TMC-TMS Communications: Overview and Demonstration

Douglas Galarus
Senior Research Associate
Program Manager

Dr. William Jameson
Research Scientist

Suzanne Lassacher
Research Associate II

Richard Wolff
Gilhousen Telecommunications Chair
Department of Electrical and Computer Engineering

Larry Hayden
Research Associate II

Gary Schoep
Research Associate

David Veneziano
Research Scientist

Jeff Sharkey
Graduate Research Assistant

Justin Krohn
Undergraduate Research Assistant

Systems Engineering, Development & Integration Program
Western Transportation Institute

Western States Rural Transportation Technology Implementers Forum
June 2008

Abstract

In cooperation with the California Department of Transportation, Montana State University's Western Transportation Institute has conducted an evaluation of communication technologies for application to TMC-TMS communications in Caltrans District 1. Wireless and wired technologies have been evaluated for prospective use, with pros and cons presented in general as well as site-specific analysis. The results of this study are applicable to other Districts and DOTS, for both rural and urban use.

This presentation will provide an overview of the project and its results, with an emphasis on wireless technologies that show promise. As part of the presentation, a “parking lot demonstration” will be conducted to demonstrate several of these technologies.

Original Caltrans Research Problem Statement

RESEARCH PROBLEM STATEMENT #TS-507
Caltrans Division of Research and Innovation
2005-2006 Research Problem Statements
November 17, 2004

I – Problem Title

Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide (2004MOB.10)

II – Research Problem Statement

There is an unmet need for a reliable and economical communications system between TMS field elements and the TMC in rural areas. In the rural parts of most of the Districts telephone and cellular coverage is not available. Satellite coverage is available in most areas but it is very expensive. In a rural environment, where communication is available, the costs are quite high, and data transfer rates and reliability are low.

Original Caltrans Research Problem Statement (continued)

III – Objective

Develop a reliable system to maintain communication between the TMC and TMS elements in a rural environment by:

* Conducting a literature search for communications methods tried elsewhere to connect field elements to the TMC.
* Choose the most promising technologies for connection in rural environment and develop test installations to prove which is most reliable and cost effective.
* Consider the use of Current State systems including 800 Mhz and microwave backbone.
* Document results in handbook form for utilization by other Districts in future installations.

The collection system could be expanded to include other field elements such as WIM and loops for traffic counts. The TMS field elements common to the rural environment are HAR, EMS, fixed and portable CMS, CCTV, and RWIS.

IV – Background

Current technology uses cellular and hardwired telephone lines which are not always easily available, have slow data transfer rates, often are not reliable and have high ongoing costs. Some elements have been connected using TCIP through cable connection but this is has proven to be very expensive as well. Some preliminary strategies have been discussed with HQ Maintenance Telecommunications to investigate the potential of using a newly established radio frequency.

Original Caltrans Research Problem Statement (continued)

V – Statement of Urgency and Benefits

A reliable, standardized, economical system is essential for the collecting of information from the rural TMS field elements. Currently communicating consistently with these elements is difficult and very costly. The crucial time for data recovery i.e. inclement weather, natural disaster, seems to be when we experience difficulties with communication. The cost savings that the Department could realize would be very significant.

VI –Related Research

Wireless data communications testing conducted across San Luis Obispo County to support EDAPTS transit management system development and operation.

VII – Deployment Potential

The deployment could be statewide, within a few years.

Why Research?

- The problem is hard.
- No-one has a one-size-fits-all solution – no "silver bullet".

Problem Origin (our understanding)

- Caltrans wanted to deploy TMS at Collier's Tunnel on US 199 near the Oregon border.
- In the absence of other options, GPRS Ethernet modems were tried and didn't work, even with a Yagi antenna.
- Environmental issues, some sort of tree fungus, prohibits microwave towers from being installed in this area for fear of spreading the fungus.
- Similar and more difficult challenges exist throughout District 1.

Proposal
February 28th, 2005

- Task 1: Literature Review
- Task 2: Technology Research and Evaluation
- Task 3: (Vendor) Demonstration
- Task 4: Document results in handbook form for utilization by other Districts in future installations

Award:

- Start Date: May 10, 2006
- End Date: June 30, 2008

Proposal – Key Features

- Technical Scope
  - Adhere to RFP
  - Investigate the following classes:
    - Wireless wideband IP networks including WiMax and mesh networks.
    - Point-to-point and point-to-multipoint RF systems.
    - Satellite based networks.
    - Commercial telecommunications infrastructure.
  - Investigate 700 MHz in light of DTV transition and associated allocation and auction
- Analysis
  - Path and Propagation
  - Cost : Net Present Worth
- Topologies
  - Star, Mesh, Multi-hop
- Demonstration by Vendors
- Handbook for use by Caltrans State-Wide

Kick-off Meeting

District 1, Eureka District Office

Monday, July 10th, 2006

- Reviewed Project Scope and Timeframe
- Discussed D1 Needs and Expectations
- Discussed Statewide Implications and Relevance
- Discussed Field Elements and Deployment Challenges
- Discussed Next Steps
- Identified Key Contacts
- Identified Specific Sites for Study

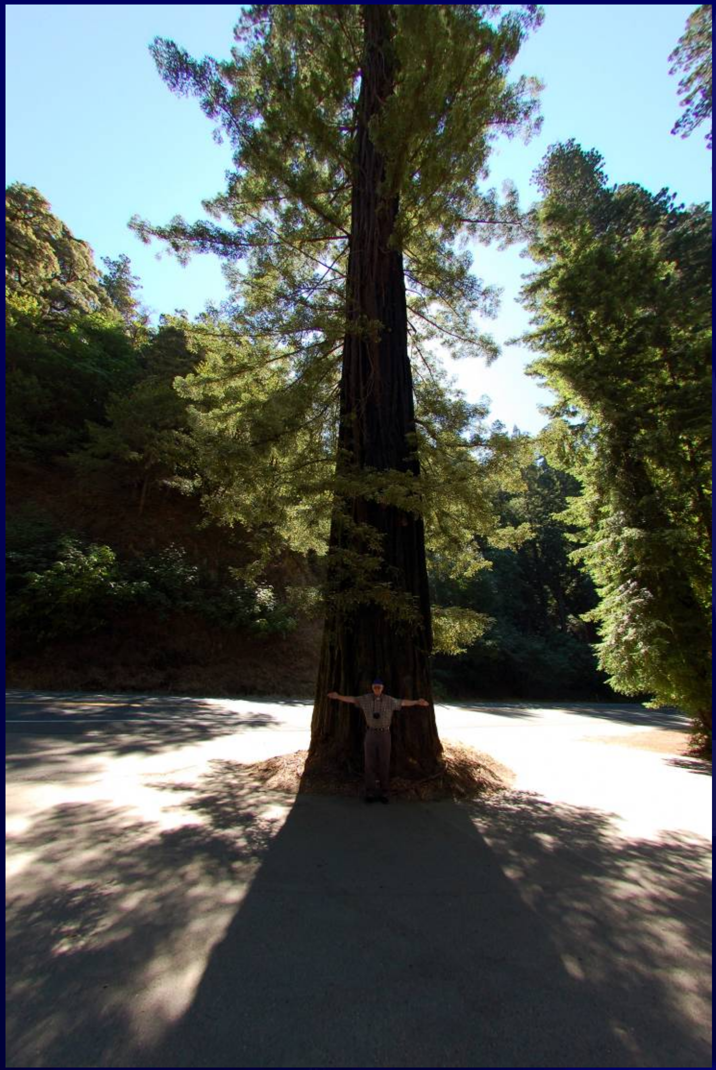
- During this trip, the WTI project team toured District 1; toured mountain-top, road-side and D2HQ sites in District 2; and met with Caltrans HQ communications staff.

Kick-off Trip Site Visits: Collier's Tunnel

Kick-off Trip Site Visits: Idlewild Maintenance Yard

Kick-off Trip Site Visits: Confusion Hill

Kick-off Trip Site Visits: Redwoods



Kick-off Trip Site Visits: D2 Bass Mountain

Kick-off Trip Site Visits: View to North from D2 Bass Mountain

Kick-off Trip Site Visits: Bass Mountain from D2 HQ

Kick-off Trip Site Visits: TMS South of Redding on I-5

Literature Review

- Project Deliverable #1
- Finalized February 2008

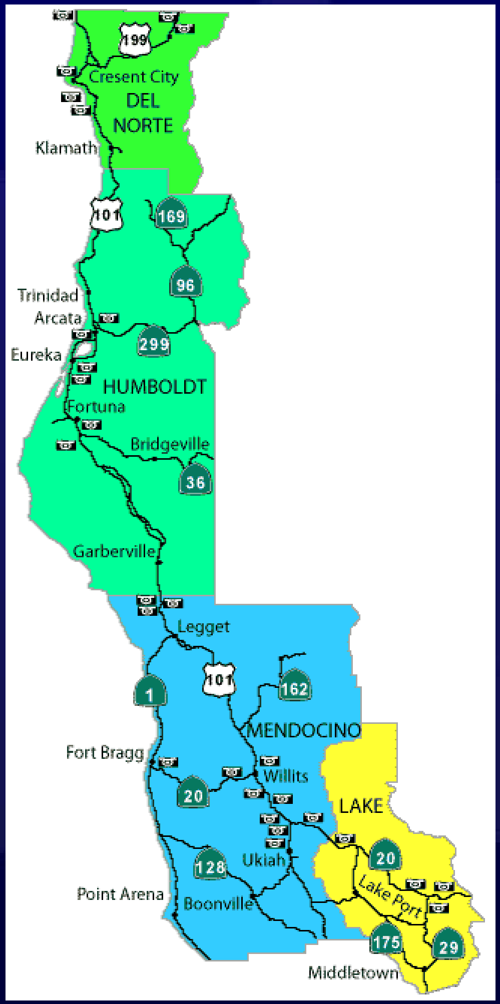
Background – D1

Includes these counties in Northwest California:

- Del Norte
- Humboldt
- Mendocino
- Lake

District 1 is responsible for maintaining 1,102.7 miles of State highway and traverses terrain profiles ranging from mountainous to valley and lakeside to coastal terrains.

The US 101 corridor runs north to south through District 1 and is often characterized as “the lifeline of the North Coast.”



District 1 is characterized by redwood forests and dense vegetation; ocean, riverside, and lakeside landscapes; and rugged mountain terrain. High levels of rainfall and fog in certain areas of the District pose unique roadway maintenance challenges. It is not uncommon for Del Norte County to receive up to 80 inches of rain per year.

The highest point in the District is Snow Mountain East at 7,056 feet, located in Lake County.

Background – D1

County	2005 Population Estimate	2005 Population per sq mi	Area (square miles)
Del Norte	28,705	27.3	1,008
Humboldt	128,376	35.4	3,572
Lake	65,147	46.4	1,258
Mendocino	88,161	24.6	3,509
Total	**310,389**		**9,347**
California	**36,132,147**	**231.7**	**155,959**

Three factors that determine capabilities:

- Environment
- Power
- Communications

Obviously, D1 is rural and faces challenges with respect to all of these.

D1 ITS Architecture - Overview

A number of ITS elements are present in locations throughout Caltrans District 1. These elements perform a wide variety of tasks, ranging from collecting data (sensors, detectors) to disseminating information (CMS', HAR), among other activities.

D1 ITS Architecture – D1 Transportation Management Center

- Coordinates transportation operations for north central California, serving Del Norte, Humboldt, Lake, and Mendocino counties.
- It is a Satellite Operation Center.
- The TMC performs a wide range of functions, including traffic surveillance, incident detection and management support, environmental monitoring, information dissemination, data collection and evacuation support.
- Given all of these functions, the TMC can be thought of as the hub to which numerous spokes (ex. field elements – CCTV, sensors, etc.) are connected.

D1 ITS Architecture – D1 Field Elements

- District 1 has deployed various field elements to facilitate environmental monitoring, data collection, traffic surveillance, incident detection and management support, and information dissemination activities.
- These include Changeable Message Signs (CMS), Highway Advisory Radios (HAR), Road Weather Information Systems (RWIS), Closed Circuit Television Cameras (CCTV), Radar CMS, Pavement Management Systems (PVMS), signal controllers, and Weigh-in-Motion (WIM) Detection Systems.
- The various systems are deployed at key locations throughout the District.
- Note that most of the cameras within District 1 are pointed at CMS for message and sign operation verification purposes.
- An estimated inventory lists 28 CCTV, 19 CMS, and 6 RWIS field elements in District 1. (2007)

D1 ITS Architecture – Current Communications Technologies

- District 1 employs an Internet Protocol (IP) –based communications network.
- Currently, the primary communications technologies used for TMC/TMS communications are Plain Old Telephone Service (POTS) dial-up and General Packet Radio Service (GPRS) cellular. (2006)
- Digital Subscriber Line (DSL) services are available in some areas, but have not been implemented as of this writing.

Case Study :

CALTRANS DISTRICT 2 FIELD ELEMENT NETWORK/INTELLIGENT TRANSPORTATION SYSTEM (ITS) NODES

- District 2 is the best example of a rural communications network deployment currently available.
- It has unique, key elements that District 1 might find of interest including:
  - a defined communications migration path,
  - a well-defined network topology consisting of a backbone and ITS nodes,
  - and the use of IP based communications.

Case Study : D2

Hybrid Network with Migration Plan

- D2 initiated many of their sites using POTS or ISDN, depending on availability, with dial-on-demand routing.
- D2 implemented a private microwave network and continues to build out. Legacy sites are subsequently migrated to microwave.
- Initially, the network used engineered, point-to-point, unlicensed links. The next step in migration is to replace unlicensed links with licensed.

Case Study : D2
Network Topology

- Microwave Backbone
- ITS Nodes – concept developed by D2 in 2001. Aggregating node that connects field elements and provides communications back to the TMC.
- Roadside LAN – most electronics are housed in the ITS node cabinet. Cat 5 and short distance fiber are used to extend Roadside LAN. 802.11 has been considered.

- All IP-Based

Prospective Technologies Identified in Literature Review - Wireless

- Wireless Fidelity (WiFi) – 802.11 a/b/g
- WiMax (802.16)
- Mesh Networks
- Dedicated Short Range Communications (DSRC)
- Cellular Technologies
- Very High Frequency High Band (VHF High Band)
- Ultra High Frequency (UHF)
- 700, 800, 900 MHz
- 2.4, 4.9. 5 GHz
- Satellite
- Other Technologies – Motorola Canopy System
- Meteor Scatter
- Point-to-Point Microwave

Prospective Technologies Identified in Literature Review - Wired

- Plain Old Telephone System (POTS)
- Integrated Services Digital Network (ISDN)
- Digital Subscriber Lines
- Fiber Optics
- Television (Cable)

Wireless Deployments Investigated

- Wi-Fi
  - Virginia Tech Transportation Institute (VTTI) Serial Wireless Networks for DOT Applications
  - Rest Areas (Texas, Iowa, Wisconsin, Michigan, Florida, Washington)
  - Differential GPS Correction (AHMCT – Cal Davis)
  - Municipal Wi-Fi / Public Safety Network (Spokane, Washington; Post Falls, Idaho)
- Wi-Max
  - Sprint Nextel (planned)
- Mesh
  - Hurricane Charley, Hardee County, Florida
  - Medford Oregon Municipal Network
- DSRC
  - ITS World Congress 2005 – Caltrans and PATH (Cal Berkeley)
- Cellular
  - WTI – Responder
  - Smart Call Box – Caltrans D11
  - California Innovative Corridors Initiative (ICI) and the ITS World Congress 2005 (Caltrans, et al)
- VHF
  - Alaska Land Mobile Radio (ALMR) – P25 Compatible
  - State of South Dakota

Wireless Deployments Investigated

- UHF
  - Montana Highway Patrol
  - Duluth Area Transportation Management System (RWIS)
  - Iowa Department of Transportation (Transit)
  - Yellowstone Park Animal Detection System
- 700 MHz
  - Utah Wireless Integrated Network (UWIN)
  - Florida's Greenhouse Project
- 800 MHz
  - Regional Communications System (RCS) Project, County of San Diego, California
  - Minnesota Department of Transportation (Mn/DOT) (includes some capability for remote ITS deployments)
- 900 MHz
  - Fresno, California Police Department
  - Capital Area Rural Transit System (CARTS) – Austin, Texas
- 2.4 GHz (non- Wi-Fi)
  - Kansas Highway Patrol and the Kansas DOT (full-motion video, portable DMS and HAR)
- 4.9 GHz
  - Cheyenne, Wyoming (includes traffic lights, access to GIS maps for firefighters, etc.)
  - Santa Cruz, CA Police Department
  - Chicago Police Department (includes video)

Wireless Deployments Investigated

- 5 GHz
  - Caltrans – Los Angeles (Image Sensing. PTZ transmitted over 2.4 GHz)
  - East Bay Municipal Utility District – Stockton
- Satellite
  - Florida Turnpike Enterprise Traffic Management Vehicle (VSAT)
  - Communication for Hurricane Charley Recovery using VSAT communication (used as gateway to Internet for mesh network spanning 60 sq mi)
- Motorola Canopy System
  - University of Oklahoma and the Oklahoma Department of Transportation (MPEG 4 Video)
  - Nevada Department of Transportation (backhaul for cameras along I-80)
- Meteor Scatter
  - Snowpack Telemetry (SNOTEL)
  - Soil Climate Analysis Network (SCAN)
- Point-to-Point Microwave
  - State of Washington Public Safety Network
  - Florida Statewide Microwave Network
  - Caltrans District 2

Wired / Landline Deployments Investigated

- Public Switched Telephone Network (PSTN) and Plain Old Telephone Service (POTS)
  - Caltrans D2
- Integrated Services Digital Network (ISDN)
  - Caltrans D2
  - King County DOT Washington (also used DSL)
- Digital Subscriber Line (DSL)
  - Video Applications in Fairfax and Alexandria, VA
- Fiber
  - Florida Gigabit Fiber Metropolitan Networks
  - Oklahoma Department of Transportation
- Cable (Television)
  - A Traffic Management System Utilizing a Digital Cable Network (Walnut Creek, California)

Suitability of Selected Communication Technologies for ITS and/or Related Uses

Topology	Max Data (Kbps)	CCTV high	CCTV med	CCTV low	CMS	RWIS	Voice
Required Data Rate (Kbps)		384	64	2	4.8	9.6	20
2.4 GHz – ISM band proprietary products	54000	P	P	P	P	P	Y
4.9 GHz – Public Safety	100,000	P	P	P	P	P	Y
5.8 GHz – ISM band proprietary products	100,000	P	P	P	P	P	Y
700 MHz	384	P	P	P	P	P	Y
800 MHz	19.2	N	N	P	P	P	Y
802.11a	54000	Y	P	P	P	P	Y
802.11b	10000	Y	P	P	P	P	Y
802.11g	54000	Y	P	P	P	P	Y
802.16 WiMax	75000	Y	P	P	P	P	Y
900 MHz	120	N	P	P	P	P	Y
Cellular, 1xRTT	307/153	N	P	P	Y	P	Y
Cellular, Edge	473	P	P	P	P	P	Y
Cellular, EV-DO	3100/1200	P	P	P	P	P	Y
Cellular, GSM	9.6	N	N	P	P	P	Y
Cellular, GPRS	160	N	P	P	P	P	Y
Analog Cellular, AMPS	9.6	N	N	P	P	P	Y

Y = Yes, P = Possibly, N = No

Suitability of Selected Communication Technologies for ITS and/or Related Uses

Topology	Max Data (Kbps)	CCTV high	CCTV med	CCTV low	CMS	RWIS	Voice
Required Data Rate (Kbps)		384	64	2	4.8	9.6	20
DSL	7,000	Y	P	P	Y	Y	Y
DSRC	54000	P	P	P	P	P	P
Fiber		Y	P	P	Y	Y	Y
Analog POTS	56	N	P	P	Y	Y	Y
ISDN	128	N	Y	P	Y	Y	Y
Mesh	54000	Y	P	P	P	P	Y
Meteor Scatter	9.6	N	N	N	P	Y	N
Microwave		Y	P	P	Y	Y	Y
Motorola Canopy (900 MHz)	3,300	Y	P	P	P	P	Y
Satellite, ISP	512/128	P	P	P	P	P	P
Satellite, Inmarsat	492	N	P	P	P	P	P
Satellite, GlobalStar	9.6	N	N	P	P	P	Y
Satellite, Iridium	2.4	N	N	P	P	P	Y
Satellite, VSAT	6200 /2000	Y	P	P	Y	Y	Y
UHF	19.2	N	N	P	P	P	Y
VHF High Band	19.2	N	N	P	P	P	Y
Cable	10,000	P	P	P	P	P	P

