Mesh Networks

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Project-oriented Advanced Training on Wireless Networking

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Outline

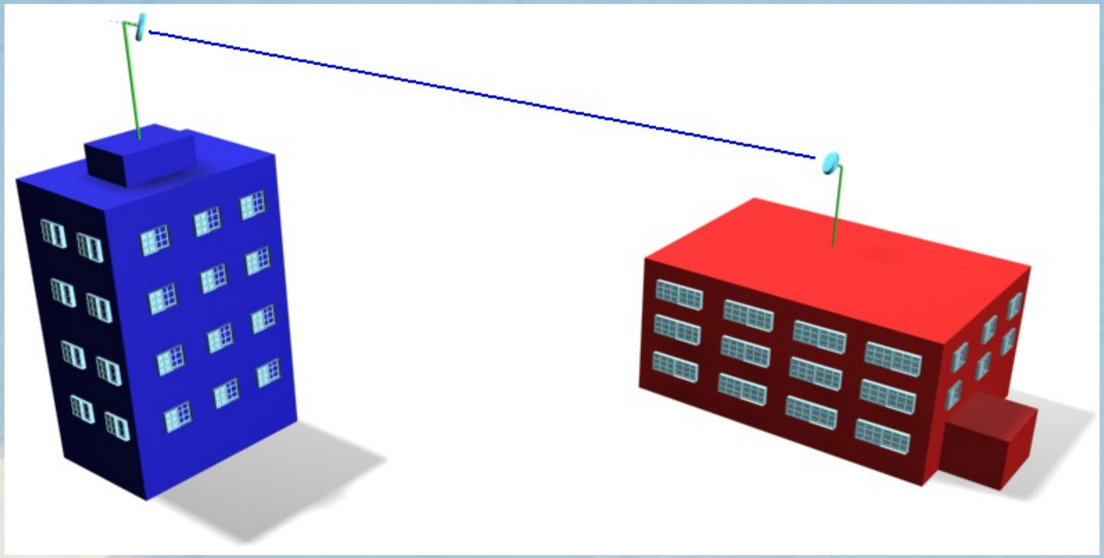
- Network Topology
- Mesh Vs Single Hop Networks
- Technical justification
- Commercial examples
- Open Source solutions
- Example of application

Mesh Networks

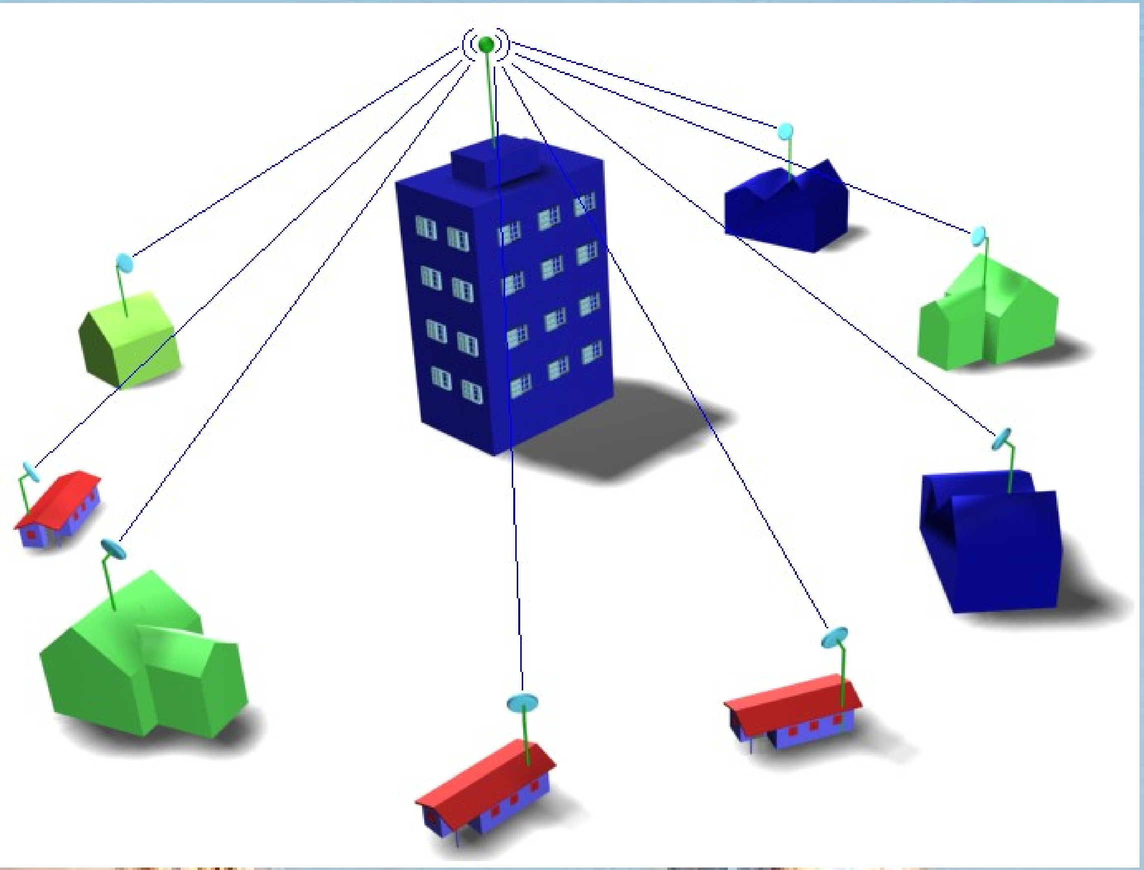
Mesh Networks, also known as *ad hoc* networks, are those in which each node supplies connectivity to adjacent nodes.

They originated in the military, but have found civilian applications for their ability to overcome some of the hurdles of traditional wireless deployments, like the need for LOS from every client to the corresponding base station and the interference arising when several networks share the same geographical area. They allow for a more robust system providing alternative path to a given station, while offering the promise of ***increasing*** the available bandwidth as the number of users increases.

