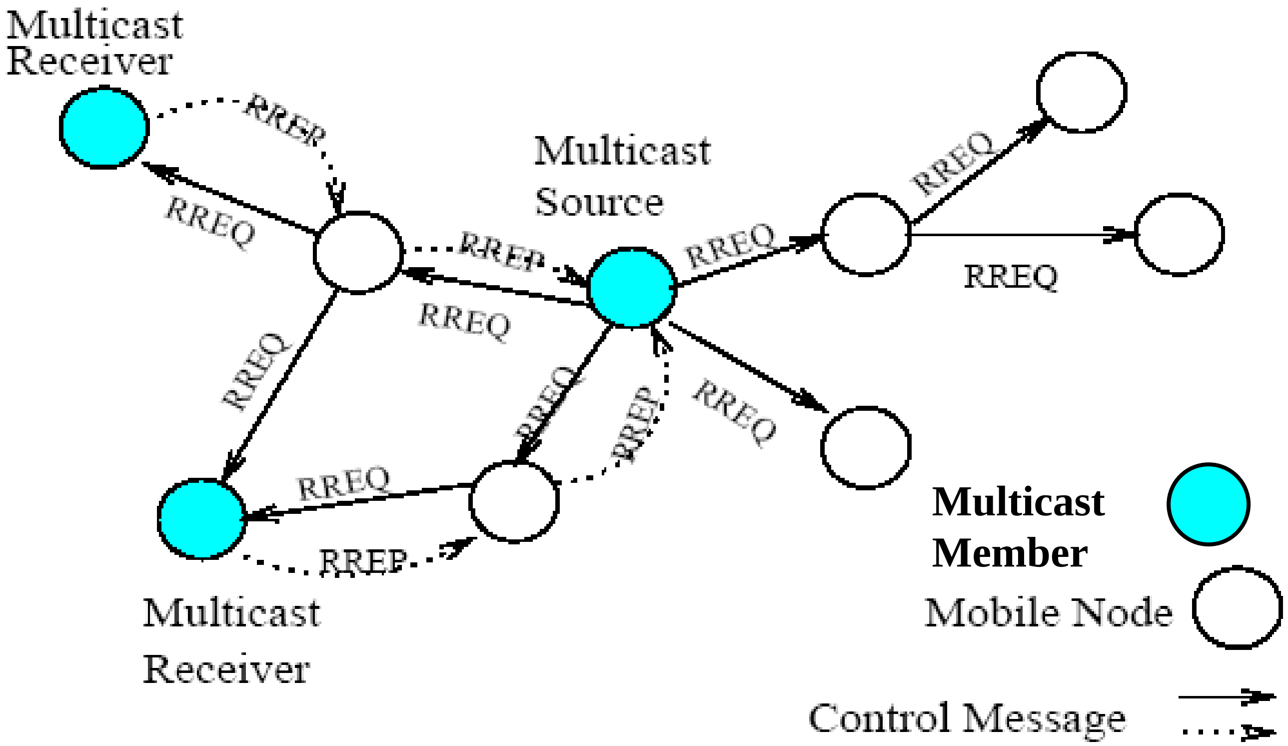
- **Nodes X and 34 are sources**
- **Nodes 11, 24, and 28 are recipients**