Y = Yes, P = Possibly, N = No

Research Analysis of Preferred Technologies and Site Evaluations

- Project Deliverable #2
- To be finalized Summer 2008

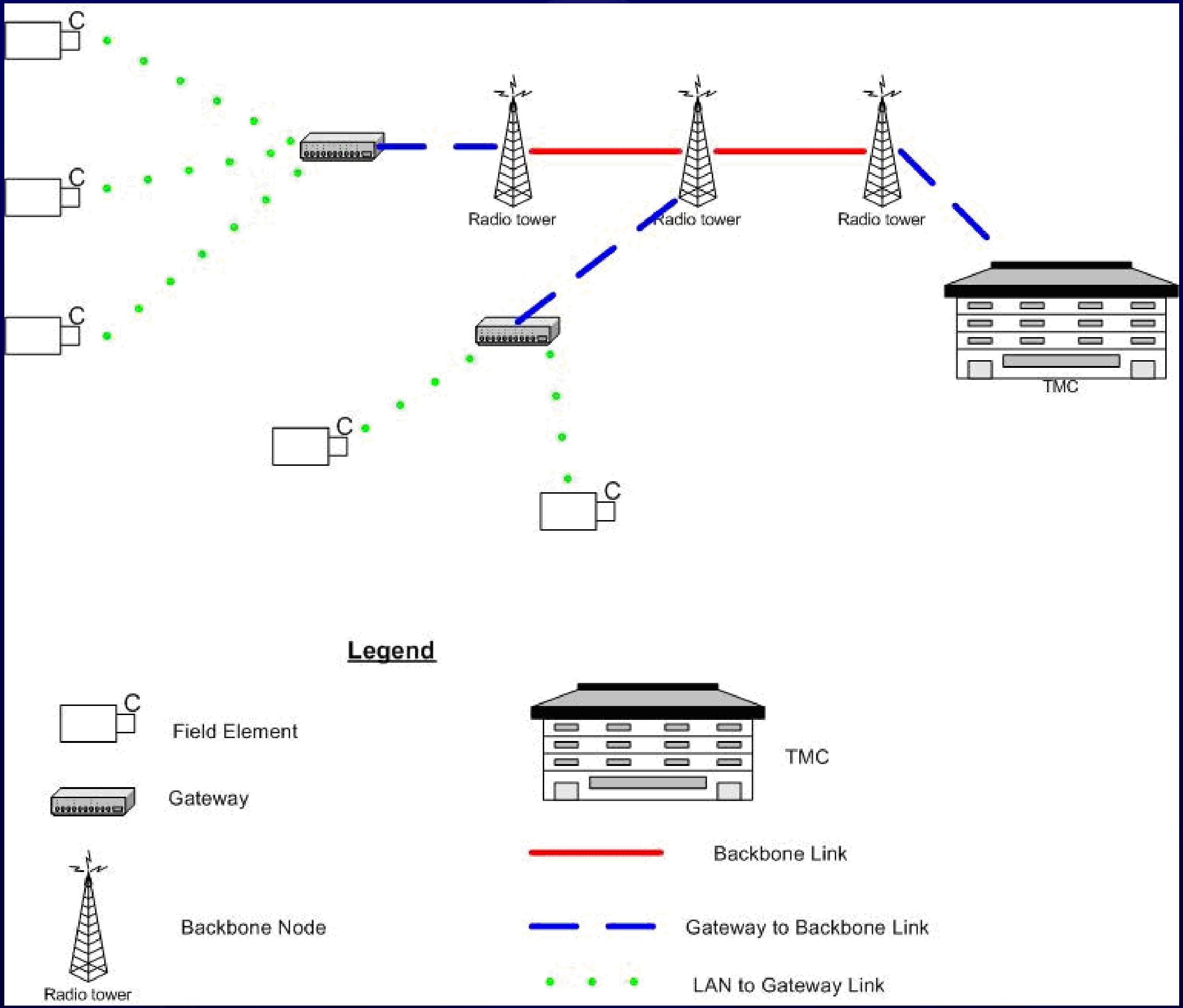
Potential for Hybrid, IP-Based Network

- IP-based network provides flexibility in deployment and expansion, enabling a “mix” of technologies.
- No one communication technology fully meets the needs of District 1.
- It shall be assumed that a “hybrid,” IP-based network is necessary.
- Multiple topologies may be considered and used.

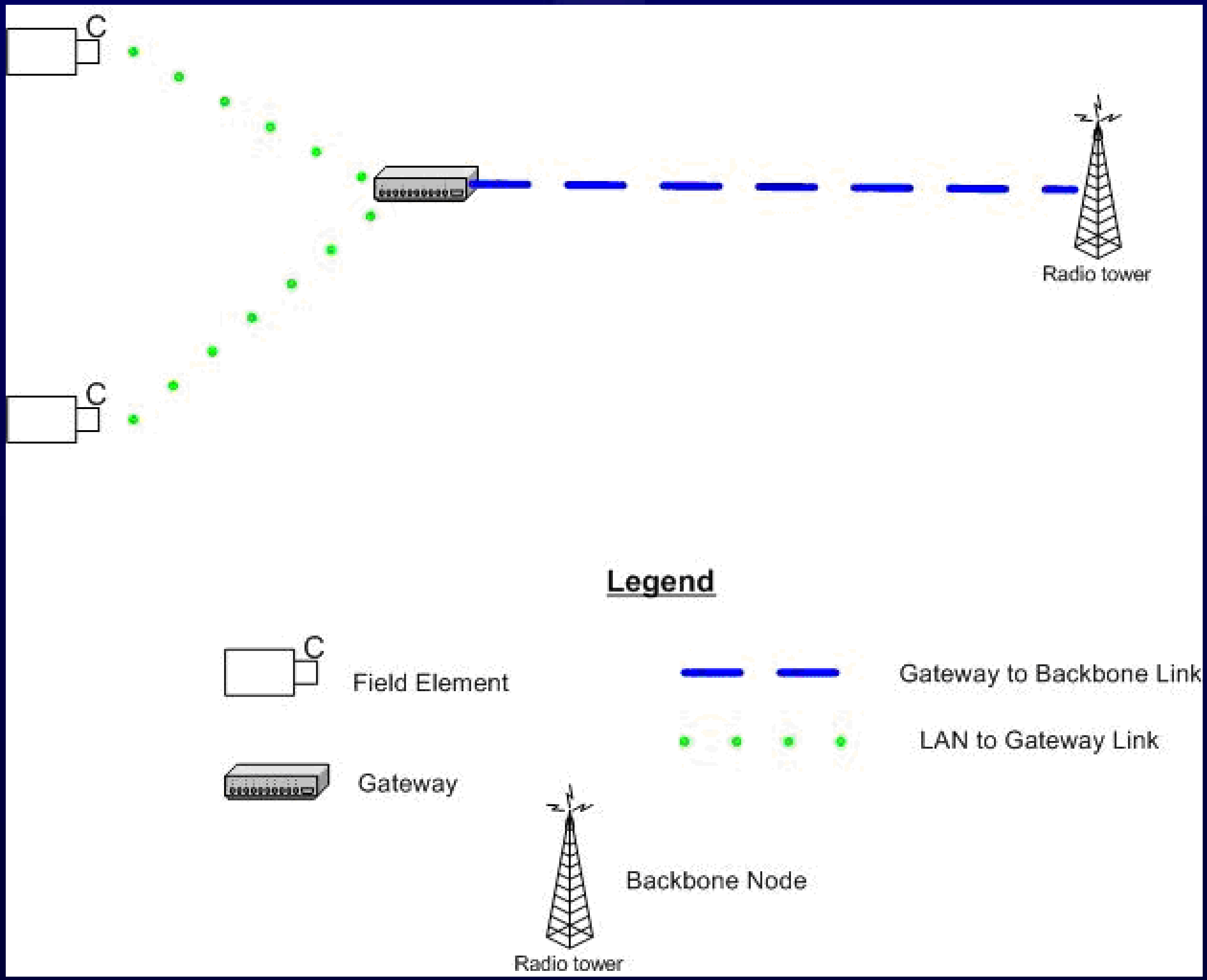
Communication Network Components

- The project team defined four primary network components for analysis:
  - Backbone
  - Gateway to Backbone
  - Roadside LAN (terminology borrowed from D2)
  - Direct TMC to TMS

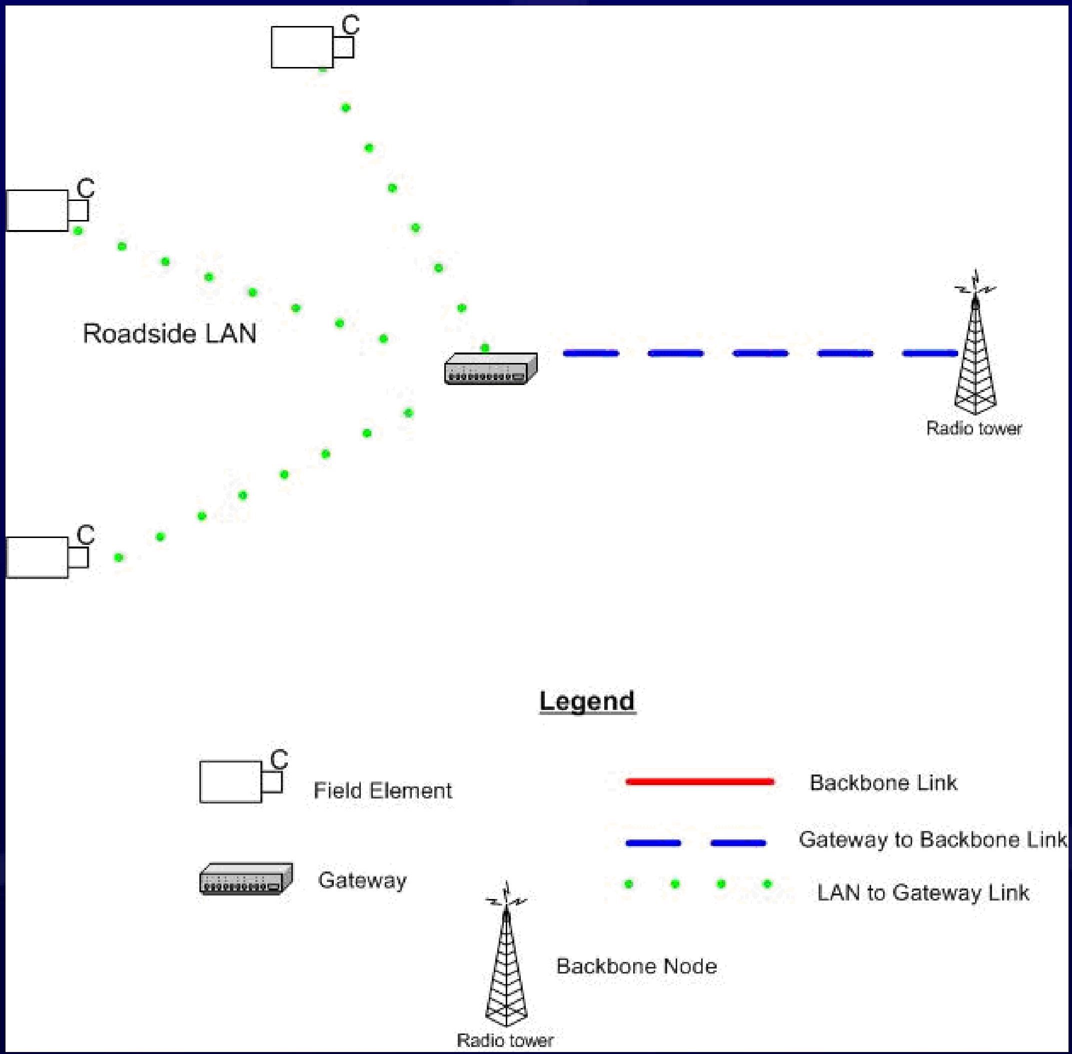
Communication Network Components : Backbone



Communication Network Components : Gateway to Backbone



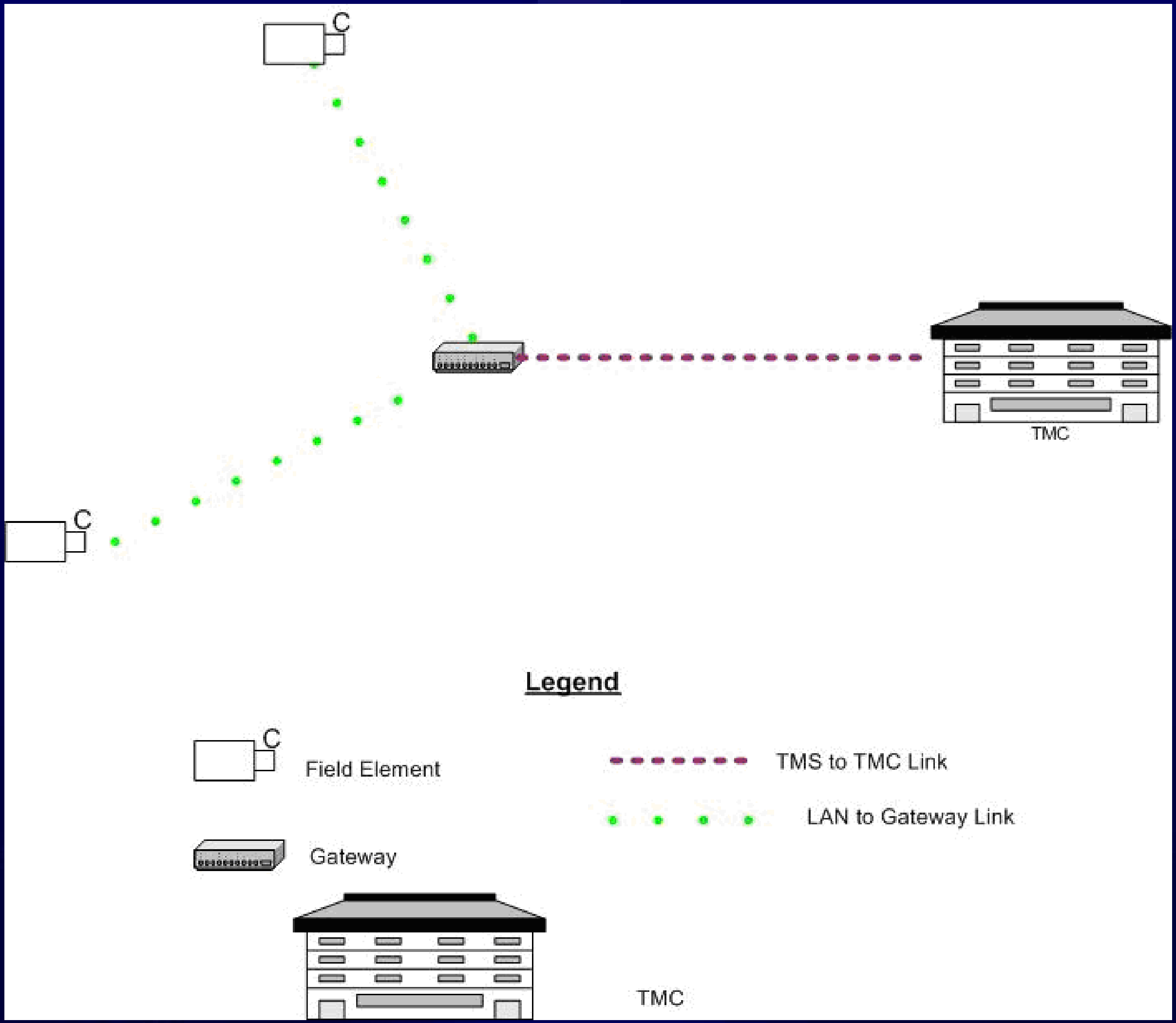
Communication Network Components : Roadside LAN



MONTANA STATE UNIVERSITY | College of ENGINEERING

Western Transportation Institute

Communication Network Components : Direct TMS to TMC



Field Element Types and Communications Requirements

Field Element Type	Required Bandwidth	Frequency of Transmission
CMS	• base data rate of 1.2 kb/s • minimum data rate of 2.4 kb/s	Approximately two per day
CCTV	• minimum data rate of 1.2 kb/s for "snapshot" • minimum data rate of 14.4 kb/s for "streaming"	Continuous on demand
RWIS	• base data rate of 9.6 kb/s • minimum data rate of 4.8 kb/s	15 minute intervals

Analysis of Communications Technologies
Wi-Fi

- Benefits include: network scalability, quick installation, low component cost, transparency to IP network communication.
- Drawbacks include: WiFi is unlicensed and very popular, thus, prone to interference; irregular terrain and vegetation will restrict use.
- Applicable in sparsely populated areas with good line of site – roadside LAN with nodes located in close proximity.

Analysis of Communications Technologies

IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax)

- Benefits include better coverage / range than Wi-Fi, mobility is an option with mobile Wi-Max, security is more robust than Wi-Fi.
- Drawbacks include potential for interference, although licensed options may be available.
- Applicable in sparsely populated areas with good line of site – roadside LAN with nodes located in close proximity; may also be considered for gateway to backbone links.

Analysis of Communications Technologies
Mesh

- Benefits include very flexible routing and redundancy; flexible and extensible topologies.
- Drawbacks include the potential for interference when using unlicensed frequencies; mesh degrades to serial, multi-hop network in rugged terrain – in this case, there may be unnecessary overhead and a non-mesh multi-hop architecture would be preferred.
- Applicable for roadside LANs or to extend connectivity to a gateway via multi-hop in the absence of better options.

Analysis of Communications Technologies

Carrier Provided Wireless (Cellular or PCS) Data Services

- Benefits include relative ease of deployment (w/ modem) where service is available, relatively high data rates for 3G services where available.
- Drawbacks include high monthly service charge, limited (but growing) availability in D1; sensitivity to traffic volume; varied availability in irregular terrain.
- Applicable in the absence of other Telco services and/or for rapid deployment where service is available – for direct TMC-TMS communications.

Analysis of Communications Technologies

Radio Frequency (RF) Communications - 150 MHz through 900 MHz Bands

- Benefits include non-line-of-sight propagation characteristics, particularly at lower frequencies; licensed frequencies will not experience interference (note that 900 MHz ISM is unlicensed).
- Drawbacks include limited bandwidth, except for 700 MHz and 900 MHz; licensing issues; re-farming may impact VHF, UHF and 800 MHz beginning in 2013; 700 MHz situation still playing out.
- 700 MHz and 900 MHz show greatest potential applicability for gateway to backbone links; 900 MHz may be applicable for backbone; VHF and UHF could potentially be used for low-data-rate applications in hard to reach areas.

Analysis of Communications Technologies

Point-to-Point Microwave Communications 2.4, 4.9, and 5 GHz Microwave Bands

- Benefits include implementation "simple" for unlicensed bands; elimination of interference using (licensed) 4.9 GHz.
- Drawbacks include interference for unlicensed bands; higher cost and license requirement for 4.9 GHz.
- Applicable in all areas of network, with greatest potential in gateway to backbone links and backbone links.

Analysis of Communications Technologies

The State of California Public Safety Microwave Network and the State of California Public Safety 800 MHz Network

- Benefits include existing site availability in much of D1.
- Drawbacks include network is generally not “capable” for application in much of D1; service cost where available can be significant.
- Applicability is generally limited at present, although future upgrades could change this. Co-location on existing sites should be considered.

Analysis of Communications Technologies

Geostationary Earth Orbit (GEO) Satellite Systems (VSAT or similar)

- Benefits include availability in areas where other service is not available.
- Drawbacks include view of sky requirements; significant equipment and monthly service costs.
- Applicable where other options are not available for direct TMC-TMS communications.

Analysis of Communications Technologies
Satellite ISP

- Benefits include availability in areas where other service is not available; lesser cost than VSAT options.
- Drawbacks include view of sky requirements; equipment and monthly service costs; may be sensitive to precipitation.
- Applicable where other options are not available for direct TMC-TMS communications.

