“Good Engineering Practice” for Wireless Networks

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www.barwn.org

NANOG 32

“Standards of Good Engineering Practice”

- Was the old set of “standards” that the government used and evolved into the current FCC’s Rules and Regulations.
- Currently meant as the “proper” and standardized way of doing things to insure uptime and minimize interference to yourself and others.

Quick review of non-licensed radios, or “Why Use 802.11?”

- Biggest reason: Non-licensed
  - Significantly less regulatory control
    - No expensive licenses or coordination.
    - The arcane regulatory knowledge needed for licensed radios is not needed.
- The hardware cost is magnitudes less than equivalent licensed technology.
  - Client cards are from $35 to $150; Access Points are from $50 to $500.
  - Even less than (non) unlicensed "carrier class" radios
    - Example: Western Multiplex/Proxim Tsunami point-to-point radios are $12,000 per end not including the thousands of $ for antennas, coax, installation, etc.

Why Use 802.11? (cont.)

- Speeds range from 11Mb/s to 54Mb/s
  - Another magnitude jump of low-cost networking hardware from a couple of years ago. (2Mb/s) or even 2 to 3 magnitudes of amateur packet radio (1.2-56Kb/s).
  - Real world speeds about 5Mb/s to 20Mb/s
- Plug and play
  - Most modern operating systems support 802.11
    - i.e. Mac OSX, *BSD, Linux, MS-Win 95 to XP.
  - Depending on implementation, it can be as easy to set up as standard wire or fiber Ethernet and in some cases easier.

Why Not Use 802.11?

- Biggest reason: Non-licensed
  - Non-existent coordination facilities.
  - Other users on the bands.
    - Folks with large organizations that lobby the FCC (ie. ARRL, SBE/NAB, Public Safety)
  - “Regulations Affecting 802.11 Deployment”:

    http://www.lns.com/papers/part15
  - You have no legal priority or recourse over any other user of the spectrum…

FCC R&R Part 15.5
General Conditions of Operation

(b) Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.

(c) The operator of a radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.

Why Not Use 802.11? (cont.)

- The protocols have problems scaling.
  - Companies like Etherlinks and Cisco have solutions
  - Modifications to the standards will help minimize interference (ie. Automatic Power Control and frequency selection)
- Outdoor deployment requires RF engineering knowledge to minimize interference issues.
- Other regulatory issues one may have to deal with for outdoor deployment.
  - Radio Frequency Radiation exposure standards
  - Local ordinances for antennas

Conclusions on issues

- Building an expensive network on 802.11 can be risky as you have no rights or priorities.
- Coordinate with other licensed and unlicensed users.
- A properly designed network will survive longer.
- Other issues can affect you like FCC Rules changes or pressure to get the FCC to enforce. Be active in watching and changing the FCC's Rules!

From Point “A” to Point “B”

- Proper radio engineering using “Good Engineering Practices” will only put enough Radio Frequency (RF) energy to get to the reception point.
- Energy will not be wasted by being distributed in other directions. This also means reuse of the spectrum by others.
- Two primary link design considerations are directionality and power (turf).

Basic Link Design

- Site Survey
  - Should be done for every deployment.
  - Depending on the complexity of the deployment, the engineering study requirements will change.
  - It gets down to - “Can you get the signal from one antenna to the other so it can be successfully used?”
- Engineering the Link
  - Antenna Requirements
    - The signal should only go where it is needed to minimize interference to other networks and to your own.
  - Signal Requirements
    - Transmitter power and signal strength needed for the receiver

Site Survey

- Short distances (< 30meters) can be determined by visual inspection.
- Longer distances will likely need to use visual with microwave path engineering software.
  - Examples:
    - EDX - www.edx.com - 10s of thousands of $
    - PathLoss - www.pathloss - ~ $4,000
    - Radio Mobile -www.cplus.org/rmw/ - Free (example later)
  - The more you pay the more accurate the uptime and coverage predictions.
    - The more expensive packages have more “knobs to turn” and are more fine-tuned to what reality is.

Site Survey (cont.)

- Real and potential interference needs to be evaluated.
  - Look around. What antennas do you see nearby?
  - Objects nearby that will cause multi-path? (future slides)
- Non-intrusive testing - sniff around:
  - Use dstumbler or netstumbler to see what SSIDs you can see.
  - Note channel usage.
  - A spectrum analyzer will reveal non-802.11 RF.
- Try it out:
  - Bring masts and 24 dBi dishes.
  - Note signal and noise levels.

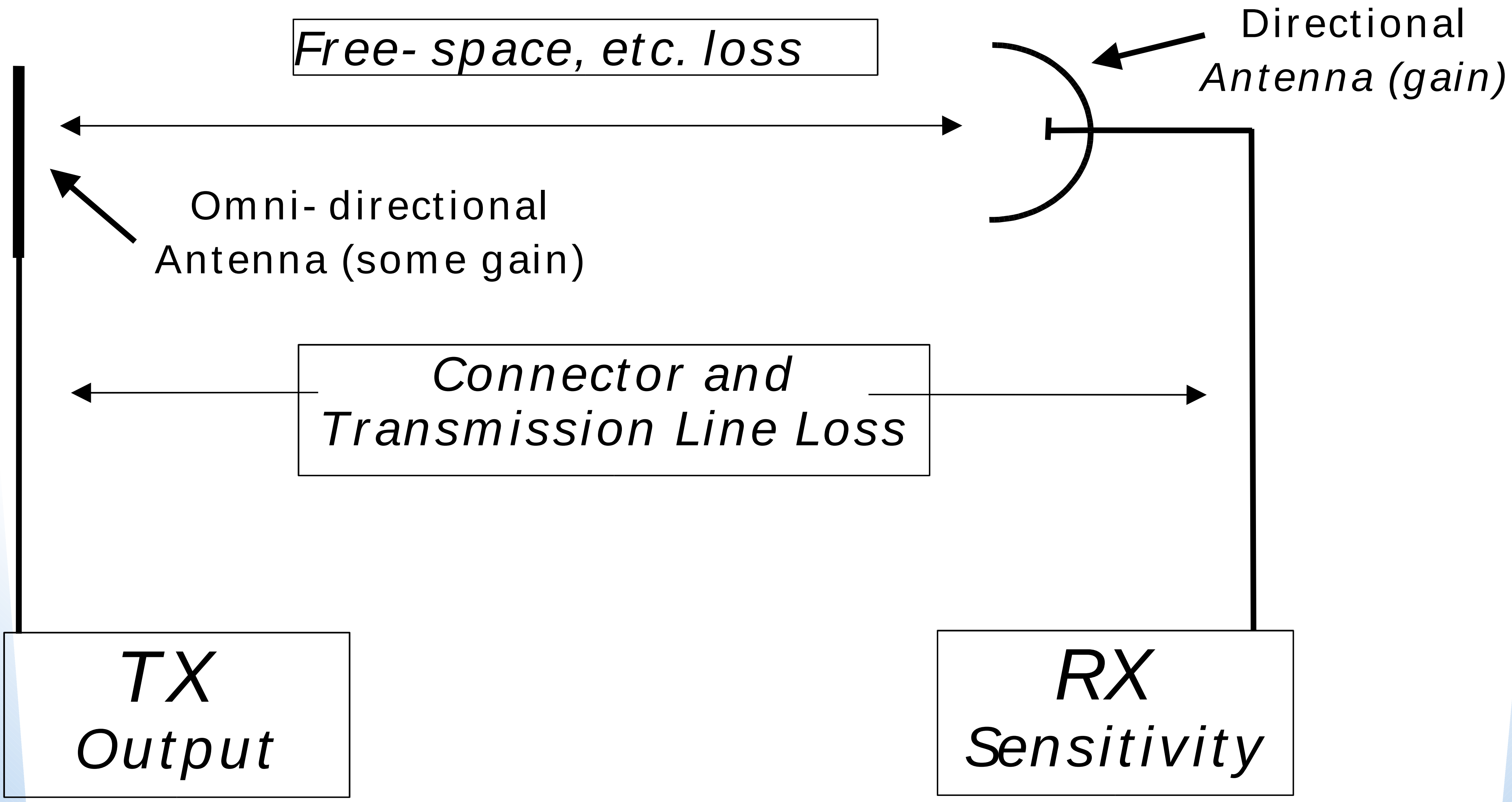
Engineering Software Design - Questions:

