# Wireless Mesh and Multi-Hop Relay Networks

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Audio/Video recordings of this lecture are available at:

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# Overview

❑ Multi-Hop Relay Networks

❑ 802.16j Mobile Multi-hop Relay (MMR)

❑ 802.15.5 WPAN Mesh Networking

❑ 802.11s Mesh Networks: Applications

❑ Wi-Fi Mesh Products

# Multi-Hop Networks

❑ **Relay**: Dedicated *carrier owned* infrastructure, Tree based topology. One end of the path is the base station

❑ **Mesh**: Routing by *subscriber* equipment, Multiple connections, mesh topology

# Multi-Hop Relay Networks

❏ Next generation networks need very high data rates

❏ Data rate ∝ 1/distance
   ⇒ High density of cell towers ⇒ High cost

❏ Multi-hop Networks have fixed infrastructure
   ⇒ Do not complex routing techniques

❏ Relays are low-cost low transmit power and have no connection to wired infrastructure

❏ More capacity due to shorter distances and frequency reuse

❏ Goal: High capacity and coverage (not absence of infrastructure)

Base          Relay          Mobile Host
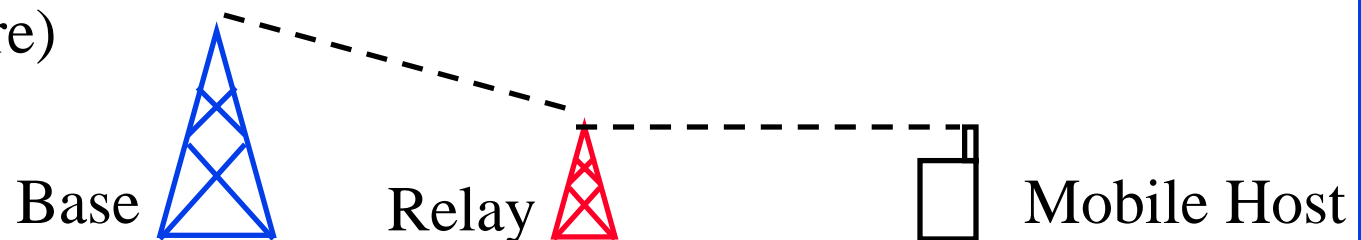
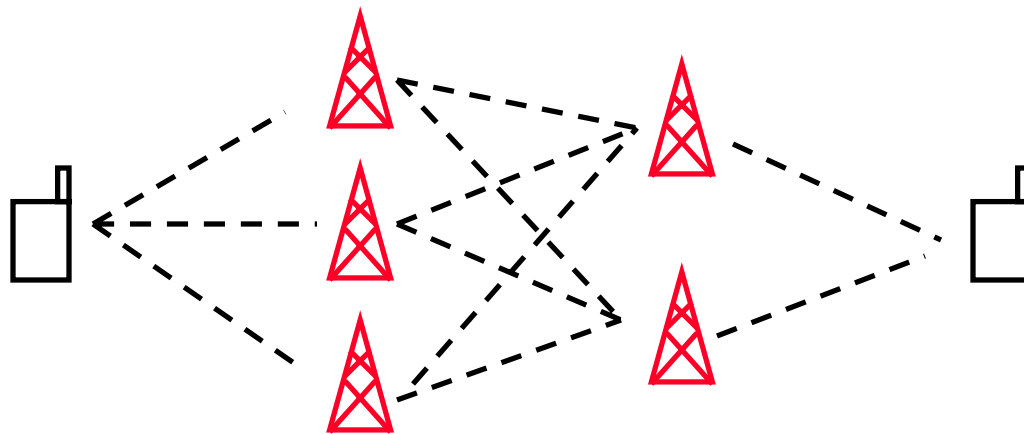# Coverage Extension

❑ Side streets can be covered by relays
❑ A series of relays can be used to forward traffic to base
❑ Relaying either in time domain or frequency domain
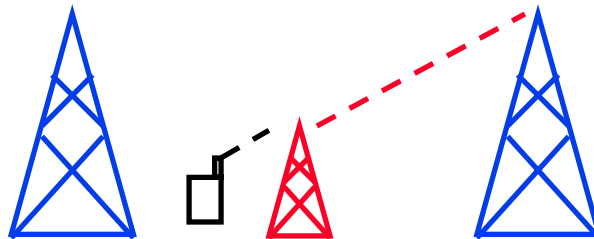
Mobile

