Ad-hoc and Mesh Networks

MAP-I

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- *What is an ad-hoc network?*
- *What are differences between layer 2 and layer 3 ad-hoc networks?*
- *What are the differences between an IEEE mesh network and an IETF MANET network?*
- *What are the differences between a mobile network and a mobile terminal?*

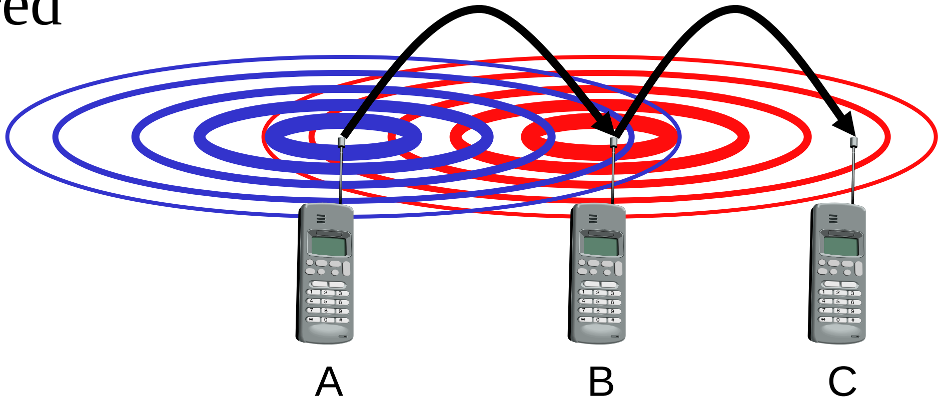
- MANET – Ad-hoc Networks
  - AODV, OLSR
- Mesh networks
  - 802.11s

Basics on ad-hoc networks

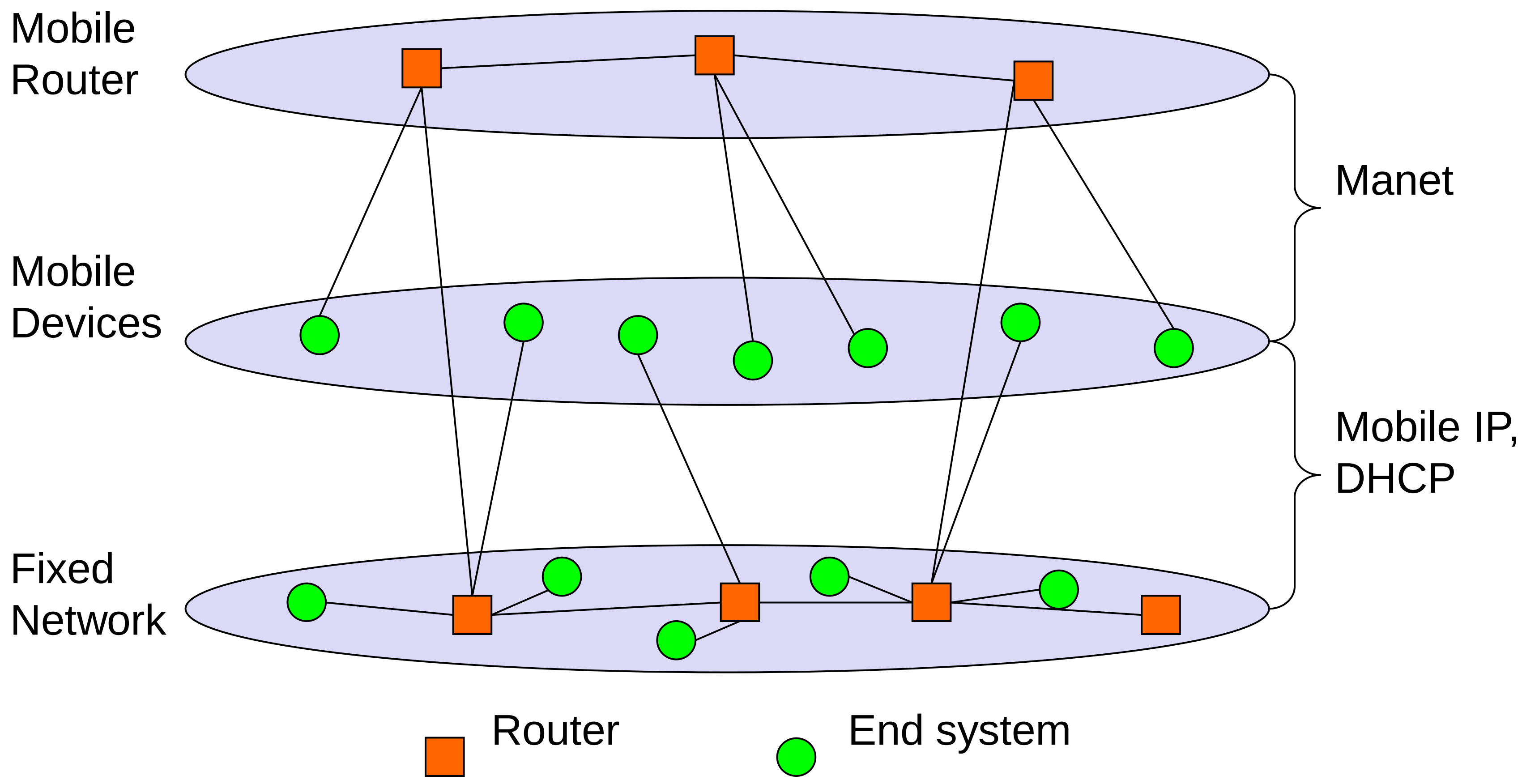
- *What is an ad-hoc network?*
- *What are the differences between and ad-hoc wireless network and a wired network?*
- *What are the characteristics of the most important ad-hoc routing protocols?*

Ad-Hoc Network (Layer 3)

- Auto-configurable network
- Working over wireless links
- Nodes are mobile ➔ dynamic network topology
- Isolated network, or interconnected to Internet
- Nodes forward traffic
- Routing protocol required

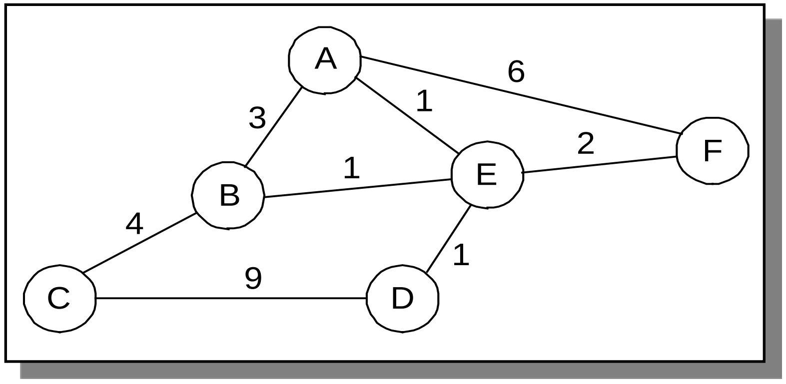


IETF MANET - Mobile Ad-hoc Networking



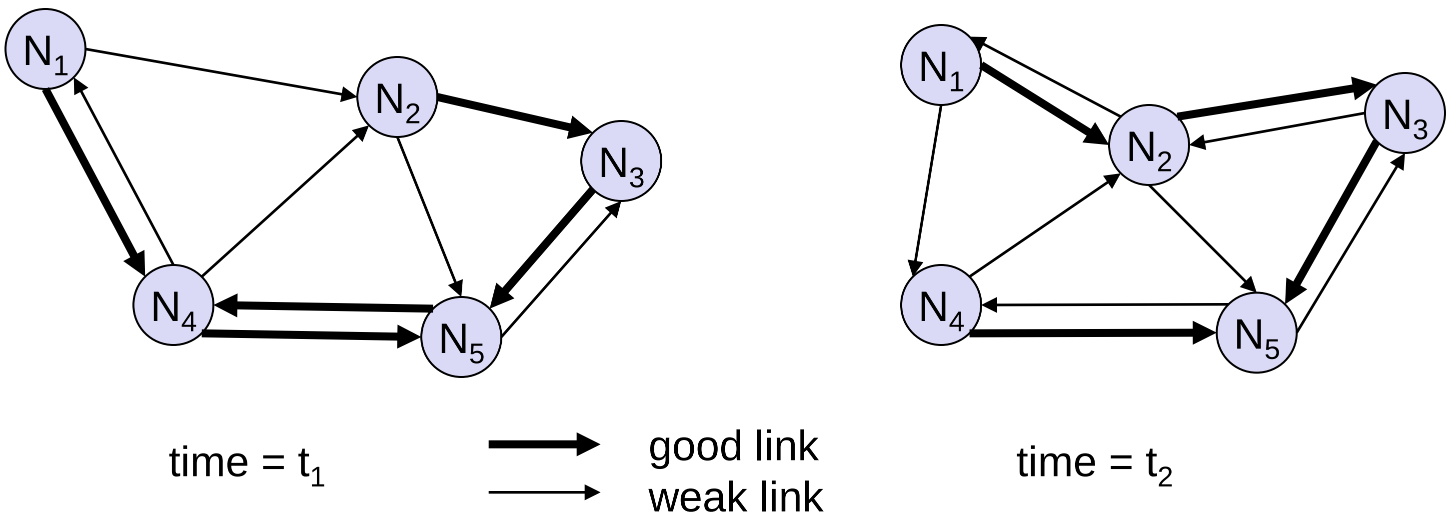
Route calculation in wired networks

- Distance vector
  - » Messages exchanged periodically with neighbours
  - » Message indicates reachable nodes and their distance
  - » Algorithm takes long time to converge
  - » Eg. RIP