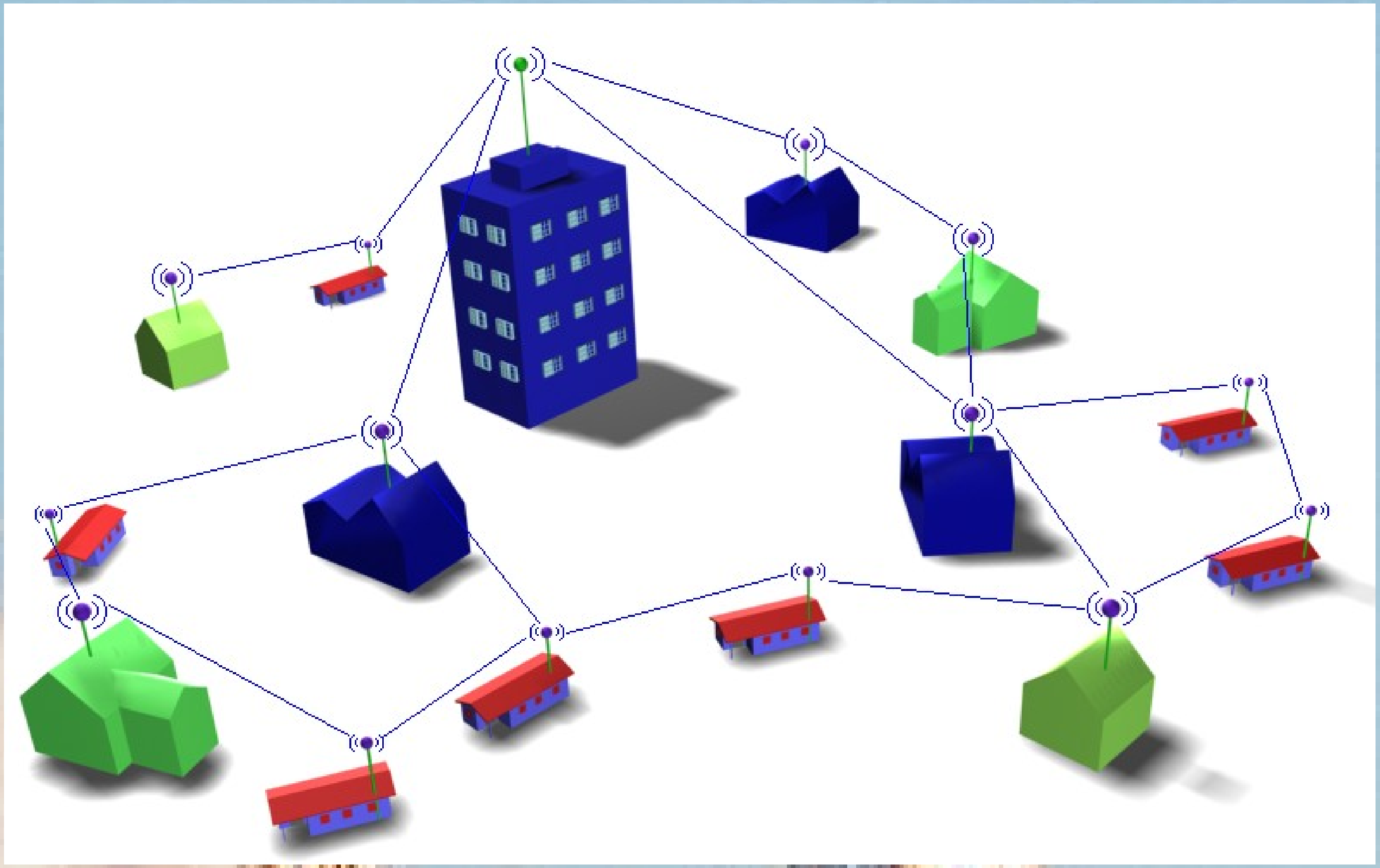
Point to Point topology



Point to Multipoint topology



Mesh Topology



Example of Mesh

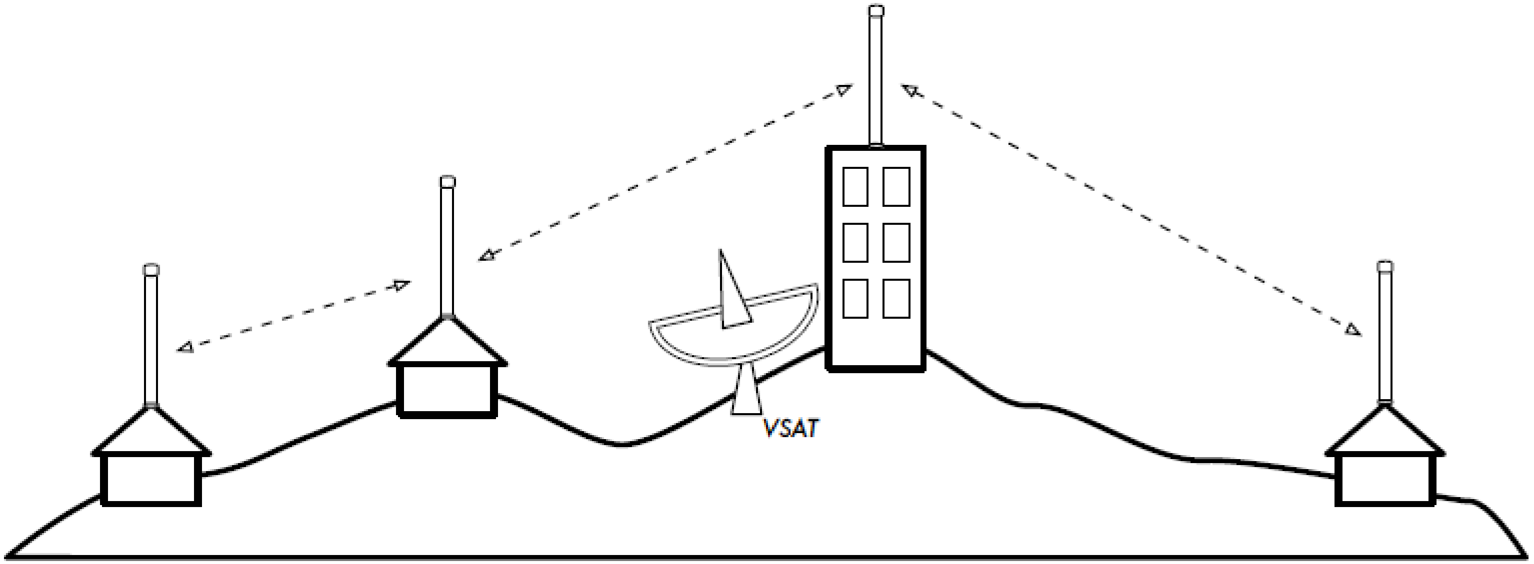


Figure 3.3: A multipoint-to-multipoint mesh. Every point can reach each other at very high speed, or use the central VSAT connection to reach the Internet.

Limitations of Mesh

- Two big disadvantages to this topology are increased complexity and lower performance. Security in such a network is also a concern, since every participant potentially carries the traffic of every other.
- There is no standard yet, although IEEE 802.11s group is working on it.
- Additional overhead needed for managing the network routing and increased contention in the radio spectrum.

Routing Protocols for Mesh

- ***Hazy Sighted Link State*** (***HSLS***)
- ***Ad-hoc On-demand Distance Vector*** (***AODV***)
- **DSR** uses source routing. It is also an on-demand protocol that allows nodes to find out a route over a network dynamically. All the packet headers of DSR contain a complete list of nodes through which they will pass to reach their destination.

- ***Optimized Link State Routing*** (***OLSR***).
- ***SrcRR***, a combination of DSR and ETX implemented by the M.I.T. Roofnet project.

Mesh routing with olsrd

The Optimized Link State Routing Daemon - olsrd - from *olsr.org* is a routing application developed for routing in wireless networks. We will concentrate on this routing software for several reasons. It is a open-source project that supports Mac OS X, Windows 98, 2000, XP, Linux, FreeBSD, OpenBSD and NetBSD. Olsrd is available for access points that run Linux like the Linksys WRT54G, Asus Wl500g, AccessCube or Pocket PCs running Familiar Linux, and ships standard on Metrix kits running Metrix Pebble. Olsrd can handle multiple interfaces and is extensible with plug-ins. It supports IPv6 and it is actively developed and used by community networks all over the world.

Mesh routing with olsrd

After olsrd is running for a while, a node knows about the existence of every other node in the mesh cloud and which nodes may be used to route traffic to them. Each node maintains a routing table covering the whole mesh cloud. This approach to mesh routing is called ***proactive routing***. In contrast, ***reactive routing*** algorithms seek routes only when it is necessary to send data to a specific node.

There are pros and cons to proactive routing, and there are many other ideas about how to do mesh routing that may be worth mentioning. The biggest advantage of proactive routing is that you know who is out there and you don't have to wait until a route is found. Higher protocol traffic overhead and more CPU load are among the disadvantages.

Mesh routing with olsrd

A node running olsrd is constantly broadcasting 'Hello' messages at a given interval so neighbours can detect it's presence. Every node computes a statistic how many 'Hellos' have been lost or received from each neighbour - thereby gaining information about the topology and link quality of nodes in the neighbourhood. The gained topology information is broadcasted as topology control messages (TC messages) and forwarded by neighbours that olsrd has chosen to be 'multipoint' relays.

The concept of multipoint relays is a new idea in proactive routing that came up with the OLSR draft. If every node rebroadcasts topology information that it has received, unnecessary overhead can be generated. Such transmissions are redundant if a node has many neighbours. Thus, an olsrd node decides which neighbours are favorable multipoint relays that should forward its topology control messages. Note that multipoint relays are only chosen for the purpose of forwarding TC messages. Payload is routed considering all available nodes. See the wndw book for details on how to implement a mesh network with olsdr

Mesh vs. Single-hop Networks

Mesh networking (also called "multi-hop" networking) is a flexible architecture for moving data efficiently between devices. In a traditional wireless LAN, multiple clients access the network through a direct wireless link to an access point (AP); this is a "single-hop" network. In a multi-hop network, any device with a radio link can serve as a router or AP. If the nearest AP is congested, data is routed to the closest low-traffic node. Data continues to "hop" from one node to the next in this manner, until it reaches its final destination.