- Can the antennas can see each other?
- Do objects cut into the Fresnel Zone?
  - How high do we need the antennas to clear?
- What is the free-space path loss?
  - First cut on what size of antennas and transmitter power output (TPO) needed.
- What is the predicted up-time of the path determined from frequency, EIRP, distance, weather, type of terrain, etc.
  - Final cut before field test of antennas and TPO.

Loss and Gain in a System

- Gain:
  - Transmitter Output Power (TPO) in dBm or Watts.
    - dBm = $10*\log_{10}$(power in milliwatts / 1 mW)
    - 0 dBm/1 mW; 15dBm/30mW; 20dBm/100mW; 30 dBm/1 W
  - Transmitter and receiver amplifiers
  - Transmit and receiving antennas.
- Loss:
  - Coax, connectors
    - ie. LMR-400: 0.22 dB per meter.
  - Free-space loss
    - dB = 92.4 + 20 Log_{10} (distance in km) + 20 Log_{10} (freq. in GHz)
  - Obstructions and Diffraction (ie. Trees, rain, etc.)
  - Atmospherics (ie. Snow/Rain, Refraction (ie. Ducting)

Simplified Path Calculation Schematic



Signal Level Through the Path

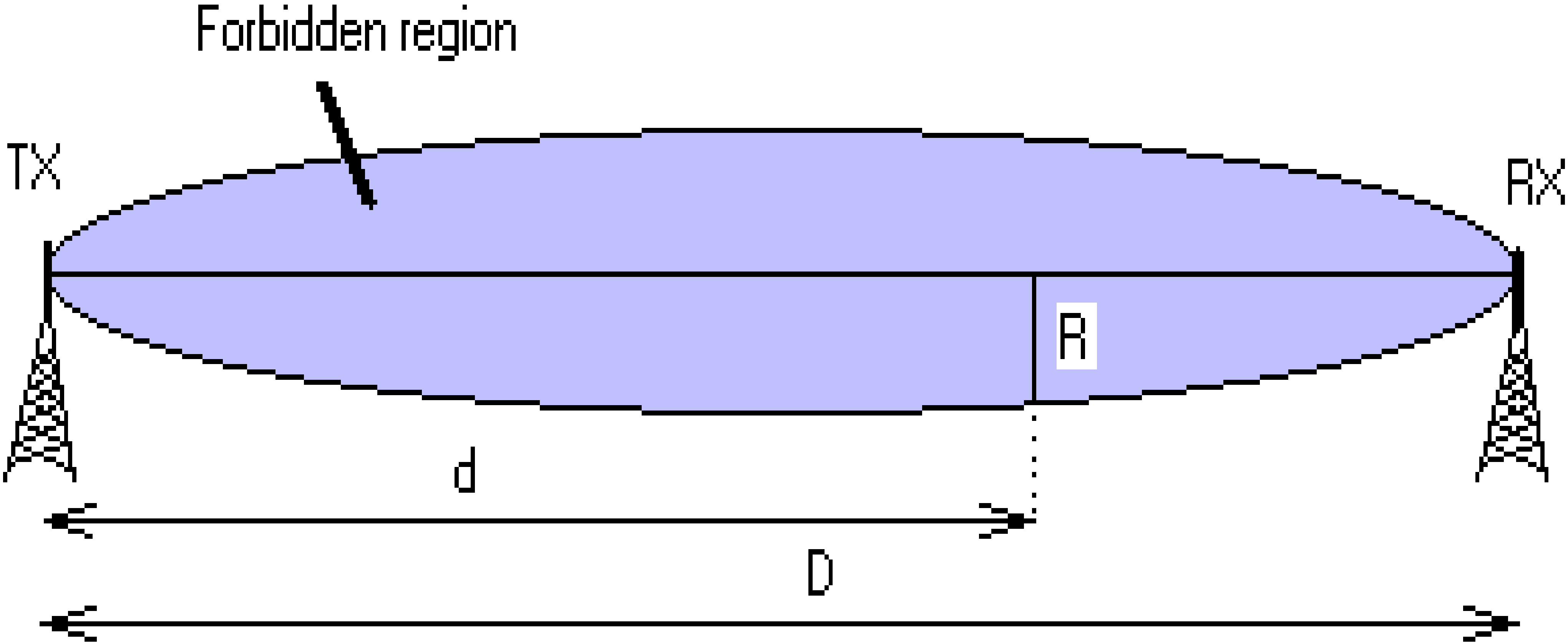
Simple Path Calculation - www.lns.com/pathcalc

Free Space Loss Path		
Frequency	2.4000	GHz
TPO	1.0000	Watts
TPO dBm	30.0000	dBm
Transmission Line Loss	2.0000	dB
TX Antenna Gain	6.0000	dBi
Path Length	5.0000	miles
Free Space Loss	118.1836	dB
RX Antenna Gain	18.0000	dBi
RX Transmission Line Loss	3.0000	dB
RX Signal	-69.1836	dBm
RX threshold	-80.0000	dBm
Fade Margin	10.8164	dB

Signal Path Loss - Through the aether...

