Introduction to Wireless Mesh Networking

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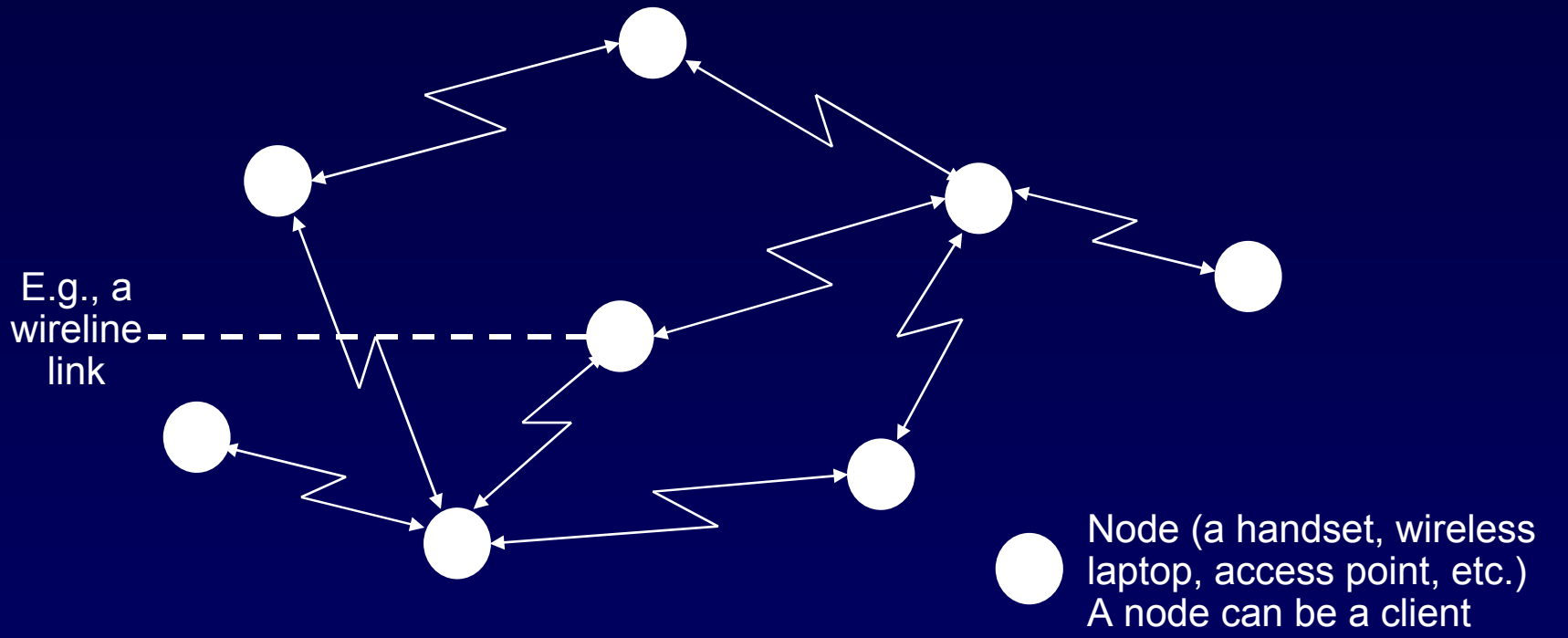