- Link state
  - » Router informs periodically the other routers about its links state
  - » Every router gets information from all other routers
  - » Lots of traffic
  - » Eg. OSPF

Route calculation in Ad-Hoc Netoworks-Characteristics



Ad-hoc network

- » Dynamic topology
  - – Depends on node mobility
- » Interference
  - – Radio communications
- » Asymmetric links
  - – Received powers and attenuation unequal in the two directions

Routing in Ad-hoc Networks

- Conventional routing protocols
  - Built for wired networks → whose topology varies slowly
  - Assume symmetric links

- In Ad-hoc networks
  - » Dynamic topology → information required to be refreshed more frequently
    - energy consumption
    - radio resources used for signaling information
  - » Wireless node may have scarce resources (bandwidth, energy) …

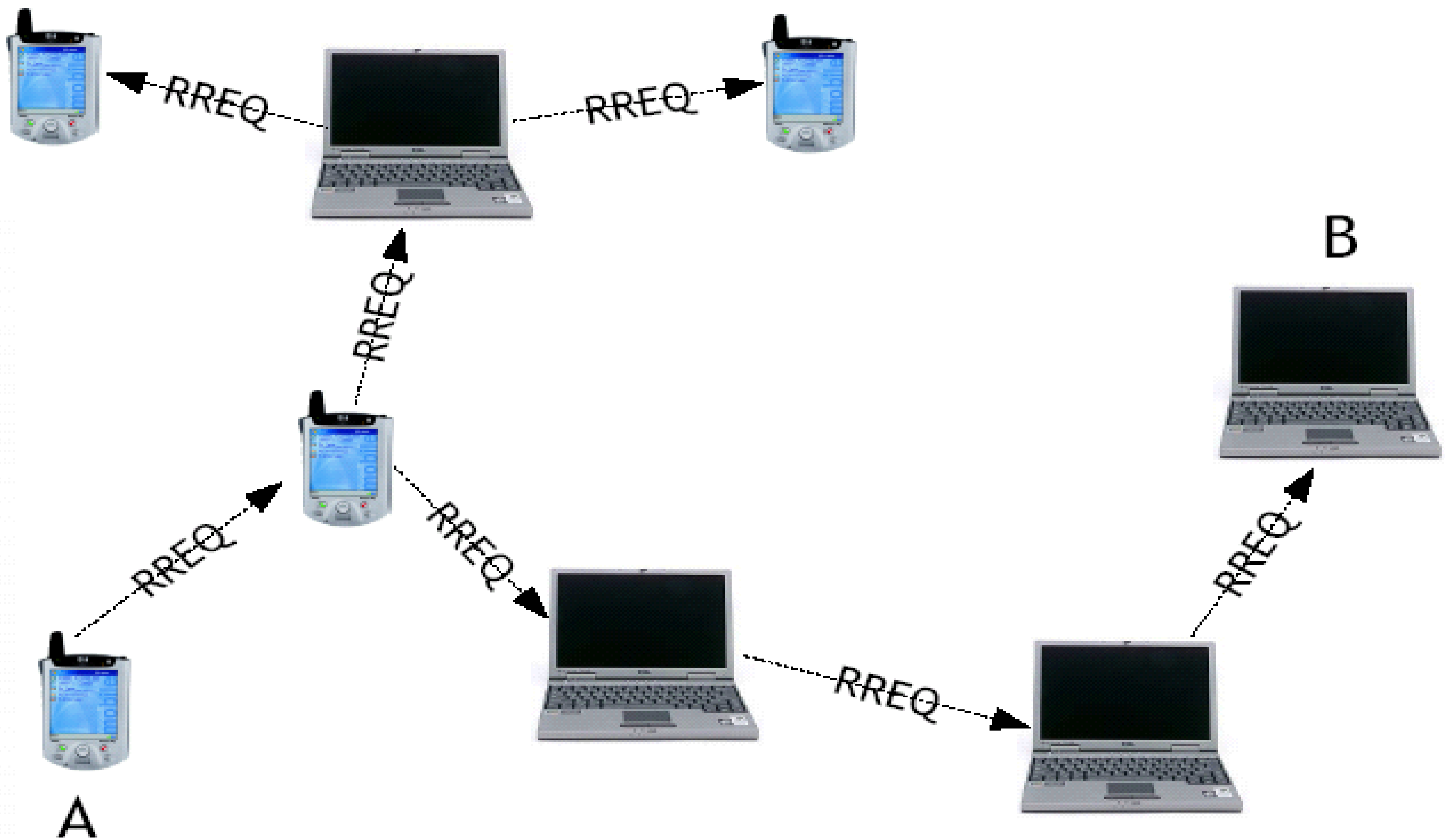
- New routing strategies / protocols for ad-hoc networks
  - 2 type : reactive e pro-active

To think about

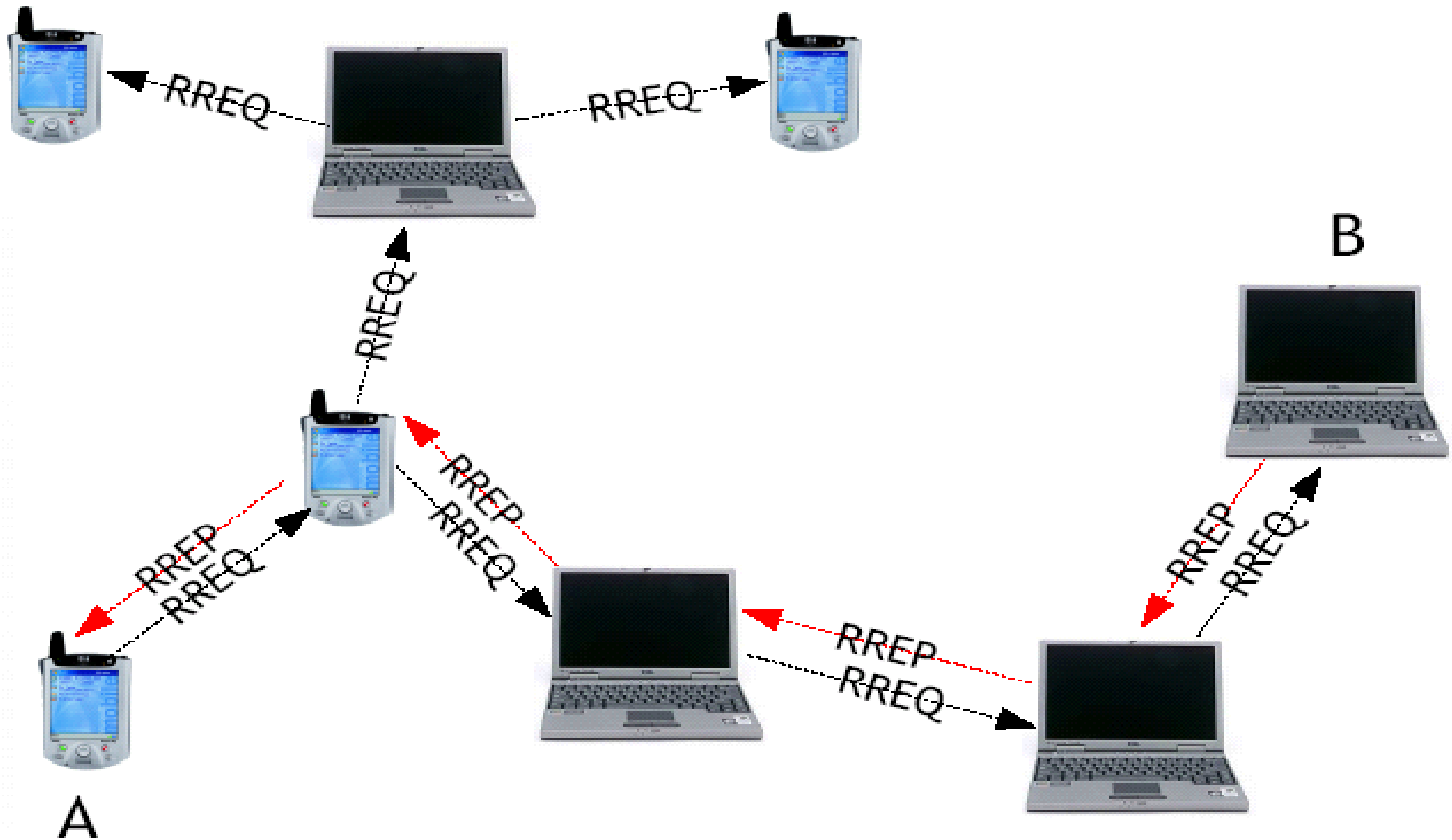
- How can we avoid a large signaling overhead (number of routing messages) in ad-hoc networks

