Wireless Mesh Technologies and Performance Evaluation

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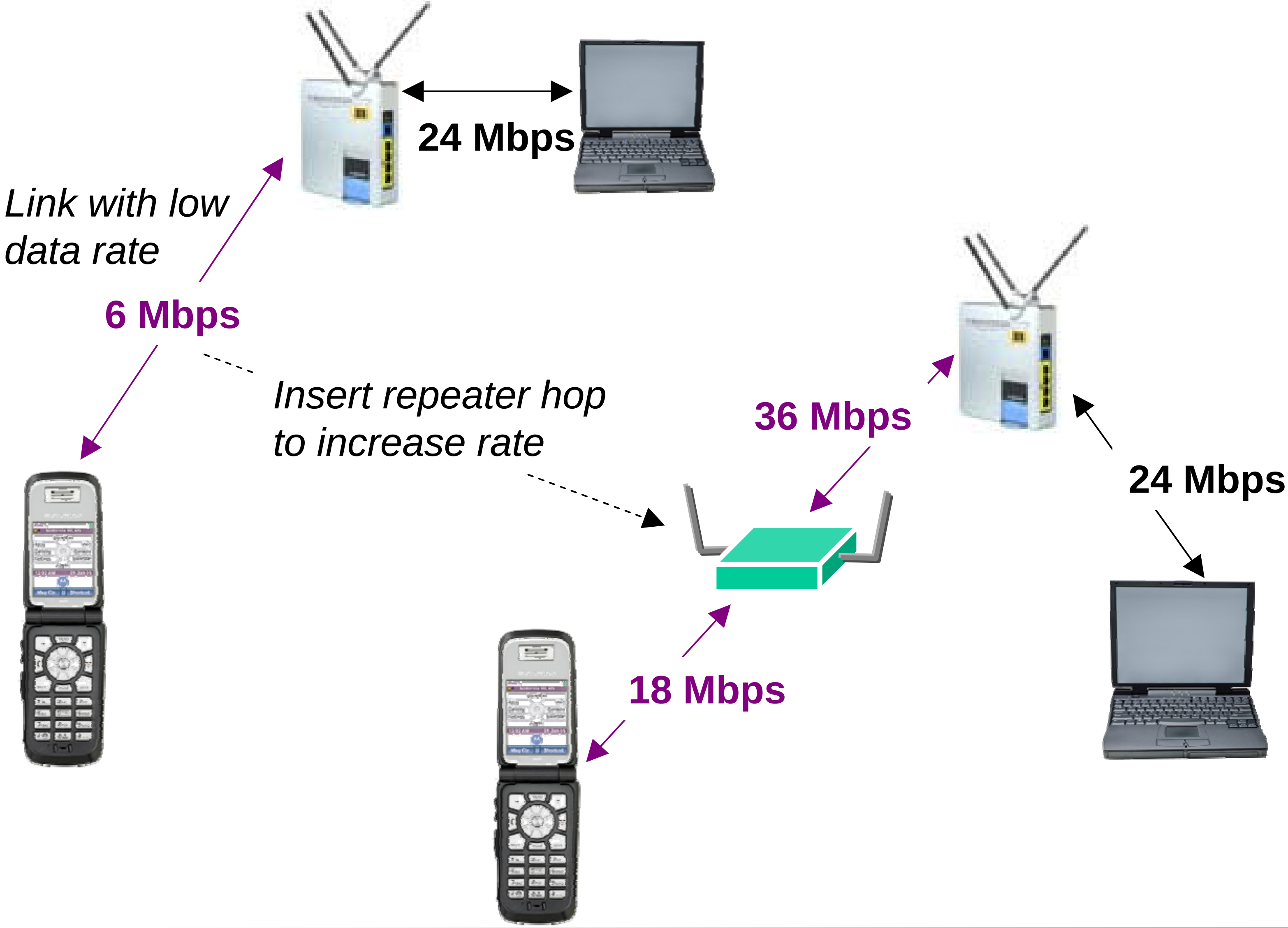
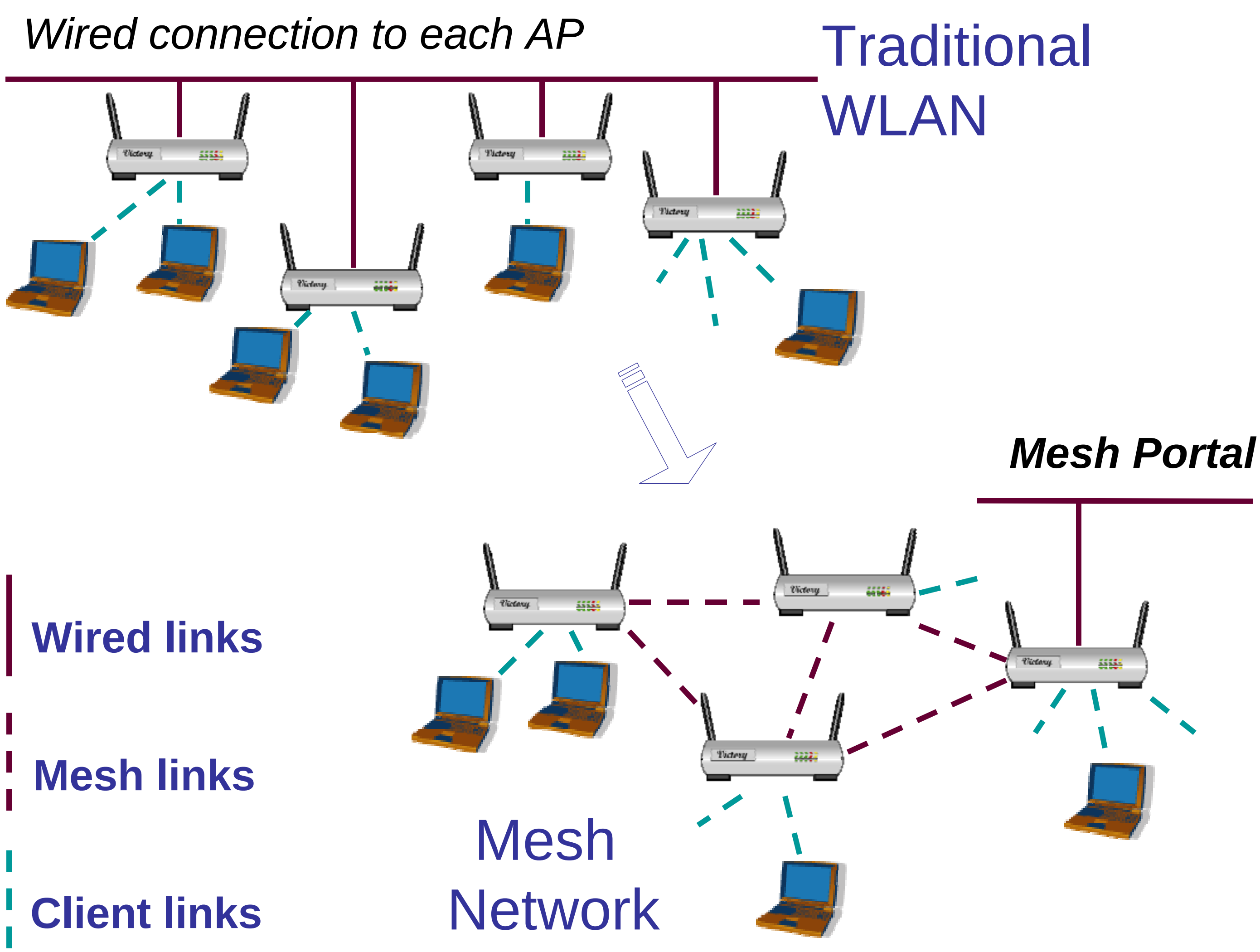
802.11s Mesh Started as Link Extension Scheme