Route Discovery and Join for Multicast

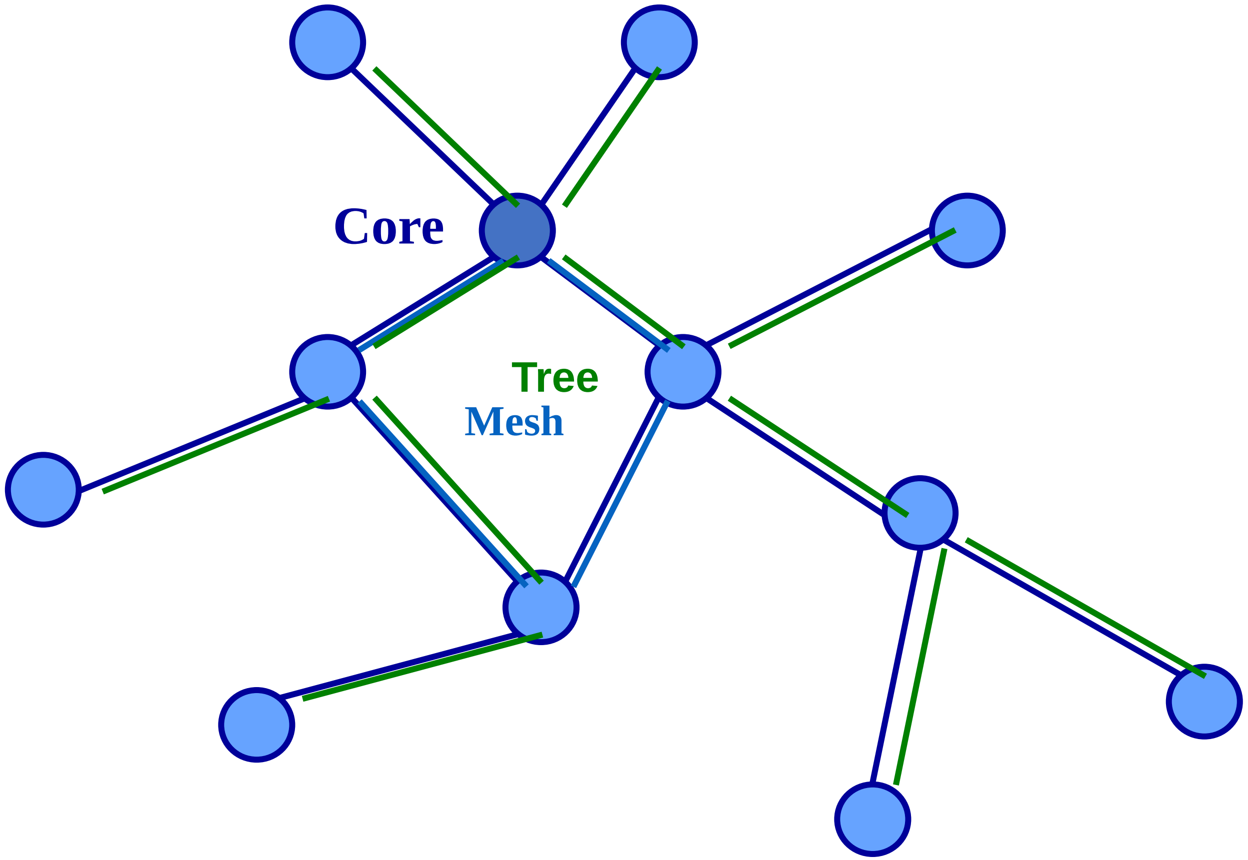
- **Multicast Ad hoc On-Demand Distance Vector Protocol**
  - ✓ Follows directly from the unicast AODV
  - ✓ Discovers multicast routes on-demand using a broadcast route discovery mechanism employing the same Route Request (RREQ) and Route Reply (RREP) messages
  - ✓ A MH originates a RREQ message when it wishes to join a multicast group, or when it has data to send to a multicast group but it does not have a route to that group
  - ✓ Only a member of the desired multicast group may respond to a join RREQ
  - ✓ If the RREQ is not a join request, any node with a fresh enough route to the multicast group may respond
  - ✓ As the RREQ is broadcasted across the network, nodes set up pointers to establish the reverse route in their route tables
  - ✓ A node receiving a RREQ first, updates its route table to record the sequence number
  - ✓ *For join RREQs, an additional entry is added to the multicast route table and is not activated unless the route is selected to be a part of the multicast tree*

Multicast AODV

- **Multicast Ad hoc On-Demand Distance Vector Protocol**
  - **Follows directly from the unicast AODV**