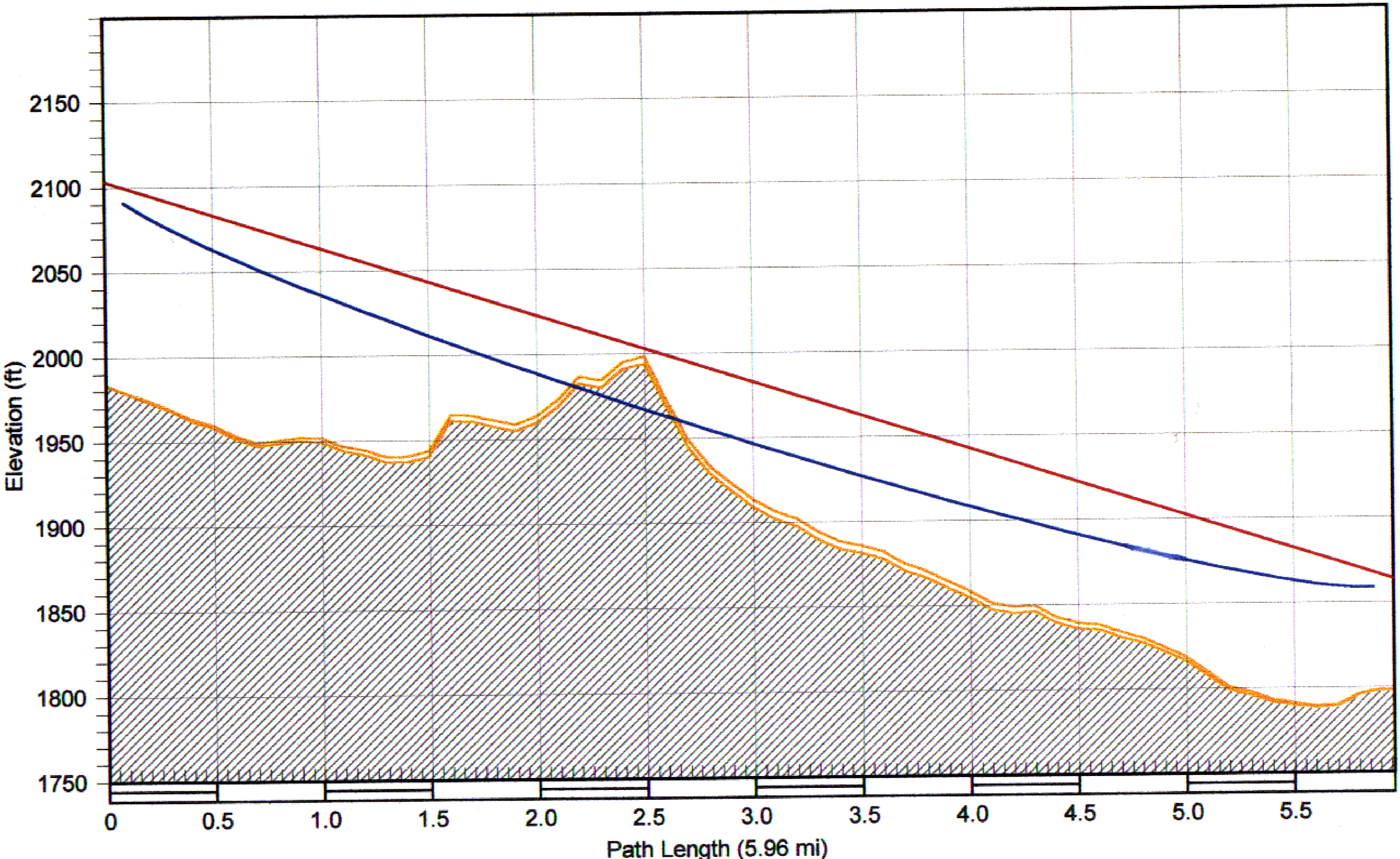
- Atmospheric Attenuation
  - Rain/Snow
  - Trees (Spring/Summer vs. Fall/Winter)
  - Typical Solution: Just need to have lots of signal
    - Needed fade margin will increase with distance.
- Refraction
  - Thermal Ducting
  - Marine Layers
  - Typical Solution: Diversity Reception
- Fresnel Zone Attenuation...

Fresnel Schematic



Fresnel Zones Calculation:

Fresnel Zones:		
Distance from TX to calc point	2.5000	miles
Path Length	5.0000	miles
Distance from RX to calc point	2.5000	miles
Frequency	2.5000	GHz
First Fresnel Zone Radius	50.9117	feet
Second Fresnel Zone Radius	72.0000	feet
Third Fresnel Zone Radius	88.1816	feet
Forth Fresnel Zone Radius	101.8234	feet



KEYAFM

Latitude	48 50 37.00 N
Longitude	099 45 02.00 W
Azimuth	241.42°
Elevation	1983 ft ASL
Antenna CL	120.0 ft AGL

Frequency (MHz) = 5800.0
K = 1.33
%F1 = 100.00

Shell Valley

Latitude	48 48 08.22 N
Longitude	099 51 54.90 W
Azimuth	61.34°
Elevation	1798 ft ASL
Antenna CL	65.6 ft AGL

Signal Path Interference - Other Considerations

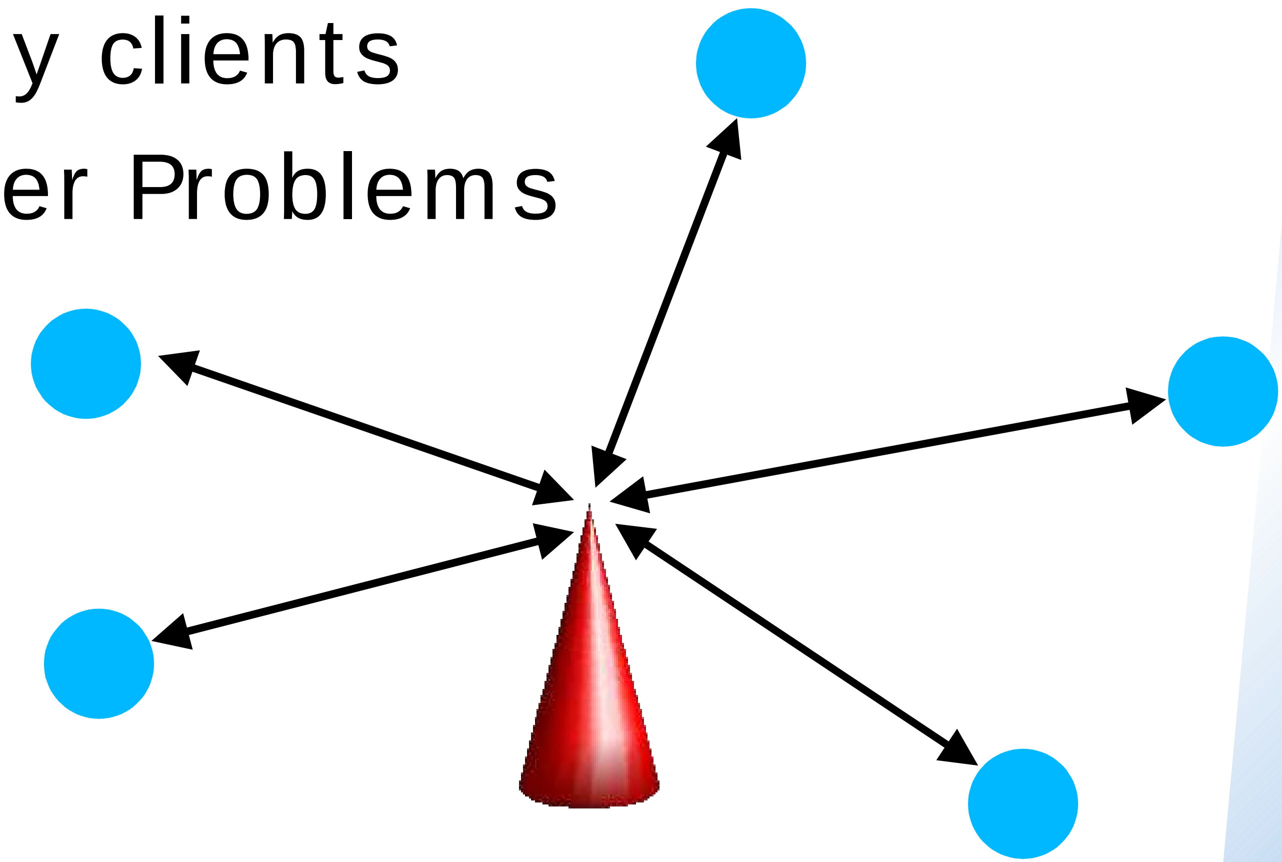
- Multi-path
  - Structures and bodies of water can create a second path that will cause interference.
  - Typical Solutions:
    - Change the polarization of the antenna
    - Change the beam-width of the antenna
      - More gain, tighter beam-width, more expense.
    - Add shielding
- Other users of the band?
  - Typical Solutions:
    - Change frequency.
    - See above

