Cellular Communications in Rural Applications

Keith Koeppen, P.E.

Caltrans, District 2

2018

Overview

- Background
  - Circuit Switched Networks
  - Packet Switched Networks
  - Cellular Technologies (Brief)
- Current and Future Challenges
- System Needs
- Potential Solutions
- Cellular Network Design
  - Network Topologies
  - Hardware
  - Final Network Architecture

Overview

- Cellular Network Deployment
  - Preselecting Sites
    - Coverage estimating tools
  - Field Coverage Verification
  - Field Installation
- Cellular Network Testing
  - Stress Testing
  - Bandwidth Considerations
  - Problems
- Cellular Network Conclusions
  - Can you reliably predetermine coverage/access?
  - Deployment strategies

Overview

- Cellular Network Conclusions (cont.)
  - Data Usage
  - Moving Forward
- Questions

Definitions/Acronyms

ADSL - Asymmetrical Digital Subscriber Line

APN - Access Point Name

CCTV - Close Circuit Television

CMS - Changeable Message Sign

CO - Central Office

GRE - General Route Encapsulation

IP - Internet Protocol

LTE – Long Term Evolution

M2M - Machine to Machine

NFSNET - National Science Foundation Network

OSPF - Open Shortest Path First

POP - Point of Presence

POTS - Plain Old Telephone System

PTSN - Pubic Telephone Switched Network

QoS - Quality of Service

RIP - Routing Information Protocol

RWIS - Roadside Weather Information System

TDM - Time Division Multiplex

TMC - Transportation Management Center

VPN - Virtual Private Network

VDSL - Very-high-bit-rate Digital Subscriber Line

WAN - Wide Area Network

Background

Circuit-Switched Networks

- What is a Circuit-Switched Network?
  - Dedicated end to end circuit and transmission channel
  - Functions as physically connected electrical circuit
- Examples
  - Plain Old Telephone System (POTS)
  - Public Switched Telephone Network (PTSN)
  - T-Carriers (T1)
- Advantages
  - Constant bandwidth and latency
  - Channel is protected from competing users

Background

Circuit-Switched Networks

- Disadvantages
  - Dedicated physical link between to devices
    - Ties up communication lines point to point for duration of call
  - Can be costly
    - Fee per unit of connection time, not information transmitted

Background

Packet-Switched Networks

- What is a Packet-Switched Network?
  - Method of grouping data into packets and sending it over a "dynamic" network
  - "Packets" can dynamically take varying paths
- Examples
  - NFSNET
  - Internet
- Advantages
  - Fault tolerance because of multiple paths end to end
  - Network optimization
  - Traffic can be routed around congested parts of networks

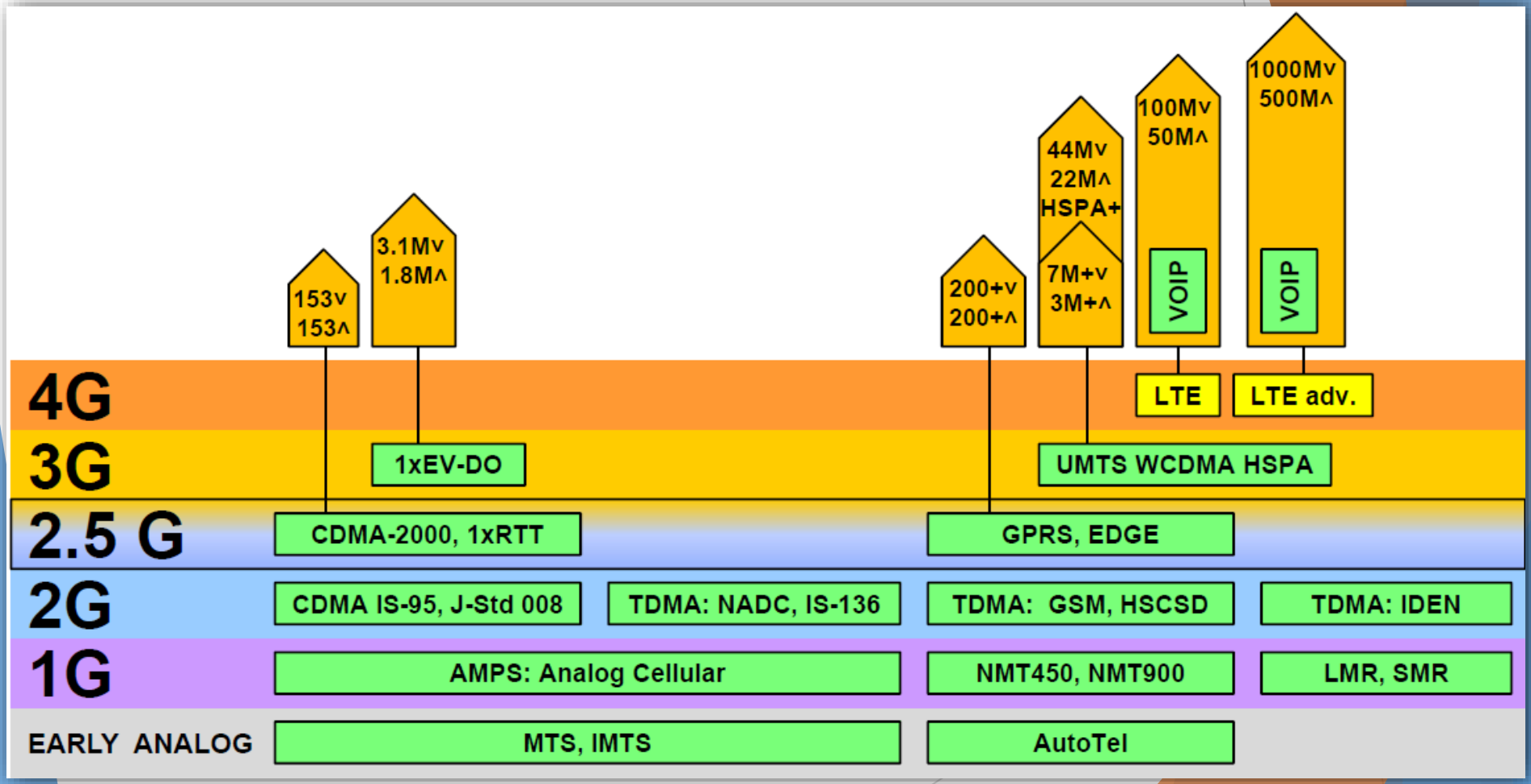
Background

Packet-Switched Networks

- Advantages (cont.)
  - Pricing structure can be based on actual data transported
- Disadvantages
  - Pricing structure can be based on actual data transported
  - Packets can be dropped/discarded on contentious link
  - Latency can vary packet to packet (jitter)
  - Variable bandwidth

Background

Cellular Technologies (brief)



Background

Cellular Technologies (brief)

- Active Deployment Timelines (US Market)
  - 1G – Analog Cellular 1981-2008
  - 2G – Digital Cellular 1992-2016(AT&T)
  - 3G – Mobile Broadband 2003-2019?
  - 4G/LTE – Native IP Broadband 2013-Present
  - 5G – Slated for late 2018-2020 initial deployment

Current and Future Challenges

VoIP and Modems

- Smaller Telecommunication Companies are migrating the “Middle Mile” to Ethernet/IP
- Modems over IP
  - Lower negotiated speed (9.8K baud)
  - Constant Retrains

Current and Future Challenges

Sunsetting Last Mile Services

- Traditional Time Division Multiplexing (TDM) Services
  - True point to point circuit switched services such as:
    - Integrated Services Digital Network (ISDN), planed 2020
    - T-Carrier services