Core Node Selection and Multicast Routing Protocol



Core-Based Approaches

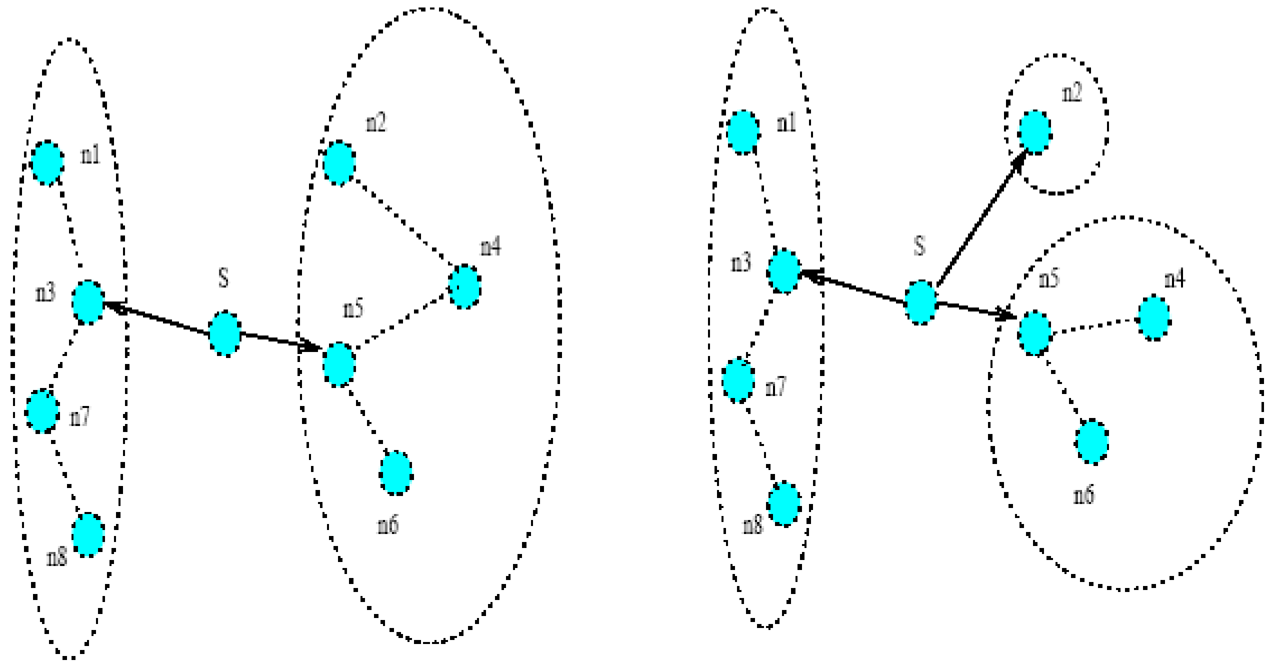
- Lightweight Adaptive Multicast (LAM)
  - Draws on the Core-Based Tree (CBT) protocol and the TORA unicast routing algorithm
  - Each multicast group initialized and maintained by a multicast server, or core
  - Any node which wants to communicate with a specific multicast group can query the directory server
  - It is more efficient due to elimination of duplicated control functionality between different protocol layers
  - LAM builds a group-shared multicast routing tree for each multicast group centered at the CORE
  - A multicast tree is source-initiated and group-shared and nodes in LAM maintain two variable, POTENTIAL-PARENT and PARENT, and two lists POTENTIAL-CHILD-LIST and CHILD-LIST
  - These potential data objects are used when the node is in a “join” or “rejoin” waiting state
  - LAM is based on CBT approach to build the multicast delivery tree
  - With one CORE for a group, LAM is not very robust

Small Group Multicast

- Location Guided Tree Construction Algorithm for Small Group Multicast
  - This is a small group multicast schemes based on packet encapsulation
  - It builds an overlay multicast packet distribution tree on top of the underlying unicast routing protocol
  - Based on two types of tree: location-guided k-array (LGK) tree and a location-guided Steiner (LGS) tree
  - Geometric location information of the destination nodes is utilized to construct the packet distribution tree without knowing the global topology of the network
  - Protocol also supports an optimization mechanism through route caching
  - In LGK tree approach, the sender first selects nearest k destinations as children nodes
  - The sender then groups the rest of the nodes to its k children as per the closeness to geometric proximity
  - Once the group nodes are mapped to its corresponding child nodes, the sender forwards a copy of the encapsulated packet to each of the k children, with its corresponding subtree as destinations
  - Process stops when an in-coming packet has an empty destination list