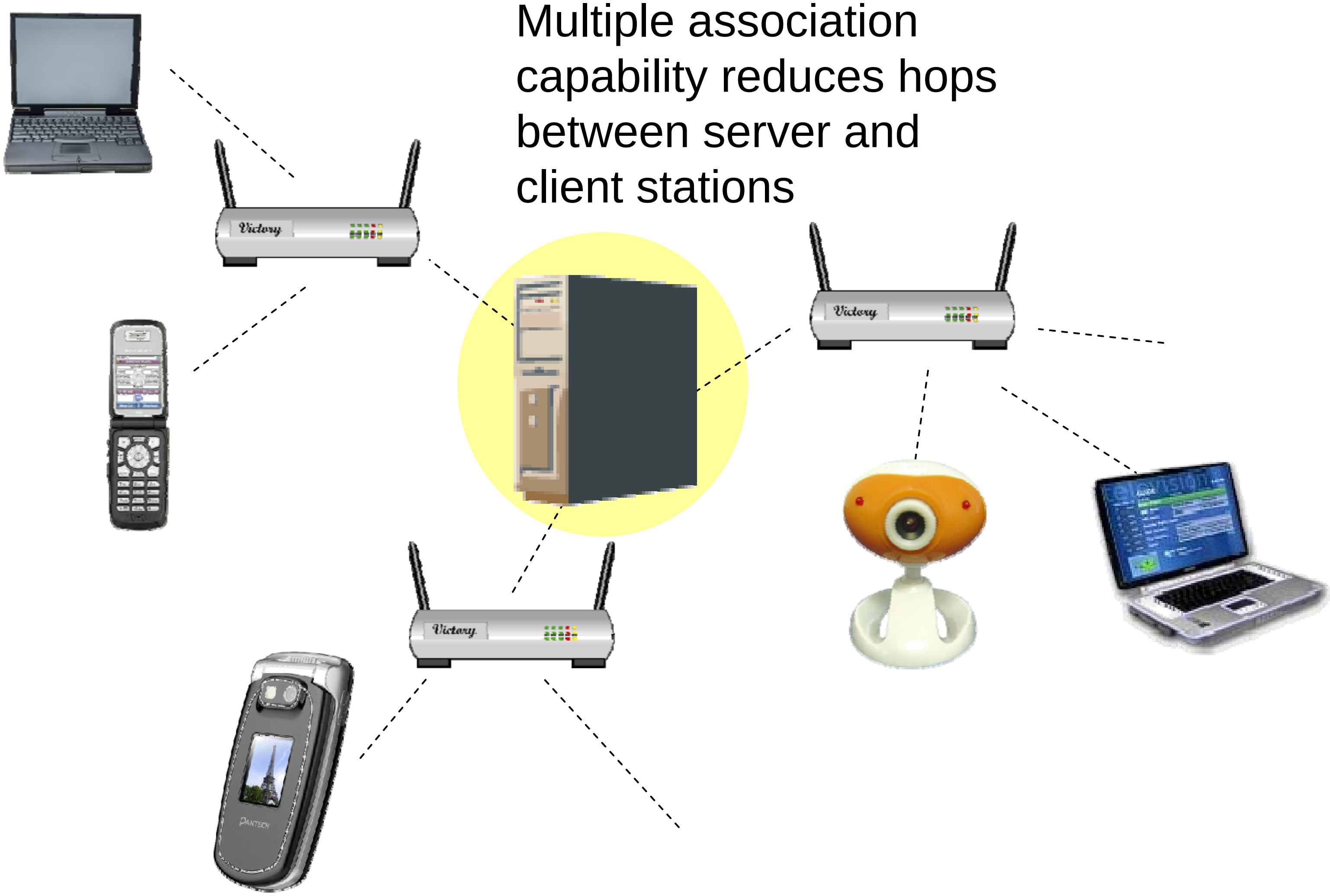


802.11s Wi-Fi Mesh



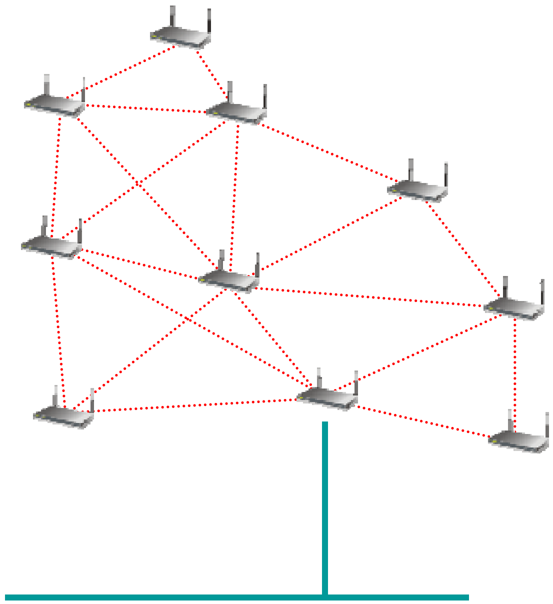
802.11s Mesh Enhanced Stations

Multiple association capability reduces hops between server and client stations



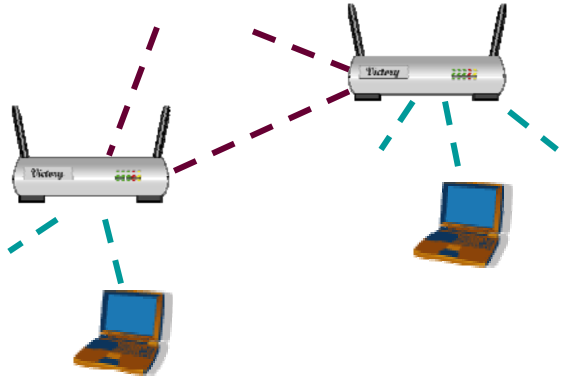
IEEE 802.11s Mesh Standard

- Wireless Distribution System with automatic topology learning and wireless path configuration
- Self-forming, self-healing, dynamic routing
- ~32 MPs per portal to make routing algorithms computationally manageable
- Distributed protocols for
  - Security
  - Power save
  - Fast Transition (roaming)



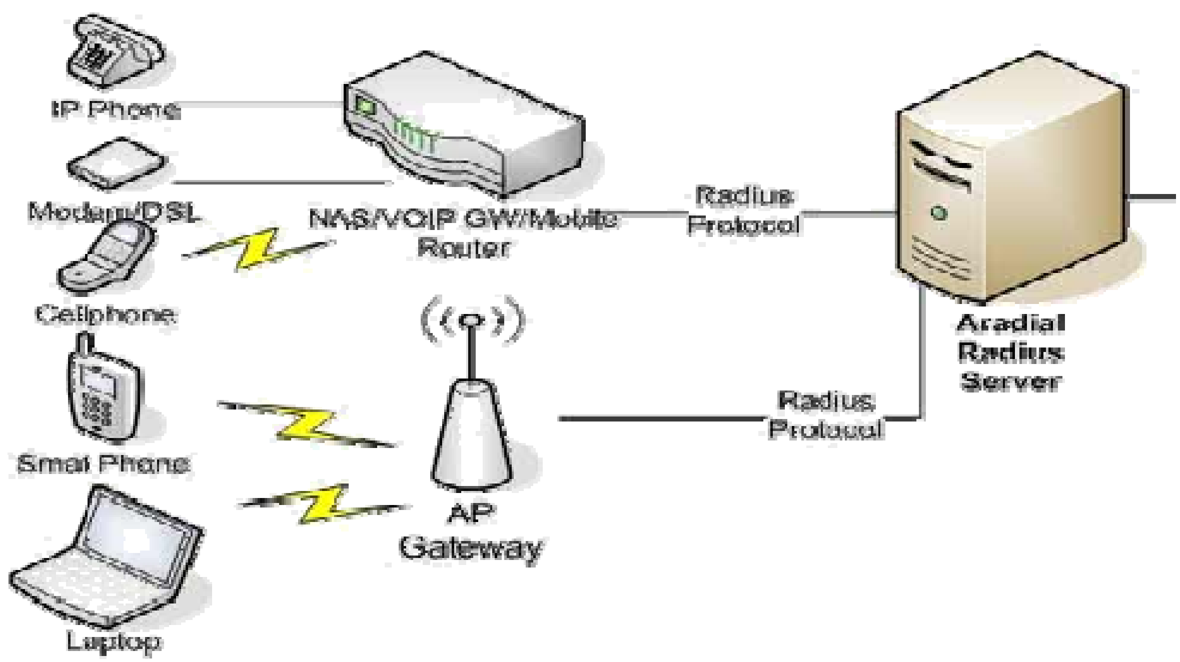
802.11s Routing Protocols

- Routing – 2 standard protocols
  - Hybrid Wireless Mesh Protocol (HWMP) - required
  - Radio Aware Optimized Link State Routing (RA-OLSR) – optional, suitable for dynamic mesh conditions where motion of nodes requires constant updates
  - Hooks provided in the standard for customized routing protocols
- Metrics are defined for paths within the mesh to help the routing algorithm select the best path.
- Hooks exist for adding customized routing protocols and path metrics



802.11s Security

- 802.11s has to make special provisions for security. In the traditional fixed infrastructure stations authenticate through APs with a centralized AAA server.
- In a mesh network MPs have to mutually authenticate with one another. 802.11s security features extend 802.11i to peer-to-peer environment.