Analysis of Communications Technologies
Low Earth Orbit (LEO) Satellite Systems

- Benefits include availability in areas where other service is not available; deployment can be relatively easy – not necessary to point antenna.
- Drawbacks include view of sky requirements, although view of fixed point not necessary; in irregular terrain and dense vegetation, service may be sparse and irregular; equipment and monthly service costs; data rates are extremely low.
- Applicable (but very limited) where other options are not available for direct TMC-TMS communications with low data rate field elements (RWIS?).

Analysis of Communications Technologies
Meteor Scatter

- Benefits include potential availability in very remote areas; widely used by other sensor networks (SNOTEL, etc); low-data rate transmission on non-line-of-sight paths up to 1000 miles.
- Drawbacks include non real-time transmission of data, path availability varies over time depending on a variety of conditions, dependency on providers in a relatively small market.
- Applicable (but very limited) where other options are not available for direct TMC-TMS communications with low data rate field elements (RWIS?).

Analysis of Communications Technologies

Plain Old Telephone Service (POTS)

- Benefits include availability in many areas; general availability of equipment, although hardened equipment may be more difficult to obtain.
- Drawbacks include dial tone unavailability during emergencies; decrease in reliability as distance from central office increases; monthly charges; low data rates.
- Applicable where available and in the absence of “better” solutions; good for initial deployments with future migration planned.

Analysis of Communications Technologies Integrated Services Digital Network (ISDN)

- Benefits include higher data rate than POTS, more robust and reliable than POTS.
- Drawbacks include higher cost than POTS.
- Applicable within 18,000 feet from "central office" or fiber terminal at "Cross Connect" point.

Analysis of Communications Technologies

Digital Subscriber Lines (DSL)

- Benefits include flexibility and high data rates.
- Drawbacks include limited availability – must be near central office or cross connect point; may have no guarantee of bandwidth; may need to address security.
- Applicable where available, but availability is less than that of POTS and ISDN.

Analysis of Communications Technologies

(Leased) Fiber Networks

- Benefits include virtually no limit on data rates and superior reliability.
- Drawbacks include significant expense and very limited availability.
- Applicable where available and affordable.

Analysis of Communications Technologies
Cable Television

- Benefits include high data rates at comparatively low cost.
- Drawbacks include limited availability in non-urban areas, bandwidth fluctuates, monthly charges.
- Applicable where available.

Analysis of Communications Technologies
T1 and Frame Relay

- Benefits include reliability and potentially high data rates.
- Drawbacks include expense, particularly relative to alternatives such as DSL.
- Applicable where available and in the absence of other alternatives.

Do-It-Yourself DSL

- Benefits include ability to use existing copper or to make a new link of moderate length.
- Drawbacks include requirements for special equipment and general expense of new deployment.
- Applicable mostly with existing compatible copper.

Analysis of Communications Technologies
Do-It-Yourself Fiber

- Benefits include virtually unlimited bandwidth and very high reliability.
- Drawbacks include the need for special, expensive equipment; deployment is expensive.
- Applicable when trenching is already occurring for other purposes and/or in conjunction with other construction.

Analysis of Communications Technologies

Do-It-Yourself (Other) Copper – Example : RS 485

- Benefits include relatively inexpensive, hardened equipment.
- Drawbacks include limited range and data rates, when compared to DSL or Fiber.
- Applicable mainly with existing copper and in the absence of other options.

Analysis of Communications Technologies
Do-It-Yourself (Other) Copper – Example : Cat5

- Benefits include relatively inexpensive, hardened equipment.
- Drawbacks include limited range when compared to DSL or Fiber.
- Applicable for short runs.

TMS Site Analysis
7 "Representative Sites"

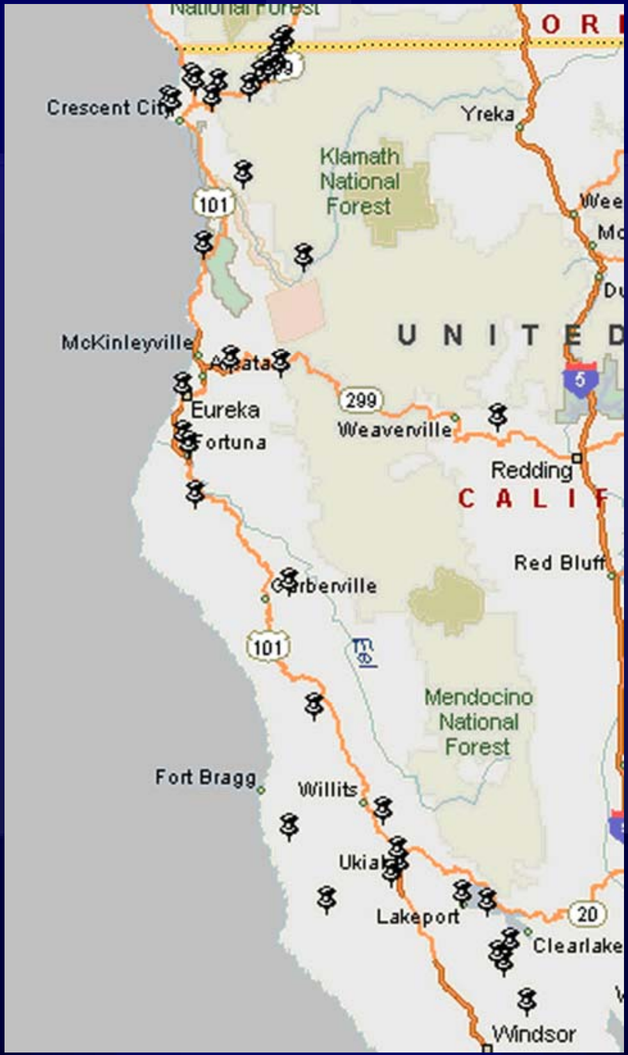
1. US 199: Collier's Tunnel North – hypothetical site – selected at the Kickoff meeting. This site is the "reason" this study was conducted.
2. US 199: Idlewild Maintenance Yard – hypothetical site – selected at the Kickoff meeting.
3. US 101: South of Cushing Creek- selected at the Kickoff meeting
4. Eureka – Wabash Maintenance Yard – selected at Kickoff meeting. (Subsequently removed because communication is well established at this location.)
5. US 101: Confusion Hill- selected at the Kickoff meeting.
6. SR 299: West of M&W Ranch Road – hypothetical site – a location between D1 and D2 on route 299 was agreed upon at the Kickoff meeting. The WTI project manager selected the final location based on this discussion.
7. SR 20: East of SR 53 - general location agreed upon by the stakeholders. The terrain features at this location differ from other areas and there is relatively little vegetation.

TMS Site Analysis
7 “Representative Sites”

TMS Site Analysis "Best Case" Backbone

- In the absence of a D1 "backbone," the project team chose to use the state 800 MHz and Microwave sites as locations of "best case" backbone nodes.
- Consistent with understanding that it would be difficult/impossible to build new sites in D1.
- Could be augmented by co-locating with agencies at other sites.
- Examined 700 MHz and 900 MHz gateway to backbone propagation.
- NOTE: the majority of these sites are not "capable" for this application at present. They are not all "connected" to form a single network.

TMS Site Analysis
"Best Case" Backbone

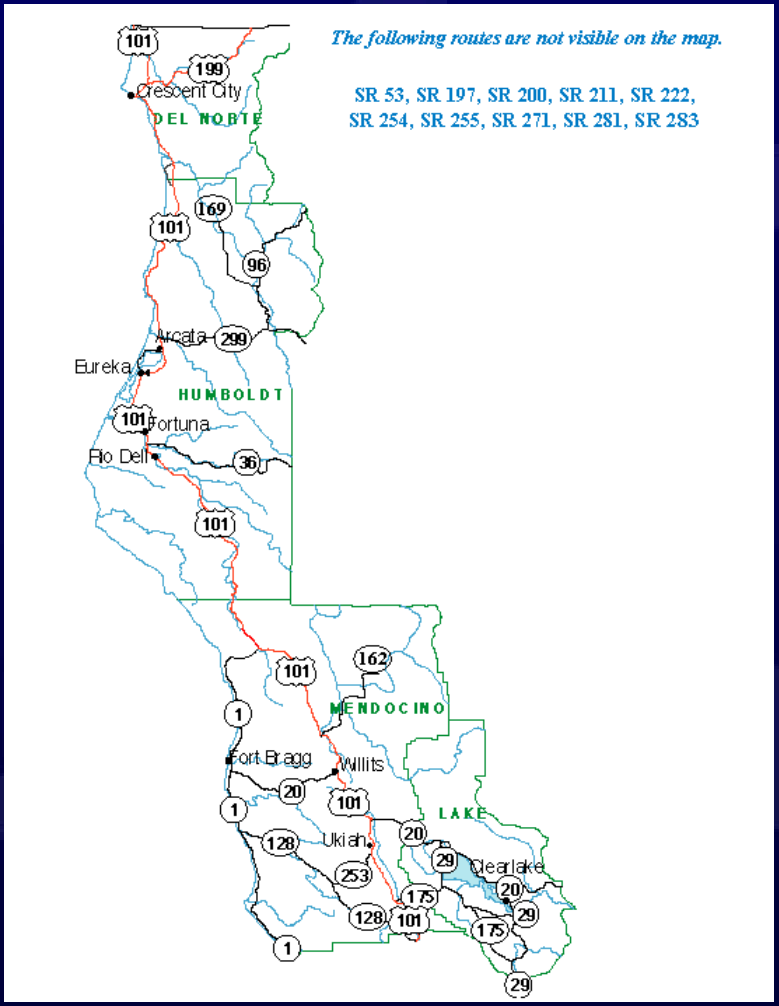


Summer 2007 Data Collection Effort

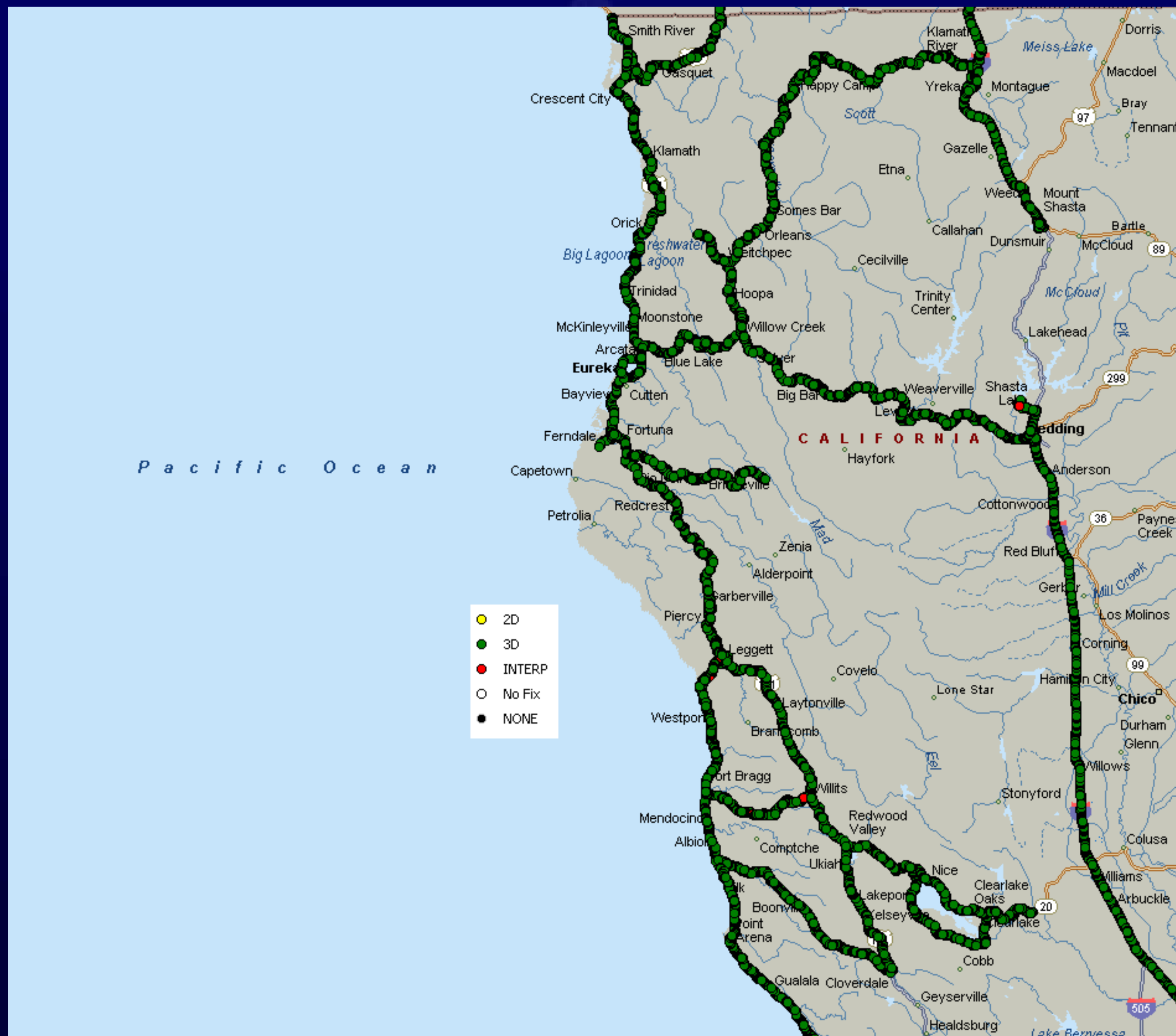
Covered all but approx. 90 miles of State road in D1 – over 90%

- US 101 (all)
- US 199 (all)
- SR 197 (all)
- SR 96 (all)
- SR 169 (all)
- SR 255 (all)
- SR 299 (all)
- SR 211 (all)
- SR 36 (all)
- SR 1 (all)
- SR 20 (all)
- SR 128 (all)
- SR 175 (No – missing approx 30 miles)
- SR 53 (all)
- SR 29 (No – approx 20 miles)
- SR 253 (No – approx 15 miles)
- SR 200 (No – small segment adjacent to US 101 and SR 299)
- SR 162 (No – approx 20 miles))
- SR 222 (No – small segment adjacent to US 101)
- SR 254 (No - small segment parallel to US 101)
- SR 271 (No - small segment parallel to US 101)
- SR 281 (No – approx 3 miles)
- SR 283 (No – small segment adjacent to US 101)

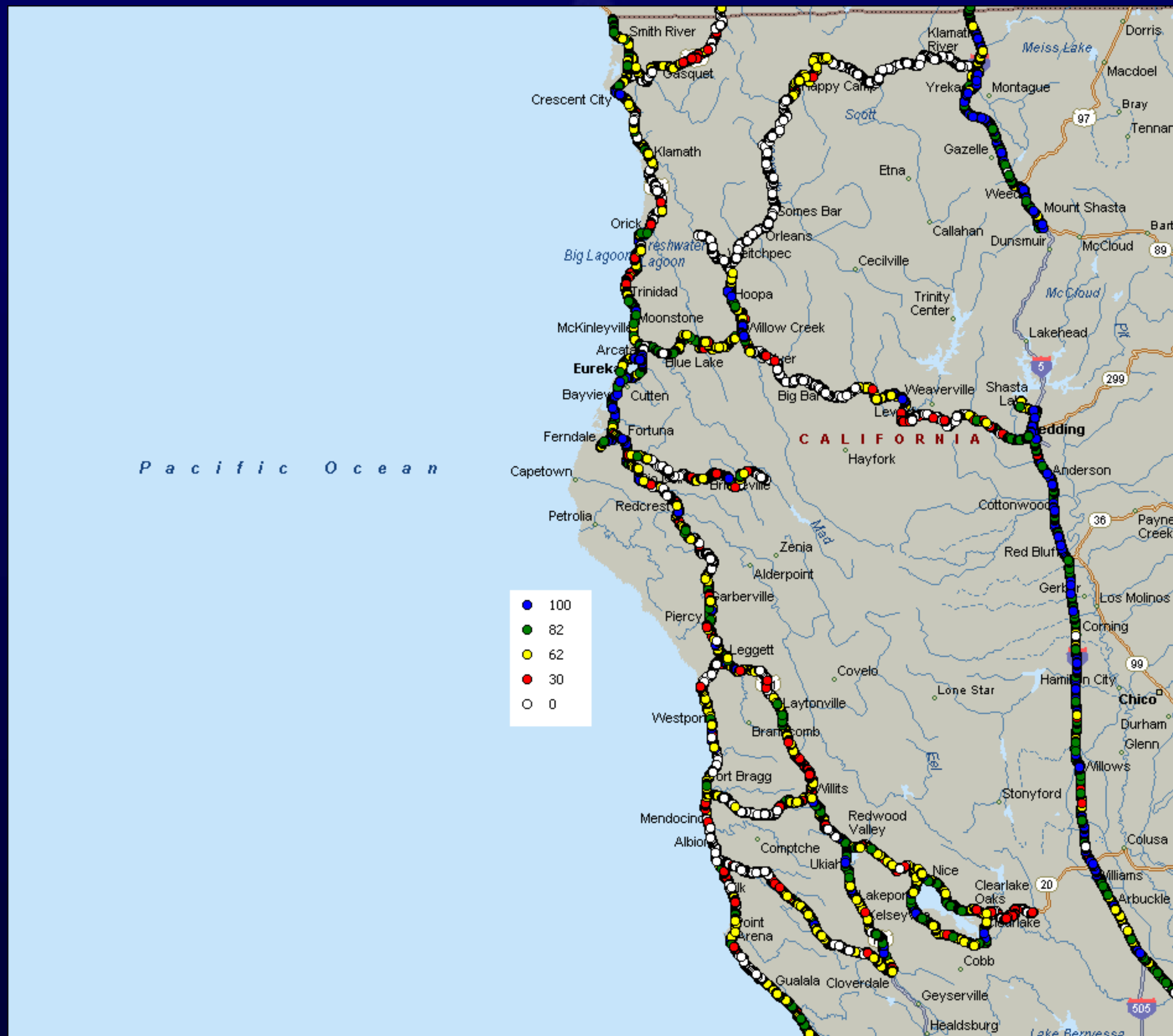
District 1 State Routes – for Reference



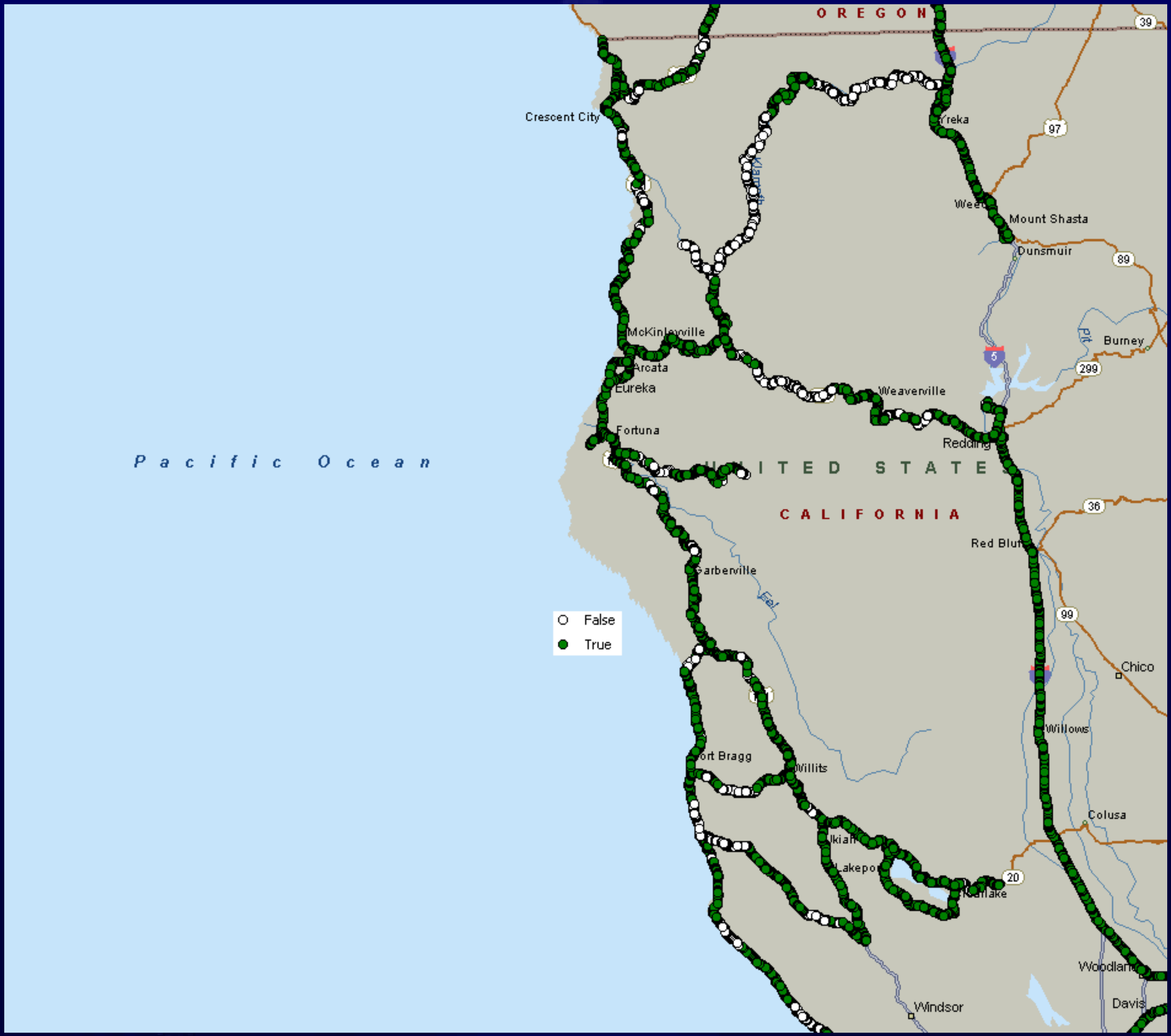
GPS Log of Summer 2007 Data Collection Effort



