Wireless Communications for Rural ITS

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Washington State
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Abstract

- The Washington State Department of Transportation has been working on identifying efficient and cost effective ways of collecting data from rural areas of the state. We took the successes and failures of previous projects and started the process of researching new technologies to fit our agency's needs. During the process we collected data from all our different divisions to determine what types of data is needed in rural areas, capacity needs, and data speeds.   To be efficient we needed to ensure the new data system could take advantage of existing resources used by our voice system.

- In 2009 we implemented a new pilot project that was focused on the mobile ITS device, the snow plow truck, using medium speed (64Kbps) IP Technology. Two mountain top radio sites were selected that provided wireless communications in an area that had little to no commercial wireless services. We were successfully providing near real-time data from the truck's onboard data collection box. The project quickly expanded to the fixed ITS devices. We successfully connected to devices 10.9 and 49 miles away.

- Currently we use high speed (above 500Kbps) and medium speed wireless communications to control over 125 rural ITS devices statewide.

Overview

- Previous Projects
  - Lessons Learned
- Existing Systems and Current Deployment
  - Projects
  - Technology
- Details
  - Engineering
  - Tools
  - Technology

Previous Projects
Lessons learned

Previous Projects

How did we get to where we are today

- Snoqualmie Pass (1994)
  - Licensed 960 MHz
  - PTP and PTMP
  - Analog
  - Limited bandwidth
- I5 Tacoma Video (1995)
  - Licensed 18 & 23 GHz
  - Analog
  - Equipment limitations
- Stevens Pass (1998)
  - Existing Voice System
  - Voice or Data?
  - What data is needed?
  - Analog
  - Limited bandwidth
- SR16 Video Project (2004)
  - Unlicensed 5.8 GHz
  - PTP and PTMP
  - Digital
  - Interference

Previous Projects

Snoqualmie Pass

- Project
  - Provide traveler information over I90 and variable posted speeds over the mountain pass. I90 is the main artery from Port of Tacoma and Port of Seattle to the Eastside of the state.
    - VMS, VSL, Speed detection, RWIS and HAR.
    - Adjusted pass speeds based on conditions.
  - Software applications were developed to communicate to the field equipment to make speed suggestions.
    - Suggested speeds automated from information gathered by ITS devices but manually executed.
  - Roadside equipment shelters were concrete huts.
  - Licensed 960 MHz Wireless Data Radios
    - Wireless equipment was analog and configured for PTP and PTMP
    - FSK 9600 Baud
    - Limited bandwidth

Previous Projects
Snoqualmie Pass

- Challenges
  - Original outside services design and installation.
    - Lack of understanding in wireless communications systems.
    - Software applications lack delays needed for wireless systems.
    - Radio path analysis (site location) was done with a handheld radio by listening to audio quality.
  - Terrain over the pass created challenges in design, installation and maintenance.
  - Environmental conditions impacted signal strength by creating multipath.

Previous Projects
Snoqualmie Pass

- Lessons learned
  - In software developed ITS solutions the delays in wireless communications as opposed to direct connect need to be taken into consideration.
  - Multi hop radios packet acknowledgement delays are accumulative and need extra time.
  - Packet size needed to be reduced to improve performance over the air.
  - Radio carrier "on time" needed to be increased due to packet retries.
  - If systems are essential and redundant, communications and control systems are needed.
    - Concrete huts were under several feet of snow in the winter or inaccessible due to avalanche danger. Hard to reset system if required.
  - Ice buildup on exposed Yagi antennas decrease performance. If ice is an issue use enclosed antennas.
  - Ensure contractor uses proper path calculation when designing wireless system.

- Current state of deployment
  - The system is still used today. After 17 years of use the system is due to be replaced this summer with a digital Mesh system.

Previous Projects
I5 Tacoma Video

- Project
  - Provide CCTV with PTZ control in the Tacoma WA area to monitor traffic congestion.
  - Licensed 18 and 23 GHz Analog Microwave.
  - NTSC composite video image over analog.
  - Took the raw composite video feed and transmitted over wireless. 1 video feed per wireless link.

- Challenges
  - Original outside services design and installation.
    - Lack of understanding in wireless communications systems.
    - Alignment of 23 GHz microwave systems
  - In an analog system the noise and video distortion was cumulative in a multi hop environment.

Previous Projects
I5 Tacoma Video

- Lessens learned
  - Was not cost effective to deploy in other areas.
  - Contract specified the use of qualified personnel to align microwave equipment was required.
    - Personnel were not skilled and this added a year delay to project completion. At 23 GHz frequencies path alignment is critical.

- Current state of deployment
  - The last path was decommissioned in 2009 and replaced by fiber.

Previous Projects
Stevens Pass

- Project
  - Provide winter operations data from the snow removal equipment (Snow Plow Truck).
  - Use existing voice communications infrastructure.
  - Collect the data in near real time to make business decision on equipment deployment and materials.

- Challenges
  - Ourselves
    - We could not decide what information was relevant to make real time decisions. Everything was sent real time. Plow up, plow down, sander on, sander off, speed, temperature.
  - The voice system was analog and limited in bandwidth. 4800 baud was the maximum rate that could be established.

Previous Projects
Stevens Pass

- Lessons learned
  - In a shared system (voice and data) voice should have the higher priority. However when resources are limited in a storm voice is always present. No data transmitted.
  - What data is needed in near real time? It is a business decision however we demonstrated that if everything is sent real time bandwidth limited systems will not be able to meet the demand.
  - Needed to be seamless to the operator.
  - More bandwidth is needed to make real time decisions.

- Current state of deployment
  - Decommissioned shortly after first winter.

Previous Projects
SR16 Video Project

- Project
  - Provide CCTV with PTZ along SR16 to monitor traffic congestion and ramp metering due to new Tacoma Narrows Bridge construction and tolling.
  - Use digital IP technology to transport the images.
  - MPEG 2 encoders were used to convert NTSC Video to a digital format and to decode at the TMC.
  - Wireless design done with state forces.
  - Provide wireless connectivity to the closest fiber hub.

- Challenges
  - Finding locations for the cameras between the rolling hills and tree line that provided good visibility for both the camera and wireless equipment.
  - Using the congested unlicensed 5.8 GHz. Outside interference as well as another WSDOT project interfering with our equipment.
  - Wireless equipment selection was not the best choice for CCTV.
  - Vendor equipment IP watchdog continuously reset the port due to one-way IP traffic, streaming video duh.
  - MPEG 2 was bandwidth hungry and early IP radios were 10 Mbps.

Previous Projects
SR16 Video Project

- Lessons learned
  - Unlicensed spectrum use is consistently changing. Using fixed frequency radios in the spread spectrum band can be challenging.
  - Frequency reuse plan.
  - Vendor and equipment selection needs to be researched prior to purchase. Ask for a demonstration in your application.
  - IP watchdog with streaming video is not a good combination. We had to add a Ping device at the TMC to ping the far end device.
  - Auto negotiation will default to 10 Mbps at half duplex. Hard set your ports. Use manage devices to monitor port speeds and duplex.
  - MPEG 4 is more friendly in a wireless system backhaul.
  - IP Packet size was too large for a multi hop system.
  - Power over Ethernet (PoE) needs additional weather proofing. Manufacturer supplied weather proofing was not efficient for the Northwest environment. Monkey poop (vapor barrier tape) is better, just remember the courtesy wrap.
  - Trees grow fast, Fresnel zone clearance.
- Current state of deployment
  - Parts are still in service, we update encoders to MPEG 4 and replace most of the wireless equipment with more reliable equipment.

Previous Projects

Lessons learned - Relevant to today's technology

- When using outside contractors for wireless design and installation specify in the contract that qualified wireless engineers and technicians be used.
- Using the correct tools for path analysis is key to project success.
    - When using design build contract we ask for a copy of the path analysis and verify path calculations.
- Unsure line of sight is verified along with path clearance, use a bucket truck or climb the tower.
- Use enclosed antennas in cold winter environments.
- If data is critical use redundant systems, especially if winter conditions make it difficult to access.
- When collecting data in a limited bandwidth system determine what data is needed near real time and what can be stored and dumped later when bandwidth is available.
- Shared voice and data systems provide operational challenges when resources are limited.
- When using IP equipment hard set ports for duplex and speed.
- When sending CCTV over IP wireless equipment verify that vendor’s equipment doesn't have a watch dog at the Ethernet port. If so, can it be disabled. A simple ping to the far end can prevent resets.
- Packet size is important in a multi-hop environment even at IP.
    - Use a network analysis tool to look at IP traffic and analyze packets and packet sizes.

Existing Systems – Current Deployments





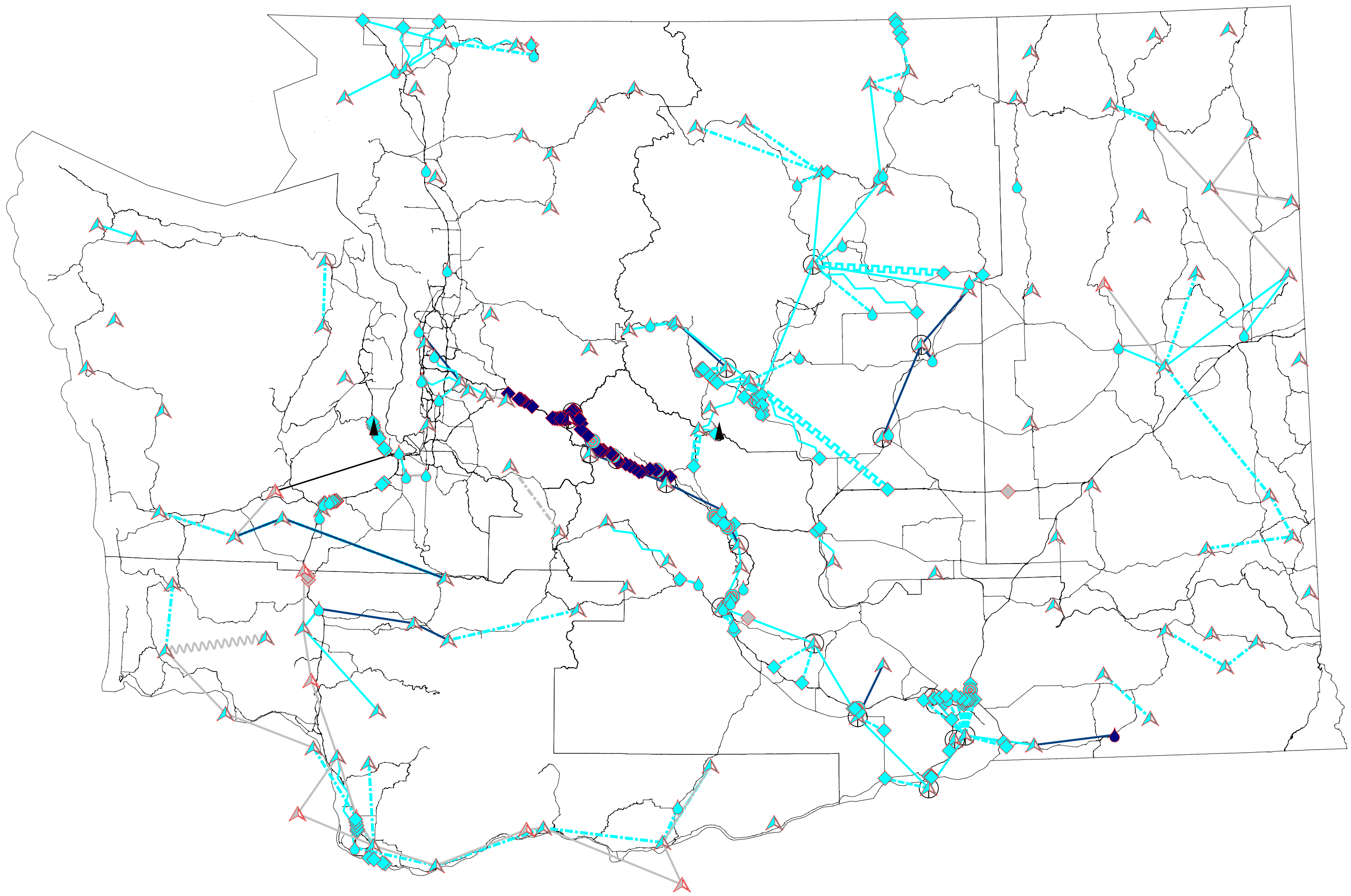






Existing WSDOT Systems

WSDOT has over 310 Wireless Communications locations



Includes sites for voice communications and ITS equipment locations

Existing WSDOT Systems

160 Wireless Communications locations support LMR voice system

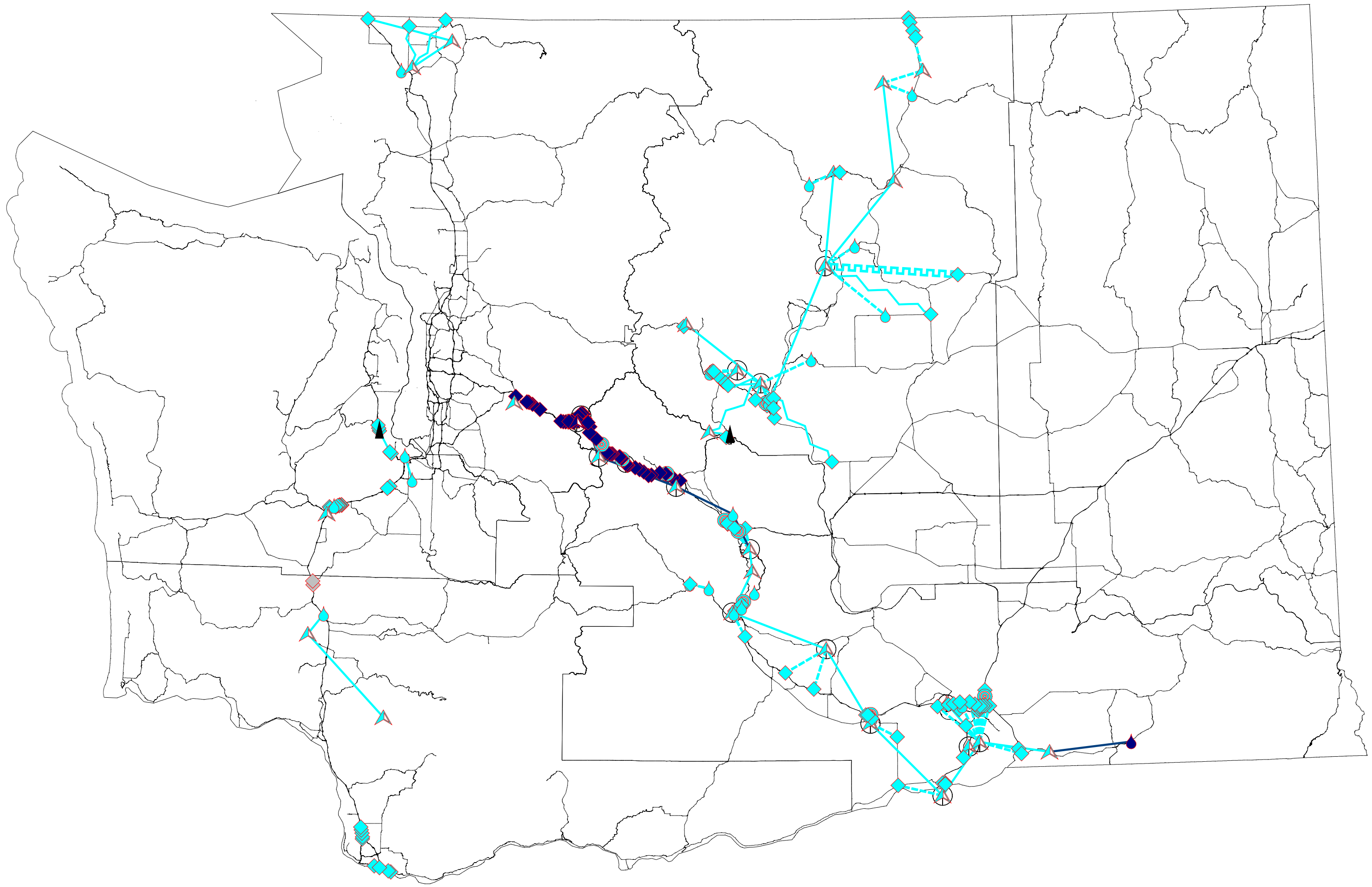
- Current deployment of the LMR system covers 95% of the state highway system.
- The current analog voice system is divided into an east and west deployment using the natural dividing line of the Cascades. Further division is the 6 individual Regions.
- The system requires communications from sites to central switches in each Region.
- Microwave is used as the backhaul from sites. Early deployment of the LMR system backhaul was primarily analog and provided by Washington State Patrol.