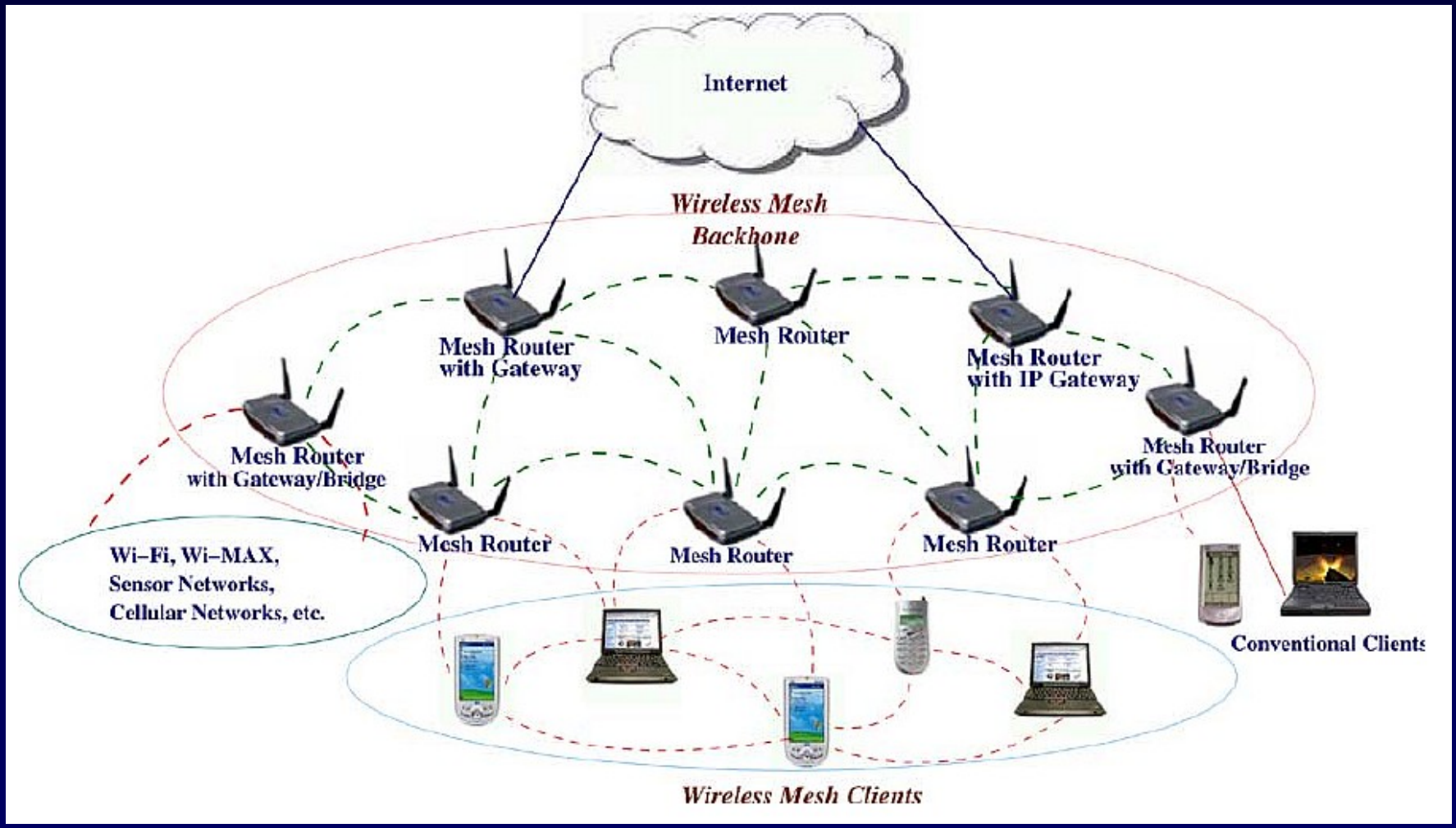
Wireless mesh networking entails repeating through intermediate fixed or mobile stations