Relay

Base
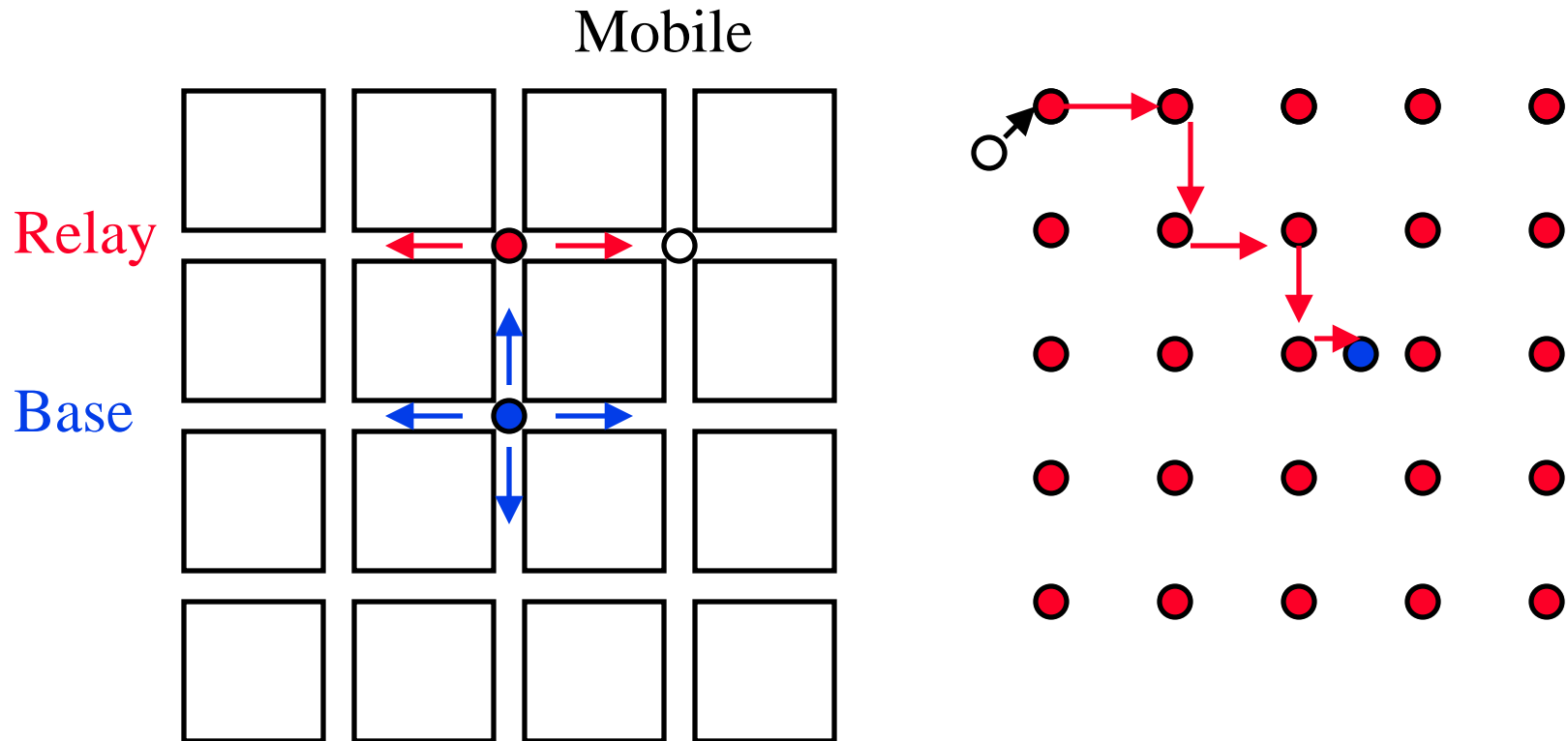
# Throughput Enhancement

❑ Virtual Antenna Arrays

❑ Multiple cooperating relays act as distributed MIMO

❑ Challenges: Synchronization, Sharing of Channel State Information

3×2 MIMO

# iCAR

- Integrated Cellular and Ad-Hoc Relaying System
- Relaying stations are used to divert traffic from congested cells to nearby lightly loaded cells
- Even existing calls can be moved
  $\Rightarrow$ Secondary relaying