Existing WSDOT Systems
Regional ITS Wireless Backhaul

- WSDOT has rural ITS deployments throughout the state. Deployment is still fractured by the 6 individual Regions. Each Region has different ITS needs and deployments.
- Our first generation ITS systems were analog, expensive and limited.
- As ITS equipment evolved we determined digital IP based backhaul was needed.
- In 2001 WSDOT started to deploy digital wireless systems to support ITS equipment.

Existing WSDOT Systems

Over 150 Wireless ITS locations and additional 50 budgeted



Includes Sites with ITS backhaul and ITS equipment locations

Existing WSDOT Systems

Regional ITS Wireless Backhaul – Licensed High Capacity

- Point to Point Systems
- Advantages
  - Fixed bandwidth up to 155 MBs or Higher
  - Longer distance up to 50 miles (at 6 GHz)
  - 6, 11, 18 & 23 GHz
  - Requires line of sight or alternative pathing
  - Licensed

- Disadvantages
  - Requires coordination
  - Costs
  - Larger antenna mounting structures

Existing WSDOT Systems

Regional ITS Wireless Backhaul – Medium Capacity

- Unlicensed
  - PTP & PTMP
  - Variable MBs Up to 54MBps
  - Up to 30 Miles
  - Near Line of Sight
  - 2.4 and 5.8 GHz
  - **Possible Interference**

- Licensed
  - PTP & PTMP
  - Variable MBs Up to 54MBps
  - Up to 30 Miles
  - Near Line of Sight
  - 4.9 GHz
  - **Interference managed by Regional Planning Committee (RPC)**

Current Deployment
4.9 GHz PTP and PTMP

- Several projects or deployments statewide. Both rural and urban deployments.
  - Over 70 licensed locations.
  - These systems are half duplex.
  - Bandwidths that will support CCTV with PTZ.
  - Can interface to any device as long as it is IP.
  - Virtually no interference, only public safety agencies in the band. Coordination with local RPC, licensing is not difficult.
  - Equipment is reliable in the harsh winter environments. We have used external antennas. In theory, if your link budget will allow, you can place the electronics in a cabinet or shelter and deploy with an external antenna via coax.
  - Variable bit rates depending on link budget and ITS device.
    - Bandwidth and modulation can be selected individually to meet a specified link budget and data rate requirement.
  - Adaptive modulation can be used to automatically adjust modulation to meet minimum link requirements.

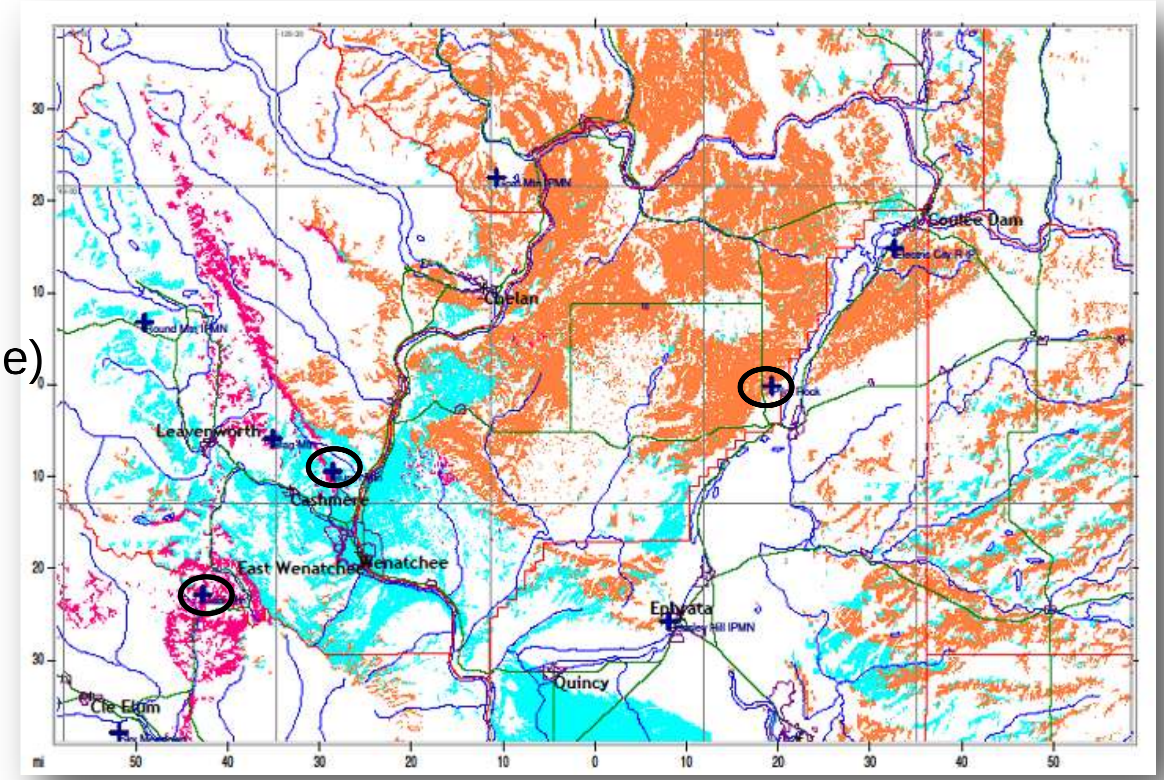
Current Deployment
4.9 GHz Mesh

- I90 Snoqualmie pass traveler information system replacement, 50 locations pending licensing.
  - The same benefits to a PTP or PTMP system in a fixed deployment.
  - Vendor provides two radios in each box. Each radio can work independently in either a north to south or virtual full duplex operation.
  - Full duplex requires two licensed frequencies and the radio will transmit on one while receiving on the other.
  - True mesh can use multiple paths to get the IP data back based on hop count for the shortest path. Can be designed for peer to peer communications (moving base)

Existing WSDOT Systems

Regional ITS Wireless Backhaul – Wide Area Systems

- Wide Area
  - Mobile & Fixed applications
  - 32 to 64 KBs
  - Up to 50 Miles
  - **Non** Line of Sight
  - Licensed
  - 700 MHz Band
  - Server to Base
  - Base to Client (mobile)
  - IP interface
  - Wire stretcher



Three sites provides over 6000 square miles of coverage in the Wenatchee area

Current Deployment

Wide Area Medium Speed

- Smart snow plow project – Stevens and Blewett Pass
  - Diversity deployment in both mobile radios and base stations.
  - Mobile and fixed deployments
    - Mobile deployments in snow removal equipment
    - Fixed ITS equipment
  - Base Stations – 2 base stations (Another 9 budgeted)
    - 3 Diversity receivers
    - Uses multipath to its advantage
    - First valid packet is passed on
  - Mobiles send data near real time for snow removal activities. AVL provides a time stamp and location for plow down (plowing), sanding or anti icing with rate of dispersal.
  - Fixed ITS devices RWIS, VMS, VSL and Snap shot cameras.
    - Dodson Rd 49 mile Path

Dodson Road

Updated: Thursday May 5, 2011 15:26 PM

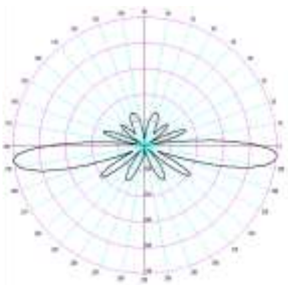
Surface Temp:	73ºF	Humidity:	29%
Air Temp:	67ºF	Dew Point:	34ºF
24hr High/Low:	69ºF / 40ºF	Visibility:	1 Mile
Pressure:	29in	Wind Speed:	21mph
Elevation:	1151ft/351m	Wind Dir:	W

Recent Weather Data

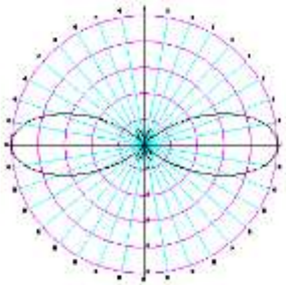
Current Deployment

Wide Area Medium Speed

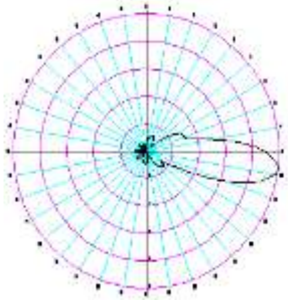
- Base stations
  - Due to the 3 diversity receivers 3 antennas will be installed. Antennas need to be spaced to provide maximum diversity efficiencies.
  - Both horizontal and vertical separation should be used.
    - We have also used two different antenna types to get maximum vertical beamwidth. This type of installation is done to match the terrain. Vertical beamwidth is key in mountain areas. The higher the gain antenna the narrower the beamwidth.
  - Base stations use an IP tunnel to communicate to the server. IP connections are required.



6 DB ONMI 6 deg DT



3 DB ONMI



8 DB Panel 7 Deg DT

Current Deployment

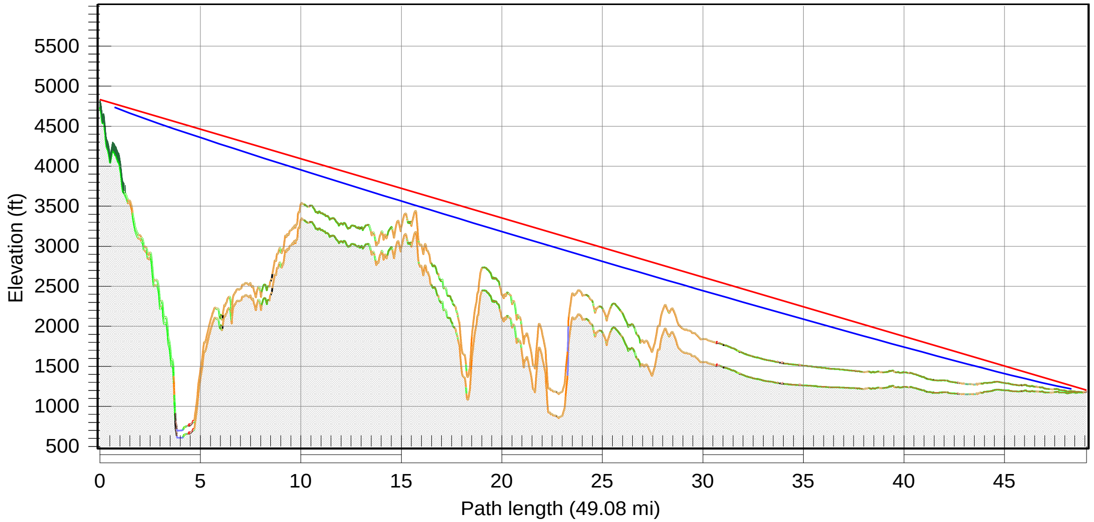
Wide Area Medium Speed

- Mobile or Fixed unit
  - Can be purchased as 64K or 32K models.
  - 32K model is a “fixed” radio; smaller box, one receiver and lower power out. Can be used at a solar powered site.
  - 64K model is a “mobile” radio; 2 diversity receivers, GPS, higher power. Will negotiate down to 32K if need to keep connectivity. Uplink and downlink can negotiate at different speeds (uplink 32K and downlink 64K). Due to the 2 diversity receivers 2 antennas need to be installed. Antennas need to be spaced to provide maximum diversity efficiencies.
  - We have used the “mobile” radio in a fixed application. Additional output power and diversity receive improvements.

Current Deployment

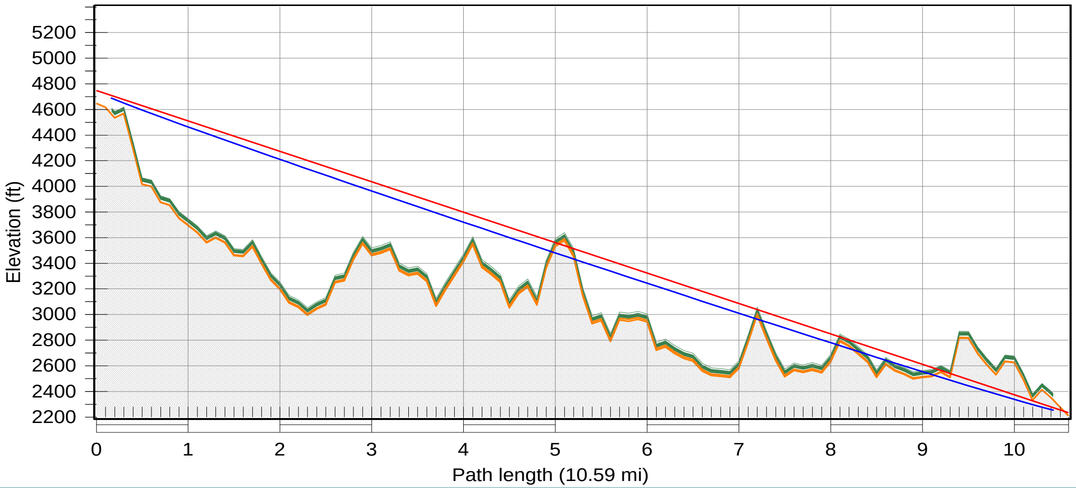
Wide Area Medium Speed

- Line of sight – Long distance 49 miles
  - Dodson Rd RWIS, VMS and Snap Shot Camera.
  - 64K mobile radio.
  - Commercial powered site using 9 DB Yagi antennas.
  - RWIS send updates every 10 min on the 5's.
  - Camera send updates every 10 min on the 10's.
  - VMS available any time.



Current Deployment
Wide Area Medium Speed

- Non Line of sight – 10 miles
  - Lauderdale VMS.
  - 32K mobile radio.
  - Commercial powered site using 9 DB Yagi antenna.
  - Previous connectivity via commercial Dialup phone line. Unreliable in the winter. After installation VMS was available on demand all winter, no outages. Been in service for 2.5 years.

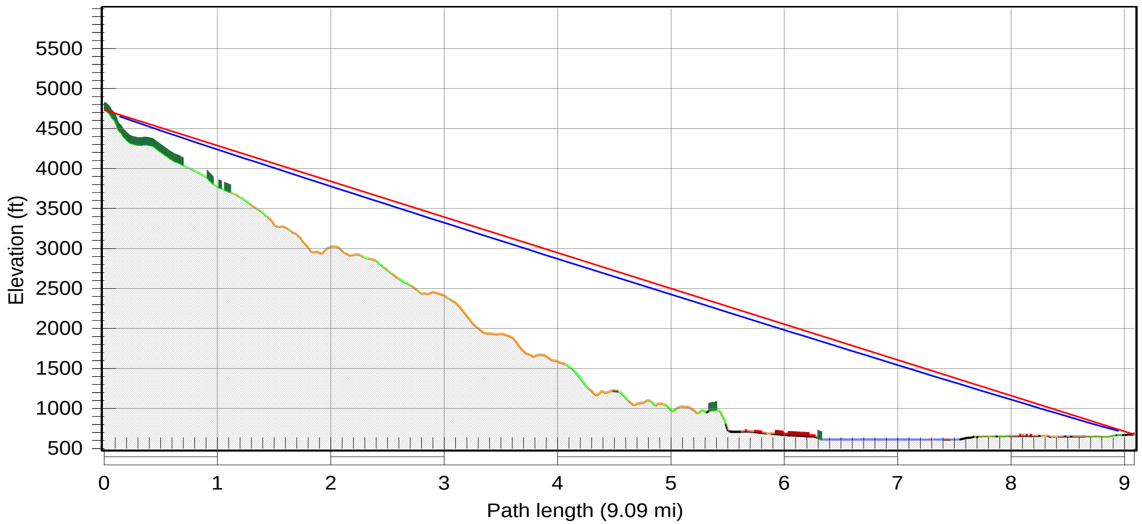


Washington State Department of Transportation

Current Deployment

Wide Area Medium Speed

- Near Line of sight, Solar – 7 miles
  - East Wenatchee HAR Flasher.
  - 32K mobile radio.
  - Solar power site using 3 DB ONMI antenna.
  - Previous connectivity via commercial cellular provided cost avoidance.