- Reach other stations (i.e., nodes) by repeating through closer nodes that have better radio paths and thus more throughput

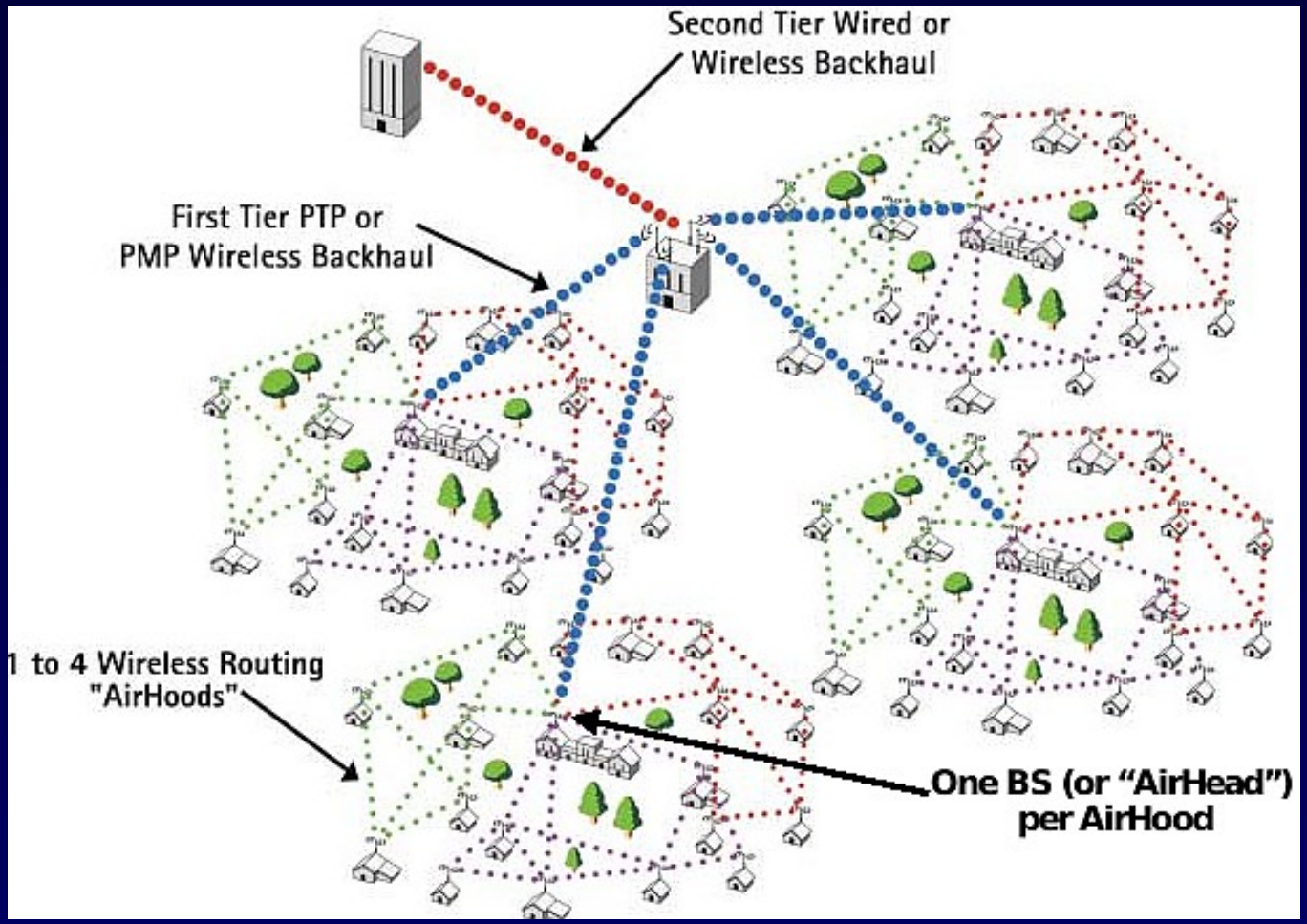


Wireless mesh clients can connect to a backbone and/or among each other, as in this example



Source: Akyildiz, A.F. et al, "Wireless Mesh Networking: A Survey", Computer Networks (2004)

Last-mile backbone solutions have been deployed, as in this example



Source: Nokia

Some images of wireless mesh clients and nodes

Fig. 2. Examples of mesh clients: (a) Laptop, (b) PDA, (c) Wi-Fi IP Phone and (d) Wi-Fi RFID Reader.

Source: Akyildiz et al

Source: WaveWireless

The important characteristics of a wireless mesh network include:

- Multi-hop wireless network that:
  - Extends coverage range without sacrificing channel capacity
  - Improves connectivity among users without line of sight
- Support for ad hoc networking, and capability of self-forming, self-healing, and self-organization.
- Mesh routers usually have minimal mobility, while mesh clients can be stationary or mobile nodes.
- Multiple types of network access
- Dependence of power-consumption constraints on the type of mesh nodes (e.g., sensor nodes and clients)

Wireless mesh networking can bring several potential benefits

- Greater spectral efficiency
- Lower-cost devices, since less transmit energy needed
- Flexibility, since every device can be a router
- Robustness, from the opportunity to use alternate paths
- Quick rollout with low initial cost hurdles
- Reliability and coverage increase as nodes are added
- Sensor nodes can operate with minimal energy consumption

