Wireless Andrew
Building a high speed Campus-wide wireless data network

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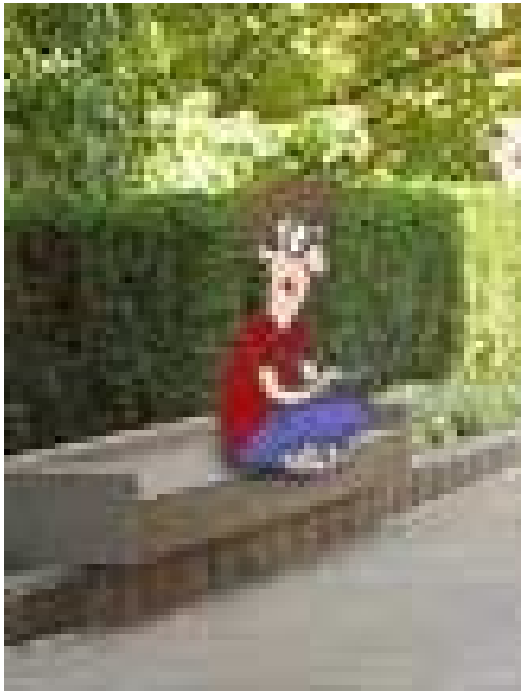
Wireless Andrew- Project Overview
Deployment Issues & Challenges



Outline

- Introduction: Wireless Andrew - 1994
  - Background and Objectives
  - Review of Wireless Technologies
  - Spread Spectrum Techniques
  - Review 802.11
  - Deployment Issues & Challenges
    - Interference
    - Throughput
    - Coverage
- Phase I Installation - 1995-97
- Phase II - 1998

Carnegie Vision -- 1994

- Establish Common Research Network
- NSF Grant - $550,000 over 2 years
- Objective: Build an *Experimental,* high-speed wireless network installed at Carnegie Mellon University
  - Integrated with “wireline” Andrew
  - Support research projects in wireless communication and mobile computing
  - Wireless access to campus network
  - Handheld Andrew: follow-on project, enhancing usability of palm and HPCs with access to campus network
  - Researcher’s “Field of Dreams”-projects involving location-based information, rapid response surveys,…
  - email,access to stored audio and imaging data, file transfers, access to the library and other databases, and full Internet Services

Wireless Vs Wire

- State of the art in 1994 was that the most users were connected over wire to Office/Campus LAN
- The mobile users however, were left to POTS (Plain Old Telephone) connection at 56K bits at best.
- A large number of mobile users needed better solution, especially at
  - Campuses
  - Airports
  - Corporate offices
    - Conference rooms
    - Visitors
- Wireless is the obvious choice but Radio Frequency signals do not behave as predictably as Wire.
- Therefore product development requires extensive field experience
- “Andrew Wireless” therefore was a necessary collaboration effort to determine if such a solution is technically feasible and cost effective.

Wireless Data Options

- Fee Based..
  - WAP : Low bandwidth for handheld
  - CDPD (Wide Area Network- WAN): Limited bandwidth 28Kps, fee based
  - Future G3/G4 may offer higher bandwidth - fee based
- These options being expensive were excluded from considerations

Wireless Data Options Contd.

- ISM Band … Free License… like Cordless phones
  - Ricochette (WAN): uses external modem
  - Wireless LANs (802.11): Preferred
  - Bluetooth: ISM Band, short distance 10 to 100 meter
- Wireless LAN 802.11 was selected as the most promising technology

ISM Band and Carnegie Challenge

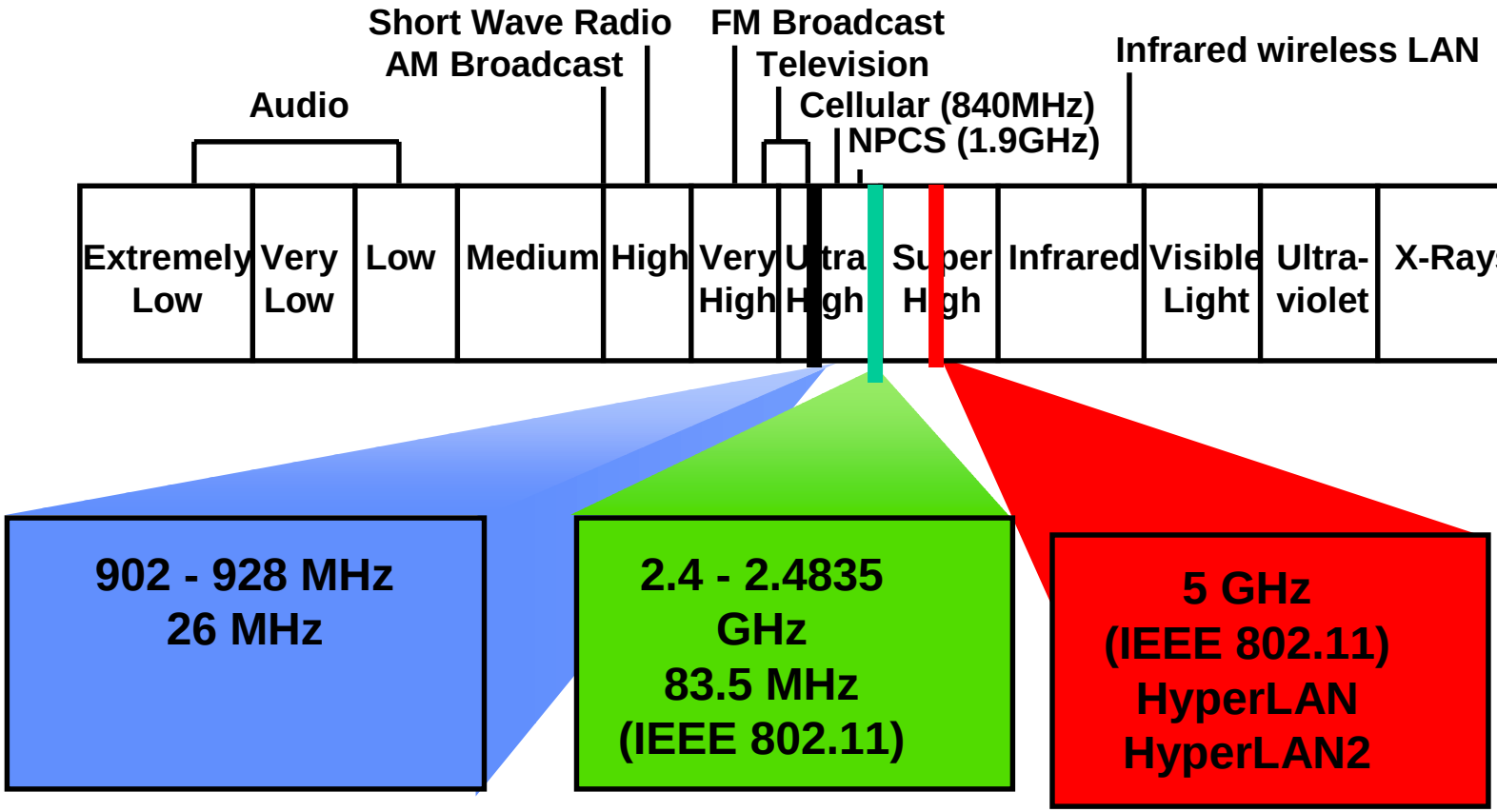
- Besides the challenge of making RF work in real life conditions, ISM Band posed another challenge
- ISM band applications were intended for small coverage area such as cordless phones in home etc by limiting power to 100mw, i.e. 1/10 watt
- The challenge then was to extend the functionality of these devices to change the coverage from 100 ft radius (Home) to mile radius (Campus)
  - The idea is to have the coverage of hundreds of these devices to overlap so that a wide area is covered.
- This of course raises many questions about overlapping coverage and resultant interference
- The throughput question was in better control due to advances in signal processing techniques such as frequency hopping and spread spectrum
- The Carnegie project was to work with the Manufacturer/s to test, modify and develop methods for future deployment