System Need

Current Build Out

- Most of our network currently on some type of circuit switched network
  - POTS – 29 sites, 35% of network
  - ISDN – 33 sites, 39% of network
  - Total – 74% of network
- Rest of the network is on state owned facilities, IP/Ethernet
  - Private Point to Point Microwave – 15 sites, 18% of network
  - Private Fiber – 7 sites, 8% of network

System Need

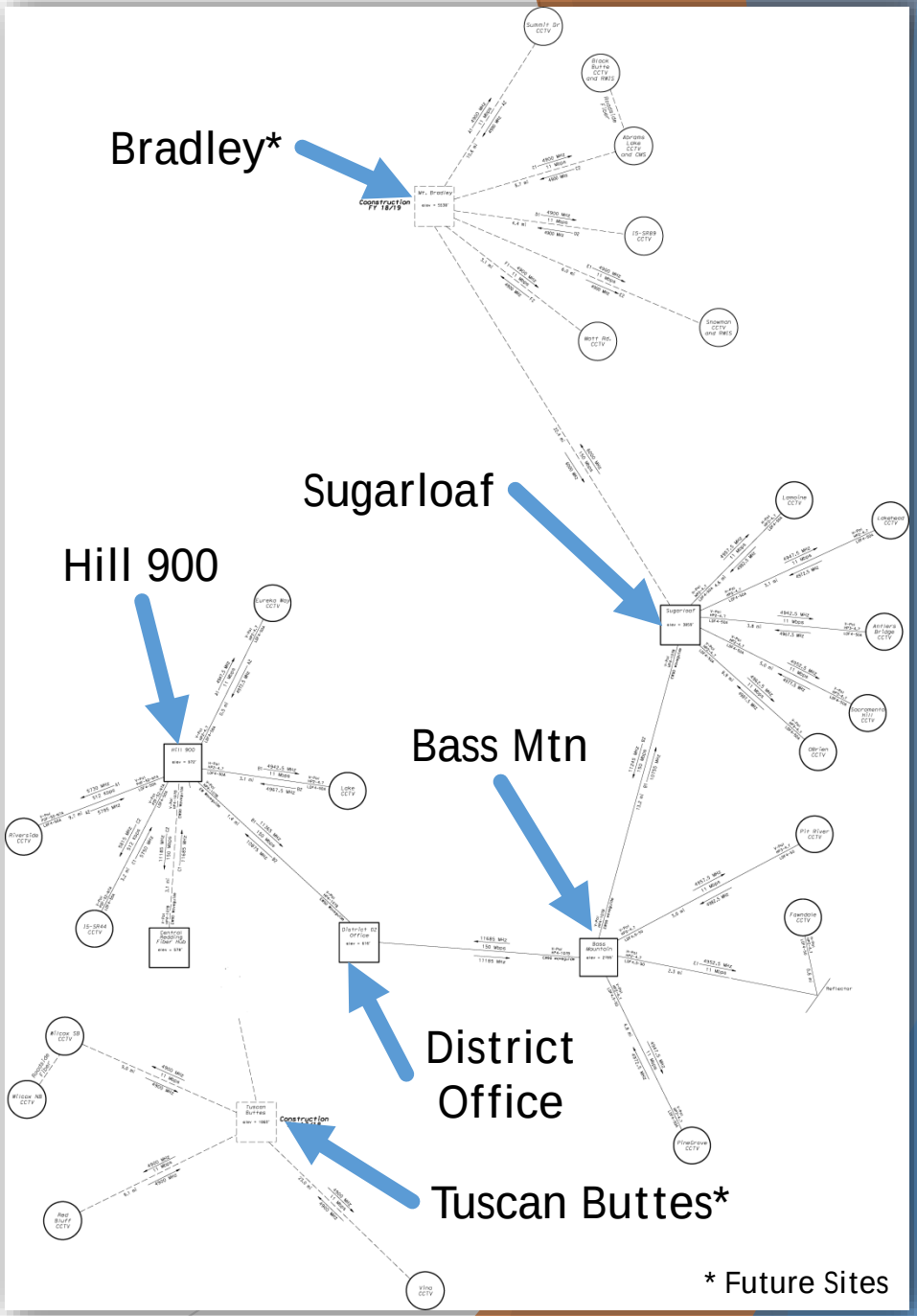
Requirements

- Reliability
  - Typically Microwave links are built out with five nines reliability (99.999%)
- Reasonable Data Throughput (128Kbps+)
- Minimized “unknowns”
- Troubleshooting options
- Control of configuration management
- Simple network topology
- Drop-in or near drop-in deployment

Potential Solutions

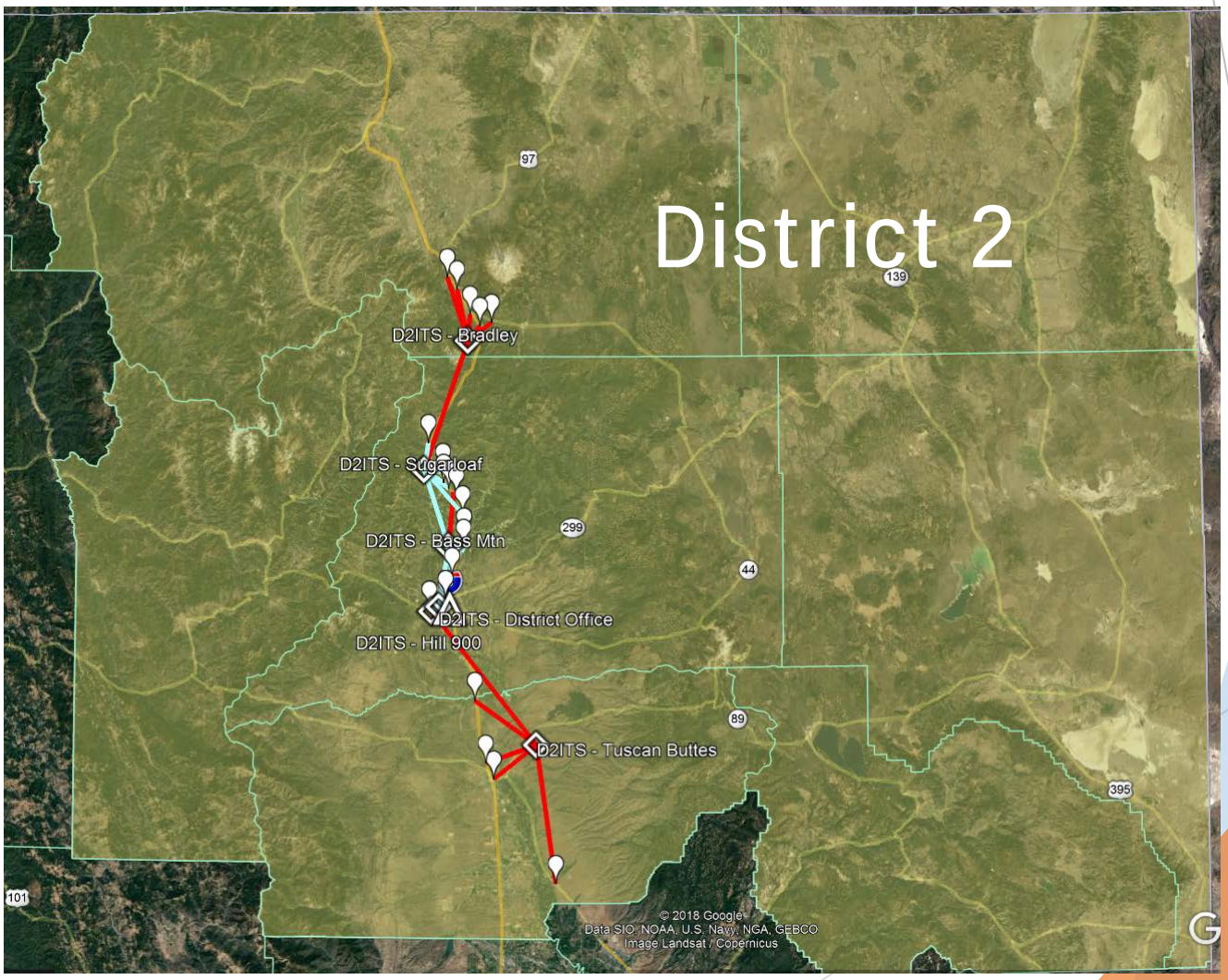
Private Microwave Network

- Current and near future build out
- 12 Sites currently on Private Microwave Network
- 10-13 Sites are planned to be built out in the next year
- Central Redding Fiber Hub backhauls though Private Microwave Network