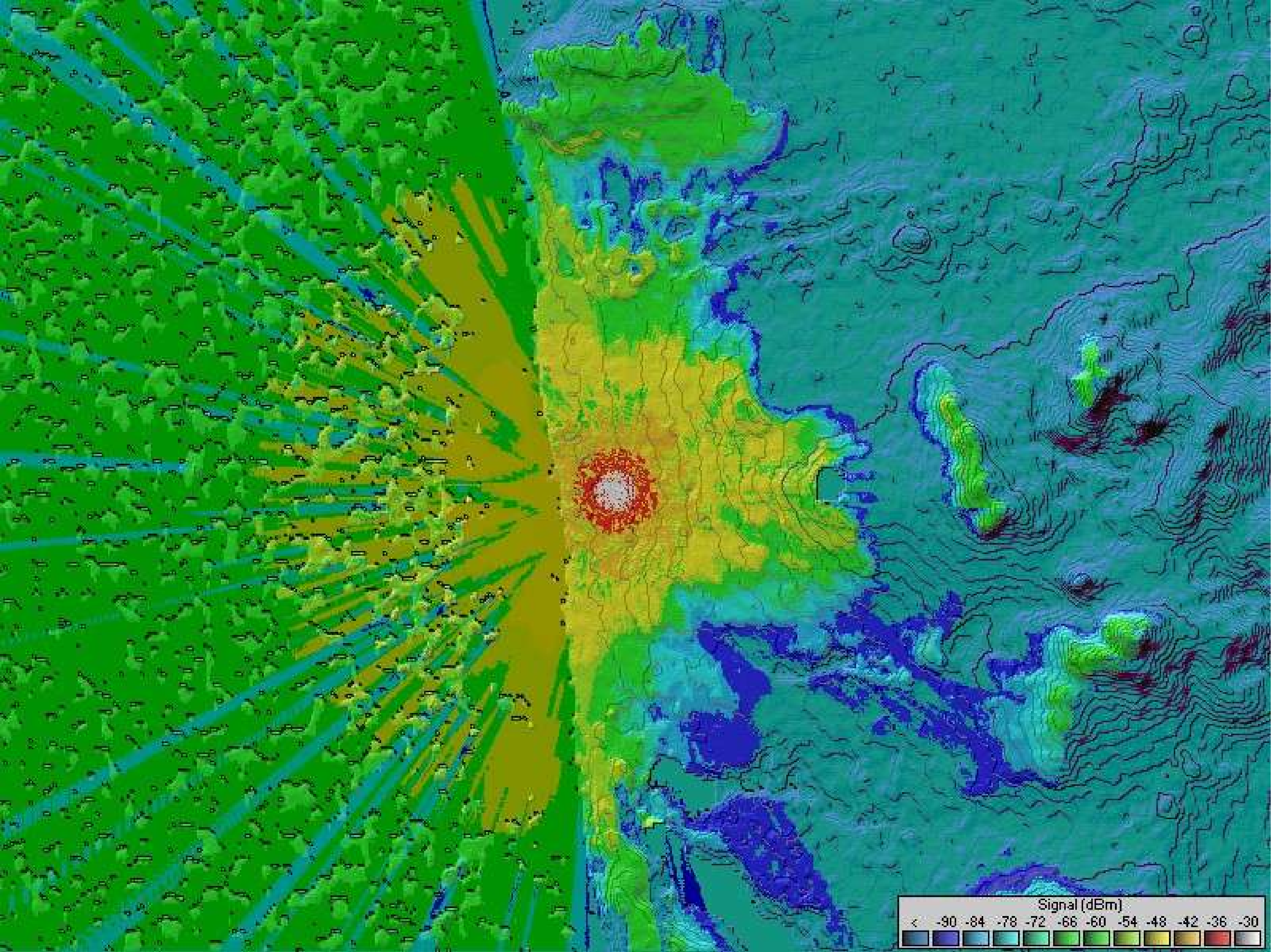
Coverage Area – Point to Multipoint

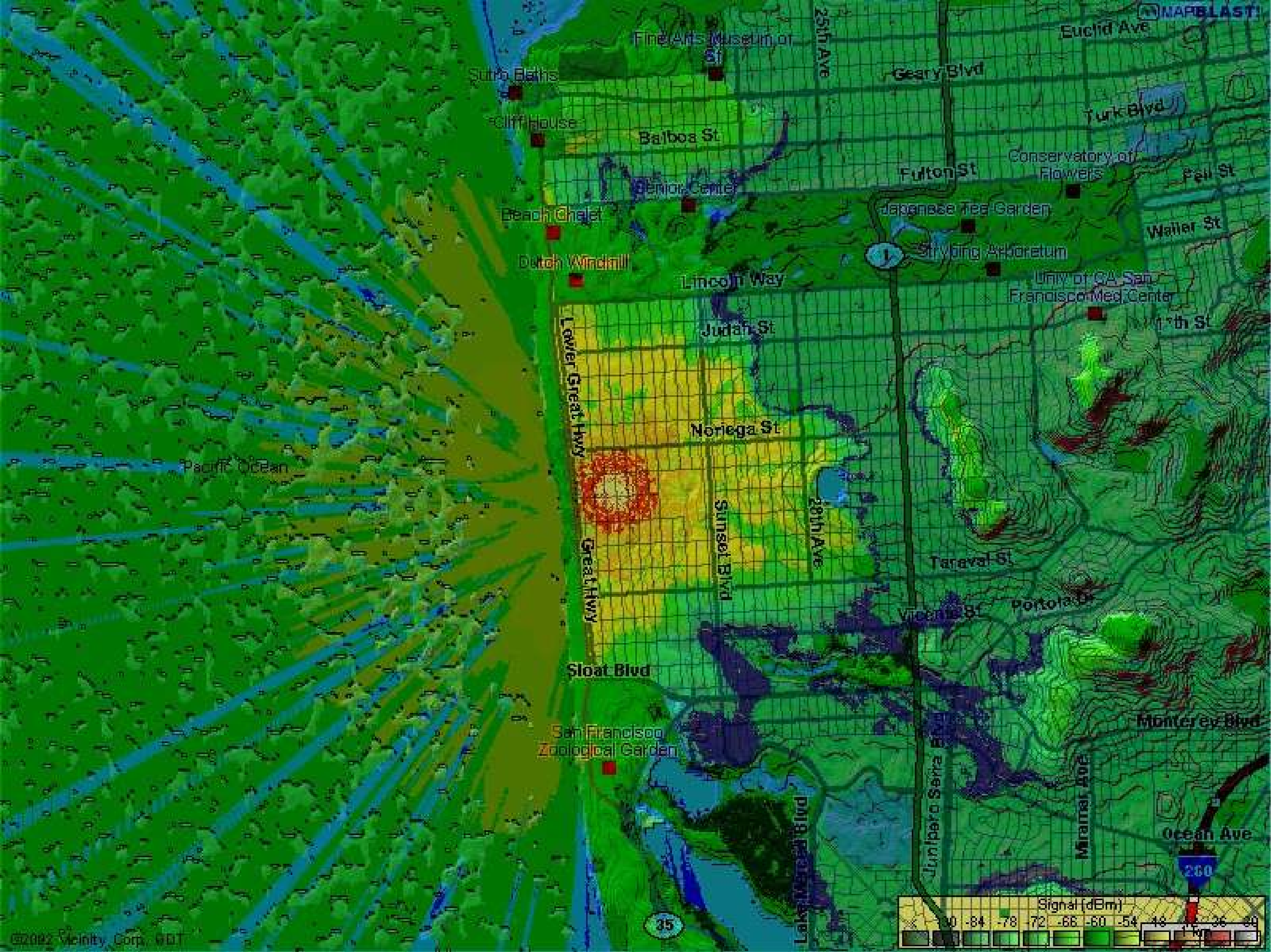
- Questions to ask yourself:
  - How many clients can see your AP?
  - What sort of signal strength can the clients expect?
  - Where are they located?
    - One area vs. all around you?
- Propagation Prediction Methods: An elaborate form of ray-tracing.
  - Longley-Rice
  - Terrain-Integrated Rough-Earth Model (TIREM)
    - Considered a better method
  - Both can over-predict 5-17dB.
  - The more expensive software modifies these methods for better accuracy.