Carnegie Challenge

- The Carnegie project was to work with the Manufacturer/s to test, modify and develop methods for future deployment
  - The question and issues they tried to answer
    - How does RF signal propagate
    - What kind of coverage you can get
    - Interference between devices .. Access Points and clients
    - High density issues like class room
    - What throughput is possible
    - What types of preparations are required for deployment
    - Surprises

Frequency Bands- ISM

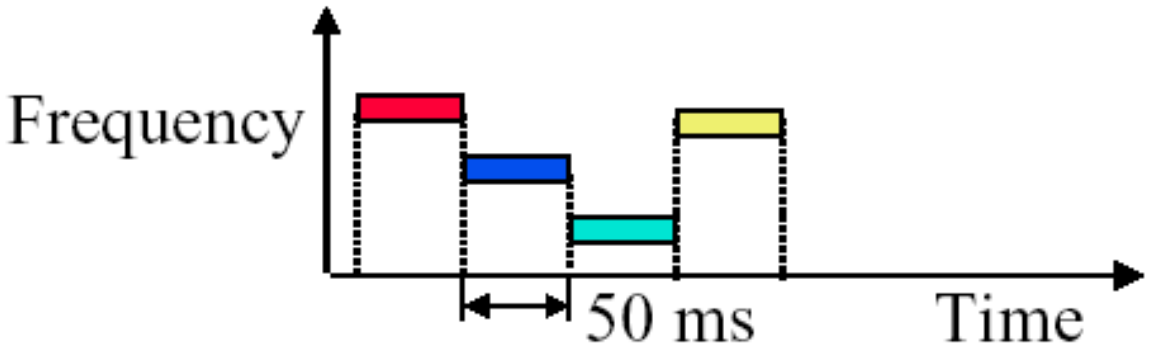
- Industrial, Scientific, and Medical (ISM) bands
- Unlicensed, 22 MHz channel bandwidth



Wireless LAN Solutions

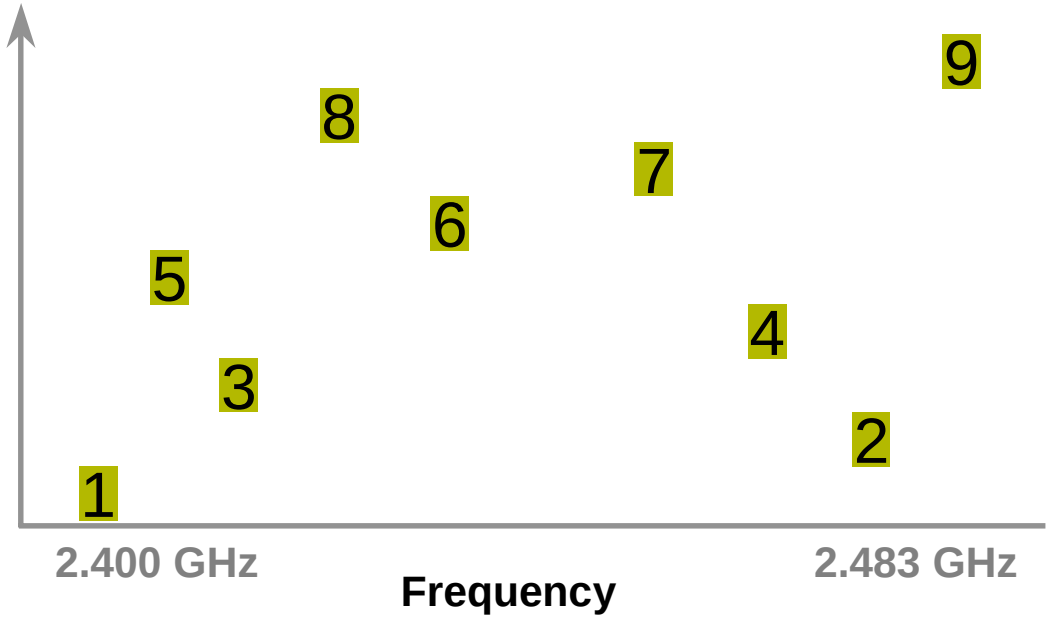
- Spread Spectrum Techniques
  - Originally intended for military use as a way to prevent jamming of communications
  - Concept is to spread the communications over a wide range of the radio spectrum making jamming difficult.
  - 2 main approaches –Frequency Hopping and Direct Sequence spread spectrum