Potential Solutions

Private Microwave Network – Entire District



Potential Solutions

Private Microwave Network

- Advantages
  - Can be designed for strict minimum reliability and throughput
    - 99.999% reliability
    - 150 Mbps backhaul licensed links
    - 11 Mbps mountain top to roadside licensed links
    - Various 2.4 GHz and 5.8 GHz links
  - Generally no or little on going costs
  - District owned equipment
  - Maintains District networking design standards

Potential Solutions

Private Microwave Network

- Advantages(cont.)
  - Maintains configuration management in district

Potential Solutions

Private Microwave Network

- Disadvantages
  - Time
    - Capital Projects can take years of design and procure equipment
  - Requires Personnel to have Radio Frequency expertise
  - Requires good suite of test and measurement tools for troubleshooting

Potential Solutions

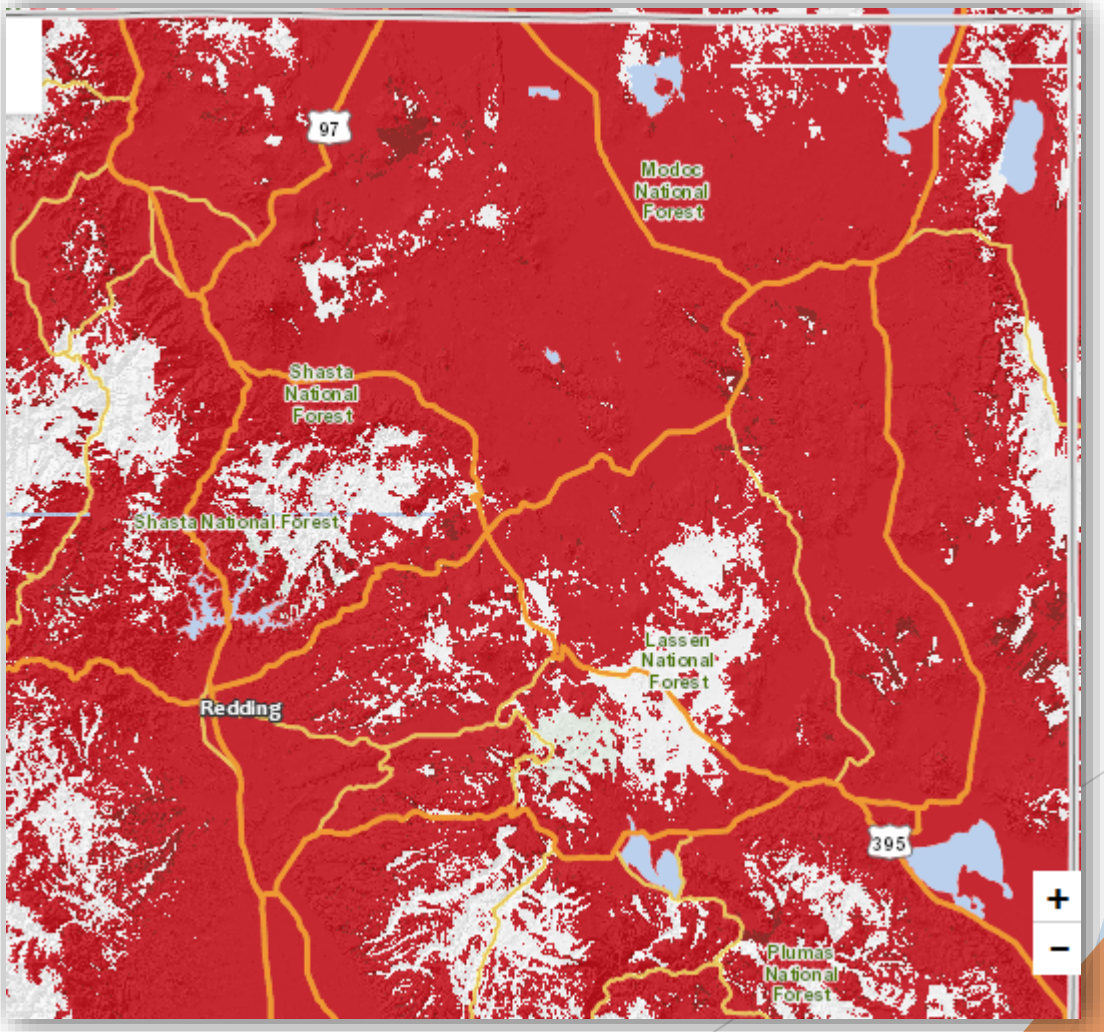
Cellular Network

- LTE has matured to the point where the data speeds are sufficient for most video and surveillance applications
  - 1 Mbps or higher upload speeds
- Cellular companies claim widespread “good” LTE coverage, especially along major traffic corridors
- Initial install cost is relatively low
- Able to upgrade sites from circuit-switched networks almost “on demand,” if we have equipment on hand
- Several Large Carriers in the District
  - AT&T
  - Verizon