Mesh networks have some key advantages over their single-hop counterparts. Three key advantages include robustness, higher bandwidth, and spatial reuse

Robustness

- Mesh is more robust than single-hop networks because it is not dependent on the performance of one node for its operation. In a single-hop network, if the sole access point goes down, so does the network. In mesh network architecture, if the nearest AP is down or there is localized interference, the network will continue to operate; data will simply be routed along an alternate path.
- Another way to achieve robustness is by using multiple routes to deliver data. A good example is e-mail, which is divided into data packets that are sent across the Internet via multiple routes then reassembled into a coherent message that arrives in the recipient's mailbox. Using multiple routes to deliver data increases the effective bandwidth of the network

Higher bandwidth

- The physics of wireless communication dictate that bandwidth is higher at shorter range, because of interference and other factors that contribute to loss of data as distance increases. One way to get more bandwidth out of the network, is to transmit data across multiple short hops. That's what a mesh network does.
- Additionally, because little power is required to transmit data over short distances, a mesh network can support higher bandwidth overall despite FCC regulations that limit maximum transmission power.
- Moreover, several points of connection to the Internet can be distributed among the nodes providing additional bandwidth

Spatial reuse

- Spatial reuse is another benefit of mesh over single-hop networks. As noted earlier, in a single-hop network, devices must share an AP. If several devices attempt to access the network at once, a virtual traffic jam occurs and the system slows. By contrast, in a multi-hop network, many devices can connect to the network at the same time, through different nodes, without necessarily degrading system performance. The shorter transmission ranges in a mesh network limit interference, allowing simultaneous, spatially separated, data flows

Technical Justification

In an urban environment, the free space loss model does not apply and the attenuation of the signal is governed by a power law exponent different from 2

Path loss is highly variable for wireless broadband

- Typically driven largely by obstacles
- Leads to the "Log-Normal" path loss model:

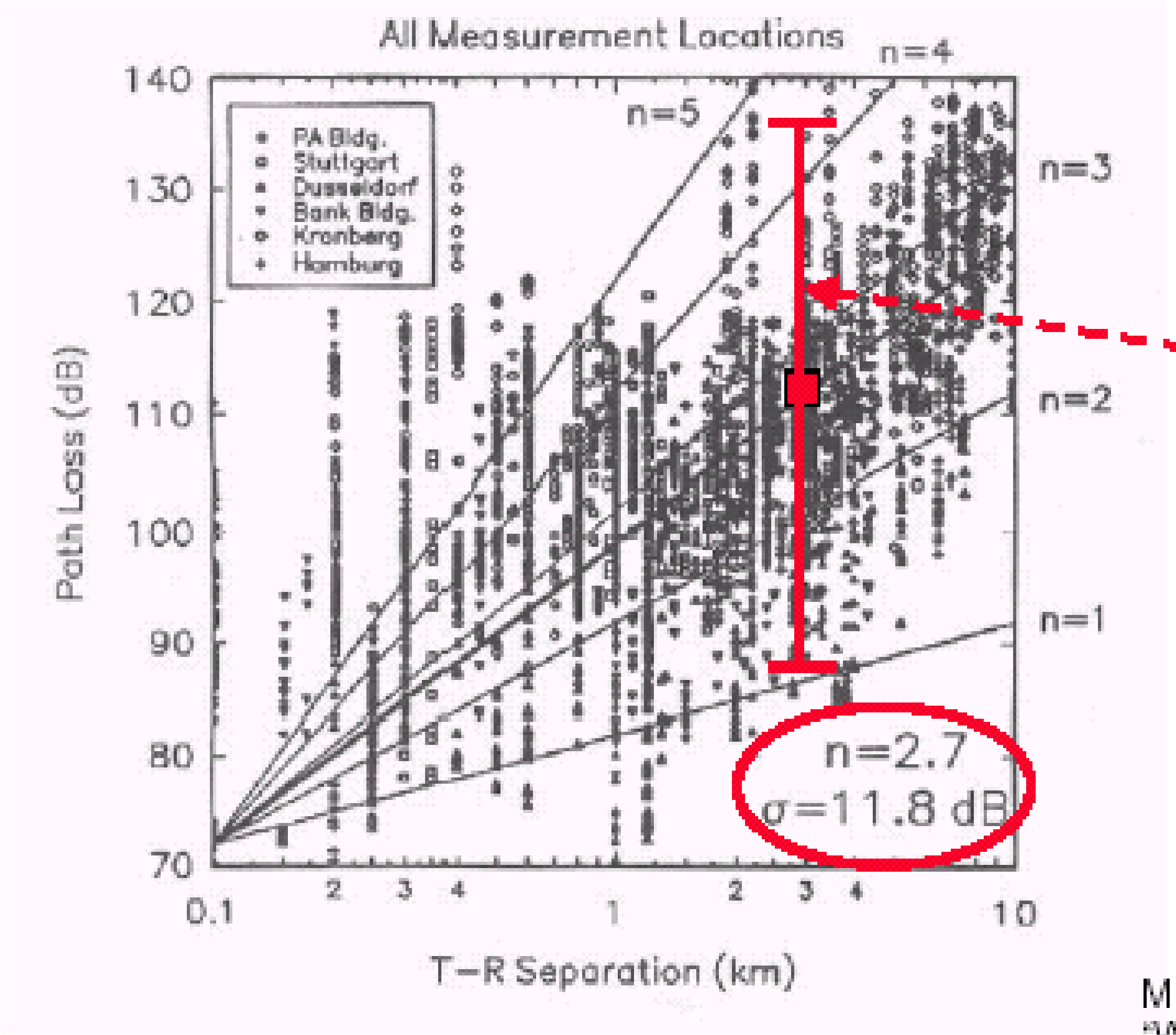
$$C + 10 \cdot n \cdot \log_{10}(\text{dist}) + X_\sigma$$

random variable X_σ with standard deviation σ

In PMP networks, large σ is bad

- Must design for worst-case; e.g., leads to $1/r^4$ or $1/r^5$ models

RF Path Loss Environment

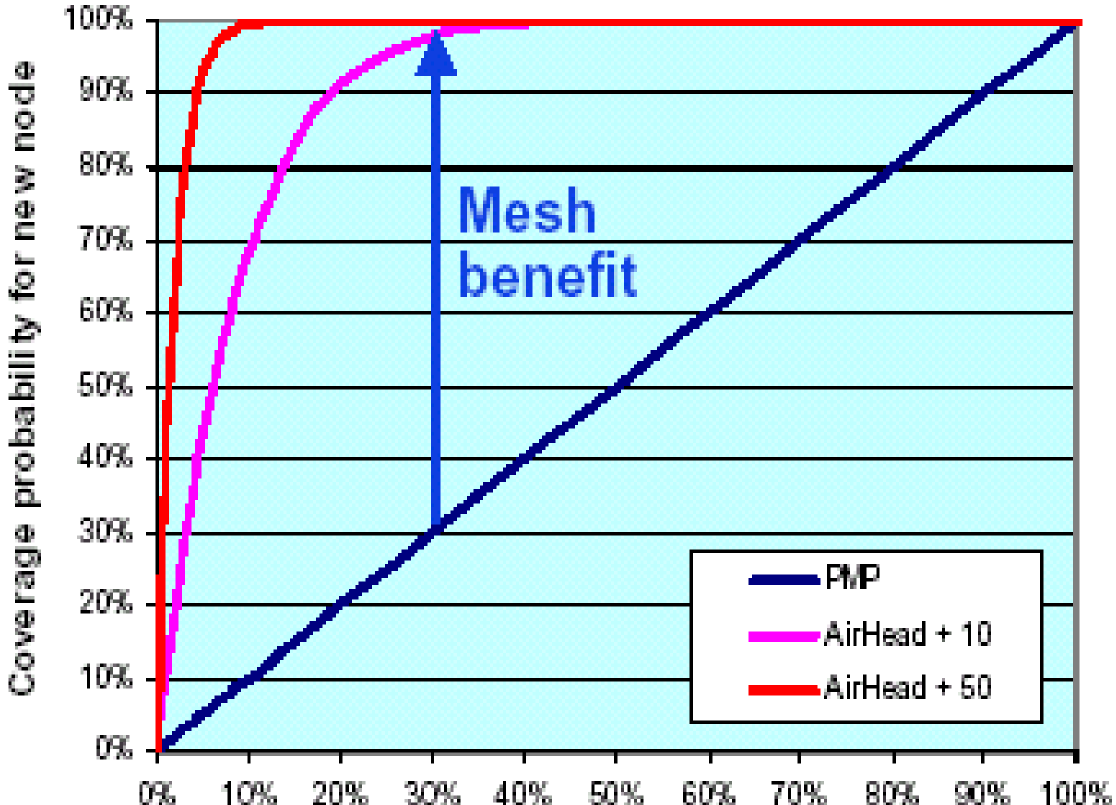


Measurement Data Source:
"Wireless Communications"
by Ted Rappaport, 1999

Solving Coverage Simplified Model

Assume standard deviation completely dominates

- Chance of a link between any pair of devices simplifies to a fixed link probability: z