Location Guided Tree Construction

Location Guided Tree Construction Algorithm for Small Group Multicast



(a) – LGK Tree (k=2) construction

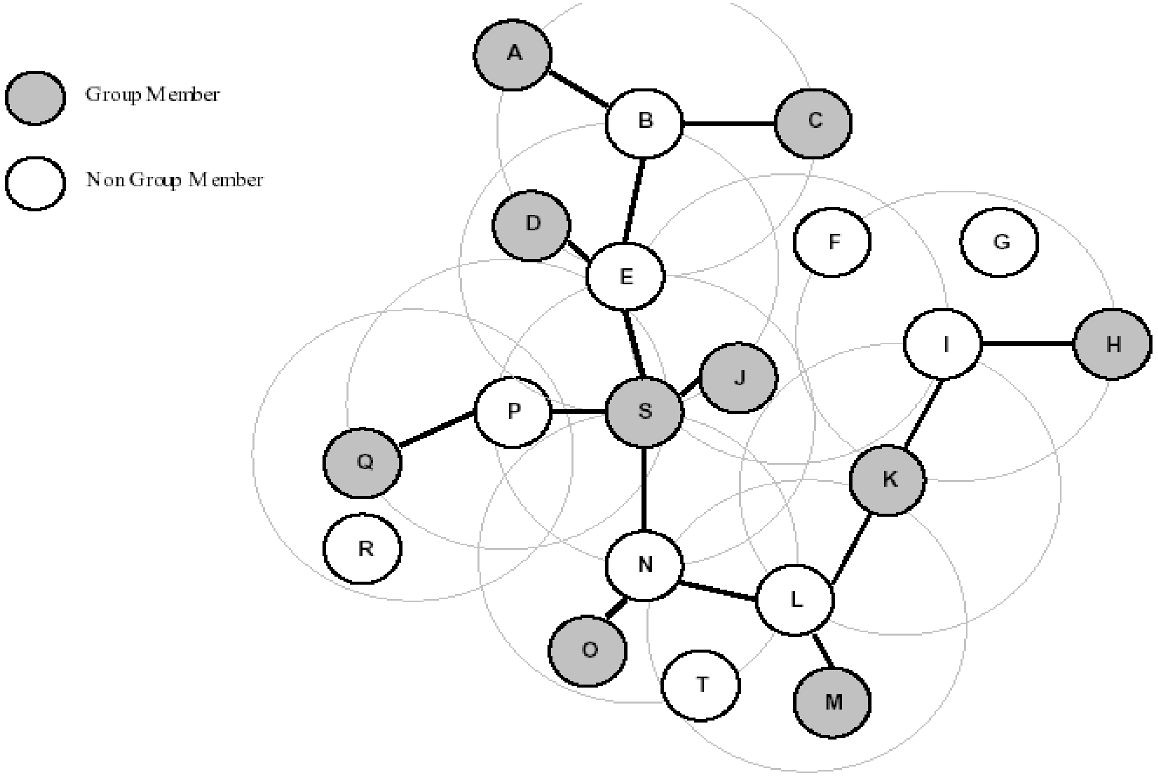
(b) – LGS Tree constuction

Zone Routing based Multicast

- ***Multicast Zone Routing***
  - Takes into consideration the hierarchical structure used by the ZRP unicast routing protocol
  - Network is partitioned into zones
  - Each node computes its own zone, determined by nodes lieing within a certain radius of the node
  - ZRP is described as a hybrid approach between the proactive and reactive routing protocols
  - Routing is proactive inside the zones and reactive between the zones
  - To create a zone, a MZR node A broadcasts an ADVERTISEMENT message with a time-to-live (TTL) equal to a pre-configured ZONE-RADIUS
  - Node B within the zone radius decrements the TTL and forwards the message if appropriate
  - Node B makes an entry in its routing table for node A, with the last hop of the ADVERTISEMENT message as the next hop towards destination
  - Nodes ZONE-RADIUS hops away from node A become border nodes, and serve as a gateway between node A's zone and the rest of the network
  - MZR begins its search within the zone before extending outward
  - A source wants to start sending multicast traffic, it initiates the construction of a multicast tree
  - A TREE-CREATE-ACK packet is sent back to the source and intermediate nodes mark in their routing tables the last hop of the TREE-CREATE-ACK as a downstream node

Multicast Zone Routing

- Border node unicasts a TREE-CREATE-ACK to the multicast source to create a link between the border node and the source
- This sequence continues until every node in the network receives a TREE-CREATE message
- Routes in MZR are updated through the use of TREE-REFRESH packets
- If a node on the multicast tree fails to receive a TREEREFRESH message after a certain time, it deletes its multicast entry
- TREE-REFRESH packets could be piggybacked on multicast data whenever possible



- MZR creates a source specific, on-demand multicast tree with a minimal amount of routing overhead
- Hierarchical approach of MZR does not conserve bandwidth during the initial TREE-CREATE flood