Frequency Hopping and Spread Spectrum



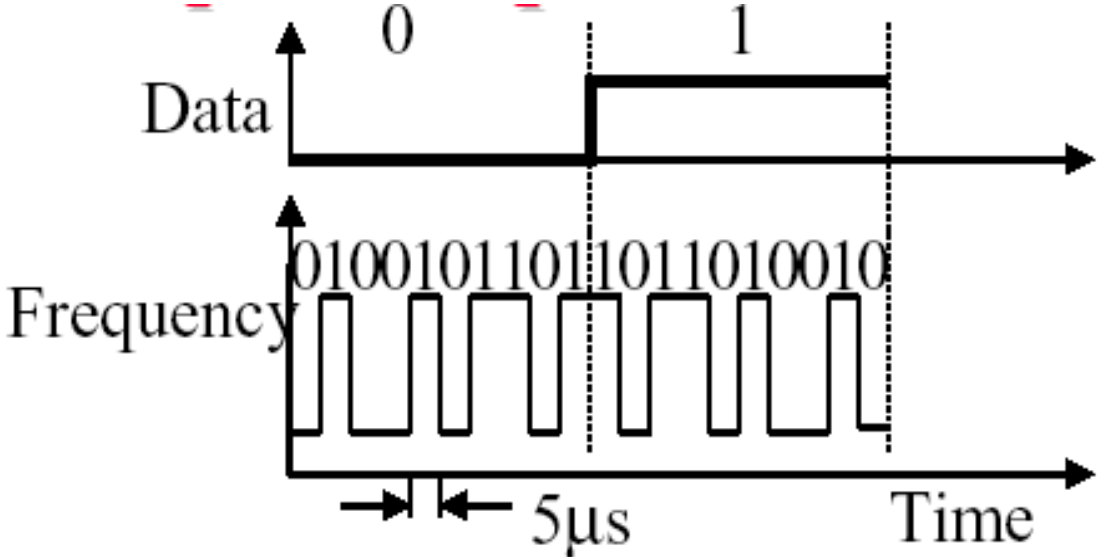
- Pseudo-random frequency hopping
- Spreads the power over a wide spectrum
  ⇒ Spread Spectrum
- Developed initially for military
- Patented by actress Hedy Lamarr
- Narrowband interference can't jam

Frequency Hopping



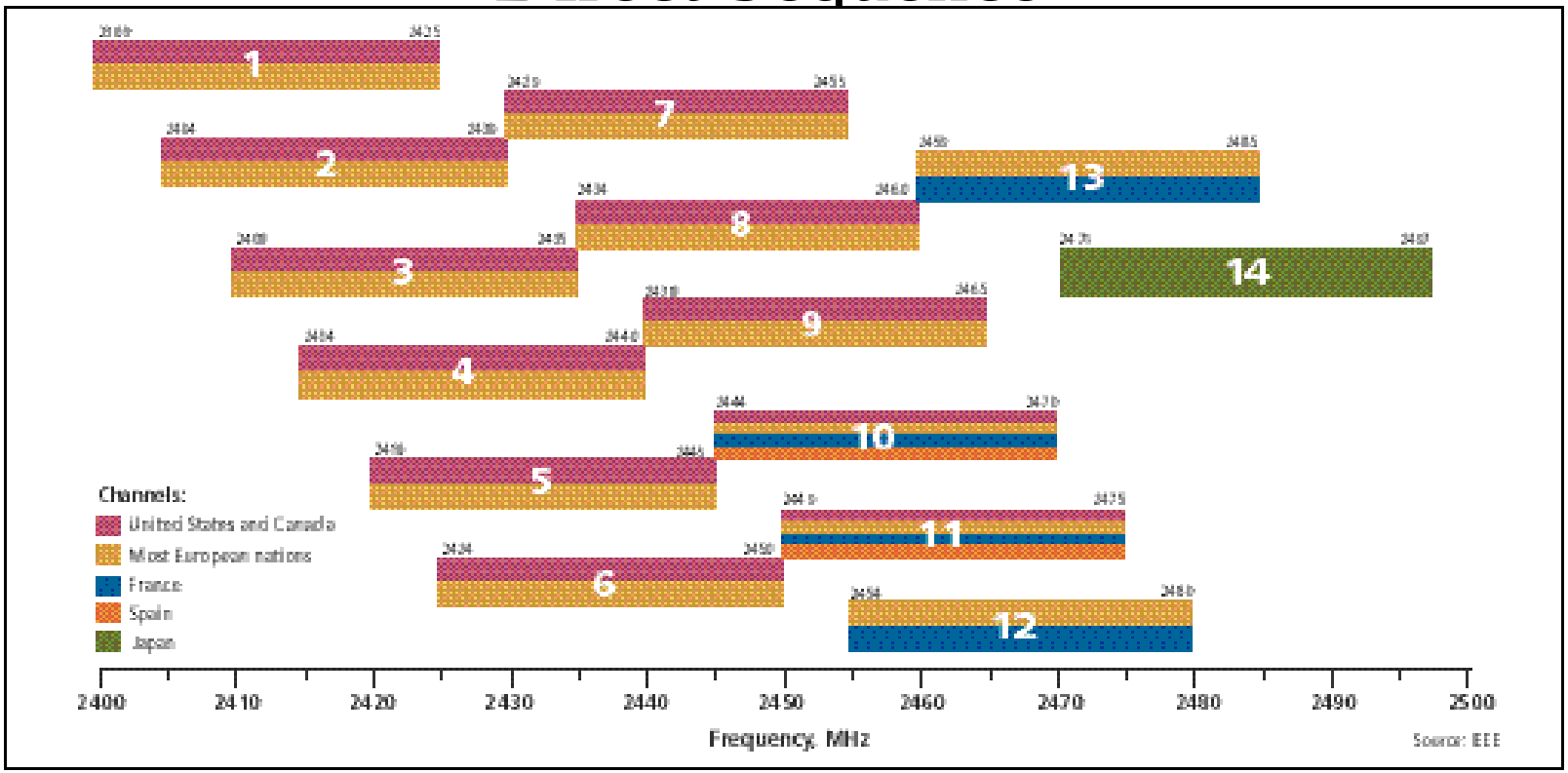
- 79 Channels, 1 MHz Each
- Changes frequency (Hops) at least every 0.4 seconds
- Synchronized hopping required