Wireless mesh networking has many possible applications

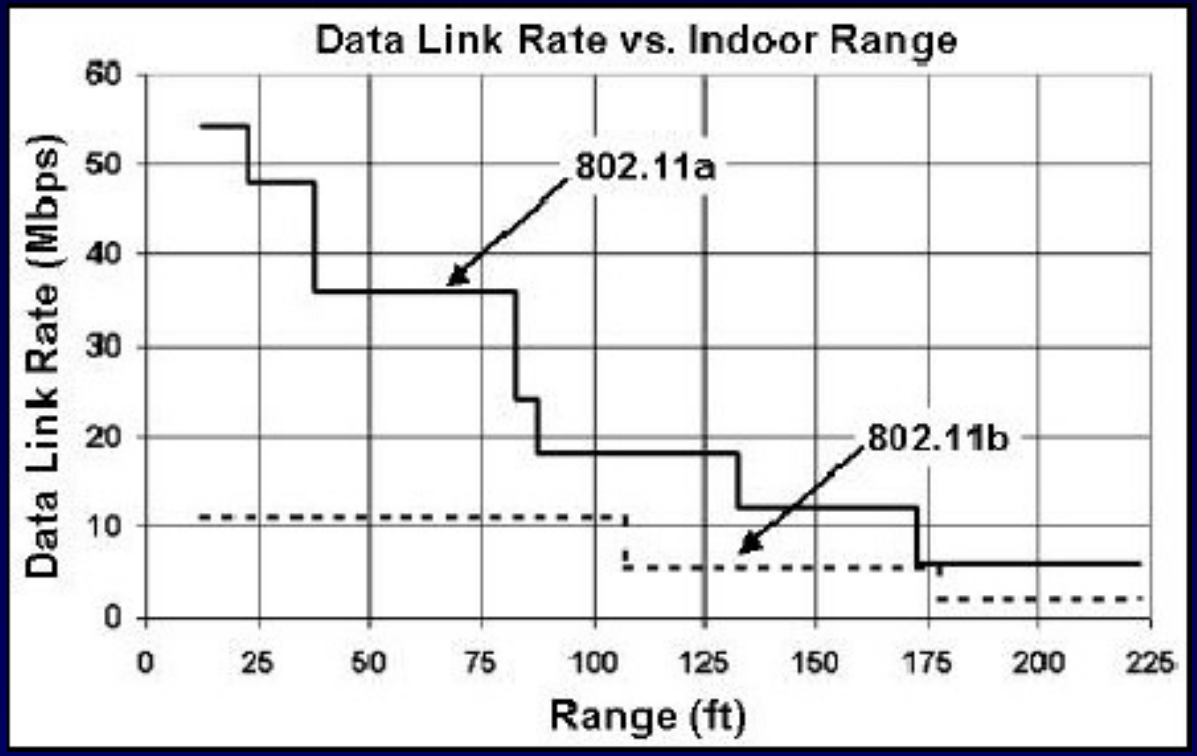
- Office WLAN environment
  - Combat growing radio congestion
  - Reduce wiring and moves/adds/changes costs
- Last-mile wireless broadband, and community networks
  - "Seed" an area with wireline-connected nodes
  - Meter reading Fixed Area Networks
- High-bandwidth networking among devices in the home
- Mobile networks
- Industrial automation
- Sensor networks
- Ad-hoc networks

The important capabilities of a mesh network include:

- Self-configuring communication and routing
- Ability to deal with hidden terminal problem
- Installation, management, QoS and resource scheduling, security, co-existence
- Interference management; interference-aware route construction
  - Including ad-hoc IP routing (e.g., AODV good for dynamic networks, DSR good for low latency)
- Scheduling and collision detection and management