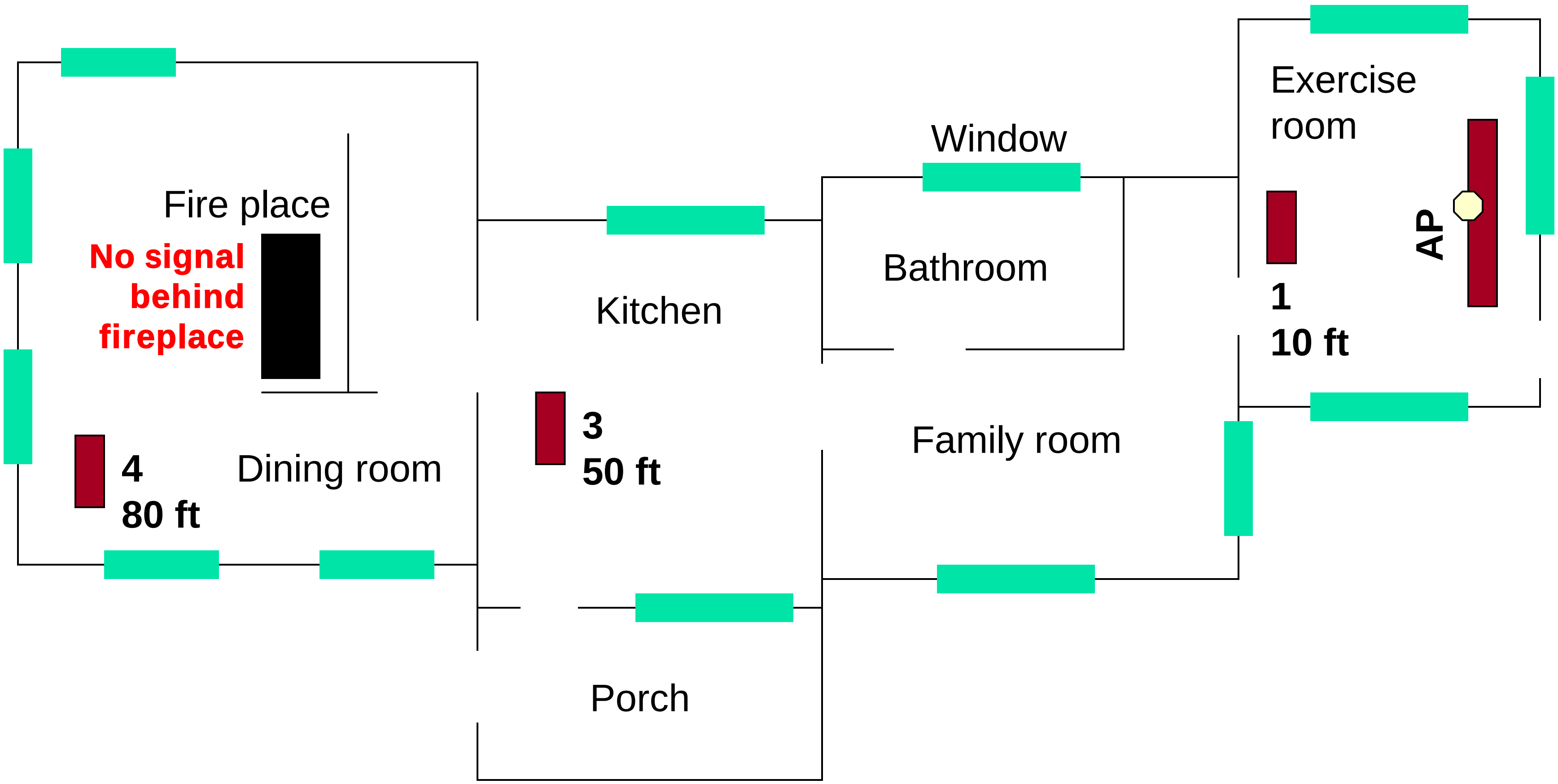
Fast Handoff in Dynamic Meshes

- To support VoIP, 802.11s needs to incorporate the fast handoff mechanisms defined in 802.11r.
  - Enable stations to roam from one mesh AP to another within approximately 50 ms without noticeable degradation in the quality of a voice call
  - In a dynamic mesh (e.g. in vehicles) MPs may be roaming with respect to other MPs and the 802.11s standard requires fast roaming of MPs with respect to one another.

Mesh in First Responder Applications

- 802.11s is considering provisions to allow battery powered mesh nodes, such as police radios, that may go into sleep mode.
  - If a mesh node goes to sleep periodically it announce sleep mode to its neighboring MPs and these MPs can save the traffic for the sleeping node and deliver it during the waking periods.
  - If wake/sleep cycles are periodic, mesh nodes need to be synchronized.