Potential Solutions

Cellular Network

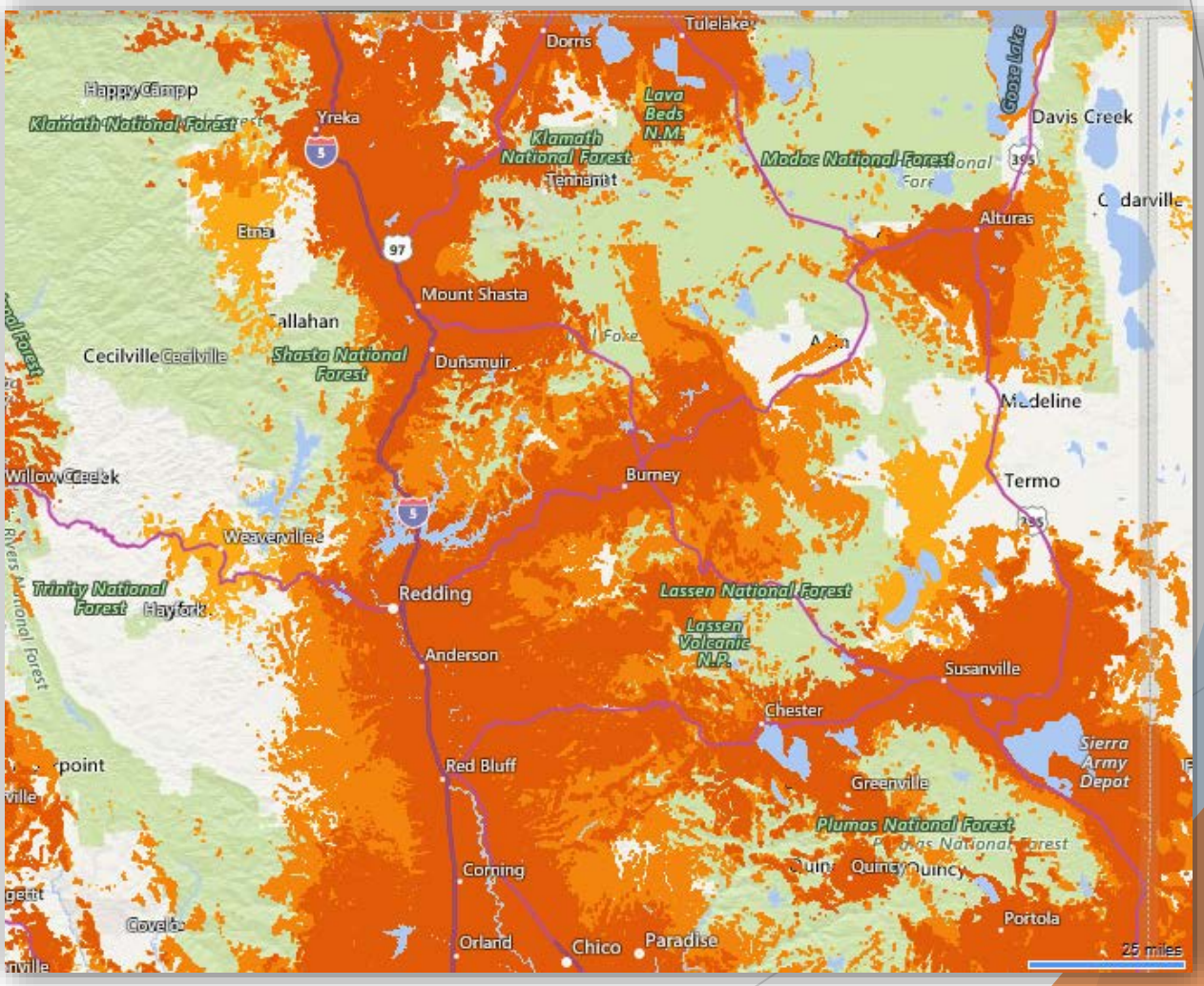
Verizon Coverage Map



Potential Solutions

Cellular Network

AT&T Coverage Map



Potential Solutions

Cellular Network

- Advantages
  - Cost of deployment
  - Ease of installation
  - Immediate update in speed to the field element
  - Ability to move away from sunsetting services faster

Potential Solutions

Cellular Network

- Disadvantages
  - Usually Asymmetrical downlink/uplink in favor of downlink (field sites only)
  - Unpredictable/unknown carrier network topology
  - Potential issues with point of presence (POP)
    - Department only authorizes very few POPs for security reasons
  - Unknown issues with radio channel congestion in crisis events
    - Potential “Denial of Service”
  - Unknown network behavior in crisis

Potential Solutions

Other Last Mile Services

Digital Subscriber Line (DSL)

- Advantages
  - Reasonable speeds depending on distance to Central Office
  - Relatively cheap
  - Service type accepted by our organization
  - Runs on existing Telco infrastructure, no build out cost
- Disadvantages
  - Distance Limitations
    - ADSL2+ about 15,000 cable feet from CO
    - VDSL about 10,000 cable feet from CO

Potential Solutions

Other Last Mile Services

Digital Subscriber Line (DSL)

- Disadvantages (cont.)
  - Network topology architecture limitations and end equipment control
    - Requires VPN to organization's centralized POPs
    - Equipment configured by IT department
  - Depending on carrier and local maintenance crew, can be very unreliable
  - Usually Asymmetrical downlink/uplink in favor of downlink
  - Not always available in remote locations

Potential Solutions

Other Last Mile Services

MetroEthernet

- Advantages
  - Reasonable speeds
  - Can have committed information rate (guaranteed bandwidth)
  - Service treated like layer 2 Ethernet
  - End equipment's configuration management remain in office
- Disadvantages
  - Build out cost per site
  - Fairly high monthly cost ($500/month/site)
  - Not always available in remote locations

Potential Solutions

Other Last Mile Services

Cable Broadband

- Advantages
  - Reasonable speeds
  - Relatively cheap
  - Service type accepted by our organization
- Disadvantages
  - Distance Limitations
  - Network topology architecture limitations and end equipment control
    - Requires VPN to organization's centralized POPs
    - Equipment configured by IT department
  - Usually only located in metropolitan areas
  - Not always available in remote locations

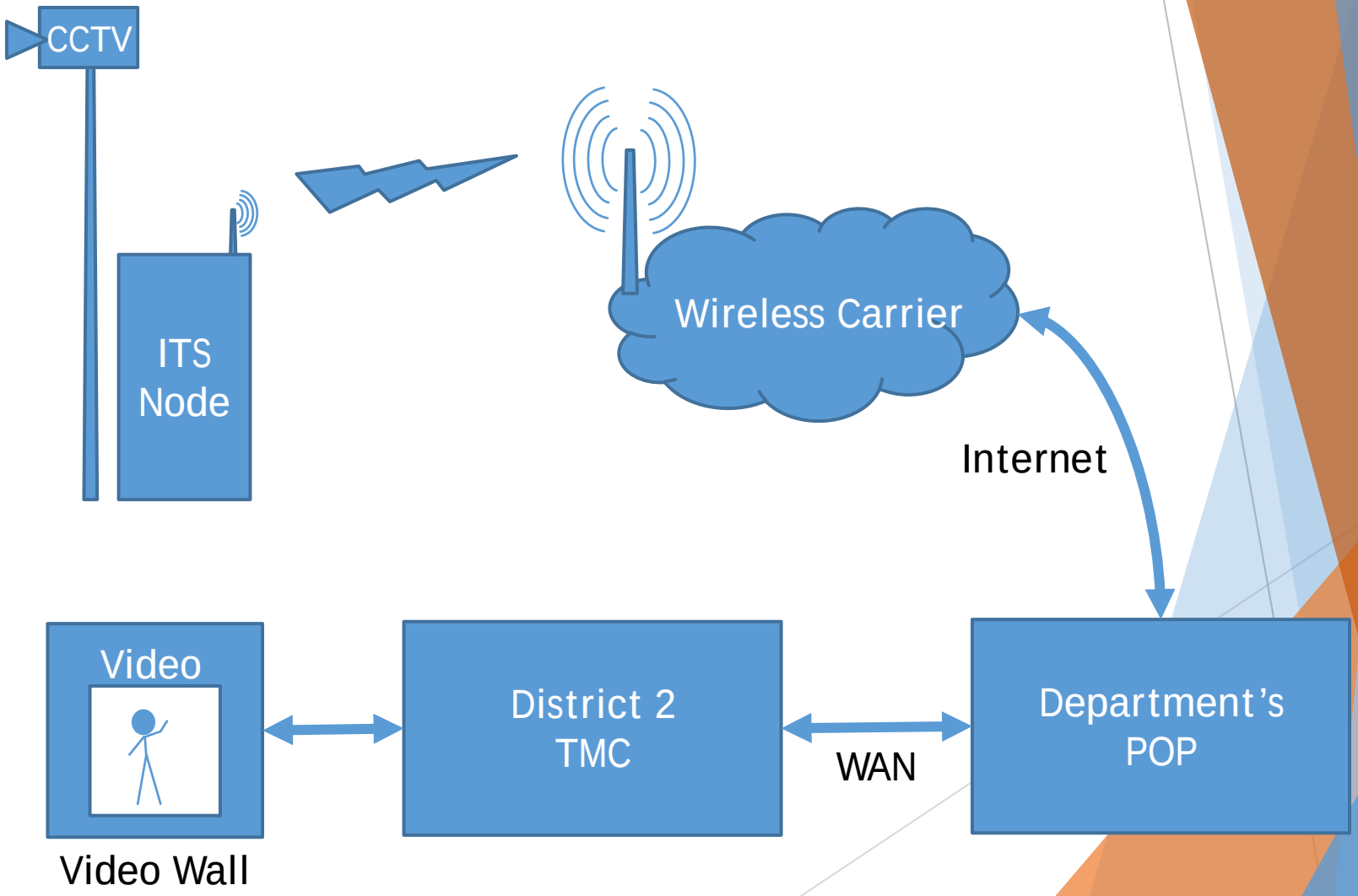
Potential Solutions

Conclusion

- Use of Cellular technology may be a good interim solution as sunsetting services that have no good replacement
- Low initial cost of install is a good way to test cellular deployment, configurations, and network throughputs