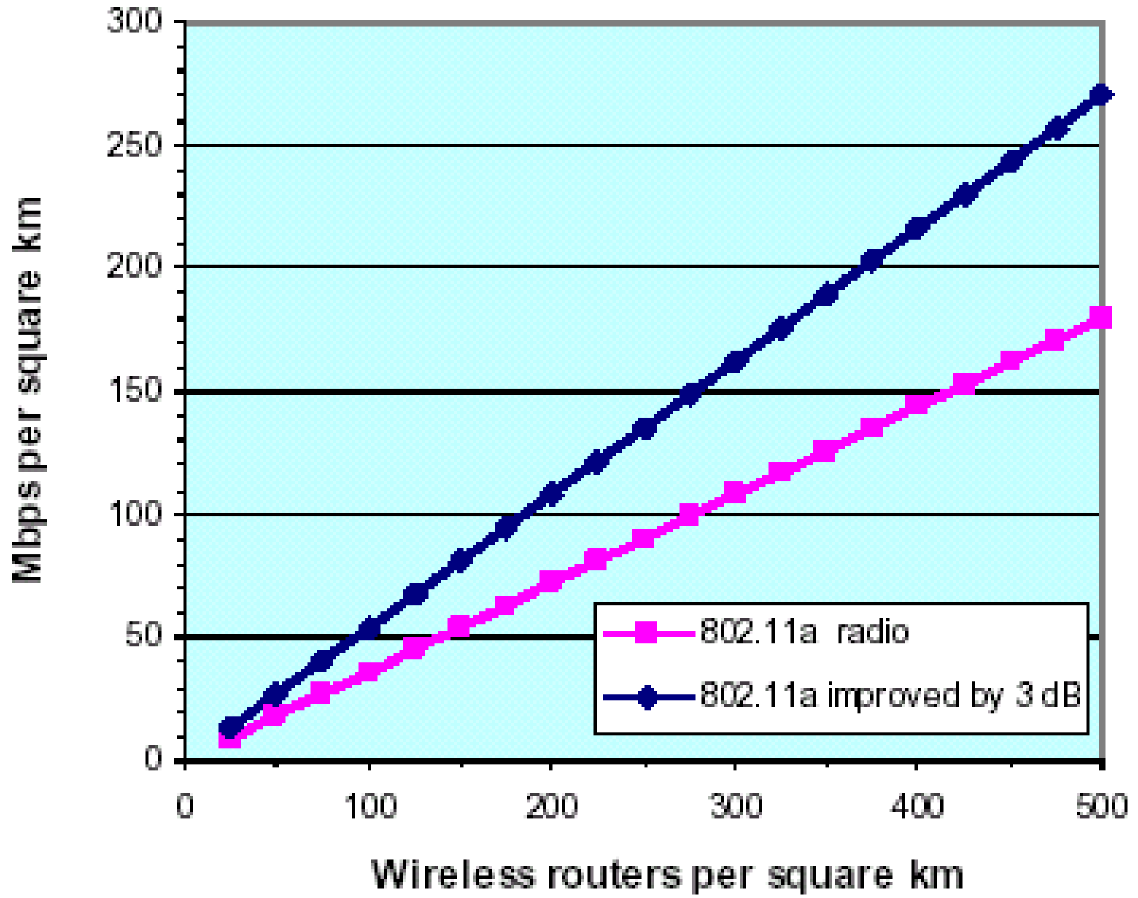


m-device mesh coverage probability $= 1 - (1 - z)^m$

Mesh coverage & robustness improve *exponentially* as subscribers are added

Scaling with Mesh Networks

- 4 channels per "cell" reused in each cell
- Average path loss $1/r^3$ active links $1/r^{2.5}$
- 802.11a-type radios



Mesh User Throughput Over Multiple-hop Paths

Simple example:

- $1/r^3$ path-loss & common noise environment
- Standard-compliant, .16a OFDM radios, 20 MHz BW

Which gives higher user throughput?

- Direct path, or
- Two-hop path?

Mesh User Throughput Over Multiple-hop Paths

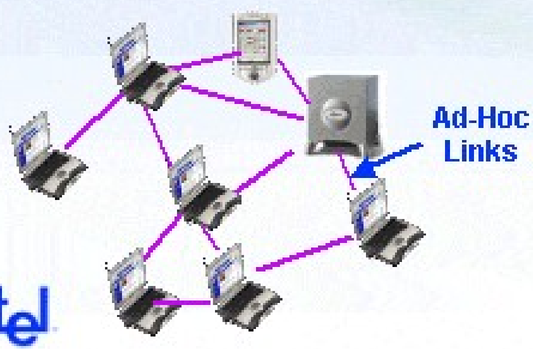
Mesh nodes adapt waveform on per-link basis

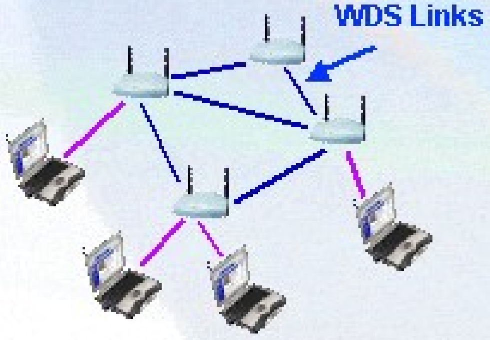
- If direct link supports QPSK ½ (16 Mbps) waveform, then
- Shorter links will use 16QAM ¾ (48 Mbps) due to 9 dB less path loss

16 Mbps over direct path; 24 Mbps over two-hop path

Example Mesh Architectures

- Ad-hoc IBSS (layer3) mesh
  - Flat network; all devices in ad-hoc mode
  - No distinction between APs and client
  - Layer3 IP routing
- Infrastructure ESS (layer2) Mesh
  - WDS backhaul between APs
  - Client devices associate with APs
    - Need not be aware of the mesh
  - Layer2 MAC routing





