Mesh Networks

Abdus Salam ICTP, February 2004

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Outline

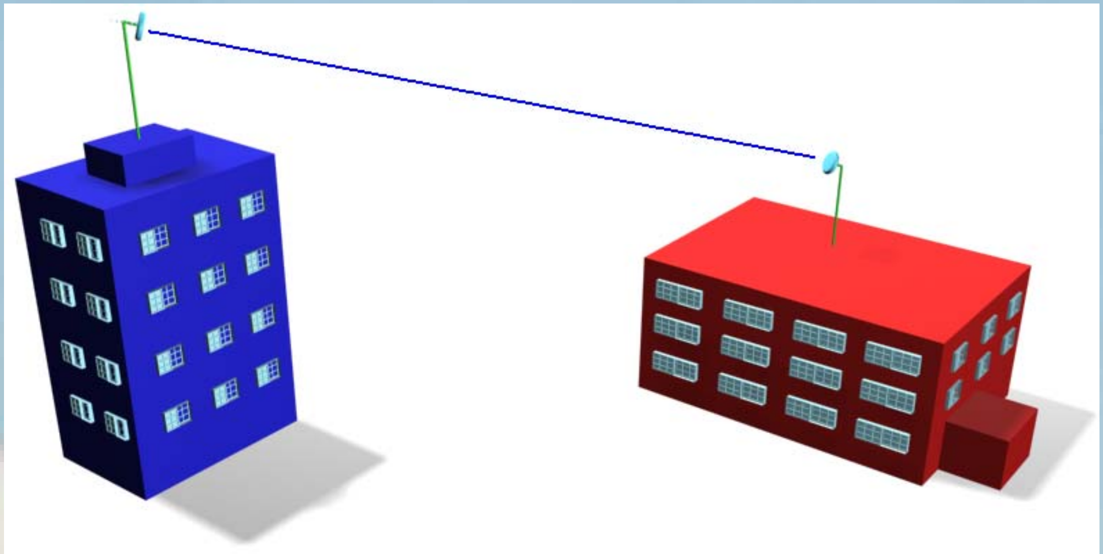
- Network Topology
- Mesh Vs Single Hop Networks
- Technical justification
- Commercial examples
- Open Source solutions
- Example of application

Mesh Networks

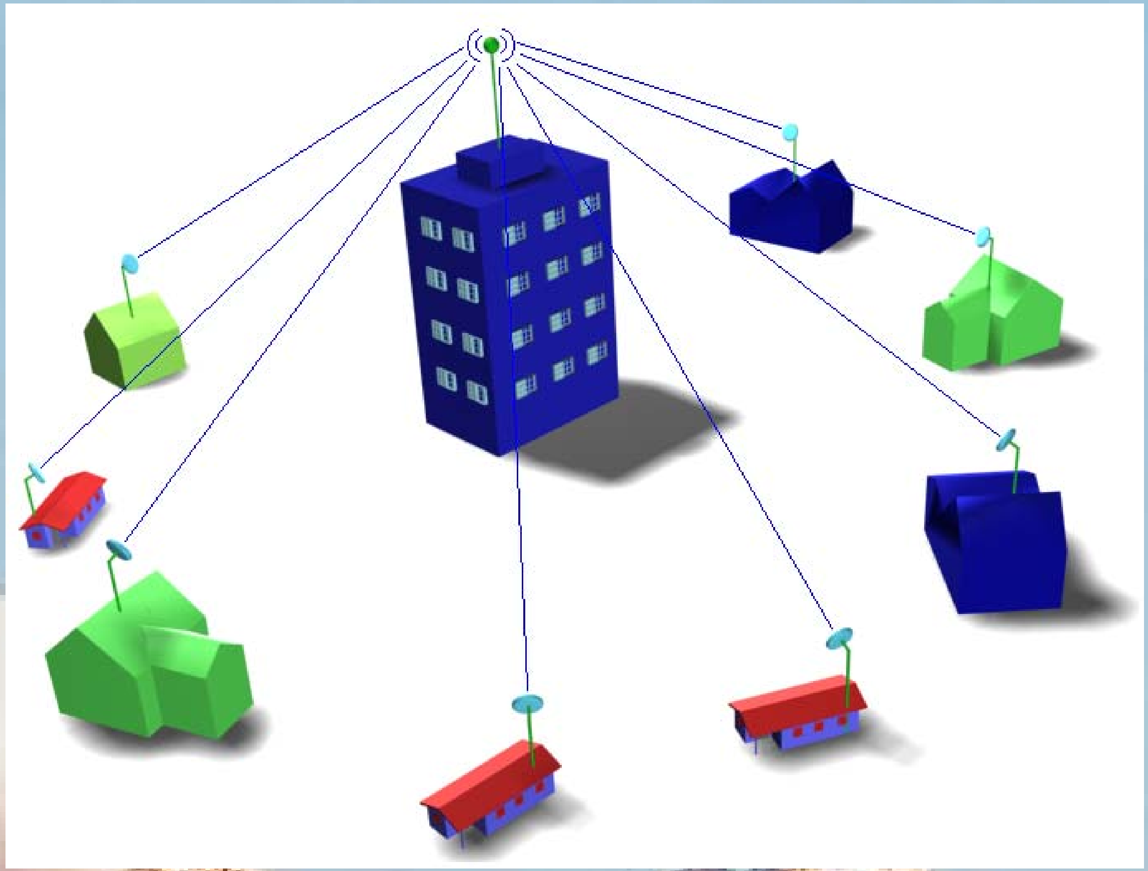
Mesh Networks, also known as *ad hoc* networks, are those in which each node supplies connectivity to adjacent nodes.

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.