Spread Spectrum



- Spreading factor = Code bits/data bit, 10-100 commercial (Min 10 by FCC), 10,000 for military
- Signal bandwidth >10 × data bandwidth
- Code sequence synchronization
- Correlation between codes ⇒Interference⇒ Orthogonal

Spread Spectrum Techniques
Direct Sequence



- 2 Mbps data rate without complex modulation scheme
- 3 Access Points can occupy same area

Comparison between DSSS vs. FHSS

Depends on application

Frequency Hopping

- Pros: Cheaper to design & develop
- Cons: May not scale to higher speeds

Direct Sequence

- Pros: Better scaling to higher speeds
- Cons: More complex to design

- Who’s winning – Direct Sequence

IEEE 802.11

- Specification For Over The Air Interface Between Wireless Clients and Base Stations (Access Points)
- Specifies MAC and PHY Layer Like 802.3 Ethernet and 802.5 Token Ring
- Conceived in 1990. Final Draft Ratified June 26, 1997

IEEE 802.11 Architecture

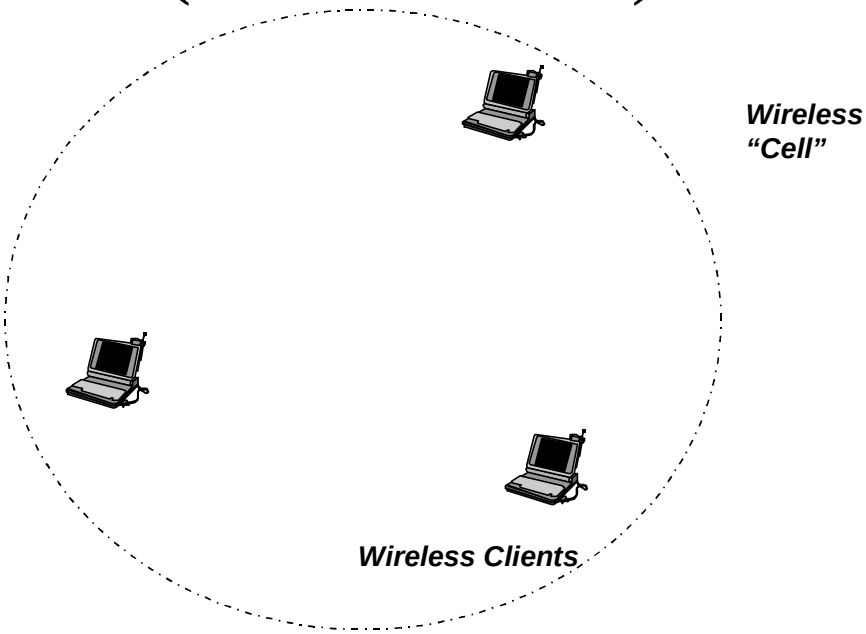
- Wireless Nodes
  - Clients
  - Access Points (AP) - interfaces to a wired network
- Basic Service Set (BSS)
  - two or more wireless nodes that have recognized each other and established communications
- Extended Service Set (ESS)
  - a series of overlapping BSSs' each containing an AP connected via a Distribution System (DS). The DS is typically Ethernet

IEEE 802.11 Architecture

- Two Connection Options:
  - –Infrastructure Network
  - –Ad Hoc Network
- Infrastructure Network
  - –Contains at least two nodes one of which is an AP
  - –client to access point (to wired network)
  - –all nodes communicate through the access point
- Ad Hoc Network
  - –client to client (no access to the wired network)

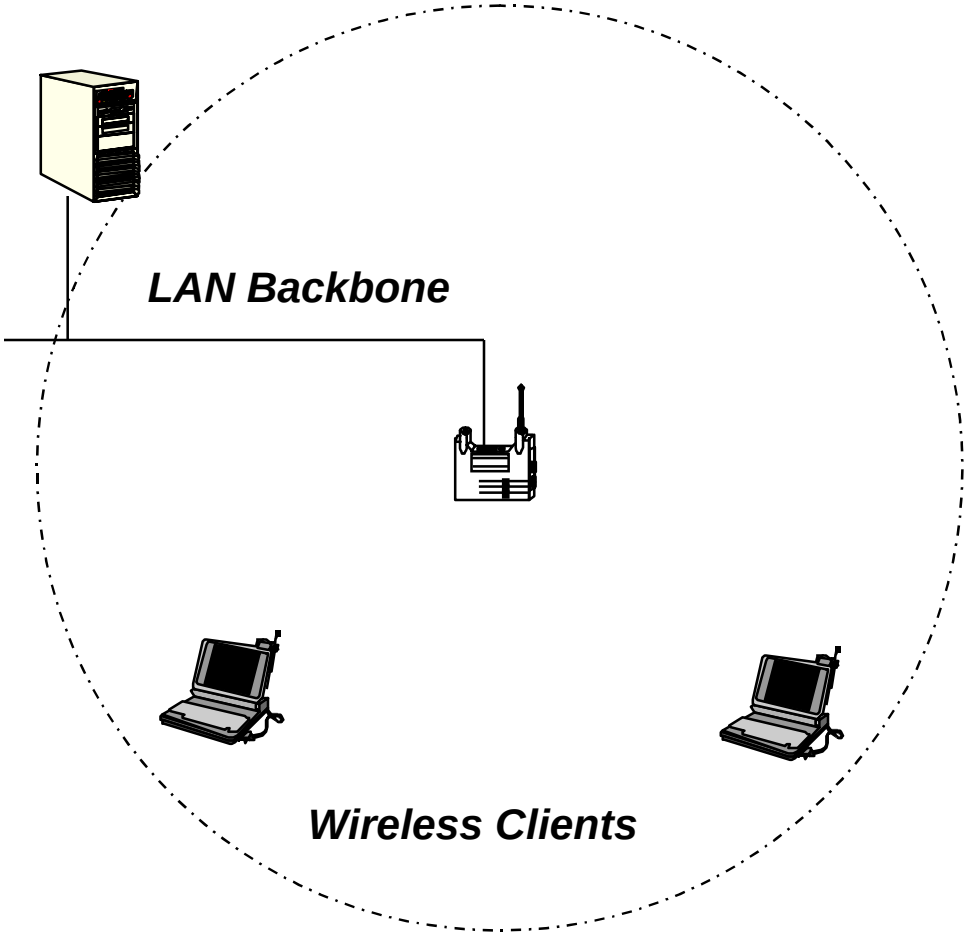
Wireless LAN
LAN Topology

Peer to Peer Configuration
(Ad Hoc mode)