Wireless Mesh for Home Video Distribution



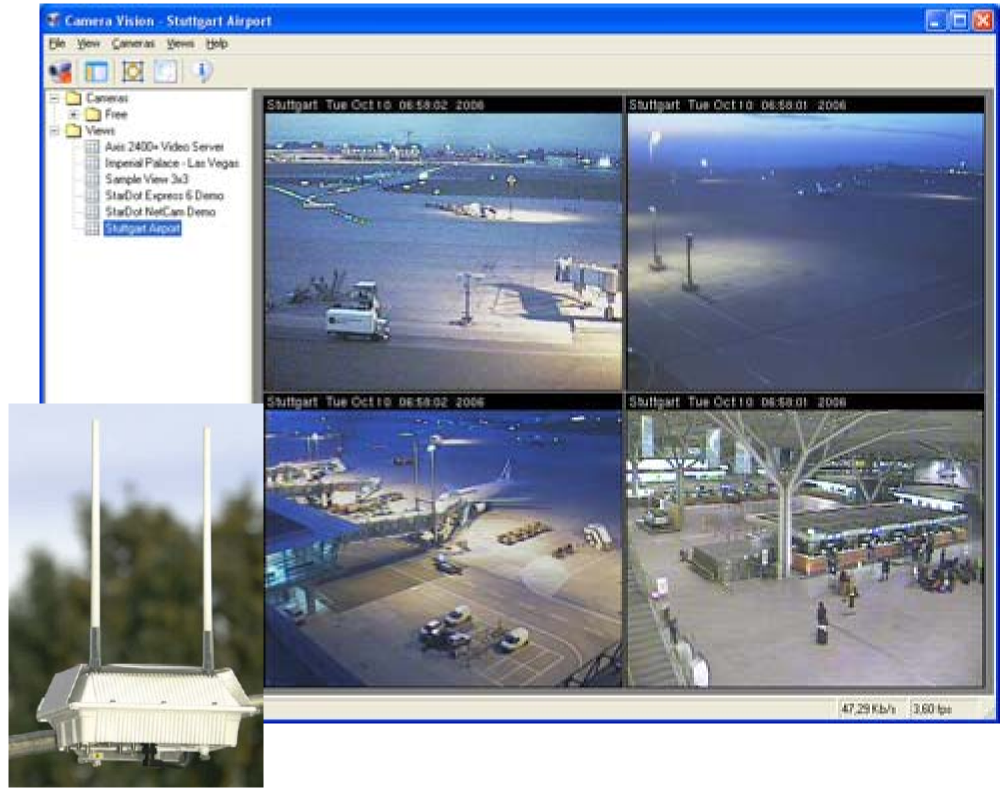
- In a home video distribution network MPs may be plugged into electrical outlets to serve as repeaters on long links or to help 'bend' transmissions around obstructions.

Throughput Performance is Critical for Video

Format		Average throughput required for high quality video	
		480i60	**1080p30**
Broadcast Cable TV	MPEG-2	8 Mbps	20 Mbps
Windows Media Video DivX XviD QuickTime	MPEG-4 Part 2	5 Mbps	12 Mbps

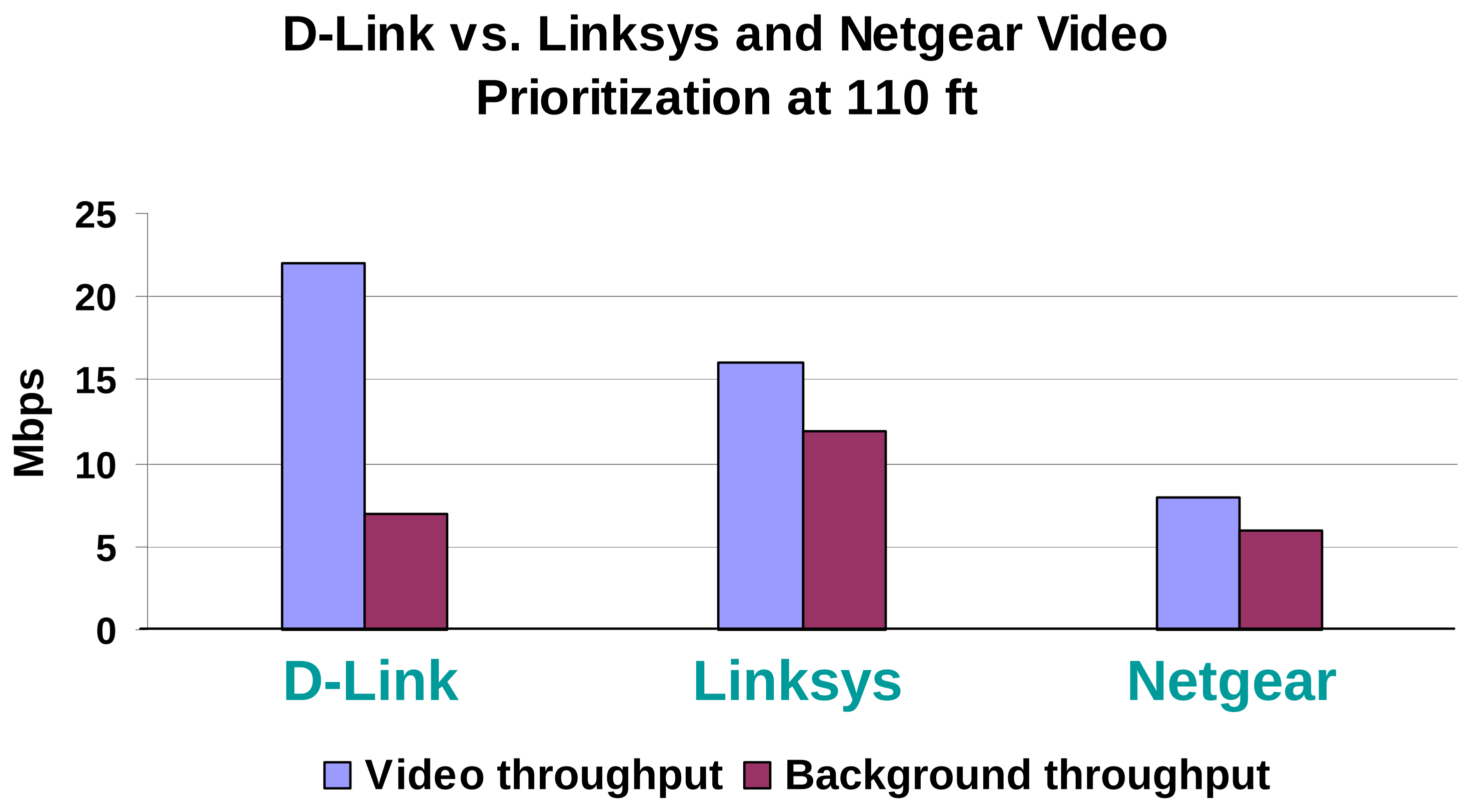
Post 9/11 Video Surveillance

- Municipalities deploying cameras attached to Wi-Fi mesh nodes for video surveillance
- Required throughput is a function of video frame rate, resolution and color
- Approximately 2 Mbps needed for full VGA, 7 frames/sec