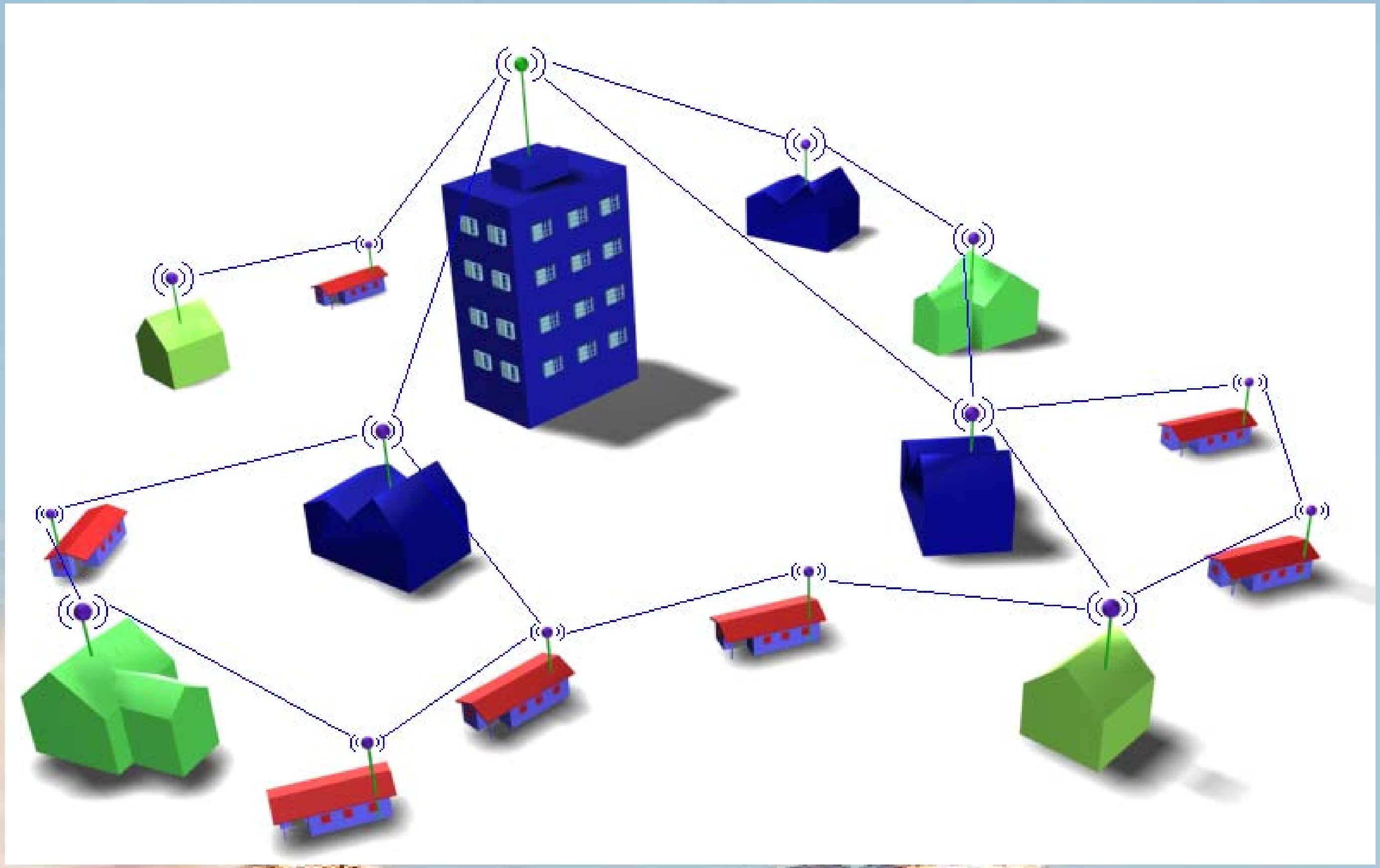
Point to Point topology



Point to Multipoint topology



Mesh Topology



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:

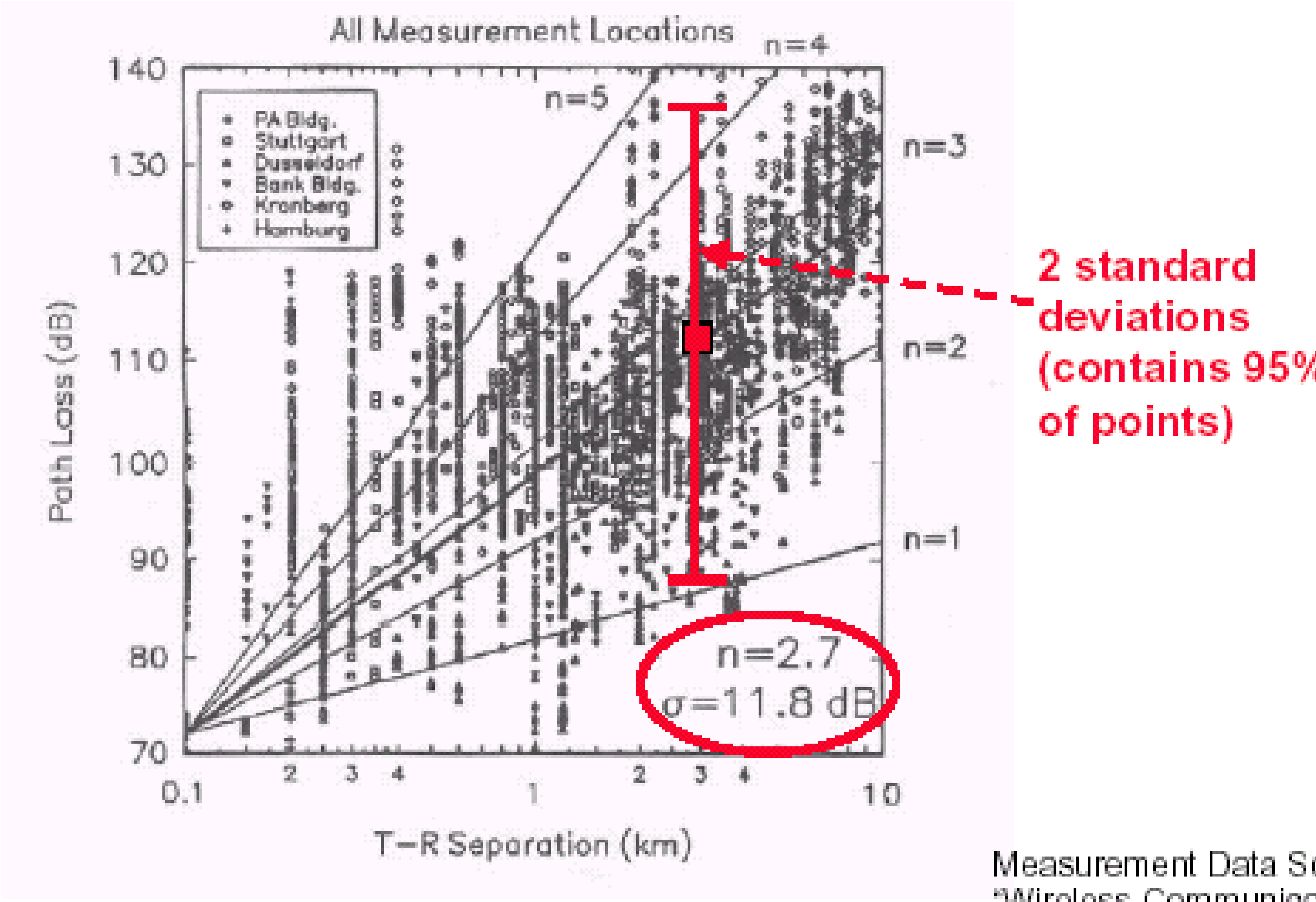
$$C + 10 \cdot n \cdot \log_{10}(\text{dist}) + X_\sigma$$