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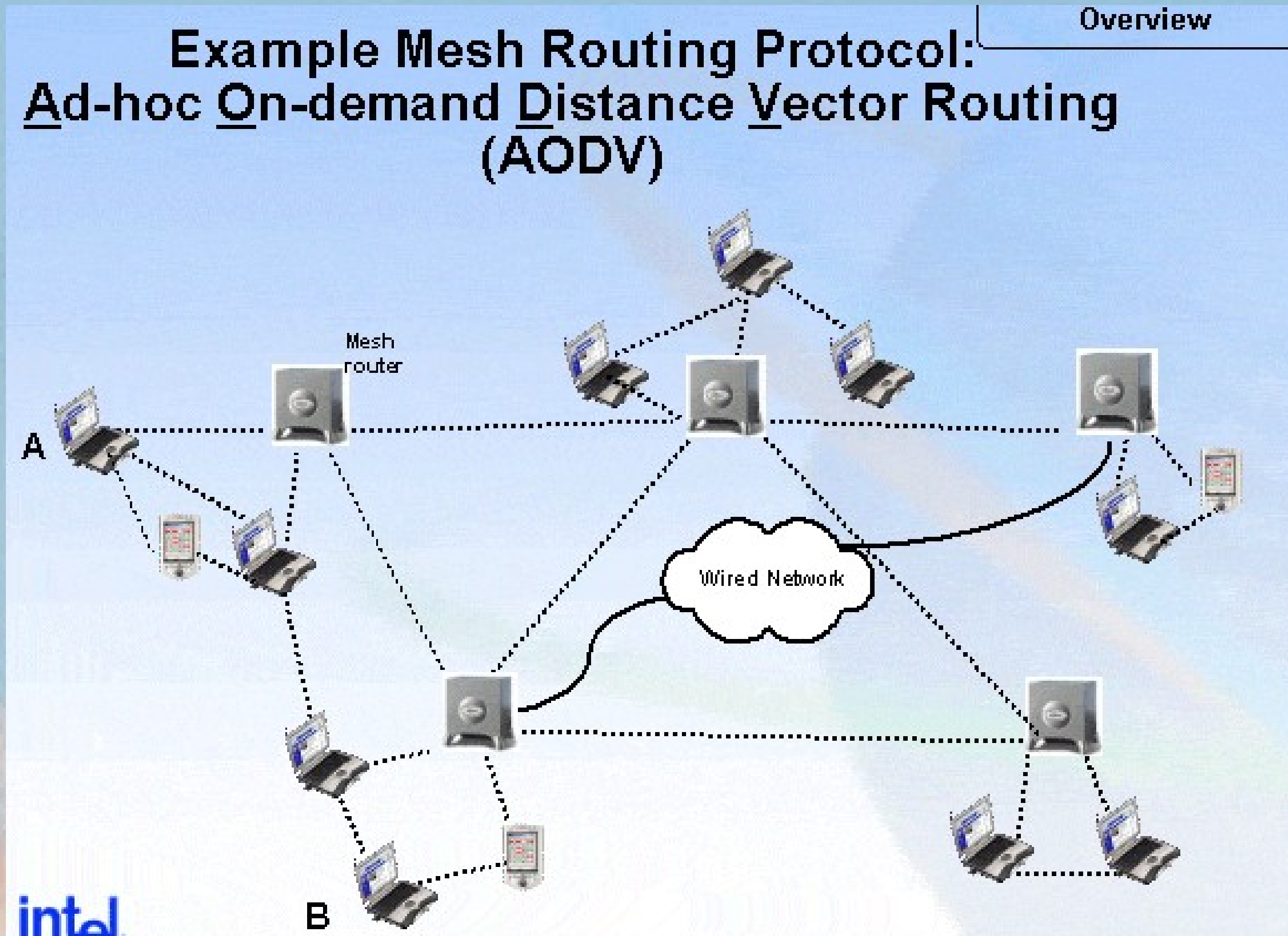
Mesh Networking: How Does It Work?

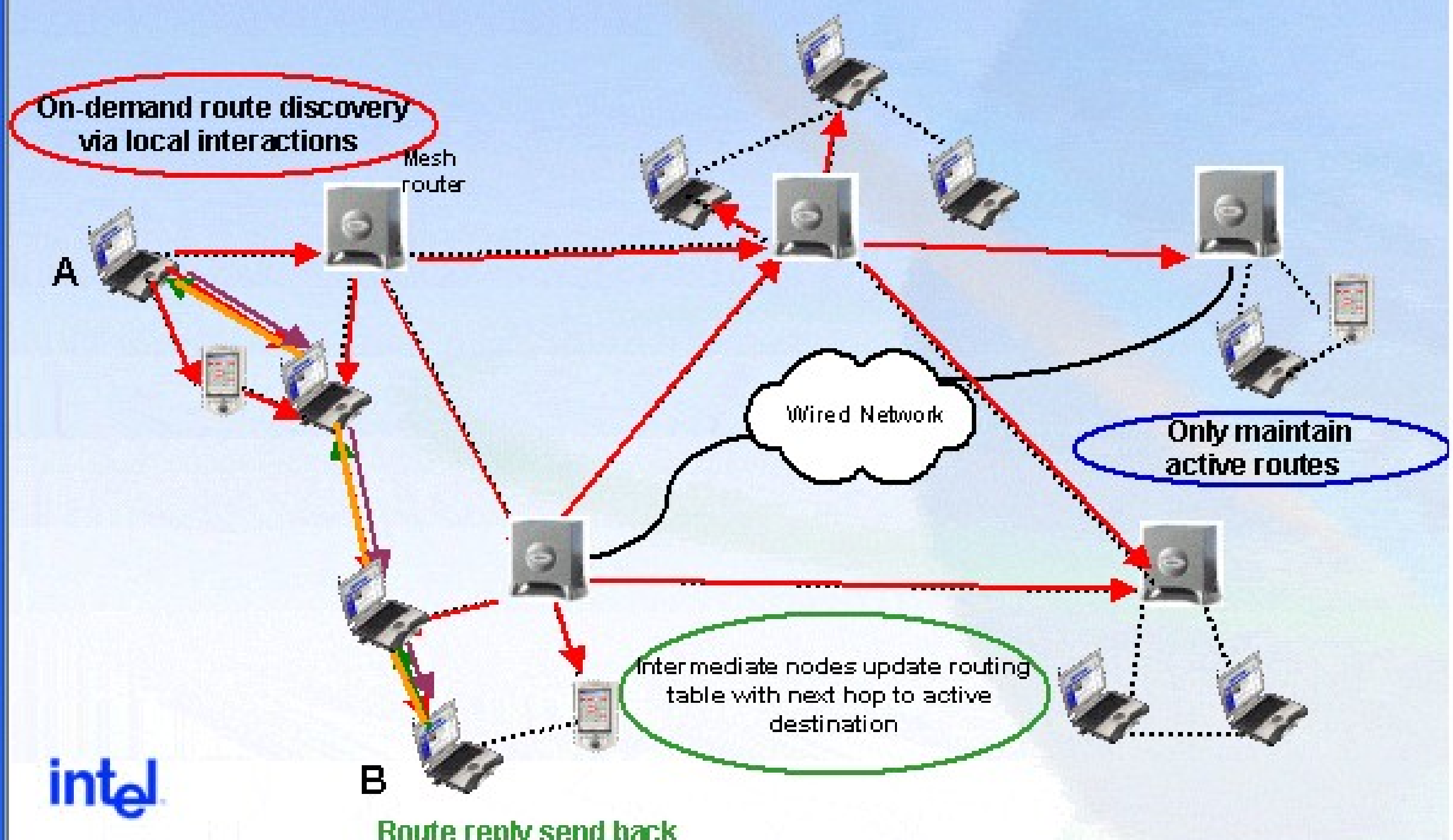
Co-operation between multiple radios using existing standards

- Nodes leverage neighbors to route messages across multiple hops
- IEEE 802.11 MAC
  - Implemented today with standard 802.11 MAC
  - MAC tuning to improve performance
- Mesh Routing to select network paths
  - Several routing protocols standardized by IETF
    - Dynamic Source Routing (DSR)
    - Optimized Link State Routing (OLSR)
    - Ad-Hoc On Demand Distance Vector (AODV)
  - Can be implemented in Layer 2 or 3


Overview
Example Mesh Routing Protocol:
Ad-hoc On-demand Distance Vector Routing
(AODV)
Mesh
router
A
Wired Network
intel
B

Overview

Example Mesh Routing Protocol: Ad-hoc On-demand Distance Vector Routing (AODV)