- Cost of an outdoor Wi-Fi Mesh node is $2-$6k, compared to ~ $80k for a WiMAX base station

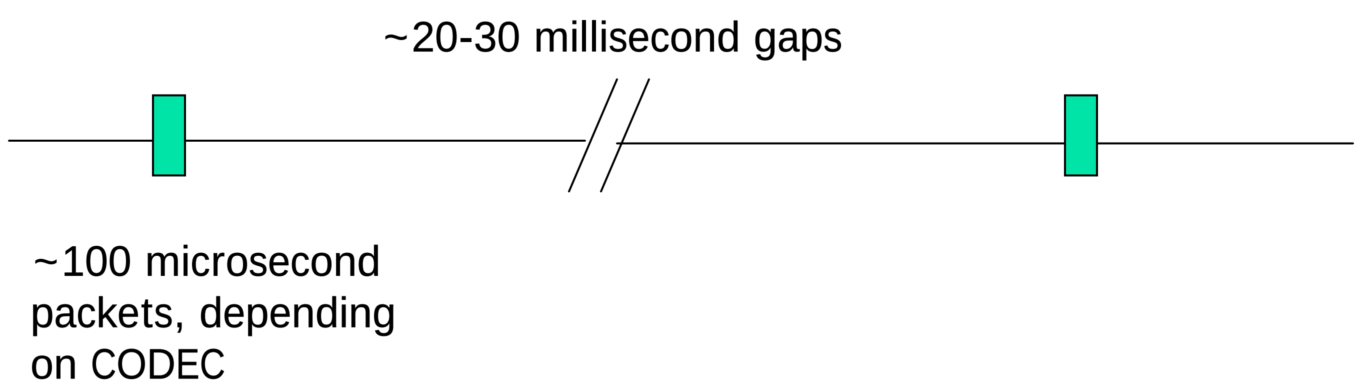
QoS For Voice and Video



- Example where D-Link router prioritizes video traffic while Linksys and Netgear do not
- Only D-Link can deliver sufficient throughput for HDTV transmission at this distance

Voice Performance

- WMM (wireless multimedia) ensures that voice and video streams get priority over other classes of traffic
- 802.11n improves VoIP performance and efficiency through protocols like, block ACK and frame aggregation
  - Aggregate short voice packets and send them as a burst, improving the efficiency of handset radio sleep cycles and saving battery power
- 802.11n PSMP (power save multimode protocol) manages sleep cycles for optimum efficiency



Voice Performance (continued)

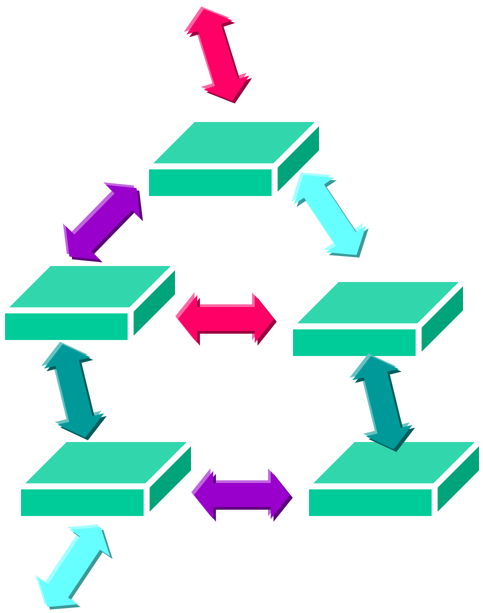
- Delay increases per hop and may be unpredictable in busy networks, causing jitter
- WMM can minimize delay and jitter for voice traffic
- Reach can be a problem in outdoor networks
    - 802.11n can increase range of handheld devices through AP transmit and receive diversity mechanisms such as STBC (Space Time Block Coding), transmit Beamforming, MRC (Maximum Ratio Combining)

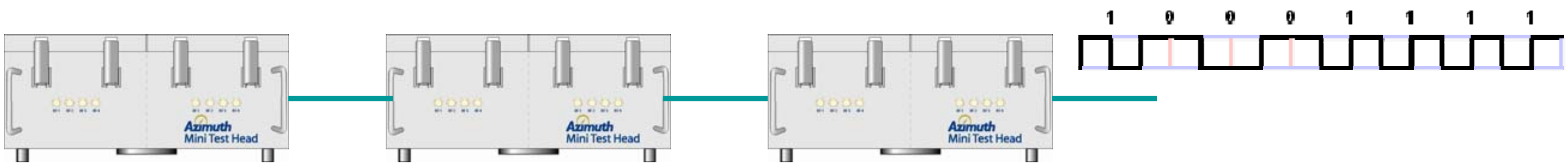
Mesh for Airborne Networking

- DoD Airborne Network for surveillance
- New generation of air traffic control
  - Airplanes communicate to each other in a mesh reporting weather and traffic conditions
  - http://www.airborneinternet.com/

Performance of a Mesh Network

- Multi-radio vs. single radio
- Throughput, QoS vs. *range*
- Throughput, QoS vs. *hops*
- Self-healing, self-forming
- Routing efficiency
- Dealing with interference