AODV – A needs to send packet to B

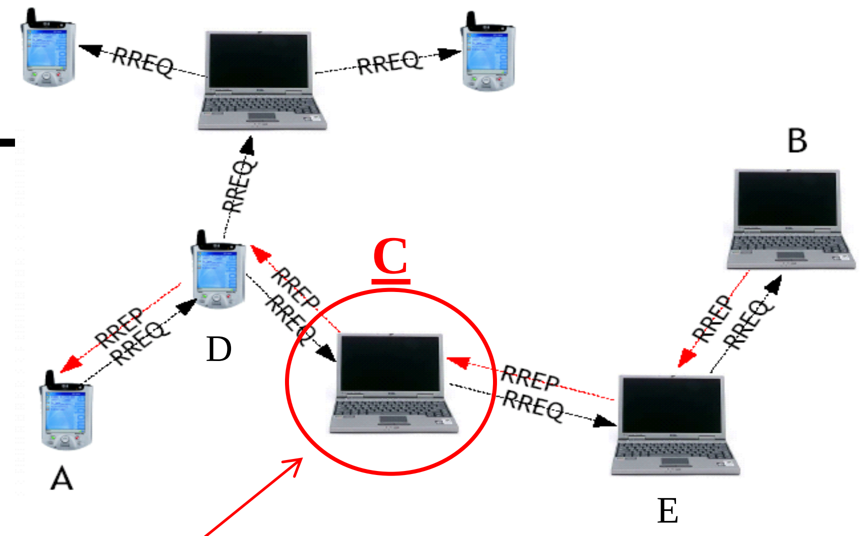
AODV – A sends RouteRequest



AODV – B replies with RouteReply



To Think About



- Write the forwarding table of Node C
  - » Before receiving RREQ
  - » After receiving RREQ e before receiving RREP
  - » After Receiving RREP

- Represent an entry of the Forwarding Table as the tupple

  `<destination, gateway, interface>`

AODV - Characteristics

» Decision to request a route
» Broadcast of *Route-request*
» Intermediate nodes get routes to node A
» *Route-reply* sent in *unicast* by same path
» Intermediate nodes get also route to node B
» Routes have *Time-to-live*, in every node
» Needs symmetric graph

Pro-active routing protocols

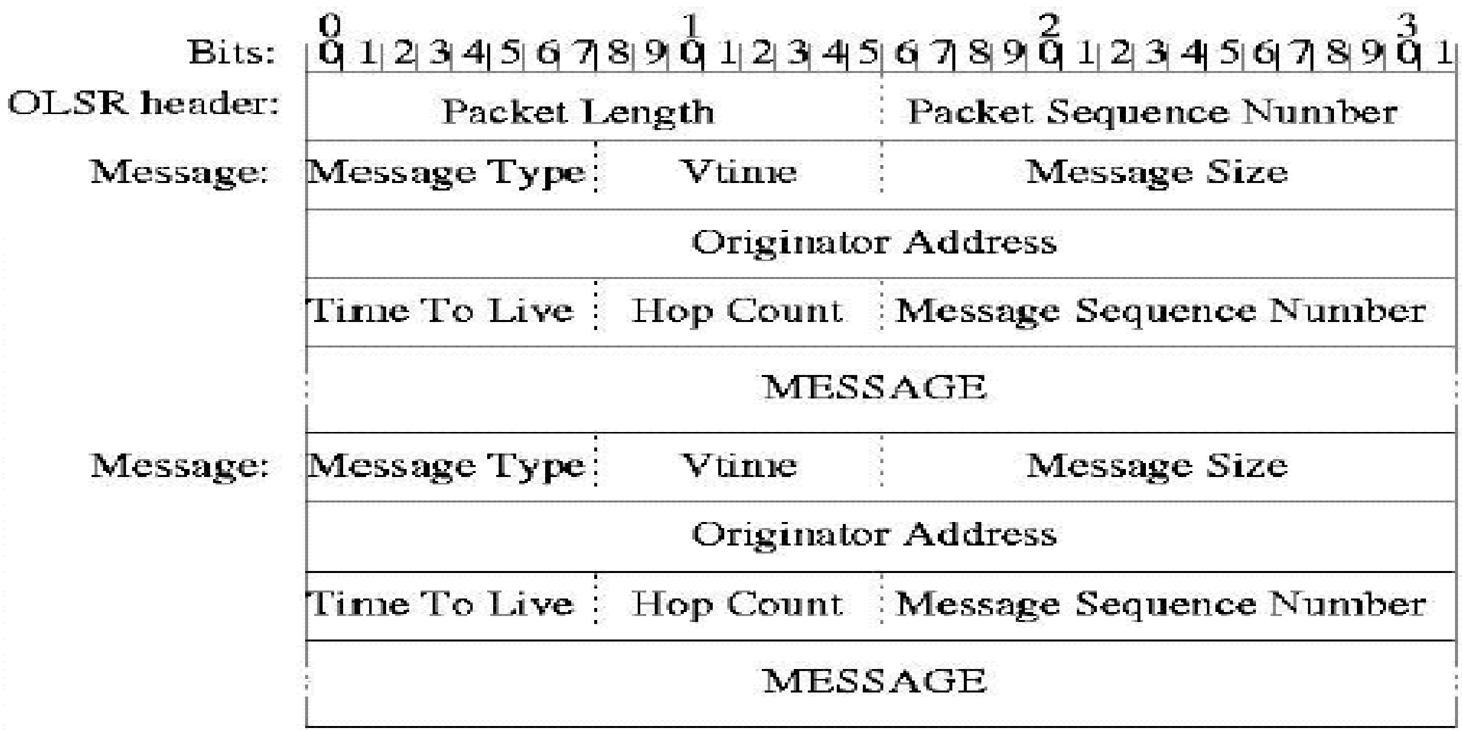
- Routes built using continuous control traffic
- Routes are maintained

- Advantages, disadvantages
  - Constant control traffic
  - Routes always available

- Example – OLSR (RFC 3626)
  - OLSR - Optimized Link-State Routing protocol

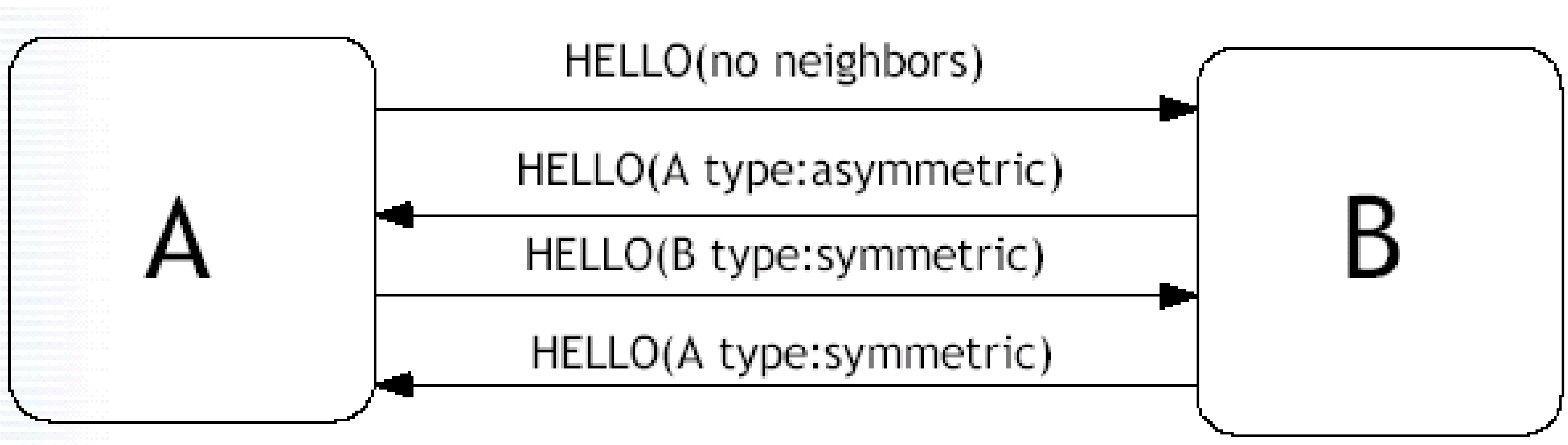
OLSR – Main functions

- Detection of links to neighbour nodes
- Optimized forwarding / flooding (MultiPoint Relaying)

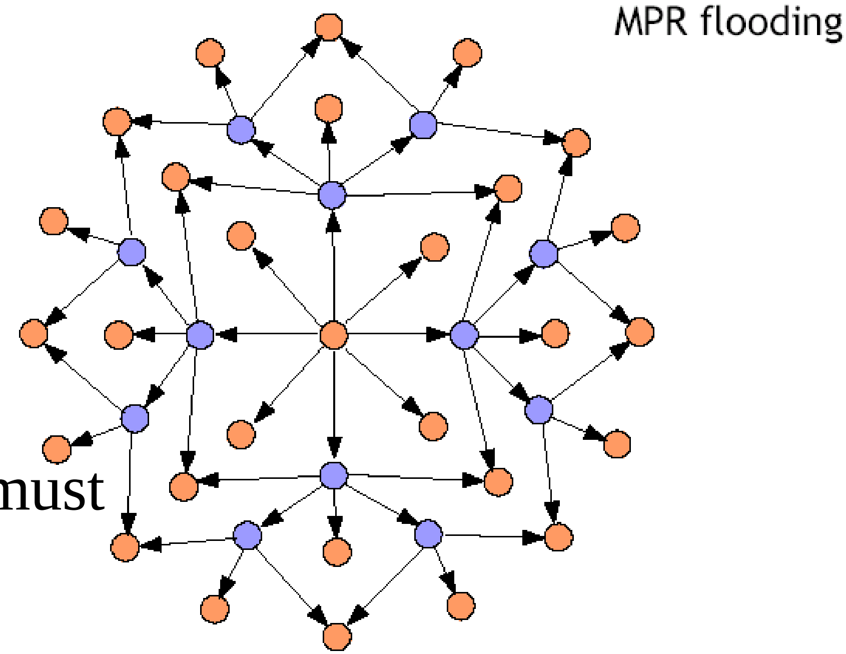


OLSR – Detecting links to neighbour nodes

- Using *HELLO* messages
- All nodes transmit periodically *HELLO* messages
- *HELLO* messages group neighbour by their state