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

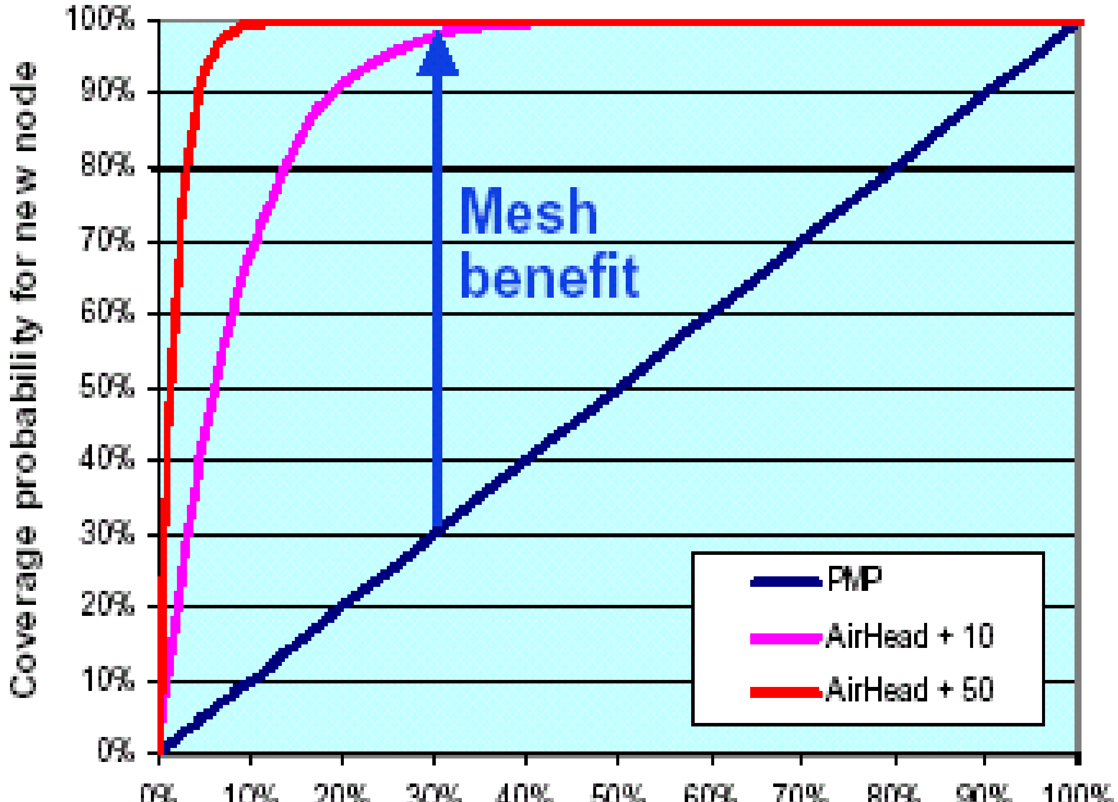


Measurement Data Source:
"Wireless Communications"
by Ted Rappaport, 1999

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

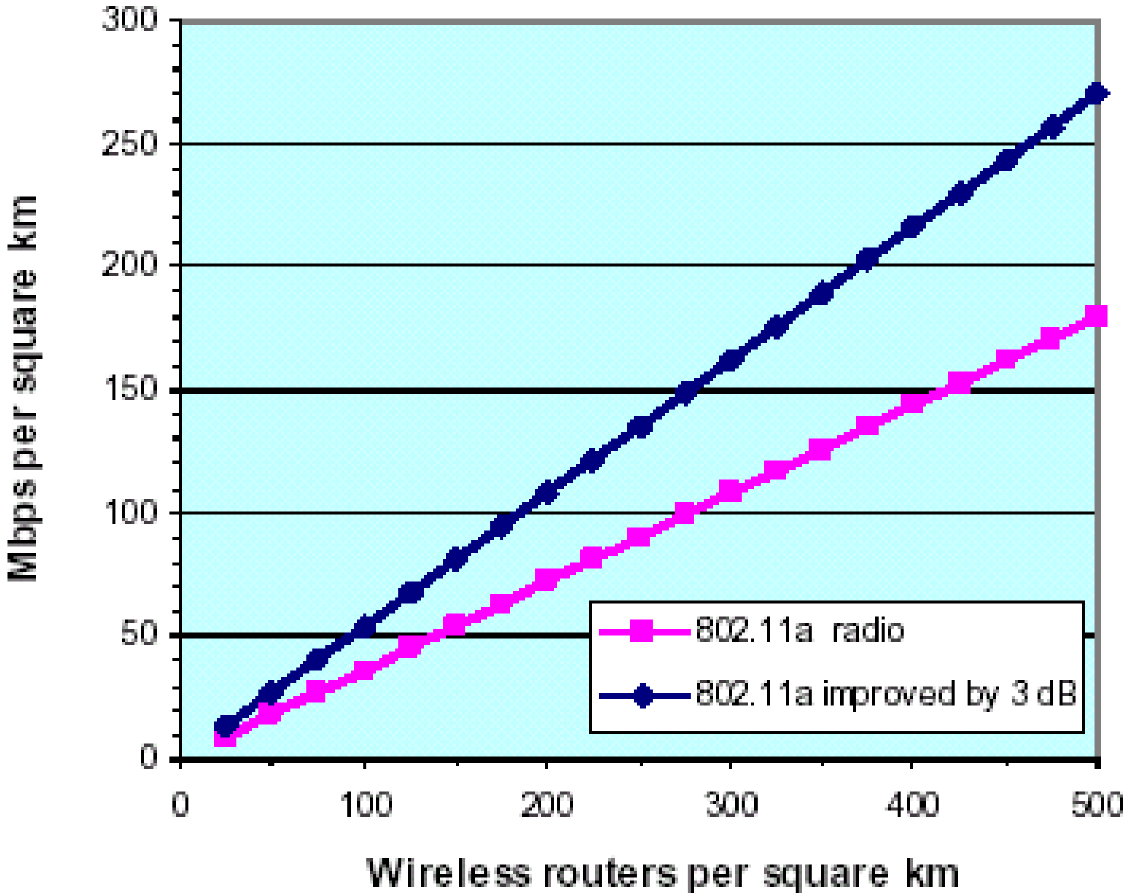


m-device mesh coverage probability = $1 - (1 - z)^{m}$

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

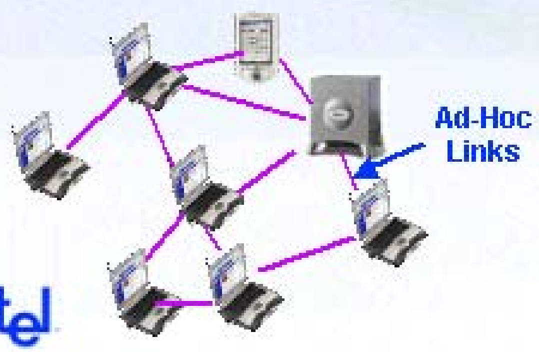
Mesh nodes adapt waveform on per-link basis

- 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

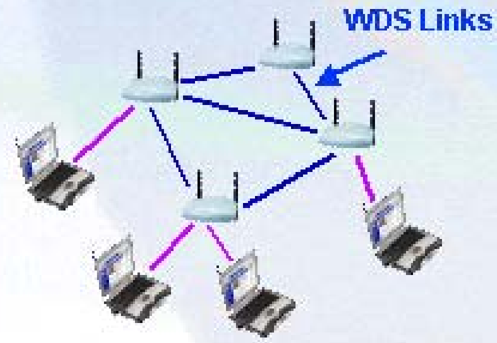
16 Mbps over direct path; 24 Mbps over two-hop path

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?