Advantages Of Mesh Networks

Reduced cost

- less wired infrastructure
- ease of installation

Extended range and coverage

- beyond wired infrastructure

Potential for energy efficiency

- low transmit power

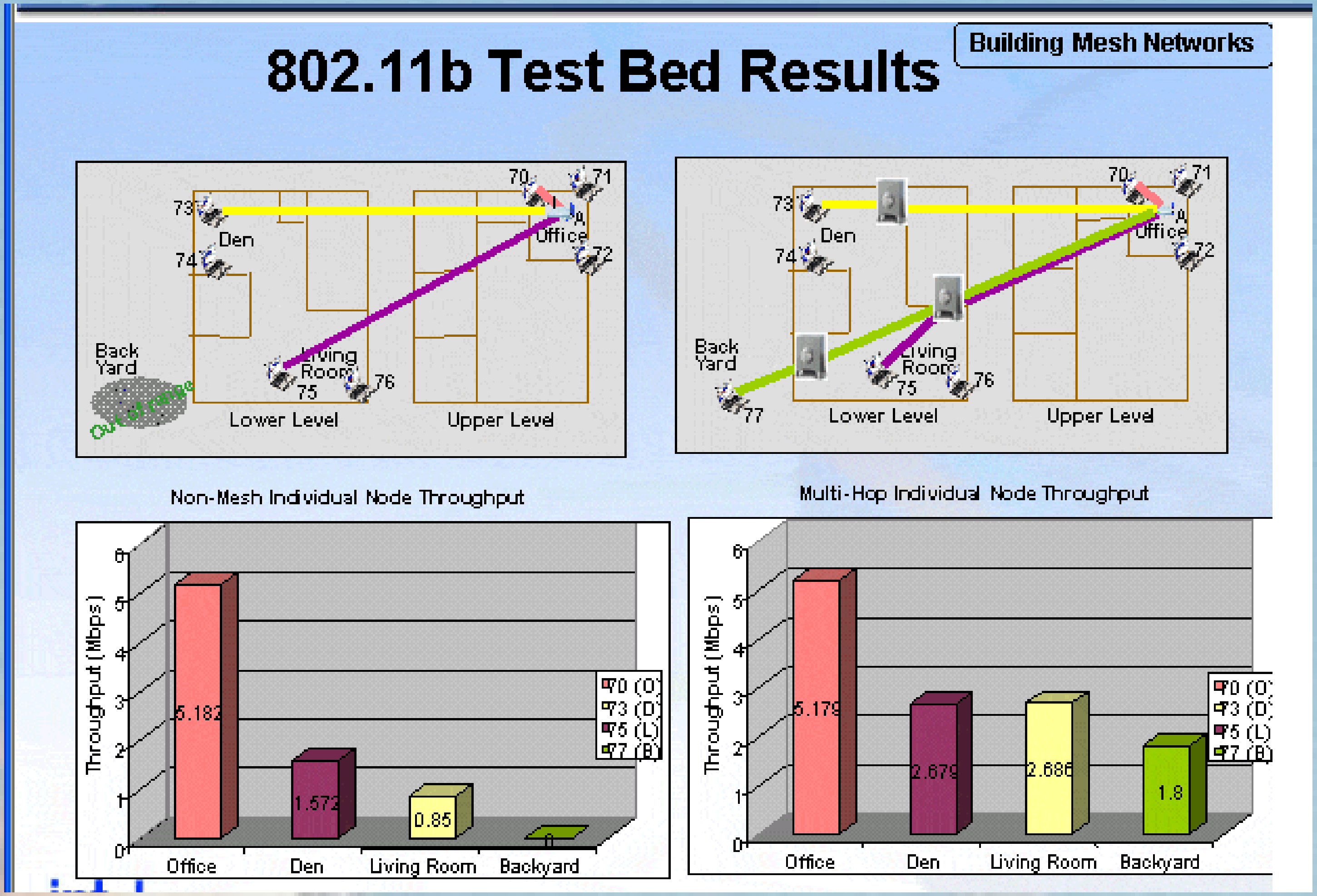
Robustness

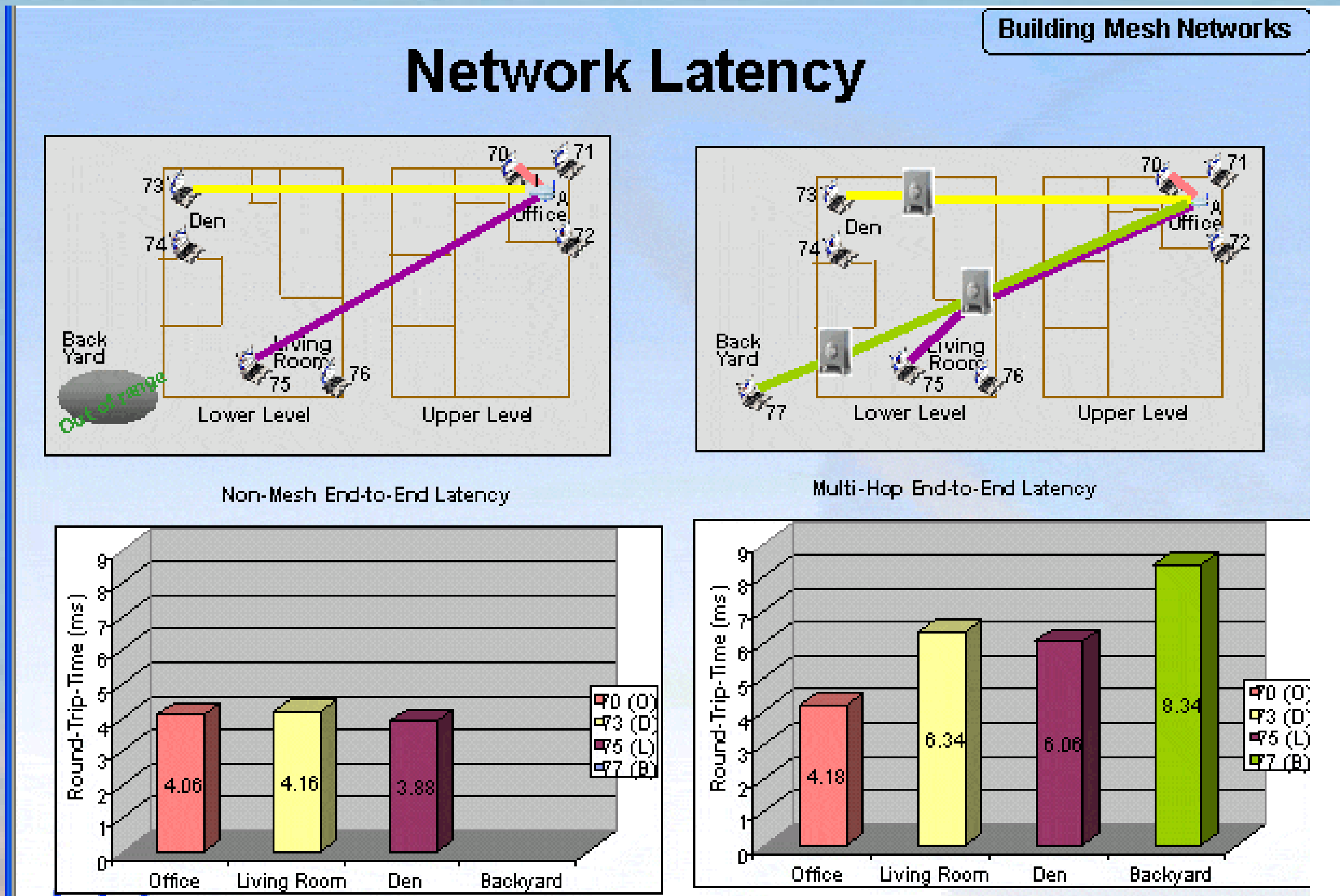
- multiple (redundant) communication paths