Cellular Network Design

Typical Network Topology – Static IP



Cellular Network Design

Typical Network Topology – Static IP

- Advantages
  - Accessible from anywhere with Internet access without special configurations
  - Easy to install, usually comes pre-configured
  - Little or no networking knowledge required
- Disadvantages
  - Accessible from anywhere with Internet access without special configurations
  - High potential of hardware security vulnerabilities be exploited
  - Network traffic may not be encrypted
  - Unable to fully test all equipment in the data path
    - Could lead to misdiagnosis and wasted troubleshooting time

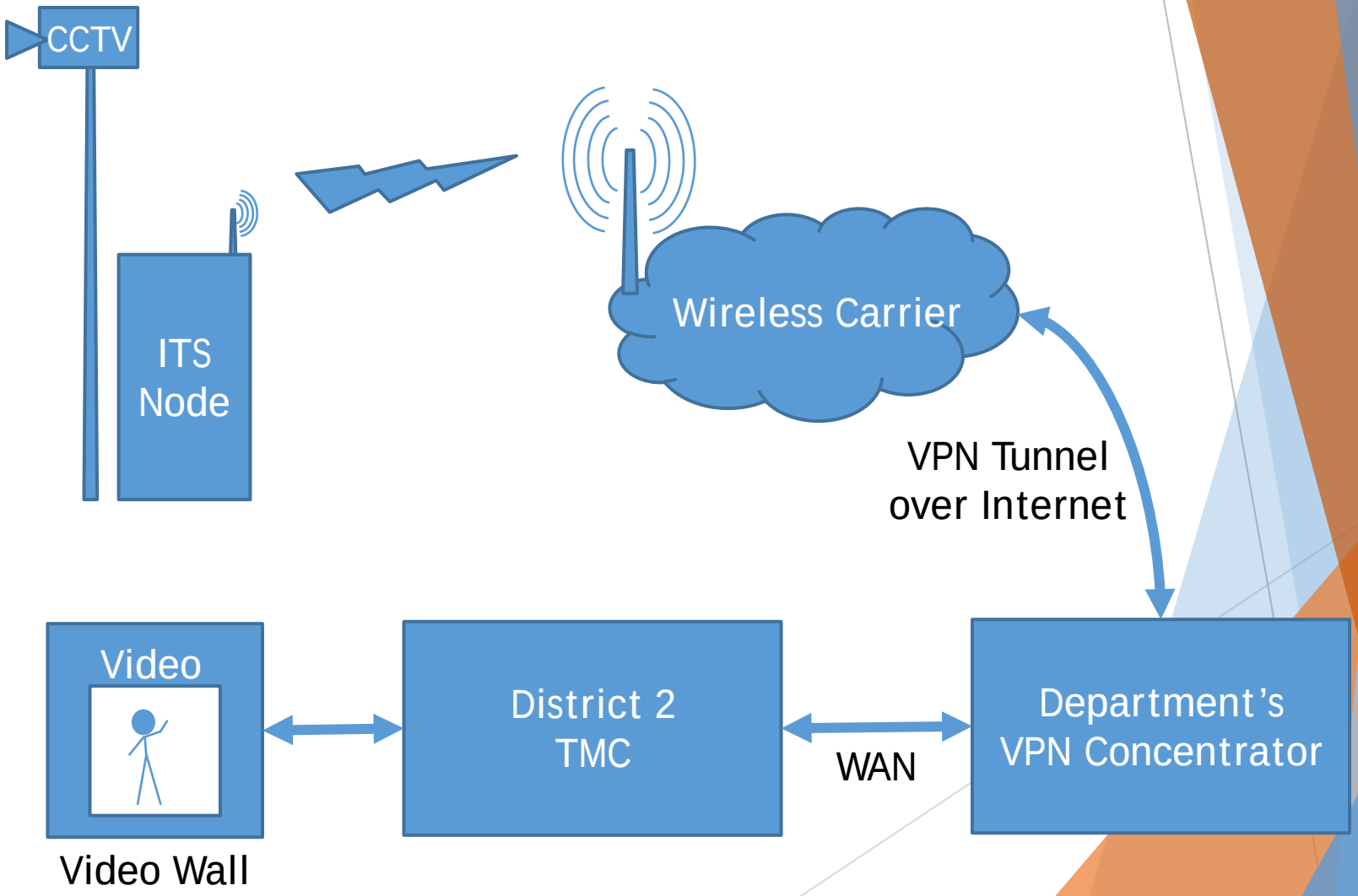
Cellular Network Design

Typical Network Topology – Static IP

- Disadvantages (cont.)
  - Potential of adding significant data traffic on IT WAN circuit
    - District WAN Circuit is currently 100 Mbps for all employees and data services
  - Geographical Diversity
    - Unknown physical paths for IT WAN circuit between HQ and District Office
    - District 1 (Eureka) was islanded in 2017 because of fires and lack of geographical path redundancy

Cellular Network Design

Typical Network Topology – VPN/IPSec



Cellular Network Design

Typical Network Topology – VPN/IPSec

- Advantages
  - Network Traffic is encrypted
  - Out of band traffic is usually blocked
- Disadvantages
  - Must comply with Department's VPN concentrator configurations, and password schemes
  - End device usually must be configured by IT Department
  - Unable to fully test all equipment in the data path
    - Could lead to misdiagnosis and wasted troubleshooting time