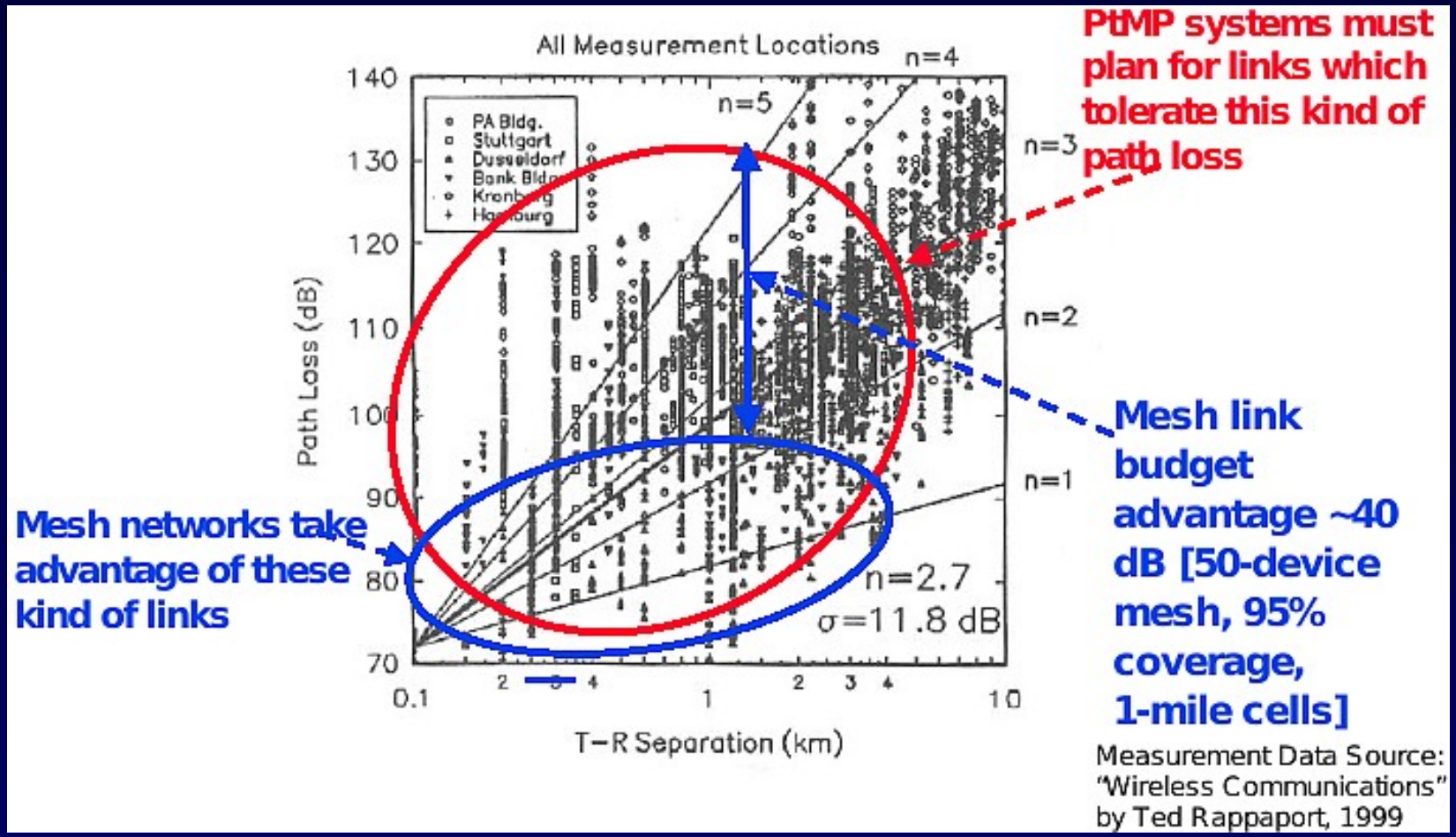
Mesh networks are good because they minimize the radio power needed (and thus potentially the cost) to carry a given amount of data in an area

- Throughput goes down with distance, as in this indoor WLAN example
- Chaining together "good" paths can give higher overall throughput



Source: Chen & Gilbert, "Measured Performance of 5 GHz 802.11a Wireless LAN Systems", Atheros Communications Inc. (2001)

Mesh networks take advantage of the good kinds of links, as in this outdoor example



Source: Nokia

Even at low elevations, only some of the feasible radio links in a dense deployment need to be used