Topology – Point to Multipoint

- Traditional Design
- One AP / Many clients
- Hidden Xmitter Problems




Signal (dBm)
< -90 -84 -78 -72 -66 -60 -54 -48 -42 -36 -30


MAPBLAST!
Euclid Ave
Fine Arts Museum of SF
25th Ave
Sutro Baths
Geary Blvd
Turk Blvd
Cliff House
Balboa St
Conservatory of Flowers
Fulton St
Fell St
Senior Center
Japanese Tea Garden
Beach Chalet
Waller St
Strybing Arboretum
1
Dutch Windmill
Lincoln Way
Univ of CA San Francisco Med Center
Judah St
Lower Great Hwy
Noriega St
Pacific Ocean
Sunset Blvd
28th Ave
Great Hwy
Taraval St
Portola Dr
Vicente St
Sloat Blvd
Monterey Blvd
San Francisco Zoological Garden
Junipero Serra Blvd
Miramar Ave
Lake Merced Blvd
Ocean Ave
280
35
Signal (dBm)
-84
-78
-72
-66
-60
-54
-48
-36
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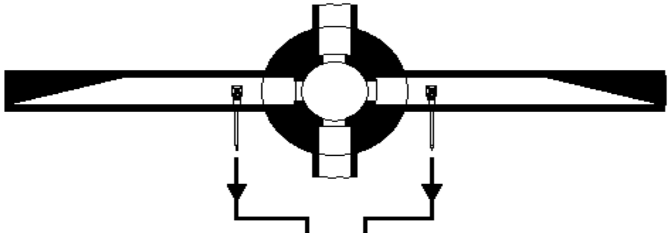
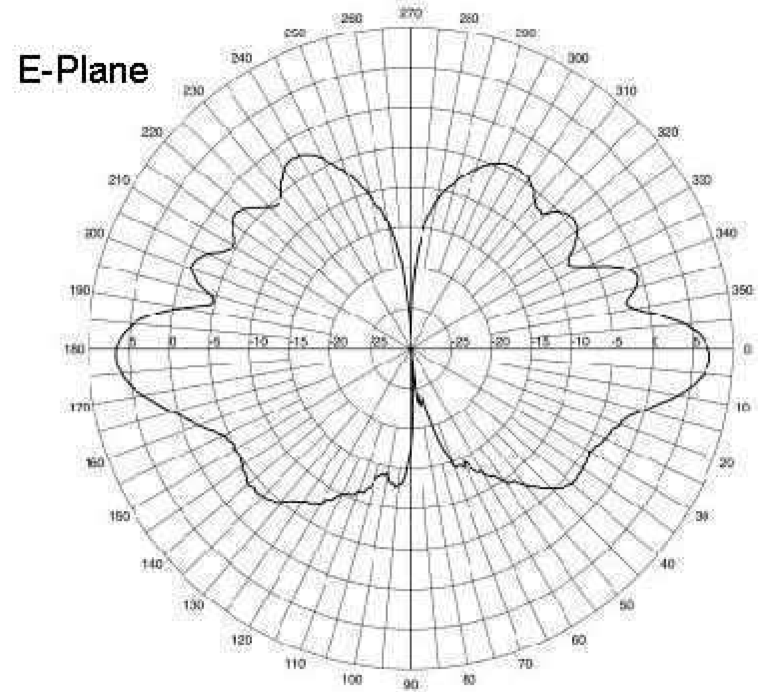
Which Antenna for the Job?

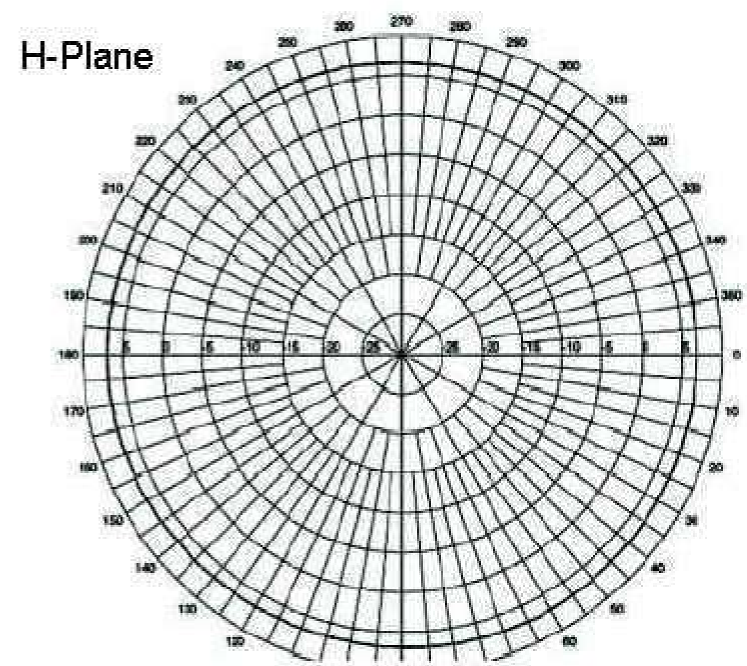
- Multi Point to Multi Point
  - Omnidirectional antennas on both ends
  - Designed is discouraged due to spectrum polution.
- Point to Multi Point
  - Omnidirectional for the "point" or "center", directional for the endpoints.
  - Typically for last mile.
- Point to Point
  - Directional for both ends.
  - Back bone links