OLSR – MultiPoint Relaying (MPR)



- MultiPoint Relaying (**MPR**)
  - » Special nodes in the network
  - » Used to limit number of nodes generating route signalling traffic
- Each node selects its MPRs, which must
  - » Be at 1 hop distance
  - » Have symmetric links
- The set of MPRs selected by a node must
  - » Be minimum
  - » Enable communication with every 2-hop-away nodes
- Node is MPR if it has been selected by other node

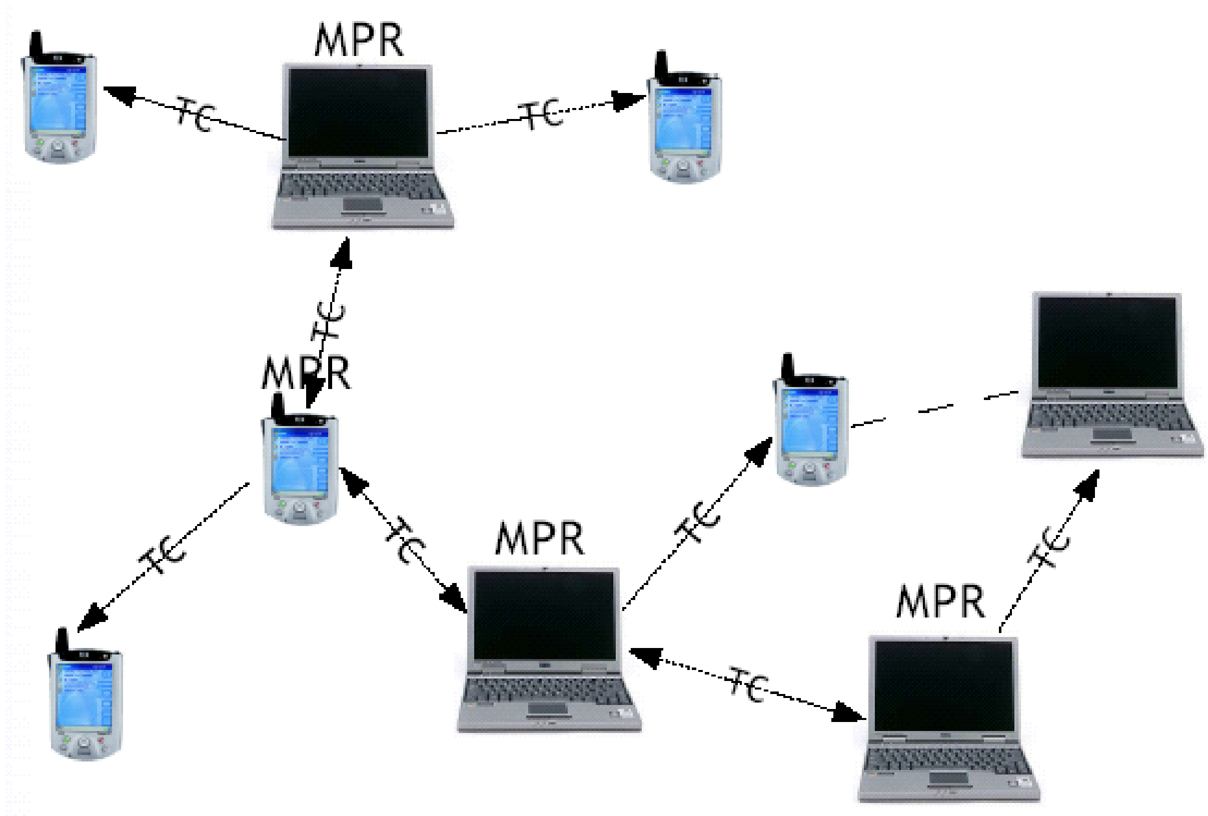
OLSR – Link State

- In OSPF, in wired networks,
  - Every node floods the network
    with information about its links state

- OLSR does the same, using 2 optimizations
  - Only the MPR nodes generate/forward link state messages
    ➔ Small number of nodes generating routing messages
  - Only nodes associated to MPR are declared in link state message
    ➔ Small message length

OLSR – Link state, example

- Messages which declare the links state
  - » "Topology Control Messages"



The IEEE 802.11 mesh networks

- *How will the 802.11s Mesh Network work?*

- Note
  - » This set of slides reflects the view of a 802.11s draft standard.

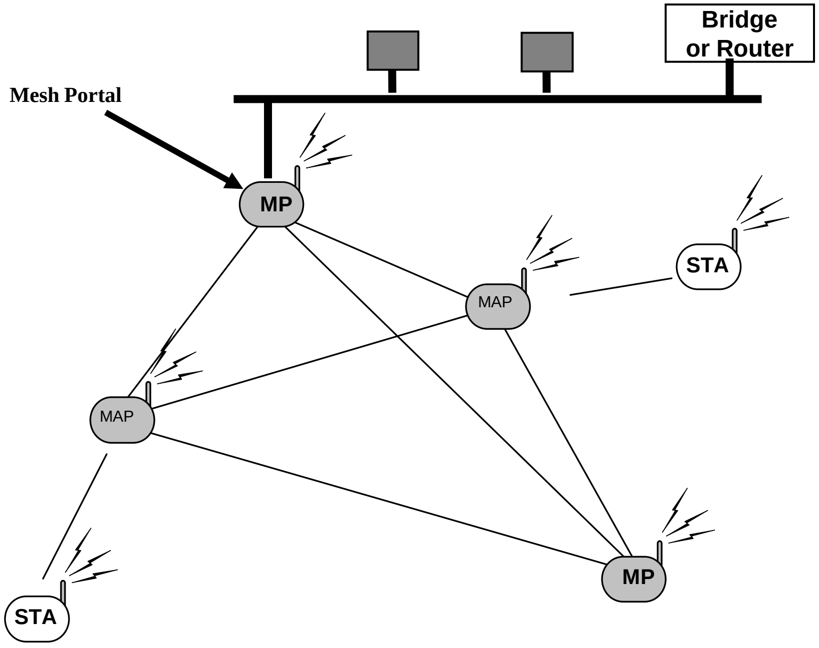
- To read
  - » GUIDO R. HIERTZ et al, “IEEE 802.11S: THE WLAN MESH STANDARD”, IEEE Wireless Communications, February, 2010

IEEE 802.11s - Main Characteristics

- Network topology and discovery
- Inter-working
- Path Selection and Forwarding
- MAC Enhancements

Elements of a WLAN Mesh Network

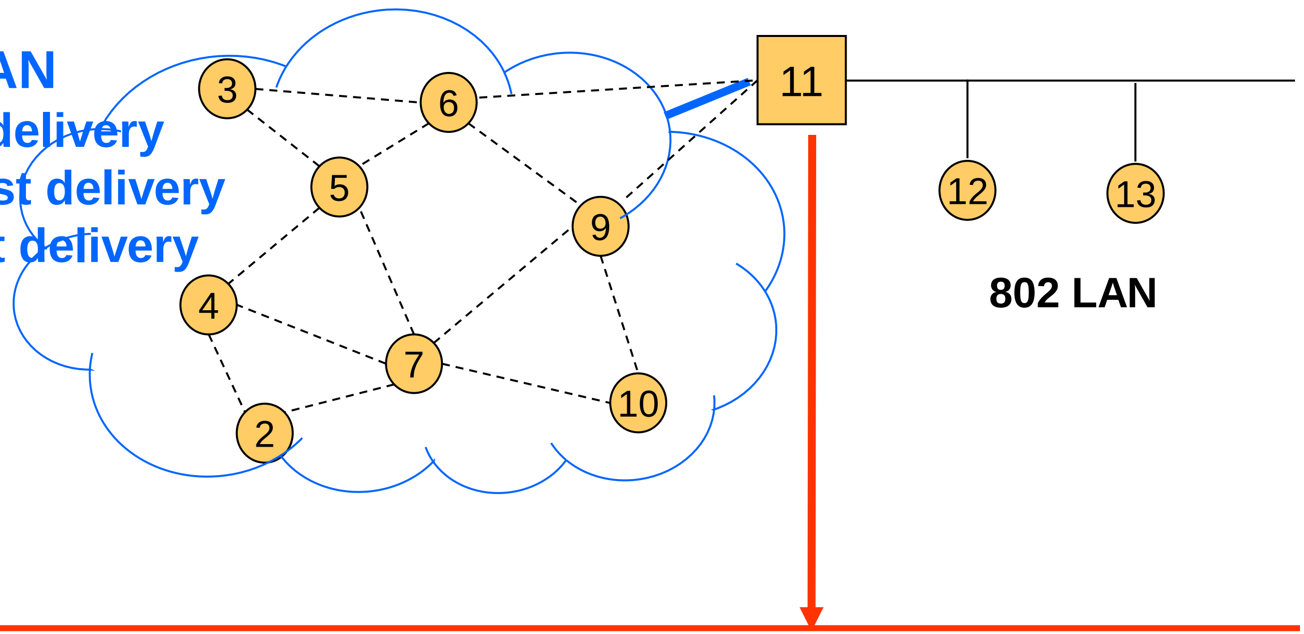
- MP - Mesh Point
  - establishes links with neighbor MPs
- MAP - Mesh AP
  - MP + AP
- MPP - Mesh Portal
- STA – 802.11 station
  - standard 802.11 STA