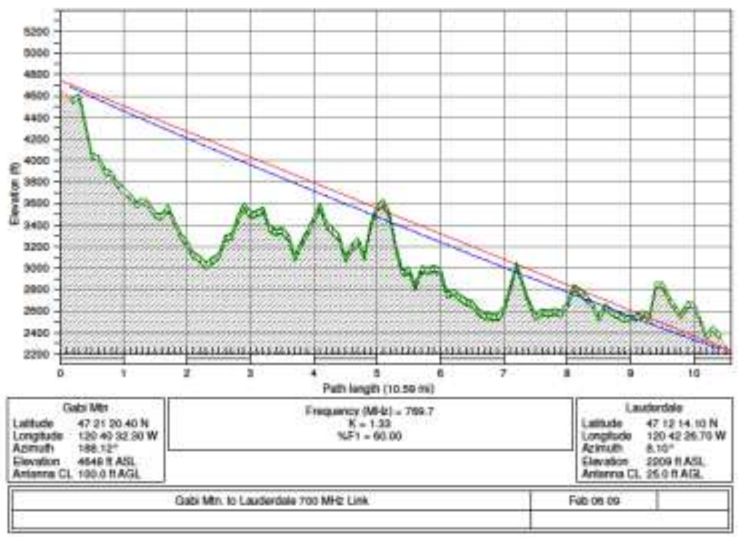
Washington State Department of Transportation

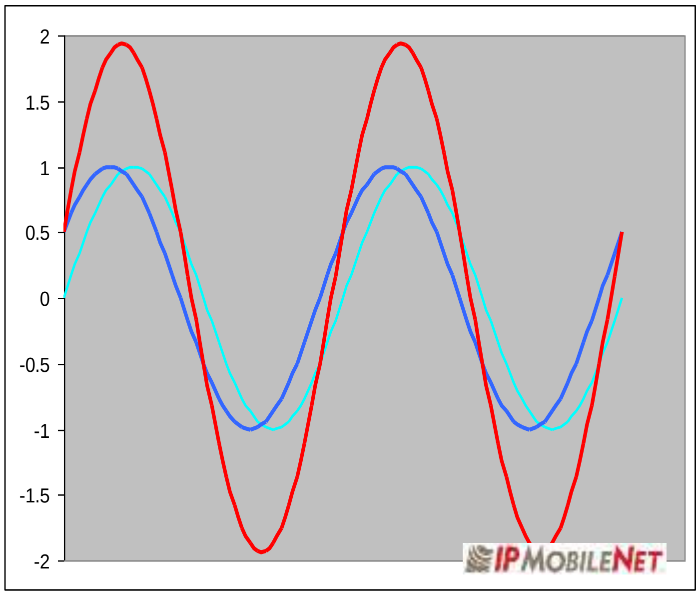
Current Deployment

Early Results

- 4.9 GHz
  - Spectrum is still relatively unused, no interference except with ourselves.
  - Equipment is quick to deploy and easy to configure.
    - I have assisted other local agencies with wireless ITS systems. There is equipment out there that is developed more for the ISP's. These can be difficult to configure.
  - Modulation options provide the flexibility needed for more diverse designs.
  - Can use standard path analysis software for design
  - MESH, still to early to tell. Project completion scheduled for this summer.
- Wide Area
  - Spectrum is available in the 700MHz band for the State of Washington.
  - Equipment is easy to install, however more equipment is required.
  - Additional engineering to deploy. Configuration is more difficult than the 4.9.
  - Coverage and diversity improvements exceeded expectations.
  - Software is still not sophisticated enough to compensate for the diversity and parallel decoding used by the vendor.
  - Diverse deployment – if you can talk IP it can be connected.
  - All that is needed is power (solar or commercial) and we can connect to the ITS device.

Engineering, Technology & Tools
The Design Details





Details

Engineering, Technology and Tools

- Engineering
  - 4.9 GHz
    - Licensing
    - Channel assignments
  - Path requirements
  - PTP and PTMP
  - 4.9 GHz Mesh
  - Wide area medium speed

- Technologies
  - 4.9 GHz
  - 700 MHz narrow band
  - Diversity

- Tools
  - Path Analysis
  - Comstudy

Engineering

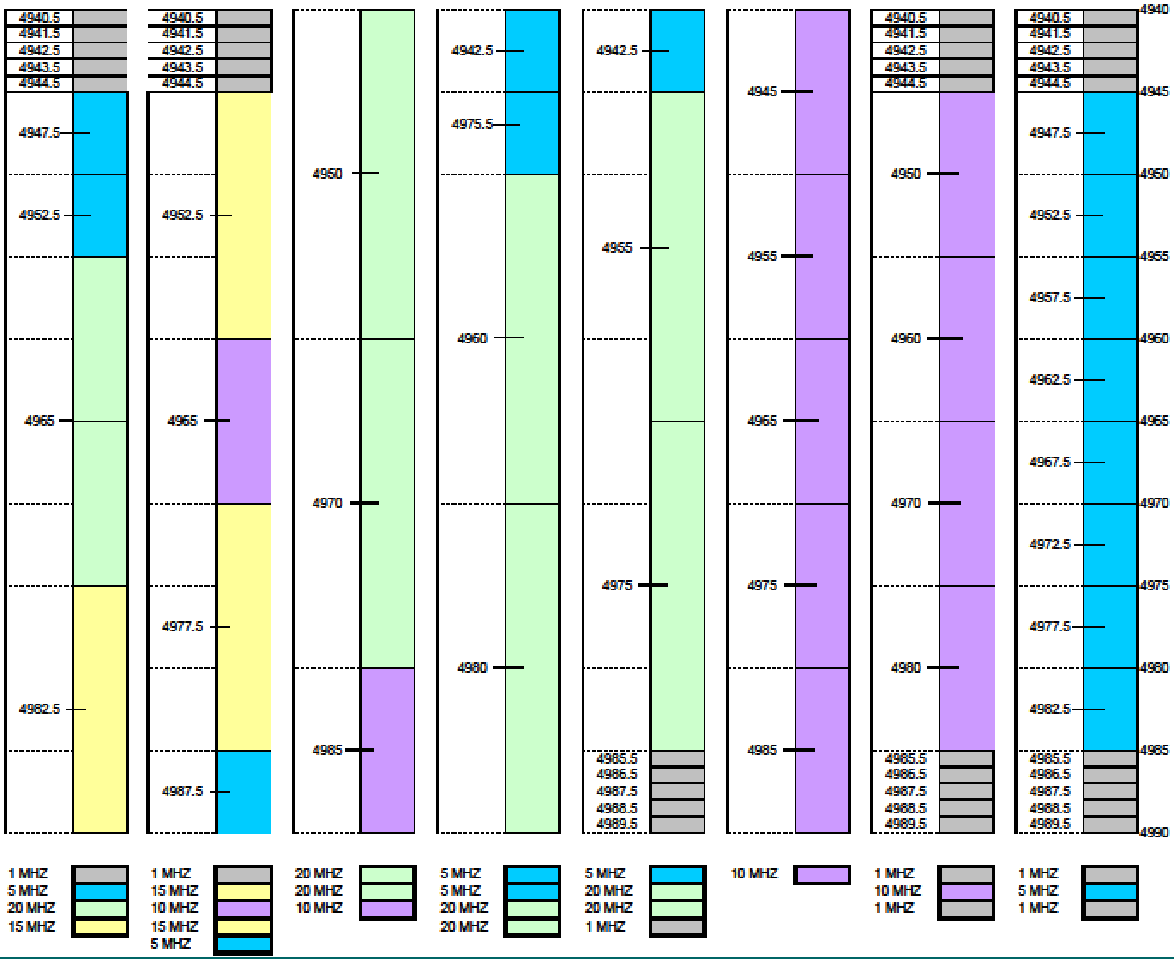
4.9 GHz Band

- 4.9 GHz Licensing
  - In 2002 the FCC designated 50 Meg of spectrum of the 4.9 GHz for public safety.
  - Devices that use this band will use the same technology as the unlicensed 5.8 GHz equipment.
  - Coordination of the 4.9 GHz band will be self coordinated via local Regional Planning Committees (RPC's).
  - Any government agency that uses the band must get a regional license. The regional license allows for the use of equipment up to one year. After the one year a location license is required.
  - Can be used in a PTP or PTMP or AdHoc.
  - PTP or Fixed links were considered secondary to AdHoc installation and may be turned off in an emergency.
  - In 2009 the FCC modified the rules to allow for fixed links to be considered primary if carrying video surveillance.
  - This rule change made the 4.9 GHz band a more valuable tool for ITS and CCTV.
  - Equipment in a 20MHz channel can provide up to 54 mbps.

Engineering

4.9 GHz Band 50 MHz of spectrum – Channel Assignments

4.9 GHz FCC Authorized Frequenct Channel Plan



Engineering

4.9 GHz Band – Channel Assigments

<table>
<tr><td>Channel</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td></tr>
<tr><td>Center Freq</td><td>4940.5</td><td>4941.5</td><td>4942.5</td><td>4943.5</td><td>4944.5</td><td>4947.5</td><td>4952.5</td><td>4957.5</td><td>4962.5</td><td>4967.5</td><td>4972.5</td><td>4977.5</td><td>4982.5</td><td>4985.5</td><td>4986.5</td><td>4987.5</td><td>4988.5</td><td>4989.5</td></tr>
<tr><td>BW</td><td colspan="18"></td></tr>
<tr><td>1 MHz</td><td>4940.5</td><td>4941.5</td><td>4942.5</td><td>4943.5</td><td>4944.5</td><td colspan="8"></td><td>4985.5</td><td>4986.5</td><td>4987.5</td><td>4988.5</td><td>4989.5</td></tr>
<tr><td>5 MHz</td><td colspan="5">4942.5</td><td>4947.5</td><td>4952.5</td><td>4957.5</td><td>4962.5</td><td>4967.5</td><td>4972.5</td><td>4977.5</td><td>4982.5</td><td colspan="5">4987.5</td></tr>
<tr><td>10 MHz</td><td>4940.5</td><td>4941.5</td><td>4942.5</td><td>4943.5</td><td>4944.5</td><td colspan="2">4950</td><td colspan="2">4960</td><td colspan="2">4970</td><td colspan="2">4980</td><td>4985.5</td><td>4986.5</td><td>4987.5</td><td>4988.5</td><td>4989.5</td></tr>
<tr><td>10 MHz</td><td colspan="6">4945</td><td colspan="2">4955</td><td colspan="2">4965</td><td colspan="2">4975</td><td colspan="6">4985</td></tr>
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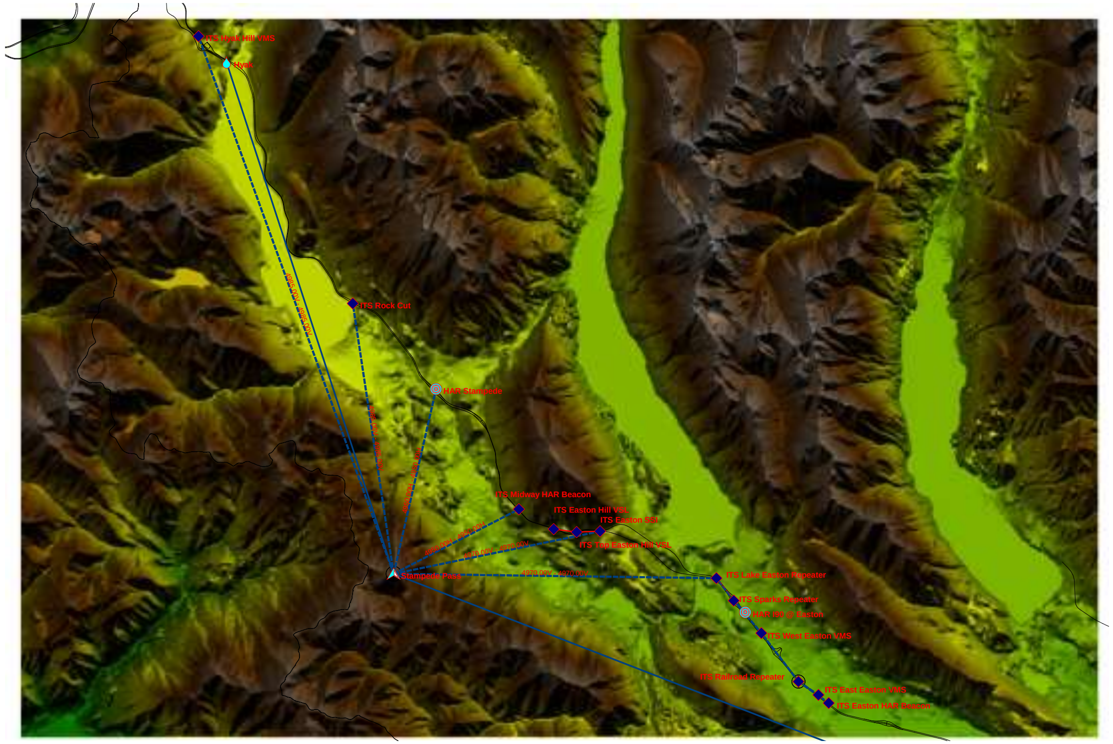
<tr><td>20 MHz</td><td colspan="8">4950</td><td colspan="4">4970</td><td colspan="6">4985</td></tr>
</table>

- Simple channel assignment tool
  - Bandwidth (BW) and Center Frequency is shaded.
  - This will allow for overlapping or adjacent channels to be used in a multi hop project.
  - Over lapping or adjacent channels need to have separation, polarity or physical (dirt, buildings, etc..).
  - Most equipment will allow for 40 MHz assignment. 40 MHz is legal outside the US, however **not** allowed in the US under current rules. Inexperienced Techs, Consultants or contractors may inadvertently program for 40 MHz assignment to get greater than 54 mbps.

Engineering

4.9 GHz Band – Channel Assignments

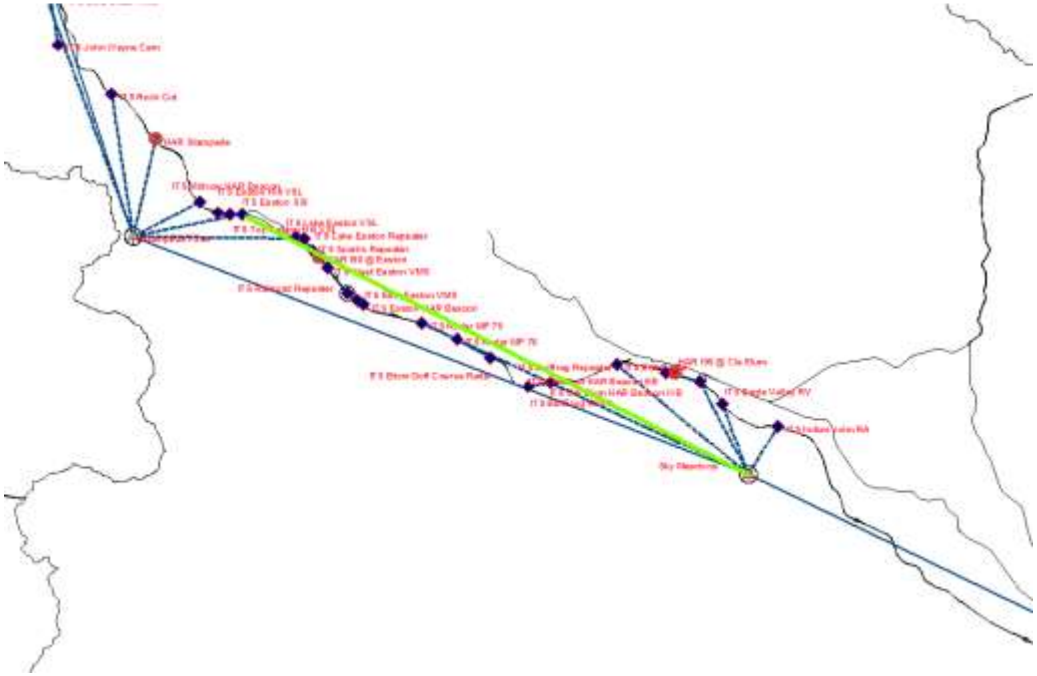
- Channel assignments from one site are somewhat simple, just the spread sheet and a map is all you need. However if there are adjacent PTP and PTMP sites the additional analysis is required.