Source Specific Multicast Tree

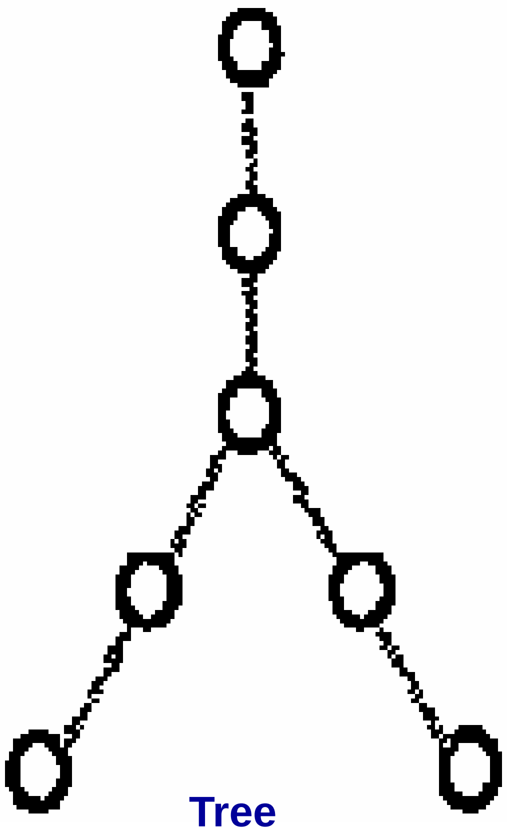
- *Multicast Optimized Link State Routing (MOLSR)*
  - MOLSR creates a source specific multicast tree
  - MOLSR is dependent on OLSR as unicast routing algorithm
  - Routers periodically advertise their ability to route and build multicast routes
  - MOLSR nodes can calculate shortest path routes to every potential multicast source
  - This is done in the same manner seen in OLSR, except that now the routes consist entirely of multicast-capable OLSR routers
  - Multicast routes are built in a backward manner similar to the method used in MZR
  - A source that wants to send multicast traffic advertises its intentions by broadcasting a SOURCE_CLAIM message to every node in the network
  - A multicast source periodically sends a SOURCE_CLAIM message to every node in the network for two reasons
  - First, it informs multicast receivers that the source is still sending data
  - Second, it allows unattached hosts to join the multicast group

Other Protocols

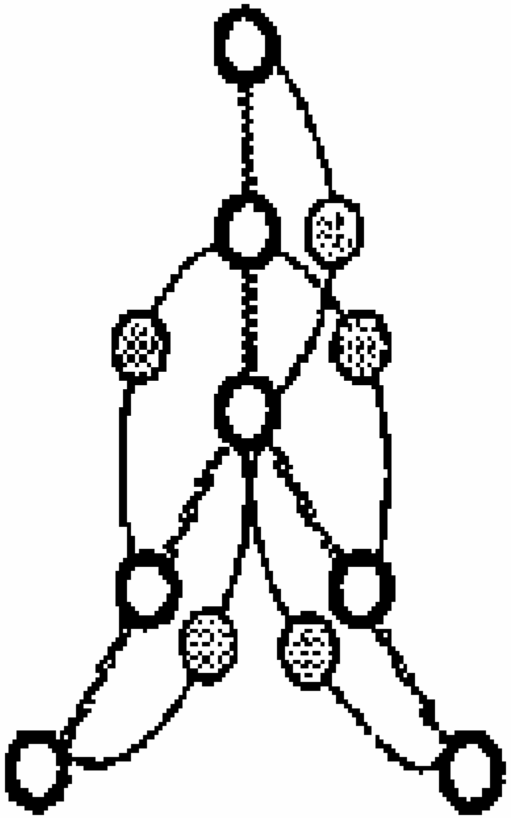
- The Associativity-Based Ad Hoc Multicast (ABAM)
  - This is an on-demand source-initiated multicast routing protocol
  - A multicast tree is built for each multicast group based on association stability
  - The link status of each node is monitored by its neighbors
  - ABAM deals with the network mobility on different levels according to varying mobility effects: branch repair when the receiver moves, sub-tree repair when a branching node moves, and full tree level repair when the source node moves
- On-demand Location-Aware Multicast (OLAM) protocol
  - OLAM assumes each node to be equipped with GPS device
  - Each node can process and take a snapshot of the network topology and make up a multicast tree (minimum spanning tree)
  - This protocol does not use any distributed data structures or ad hoc routing protocol as foundation and full tree level repair when the source node moves
- Adaptive Demand-Driven Multicast Routing (ADMR)
  - A protocol that attempts to reduce non-on-demand components
  - ADMR uses *tree flood* to enable packets to be forwarded following variant branches in the multicast tree
  - A multicast packet in ADMR floods within the multicast distribution tree only towards the group’s receivers
- The Spiral-fat-tree-based On-demand Multicast (SOM) protocol
  - A spiral fat tree is built as the multicast tree to increase the stability of the tree structure
  - By using link redundancy of the fat tree, failed links will be easily replaced.