L2 Mesh Network - Emulates 802 LAN Segment

Broadcast LAN

- **Unicast delivery**
- **Broadcast delivery**
- **Multicast delivery**

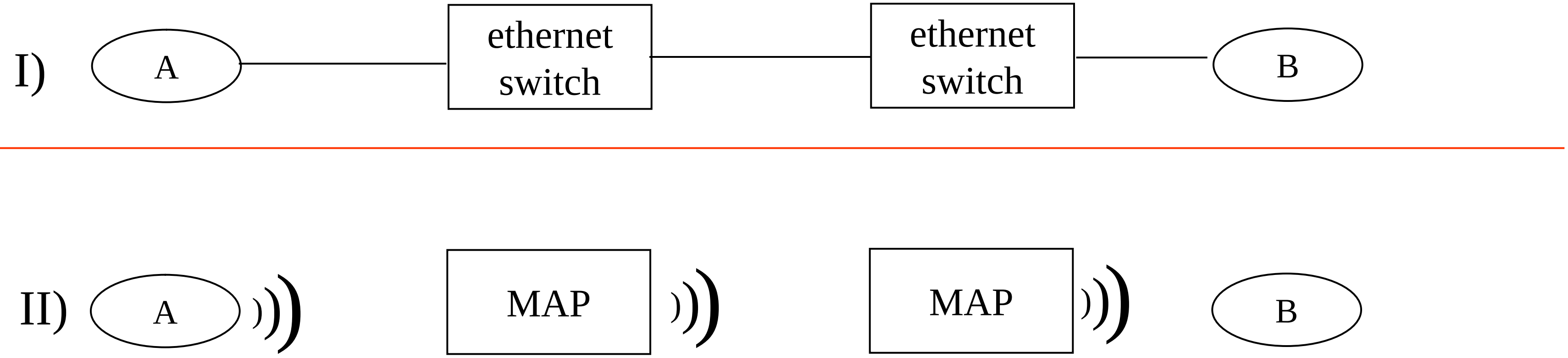


Support for connecting an 802.11s mesh to an 802.1D bridged LAN

- Broadcast LAN (transparent forwarding)
- Learning bridge
- Support for bridge-to-bridge communications: Mesh Portal participates in STP

To think about

- Suppose A sends a frame to B (MAC layer). What MAC addresses are required for the frame transmitted between the two Ethernet switches?
- And what MAC addresses are required for the frame transmitted between the two MAPs? Why are the 2 cases different?



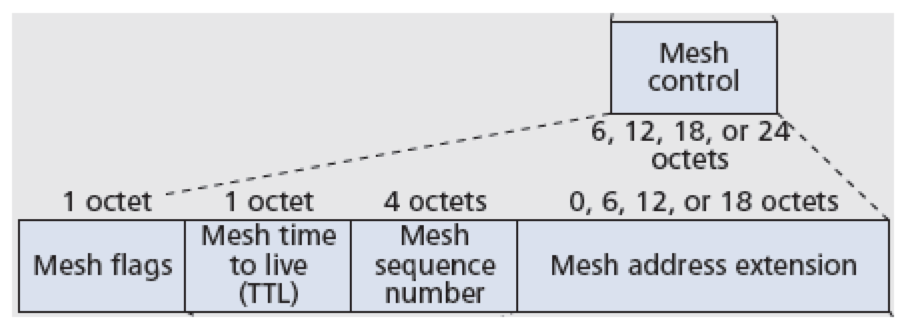
Mesh Data Frames

- Data frames
  - » based on 802.11 frames - 4 MAC address format
  - » extended with: 802.11e QoS header, and new Mesh Control header field

2	2	6	6	6	2	6	2	6-24		4
Frame Control	Dur	Addr 1	Addr 2	Addr 3	Seq Control	Addr 4	QoS Control	Mesh Control	Body	FCS

MAC Header

- Mesh Control field
  - » TTL – eliminates possibility of infinite loops (recall these are mesh networks!)
  - » More addresses are required for particular situations



Topology Formation

- Mesh Point discovers candidate neighbors
  - » based on beacons that contain mesh information
    - – WLAN Mesh capabilities
    - – Mesh ID
- Membership in a WLAN Mesh Network
  - » determined by (secure) association with neighbors

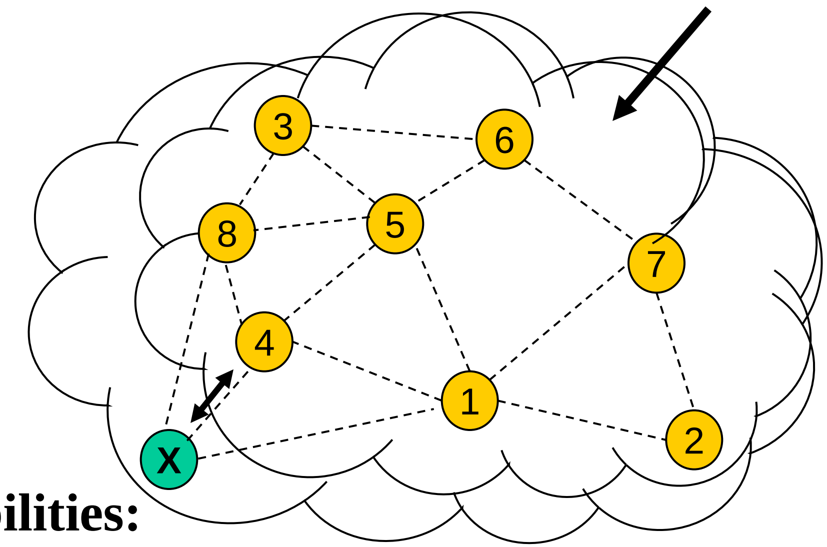
Mesh Association

1. **MP *X* discovers Mesh *mesh-A* with profile *(link state, …)***

2. **MP *X* associates / authenticates with neighbors in the mesh, since it can support the Profile**

3. **MP *X* begins participating in link state path selection and data forwarding protocol**

MeshID: *mesh-A*
Mesh Profile: *(link state, …)*

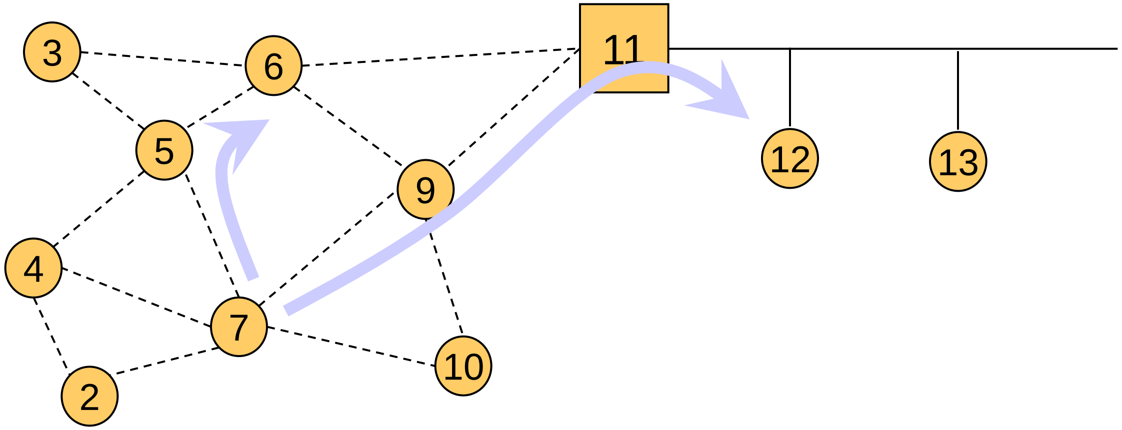


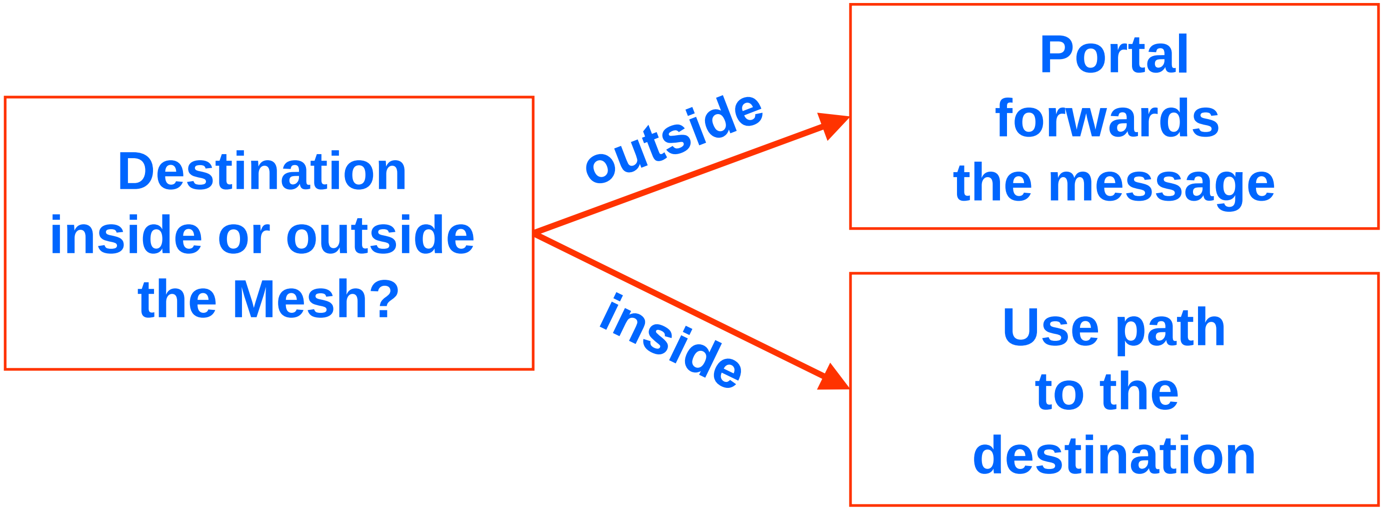
Capabilities:
Path Selection: distance vector, link state