# 802.16j Mobile Multi-hop Relay (MMR)

❑ Three types of Relays: Fixed, Nomadic (special events, Indoor), Mobile Relays (Trains)
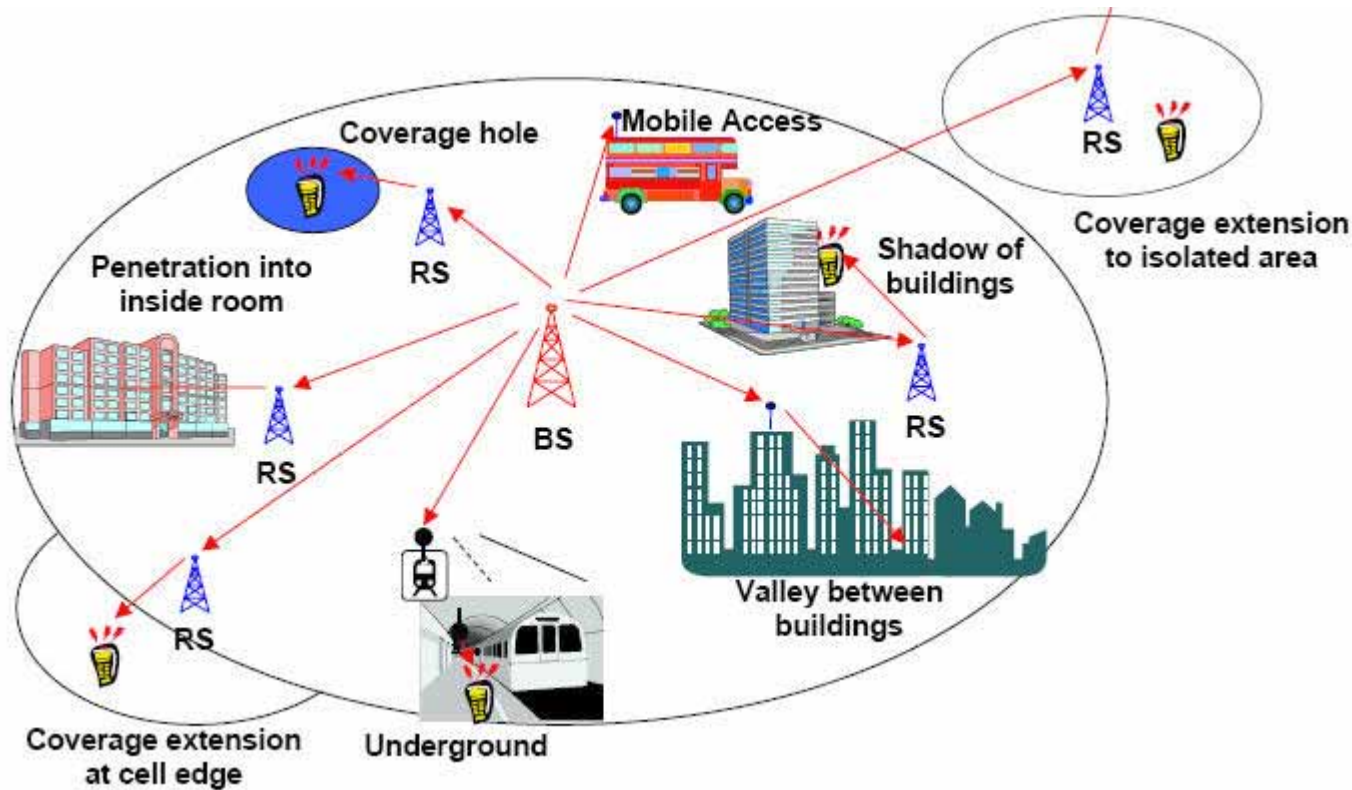
# 802.16j Technical Issues