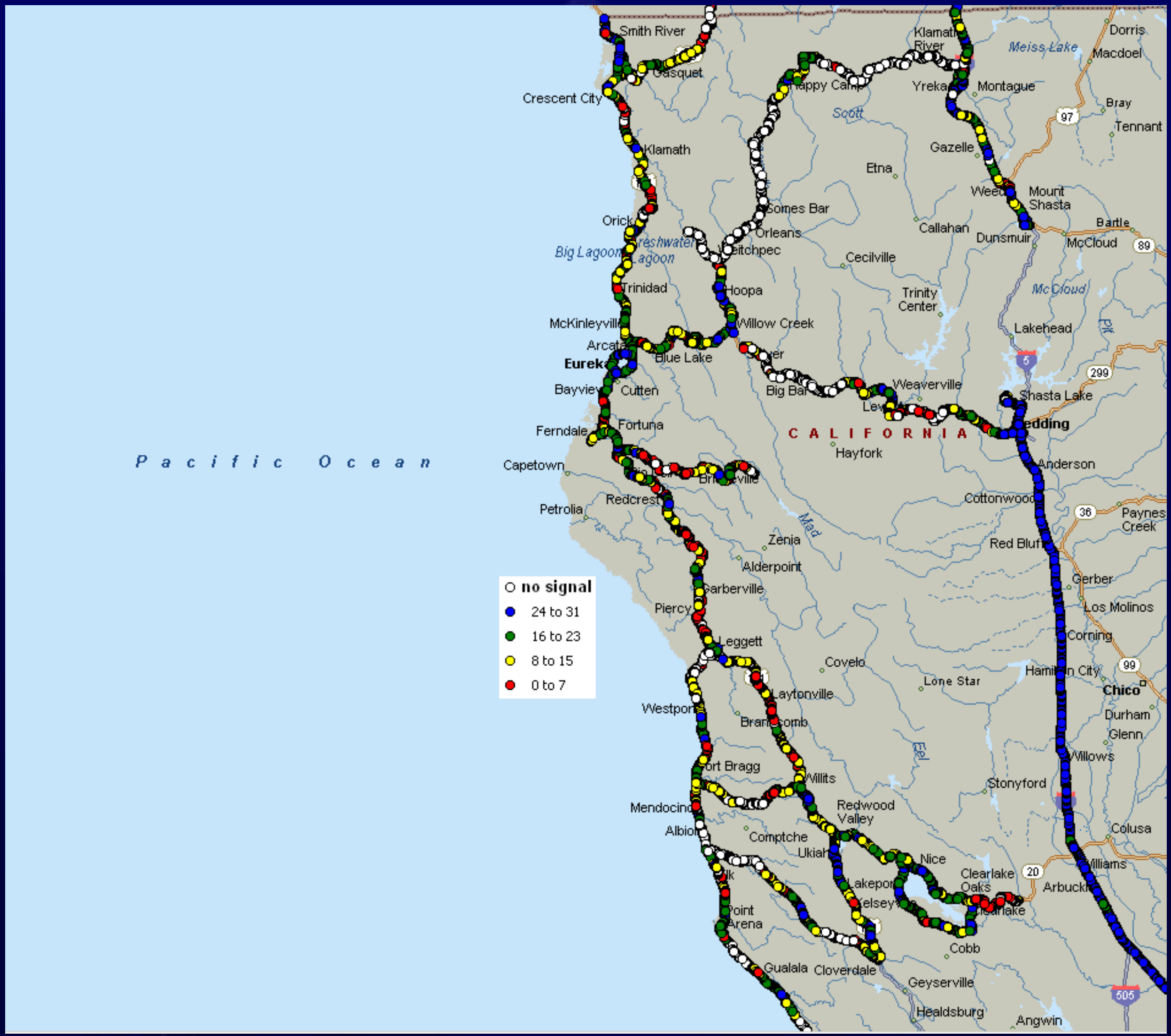
SmartPhone CDMA Signal Strength Log - Summer 2007



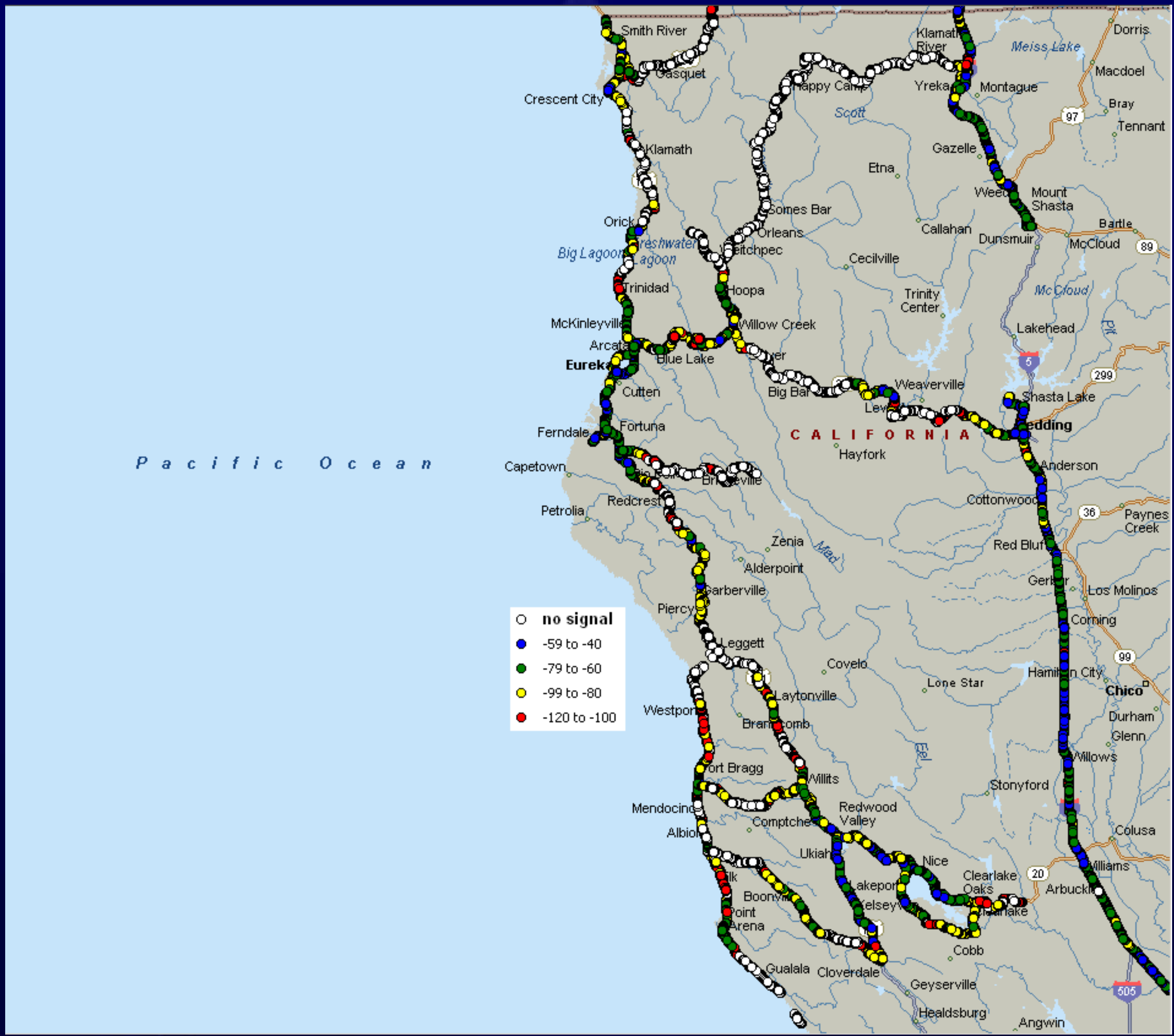
SmartPhone 1xRTT Availability Log - Summer 2007



LandCellular CDMA Signal Strength Log - Summer 2007



Airlink Raven GPRS Signal Strength Log - Summer 2007

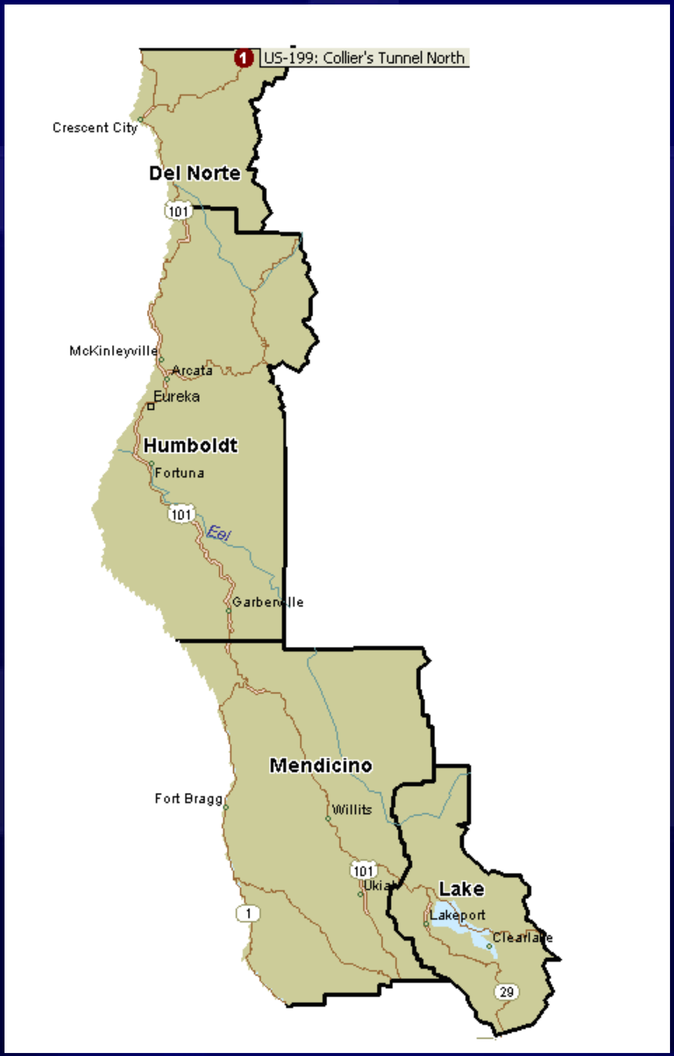


Cellular Sites – Identified from FCC Database (Could be considered another "best case" backbone)

Example Site Analysis – US 199, Collier's Tunnel

- Location: post mile 34 at 123.74 deg W longitude, 41.97 deg N latitude.
- Attempting to deploy a CCTV near north entrance of tunnel.
- Power is available.
- Telco landline service could not be verified in proximity (rest area on south end of tunnel does not have phone, to our knowledge).

Example Site Analysis – US 199, Collier's Tunnel



Example Site Analysis – US 199, Collier's Tunnel

Example Site Analysis – US 199, Collier's Tunnel

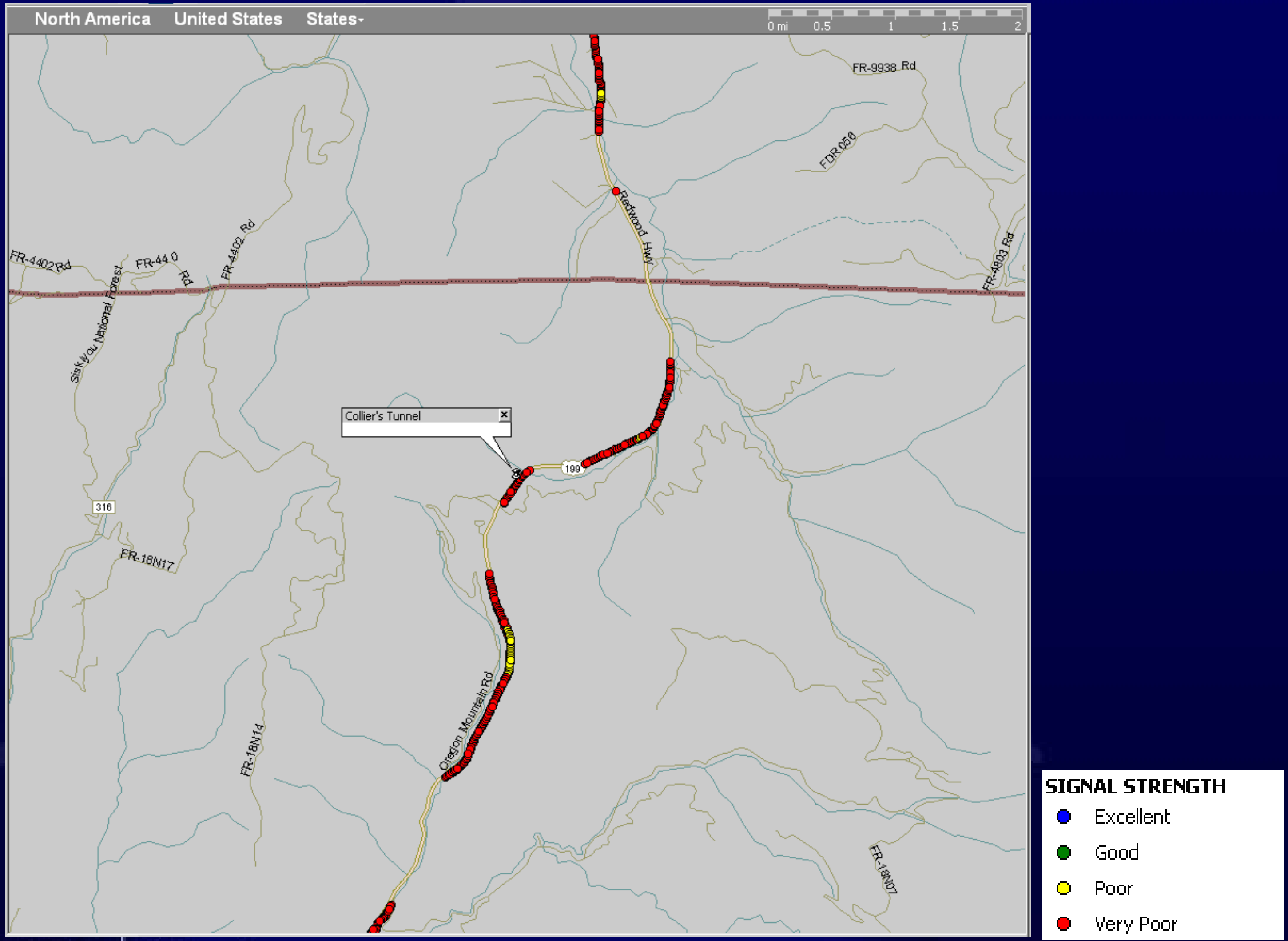
Example Site Analysis – US 199, Collier's Tunnel
Telco - Landline

- POTS, DSL, and ISDN are currently not available at this site.
- Such service may be available at the rest area on the south side of the tunnel, but we have not been unable to confirm this.
- Since a camera at the rest area is not in service, it is assumed that none of these services are available there.
- We are unaware of other nearby service in proximity.
- We found it challenging to get further assistance/information from Telcos …

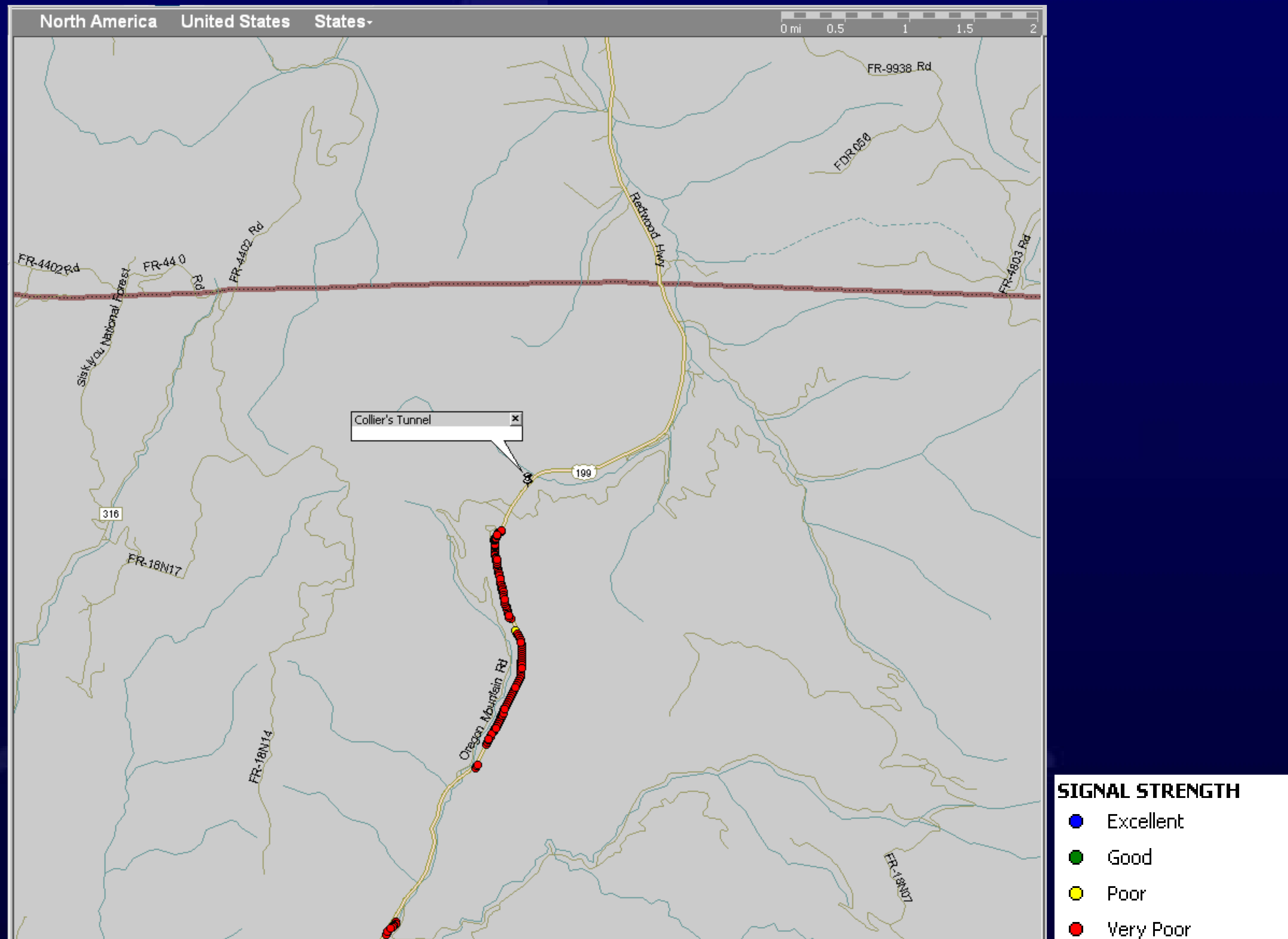
Example Site Analysis – US 199, Collier's Tunnel Cellular

- Verizon indicated that cellular was available.
- WTI measurements showed weak service at best available in proximity.