Controlled RF Environment Test

Throughput

Packet loss

Delay, jitter

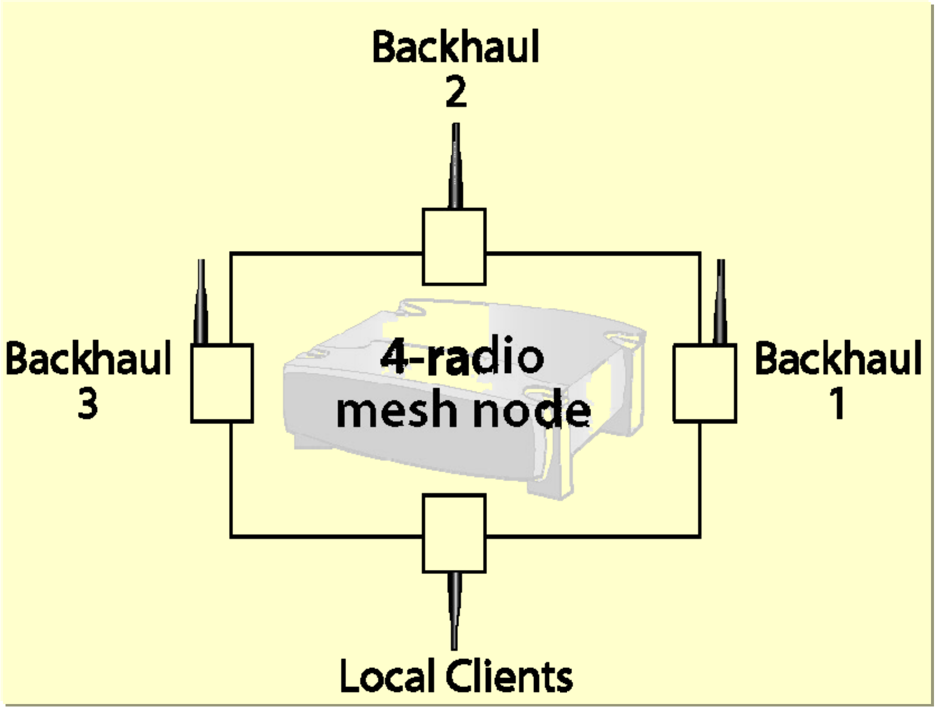
— Performance vs. Hops, vs. Range

Vary attenuation

Emulate channel conditions

Simulate node failure

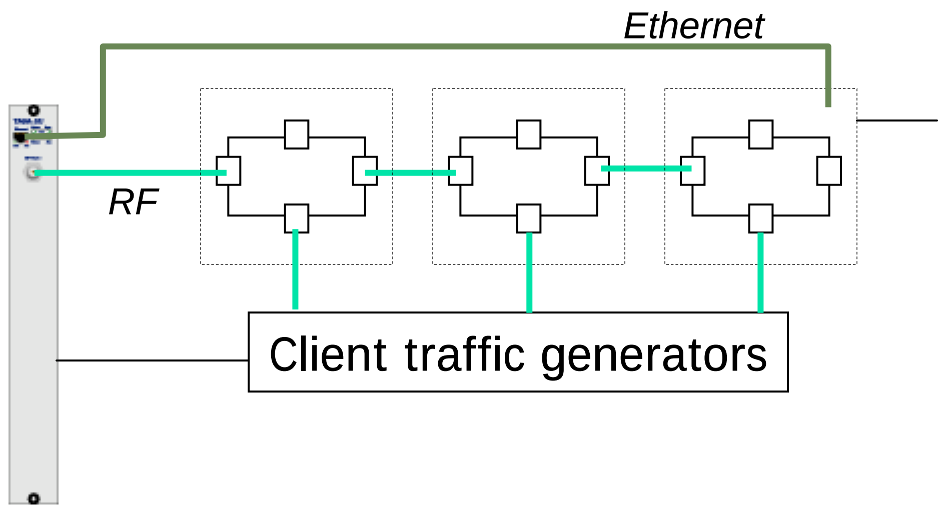
Control network topology



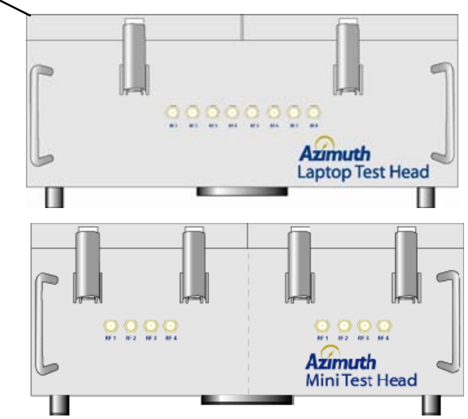
Test Parameters for Evaluation of Wireless Mesh Performance

- **Number of hops**
  - Throughput and QoS are directly impacted by the number of hops through the mesh network.
  - Measurements should be performed over different hop counts and plotted vs. hops.
- **Number of users per hop**
  - Emulate traffic load from groups of clients using data, voice and video services. Emulate 802.11e prioritization for voice data and video per group.
- **Traffic load per hop**
  - Emulate a variety of traffic loads and packet sizes at each mesh hop.
- **Backhaul traffic load**
  - Each mesh node routs local traffic and forwards traffic from other nodes via its backhaul links. Depending on the efficiency of the routing algorithms congestions can occur on backhaul links impacting performance of the entire mesh. Configure traffic source and destination addresses in such as way as to exercise routing logic.