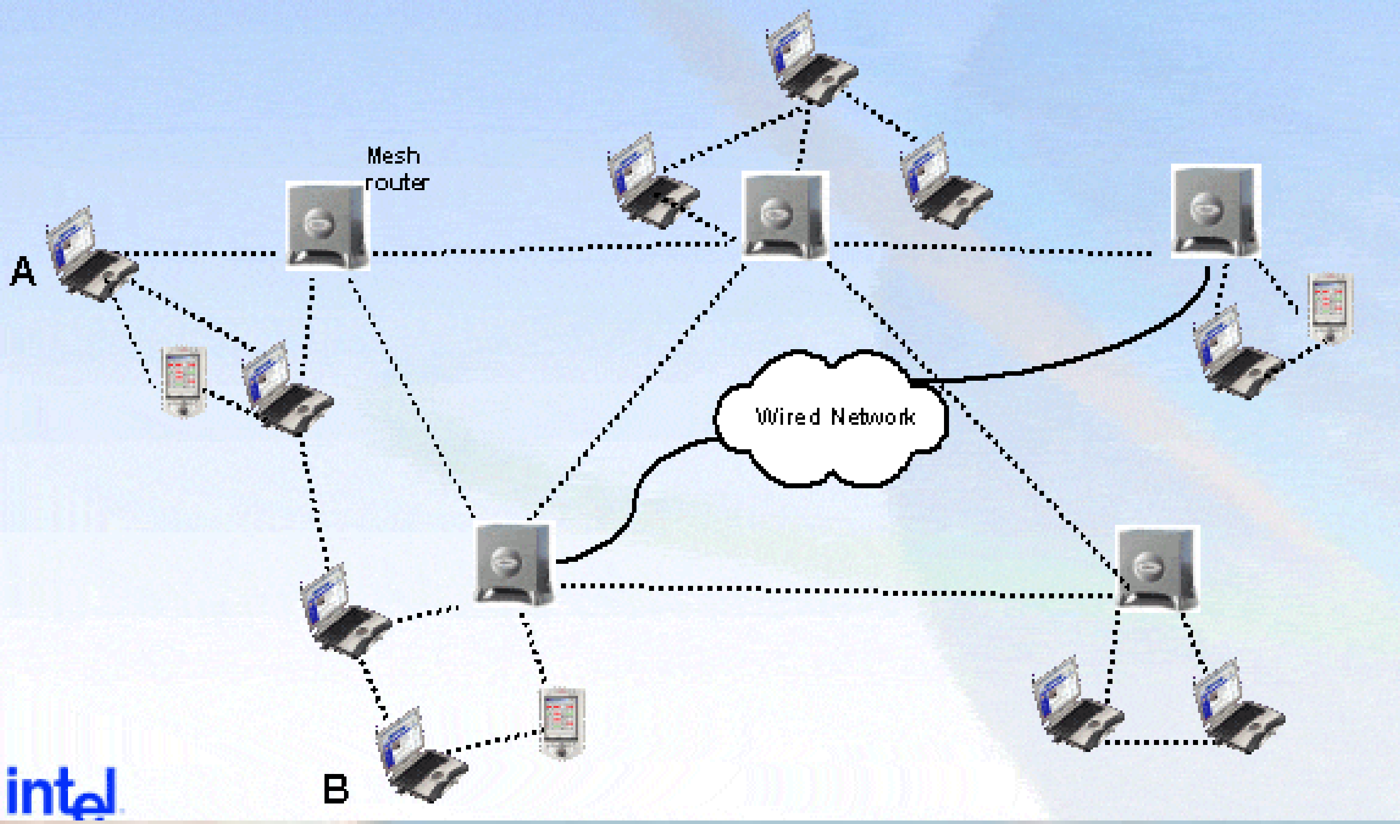
Co-operation between multiple radios using existing standards

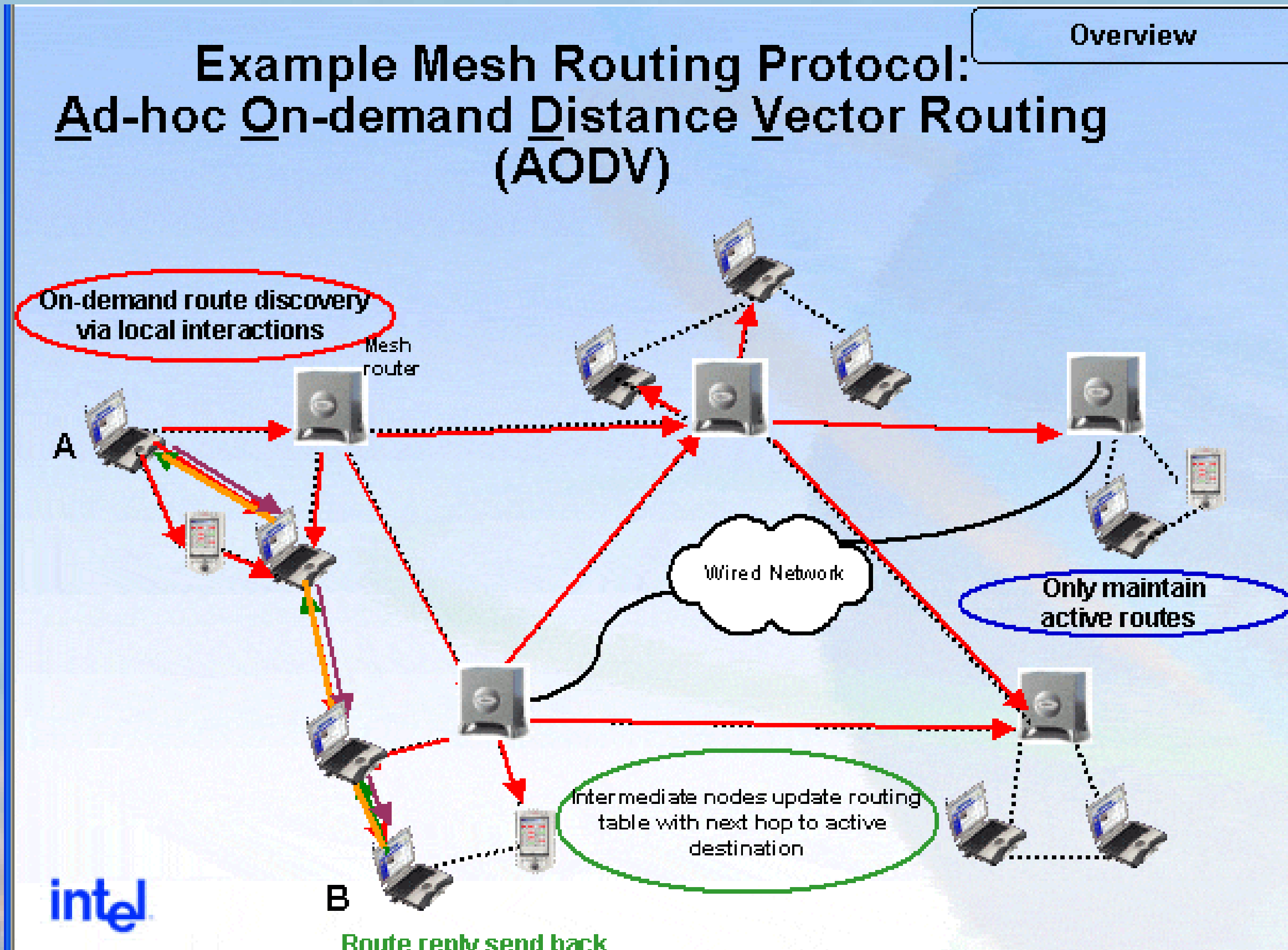
- Nodes leverage neighbors to route messages across multiple hops