Spiral-fat-tree-based On-demand Multicast (SOM) protocol

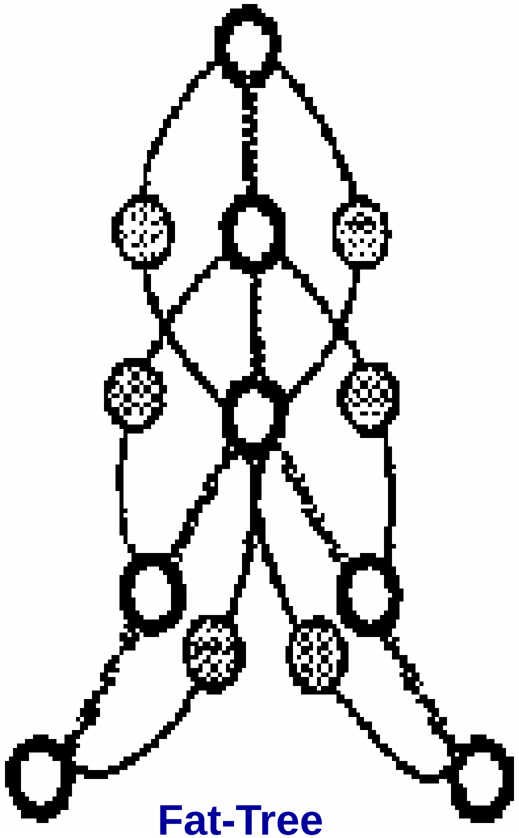
A spiral fat tree is built to increase the stability of the tree structure



Tree



Fat-Tree



Fat-Tree

Mesh based Approach

- Mesh-based multicast protocols may have multiple paths between any source and receiver pairs
- Mesh-based protocols seem to outperform tree-based proposals due to availability of alternative paths
- A mesh has increased data-forwarding overhead
- The redundant forwarding consumes more bandwidth
- The probability of collisions is higher when a larger number of packets are generated

Mesh based Approach

- On-Demand Multicast Routing Protocol
- Core-Assisted Mesh Protocol
- Forwarding Group Multicast Protocol
- Other Protocols

On-Demand Multicast Routing Protocol

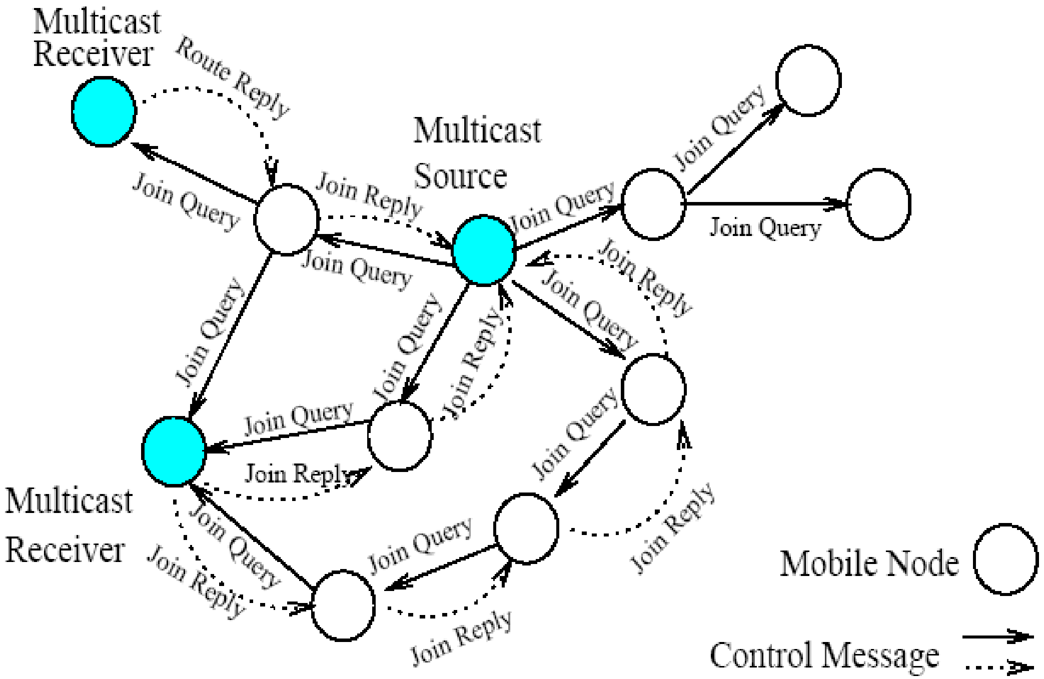
- Mesh-based protocol employing a forwarding group concept
- Only a subset of nodes forwards the multicast packets
- A soft state approach is taken in ODMRP to maintain multicast group members
- No explicit control message is required to leave the group
- The group membership and multicast routes are established and updated by the source on demand
- If no route to the multicast group, a multicast source broadcasts a Join-Query control packet to the entire network
- This Join-Query packet is periodically broadcasted to refresh the membership information and updates routes

On-Demand Multicast Routing Protocol

- After establishing a forwarding group and route construction process, a source can multicast packets to receivers via selected routes and forwarding groups