Different Antennas for the Job

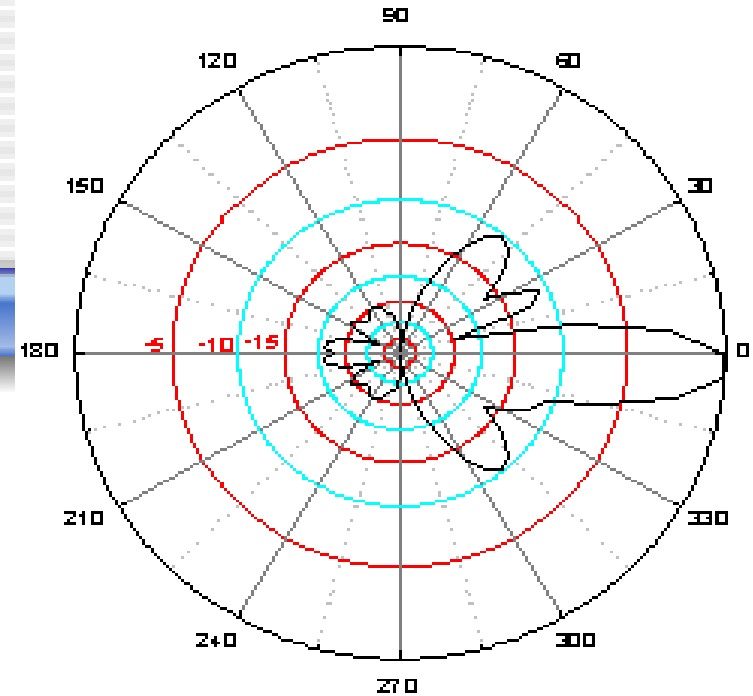
- Point to Multipoint
  - Di-pole
    - Typical PC card antenna
    - Very low gain, radiates in almost all directions equally
    - Horizontal Polarization
  - Omni-Directional
    - Usually has gain: 0 to 15 dBi – Lower gain better for tall mounts.
    - Typically Radiates equally well on the horizontal plane.
    - Vertical Polarization
  - Panel or Sector
    - Used to cover a section of a flat area.
    - Has gain: 3 to 18 dBi
    - Horizontal beam width is typically 10 to 120 degrees.
    - Vertical beam width is typically 10 to 45 degrees




E-Plane

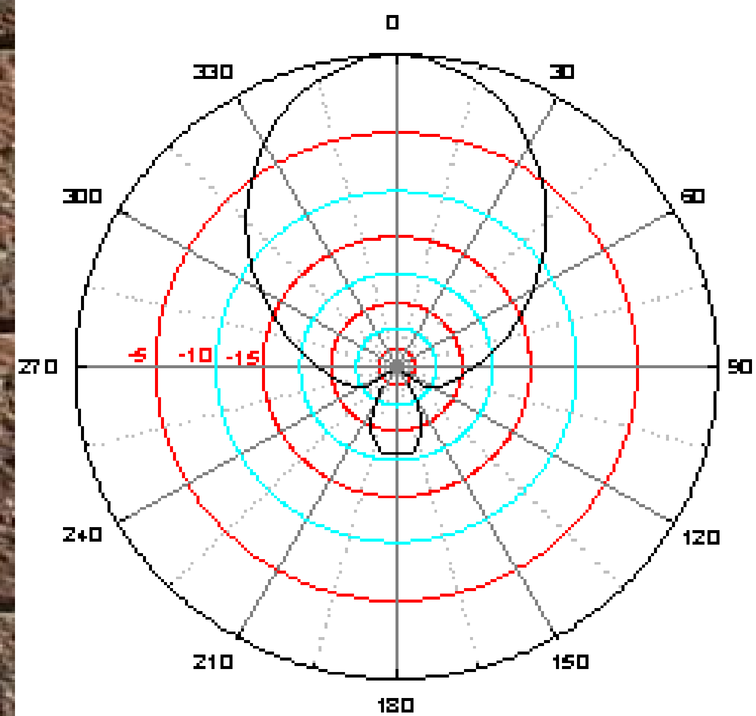

H-Plane

Panel Antennas



Great for targeting an area to serve. Typically put around a tower to segment coverage of an “omni”.

Make: SuperPass
Model: SPFPGH14S
Gain – 14 dBi
Hort. Beam – 60 deg.
Vert. Beam – 18 deg.



Directional Antennas

- Does <u>not</u> radiate in all directions
- The more focused the antenna, the higher the gain.
- Will have either vertical, horizontal or circular polarization

Why Use a Directional Antenna?

- Helps your system and be a good neighbour.
- Raise the effective power to the distant point you are trying to serve.

  Helps with the fade margin.
- Reduce interference to the path.

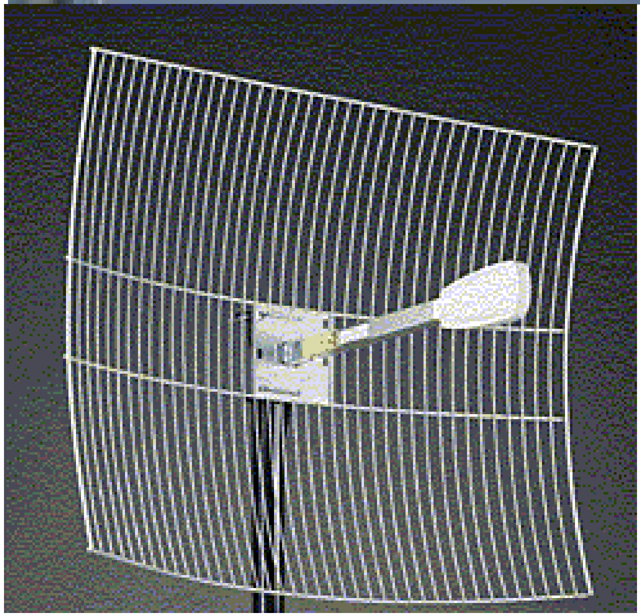
  Your receiving antennas will be less sensitive to off-axis signals (ie. Other transmitters or multi-path).
- Reduce interference to others.

  Transmitting antennas will send less signal to off-axis receivers.