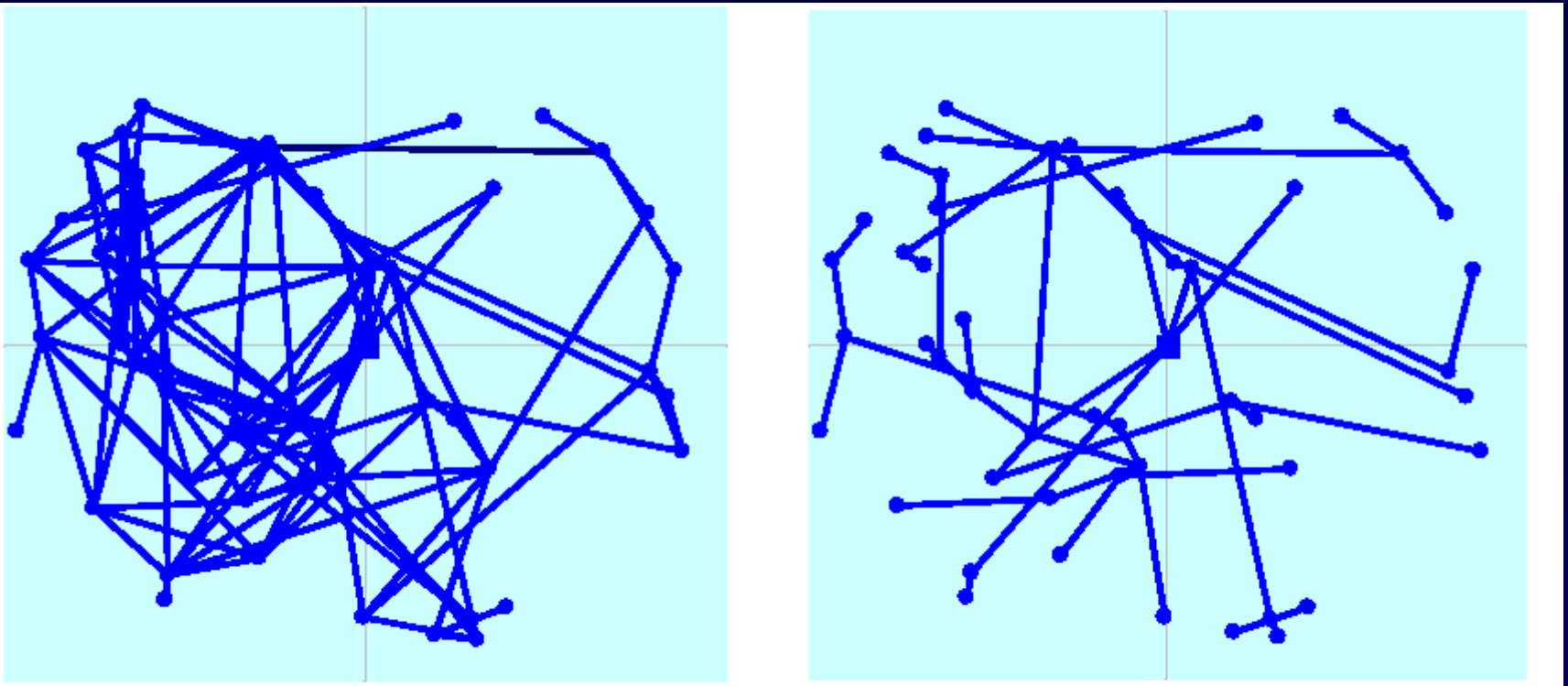
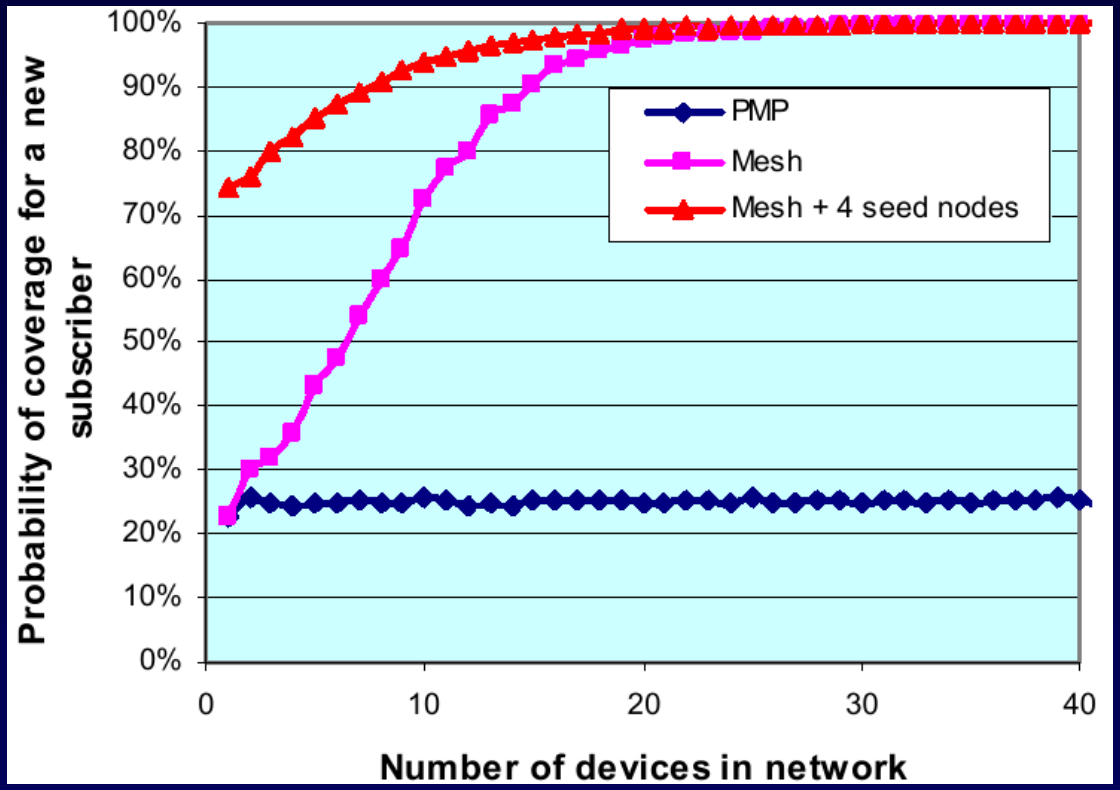