- To leave the group, source simply stops sending Join-Query packets

- If a receiver no longer wants to receive from a particular multicast group, it does not send the Join-Reply for that group



Core-Assisted Mesh Protocol

- Supports multicasting by creating a shared mesh for each multicast group
- Meshes thus created, helps in maintaining the connectivity to the multicast users, even in case of node mobility
- It borrows concepts from CBT, but the core nodes are used for control traffic needed to join multicast groups
- Assumes a mapping service by building and maintaining the multicast mesh
- Nodes are classified as: simplex, duplex and non-member
- CAMP uses a receiver-initiated method for routers to join a multicast group
- CAMP ensures the mesh to contain all reverse shortest paths between a source and the recipients

Mesh based Approach

- Forwarding Group Multicast Protocol
  - Can be viewed as flooding with “limited scope”
  - Flooding is contained within a selected forwarding group (FG) nodes
  - Makes innovative use of flags and an associated timer to forward multicast packets
  - Uses two approaches to elect and maintain FG of forwarding nodes: FGMP-RA (Receiver Advertising) and FGMP-SA (Sender Advertising)

Mesh based Approach

- Other Protocols
  - A local routing scheme is proposed in the Neighbor Supporting ad hoc Multicast routing Protocol (NSMP)
  - Two types of route discovery: flooding route discovery and local route discovery
  - Intelligent On-Demand Multicast Routing Protocol (IOD-MRP) is a modified version of CAMP by employing an on-demand receiver initiated procedure to dynamically build routes and maintain multicast group membership instead of using cores
  - Source Routing-based Multicast Protocol (SRMP) applies the source routing mechanism defined by the DSR unicast protocol in a modified manner, decreasing the size of the packet header
  - Protocol operates in a loop-free manner, minimizing channel overhead and making efficient use of network resources

Stateless Approaches

Differential Destination Multicast

- Meant for small-multicast groups operating in dynamic networks of any size
- DDM lets source to control multicast group membership
- Each node along the forwarding path remembers the destinations to which the packet has been forwarded last time and its next hop information
- At each node, there is one Forwarding Set (FS) for each multicast session
- The nodes also maintain a Direction Set (DS) to record the particular next hop to which multicast destination data are forwarded
- Source node, FS contains the same set of nodes as the multicast Member List (ML)
- In the intermediate nodes, the FS is the union of several subsets based on the data stream received from upstream neighbors
- Associated with each set FS_k, there is a sequence number SEQ(FS_k) which is used to record the last DDM Block Sequence Number seen in a received DDM data packet from an upstream neighbor k

Stateless Approaches

DSR Simple Multicast and Broadcast Protocol

- Designed to provide multicast and broadcast functionality
- It utilizes the Route Discovery mechanism defined by the DSR unicast protocol to flood the data packets in the network
- It can be implemented as a stand-alone protocol
- In fact, it does not rely on unicast routing to operate
- If DSR has already been implemented on the network, minor modifications are required to enable this protocol