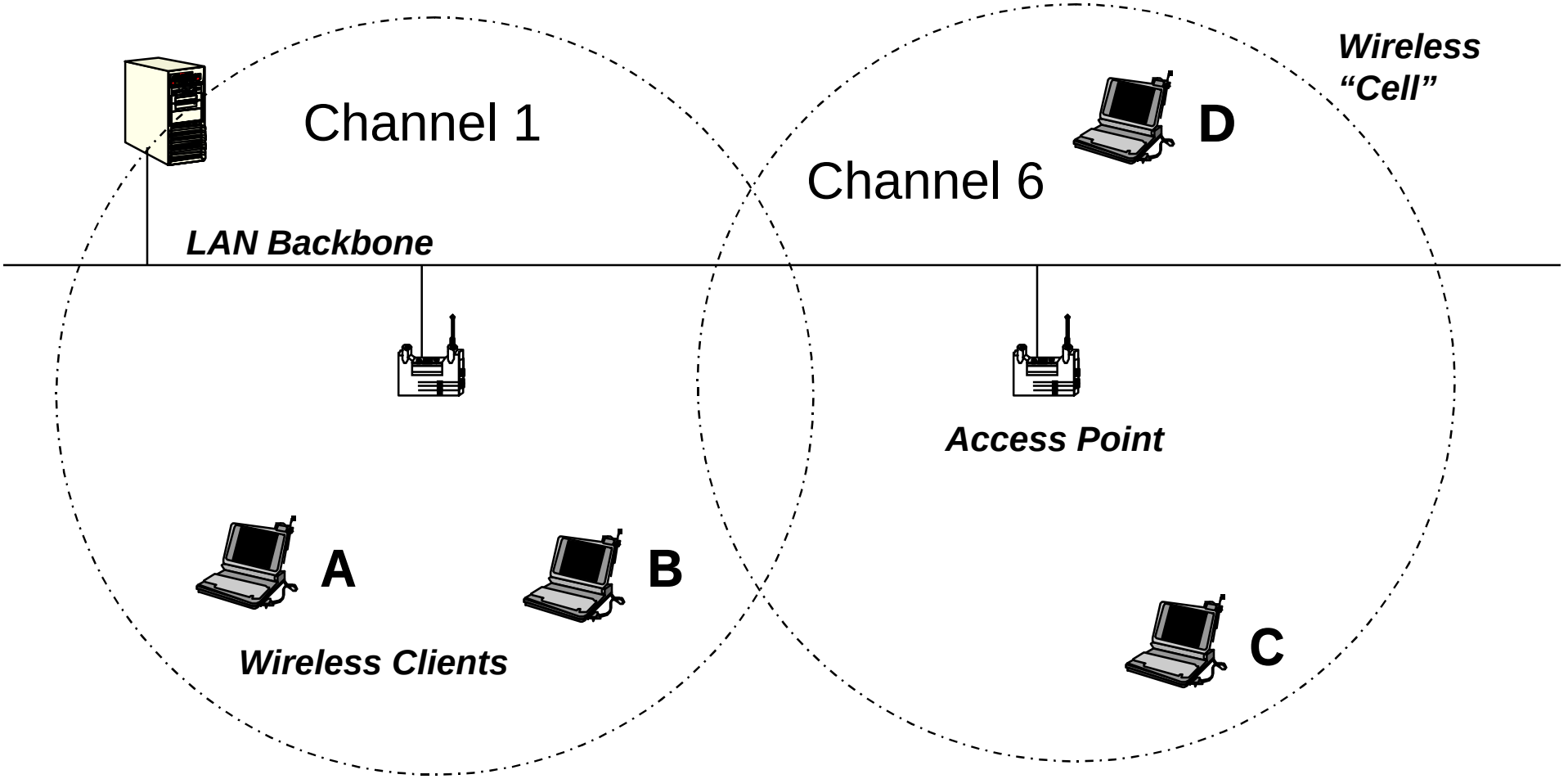
Wireless LAN

Typical Single Cell Coverage



Wireless LAN

Typical Multicell Topology



IEEE 802.11- Standards Status

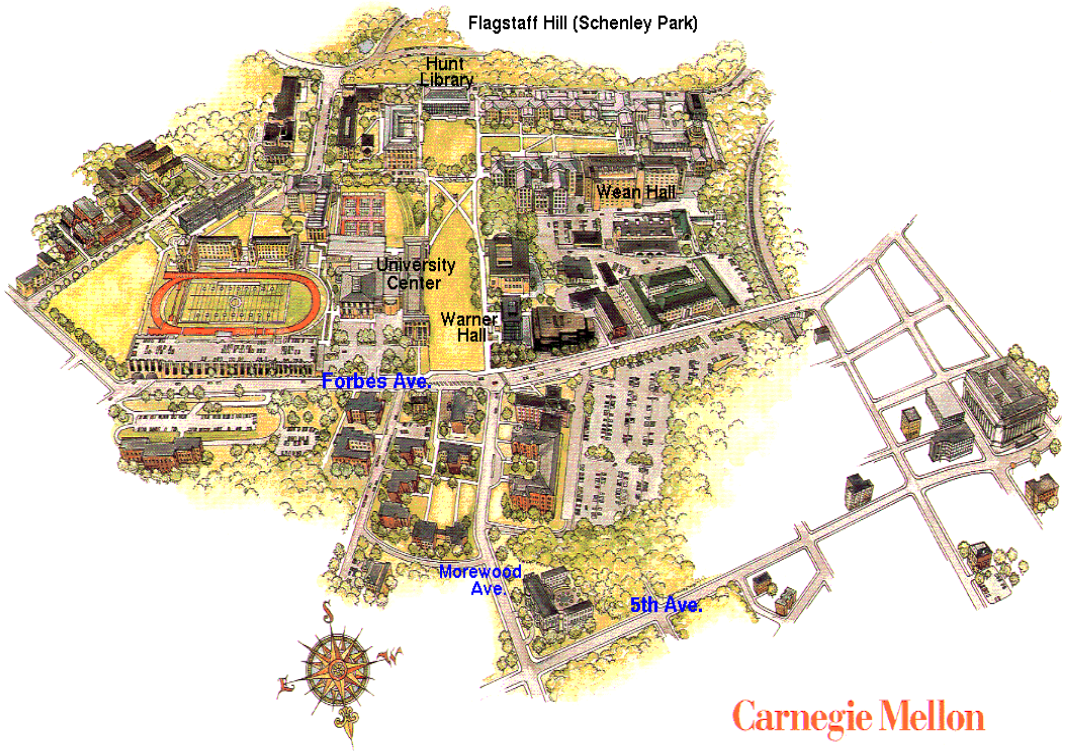
- Although Standards Based, No Guarantees Of Vendor Interoperability… Therefore lots of field testing is necessary
- No AP to AP Coordination For Roaming
- No 802.11 Conformance Test Suite…see University of New Hampshire web site