Cellular Network Design

Typical Network Topology – VPN/IPSec

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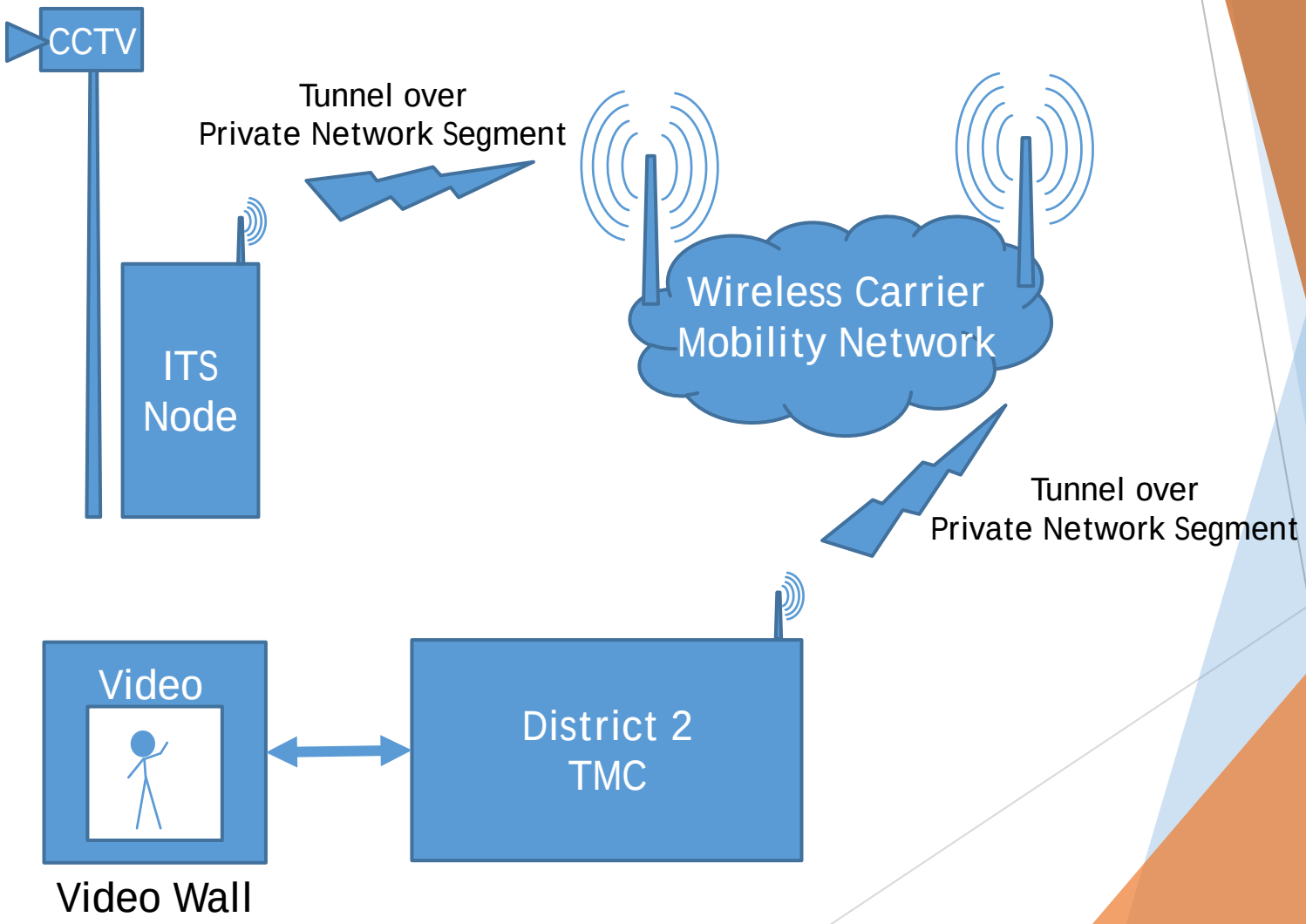
Cellular Network Design

Desired Network Topology – Zero Point Tunnel



Cellular Network Design

Desired Network Topology – Zero Point Tunnel

- Advantages
  - Establishes an "Island" Private Network
    - Network Traffic stays on respective wireless company's mobility networks
    - Traffic never traverses the Internet
  - Allows for testing equipment at both ends of tunnel
  - Allows for configuration management to be maintained in district.
  - Allows for multiple tunnel entry points
    - Allows for multiple physical tunnel entry points if needed for Geographical Diversity and traffic loading
    - Allows for deployment strategies that allow for carrier diversity

Cellular Network Design

Desired Network Topology – Zero Point Tunnel

- Disadvantages
  - Potential for District Office Zero Point tunnel entry point becoming impacted by congestion

Cellular Network Design

Hardware – Modem/Router

Sierra Wireless

- Started off with the recommendation of IT for hardware
  - Sierra Wireless GX440
- Could not configure equipment to desired network configuration
- Easy to use and make configuration changes
- Most likely best for single devices with standard enterprise style configurations

Cellular Network Design

Hardware – Modem/Router

Cisco

- Cisco Platform
  - Cisco 1921 Integrated Service Router
  - Same form factor as existing network equipment
  - Drop in replacement
- Cisco offered various cell modules
  - AT&T: EHWIC-4G-LTE-AT
  - Verizon: EHWIC-4G-LTE-VZ

Cellular Network Design

Hardware – Modem/Router

Digi

- Small form factor
- Easy to configure
- Integrated in to Cisco HUB and Spoke design (more later)
  - Evaluated After initial deployment started
- Lower power draw
- Would work for small, low power, pole mounted single device type applications
  - Microwave Vehicle Detection System
  - Roadside Weather Information System

Cellular Network Design

Hardware – Antennas

District Office

- Amphenol tower mounted antenna
  - Omnidirectional
  - Dual Band
  - Vertical polarization
    - 1.24 dBi gain for 696-960 MHz
    - 3.4 dBi gain for 1710-2700 MHz

Cellular Network Design

Hardware – Antennas

Cabinet Mount (Trial)

- MobileMark surface mounted antenna
  - Omnidirectional
  - Dual Band
    - 3 dBi gain for 694-960 MHz
    - 5 dBi gain for 1700-2700 MHz
  - SMA 5’ pigtail
    - Required for non-destructive installation method

Cellular Network Design

Hardware – Antennas

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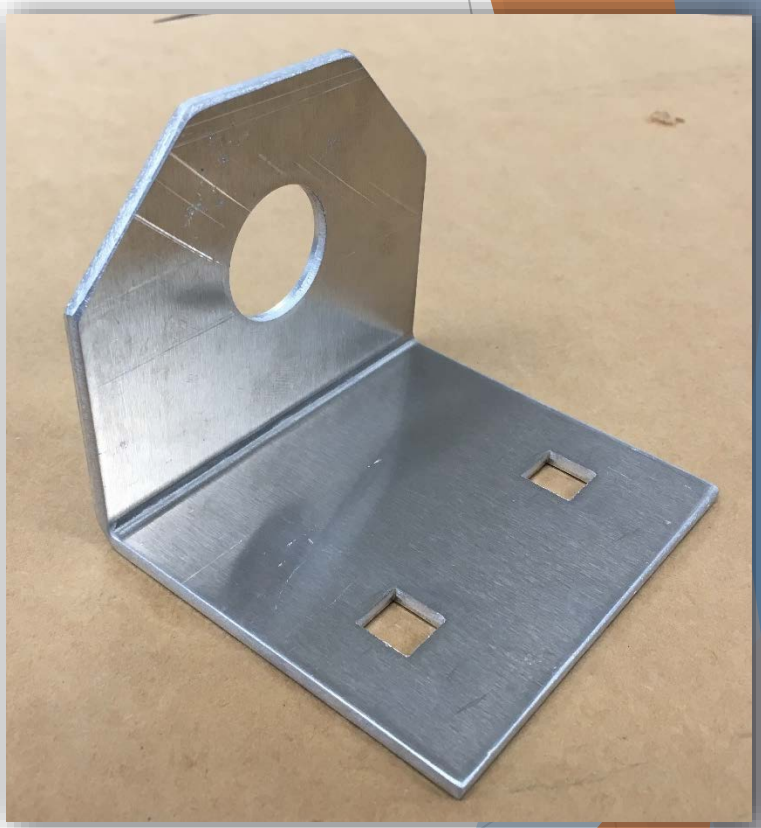
- Custom non-destructive bracket
  - Bent cabinet lifting bracket



Cellular Network Design

Final Network Architecture

Hub and Spoke

- Requirements for Wireless Provider Networks
  - Private Access Point Name (APN)
  - Flat Layer 3 Class C Network (254 hosts max)
    - Network addressing scheme defined by customer
  - Must be an “islanded” network
    - Same as devices all connected to a switch without an “uplink”
    - Traffic must remain on Mobility Network, usually separate VLAN on Mobility Network