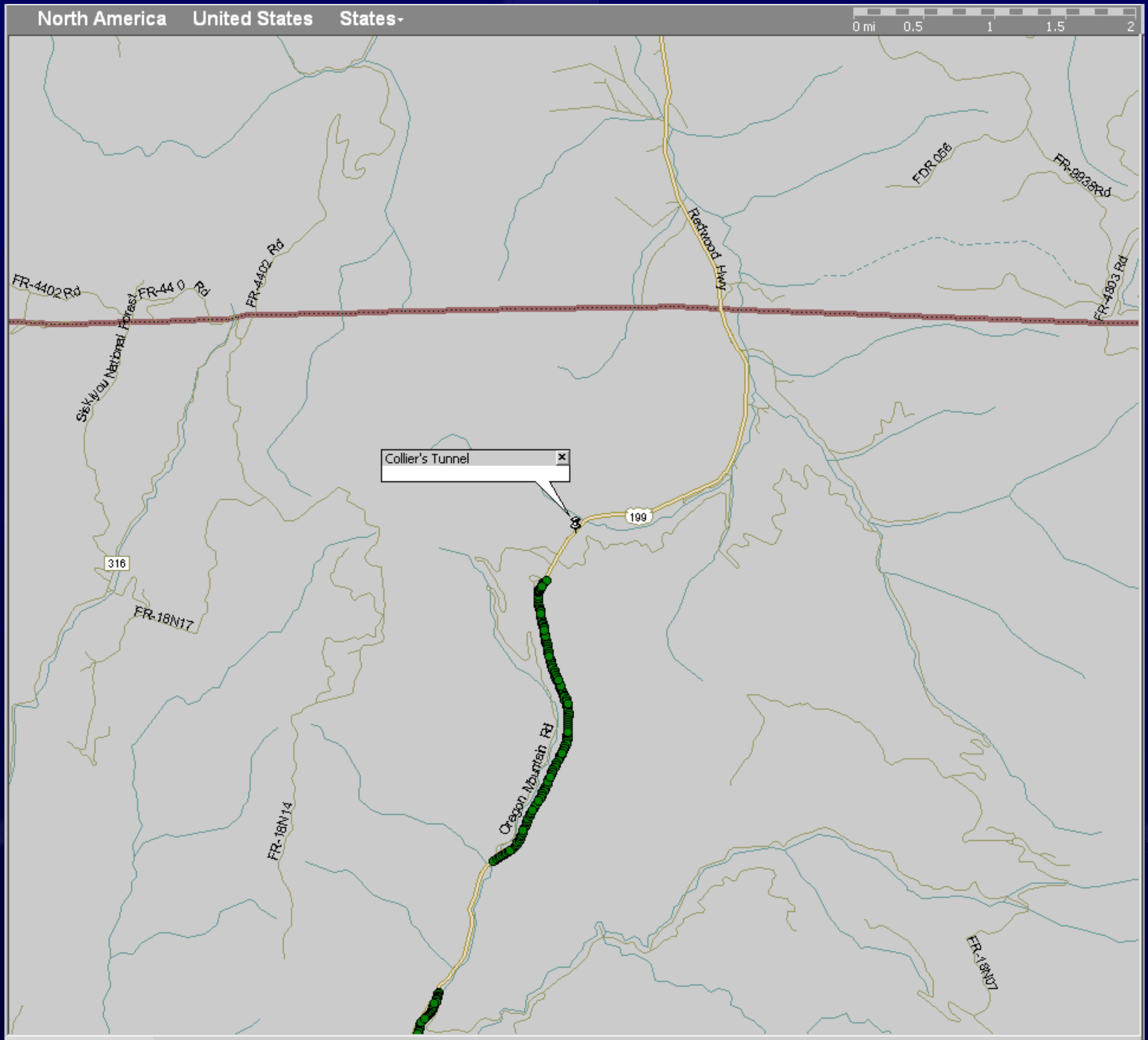
Example Site Analysis – US 199, Collier's Tunnel
Cellular – WTI measurements – CDMA w/ Land-Cellular Modem



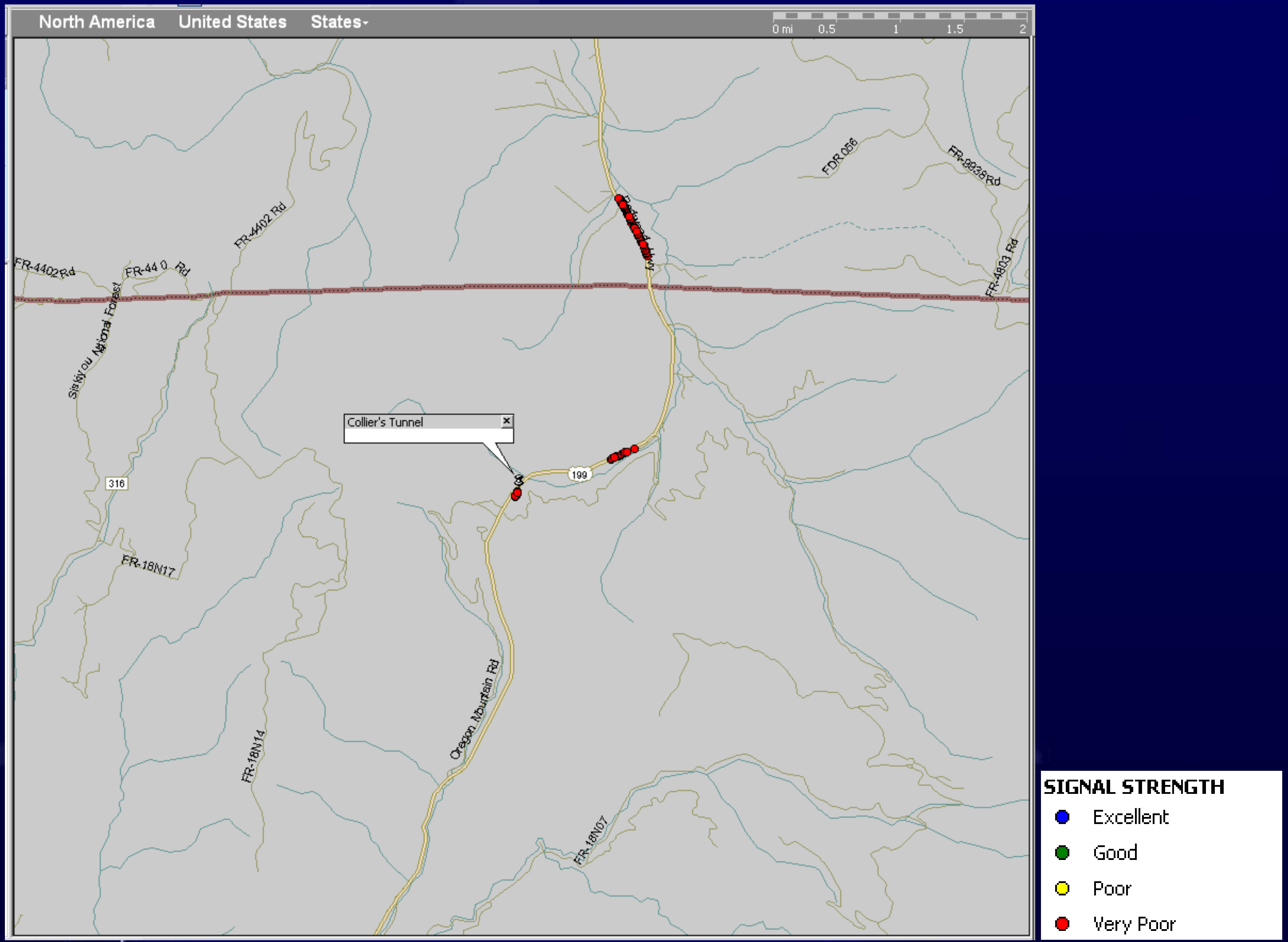
Example Site Analysis – US 199, Collier's Tunnel Cellular – WTI measurements – CDMA w/ SmartPhone



Example Site Analysis – US 199, Collier's Tunnel
Cellular – WTI measurements – CDMA 1xRTT w/ SmartPhone

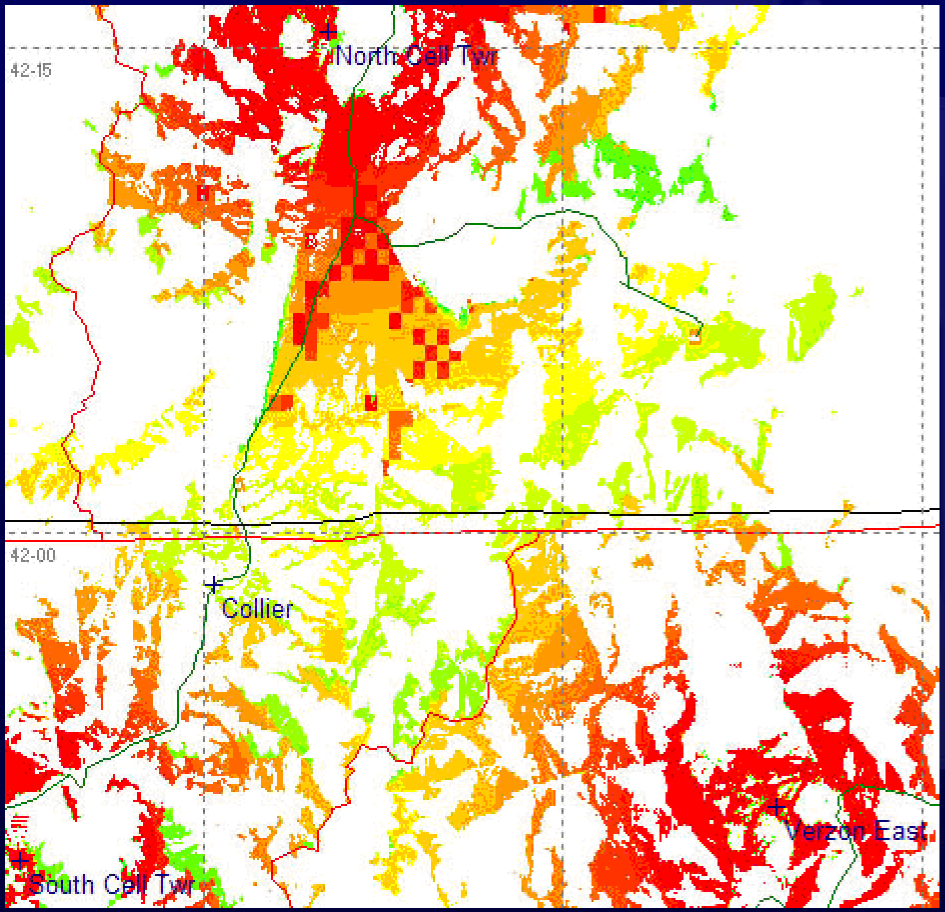


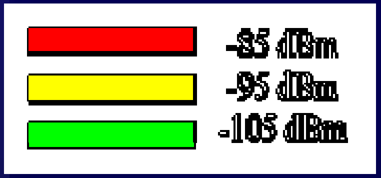
Example Site Analysis – US 199, Collier's Tunnel
Cellular – WTI measurements – GPRS w/ Airlink Raven Modem

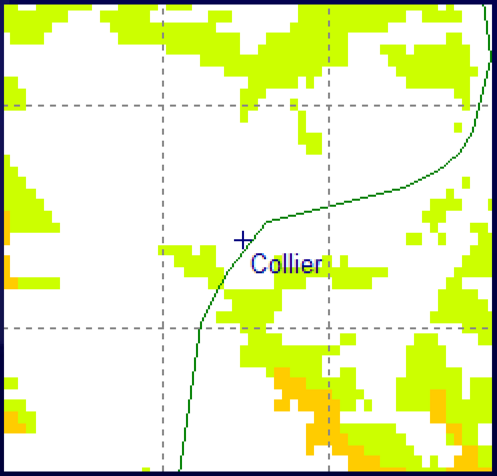


Example Site Analysis – US 199, Collier's Tunnel Cellular – Nearest Towers

Example Site Analysis – US 199, Collier's Tunnel Cellular – Modeled Cell Coverage







Example Site Analysis – US 199, Collier's Tunnel
Cellular – Obstruction to the North and on all sides

Example Site Analysis – US 199, Collier's Tunnel Cellular – Conclusion

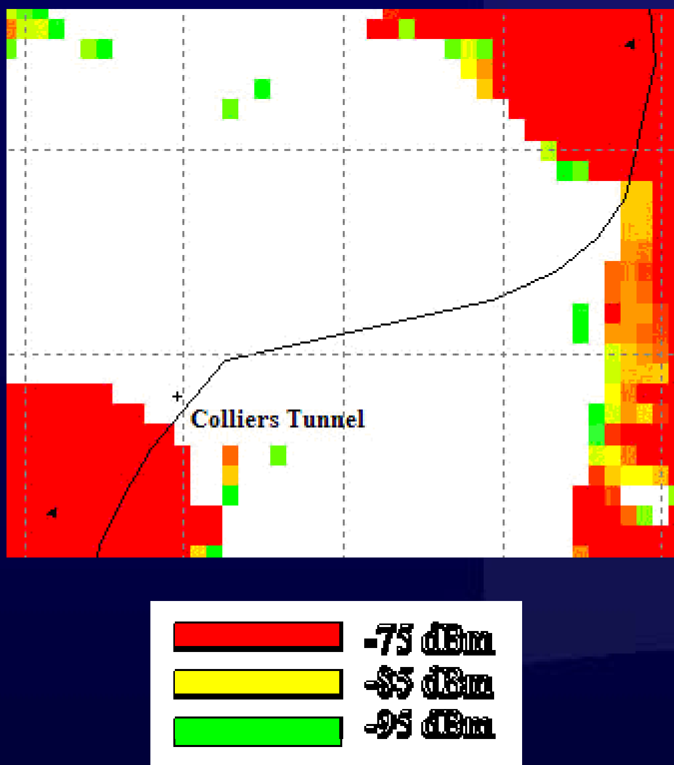
- Cellular is not viable at this time for CCTV. (Includes possibility of selecting nearby site for comm. and using relay.)
- Further expansion of cellular network would be required for service in this location.

Example Site Analysis – US 199, Collier's Tunnel
State Network / Backbone

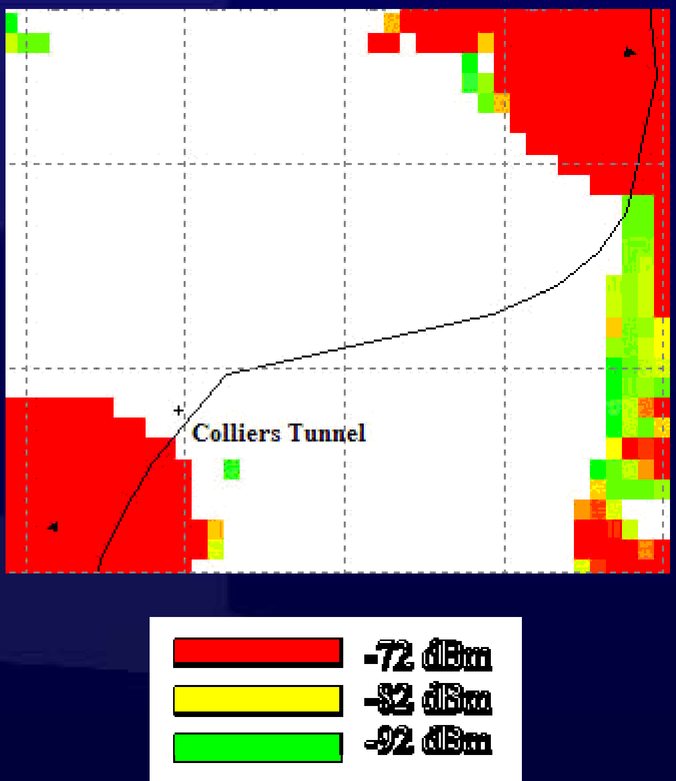
- There are two 800 MHz sites within two miles of Collier's Tunnel.
- These sites are understood to be repeaters, with no external connectivity.
- Even if there was connectivity, they could only support low-data-rate services – perhaps an RWIS.
- Propagation studies show that neither 700 MHz or 900 MHz could be used for direct connectivity. A relay (wired or wireless) would be necessary. (VHF or other lower frequencies would not be considered because they do not offer a sufficient data rate. Higher frequencies would suffer from lack of line-of-sight.)

Example Site Analysis – US 199, Collier's Tunnel
State Network / Backbone

700 MHz



900 MHz



MONTANA STATE UNIVERSITY | College of ENGINEERING

Western Transportation Institute

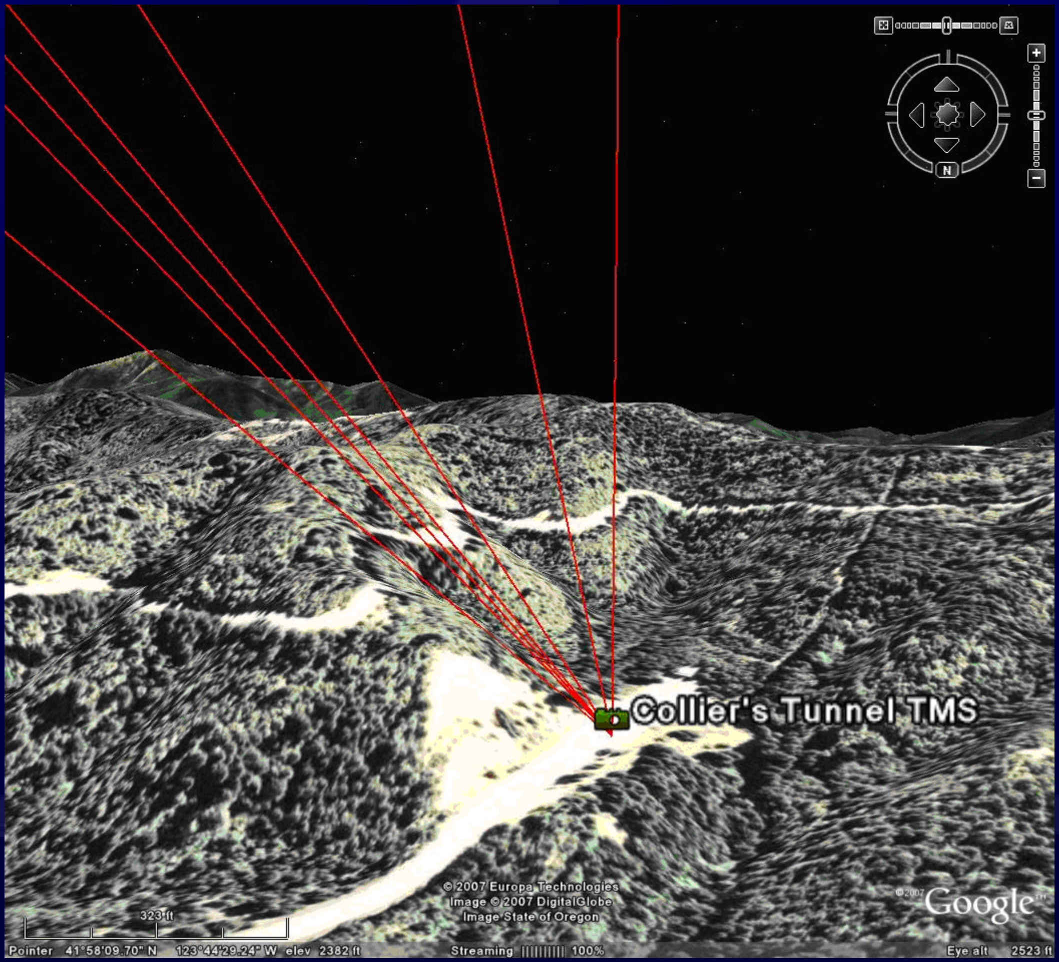
Example Site Analysis – US 199, Collier's Tunnel
State Network / Backbone - Conclusions

- At present, these sites are not usable.
- If future expansion adds external connectivity, then one of these sites could be used. However, a relay would be necessary for "gateway" connectivity.