IEEE 802.11 Evolution

Spec.	Description	Est. Data Rate	Act. Data Rate	Frequency
802.11	Most widely deployed	2 Mbps	1.6 Mbps	2.4GHz
802.11b	ratified 9/99	11 Mbps	5.5 Mbps	2.4GHz
802.11a	In development	54 Mbps	25 Mbps	5GHz
HiperLAN	Developed by European	24 Mbps	11 Mbps	5GHz

Carnegie Mellon Background

- 50+ buildings on 100+ acre campus
- Half of buildings are on contiguous main campus
- No Standard Existed for Wireless LANs
  - Evaluation + Selection: ATT/Lucent 915Mhz
- Deployed network in 6 campus buildings
- Enable use by approximately 150 users
- Research Network = Limited Support



Early adopters in use of distributed computing and networks (Andrew Project)

Wireless Andrew Subnet

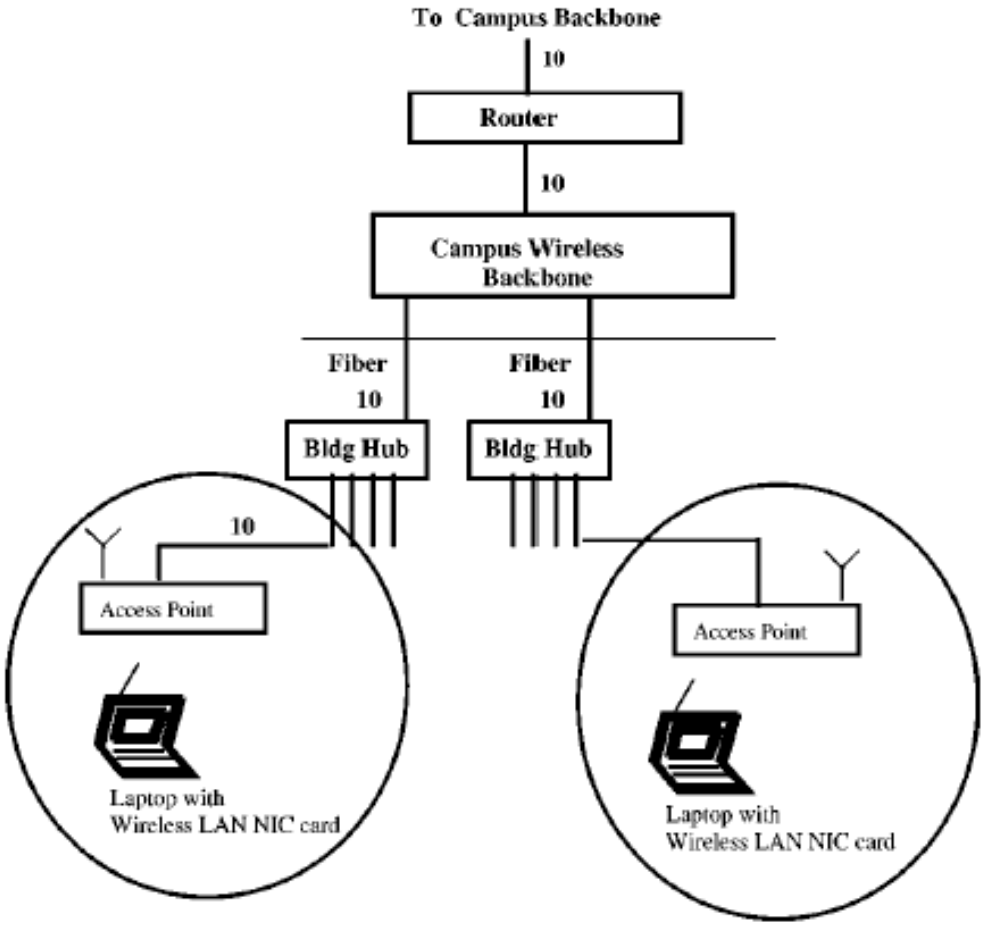


Figure 1. The Wireless Andrew subnet.

- Andrew wireless envisions
  - Wireless supports existing uses
  - Separate network

Selection of Partner

- Concern for Selecting Partner:
  - Scalability of products and systems
  - Ability to design an effective network
  - Ability to manage the wireless network and provide operational service levels acceptable to wireline Andrew users.
- Competitive Vendors
  - Xircom, Proem and Lucent
  - Key Parameter:
    - Coverage, Throughput, Form factor, Ease of use and Apple MAC support and PC support.
- Coverage cost per unit
  - 1.0 -> 915 MHz, 1.67 -> 2.4 GHz, 3.76 -> Xircom's product
- In 1995, They decided to work with 915 MHz WaveLAN product from Lucent Technology.
- In 1999, they have competed the coverage of whole campus with latest 2.4 GHz technology from Lucent

Initial Lab tests for selection of partner

Table 1
Tested products.

	Xircom	Proxim	Lucent
Frequency	2.4 GHz	2.4 GHz	915 MHz
Transmission	FH	FH	DS
Claimed data rate	1 Mbit/s	1.6 Mbit/s	2 Mbit/s

Table 2
Typical performance test.