Engineering

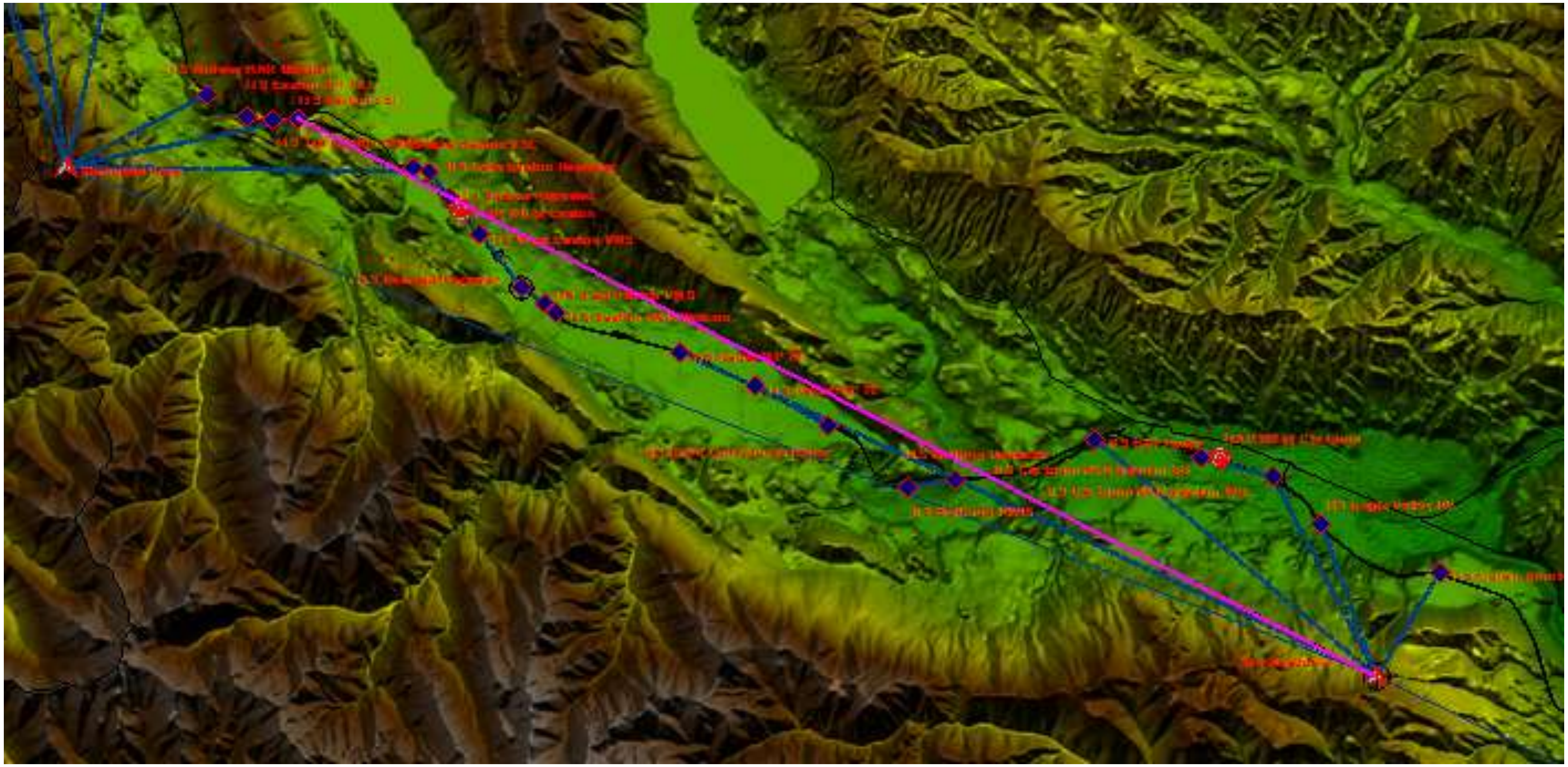
4.9 GHz Band – Channel Assignments

- Determine same frequency assignments. Using path analysis software I can draw a path from the potential interferer. Is there dirt in the path?



Engineering

4.9 GHz Band – Channel Assignments



Using the GIS Data from the software program, no mound of dirt in the way.
Need to do additional analysis.

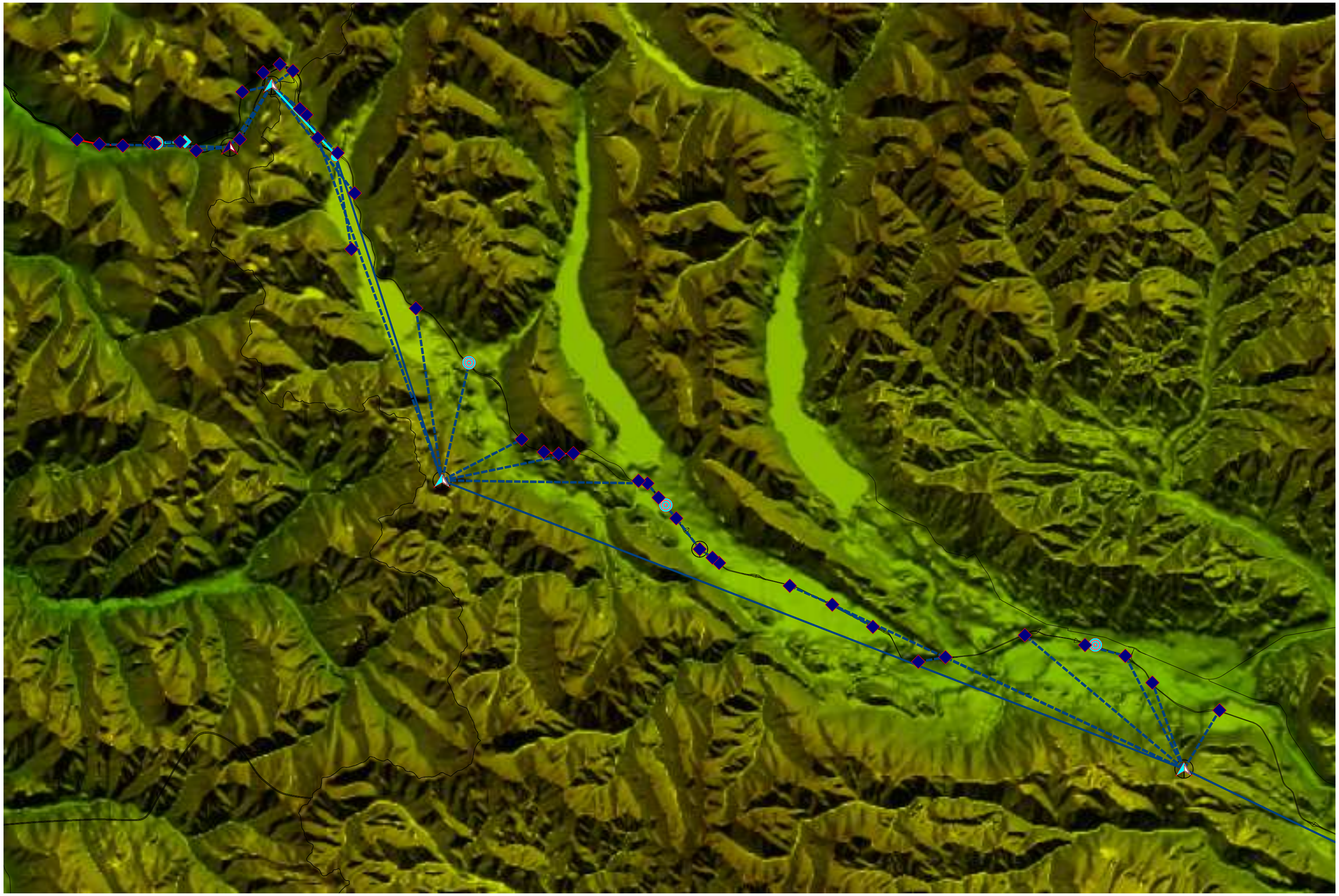
Engineering

4.9 GHz Band – Channel Assignments

- Using the diffraction tool I can draw the path and line of sight. There is some dirt and possible trees in the path.
- Total losses are 182.74 DB.
- Good separation however If I change polarization then my chance of interference is almost nil.

Engineering

4.9 GHz Band – Channel Assignments, several AP's along the pass



Engineering

4.9 GHz Band – Channel Assignments

- Frequency planning for adjacent sites I will use the same tool and then look at the possible overlaps.
- Alternate horizontal and vertical polarization for co-channel and adjacent channel assignments

Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Center Freq	4940.5	4941.5	4942.5	4943.5	4944.5	4947.5	4952.5	4957.5	4962.5	4967.5	4972.5	4977.5	4982.5	4985.5	4986.5	4987.5	4988.5	4989.5
BW																		
1 MHz	4940.5	4941.5	4942.5	4943.5	4944.5									4985.5	4986.5	4987.5	4988.5	4989.5
5 MHz	4942.5					4947.5	4952.5	4957.5	4962.5	4967.5	4972.5	4977.5	4982.5	4987.5				
10 MHz	4940.5	4941.5	4942.5	4943.5	4944.5	4950		4960		4970		4980		4985.5	4986.5	4987.5	4988.5	4989.5
10 MHz	4945						4955		4965		4975		4985					
20 MHz	4942.5					4955				4975				4985.5	4986.5	4987.5	4988.5	4989.5
20 MHz	4942.5					4947.5	4960				4980							
20 MHz	4950								4970				4985					

Stampede Pass

Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Center Freq	4940.5	4941.5	4942.5	4943.5	4944.5	4947.5	4952.5	4957.5	4962.5	4967.5	4972.5	4977.5	4982.5	4985.5	4986.5	4987.5	4988.5	4989.5
BW																		
1 MHz	4940.5	4941.5	4942.5	4943.5	4944.5									4985.5	4986.5	4987.5	4988.5	4989.5
5 MHz	4942.5					4947.5	4952.5	4957.5	4962.5	4967.5	4972.5	4977.5	4982.5	4987.5				
10 MHz	4940.5	4941.5	4942.5	4943.5	4944.5	4950		4960		4970		4980		4985.5	4986.5	4987.5	4988.5	4989.5
10 MHz	4945						4955		4965		4975		4985					
20 MHz	4942.5					4955				4975				4985.5	4986.5	4987.5	4988.5	4989.5
20 MHz	4942.5					4947.5	4960				4980							
20 MHz	4950								4970				4985					

Sky meadows

Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Center Freq	4940.5	4941.5	4942.5	4943.5	4944.5	4947.5	4952.5	4957.5	4962.5	4967.5	4972.5	4977.5	4982.5	4985.5	4986.5	4987.5	4988.5	4989.5
BW																		
1 MHz	4940.5	4941.5	4942.5	4943.5	4944.5									4985.5	4986.5	4987.5	4988.5	4989.5
5 MHz	4942.5					4947.5	4952.5	4957.5	4962.5	4967.5	4972.5	4977.5	4982.5	4987.5				
10 MHz	4940.5	4941.5	4942.5	4943.5	4944.5	4950		4960		4970		4980		4985.5	4986.5	4987.5	4988.5	4989.5
10 MHz	4945						4955		4965		4975		4985					
20 MHz	4942.5					4955				4975				4985.5	4986.5	4987.5	4988.5	4989.5
20 MHz	4942.5					4947.5	4960				4980							
20 MHz	4950								4970				4985					

Dodge Ridge

Engineering

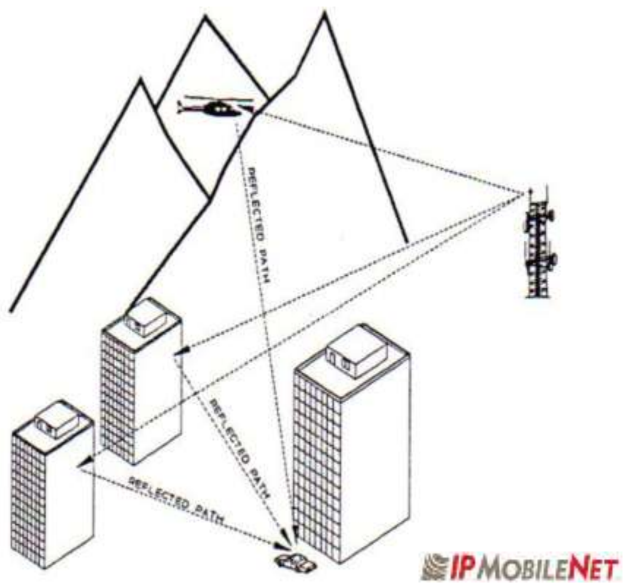
Path Analysis

- Path Reliability
  - Path reliability is key to the success of any PTP or PTMP wireless system. Commercial industry standards for digital microwave a bit error rate (BER) of 10-3 or a fade outage of < 3 seconds. We normally shoot for 99.999% of link reliability. However we will design for less than 5 nines of reliability in a shorter path. Provided the fade margin meets a minimum requirement.

- Fade Margin
  - Fade margin is also another factor that needs to be considered of any PTP or PTMP wireless system. The fade margin is the amount of signal strength above the receiver threshold. This is the amount of signal that can be lost due the environment or other factors before the link will fail. Commercial standards typically look for a 30DB fade margin with a non obstructed path. Shorter paths PTP or PTMP we will go as low as 20DB fade margin at 4.9 GHz frequencies. Higher frequencies or diffracted paths require greater fade margins. Frequencies above 11 GHZ are impacted by weather events. Diffracted paths are impacted by changes in the atmosphere and surface conditions.

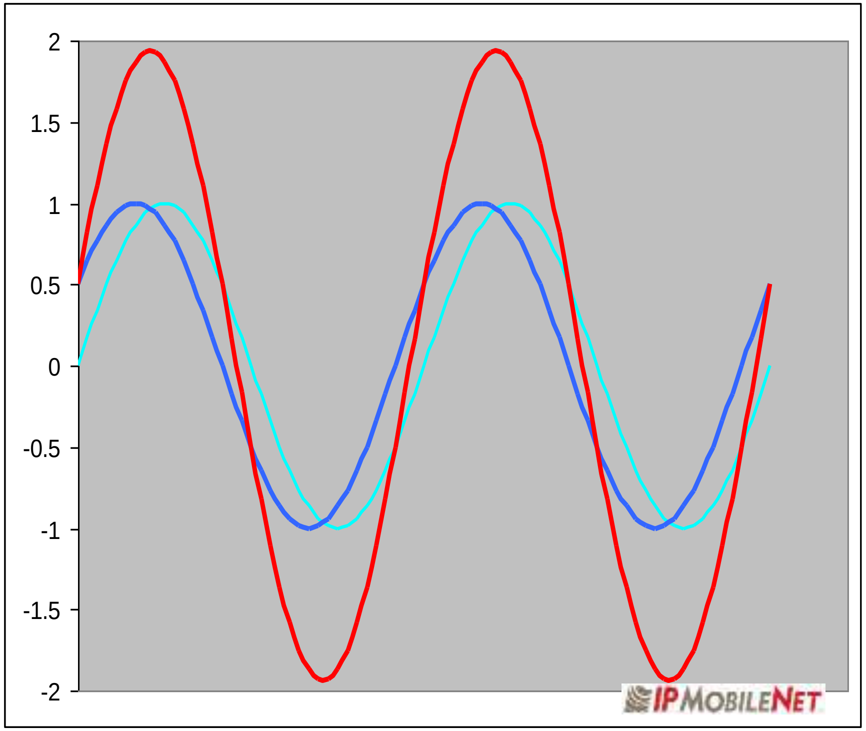
Engineering
Path Analysis

- Multipath
  - Multipath will have an impact on your systems reliability. Multipath fading is caused by the vector addition of multiple coherent signals with random phase and amplitude.
  - Multipath fading is a spatial phenomenon, with deep nulls occurring at half wavelength intervals, two properly spaced antennas are very unlikely to simultaneously experience a deep fade.