Example Site Analysis – US 199, Collier's Tunnel Satellite and Other

- Meteor Scatter does not offer sufficient data rate for CCTV.
- LEO Satellite Services (Iridium, Globalstar, Orbcomm) do not offer sufficient data rates for CCTV.
- Fixed GEO services may be considered. (HughesNet, Inmarsat, VSAT). Note that WildBlue is not considered because of anticipated problems with rain/snow.

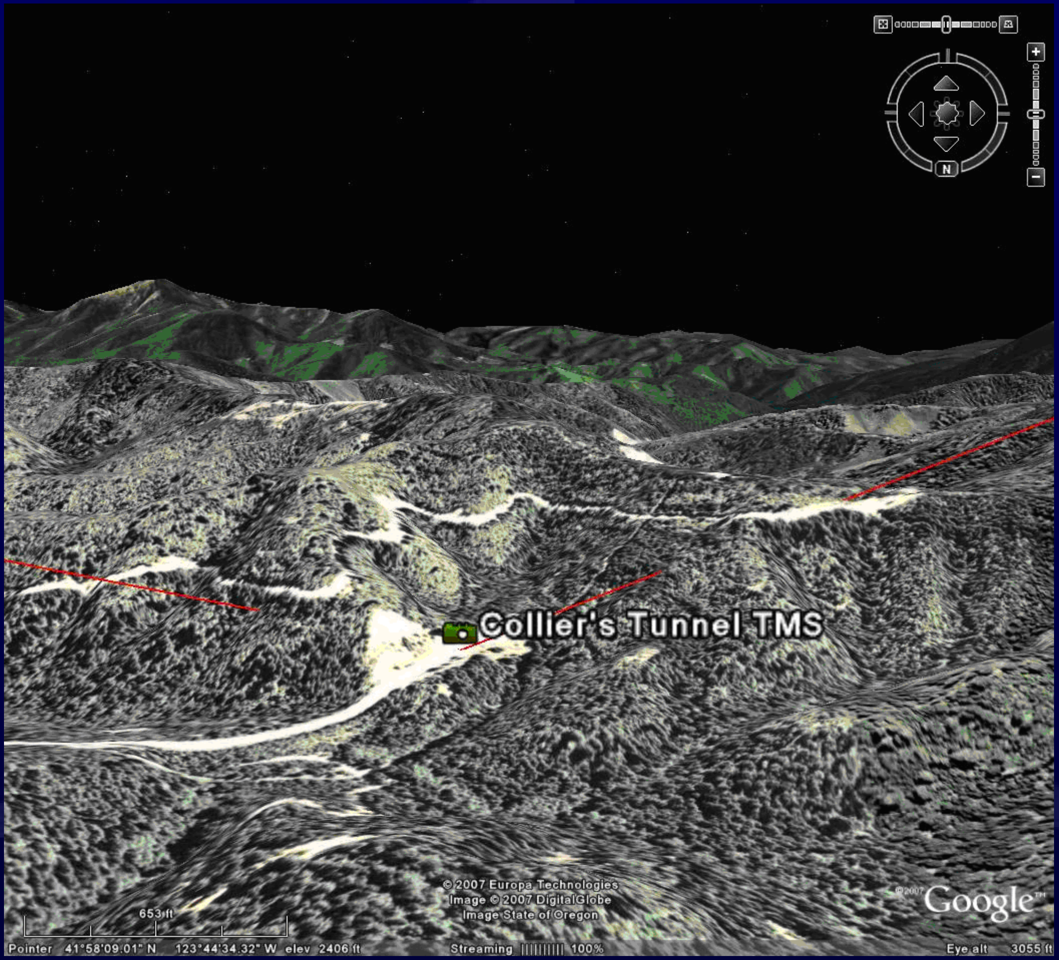
Example Site Analysis – US 199, Collier's Tunnel
Satellite – Visibility of HughesNet Satellites



MONTANA STATE UNIVERSITY College of ENGINEERING

Western Transportation Institute

Example Site Analysis – US 199, Collier's Tunnel Satellite – Visibility of Inmarsat Satellites



Example Site Analysis – US 199, Collier's Tunnel
Satellite – Visibility of VSAT Systems Satellites

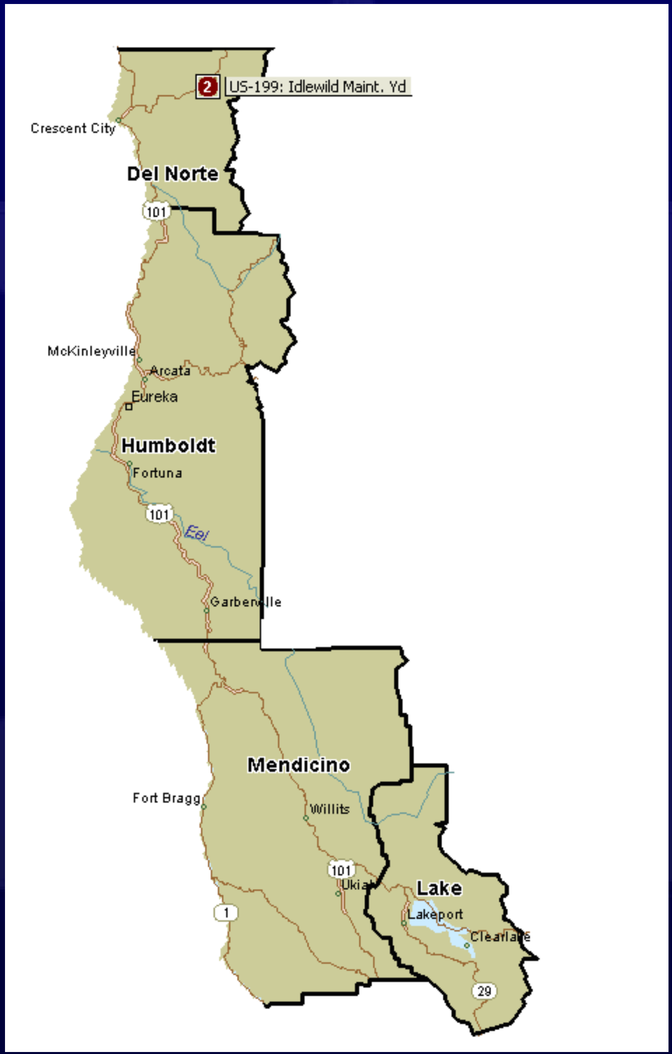
Example Site Analysis – US 199, Collier's Tunnel Satellite - Conclusions

- HughesNet offers the greatest chance for success of satellite systems at this site.
- Siting is important because obstruction to the south (terrain and vegetation) may be problematic.
- Need to determine if available bandwidth is sufficient, including the potential for throttling and congestion, and whether latency is an issue.

Example Site Analysis – US 199, Collier's Tunnel
Overall Conclusions

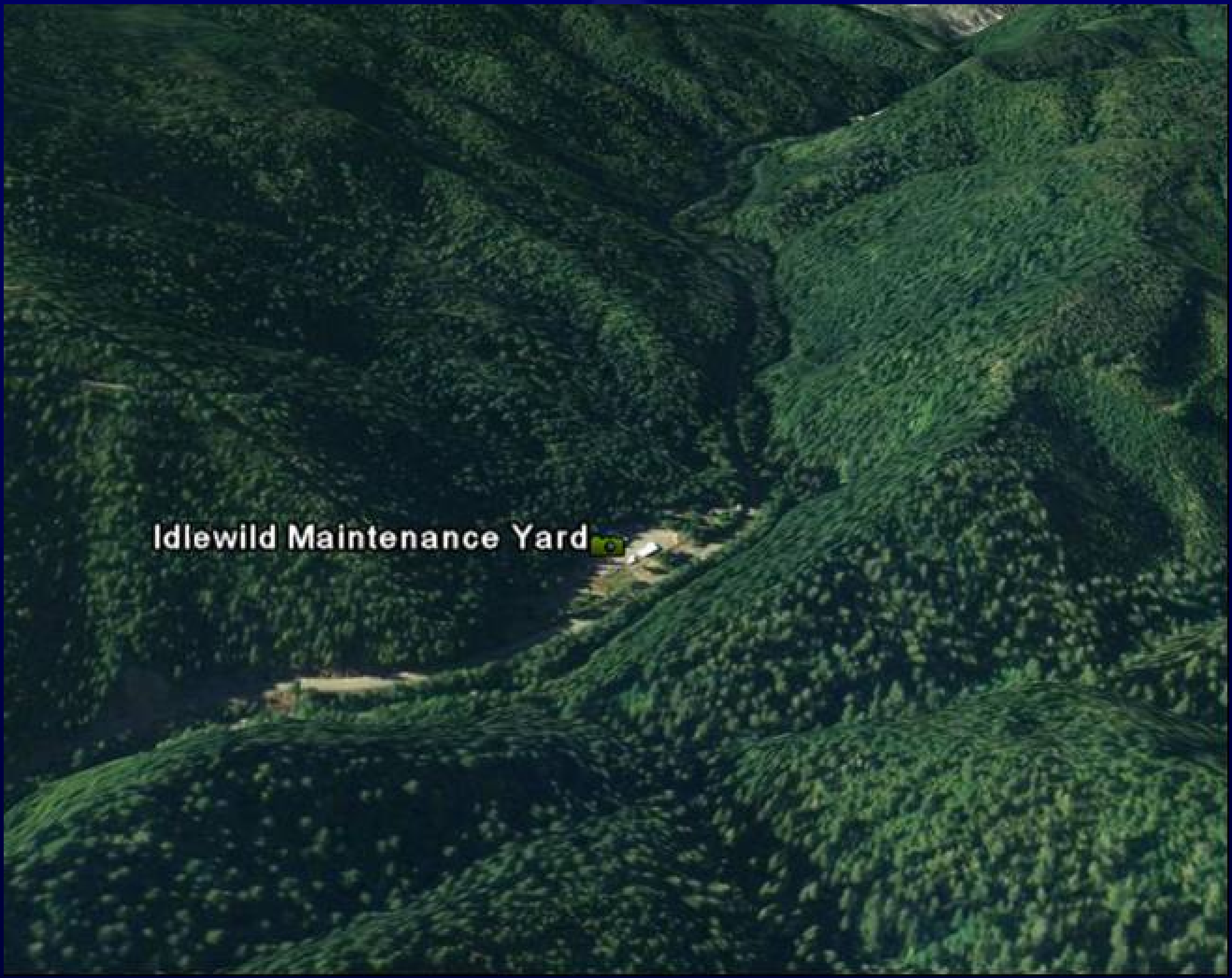
- The only service that could work at present is satellite. Care must be taken in siting. Cost and other issues may be problematic.
- Future expansion of state network or telco services, including cellular, may increase options.

Further Site Analysis – US 199 - Idlewild Maintenance Yard



Further Site Analysis – US 199 - Idlewild Maintenance Yard

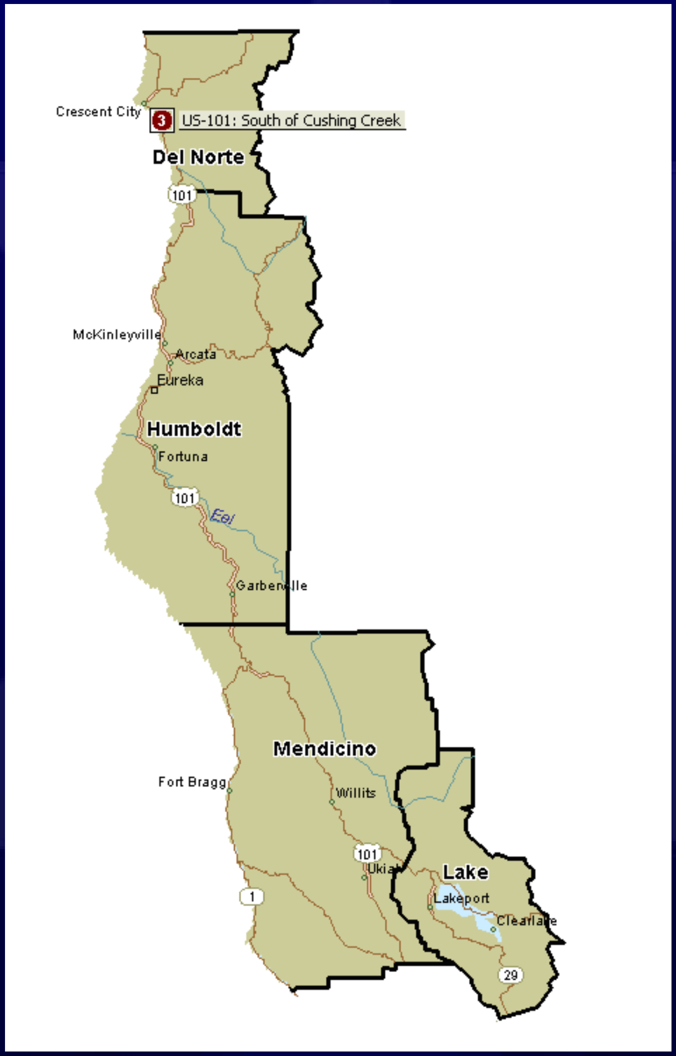
Further Site Analysis – US 199 - Idlewild Maintenance Yard



Further Site Analysis – US 199 - Idlewild Maintenance Yard
Overall Conclusions

- Connection to the “backbone” would be viable here, assuming the backbone had external connectivity.
- Cellular service is available and, with Yagi antennas positioned at optimal locations, it could provide service.
- We were unable to verify telco landline services at this site.
- Satellite is in use at this site and could be used for this application. Careful siting is important because this site is in a canyon.

Further Site Analysis – US 101 South of Cushing Creek



Further Site Analysis – US 101 South of Cushing Creek

Further Site Analysis – US 101 South of Cushing Creek

Further Site Analysis – US 101 South of Cushing Creek
Overall Conclusions

- Telco landline services are in use at this site and certainly could continue to be used.
- Connection to the “backbone” is possible here.
- Cellular is available, but a high-gain, Yagi antenna would need to be positioned at an optimal location for service.
- Satellite could be used, but dense vegetation would make it challenging to get a clear view of the sky.

Further Site Analysis – US 101 – Confusion Hill

Further Site Analysis – US 101 – Confusion Hill

Further Site Analysis – US 101 – Confusion Hill

Further Site Analysis – US 101 – Confusion Hill
Overall Conclusions

- Telco landline services are in use at this site and certainly could continue to be used.
- Connection to the "backbone" may be possible here with the use of a single repeater.
- Cellular is available, but a high-gain, Yagi antenna would need to be positioned at an optimal location for service.
- Satellite could be used, but the mountain face to the East would make it challenging to get a clear view of the sky.

Further Site Analysis – SR 299 – Hypothetical Site

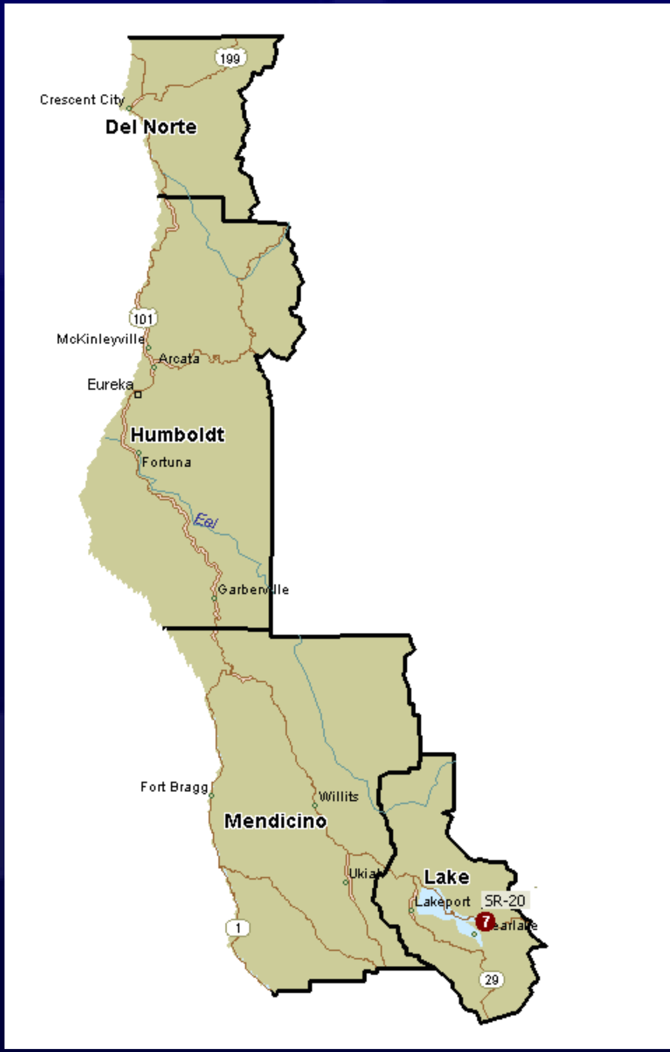
Further Site Analysis – SR 299 – Hypothetical Site

Further Site Analysis – SR 299 – Hypothetical Site

Further Site Analysis – SR 299 – Hypothetical Site Overall Conclusions

- Telco landline services may be available at this site but we were not able to verify that.
- Connection to the “backbone” may be possible here.
- Cellular is available, but a high-gain, Yagi antenna would need to be positioned at an optimal location for service.
- Satellite could be used, but the surrounding mountains make it challenging to get a clear view of the sky.

Further Site Analysis – SR 20 Lake County



Further Site Analysis – SR 20 Lake County

Further Site Analysis – SR 20 Lake County

Further Site Analysis – SR 20 Lake County
Overall Conclusions

- Telco landline services are in use at this site and certainly could continue to be used. An alternative to POTS here is ISDN, which could provide better data rates.
- Connection to the "backbone" may be possible here with the use of a single repeater.
- Cellular is available, but a high-gain, Yagi antenna would need to be positioned at an optimal location for service.
- Satellite could be used, and the area is relatively clear of sky obstruction. (Vegetation and Terrain are moderate).

Site Analysis
Overall Conclusions

- D1 provides many challenges, some may be insurmountable at present. (Collier's Tunnel)
- The state networks (Microwave and 800 MHz) are of general benefit because of their sites, not necessarily the service. However, this is of no benefit without backhaul capability.
- Telco landline service, where available, may be the best option.
- Cellular service continues to expand, with increased service and bandwidth. The monthly charge may be an issue though.
- Satellite service could be considered as a last resort, but can be problematic.
- There is no single "silver bullet" solution.
- There is no substitute for analysis by an RF engineer that accounts for site-specific, organization-specific and time-sensitive details including present and anticipated future needs and capabilities.

700 MHz Update

- The public safety D-block was not purchased in the recent FCC auction. It will likely re-surface, but that will take time. We estimate that it would take up to 10 years to have a significant impact on D1. When in place, we anticipate that it could be used, as part of public safety, for this application. However, it is highly unlikely that it will provide complete coverage of D1.
- Verizon Wireless was successful in acquiring the 700 MHz C-block and plans to deploy a “4G” network using “long-term evolution (LTE)” technology. Considering Verizon’s recent expansion in D1, this could have a very positive impact in terms of capability and coverage.
- Other efforts such as Sprint/Clearwire WiMax may have an impact too, but Verizon may have the upper hand here.