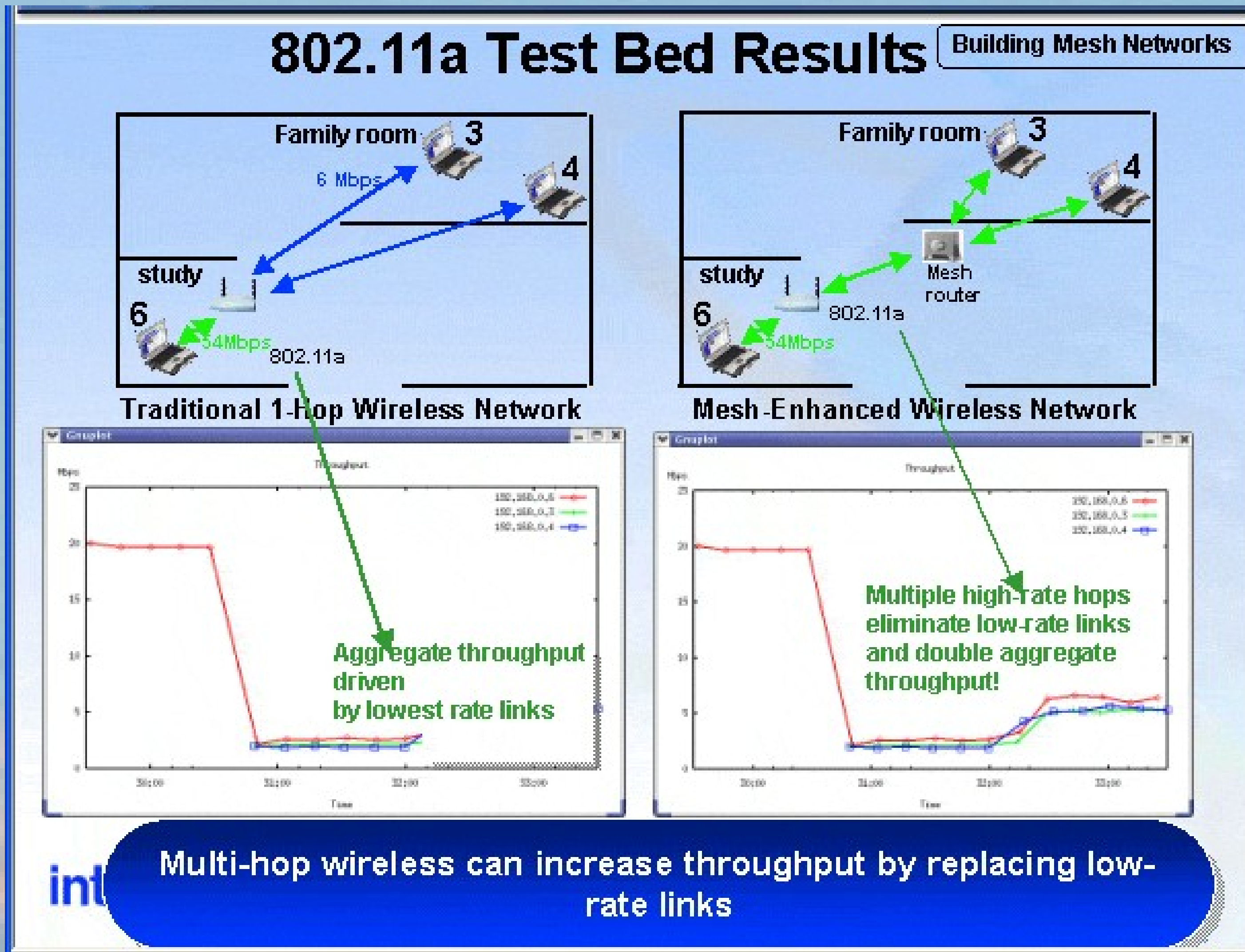
Potential for performance improvement

- throughput and capacity

802.11b Test Bed Results



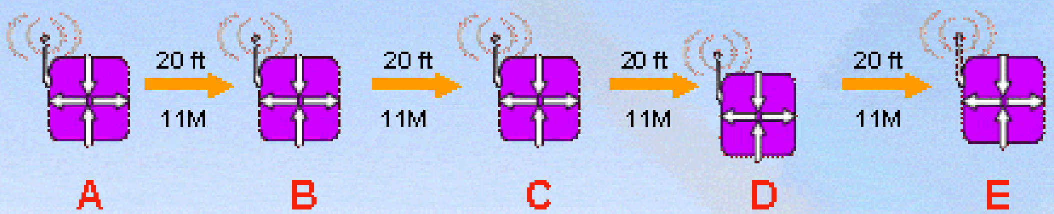

Building Mesh Networks
Network Latency
70
71
73
Den
74
72
Office
Back Yard
Out of range
Living Room
75
76
77
Lower Level
Upper Level
Non-Mesh End-to-End Latency
Multi-Hop End-to-End Latency
Round-Trip-Time (ms)
4.06
4.16
3.88
4.18
6.34
6.06
8.34
Office
Living Room
Den
Backyard
70 (O)
73 (D)
75 (L)
77 (B)


802.11a Test Bed Results
Building Mesh Networks
Family room
3
4
6 Mbps
study
6
54Mbps
802.11a
Traditional 1-Hop Wireless Network
Family room
3
4
Mesh router
study
6
802.11a
54Mbps
Mesh-Enhanced Wireless Network
Aggregate throughput driven by lowest rate links
Multiple high-rate hops eliminate low-rate links and double aggregate throughput!
Multi-hop wireless can increase throughput by replacing low-rate links

Ongoing Research

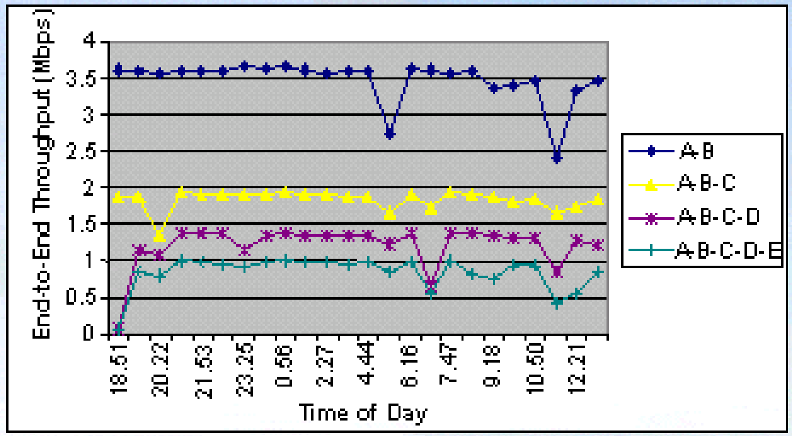
Test-bed Results

End-to-End Throughput In A Multi-Hop Chain



Average Throughput:

A-B	3.48 Mbps
A-B-C	1.83 Mbps
A-B-C-D	1.21 Mbps
A-B-C-D-E	0.83 Mbps



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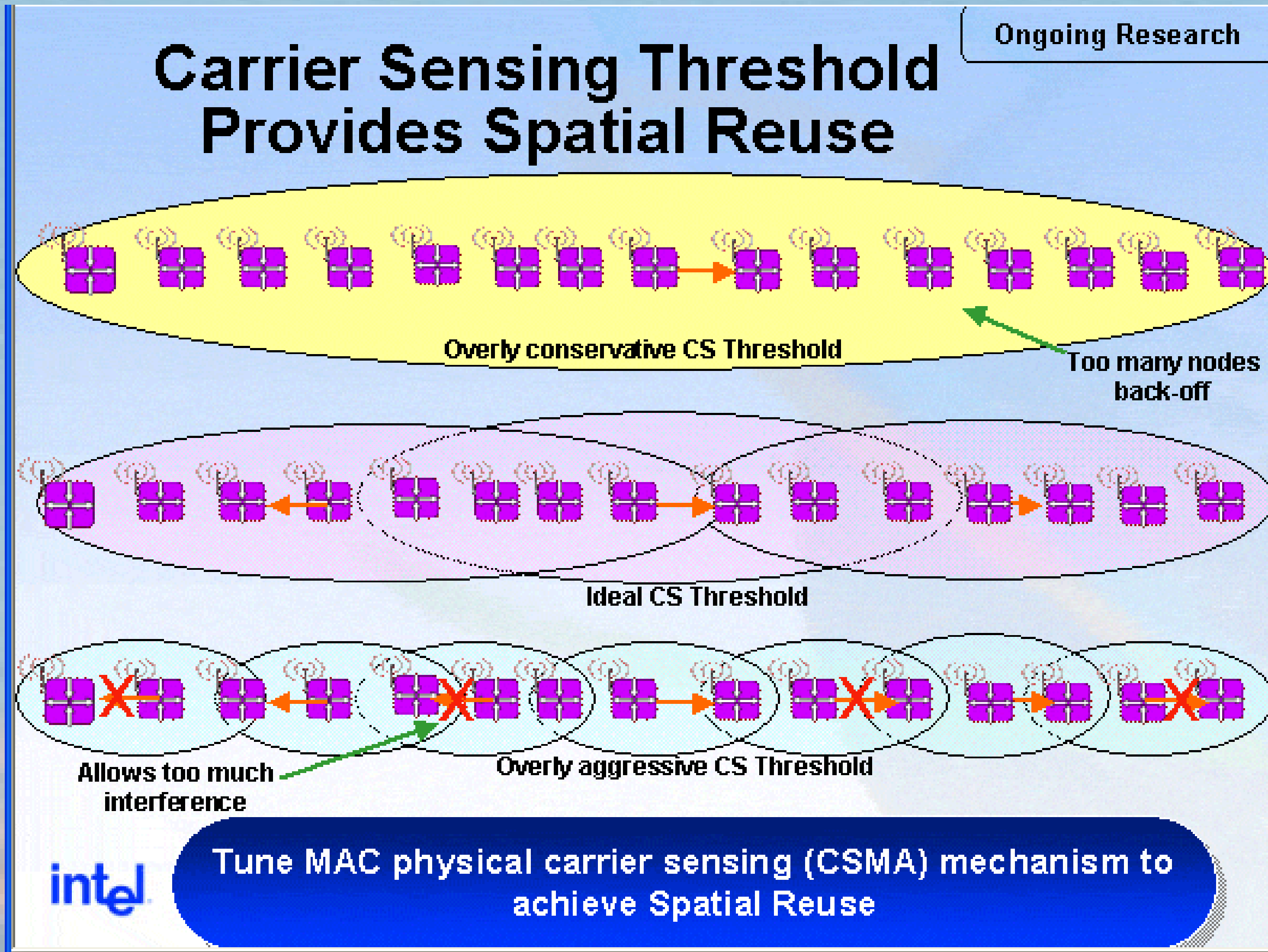
802.11 MAC protocol limits full exploitation of multi-hop throughput