- 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

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




Overview
Example Mesh Routing Protocol:
Ad-hoc On-demand Distance Vector Routing
(AODV)
On-demand route discovery via local interactions
Mesh router
A
B
Wired Network
Only maintain active routes
Intermediate nodes update routing table with next hop to active destination
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Route reply send back

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

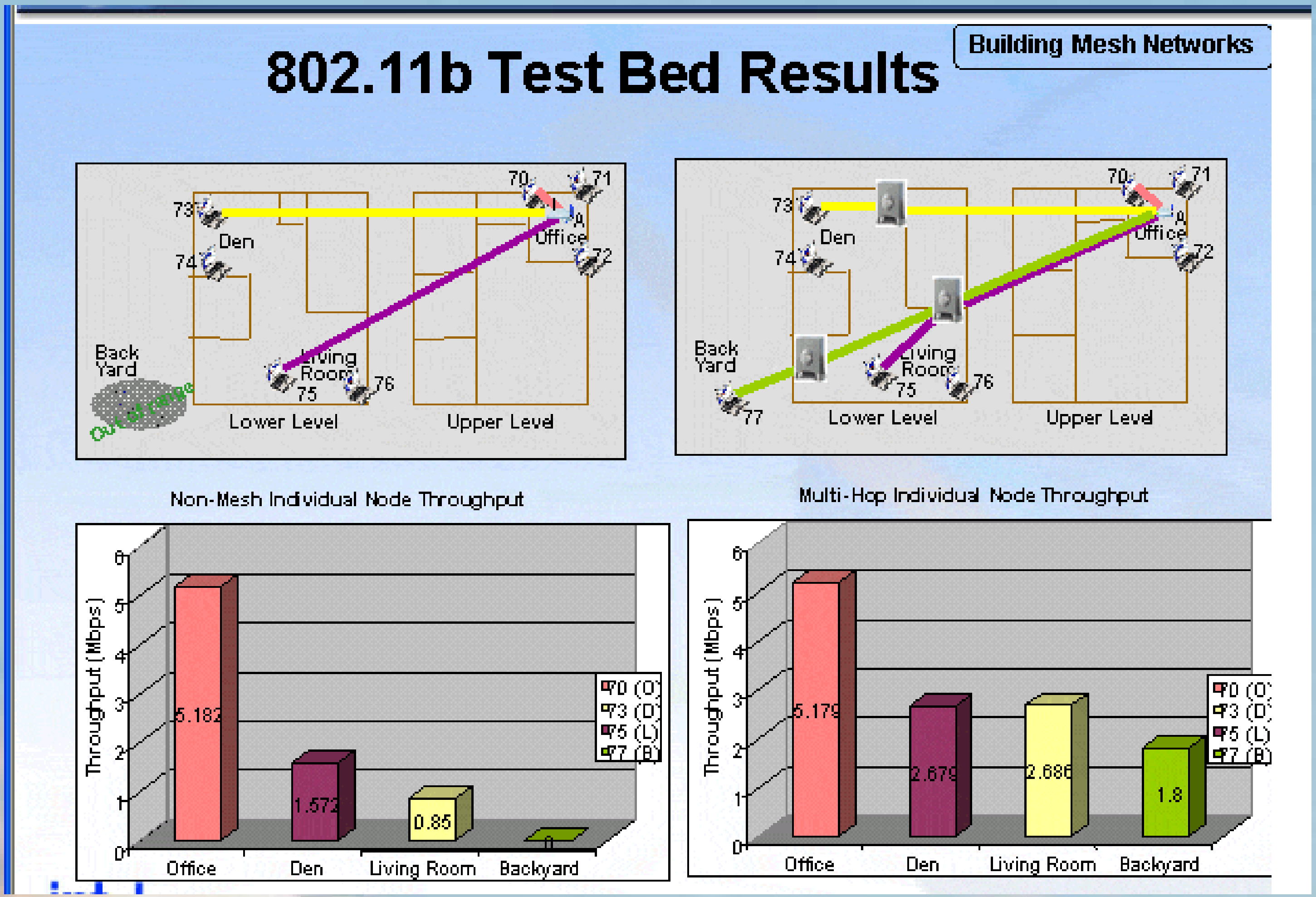
- throughput and capacity

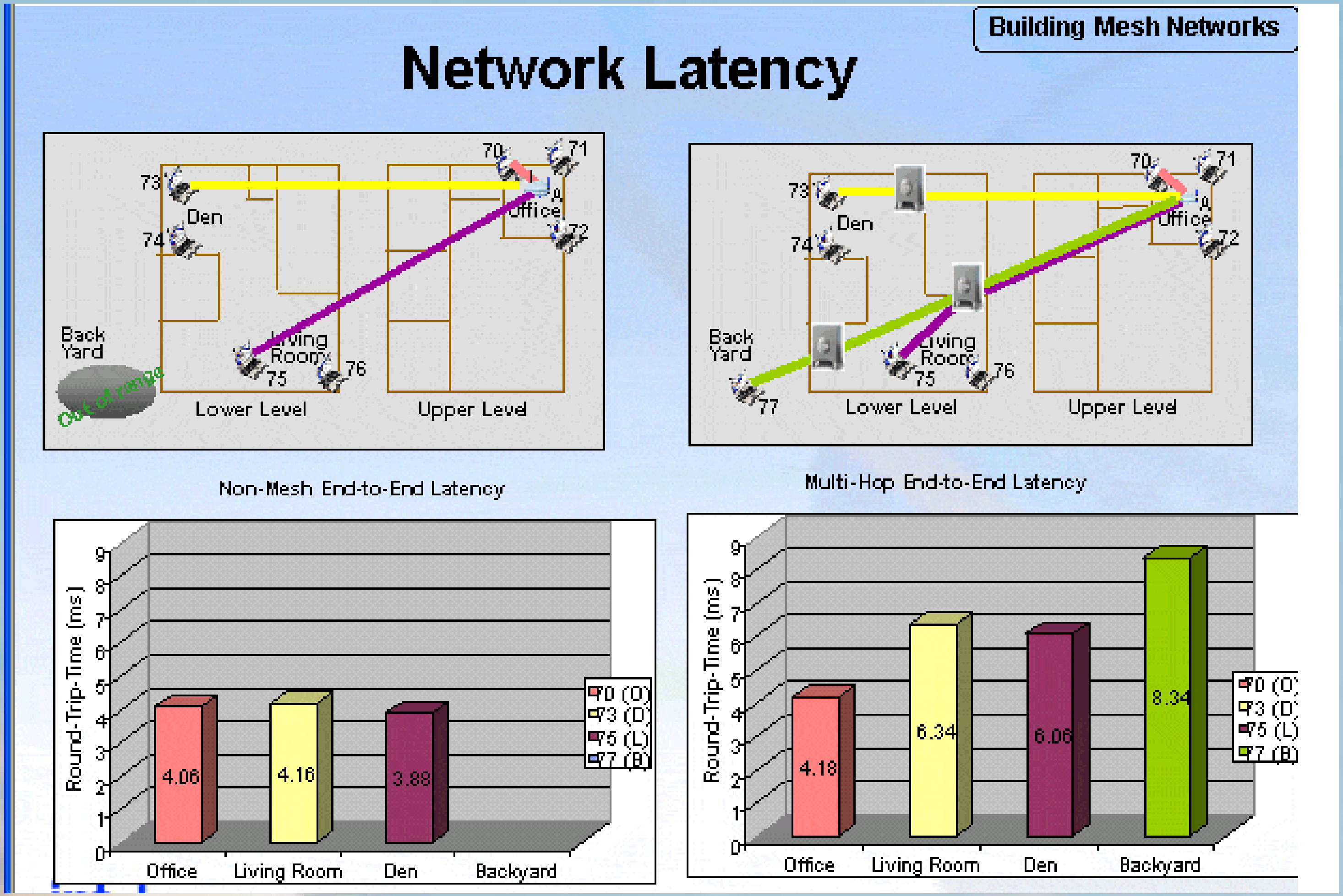
- Intel® Centrino™ mobile technology
  - Configure wireless NIC to run in ad-hoc mode
  - Join existing ad-hoc network or start new one
  - Run mesh routing protocol