- Centralized vs. distributed control:
  Functional division between Base and Relay

- Scheduling

- Radio Resource management

- Power Control

- Call Admission and Traffic Shaping Policies

- QoS: Network wide load balancing,
  Congestion control

- Security

- Management

**Note**: Routing is not an issue with fixed relays

# Multi-Hop Relay Networks: Summary

❑ Relay concept applies to Cellular Networks and to Wireless Access

❑ Relays can help overcome obstacles

❑ Relays help improve the capacity by decreasing the distance

❑ Relays help decrease the cost since they are much cheaper than base stations

❑ Routing with fixed relays is simple

❑ Increasing delays
   $\Rightarrow$ Number of hops must be limited to two or three

❑ Distributed MIMO $\Rightarrow$ Improvement in data rates

# Mesh Networks

❑ WPAN Mesh: 802.15.5

❑ WLAN Mesh: 802.11s
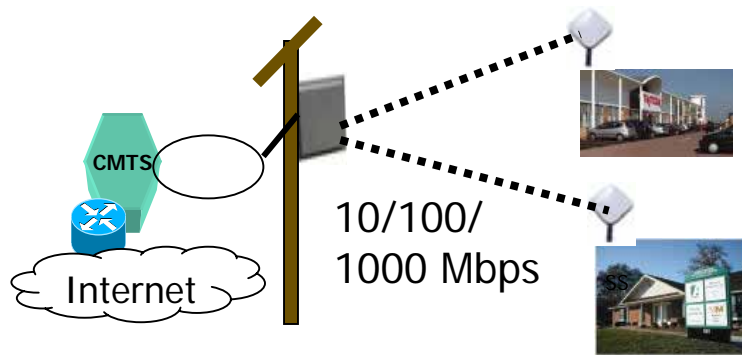
# 802.15.5 WPAN Mesh Networking

❑ Goal: Range Extension, *Routing Redundancy*

❑ Issues:

➢ Handle Multiple Master devices

➢ Handle multiple super frame coexistence

➢ Fair sharing of channel time

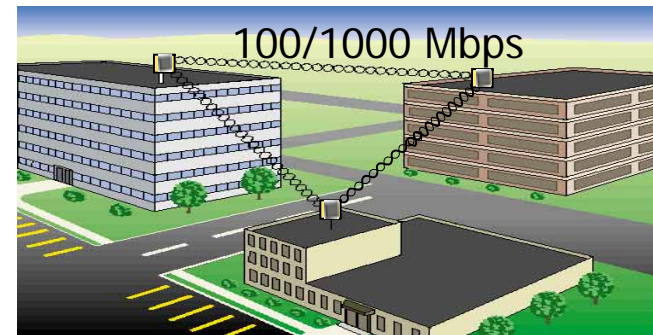➢ Minimal changes to 802.15.3 and 802.15.4

Pico nets

Mesh Control and Data path
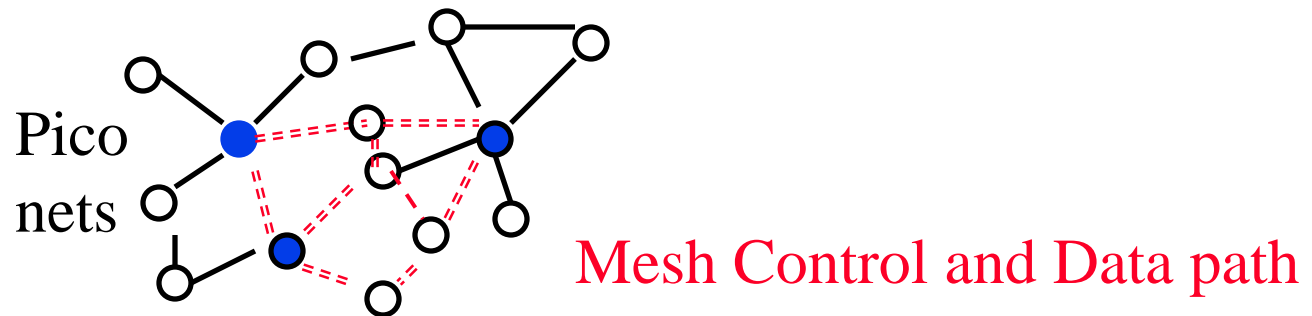
# 802.11s Mesh Networks: Applications