Engineering
Path Analysis

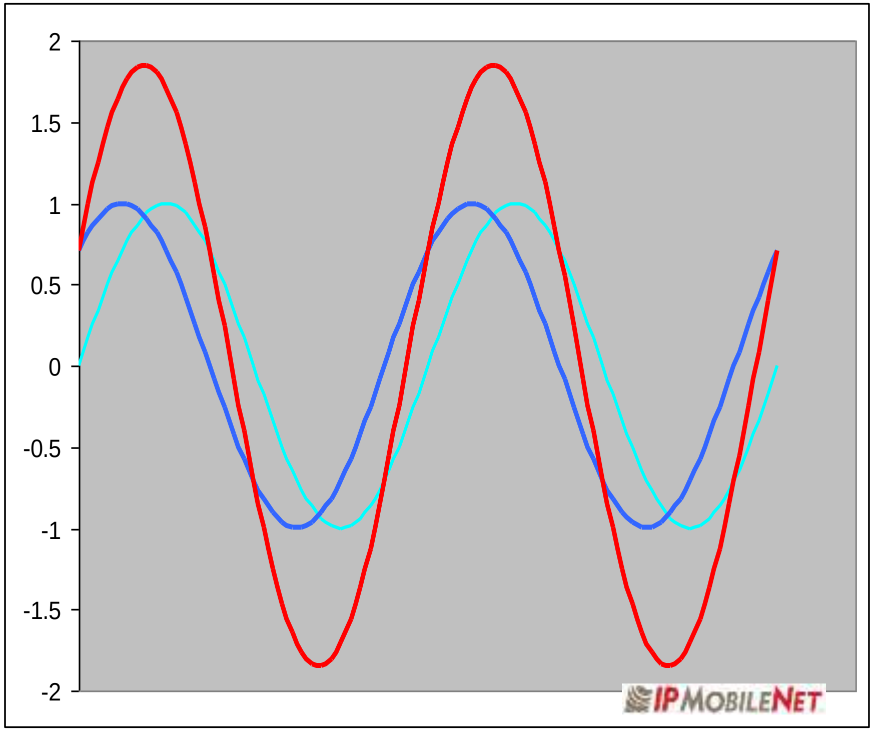
- Multipath
  - Multipath will have a positive as well as negative effect on the signal depending on the phase in which the signals meet the antenna. Two signals meeting 30 deg out of phase will create an improved signal.



Red line = sum of the two blue signals

Engineering
Path Analysis

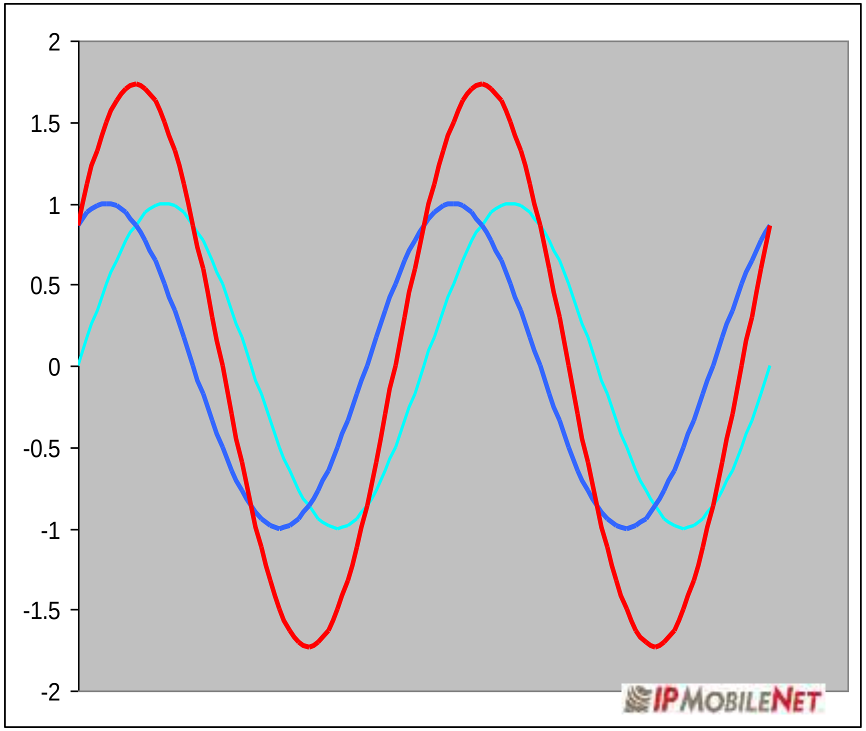
- Multipath
  - 45 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

- Multipath
  - 60 Deg out of phase

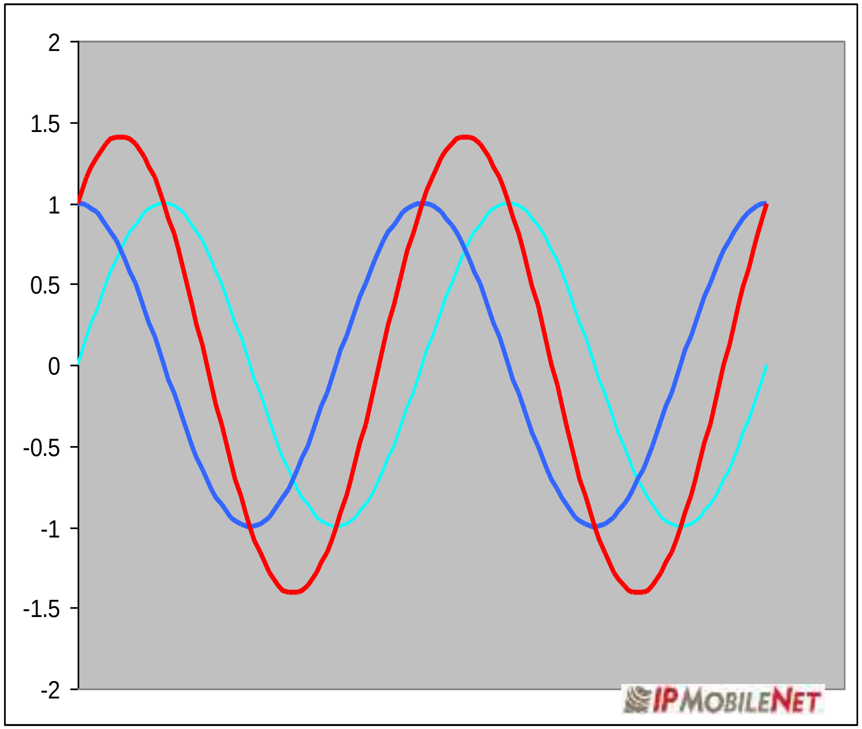


Red line = sum of the two blue signals

Engineering

Path Analysis

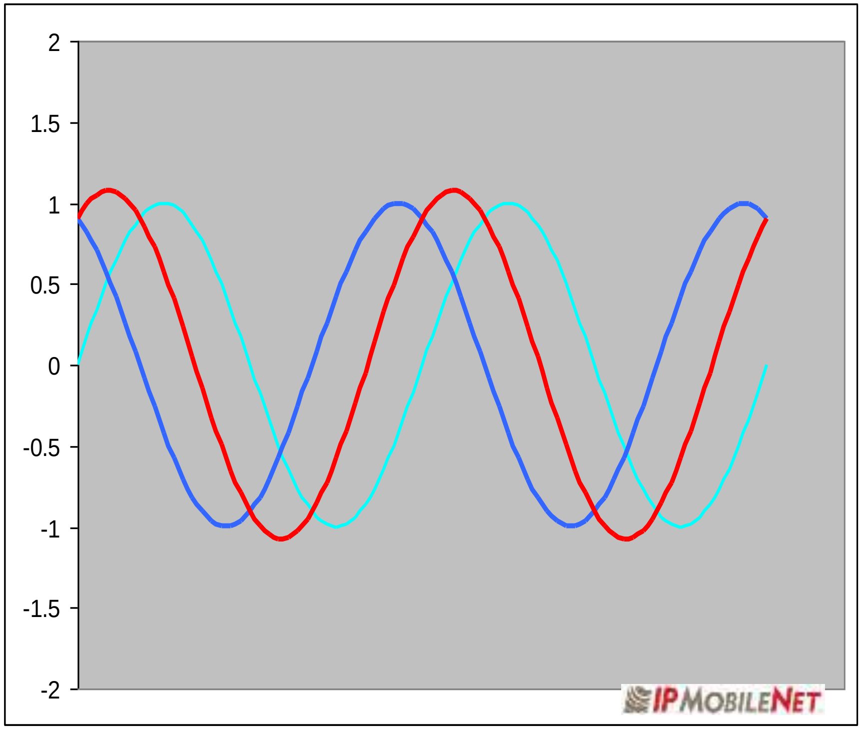
- Multipath
  - 90 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

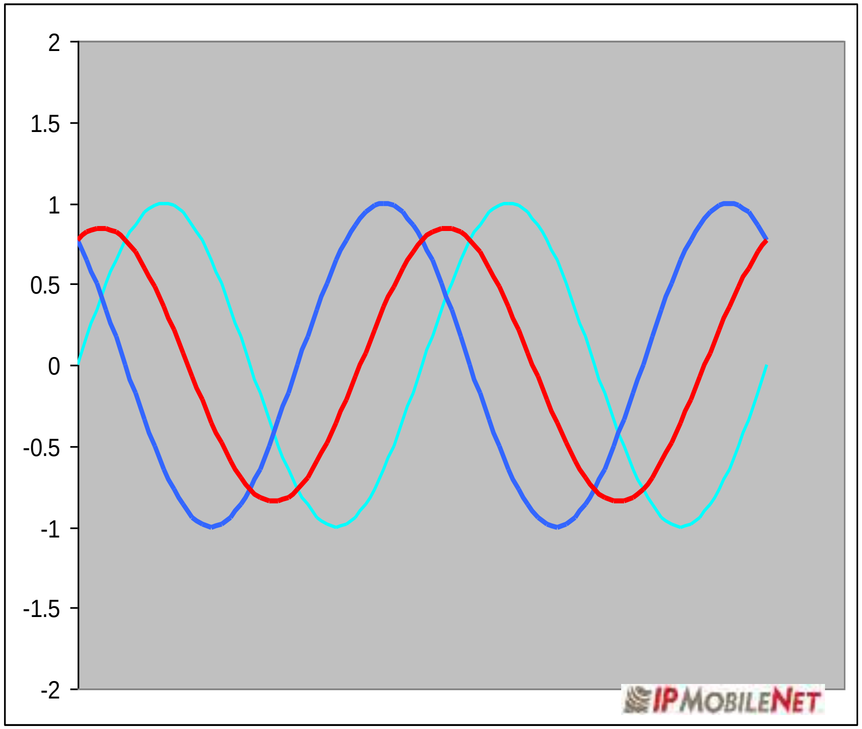
- Multipath
  - 115 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

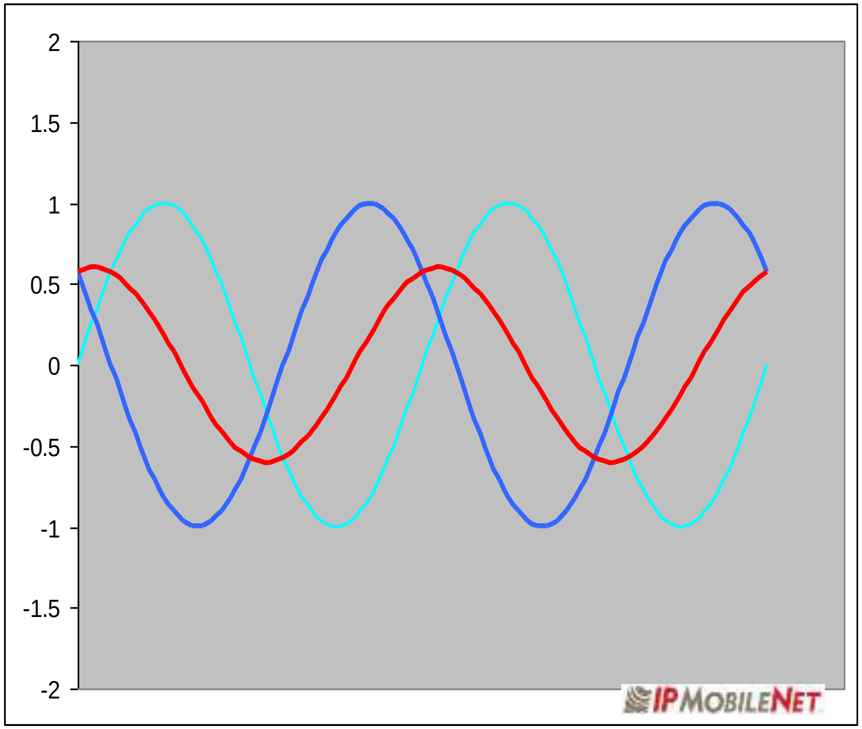
- Multipath
  - 130 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

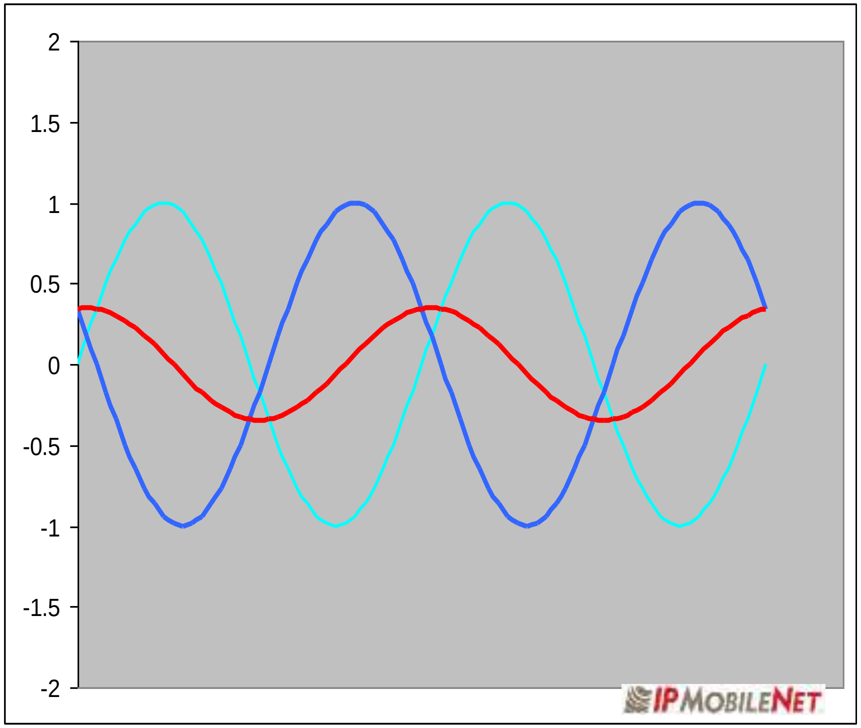
- Multipath
  - 145 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

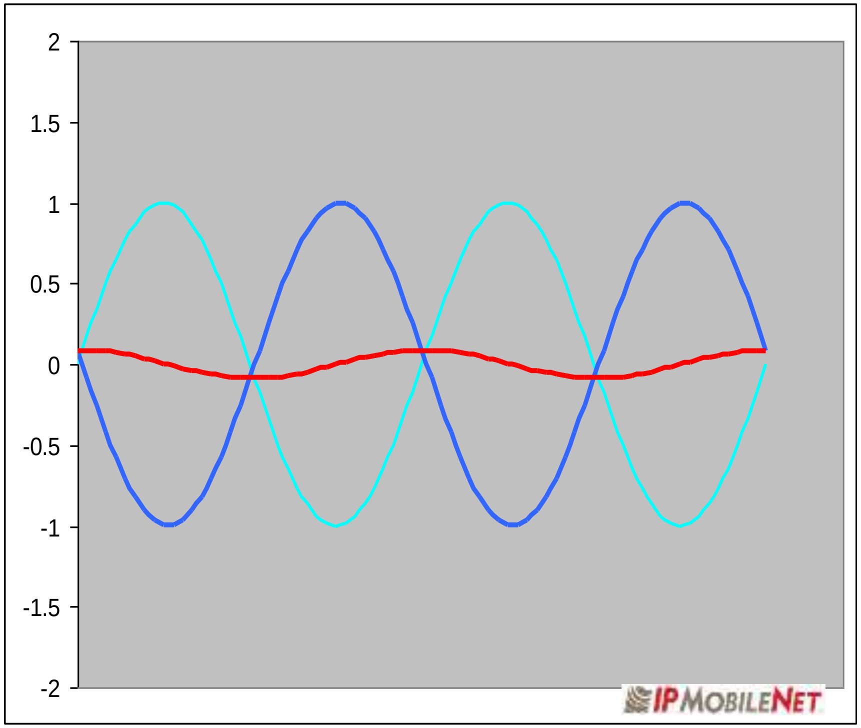
- Multipath
  - 160 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