Cellular Network Design

Final Network Architecture

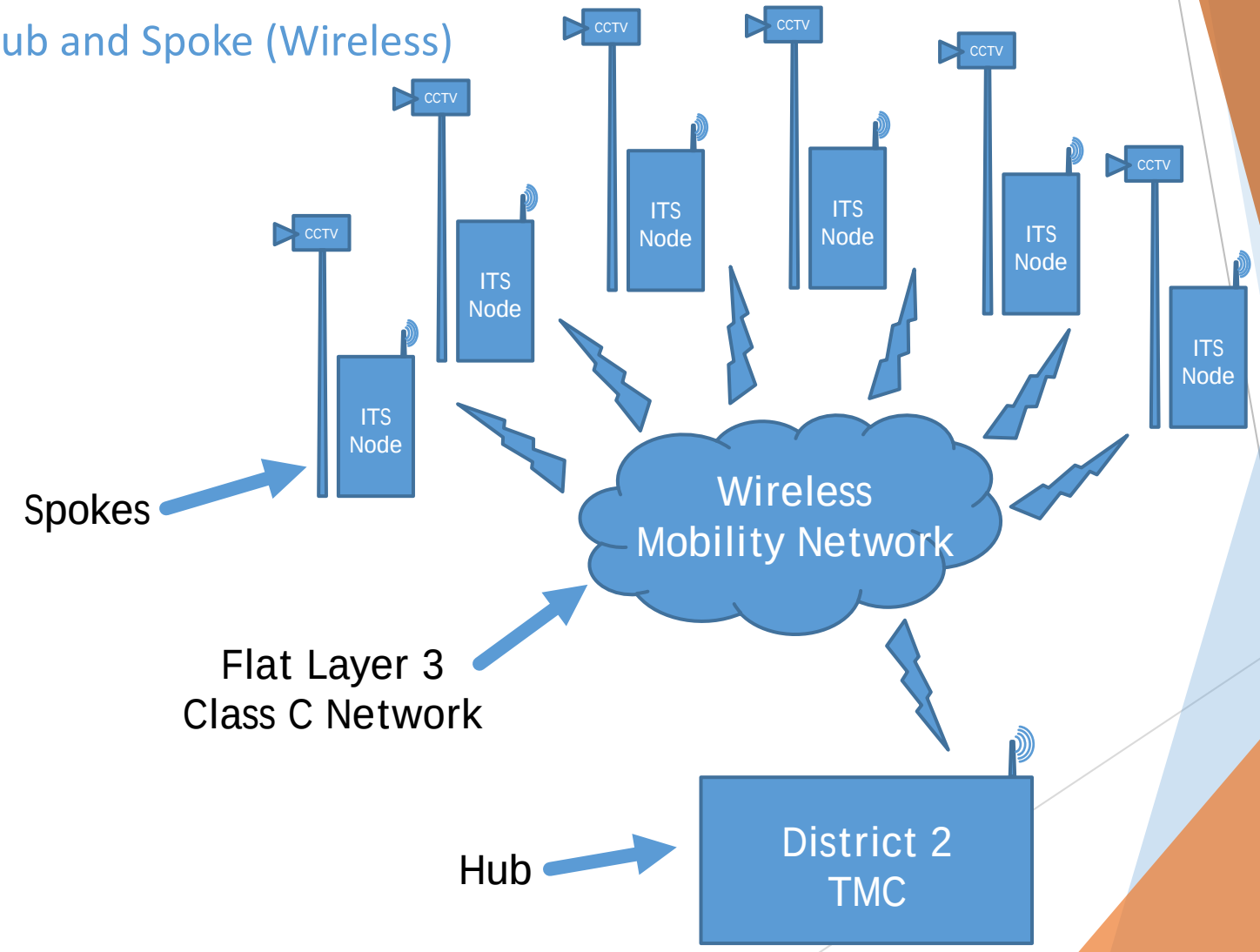
Hub and Spoke

- Network Configuration
  - "HUB" router is located at the District Office
    - Provides an interconnect point between the Field Element Network and Mobility Networks (Zero Point Tunnel)
  - General Route Encapsulation (GRE) tunnels are used to maintain layer 3 routing used on Field Element Network
    - GRE used because of low overhead and simplicity
    - HUB router uses mGRE to listen for remote field routers
    - Field routers negotiate with HUB router to establish tunnel

Cellular Network Design

Final Network Architecture

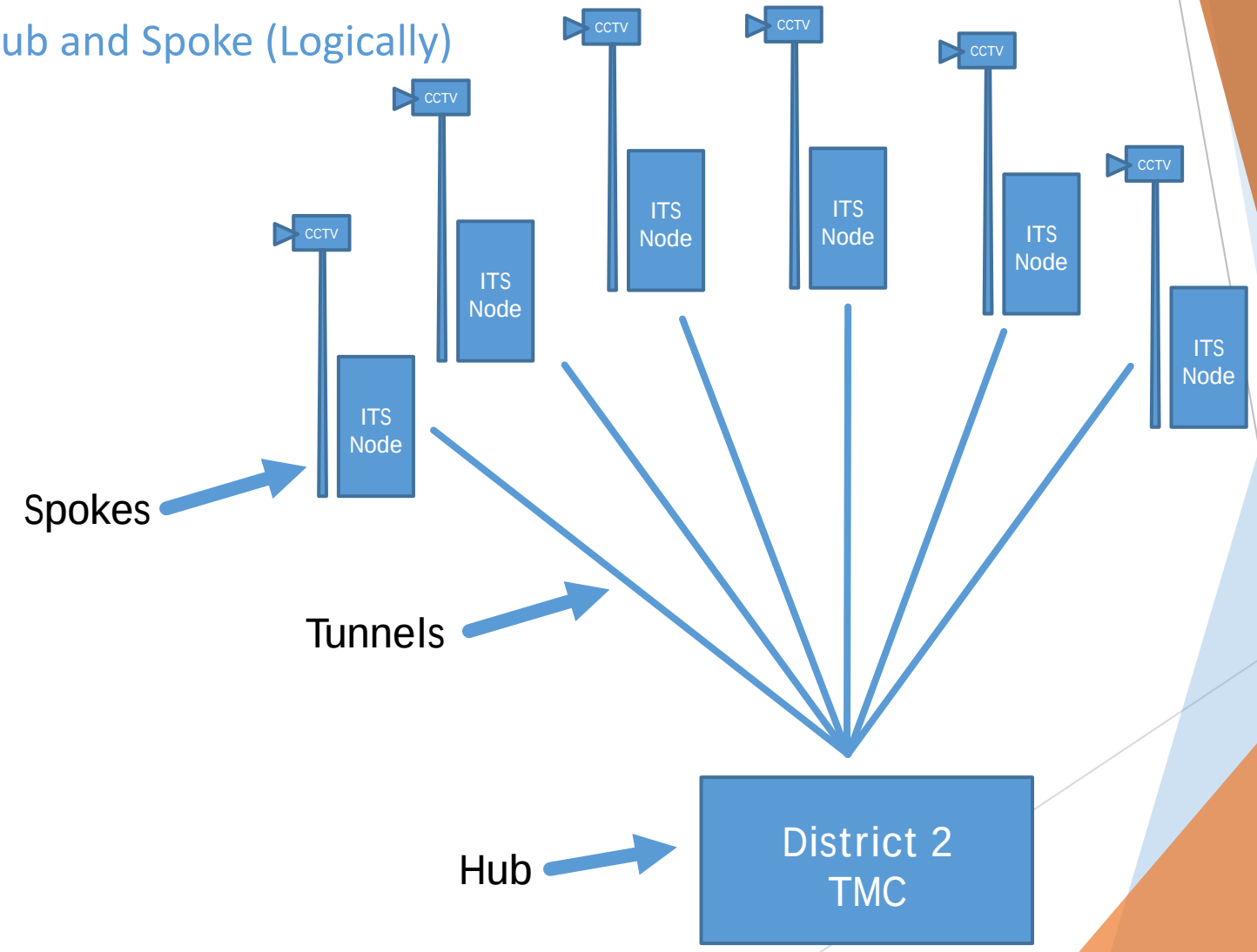
Hub and Spoke (Wireless)