One active protocol in one mesh

but alternative protocols in different meshes

Interworking - Packet Forwarding





Hybrid Wireless Mesh Protocol (HWMP)

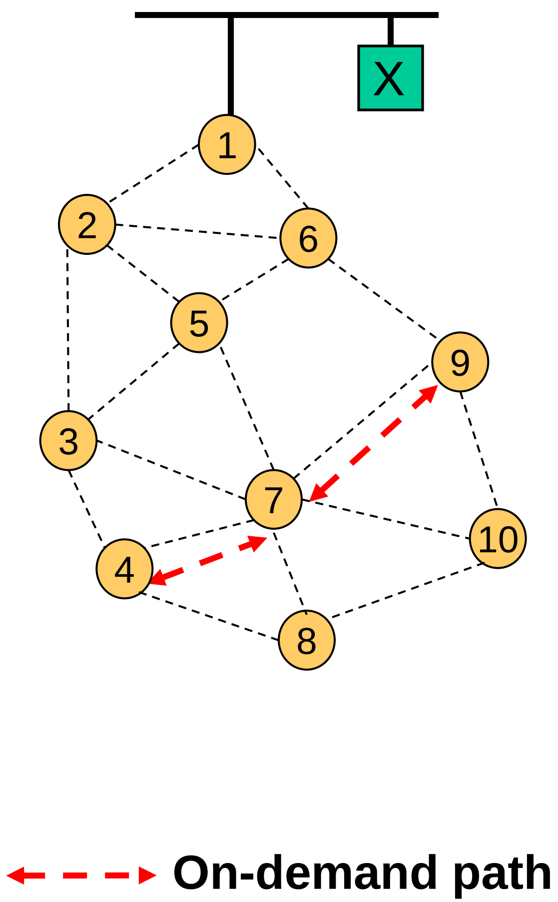
Combines

» on-demand route discovery
  - based on AODV

» proactive routing to a mesh portal
  - distance vector routing tree built and maintained rooted at the Portal

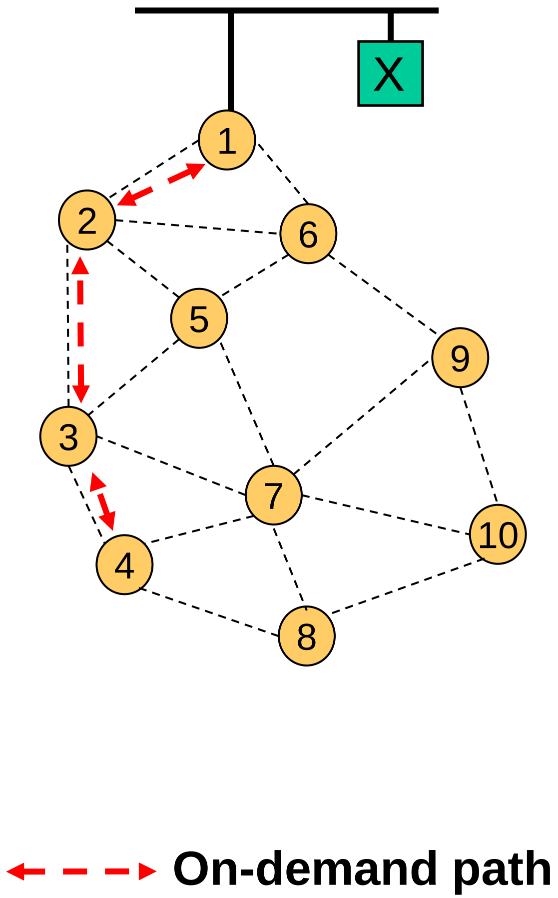
HWMP Example 1:
No Root, Destination Inside the Mesh

- Communication: MP4 → MP9
- MP4
  - checks its forwarding table for an entry to MP9
  - If no entry exists, MP4 sends a broadcast RREQ to discover the best path to MP9
- MP9 replies with unicast RREP
- Data communication begins



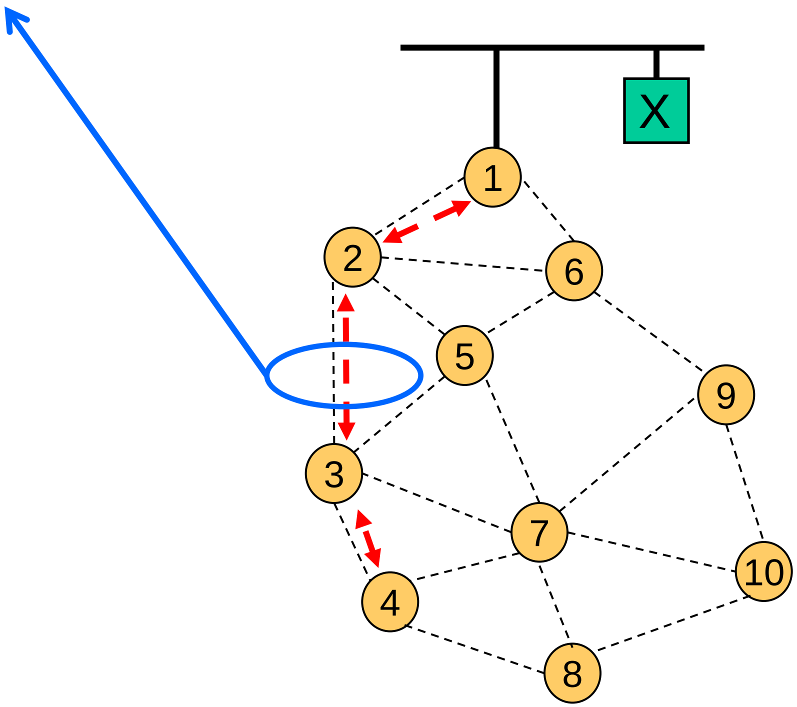
HWMP Example 3:
No Root, Destination Outside the Mesh

- Communication: MP4 → X
- MP4
  - » first checks its forwarding table for an entry to X
  - » If no entry exists, MP4 sends a broadcast RREQ to discover the best path to X
  - » When no RREP received, MP4 assumes X is outside the mesh and sends messages destined to X to Mesh Portals
- Mesh Portal that knows X may respond with a unicast RREP



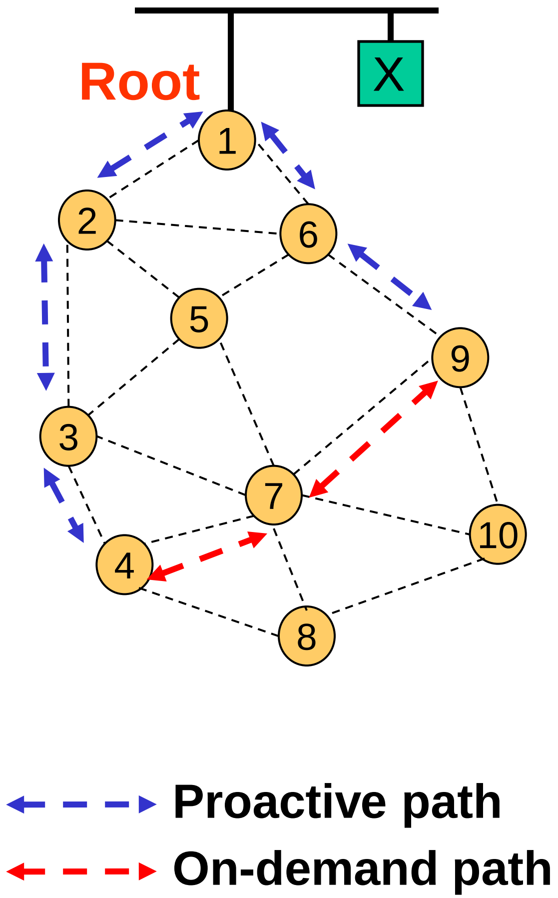
To Think About

- How many addresses are required in this frame?