## MSOs/CLEC/Municipal
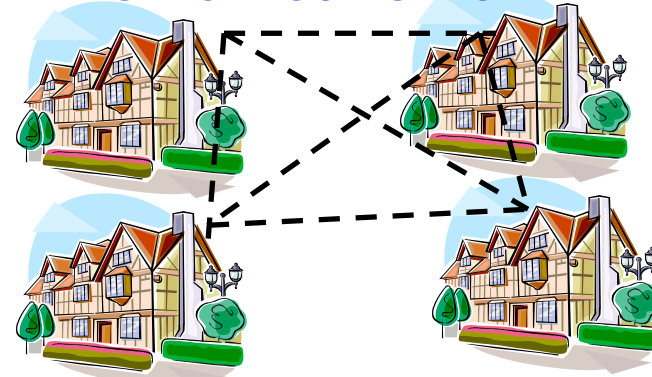
CMTS

Internet

10/100/
1000 Mbps

SS

## Enterprise Campus

100/1000 Mbps

## Emergency Response

## Home Networks

# 802.11s Device Classes

❑ Stations (STA): Non-mesh capable station

❑ Mesh Points (MP): Mesh capable station

❑ Mesh AP (MAP): MP + AP

❑ Mesh Portal (MPP):  Entry/exit to wired network. Support transparent bridging, address learning, and bridge-to-bridge communication (spanning tree etc).

❑ Root Portal: MPP configured for topology building. Elected to become the root of the default forwarding tree
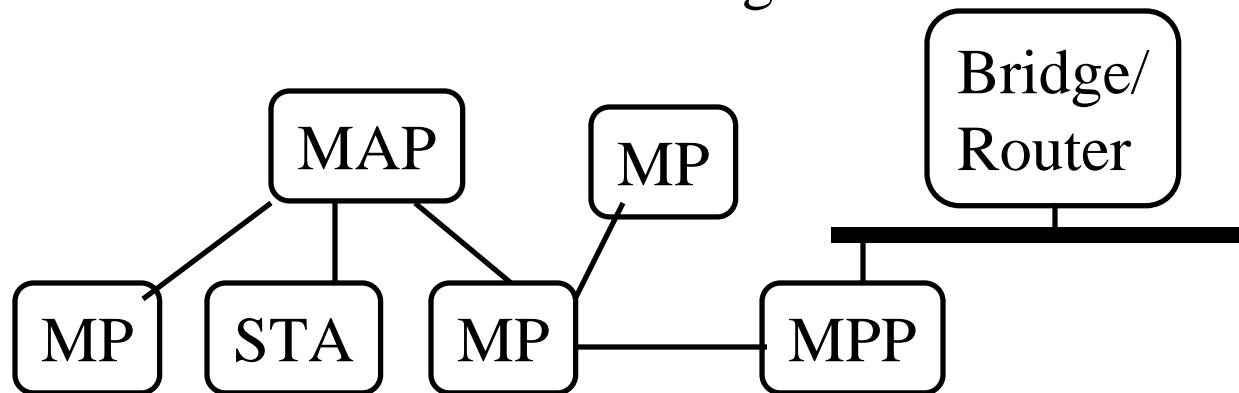
# 802.11s Hybrid Wireless Mesh Protocol

❑ Two Configurations: With Root Portal and Without Root Portal Route Discovery:

❑ W/O Root Portal:

➢ On-demand *Radio Metric* AODV (RM-AODV)
   Cost = Amount of air time consumed per packet transmission

➢ Radio Aware OLSR Path Selection Protocol (Optional)
   Frequency of LS forwarding is reduced with hops
   (Fish eye state routing)

❑ W Root Portal: Most of the traffic is to the root.

➢ Proactive. Tree based distance vector routing.