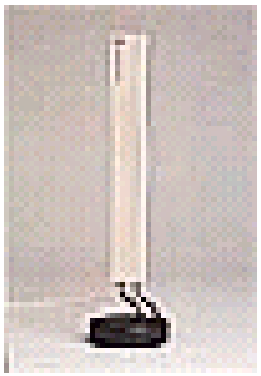
	Xircom	Proxim	Lucent
Latency/failed pings			
1 Laptop	38 ms/2	32 ms/63	27 ms/0
2 Laptops	41 ms/1	35 ms/377	28 ms/0
3 Laptops	–*	43 ms/645	28 ms/1
Data rate bit/s			
1 Laptop	233,453	311,292	360,951
2 Laptops	135,591	202,476	347,853
3 Laptops	–*	141,268	329,804

Lucent WaveLAN Product

- Phase I was composed of two main elements:
  - The Lucent WaveLAN access points / WavePoint units.
    - Radio base station, mounted in a fixed position, connected to wired local network.
    - Contains a transmitter,receiver,antenna, and a bridge.
  - Network adapters/WaveLAN units.
    - Using direct sequence spread spectrum and CSMA/CA medium access control.
    - Contains a transmitter,receiver,antenna and the hardware provides the data interface to the mobile computer.
    - Available in PCMCIA and is installed in a mobile.

- This equipment uses a direct sequence spread spectrum to provide a raw data rate of 2Mbps.

Key Components- Wireless LAN



Access Point - network device that links wireless stations to the wired network -- $200/unit

Wireless NIC cards- EISA bus or PC card - radio transceivers for the end users --

$795/card

~~$595/card~~

~~$275/card~~

~~$150/card~~

$95/card

Design factors to consider

- Interference
- Throughput
- Coverage Vs. Capacity.
- Wireless design is as much Art as Science.
- The wireless industry is evolving their products to support campus environments (but they are still behind the wired side of networking).

Interference Sources

- ISM band is shared band between 902-928 MHz. Different users and applications operates in this band.
- Applications operates in ISM 902-928 MHz band (Potential sources of interference):
  - Wireless stereo speakers
  - Industrial heaters
  - Food preparation equipment
  - Military radar
  - Video Surveillance cameras
  - Commercial location and monitor services
  - Cordless phones operated in 915 MHz and 2.4 GHz
- Interference: Different users and application operates in the same frequency, they interference to each other.
- The problem with so many devices using the same band is that the interference is likely and given 802.11 specs, it will reduce the throughput

Solutions for Interference.

- To overcome effects of foreign interference one can add more access point effectively increasing the signal to client devices. However this will increase the interference between access points themselves.
- These problems were resolved by configuring the access point appropriately that changed the coverage area and creation of additional channel.
- The process however is experimental.
- One has to map out the deployment area in terms of presence of signals in ISM band using spectrum analyzer
- Additional configuration effort is required either to overcome foreign interference or overlapping coverage problems.

Throughput

- Their main concern was the performance in a situation where a large number of users, request simultaneous services.
- They found from experiment that data throughput of 2 Mbit/s was reduced as they increased the device but it was reasonably shared among wireless devices.

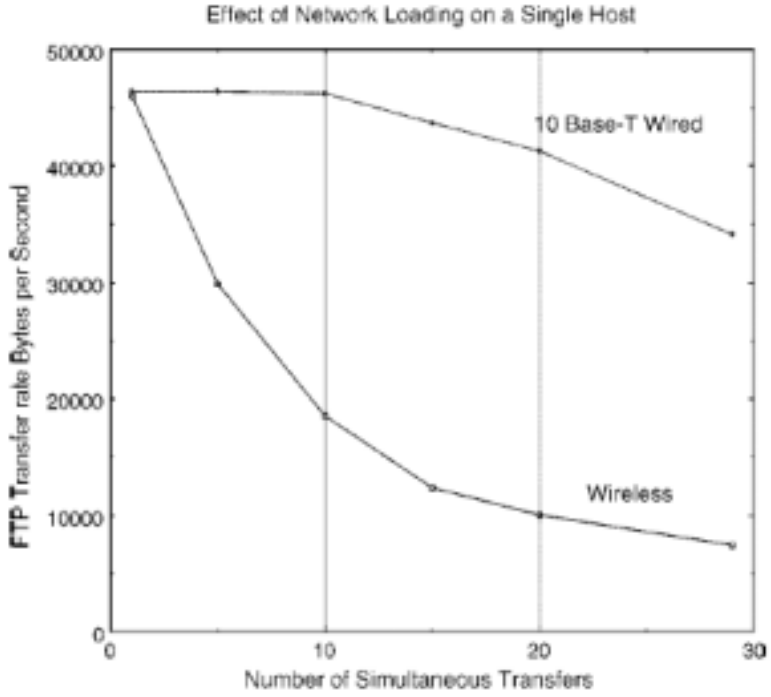


Figure 2. Effect of network loading on a single host.

Throughput Contd..

- In class room environment, it was possible that one access point may not be sufficient to provide for sufficient throughput. Additional access points were necessary.
- This however led to interference problem between APs
- Lucent however provided ways to configure the APs and additional channels in APs that could help with the interference problem.
- This has been an acceptable solution but requiring lots of testing, experimenting on the site.
  - This will remain a matter of cost and concern until more automated way of changing the coverage and channel selection is arrived at.

Design Issues (Coverage)

- To design network with good performance and economics is the main factor.
- Ensure that reasonable coverage is provided through out the service area.
- Two issues:
  - Holes in coverage
    - Examine the building drawings, estimate coverage, place the access points, signal-noise ratio, then fill coverage holes with additional access points.
  - Marginal Coverage Areas
- Cost perspective, place the access points as far as apart for coverage.
- It causes coverage gap problem, where there is no service available.
- Solution to place the additional access points
- Coverage area of a access point is relatively small, terrain is not a propagation issue.
- The layout and construction of buildings determine the coverage area of each access points.
- IEEE 802.11 protocol is contention-oriented, it provides a mechanism which allows all units to share the bandwidth resource.
- This contention-oriented protocol makes interference between access points, which is a problem.
- Rules of thumb are inadequate.