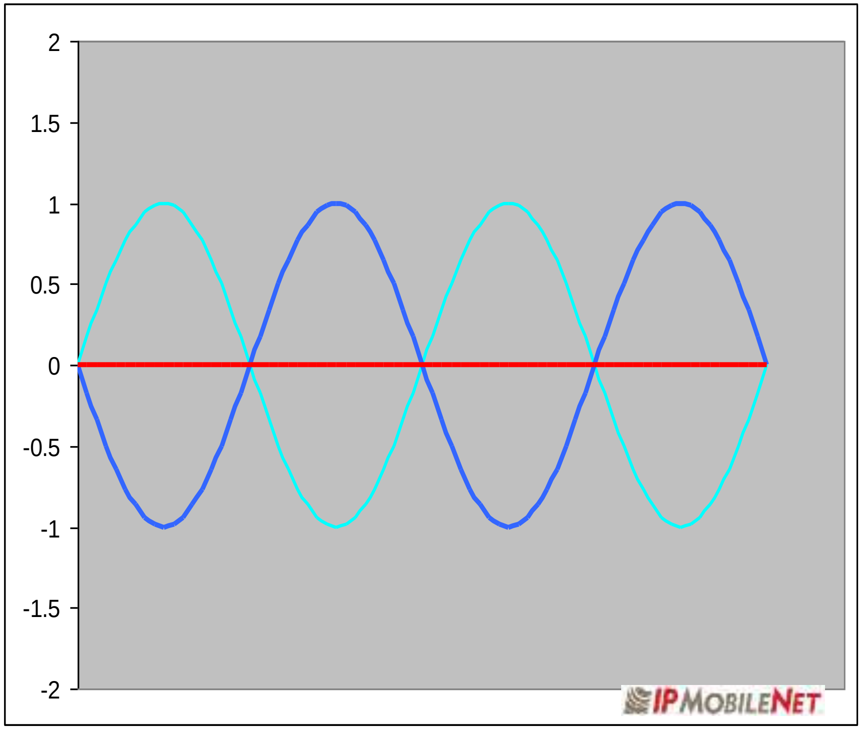
- Multipath
  - 175 deg out of phase



Red line = sum of the two blue signals

Engineering
Path Analysis

- Multipath
  - 180 deg out of phase

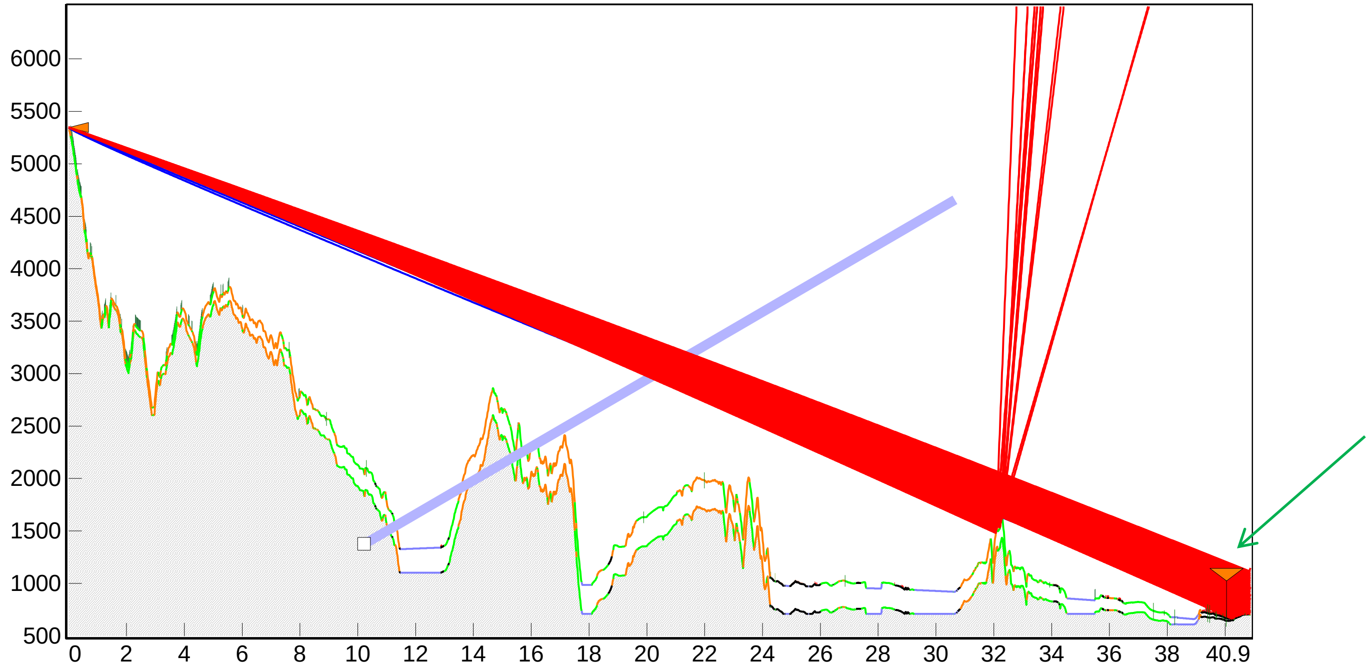


Red line = sum of the two blue signals

Engineering

Path Analysis

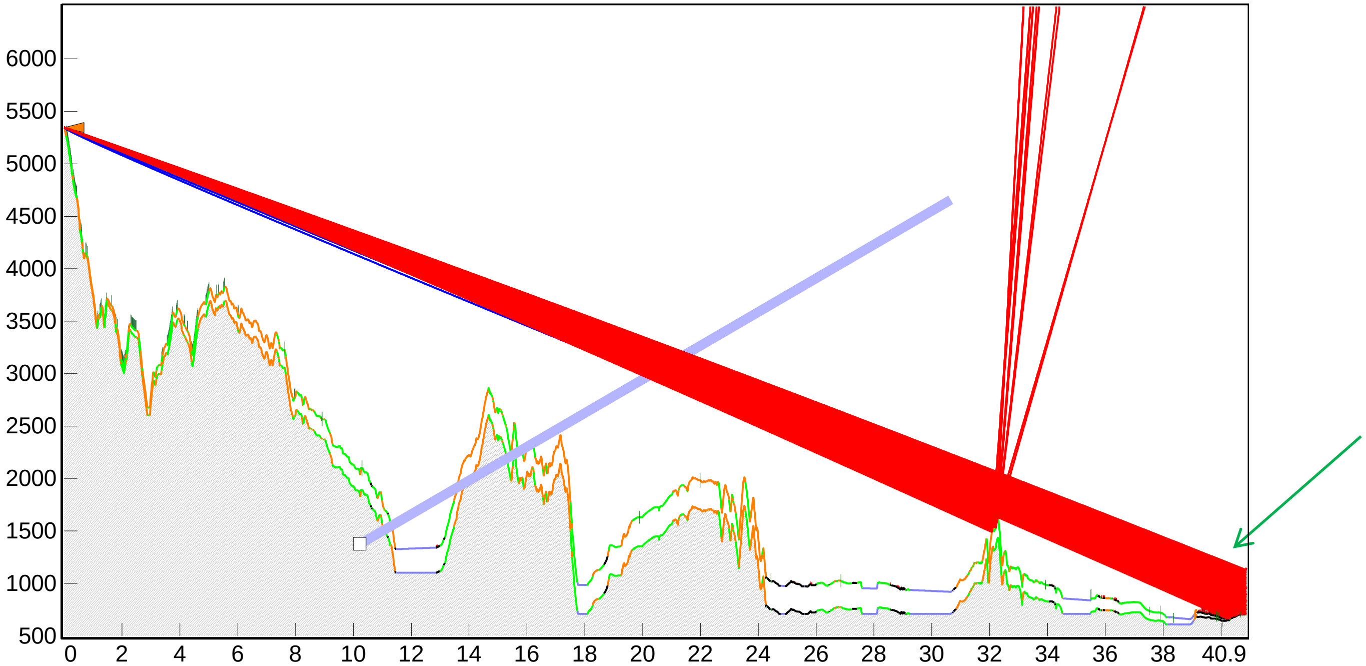
- Diversity
  - Diversity receivers are one why to combat multipath or shadow fading. In theory as one receiver is negatively impacted the other receiver will be less impacted.
  - In the case below, main antenna from Goat Mt at 15' has a reflective point to the Old Station main antenna at 36'.



Engineering

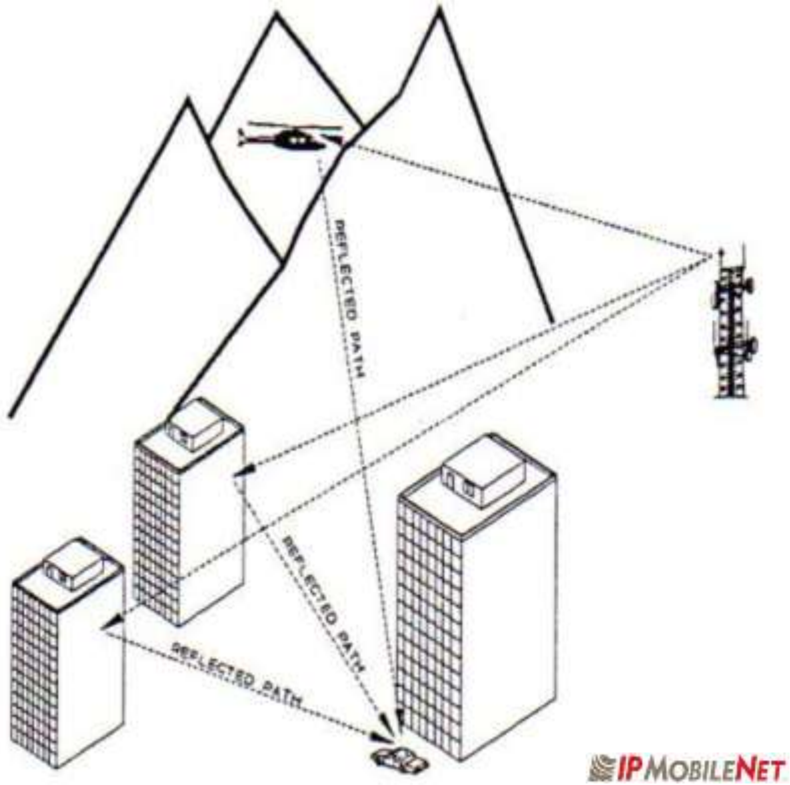
Path Analysis

- Diversity
  - Same path, the main antenna from Goat Mt at 15’ has no reflective point to the Old Station diversity antenna at 50’ using the same angle.



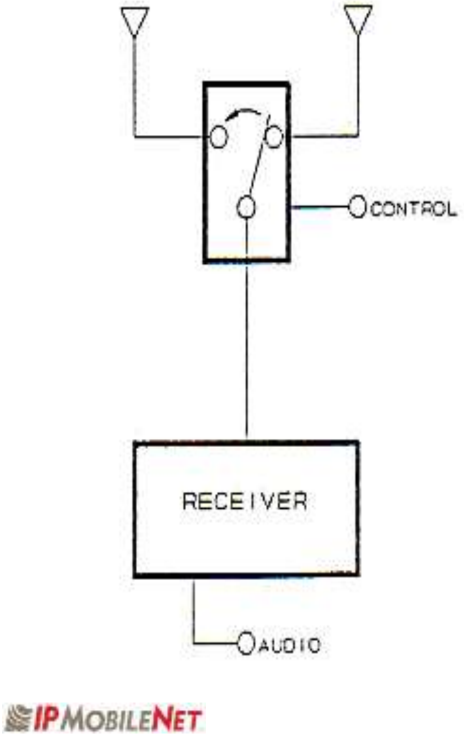
Engineering
Path Analysis

- Diversity
  - The same diversity improvements can be applied in a wide area deployment. Antenna “A” on the vehicle or ITS location will not be impacted the same as antenna “B”.



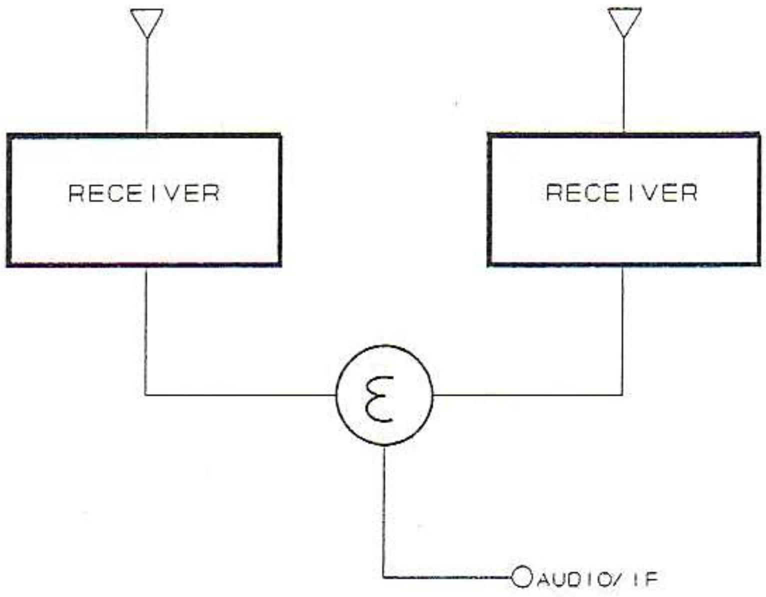
Engineering
Path Analysis

- Diversity
  - There are 3 types of diversity improvement schemes
    - Switched antenna
    - Receiver combination
    - Receiver selection
  - Switched Antenna
    - A single receiver has two or more antennas.
    - As the signal quality drops on one antenna the receiver switches to the other antenna.
    - Not the best solution the other antenna could be worse when switched.
    - Our LMR system was originally designed with this diversity. Works great in Kansas, not in the Pacific Northwest. Too much multipath.
    - After a year we disabled the diversity and use one antenna.



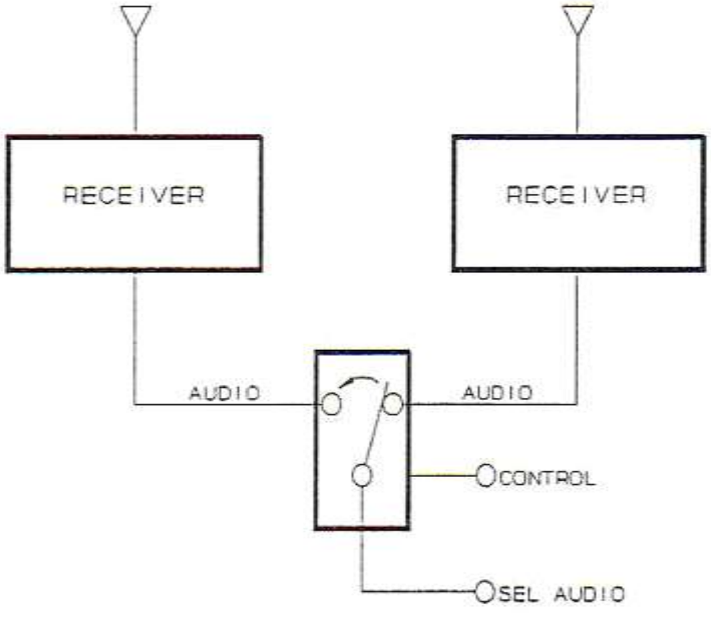
Engineering
Path Analysis

- Diversity
  - Receiver Combination
    - Two or more receivers each with its own antenna.
    - Uses a combining network at the audio or IF level from receivers.
    - Signals can be weighed according to to individual quality
    - May end up with less then the best
    - Caused by adding poor signal to good signal.