Multi-hop Mesh Test Configuration

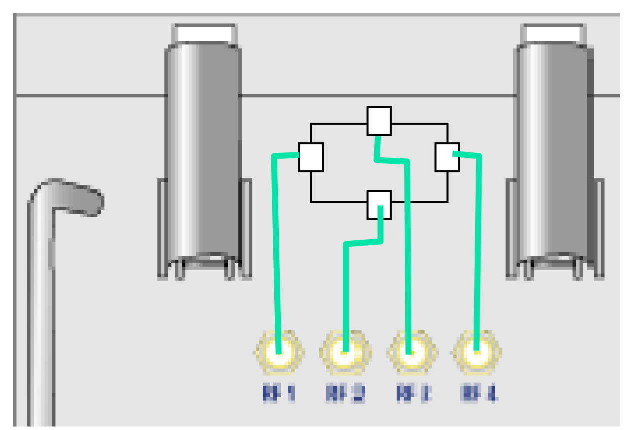


Shielded Test Heads



Traffic generators emulate multi-station traffic; analyzer measures throughput, packet loss, delay and jitter through a variable number of hops

Traffic can be injected at each hop



Test Mesh Mobility Conditions

- Emulate motion of clients with respect to mesh nodes.
- Emulate motion of mesh nodes with respect to other mesh nodes (e.g. a bus with a mesh node moving through the city mesh.)
- Emulate multiple clients moving at the same time.
- Emulate different velocities of motion, for example, people walking, mesh nodes on busses and trains, etc.
- Emulate different cell overlap conditions.

Wireless Mesh Test Parameters

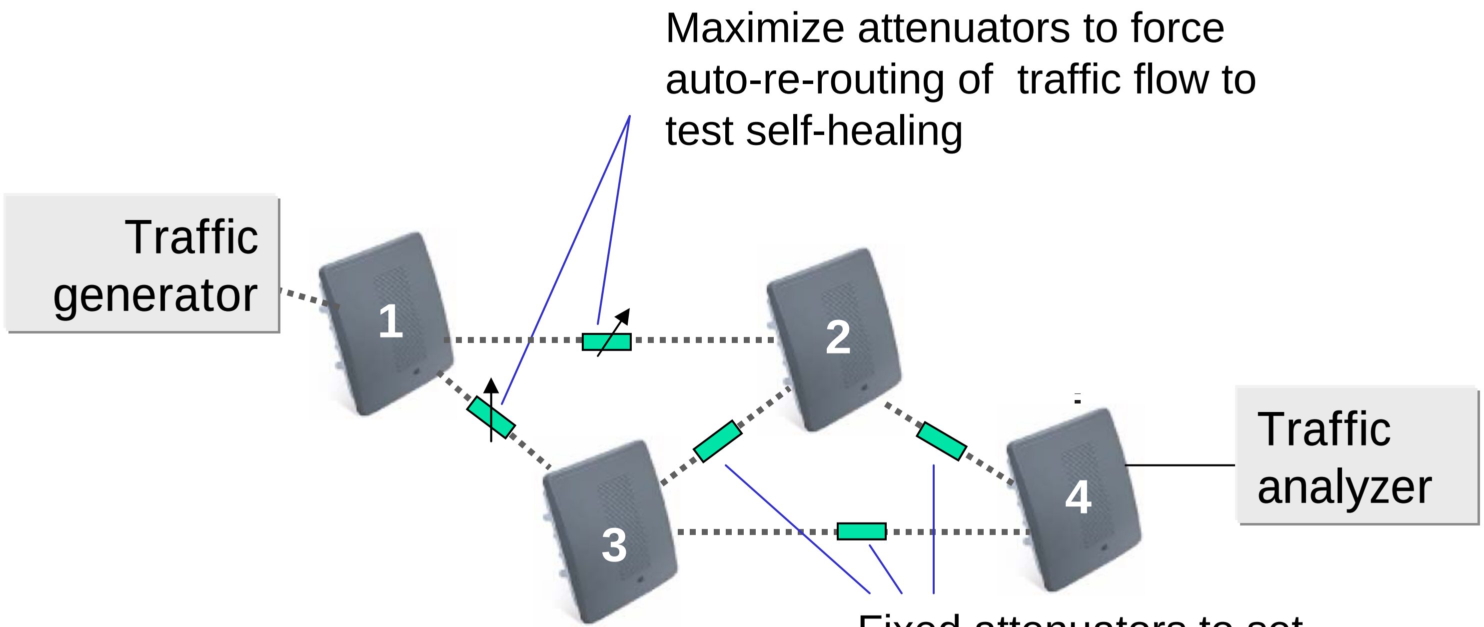
- **Direction of traffic flow**
  - Throughput and QoS must be measured in upstream and downstream directions. The test application should allow controlled upstream, downstream and bi-directional measurements.
- **Number of radios in mesh nodes**
  - Number of radios in mesh nodes significantly impacts performance. Perform measurements with different number of radios activated and compare the results.
- **Security settings**
  - Throughput and routing efficiency may be impacted by security settings. Test with a variety of standard IEEE 802.11i security settings for groups of emulated clients.
- **QoS settings**
  - Emulate a mix of data, voice and video clients while measuring throughput and QoS to test ability of mesh infrastructure to prioritize voice and video over data. Plot voice and video quality metrics vs. hops, vs. load and other settings.

Wireless Mesh Test Parameters (continued)

- **Range and multipath conditions**
  - Emulate path loss and multipath conditions between clients and mesh nodes. Measure and plot throughput and QoS (packet loss, delay and jitter) vs. path loss and multipath models.
  - Emulate path loss and multipath conditions between backhaul radios. Measure and plot throughput and QoS vs. multipath models and path loss.
- **Interference including adjacent-channel interference (ACI) and co-channel interference**
  - Throughput and QoS performance is affected by interference. Co-channel and ACI are normal in mesh networks since neighboring radios can communicate on the same or adjacent channels and interfere with the channel under test. Perform throughput and QoS measurement in the presence of co-channel interference and ACI.

Azimuth Channel Emulator

Self Healing Self Forming Test Configuration



Fixed attenuators to set traffic flow via one branch or another to test self configuration

Fail-over conditions

Emulate failure conditions by setting programmable attenuators to cause traffic flow reconfiguration.

Conclusion

- Strong economics for Wi-Fi Mesh, IEEE standard will help bring prices down
- Enables pervasive connectivity for many applications
- Video and voice have stringent performance requirements
- Testing is critical for success of mesh networks