# Common Channel Framework

❑ All stations use a single control channel

❑ Stations dynamically select the data channel

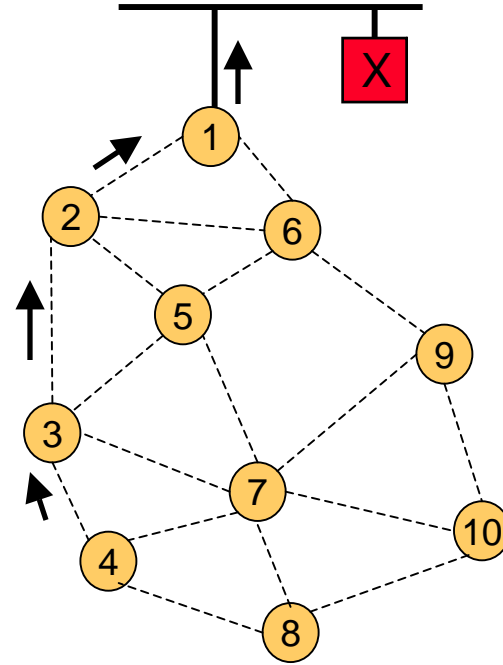❑ They announce it on the common control channel using RTX/CTX (Not RTS/CTS) packets
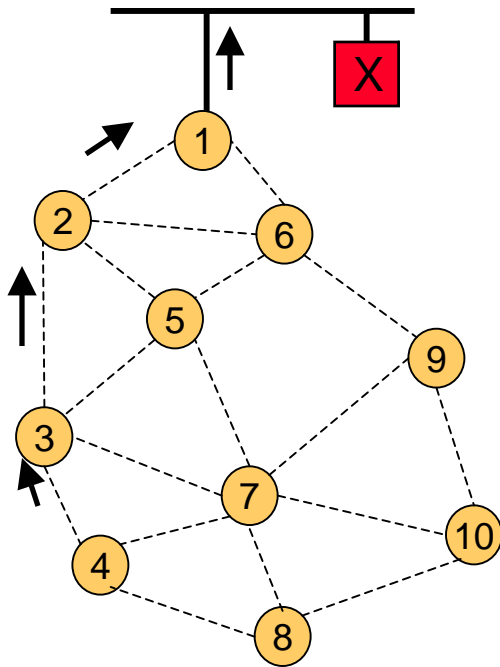
# 802.11s Examples
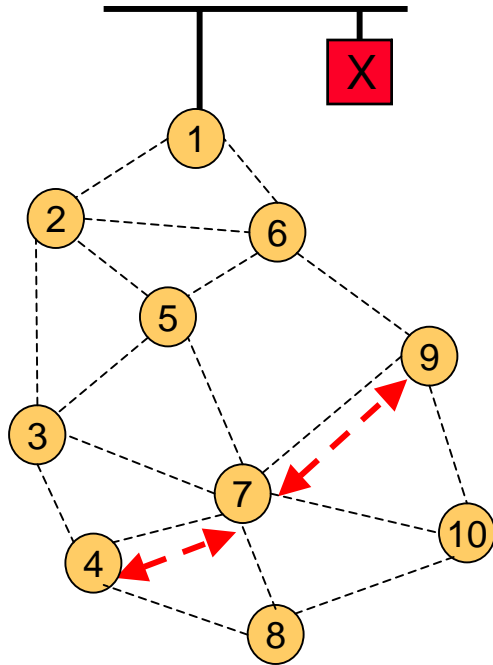
4->9
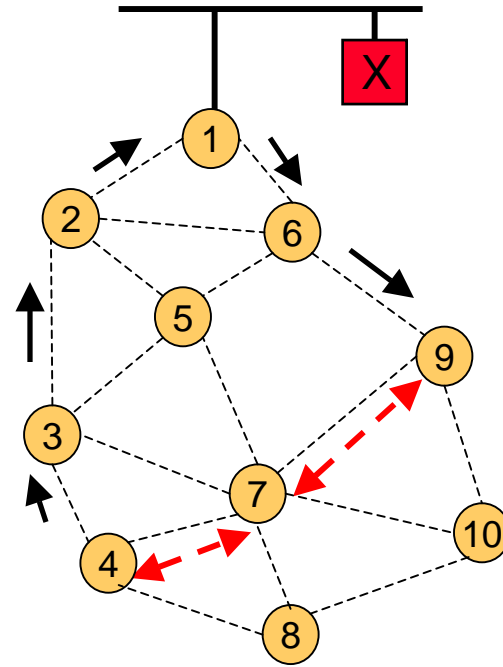4 sends RREQ
9 sends RREP