Engineering
Path Analysis

- Diversity
  - Receiver Selection
    - Two or more receivers each with a dedicated antenna monitored for quality of signal.
    - Control selects the best signal or highest signal to noise level.
    - The selection scheme is the one proven to work best in field tests and the one used in IPMN's patented diversity scheme.
    - Early results show that the system out perform calculated predictions.



IPMOBILENET

Engineering
Path Analysis

- Path profiling
  - Preliminary planning or analysis
    - Determine data requirements
    - Select equipment type based on the application requirements
    - Select preliminary antenna heights
    - Path analysis to determine if it can be accomplished
  - Field Survey
    - Verify location latitude and longitude (critical for licensed radios)
    - Power availability
    - Antenna mounting structure
    - Building or cabinet space
    - Verify line of sight; is there a billboard, water tower or tree line in the way? Flash the path if needed. If the tower is lighted, spot at night or change to day time lighting.
  - Finalize Path profile
    - Using data from the field survey correct profile.
    - Frequency coordination and licensing

Technology

4.9 GHz PTP and PTMP

- Licensed
  - Requires a Statewide license
  - EIRP Limitations
    - Based on channel bandwidth
    - Maximum antenna gain is 26 Dbi
    - Can use a higher gain antenna in a PTP or PTMP for better separation, however power output will need to be reduced db for db not to exceed the EIRP limits

FCC Power Limits 4.9 Ghz		
Channel bandwidth	Low-Power device	High Power Device
1 MHz	7 dbm	20 dbm
5MHz	14 dbm	27 dbm
10MHz	17 dbm	30 dbm
15MHz	18.8 dbm	31.8 dbm
20MHz	20 dbm	33 dbm

FCC EIRP Limits 4.9 GHz (Directional Antenna)		
Channel bandwidth	Low-Power device	High Power Device
1 MHz	16 dbm	46 dbm
5MHz	23 dbm	53 dbm
10MHz	26 dbm	56 dbm
15MHz	27.8 dbm	57.8 dbm
20MHz	29 dbm	59 dbm

Technology

4.9 GHz PTP and PTMP

- Path requirements
  - Near line of sight
  - Use adaptive modulation as a design tool
    - Great for the “What if” scenarios.

- Engineering
  - PTP Engineer as Redundant
    - You can engineer as a redundant path or system. Requires two radios, antenna and frequencies. Frequencies need to be spaced to provide separation.
    - Use a horizontal/vertical antenna configuration to provide additional separation
    - Requires a managed switch that will do load sharing or port costs. Load sharing will provide 2 times the bandwidth and in a failure, the pipe will be smaller. Using port costs one path will always be down. Both can work. I prefer the load sharing solution.

Technology

4.9 GHz Mesh

- Licensed
  - Requires a Statewide license
  - Considered PTMP
  - EIRP Limitations
    - Same
- Path requirements
  - Near line of sight
- Engineering
  - Multiple paths
    - Uses shorted hop count. Design for a specific path knowing that other paths are available.
  - Antenna Configuration
    - Onmi or Directional? All depends on the application.

Engineering

PTP and PTMP systems

- PTP
  - Data requirements, large data requirements or backhaul will need higher bandwidth licensed system. Smaller data requirements can be designed in the unlicensed or 4.9 GHz bands.
  - Location and weather impacts may require alternate antenna configuration then supplied by 4.9 GHz vendors.
  - Power over Ethernet (PoE) use outdoor cable.
  - Antenna mounting structure needs. Different needs based on path requirements. Pizza box or Hot tub?

Engineering
PTP and PTMP systems

- PTP
  - Pizza Box

Engineering
PTP and PTMP systems

- PTP
  - Hot tub

Engineering

PTP and PTMP systems

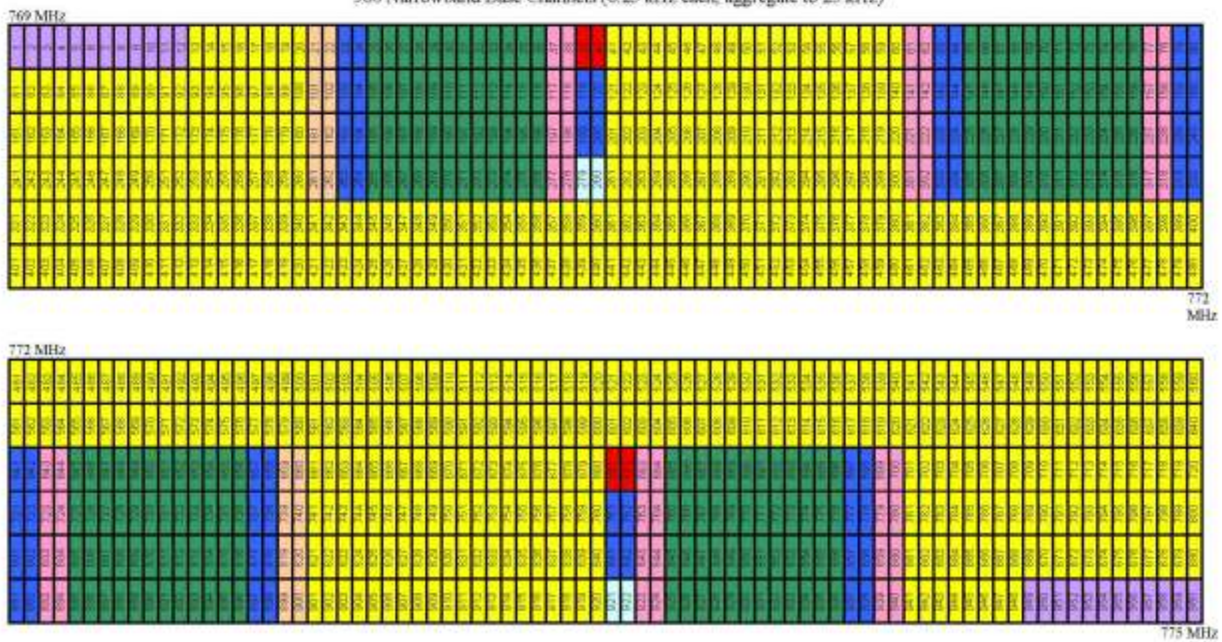
- PTMP
  - Determine each leg's data requirements. If a leg has a PTZ Camera and the others are controlling data devices set additional hits in a cycle. The unit can be programmed as an example (1,1,1,2,3,1,1,4,5). If leg 1 has the camera better video and better controls.
  - Maximize your vertical and horizontal beamwidth for the systems AP (Access Point). Use a panel or dish antenna to get better gains from the CPE (Customer Premises Equipment).
  - The AP antenna should be aligned based on the following:
    - If one leg is at a greater distance align (or set center line) for best signal on this path. The shorter paths will be slightly reduced in Receive Signal Strength(RSL).
    - If all legs are relatively equal align (or set center line) for best signal on most paths. All will not be equal.
    - If one leg is more critical align for best RSL on that path.

Technology
700MHz Narrow Band

- Licensed
  - Requires a Statewide license
  - 25MHz Channel

700 MHz BAND PLAN per Second R&O in PS Docket 06-229

960 Narrowband Base Channels (6.25 kHz each, aggregate to 25 kHz)



Narrowband Channels

- Two may be combined provided that the lower channel number is odd (e.g., 1, 3, 5)
- Four may be combined provide that the lower channel number is 1 + 4n, n = 0 to 479 (e.g., 1, 5, 1917)
- Channel numbers for combined channels are designated by the lowest and highest channel numbers separated by a hyphen, e.g., "1-2" and "1-4".
- Narrowband channels must maintain a data throughput efficiency of not less than 4.8 kbps for each 6.25 kHz of bandwidth

General Use
Interoperability
Reserve
State License
Low Power
2ndary Trunking
I/O Nationwide Call
I/O Low Speed Data

Technology

700MHz Narrow Band

- Path requirements
  - Can be non line of sight
  - We have paths of up to 49miles

- Engineering
  - Diversity improvements
    - Increase the predicted coverage as well as reliability of the system.
    - Use both PTP and Wide area software analysis to determine available coverage.
  - Antenna Configuration
    - Provide separation between antennas to get maximum diversity improvements.
- Live
  - View mobile
  - Winter Ops live page

Engineering
Wide Area Medium Speed

- Wide Area
  - Our current vendor uses 3 diversity receivers and antennas. This can create challenges for the base station site location. More than the normal tower real estate required.
  - 2/3 of the costs to deploy the base station is the antenna system. This is due to the fact the we are designing for future base stations to be installed.
  - It is a 12 VDC system and can create some challenges for site installation. Microwave systems and multiplex equipment are typically -48 or 24VDC. DC to DC converter may be required.
  - They do operate in a 25KHz channel. 700MHZ channel spacing is 12.5KHz so two adjacent 12.5 channels are required.

Engineering
Wide Area Medium Speed

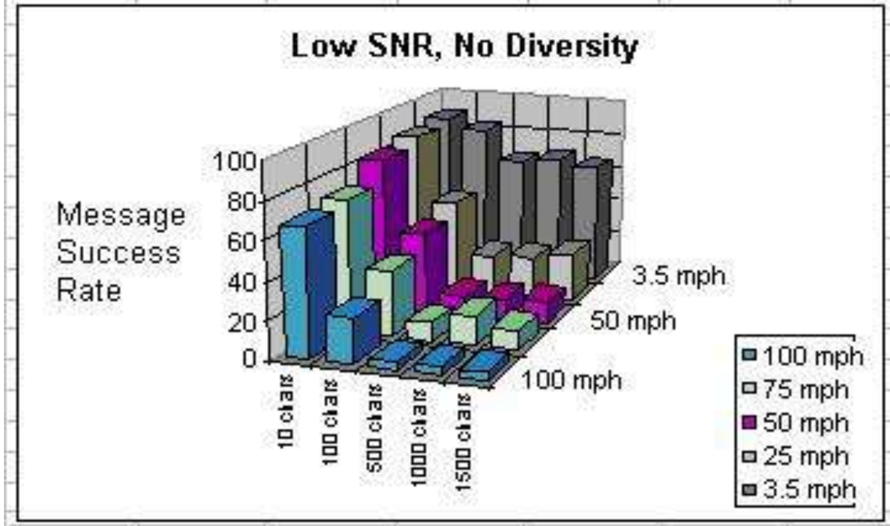
- Wide Area
  - Coverage predictions can be a challenge, sort of, software will not take into consideration the diversity improvements of the base stations or mobiles.
  - Mobile/fixed locations only require 1 or 2 antennas depending on the location requirements. 64Kbps must use a mobile, 2 antennas.
  - Radios (modems) are 12VDC.
  - Accept an IP interface to end equipment.

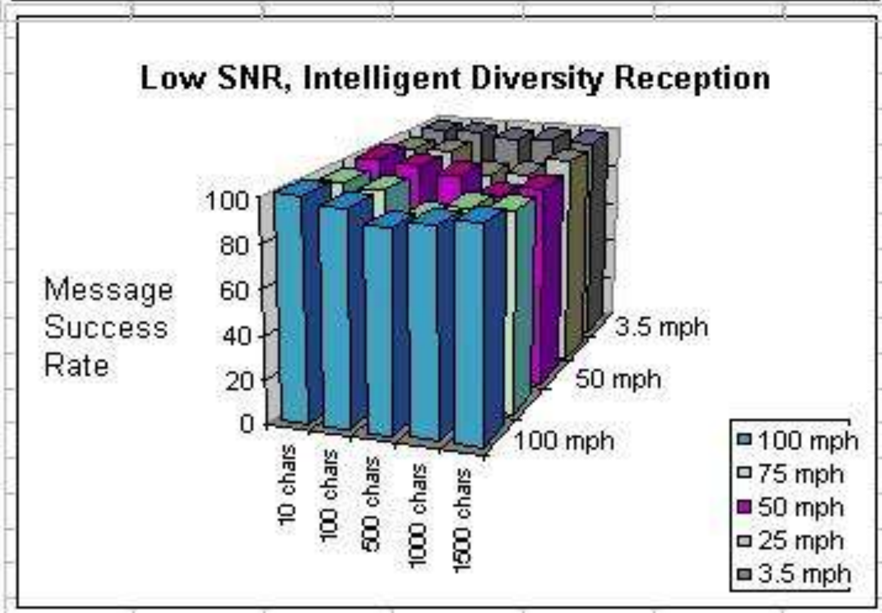
- Diversity Improvements
  - Diversity reception exploits the physics of the multipath to the benefit of the user.
  - Receiver selection process continuously selects the receiver with the highest signal to noise (SNR) ratio at any particular point in time (~100,000 times/sec)
  - The end results when engineering the system you will have better then predicted coverage and receive signal level (RSL).

Engineering

Wide Area Medium Speed

- Diversity Improvements
  - The IPMN Intelligent Diversity Scheme significantly increases success of a packet successfully reaching it's destination.





Washington State Department of Transportation

Tools
Path Analysis

- WSDOT
  - We use two different engineering tools for providing path calculations and coverage predictions.

  - Pathloss
    - Path analysis tool. Version 5.0 (newest release) can export to GIS and Google Earth, accept GIS overlays, and uses multiple terrain clutter data. No need to purchase terrain data; it can be downloaded free from USGS and imported to the program. 10 meter statewide some 3 meter available in areas. Accurate terrain data is key to preliminary design and multipath calculations. New group manager tool provides flexibility for projects while keeping a statewide warehouse of data. We have yet to use all the tools available from the software.
  - Comstudy
    - Area coverage tool. Currently using version 2.0 will provide wide area coverage plots. Typically used for FCC licensing activities for our LMR system. However will work for wide area data plots. May or may not be the best tool, but it is the tool we are using.

