Wireless Mesh and Multi-Hop Relay Networks

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Audio/Video recordings of this lecture are available at:

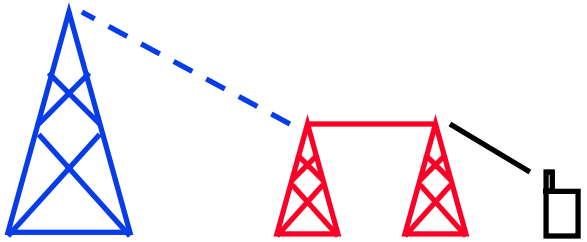
http://www.cse.wustl.edu/~jain/cse574-10/

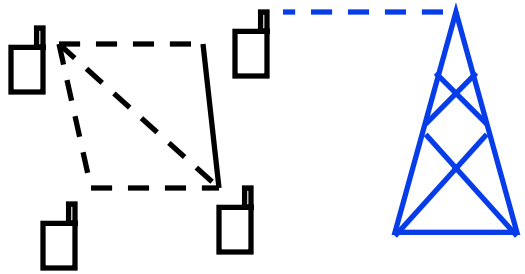
Overview

- 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

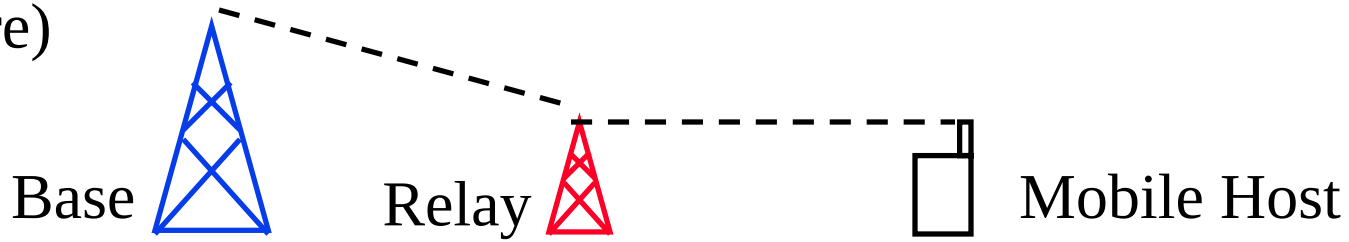




Ref: http://en.wikipedia.org/wiki/Mesh_networking

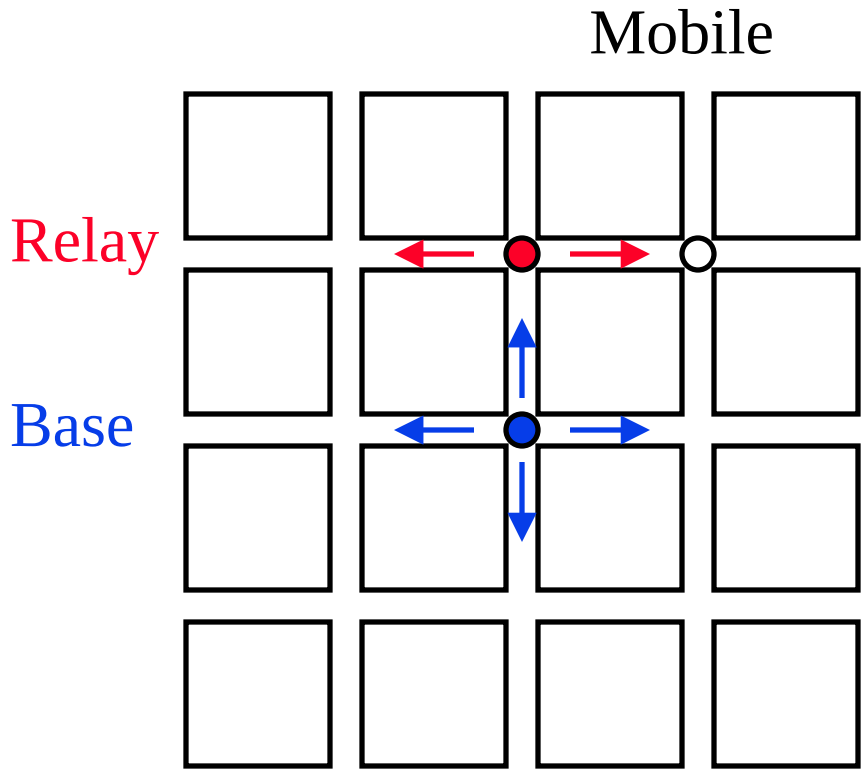
Multi-Hop Relay Networks

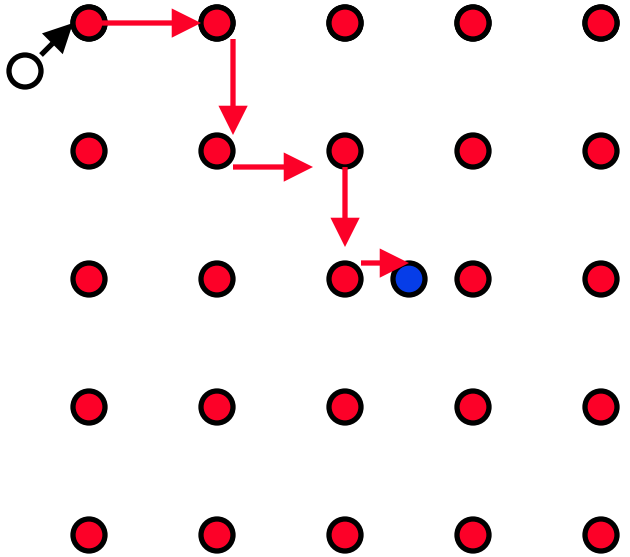
- Next generation networks need very high data rates
- Data rate $\propto$ 1/distance
  $\Rightarrow$ High density of cell towers $\Rightarrow$ High cost
- Multi-hop Networks have fixed infrastructure