Figure 12 -- 50-device wireless routing network showing all of the usable links (on left) and only the active, minimum-delay-path links on the right (path loss exponent 3, standard deviation 10 dB).

Source: Nokia

Coverage grade of service is greatly enhanced over PMP, particularly with the addition of seed nodes

- With 50 nodes and 4 seed nodes, more than 95% of subscribers can be within 2 hops of the backhaul point



Source: Nokia

Some wireless mesh hooks exist or are being built into standards

- WiMax -- 802.16-2004 supports mesh working, including centralized and distributed scheduling
  - Better granularity (TDMA) than 802.11 (RTS/CTS)
  - Mesh will be critical for 802.16e mobile
- WiFi -- P802.11s ESS (Enhanced Service Set) consensus proposal under consideration
- Personal Area Networks -- New MAC proposed in 802.15.3a UWB; mesh hooks exist in 802.15.4 Zigbee; discussions ongoing in P802.15.5
- IETF actively addressing mesh routing issues
- We are not at the commodity stage quite yet

Proprietary implementations and enhancements will continue to be important, because standards and design issues remain

- Scaleability
- Self-organization and self-configuration
- Security
- Network integration

Scaleability is an important factor to be managed

- Throughput, end-to-end delay and fairness not currently scaleable with nodes or hops
  - E.g., capacity has to be shared among links in a single-channel radio system
- Alleviate by
  - Adding more seed nodes
  - Increasing capacity through
    - More radio channels
    - Higher transmission speed
  - Develop new MAC, routing and transport protocols

Other issues must be managed

- Self-organization and self-configuration
  - Current standards can only partially realize this objective
- Security
  - Comprehensive mechanisms are needed to prevent or counter attacks across different protocol layers
- Network integration
  - Current implementations have limited capabilities of integrating heterogeneous wireless networks

Mesh wireless networks provide opportunities for wireless deployments in a wide range of areas

- Improved spectral efficiency through focusing on the better radio links that can be utilized without sacrificing channel capacity
- Quick rollout possible with low start-up costs
- Last mile, office, mobile, home, industrial and sensor applications
- Standards are moving forward quickly, but proprietary implementations and enhancements will continue to be important