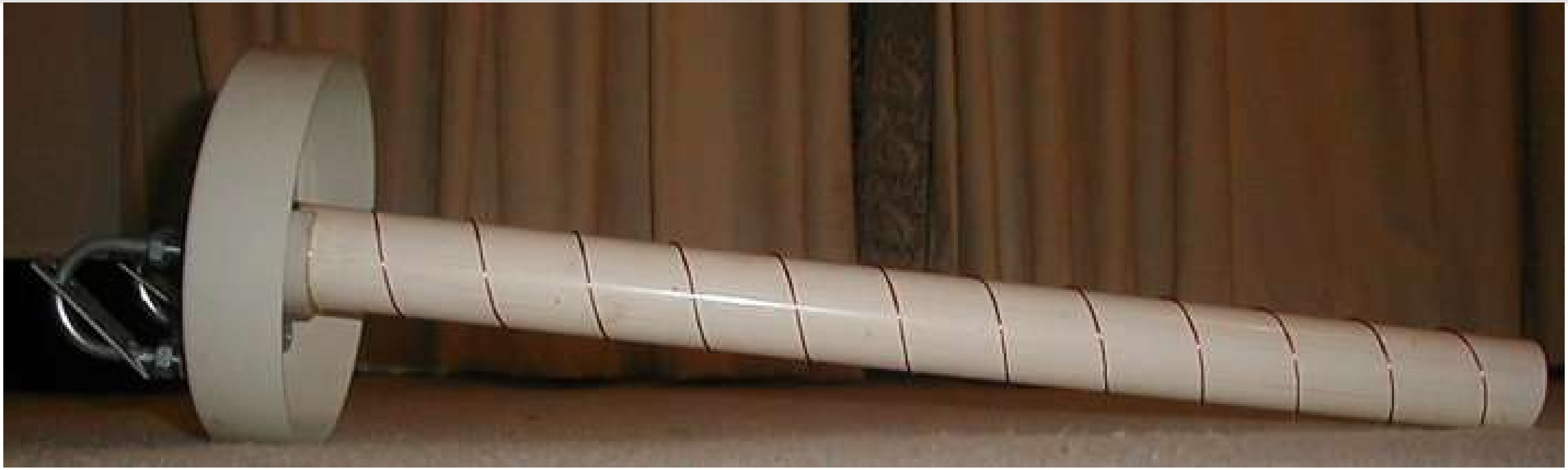
Antennas 101 continued… P2P

- Yagi
  - 5 – 18 dBi of gain
  - Vertical or horizontal polarity

- Parabolic
  - “Dish” shaped
  - Larger than a Yagi
  - 15 – 36 dBi of gain
  - Vertical or horizontal polarity



Helical Antennas



- Has circular polarization
  - Left or right handed
  - Great for multi-path problems (see next slide)
- Gain is 10 – 25 dBi

Antenna Polarity

- Polarity is a product of the design of the antenna.
- Each end of the link must match.
- It can be used to minimize multi-path and interference.
- Typical Polarities:
  - Horizontal
    - Avoids multi-path from vertical objects like buildings
  - Vertical
    - Avoids multi-path from horizontal objects like the ground, bodies of water.
  - Circular
    - It can avoid multi-path from “odd-number bounced sources.
    - Left or right handed

Frequency Coordination

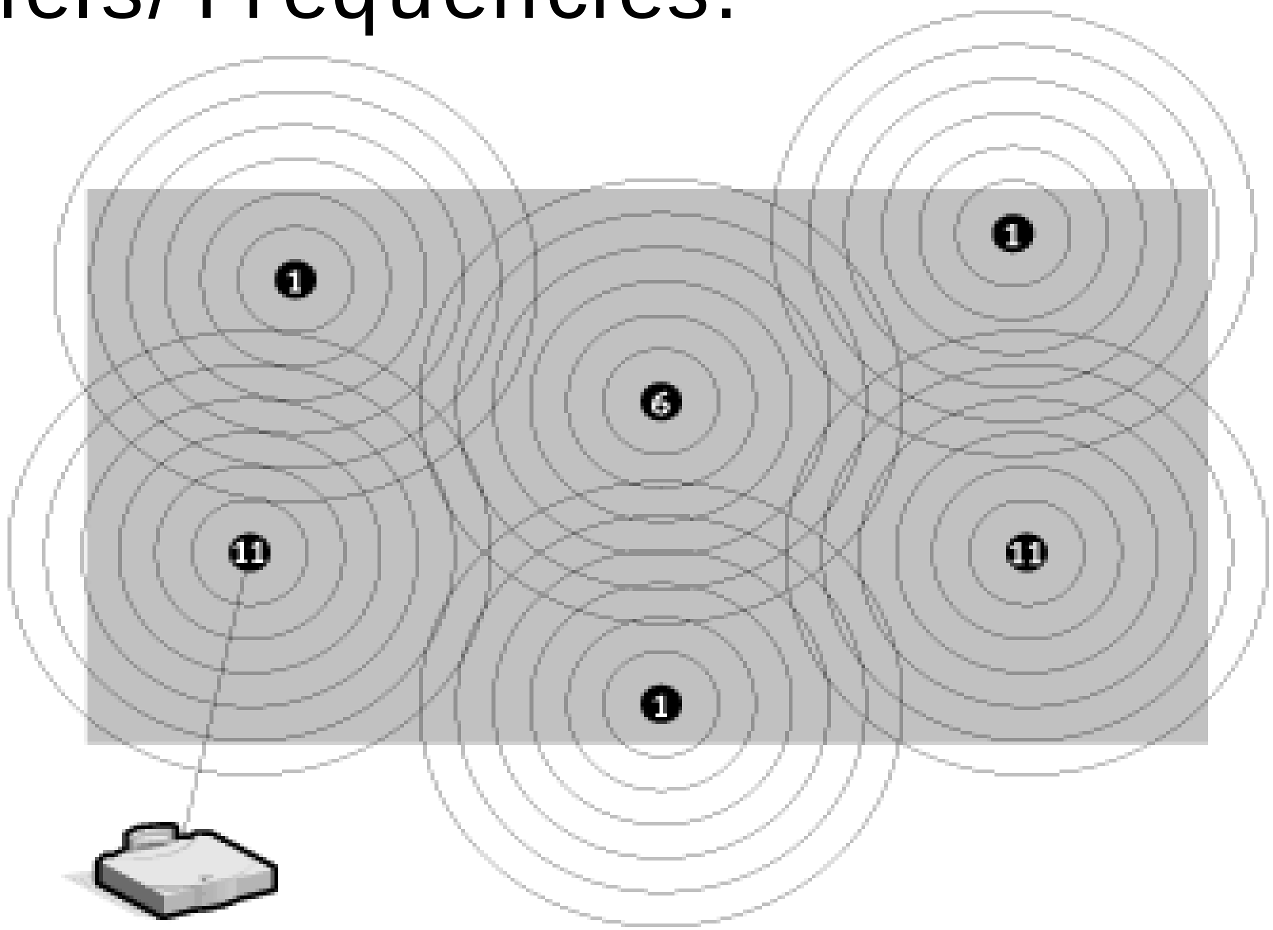
- The bands are crowded and the channels overlap.
  - @ 2.4GHz only channels 1, 6 & 11 do not overlap. (next slide.)
- Need to coordinate internally.
- Need to coordinate with other band users.
  - 2.4 is used by non-licensed and licensed users
    - Licensed users are: Amateurs, ENG, Public Safety, etc.
  - Find out who may be using the band in your area.
    - Ie. Mountain tops may have licensed users.
  - Better would be to use a spectrum analyzer and try to identify the users.
  - Worst case: just fire it up and find out what works.

Frequencies of 802.11b Channels at 2.4 Ghz

Channel	Bottom (Ghz)	Center (Ghz)	Top (Ghz)
1	2.401	2.412	2.423
2	2.406	2.417	2.428
3	2.411	2.422	2.433
4	2.416	2.427	2.438
5	2.421	2.432	2.443
6	2.426	2.437	2.448
7	2.431	2.442	2.453
8	2.436	2.447	2.458
9	2.441	2.452	2.463
10	2.446	2.457	2.468
11	2.451	2.462	2.473

Multiple Aps vs. Frequencies

- APs should not overlap Channels/ Frequencies.



Access Points – Examples...