  $\Rightarrow$ Do not need complex routing techniques
- Relays are low-cost low transmit power and have no connection to wired infrastructure
- More capacity due to shorter distances and frequency reuse
- Goal: High capacity and coverage (not absence of infrastructure)



Coverage Extension

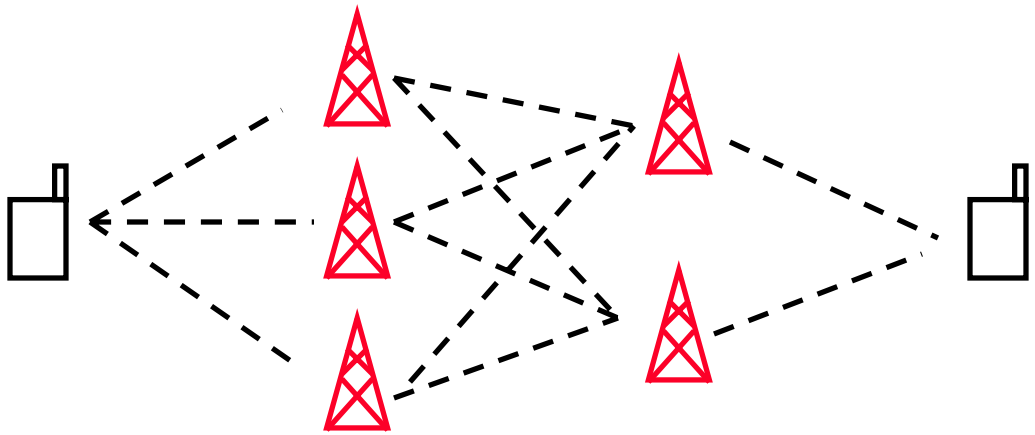
- Side streets can be covered by relays
- A series of relays can be used to forward traffic to base
- Relaying either in time domain or frequency domain





Throughput Enhancement

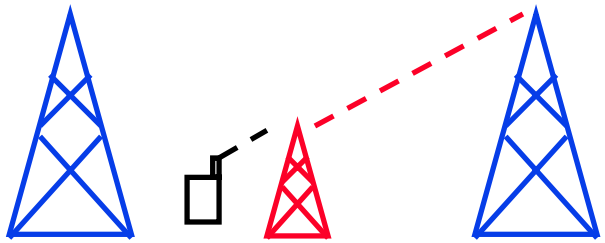
- Virtual Antenna Arrays
- Multiple cooperating relays act as distributed MIMO
- Challenges: Synchronization, Sharing of Channel State Information