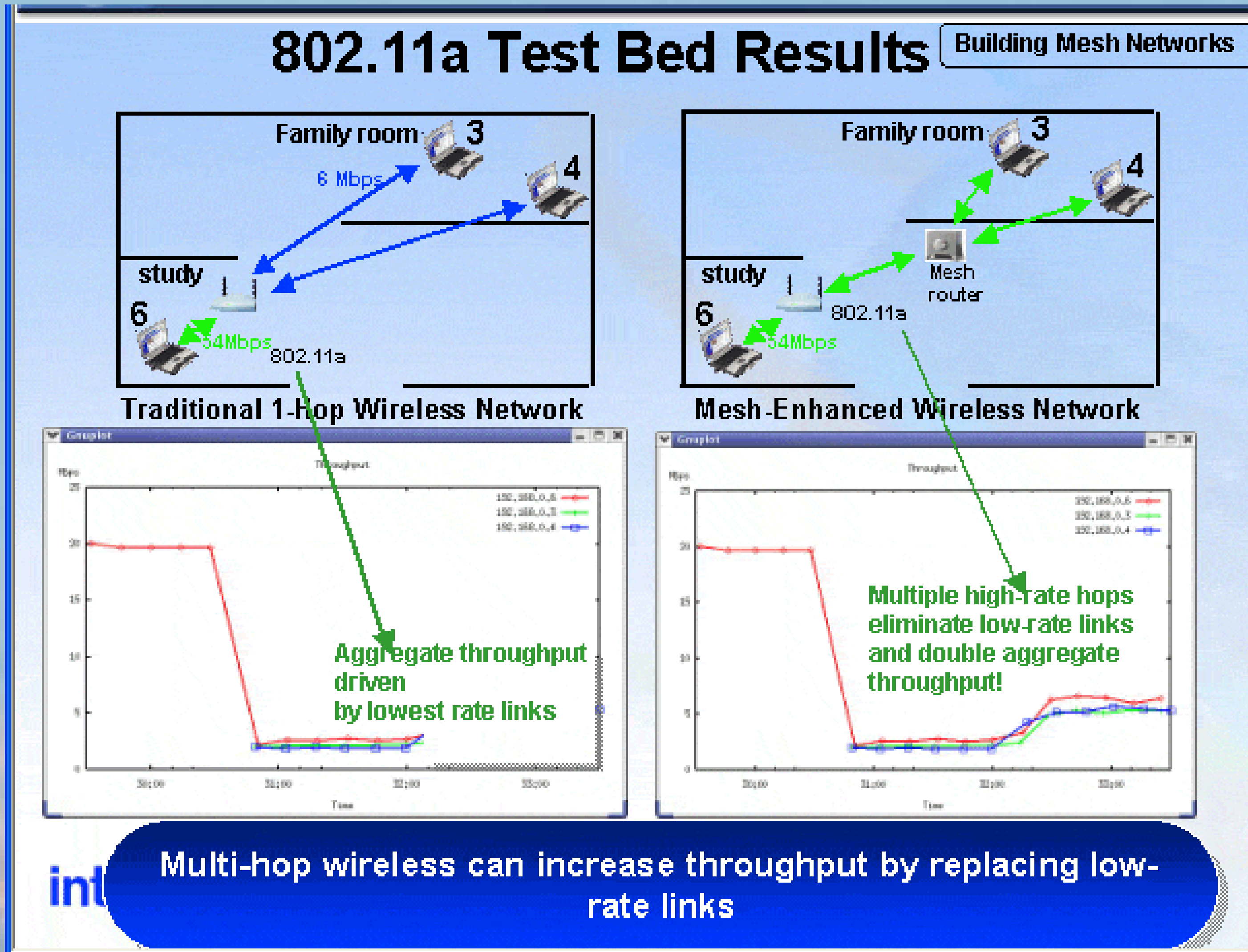
Using Intel AP Solutions

- IXP425 Reference Platform
  - Add mesh routing modules
  - Add mesh-networking startup steps to start-up script
  - Make a new image and re-flash the board

IXP425 Reference Platforms mesh friendly


Building Mesh Networks
802.11b Test Bed Results
70
71
73
Den
74
Office
72
Back Yard
Out of range
Living Room
75
76
Lower Level
Upper Level
77
Non-Mesh Individual Node Throughput
Multi-Hop Individual Node Throughput
Throughput (Mbps)
5.182
1.572
0.85
0
5.179
2.679
2.686
1.8
Office
Den
Living Room
Backyard
70 (O)
73 (D)
75 (L)
77 (B)

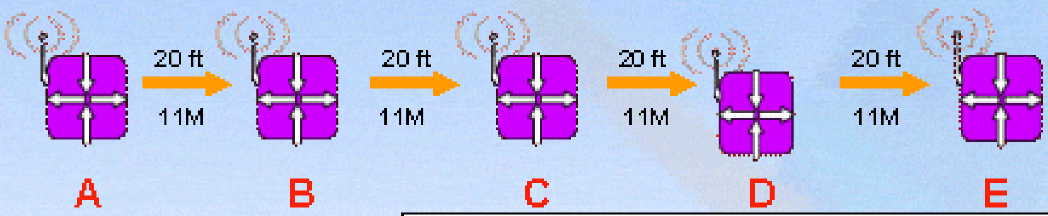

Building Mesh Networks
Network Latency
Den
Office
Back Yard
Living Room
Out of range
Lower Level
Upper Level
Non-Mesh End-to-End Latency
Multi-Hop End-to-End Latency
Round-Trip-Time (ms)
Office
Living Room
Den
Backyard
4.06
4.16
3.88
4.18
6.34
6.06
8.34