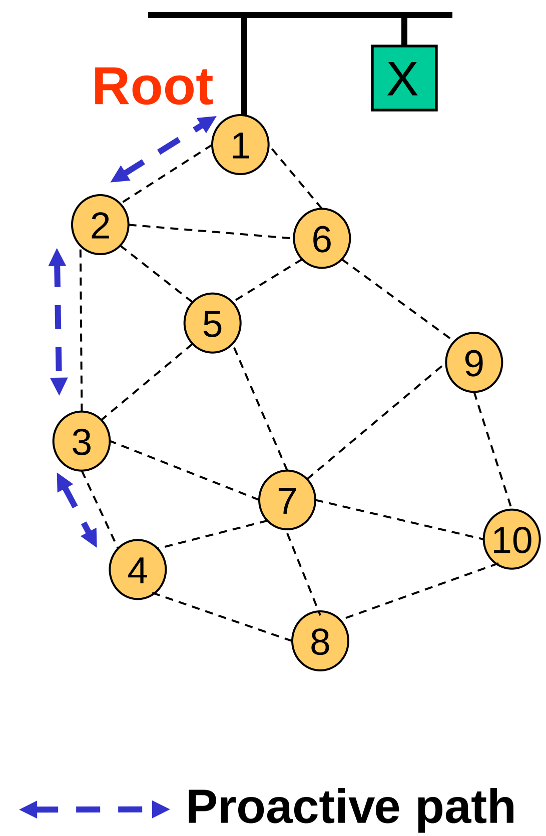
HWMP Example 2:
Root, Destination Inside the Mesh

- Communication: MP 4 → MP 9
- MPs learn Root MP1 through Root Announcement messages
- MP 4 checks its forwarding table for an entry to MP9
- If no entry exists, MP4 forwards message on the proactive path to Root MP1
- When MP1 receives the message, it forwards on the proactive path to MP9
- MP9, receiving the message, may issue a RREQ back to MP 4 to establish a path that is more efficient than the path via Root MP1



HWMP Example 4: Root, Destination Outside the Mesh

- Communication: MP4 → X
- MPs learn Root MP1 through Root Announcement messages
- If MP4 has no entry for X in its forwarding table, MP 4 may forward the message on the proactive path toward the Root MP1
- When MP1 receives the message, if it does not have an active forwarding entry to X it may assume the destination is outside the mesh
- Mesh Portal MP1 forwards messages to other LAN segments



Radio Aware OLSR (RA-OLSR)

- OLSR may be used in alternative to AODV
- RA-OLSR proactively maintains link-state for routing

Routing metrics in Wireless Networks - ETX (Expected Transmission Count)

- Successful transmission probabilities for forward / reverse link
  - Sf: probability data packet successfully arrives to recipient
  - Sr: probability ACK packet is successfully received
- ETX=1/(Sf*Sr)
- E.g.: Sf=0.6, Sr=0.5, ETX=3,3
- Routing protocol
  - finds path that minimizes sum of ETXs

Routing metrics in Wireless Networks - ETT (Expected Transmission Time)

- Improves ETX by considering also link bandwidth
- Packet size = *S*, Link bandwidth = *B*
- $ETT = ETX * S / B$ *(sec)*

Routing Metric in IEEE 802.11s – Airtime Link Cost

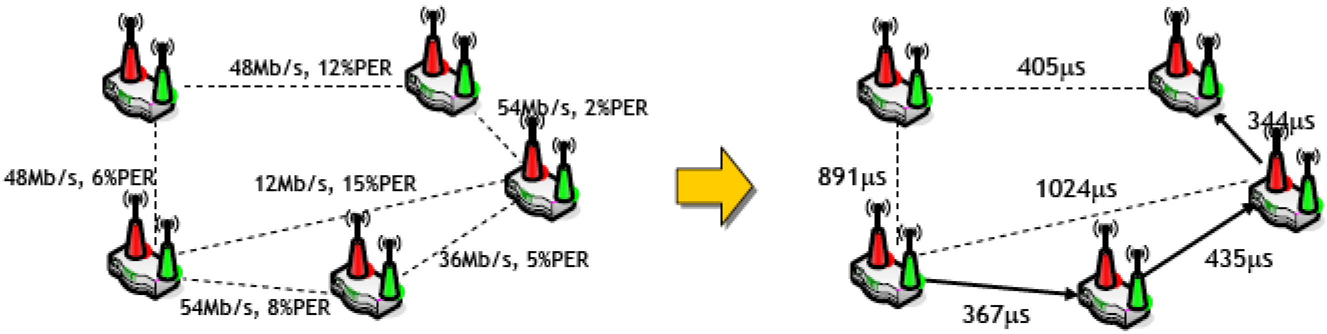
802.11s default routing metric: Airtime link Cost

- » Amount of time required to transmit a frame

$$C_a = \left[O_{ca} + O_p + \frac{B_t}{r}\right] \frac{1}{1 - e_{pt}}$$

- » r = transmission bitrate
- » e_{pt} = frame error ratio

Parameter	Value (802.11a)	Value (802.11b)	Description
O_{ca}	75μs	335μs	Channel access overhead
O_p	110μs	364μs	Protocol overhead
B_t	8224	8224	Number of bits in test frame

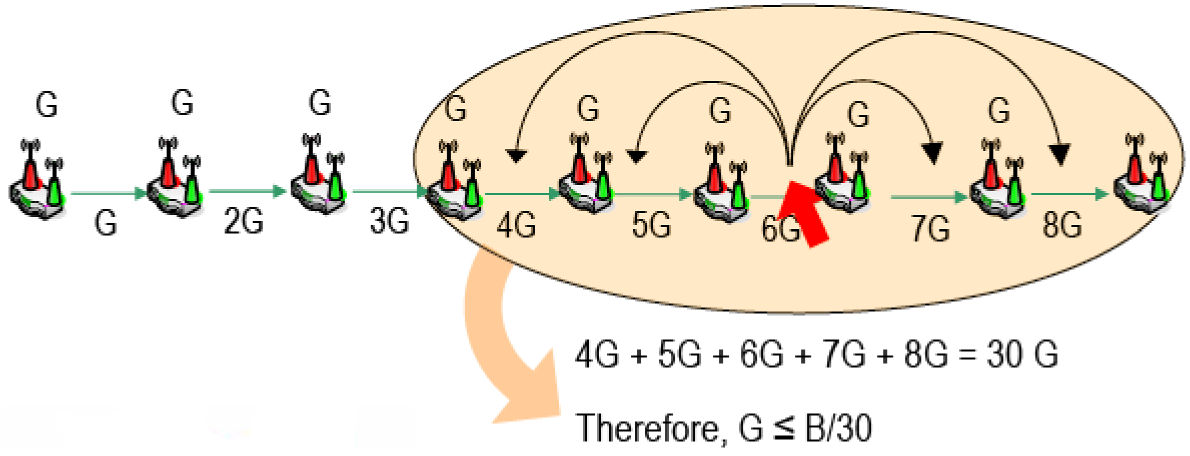


Problem in Mesh Networks – Nominal Capacity at MAC Layer

Assume all nodes send same traffic G towards GW

» Capacity of WMN is smaller than capacity of wireless LAN
  – due to multi-hop forwarding

» Capacity can be bounded by the bottleneck collision domain

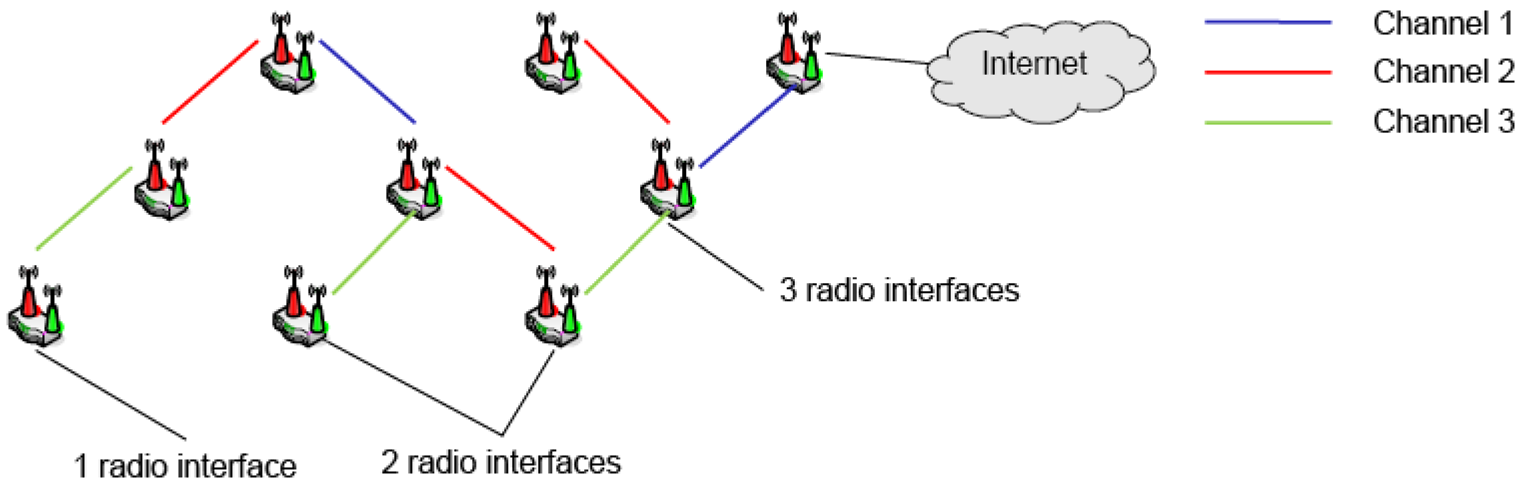


Multi-channel, Multi-radio

- WMN depends on MAC protocols
- Distributed MAC protocols
  - » Single channel, single radio
    - – One radio interface per node, one static channel
  - » Muti-channel, single radio
    - – One radio interface per node
    - – Fast channel switching
  - » Multi-radio
    - – Multiple radio interfaces in use
    - – Usually working in different channels