3×2 MIMO

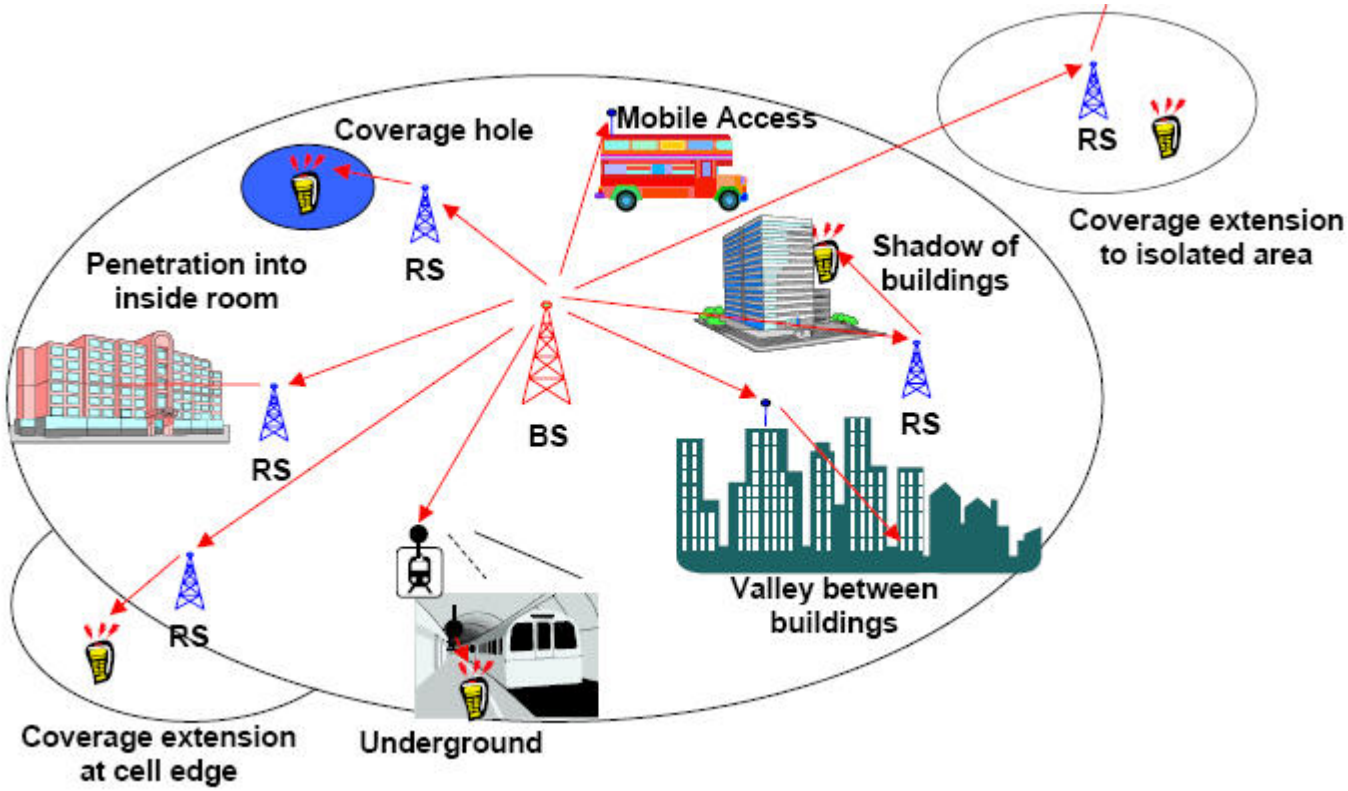
iCAR

- 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

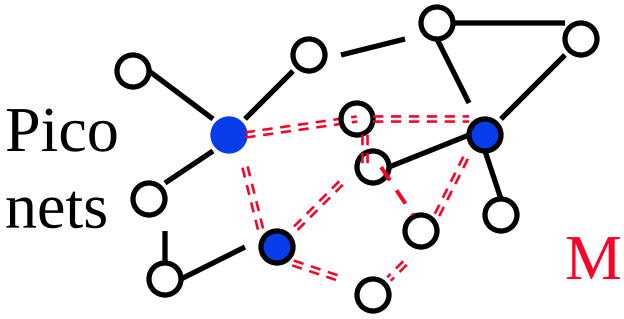
- Relay concept applies to Cellular Networks and to Wireless Access
- Relays can help overcome obstacles
- Relays help improve the capacity by decreasing the distance
- Relays help decrease the cost since they are much cheaper than base stations
- Routing with fixed relays is simple
- Increasing delays
  $\Rightarrow$ 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

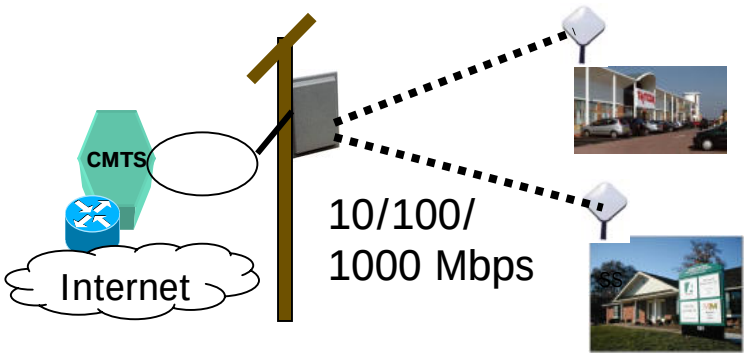
- Goal: Range Extension, *Routing Redundancy*
- Issues:
  - Handle Multiple Master devices
  - Handle multiple super frame coexistence
  - Fair sharing of channel time
  - Minimal changes to 802.15.3 and 802.15.4