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

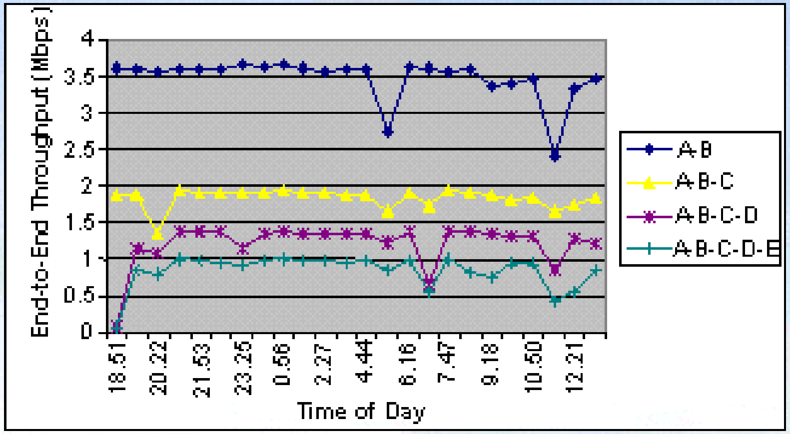
Test-bed Results

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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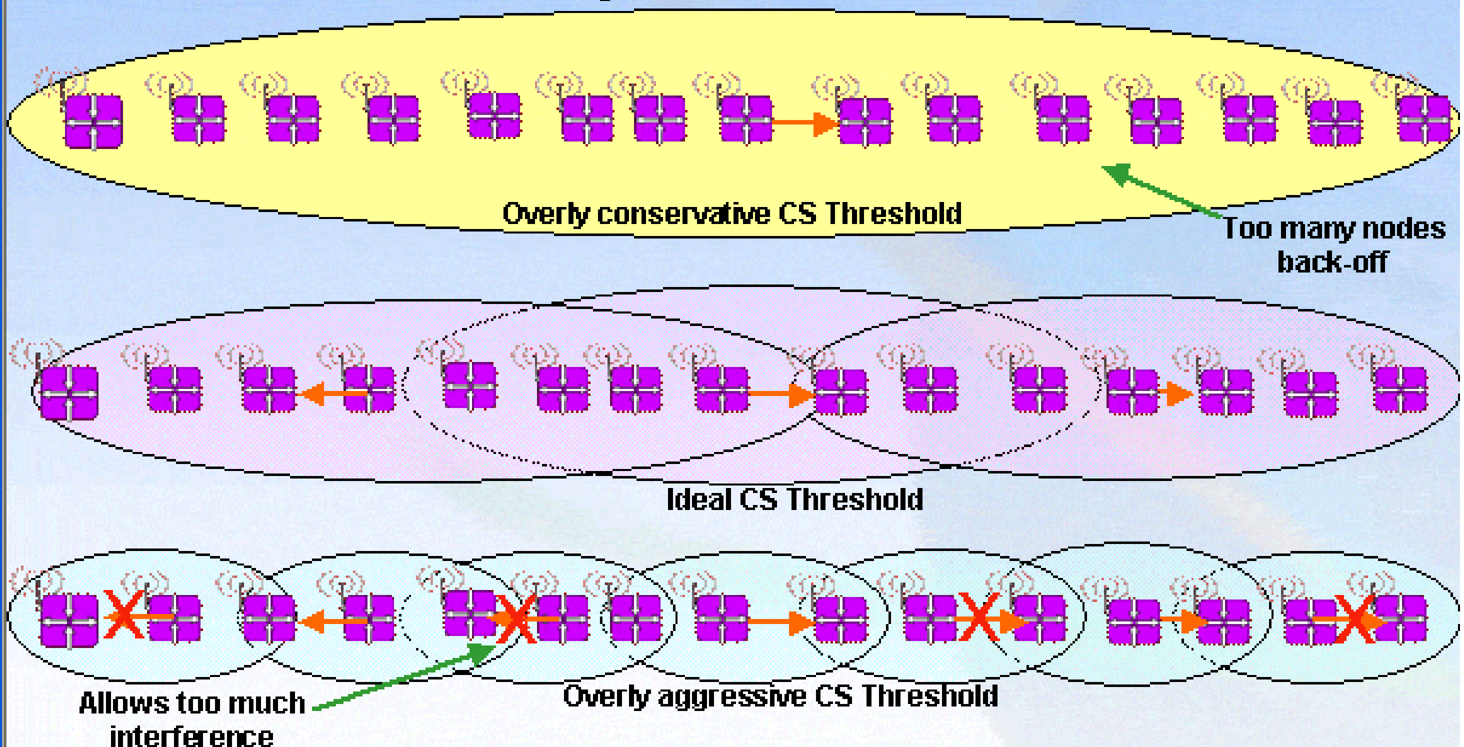
802.11 MAC protocol limits full exploitation of multi-hop throughput

Ongoing Research

Carrier Sensing Threshold Provides Spatial Reuse



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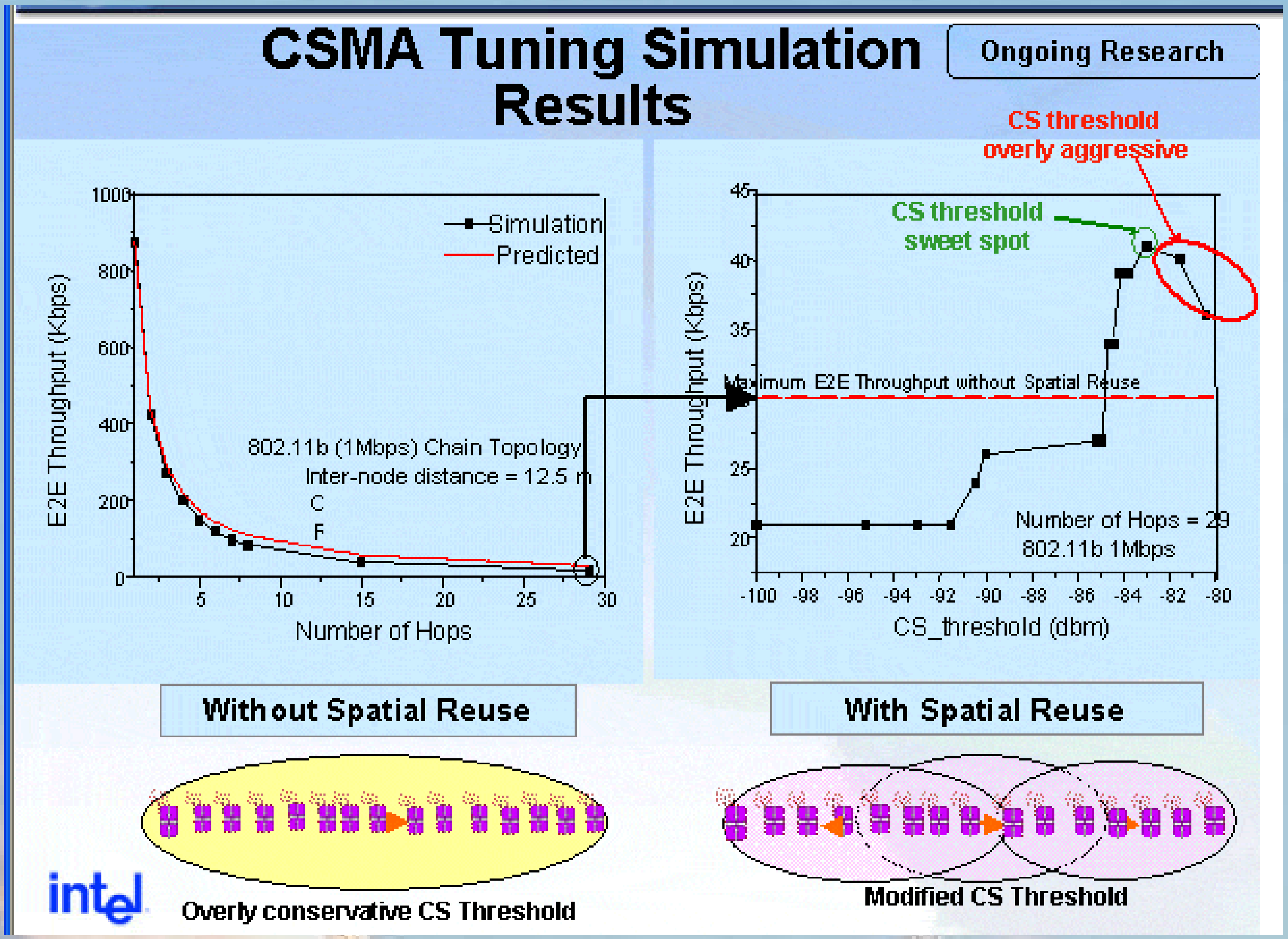
Tune MAC physical carrier sensing (CSMA) mechanism to achieve Spatial Reuse