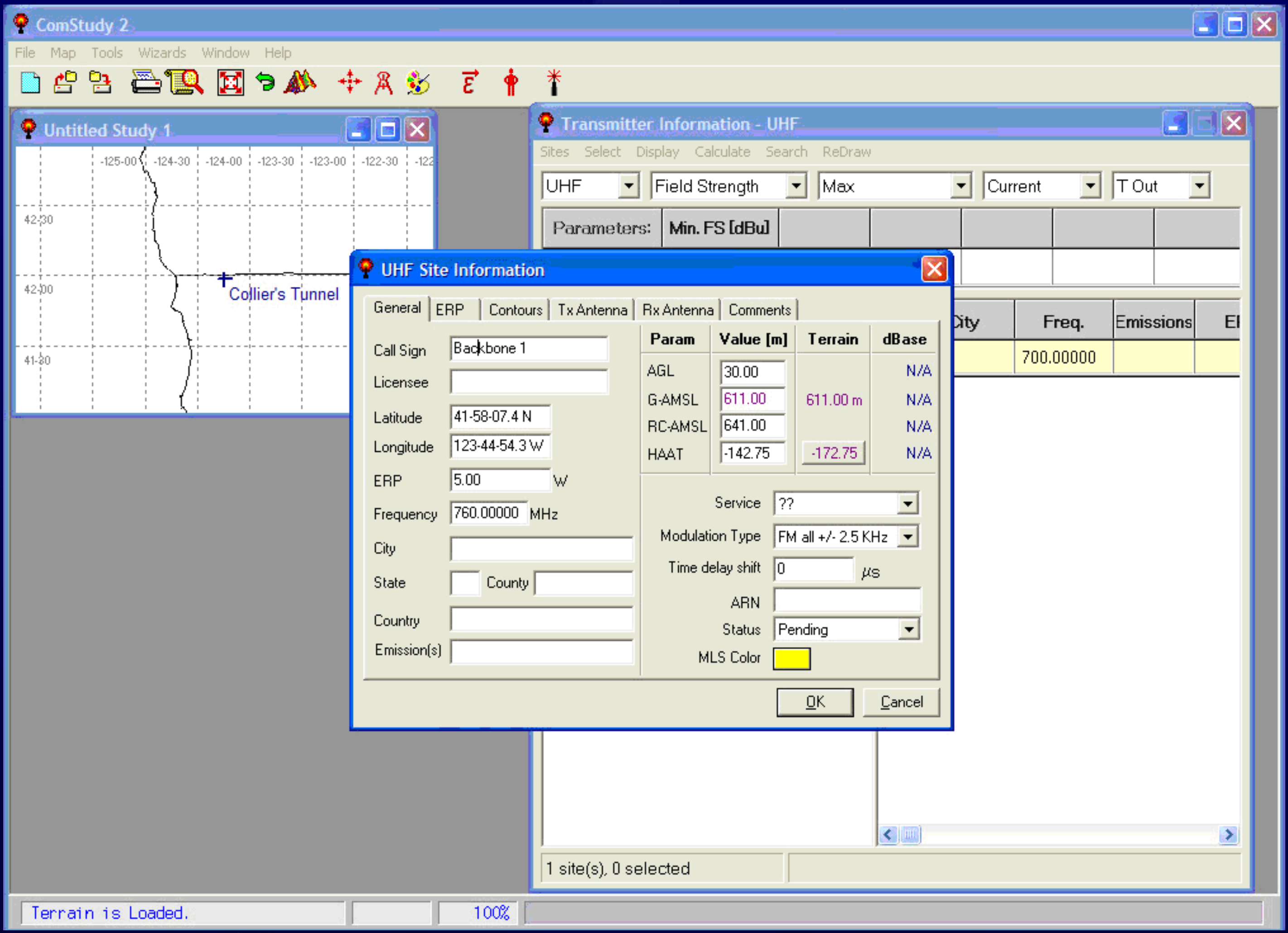
Handbook

- Project Deliverable #3
- To be finalized Summer 2008 (pending review)
- Focuses on methodology and tools.

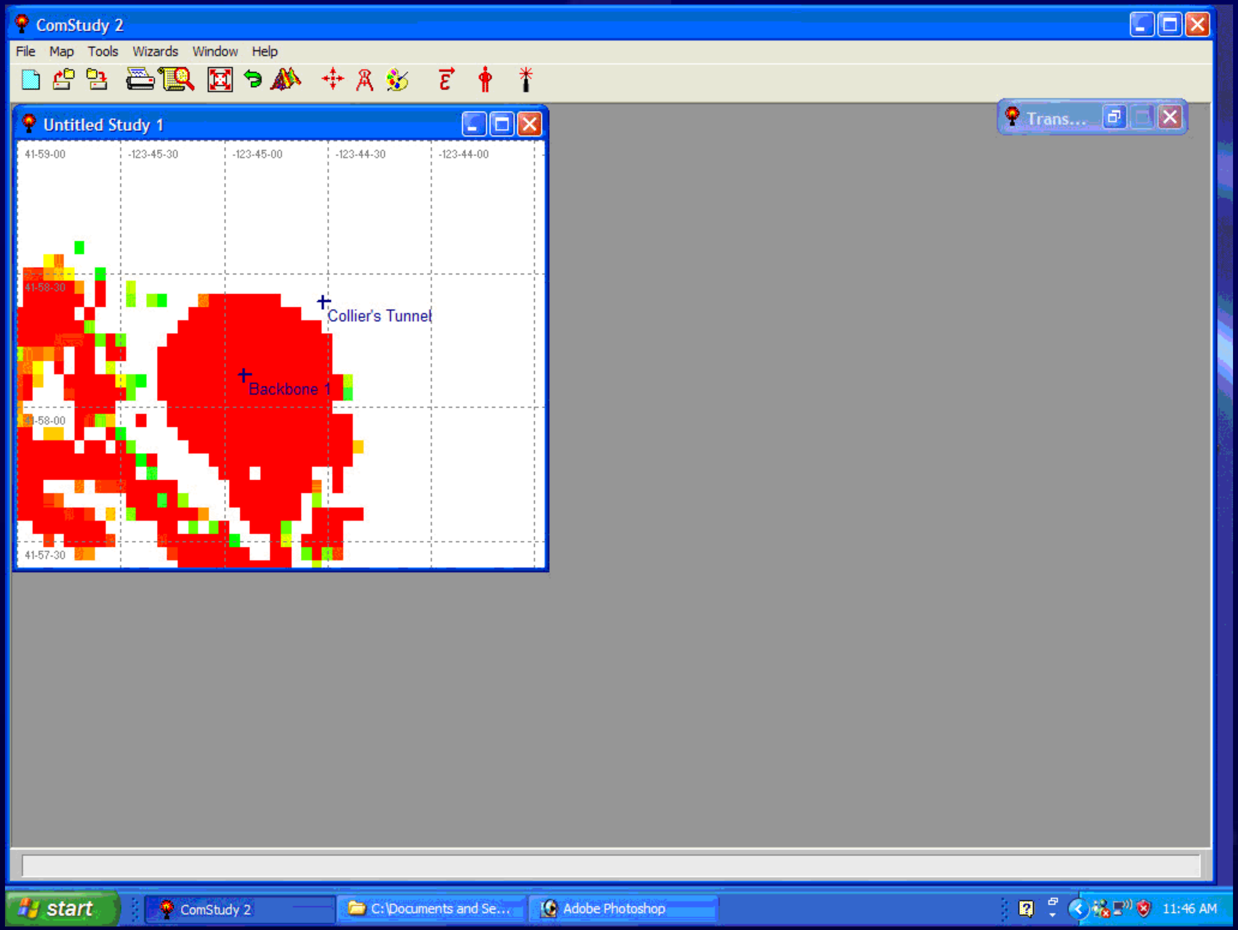
ComStudy 2.2

- Used to compute field strength plots for RF systems.
- It generates maps that graphically describe an area in which a receiver (e.g., a field element or mobile) will receive a useable signal from a base station (or from several base stations). This is called the coverage area.
- It can be used to determine coverage at any specific point or group of points, such as a field element or multiple field elements, or for mobile units that may operate within the area of coverage.
- It is designed to give the user the capability to determine radio system useful coverage over a general area of interest.

ComStudy 2.2


ComStudy 2
Untitled Study 1
Collier's Tunnel
Transmitter Information - UHF
UHF Site Information
General
ERP
Contours
Tx Antenna
Rx Antenna
Comments
Call Sign
Backbone 1
Licensee
Latitude
41-58-07.4 N
Longitude
123-44-54.3 W
ERP
5.00
W
Frequency
760.00000
MHz
City
State
County
Country
Emission(s)
Param
Value [m]
Terrain
dBase
AGL
30.00
G-AMSL
611.00
611.00 m
RC-AMSL
641.00
HAAT
-142.75
-172.75
N/A
Service
Modulation Type
FM all +/- 2.5 KHz
Time delay shift
ARN
Status
Pending
MLS Color
OK
Cancel
Freq.
Emissions
700.00000
1 site(s), 0 selected
Terrain is Loaded.
100%

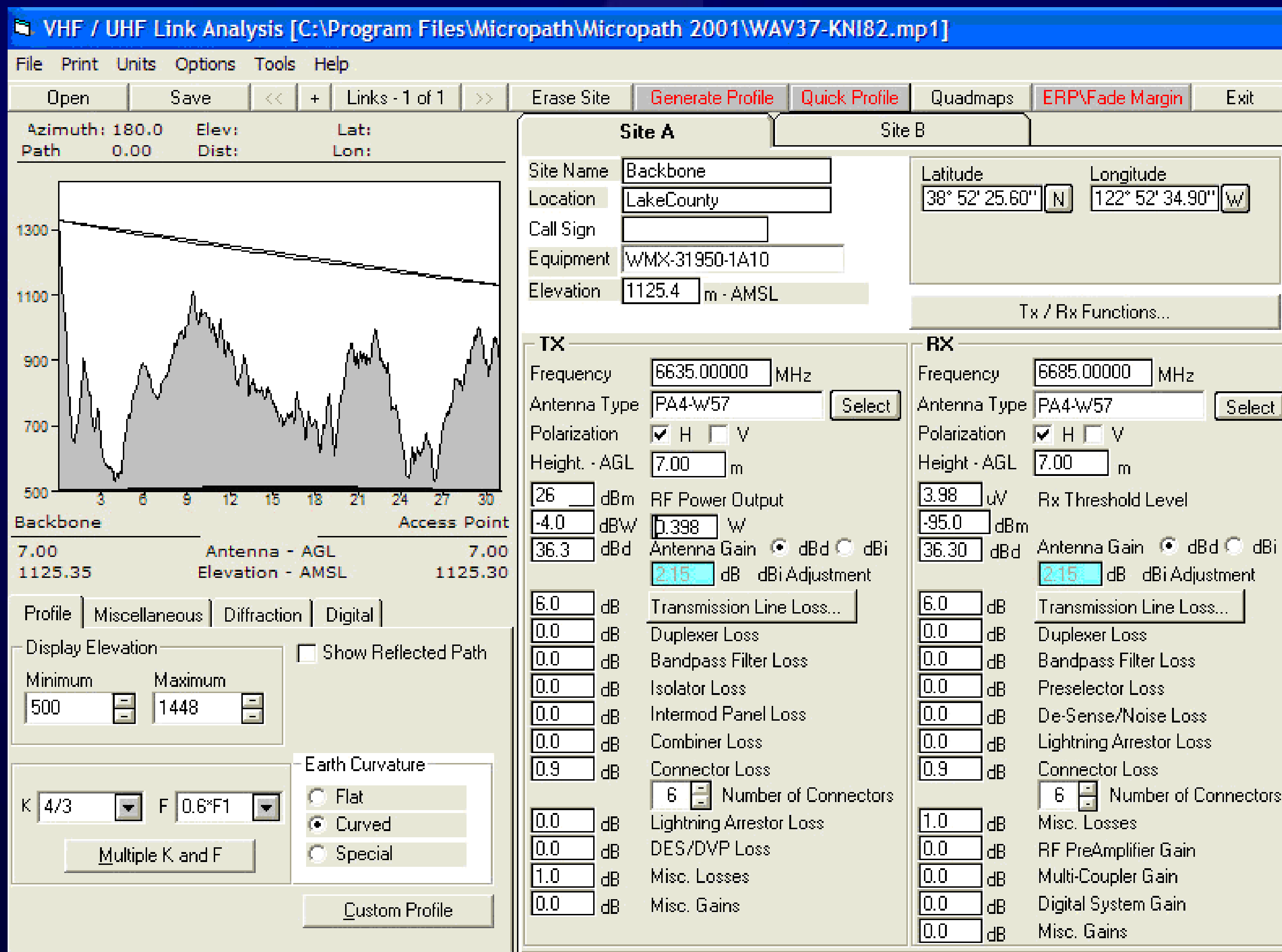
ComStudy 2.2


ComStudy 2
File Map Tools Wizards Window Help
Untitled Study 1
Collier's Tunnel
Backbone 1
Trans...
start
ComStudy 2
Adobe Photoshop
11:46 AM

MicroPath

- MicroPath is designed to compute point-to-point path profiles, primarily for microwave sites (but also Very High Frequency (VHF) and higher frequency sites such as Ultra High Frequency (UHF) and 700, 800 and 900 MHz).
- These profiles enable the user to determine if there is a viable communication path between two sites.
- It is a comprehensive program that also computes such data as path loss, fade margin and reflected path. It does not, however, have 10 meter resolution.
- It is currently used in some Caltrans Districts (e.g., D2) in designing point-to-point microwave systems.
- Whenever ComStudy coverage of individual field elements may be questionable, MicroPath can provide a more precise determination of coverage.

MicroPath

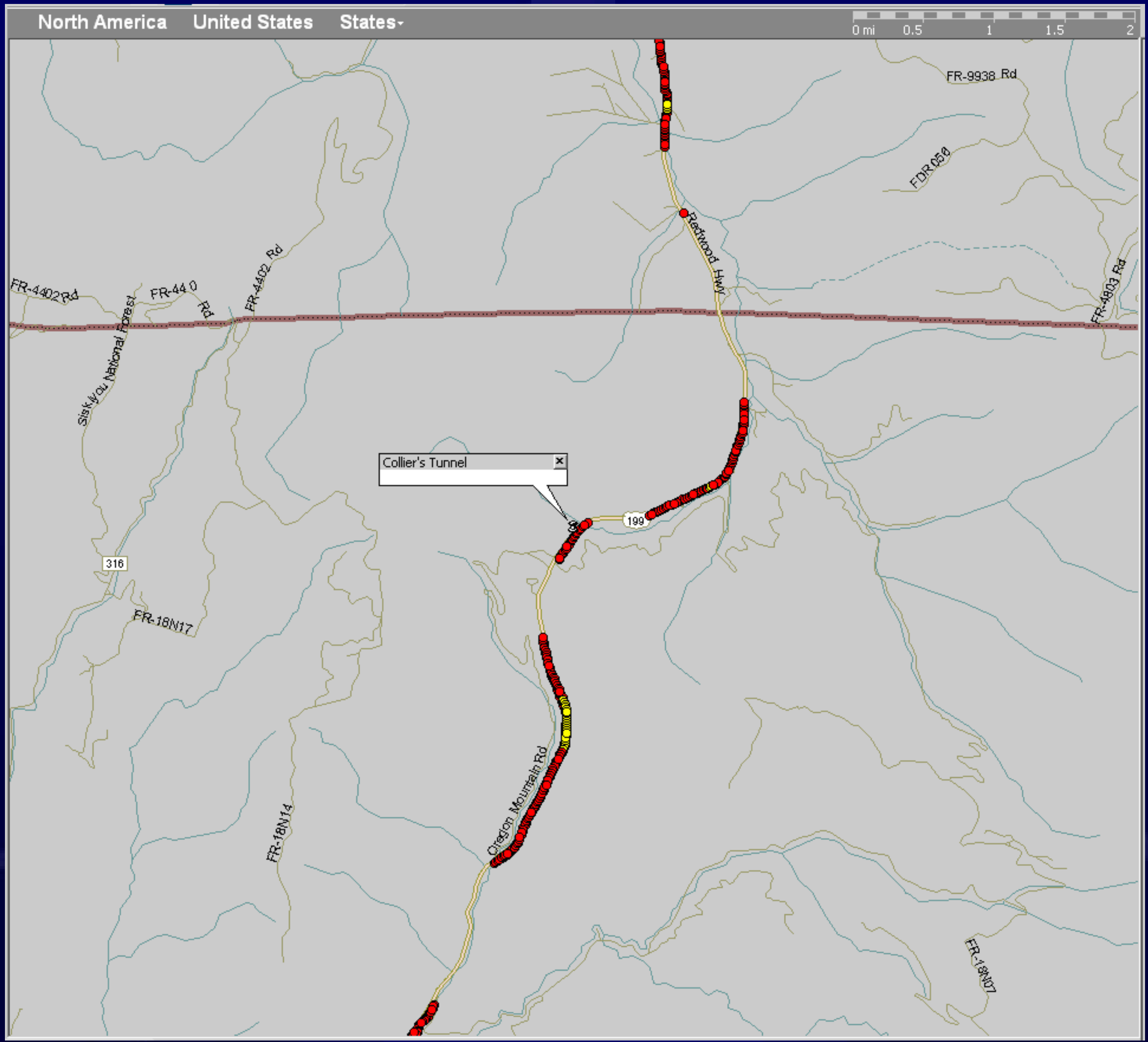


VHF / UHF Link Analysis [C:\Program Files\Micropath\Micropath 2001\WAV37-KNI82.mp1]
File Print Units Options Tools Help
Open Save << + Links - 1 of 1 >> Erase Site Generate Profile Quick Profile Quadmaps ERP\Fade Margin Exit
Azimuth: 180.0 Elev: Lat:
Path 0.00 Dist: Lon:
1300 1100 900 700 500
3 6 9 12 15 18 21 24 27 30
Backbone Access Point
7.00 Antenna - AGL 7.00
1125.35 Elevation - AMSL 1125.30
Profile Miscellaneous Diffraction Digital
Display Elevation
Minimum 500 Maximum 1448
Show Reflected Path
Earth Curvature
Flat
Curved
Special
K 4/3 F 0.6*F1
Multiple K and F
Custom Profile
Site A Site B
Site Name Backbone
Location LakeCounty
Call Sign
Equipment WMX-31950-1A10
Elevation 1125.4 m - AMSL
Latitude 38° 52' 25.60" N
Longitude 122° 52' 34.90" W
Tx / Rx Functions...
TX
Frequency 6635.00000 MHz
Antenna Type PA4-W57 Select
Polarization H V
Height - AGL 7.00 m
26 dBm RF Power Output
-4.0 dBW 0.398 W
36.3 dBd Antenna Gain dBd dBi
2.15 dB dBi Adjustment
6.0 dB Transmission Line Loss...
0.0 dB Duplexer Loss
0.0 dB Bandpass Filter Loss
0.0 dB Isolator Loss
0.0 dB Intermod Panel Loss
0.0 dB Combiner Loss
0.9 dB Connector Loss
6 Number of Connectors
0.0 dB Lightning Arrestor Loss
0.0 dB DES/DVP Loss
1.0 dB Misc. Losses
0.0 dB Misc. Gains
RX
Frequency 6685.00000 MHz
Antenna Type PA4-W57 Select
Polarization H V
Height - AGL 7.00 m
3.98 uV Rx Threshold Level
-95.0 dBm
36.30 dBd Antenna Gain dBd dBi
2.15 dB dBi Adjustment
6.0 dB Transmission Line Loss...
0.0 dB Duplexer Loss
0.0 dB Bandpass Filter Loss
0.0 dB Preselector Loss
0.0 dB De-Sense/Noise Loss
0.0 dB Lightning Arrestor Loss
0.9 dB Connector Loss
6 Number of Connectors
1.0 dB Misc. Losses
0.0 dB RF PreAmplifier Gain
0.0 dB Multi-Coupler Gain
0.0 dB Digital System Gain
0.0 dB Misc. Gains

MapPoint (or more sophisticated GIS - ArcGIS)

- MapPoint is a software program for displaying, geographically, data that has been collected with a GPS receiver, for example, and saved as a Comma Separated Variable (CSV) or Microsoft Excel (.xls) file.
- It was chosen for use on this project because it is simple to use and displays data/results effectively. It was used in the project to locate areas along highways to determine where cellular coverage was available, for example.
- One means of using the tool is to record on-site field strength measurements at field elements from State 800 MHz sites. This could be very useful in determining if a field element would be covered by an RF system being considered for implementation.