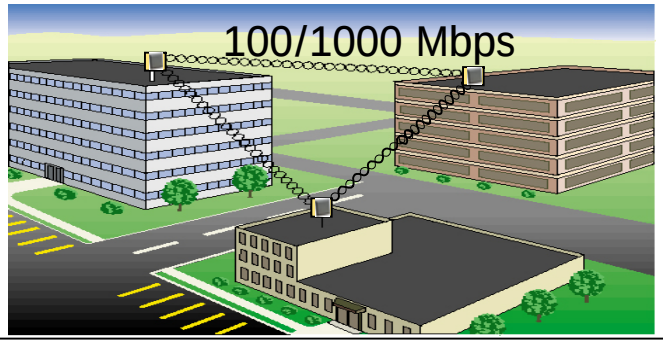
Mesh Control and Data path

802.11s Mesh Networks: Applications

MSOs/CLEC/Municipal

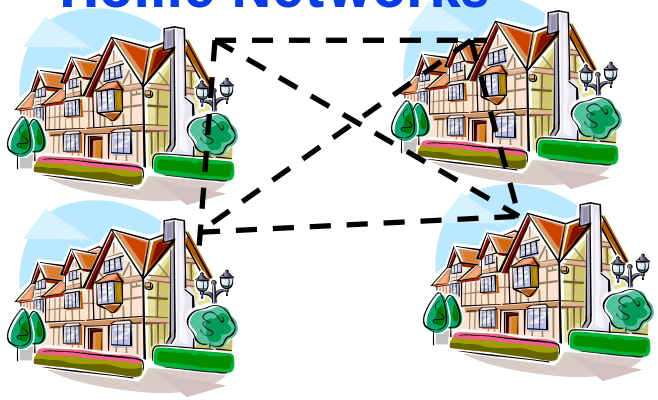


Enterprise Campus



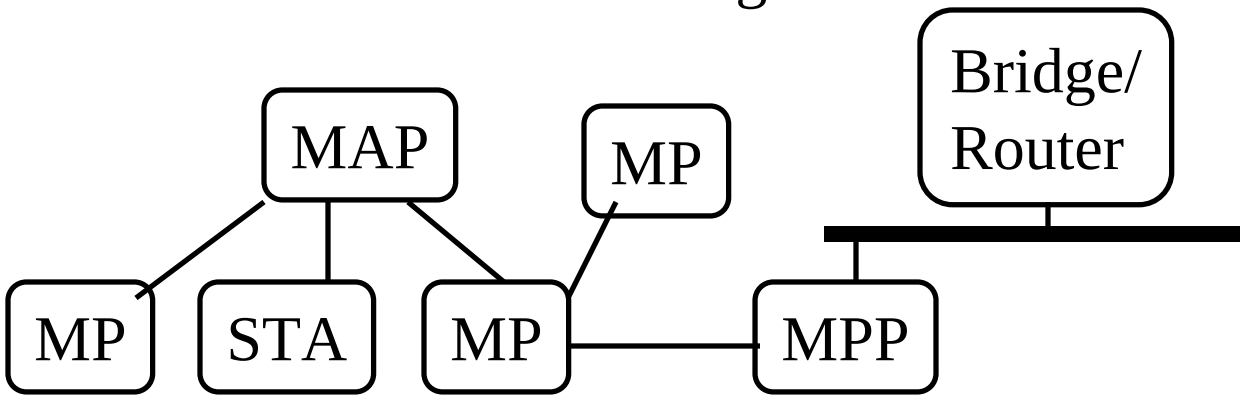
Emergency Response

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



Ref: http://en.wikipedia.org/wiki/IEEE_802.11s

802.11s Hybrid Wireless Mesh Protocol

- Two Configurations: With Root Portal and Without Root Portal

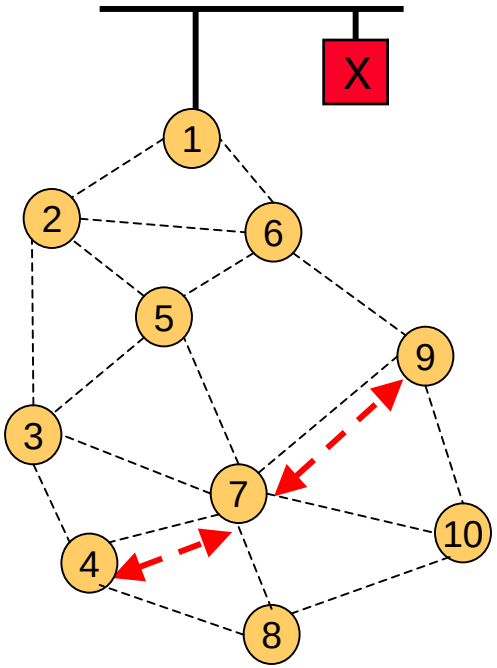
Route Discovery:

- 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.