CSMA Tuning Simulation Results
Ongoing Research
CS threshold overly aggressive
CS threshold sweet spot
Simulation
Predicted
E2E Throughput (Kbps)
802.11b (1Mbps) Chain Topology
Inter-node distance = 12.5 m
Number of Hops
Maximum E2E Throughput without Spatial Reuse
Number of Hops = 29
802.11b 1Mbps
CS_threshold (dbm)
Without Spatial Reuse
With Spatial Reuse
Overly conservative CS Threshold
Modified CS Threshold
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Mesh Networks activity

Welcome to the UCLA Wireless Adaptive Mobility Laboratory!

The WAM (Wireless Adaptive Mobility) Lab supports research projects in the area of mobile, wireless communications. It sponsors both graduate and undergraduate research programs. Currently, the main themes of our research are: (a) Design and performance evaluation of wireless, mobile, multimedia network protocols with focus on ad hoc, multihop, self configuring networks; (b) Development/maintenance of a simulation platform based on the PARSEC language which will serve for consistent comparison of protocols and for portable code implementation, and; (c) Implementation and testing of key wireless network protocols and applications using a wireless network testbed which is based on commercial laptops and radios. The WAM Lab is funded by both Industry and Government research grants.

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http://www.cs.ucla.edu/NRL/wireless/

Mesh Networks

Nokia developed a mesh networks solution called *rooftop networks* but later abandoned it. I suspect that the main reason was that the topology calls for a collaborative endeavor , ill suited for a commercial environment in which there are no encouragement for a customer to keep the station operation when he is not using it.

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

But we are more interested in public domain solutions like the one offered by LocustWorld from U.K.

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

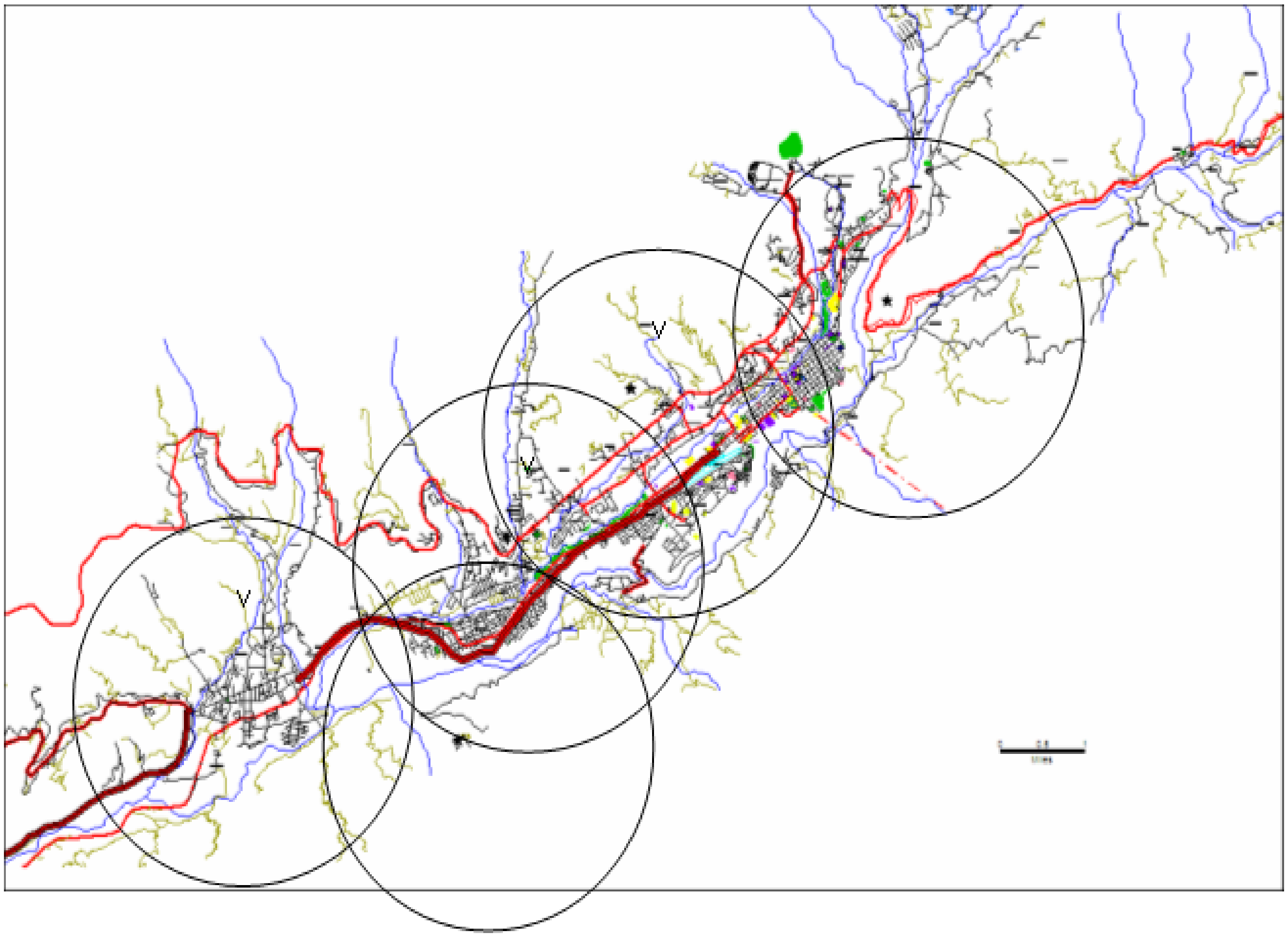
  and antenna for $400

Mesh Networks on DIY

- Using any available computer
- Linux kernel with Mesh software (open source) LocustWorld
- PCI-Radio and external antenna $50
- Homemade omni ant or cantenna, pigtail
- Ultramesh.com also offers commercial 12 dBi omni for $90

Proposed Mesh Network for Merida

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



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- Mobile Mesh Home Page
- http://www.mitre.org/tech_transfer/mobilemesh.html