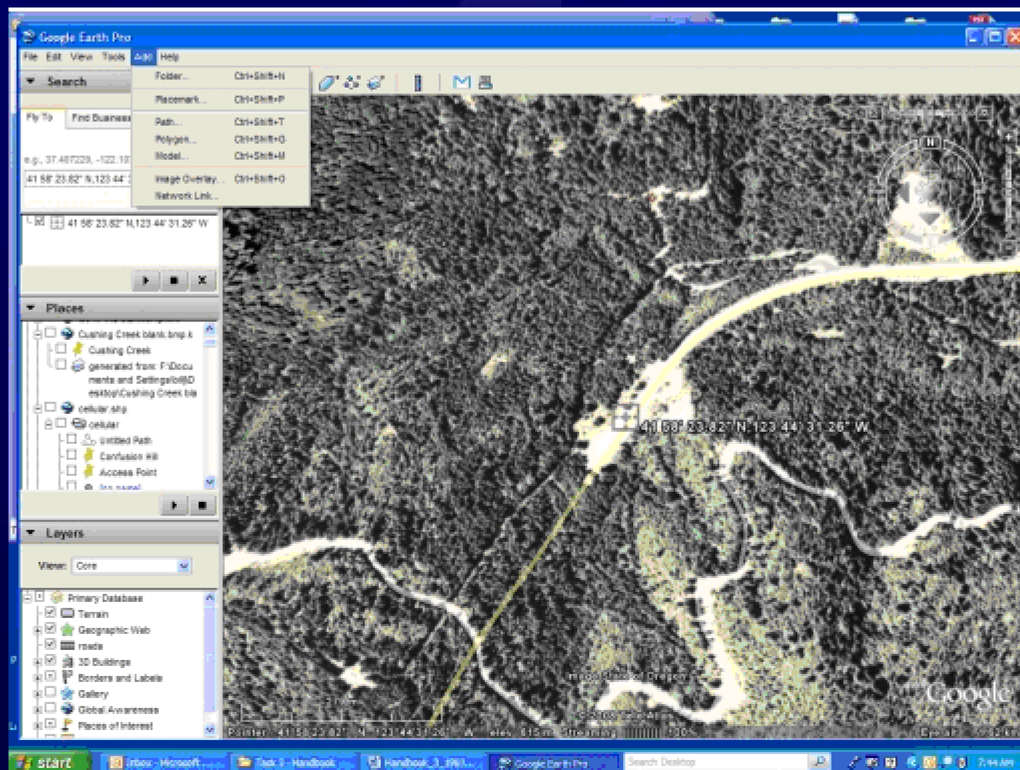
MapPoint (or more sophisticated GIS - ArcGIS)



Google Earth

- One application for the use of Google Earth (GE) is to view actual satellite images of local terrain in areas where field elements and base stations are located.
- Google Earth uses satellite imagery, maps, and three dimensional renderings of terrain and buildings to display geographical information. It is available for download from the web at no charge for the basic application.
- Users may enter the name of a particular location (if the location is fairly well-known), or enter latitude and longitude information to view the geographic nature of a specific location.
- Google Earth is particularly useful when trying to identify, resolve, or examine a particular location in greater detail. The application incorporates various tools that provide the user with multiple capabilities. One feature of the program that enables the user to place icons on the image to mark significant areas or features.
- (We used Google Earth to help resolve inconsistencies in locations provided by FCC.)

Google Earth



* Use with caution. Google Earth is not a replacement for on-site analysis by an RF engineer. It is a visualization tool.

Excel – Net Present Worth / Net Present Value

$$NPW = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t}$$

$t =$ the time of the cash flow

$N =$ the Total time of the project

$r =$ the discount rate

$C_t =$ the net cash flow at time t

Calculates the (present) value in today's dollars of an investment. Can be used to compare leased purchases with direct purchases. Can compare cost of landline, cellular, satellite and DIY deployments.

* Use with caution: It is hard if not impossible to predict the costs that are not within your control. And, you may not be able to fully associate a cost/value to some things.

Other

- StudyToEarth (developed by WTI)
- FCC Database
- USGS Elevation Data

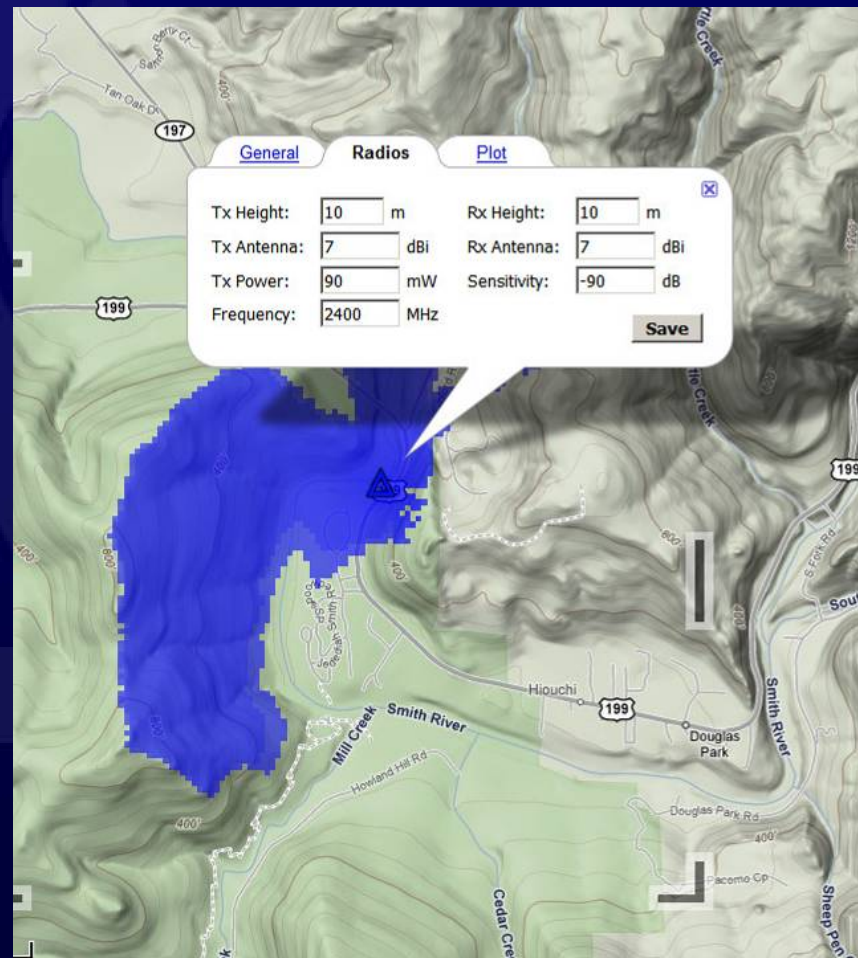
Other – "Study to Earth"

Added "Bonuses"

- Jeff Sharkey's WTI Fellowship work and software developed within. (WTI/UTC Funded)
- WTI Staff demonstration of wireless technologies (WTI/UTC Funded).

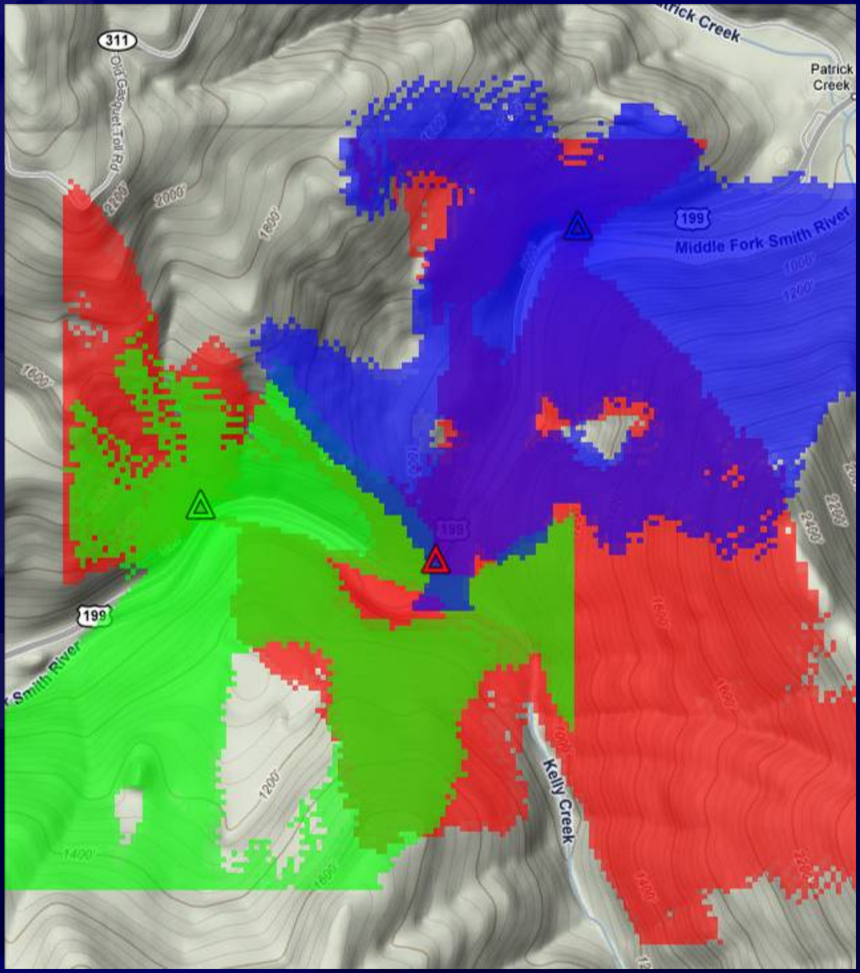
Design Tool – Jeff Sharkey, et al

- Rapid analysis in browser
- Control over detailed radio parameters
- Longley-Rice propagation model
- 10-meter elevation and 30-meter vegetation data



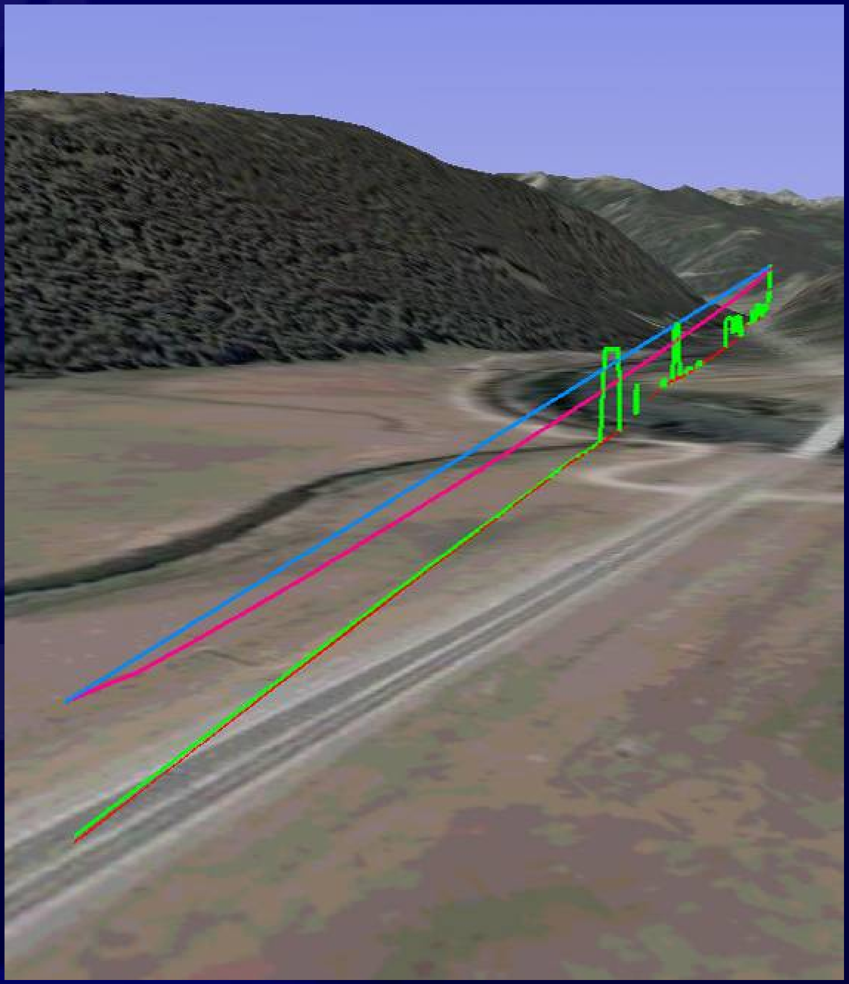
Design Tool

- Select radio sites for relaying through rough terrain areas
- Overlapping colors show areas covered
- Drag-and-drop to reposition nodes and test alternate configurations

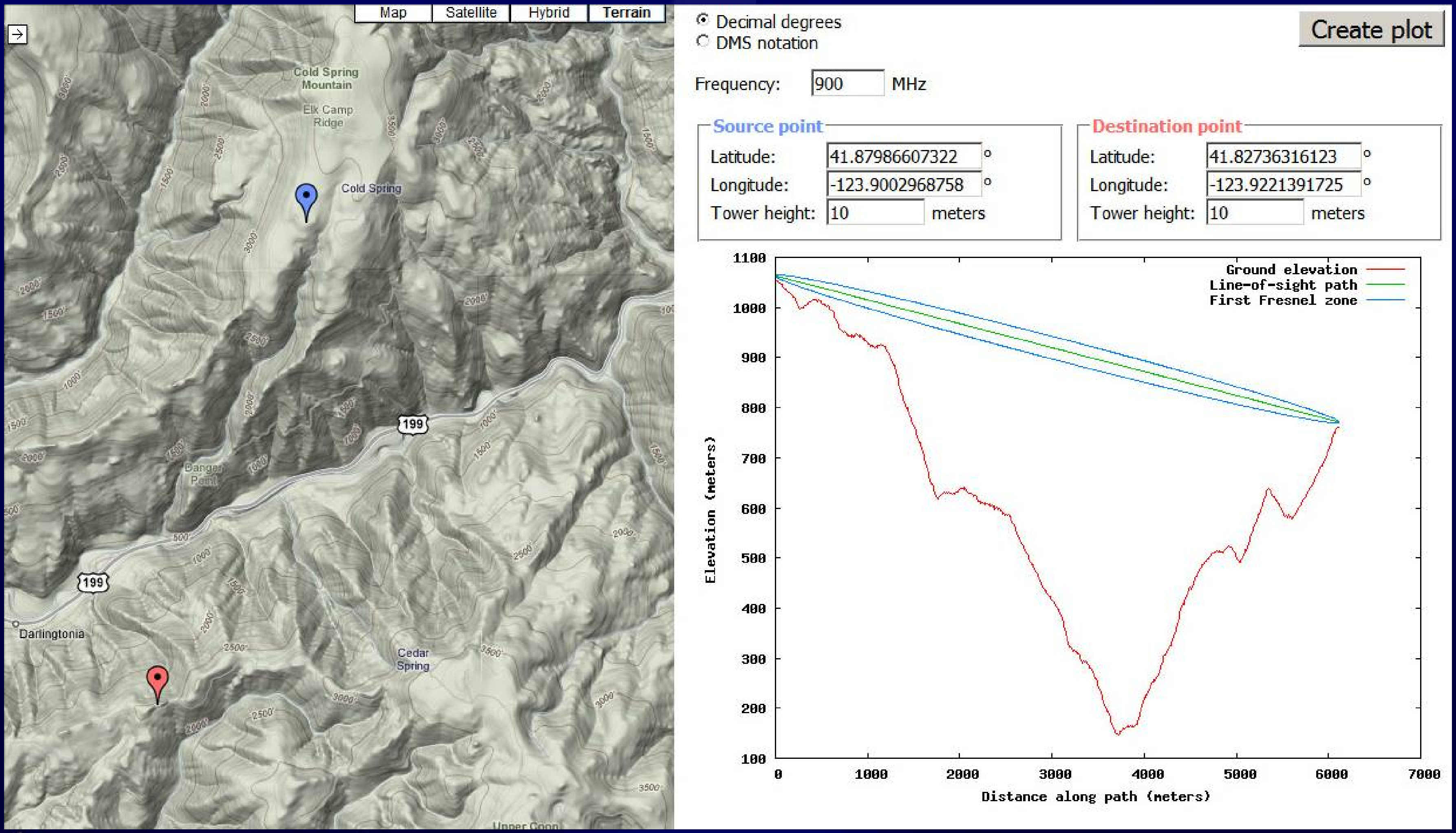


Design Tool

- Export of path profiles into Google Earth for 3D visualization
- Drag-and-drop path plots in browser with detailed radio parameters



Design Tool



Map
Satellite
Hybrid
Terrain
Cold Spring Mountain
Elk Camp Ridge
Cold Spring
199
Darlingtonia
Cedar Spring
Decimal degrees
DMS notation
Create plot
Frequency: 900 MHz
Source point
Latitude: 41.87986607322 °
Longitude: -123.9002968758 °
Tower height: 10 meters
Destination point
Latitude: 41.82736316123 °
Longitude: -123.9221391725 °
Tower height: 10 meters
Ground elevation
Line-of-sight path
First Fresnel zone
Elevation (meters)
Distance along path (meters)

WTI / MSU CE Trailers

Features:

Multiple Wireless Communication Systems
Mobile wireless LAN / Hotspot
Adjustable Mast Height (17’ to 35’)
Onboard 840 AH Battery Power
250 Watt Solar Charging Power
Configurable for Multiple Sensors
Mobile
Four Outriggers for stability

Issues:

Power Duration Dependent on Sunshine
Wireless Communication Options dependent on Location
Number/Power Requirements of Sensors Limit
Deployment time

Cost:

Trailer w/power : $15k
Development: $25k

Motorola Canopy

Vendor Specs:
Frequency Band: 902-928 MHz
Max Data Rate: 4 Mbps
Max Range: 40 miles
Topology: Point to Multi-Point:

Features:
Built in spectrum analysis tool
Web based configuration
Available with integrated or external antenna
IP based network
Good non-line-of-sight performance

Issues:
Proprietary technology – no interoperability with other manufacturers equipment
Uses ISM band which has a high potential for Interference
Lower data rate than higher frequency radios

Cost:
Access Point: $1855
Subscriber Module: $725

Proxim Tsunami 802.16e “Mobile WiMax”

Specs:

Frequency Bands: 5.2, 5.4, 5.8 GHz
Max Data Rate: 54 Mbps
Max Range: 6 miles at 9 Mbps
11.5 miles at 3 Mbps
14.5 miles at 1 Mbps
with 18dBi antennas and 15dB fade margin

Topology: Point to Multi-Point
Point to Point

Features:

Web based configuration
Available with integrated or external antenna
Dynamic Data Rate Selection

Issues:

ISM band subject to interference
Limited non line-of-sight performance

Cost:

Access Point: $2,184
Subscriber Module: $1,295

HughesNet Satellite

Specs:

Frequency Bands: Ku and Ka band
Max Data Rate: 90Mbps downlink
1.6Mbps uplink
Max Range: NA
Topology: Leased network

Features:

0.98 Meter dish and 2 watt radio for rain fade immunity
High speed connection to the Internet possible in most of N. America
Does not use spot beams, so system can be nomadic
Several satellites are available, so line-of-site issues are minimized

Issues:

No local (USA) tech support
Low initial cost, high long-term cost

Cost:

Dish, transceiver, mount: $1000
Monthly Service: $70 – 1Mbps downlink
200Kbps uplink

Sierra Wireless EV-DO Rev A Cellular – Verizon

Specs:

Frequency Bands: 850 MHz ,1.9 GHz
Max Data Rate: 1.4Mb/s downlink, 0.8Mb/s uplink
Typical Data Rate: 0.7Mb/s downlink, 0.3Mb/s uplink
Max Range: N/A
Topology: Leased Network

Features:

Web based configuration
Deployable anywhere cellular service is available
Distance between nodes doesn't matter

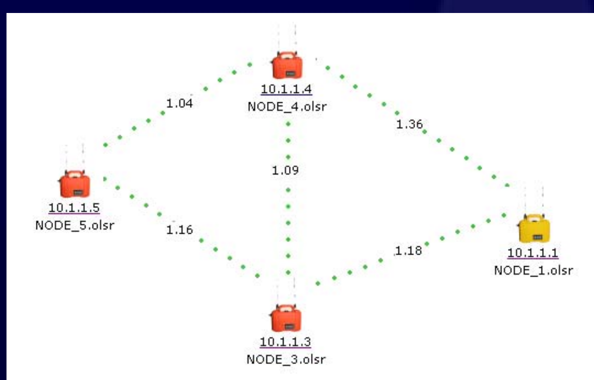
Issues:

Not available in some areas – connectivity & bandwidth dependant on provider's network
Low initial cost – high 10 year cost
More latency than direct links – traffic travels from phone to cell tower to internet to final destination
Dependant upon external infrastructure
Limited to 5GB per month without overage charges

Cost:

Radio: $600-$700
Monthly Service: $60

WTI MeshBox



Specs:
Frequency Bands: 2.4 GHz ISM
Max Data Rate: ~24Mb/s
Max Range: 1100 feet with omni-directional antenna
Topology: Mesh

Features:
Low cost per unit
Configurable and extendable by using open source firmware
OLSR mesh protocol allows for multi-hop robust communications

Issues:
Single radio restricts bandwidth
MeshBox designed for demonstration and not production use
Uses unencrypted communications
Limited to 2.4GHz band

Cost:
Unit: $110
Development: $$$

Questions ?