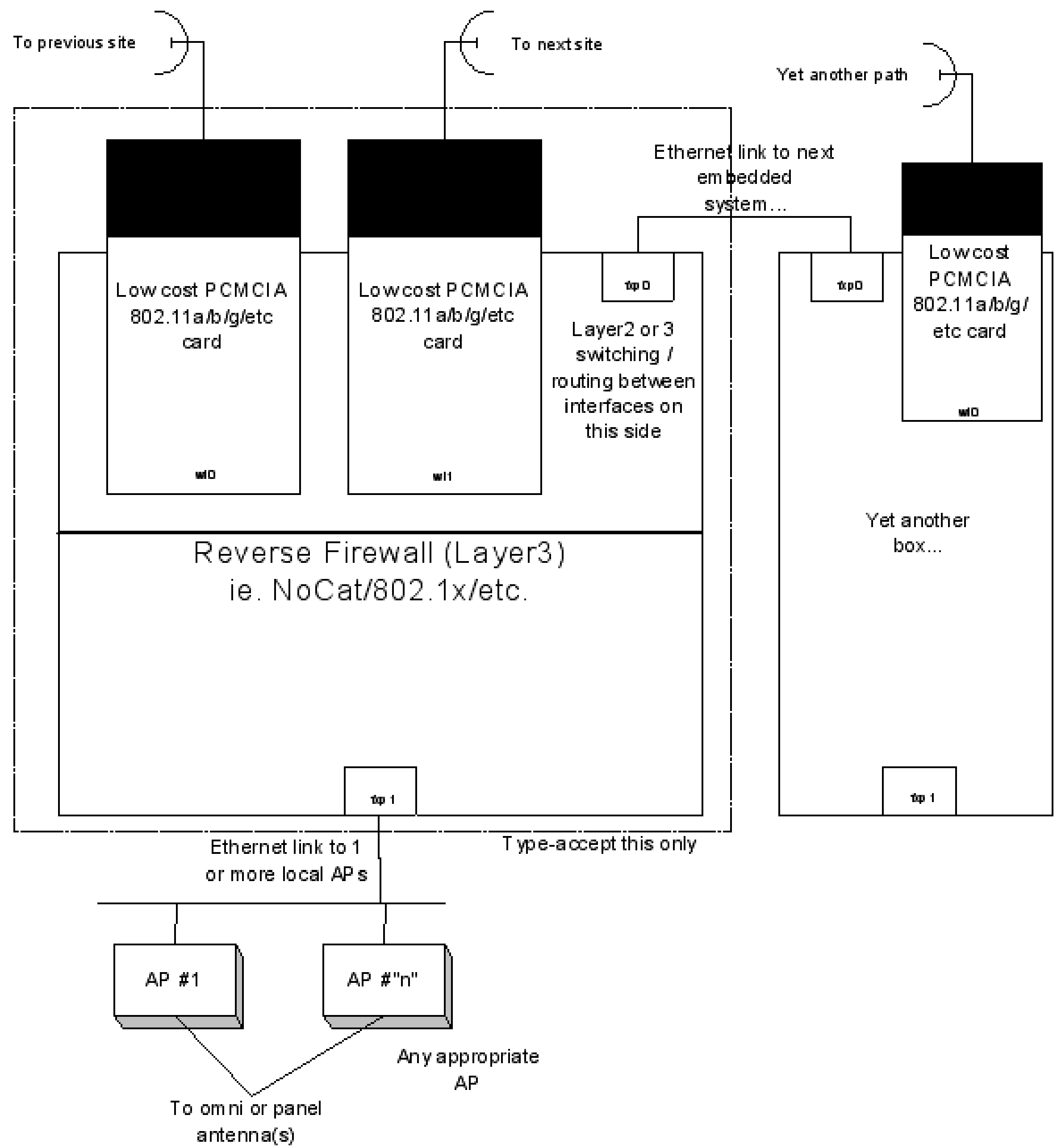
- Range in costs from $50 to $1000
- High end to low:
- Cisco 1200
  - Supports 802.11b, 802.11a & 802.11g
  - Space for 2,048 MAC addresses
  - ~$600 to $800
- Cisco 350
  - Next step in the “Aironet” line from the 340 series.
  - ~$500 to $1000
  - Space for 2,048 MAC addresses

Home-brew APs - An Example

- Soekris 4521 - www.soekris.com
- 2 PCMCIA slots and 1 mini-PCI for radios (3 radios total)
- GEODE CPU - like a 486@133MHz
- 2 100base-T
- CompactFlash slot
- FreeBSD 4.10 in < 32 MB
  - IPFW, NAT, NoCat, Open1X (open1x.org), altq, etc.

BAWRN Designed Hardware

- Layer 2/3 switching/routing between radios via 802.11 and cat-5.
- Layer 2/3 to access points
- Can run “fancy” routing protocols such as spanning tree or BGP.
- Can also be its own AP.



Other Hardware Considerations

- Amplifiers
  - Great for TX and RX issues if used properly.
  - Best installed next to the antenna to overcome cable loss.
  - Can cause more “RF pollution” with excessive power. Quality varies by make and model.
  - Regulation issues – Equipment Certification. (Soon to be deregulated)
- Cables
  - Bigger the better for longer runs as you will have lower loss.
- Battery Backup
  - How critical is it if the power goes out?
- Grounding and Lighting Arrestors
  - Static and lighting can do some rather dramatic damage.

Grounding

- No 100% way to protect from large direct lighting hits. You can minimize damage with static build-up and small discharges through proper grounding.
- Static and lighting will tend to build up on the highest devices (antennas, towers, etc.).
- Biggest damage comes from a strike to a single point.
  - One solution: "Static-Cat" like static dissipation

Grounding (cont.)

- Discharges will go through the most "direct" route to/from ground.
- Don't design installations where your equipment is the best path.
  - Tower/Pole Grounding
  - Transmission Line Grounding
    - At antenna mount and base of tower.
    - Gas discharge devices (example next slide)
- Provide a proper ground and common Point.

Grounding and Lighting Arrestors...

- Gas discharge grounding termination.
- Goes in-line with transmission line.
- Protects center conductor strikes.
- Doesn't conduct until strike.

Additional Weather Proofing

- Seal transmission line connections.
  - Wrap all connections with rubber tape and then a UV proof tape.
  - Don't reuse connectors. Cheaper in the long run to purchase new.
- Use outdoor cable (coax and ethernet)
- Provide drip loops for transmission lines before entrances to equipment and buildings.
- Use light colours on equipment to keep internal heat down.

Future...

- How can we increase bandwidth while still addressing the physics (turf and spectrum)? Possible steps:
  - 802.11H – Spectrum Managed 802.11a
    - Automatic power control
    - Automatic frequency selection
    - Needed for EU and something 802.11a/b/g should have.
  - Mesh
    - MeshNetworks, et. al.
  - Phased-Array Antennas
    - Vivato, et. al.
  - Active and passive coginitive radios.

Resources

- Books
  - “Building Wireless Community Networks” - Rob Flickenger – O'Reilly
  - “802.11 Wireless Networks” - Matthew Gast – O'Reilly
- http://www.freenetworks.org
  - The “meta” site for the community groups such as:
    - Bay Area Wireless Users Group - http://www.bawug.org
      - Great mailing list
- http://www.ieee.org
  - The standards body for 802.(n)(x)

Thank You and Q&A

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