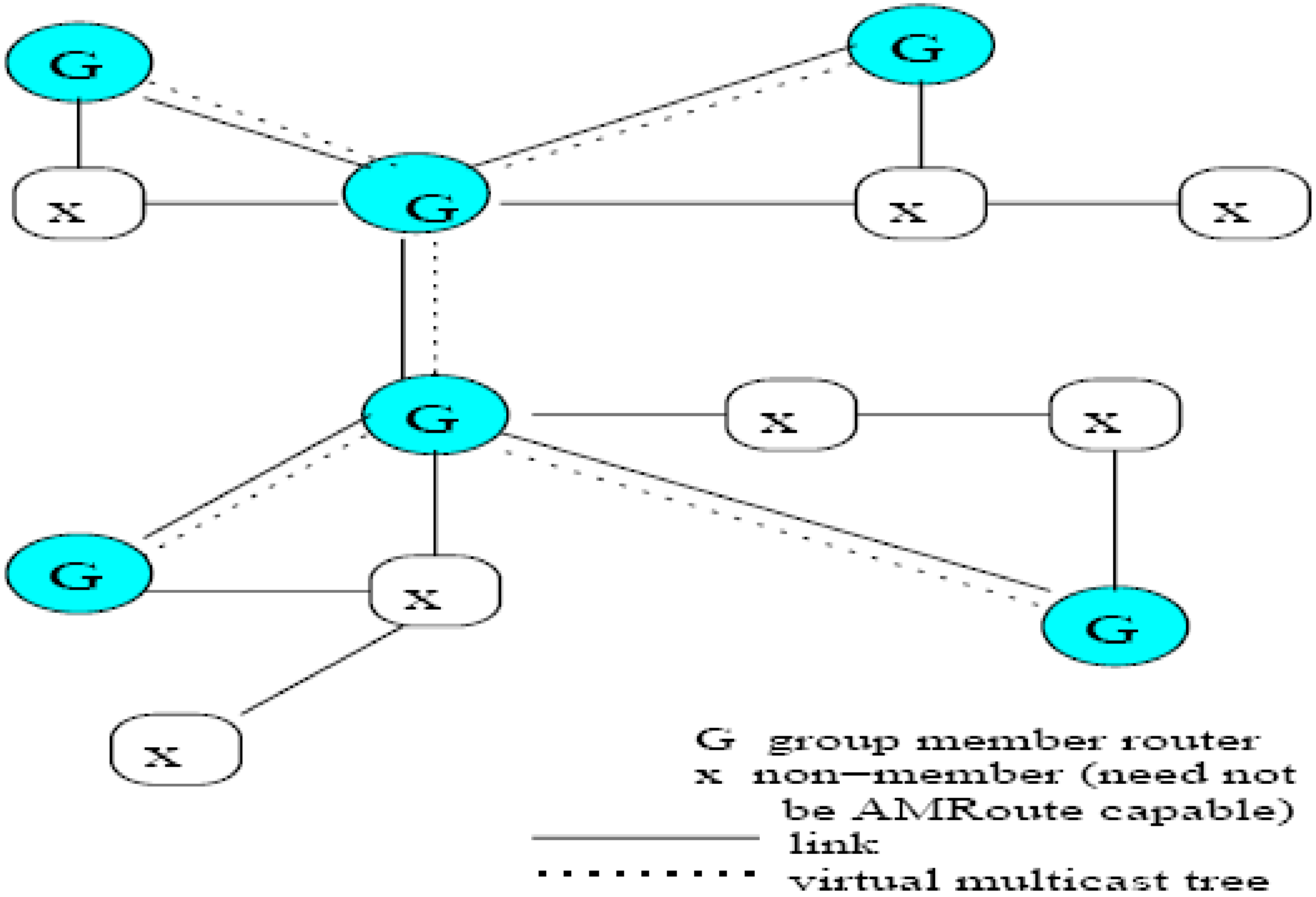
Hybrid Approaches

Ad hoc Multicast Routing Protocol (AMRoute)

- Creates a bi-directional, shared tree by using only group senders and receivers as tree nodes for data distribution
- The protocol has two main components: mesh creation and tree setup
- The *mesh creation* identifies and designates certain nodes as logical cores and these are responsible for initiating the signaling operation and maintaining the multicast tree to the rest of the group members
- A non-core node only responds to messages from the core nodes and serves as a passive agent
- The selection of logical core in AMRoute is dynamic and can migrate to any other member node, depending on the network dynamics and the group membership
- AMRoute does not address network dynamics and assumes the underlying unicast protocol to take care

Hybrid Approaches

■Ad hoc Multicast Routing Protocol



Hybrid Approaches

Multicast Core-Extraction Distributed Ad Hoc Routing

- The main idea is to provide the efficiency of the tree-based forwarding protocols and robustness of mesh-based protocols by combining these two approaches
- The infrastructure is robust and data forwarding occurs at minimum height trees

Mobility-based Hybrid Multicast Routing

- Designed to provide multicast and broadcast functionality
- Built on top of the mobility-based clustering infrastructure
- The structure is hierarchical in nature
- The mobility and positioning information is provided via a GPS for each node
- Cores are employed in both AMRoute and MCEDAR, as well as in many tree and mesh multicast algorithms

Comparison of Multicast Approaches

Protocol	Topology	Loop Free	Dependence on Unicast Protocol	Periodic Message	Control Packet Flooding Done/Required
Flooding	Mesh	Yes	No	No	No
AMRoute	Hybrid	No	Yes	Yes	Yes
AMRIS	Tree	Yes	No	Yes	Yes
MAODV	Tree	Yes	Yes	Yes	Yes
LAM	Tree	Yes	Yes	No	No
LGT-Based	Tree	Yes	No	Yes	No
ODMRP	Mesh	Yes	No	Yes	Yes
CAMP	Mesh	Yes	Yes	Yes	No
DDM	Stateless Tree	Yes	No	Yes	No
FGMP-RA	Mesh	Yes	Yes	Yes	Yes
FGMP-SA	Mesh	Yes	No	Yes	Yes
MCEDAR	Hybrid	Yes	Yes	Yes	Yes