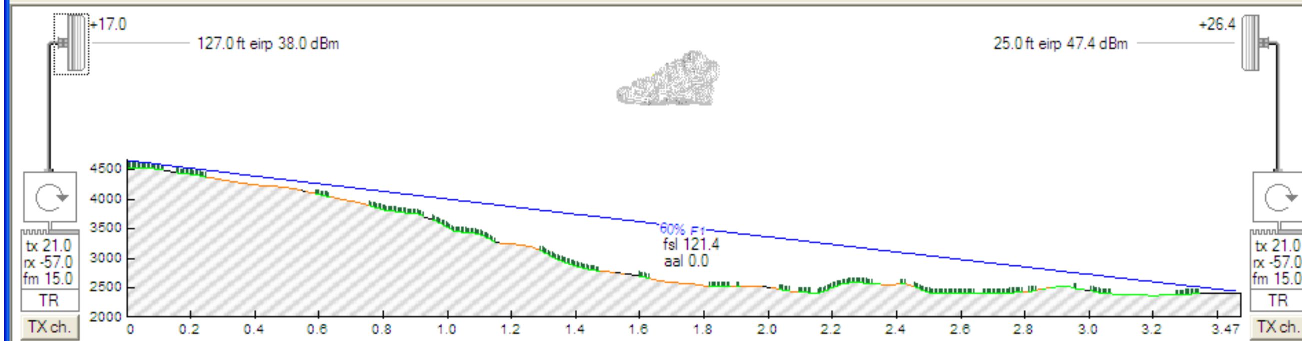
Tools

Path Analysis

- Pathloss 5.0
  - Demonstration

PL50 Link - Transmission Analysis - stampede pass-har stampede.pl5

Files Design Configure Operations Design link Report Help



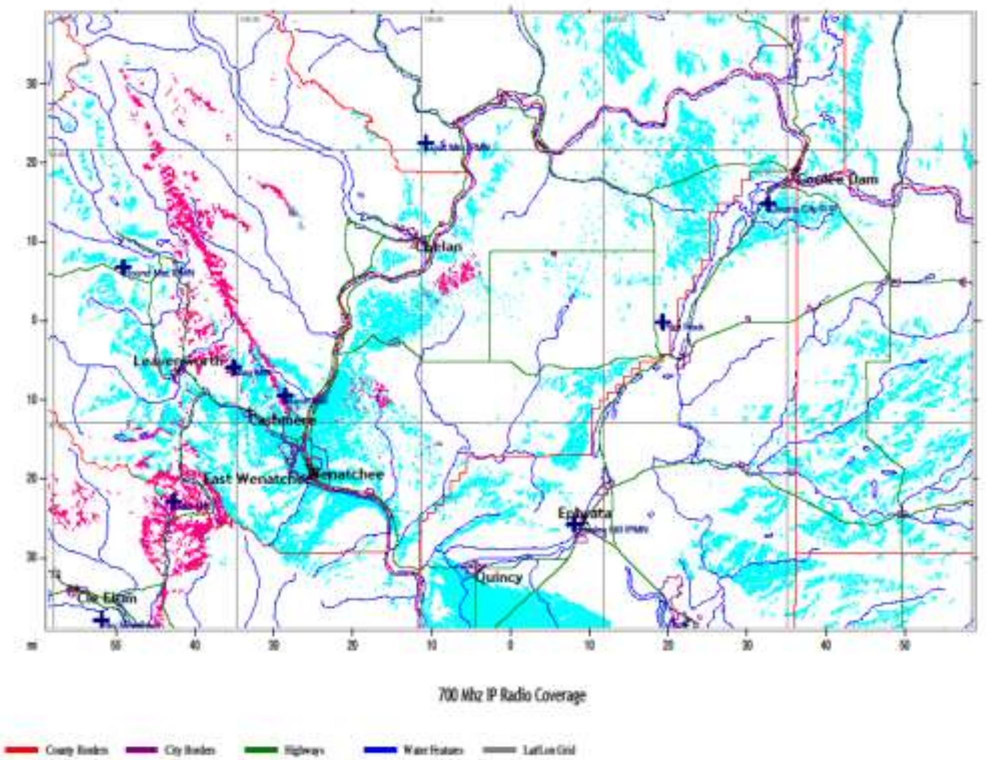
EIRP (dBm)	38.00	47.40
Free space loss (dB)	121.37	
Atmospheric absorption loss (dB)	0.04	
Net path loss (dB)	78.01	78.01
Receive signal (dBm)	-57.01	-57.01
Thermal fade margin (dB)	14.99	14.99
Worst month multipath availability (%)	99.99832	99.99832
Worst month multipath unavailability (sec)	44.05	44.05
Annual multipath availability (%)	99.99971	99.99971
Annual multipath unavailability (sec)	92.51	92.51
Annual 2 way multipath availability (%)	99.99941	
Annual 2 way multipath unavailability (sec)	185.01	
Polarization	Horizontal	

Stampede Pass | 4950.0 MHz - H | TR-TR | Adaptive modulation | Vigants - Barnett | mi - ft | HAR Stampede

Tools
Path Analysis

- Comstudy – Area coverage examples

Gabi and Burch

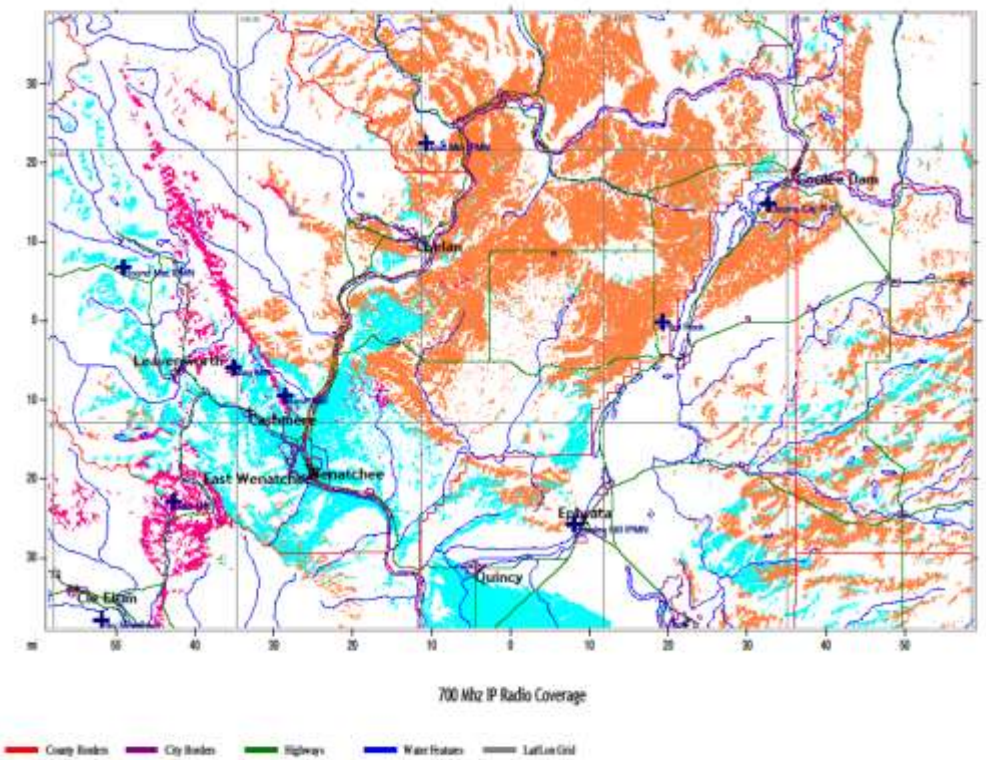


700 Mhz IP Radio Coverage

Tools
Path Analysis

- Comstudy – Area coverage examples

Gabi,Burch and Goat



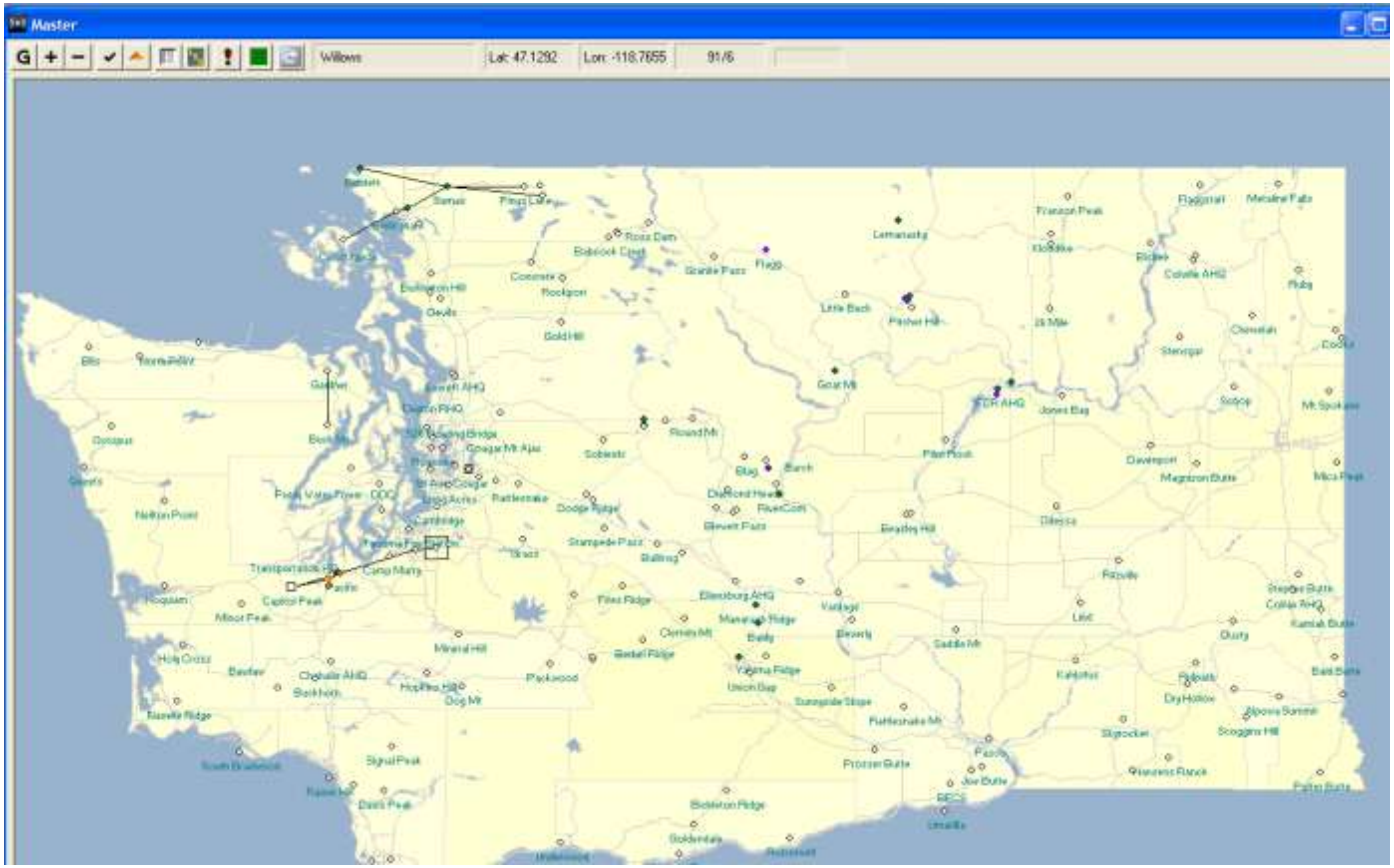
700 Mhz IP Radio Coverage

Tools
Monitoring

- WSDOT
  - NGM/TSM8K
    - Monitoring the wireless system has been a goal for WSDOT for years. However manufacturers all have their different tools. SNMP has made monitoring the wireless system a reality. WSDOT found a manufacturer that is on the WSCA contract thru Alcatel that can monitor various equipment manufacturers as well as SNMP. FIAL (local to the Northwest) will add other SNMP devices to the monitoring system, for a fee. An advantage to the system is that a NOC (Network Operations Center) is not required. The NGM will email or text technicians to inform them of an alarm event.
    - In the past our wireless system was unmonitored, we fixed it when the customer complained, “its broke”. The goal is to fix the problem before the customer knows it was a problem.

Tools
Monitoring

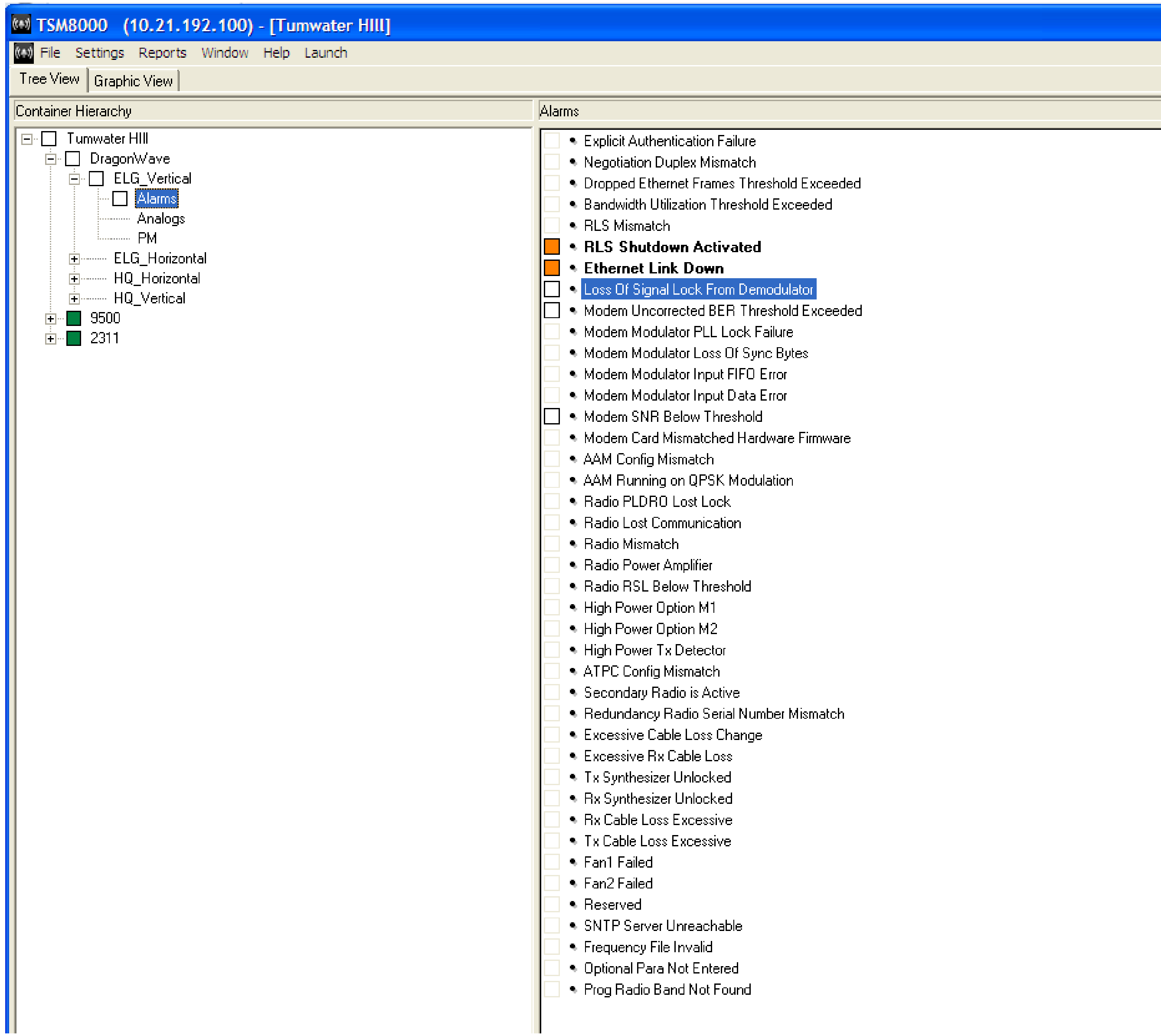
- WSDOT
  - NGM/TSM8K



Tools

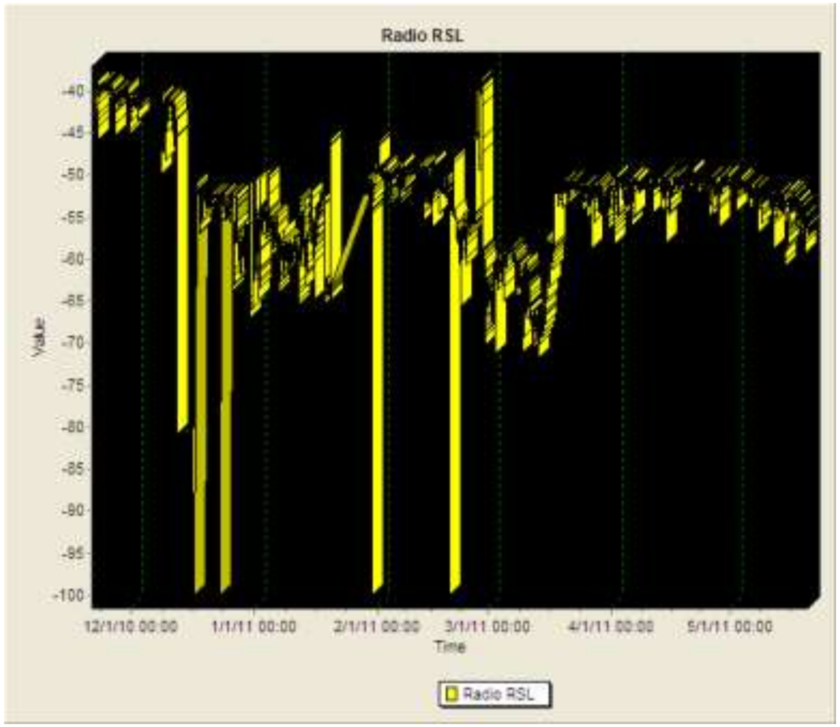
Monitoring

- WSDOT
  - NGM/TSM8K
  - One site several 5 wireless Radios as well as an SNMP alarm panel that allows for 32 inputs, 16 controls and 16 analog inputs.



Tools
Monitoring

- WSDOT
  - Live RSL's
    - RSL can be set as a Preventive Maintenance (PM) point. As a PM point the system will request an RSL level every 5 min's and save. We can then look at history, or storm event impacts on the path.



Questions