Ongoing Research
Carrier Sensing Threshold
Provides Spatial Reuse
Overly conservative CS Threshold
Too many nodes
back-off
Ideal CS Threshold
Allows too much
interference
Overly aggressive CS Threshold
intel
Tune MAC physical carrier sensing (CSMA) mechanism to
achieve Spatial Reuse

Commercial Mesh Networks

Nortel from Canada has several mesh networks installed, the biggest covering the whole city of Taipei in Taiwan, but now Golden Telecom will Launch Moscow's First Wireless Mesh Network with Nortel Solution Network Covers 3.9 Million Moscow Households **MAY 02, 2006**

Mesh Networks from Maitland, Fla. In U.S.A, is still offering its own solution, as is Tropos from California, along with a number of other vendors, including Intel.

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Mesh Networks

. Locust World Mesh offers a freely downloadable Linux based software that implements the idea on any available computer with wireless cards which allows for a very inexpensive set up.

They also offer a Linux box with preinstalled software with wireless 802.11b

and antenna for $400

http://www.linuxdevices.com/files/misc/meshbox.gif

http://www.locustworld.com/

DIY Mesh Networks

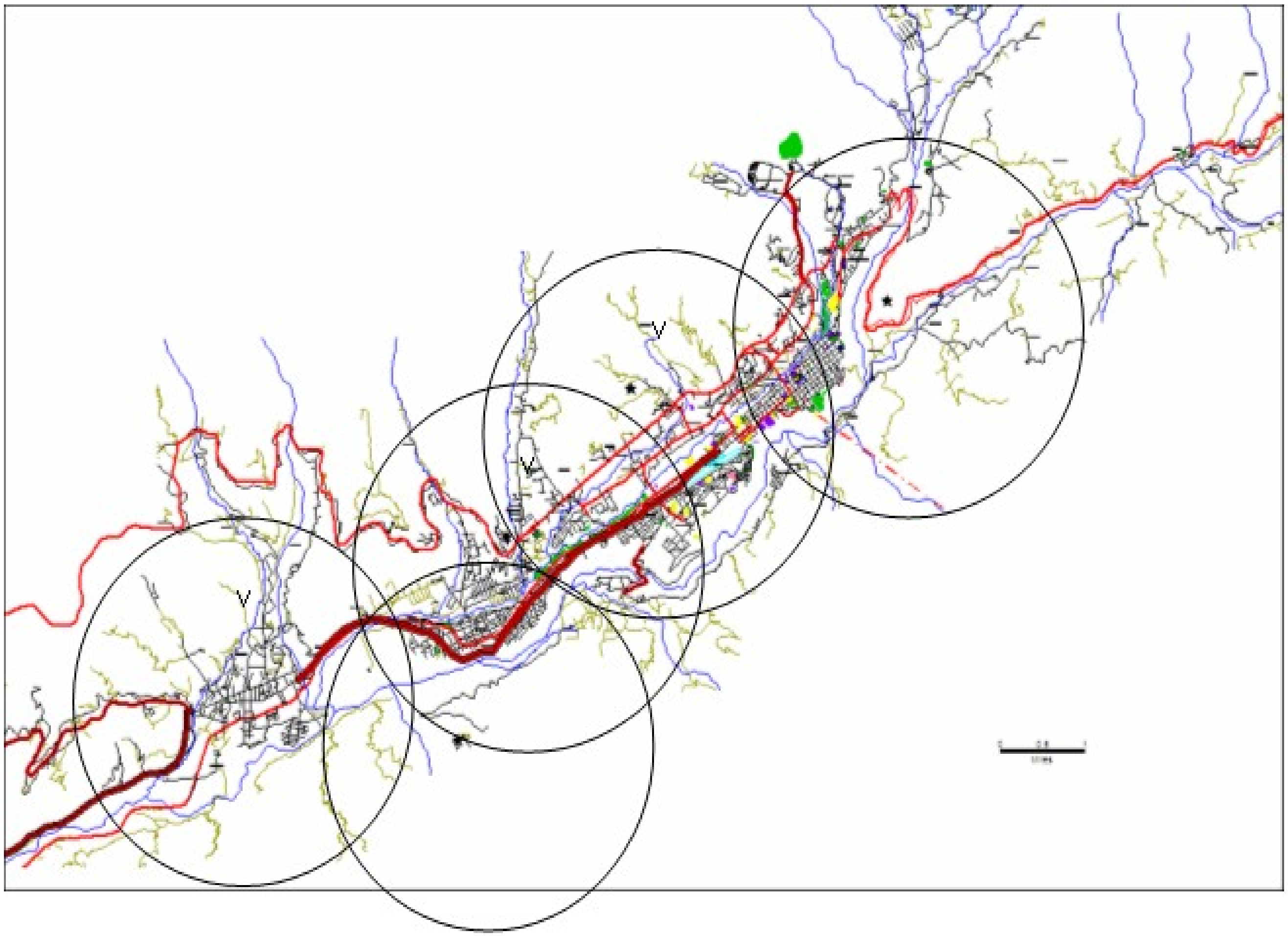
- Using any available computer
- PCI-Radio and external antenna $50
- Homemade omni ant. or cantenna, pigtail
- Ultramesh.com also offers commercial 12 dBi omni for $90

DIY Mesh Networks

- Linux kernel with Mesh software (open source) LocustWorld, implements AODV
- Freifunk firmware for Linksys WRT54 and other consumer type wireless routers. Implements OLSDR
- Cu-Win project at University of Urbana-Champain in Illinois,USA. Live distribution of BSD with embedded high efficiency Mesh Protocol

Proposed Mesh Network for Merida

Red Teleinformática de Ciencia, Tecnología e Innovación del Estado Mérida (RETICyT)



References

- “Ad Hoc On Demand Distance Vector (AODV) Routing”, 2001
- http://www.ietf.org/internet-drafts/draft-ietf-manet-aodv-08.txt
- IETF, Manet Group
- www.nortel.com
- “The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks”, 2001
- http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-05.txt
- Mobile Mesh Home Page
- http://www.mitre.org/tech_transfer/mobilemesh.html
- **Performance Evaluation of Important Ad Hoc Network Protocols by S. Ahmed and M. S. Alam** EURASIP Journal on Wireless Communications and Networking Volume 2006, Article ID 78645, Pages 1–11 DOI 10.1155/WCN/2006/78645
- **Freifunk**firmware in English: http://freifunk.net/wiki/FreifunkFirmwareEnglish