Design Issues (Capacity)

- Design should consider the issue of capacity.
- To use multiple access point to serve a high density group, located in a small area.
- Design should be both coverage-oriented and capacity-oriented.
- Two design layout techniques which are useful in high-density capacity situations:
  - Adjusting the receiver threshold setting
    - The WaveLAN product allows to set threshold settings, controlling the size of the coverage area of the access point.
  - Using the frequency reuse
    - In 2.4 GHz band, access points can operate on separate non-interfering channels.
- Wireless Andrew uses coverage oriented techniques - capacity areas, Combination of coverage & capacity oriented techniques - high-capacity areas.

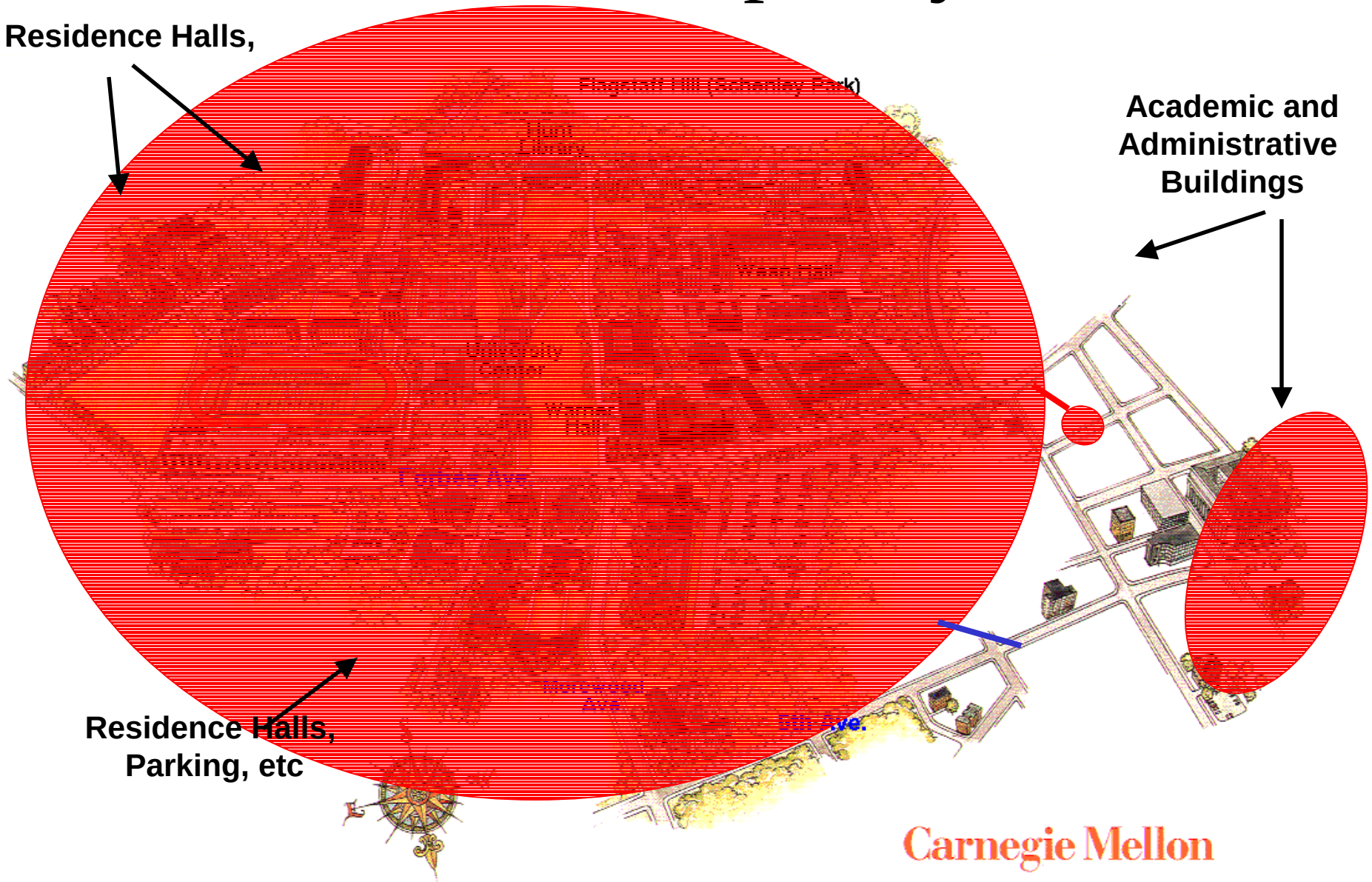
Troubleshooting Issues

- Lack of tools suitable for management of a large dispersed wireless network.
- Dispersed nature of devices compared to wireline units.
- Difficulty in diagnosing problems in the link between the access point and the end user.
- The mobile nature of possible problem source

Where are we now?

- We cover 30+ buildings (to date)- 350 APs
- We cover over 3 M sq. ft. of office/lab/classroom space
- We cover roughly 99% of the academic campus.
- We have 2000+ users
- We are planning a summer expansion of wireless coverage to the dormitories – 30 Bldg., 800KSq Ft of interior space, approx 3000 “beds”.

Wireless Campus by 9/01



How Much?? $$$, coverage

- Average cost of wireless: <$1K for AP, <$1K for power/data install, + wired network infrastructure costs+design labor costs.
- Avg. pwr/data install schedule– 8 locations / wk
- Avg. AP installs - 8 per day
- AP to sq.ft. density: depends on building construction and arch concerns, ex: older construction 25 A.P.s cover 228Ksq.ft., newer construction 12 A.P.s cover 210Ksq.ft.
- Best coverage 17.5Ksqft/AP, Worst 3.4Ksqft/AP
- Your mileage WILL VARY!!!

Wireless Andrew Configurations

- Workstations/OS
  - Windows 95, 98, NT, 2000
  - Macintoshes
  - Linux
  - Windows CE
- Applications
  - data files
  - Internet/Intranet
  - email
  - Web
  - centralized calendar

Wireless Andrew Issues/Futures

- Coverage Vs capacity – Why not both?
- “Airspace policy” and interference – Bluetooth,…
- Keeping up with demand- scaling issues
- Security-Authentication- 802.1x ??
- Next Gen 802.11(a) –5Ghz Issues:

  Fork-lift upgrade? Ease of transition?

Q & A