4->X
4 sends RREQ
No Resp
$\Rightarrow$ 4 forwards to MPP 1

# 802.11s Examples



4->X
4 forwards to MPP1
MPP1 sends to X

4->9
4 forwards to MPP1
MPP1 sends to 9
9 Issues RREQ
4 sends RREP

# Wi-Fi Mesh Products

❑ **LocustWorld.com**
  ➢ MeshAP S/W: Freeware from locustworld.com. Allows computers to act as wireless routers.
  ➢ Uses AODV protocol. Problem of false DVs.
  ➢ MeshBox: Complete hw/sw package
  ➢ MeshBox 2 or MexBox: Uses two Wi-Fi radio modules. Successive routers could share a channel, e.g., 1+2, 2+3, 3+1 among three routers.

❑ **FireTide Network**:
  ➢ HotPort 4.9 GHz Public Safety Mesh Nodes,
  ➢ HotPort Indoor Mesh Nodes,
  ➢ HotPort Outdoor Mesh Nodes.
  ➢ Uses MANET (Topology Bradcast based on Reverse Path Forwarding (TBRPF) protocol

# Wi-Fi Mesh Products (Cont)

- Motorola Mesh Networks,
  http://www.motorola.com/mesh/index.htm

- Tropos Networks, www.tropos.com

- PacketHop Communications, www.packethop.com

- MeshDynamics, http://www.meshdynamics.com/index.html

- SkyPilot Networks, http://www.skypilot.com/

- Proxim Wireless, http://www.proxim.com/can/index.html

- Nortel Networks,
  http://www2.nortel.com/go/solution_content.jsp?segId=0&catId=0&parId=0&prod_id=47160&locale=en-US

- WaveWireless, www.wavewireless.com

# Summary
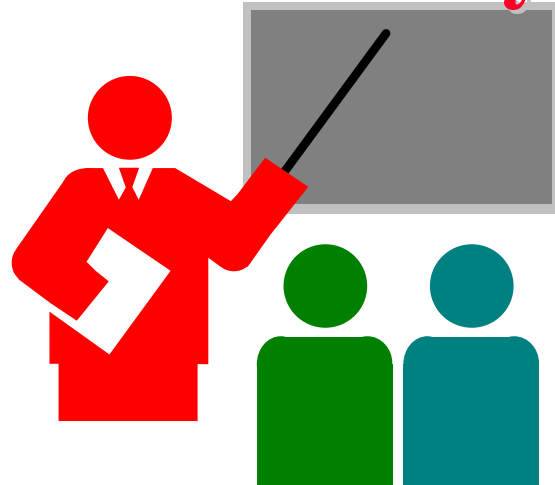


- ❑ Multi-Hop Relay Networks are designed for coverage extension and throughput enhancements
- ❑ 802.16j Mobile Multi-hop Relay (MMR) standard allows for fixed, nomadic, and mobile relays
- ❑ 802.15.5 WPAN Mesh is being designed for routing redundancy and range extension
- ❑ 802.11s Mesh Networks use RM-AODV and RA-OLSR for on-demand routing along with pro-active tree based routing

# References

- R. Tafazolli (ed), "Technologies for the Wireless Future," Wiley, 2005, 576 pp., ISBN: 0470012358

- Murthy and Manoj, Chapter 13

- G. Held, "Wireless Mesh Networks," Auerbach Publications, 2006, ISBN:0849329604

- I. F. Akyldiz, et al, "Wireless Mesh Networks: A Survey," Computer Networks, 2004, http://www.ece.gatech.edu/research/labs/bwn/mesh.pdf