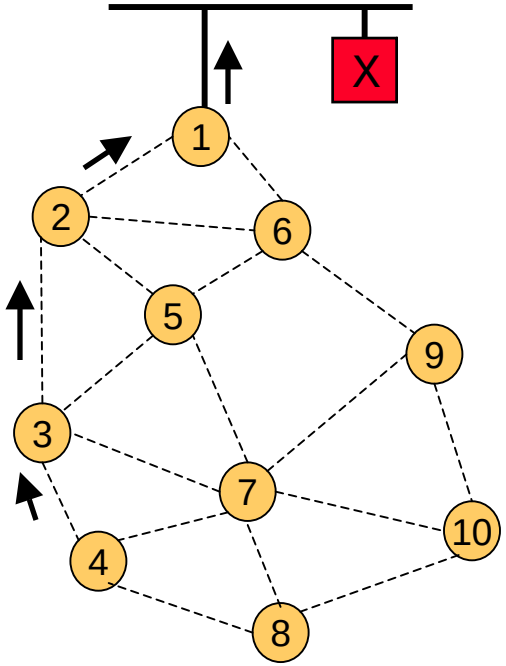
Common Channel Framework

- 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

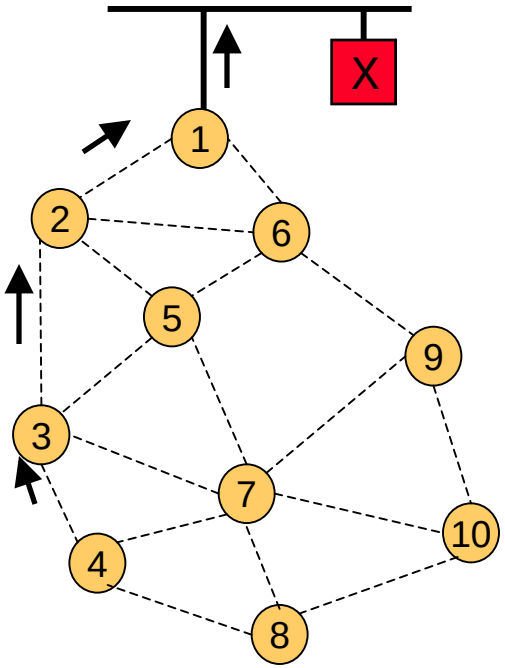


4->9
4 sends RREQ
9 sends RREP

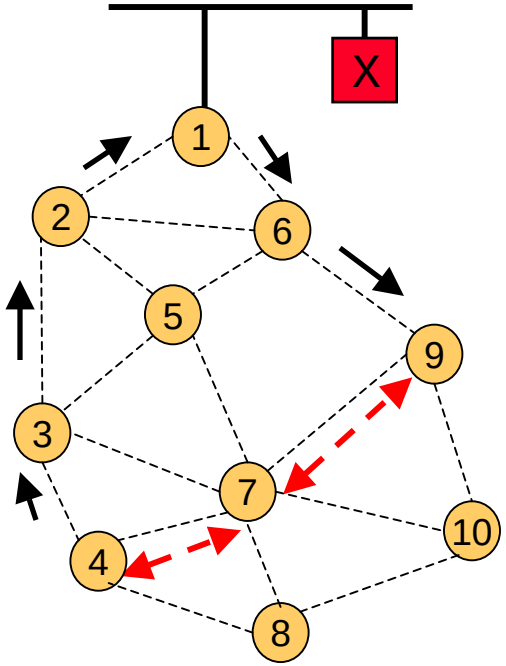


4->X
4 sends RREQ
No Resp
$\Rightarrow$ 4 forwards to MPP 1

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

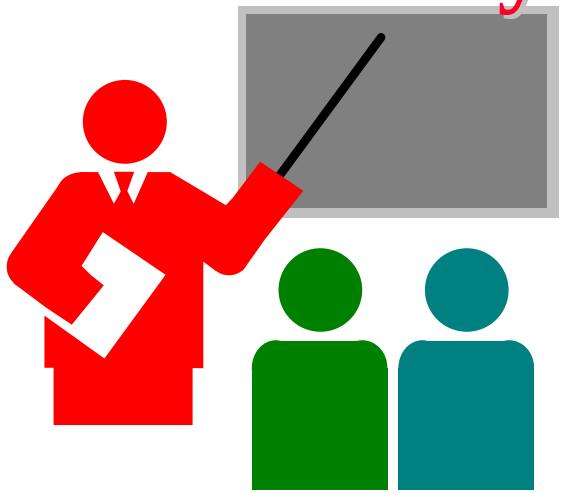
Wi-Fi Mesh Products

- **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

Related Wikipedia Pages

- http://en.wikipedia.org/wiki/Wireless_mesh_network
- http://en.wikipedia.org/wiki/Mesh_networking
- http://en.wikipedia.org/wiki/History_of_wireless_mesh_networking
- http://en.wikipedia.org/wiki/IEEE_802.11s
- http://en.wikipedia.org/wiki/IEEE_802.15.4-2006
- http://en.wikipedia.org/wiki/IEEE_802.16
- http://en.wikipedia.org/wiki/Wireless_community_network
- http://en.wikipedia.org/wiki/Switched_mesh
- http://en.wikipedia.org/wiki/Shared_mesh

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

List of Acronyms

- AODV Ad-hoc On-demand Distance Vector
- AP Access Point
- GHz Giga Hertz
- MANET Mobile Ad-Hoc Networks
- MIMO Multiple Input Multiple Output
- MMR Mobile Multi-hop Relay
- MP Mesh Point
- MPP Mesh Portal
- OLSR Optimized Link State Routing Protocol
- RM Radio Metric
- RTX Request to Transmit
- STA Station
- WPAN Wireless Personal Area Network