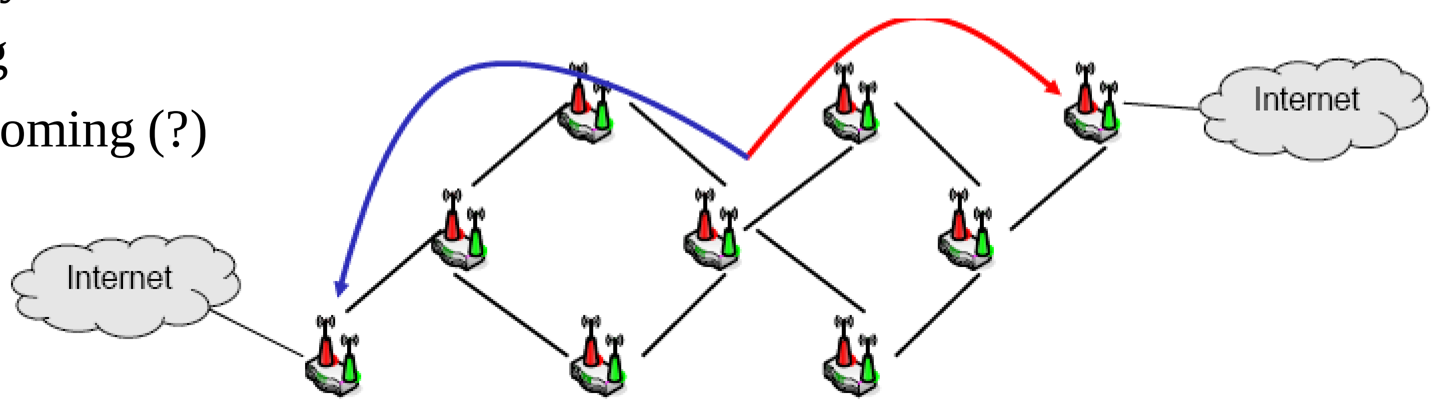
Multi-channel multi-radio WMN

- Complex network planning
  - Channel assignment, Routing
- Research on topology control required!



Multi-gateway WMNs

- Multiple gateways to the Internet
- Important to
  - » Keep routes to the Internet short (few hops)
  - » Increase access capacity
- Problems
  - » Gateway detection
  - » Routing
  - » Multi-homing (?)

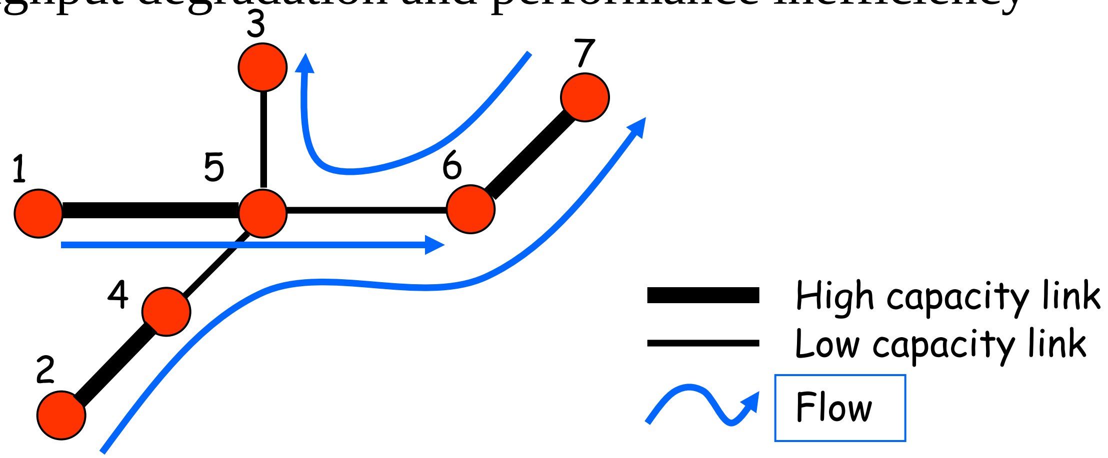


MAC Enhancements for Mesh

- Intra-mesh Congestion Control
- Common Channel Framework (Optional)

Need for Congestion Control

- Mesh characteristics
  - » Heterogeneous link capacities along the path of a flow
  - » Traffic aggregation: Multi-hop flows sharing intermediate links
- Issues with the 802.11 MAC for mesh
  - » Nodes blindly transmit as many packets as possible, regardless of how many reach the destination
  - » Results in throughput degradation and performance inefficiency



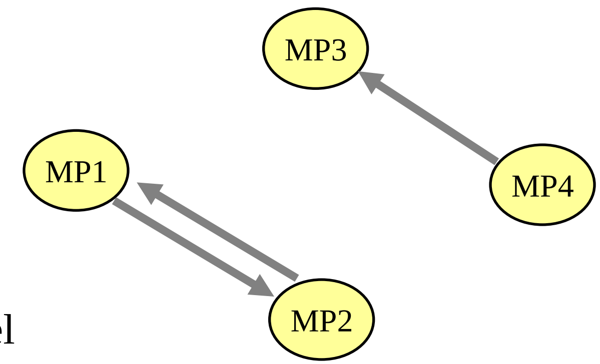
Intra-Mesh Congestion Control Mechanisms

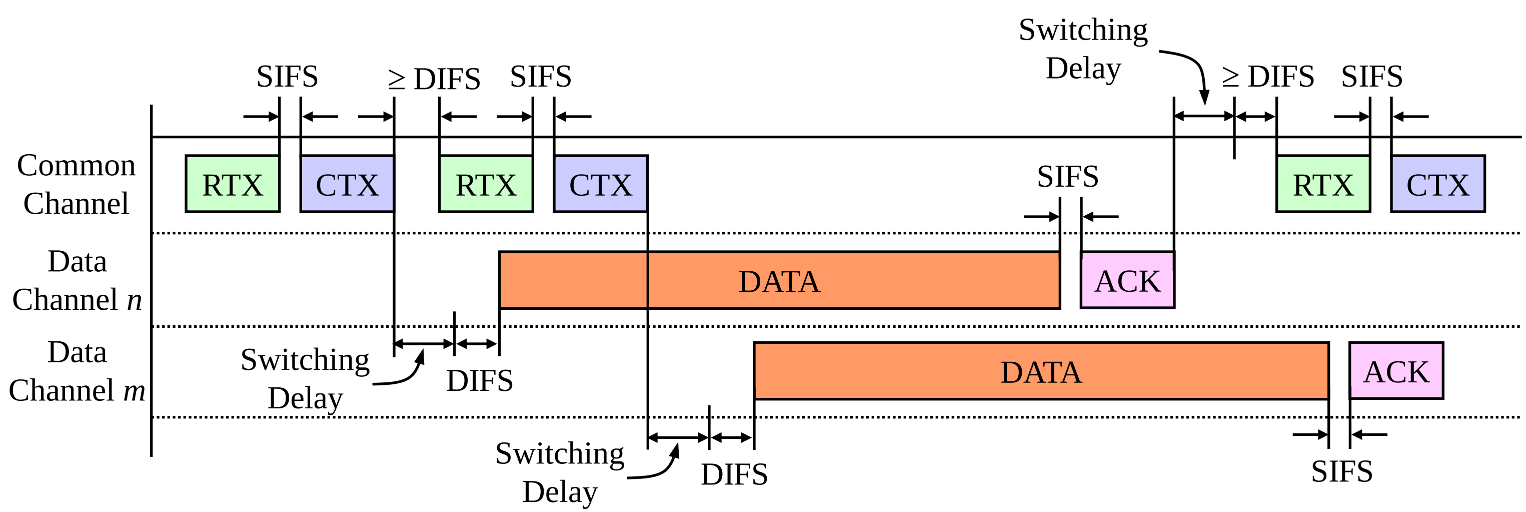
- Local congestion monitoring (informative)
  - » Each node actively monitors local channel utilization
  - » If congestion detected,

    notifies previous-hop neighbors and/or the neighborhood
- Congestion control signaling
  - » Congestion Control Request (unicast)
  - » Congestion Control Response (unicast)
  - » Neighborhood Congestion Announcement (broadcast)

Common Channel

- Common channel
  - Unified Channel on which MPs jointly operate
  - Using RTX, the transmitter suggests a destination channel
  - Receiver accepts/declines the suggested channel using CTX
  - The transmitter and receiver switch to the destination channel
  - Data is transmitted
  - Then they switch back





Control Frames

- Request to Switch (RTX) Frame

2	2	6	6	2	4
Frame Control	Duration/ ID	RA	TA	Destination Channel Info.	FCS

- Clear to Switch (CTX) Frame

2	2	6	2	4
Frame Control	Duration/ ID	RA	Destination Channel Info.	FCS