Cellular Network Design

Final Network Architecture

Hub and Spoke (Logically)



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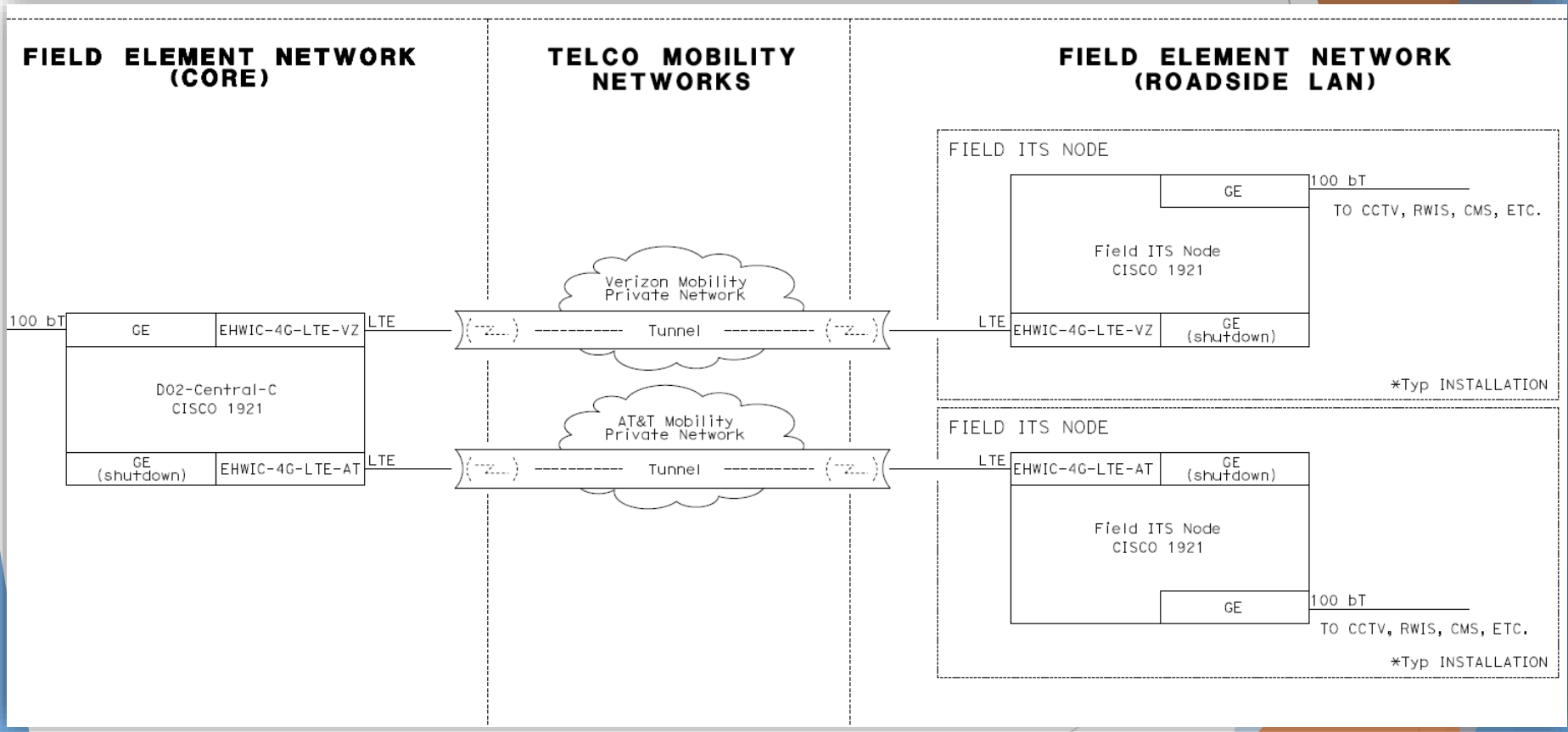


Cellular Network Deployment

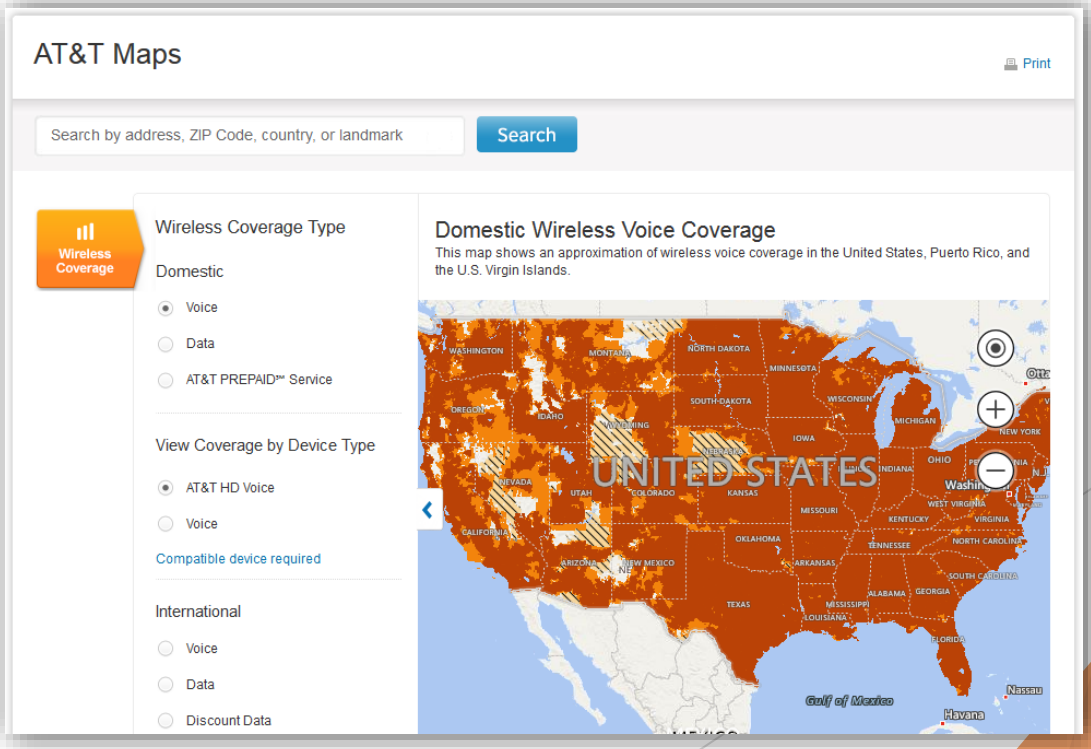
District Office Install

Cellular Network Deployment

Preselecting Sites

- Does my site have cellular coverage?
  - AT&T Coverage Map

https://www.att.com/maps/wireless-coverage.html



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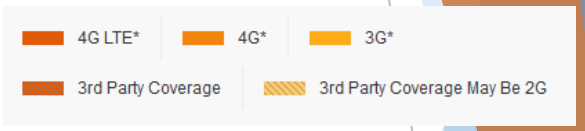
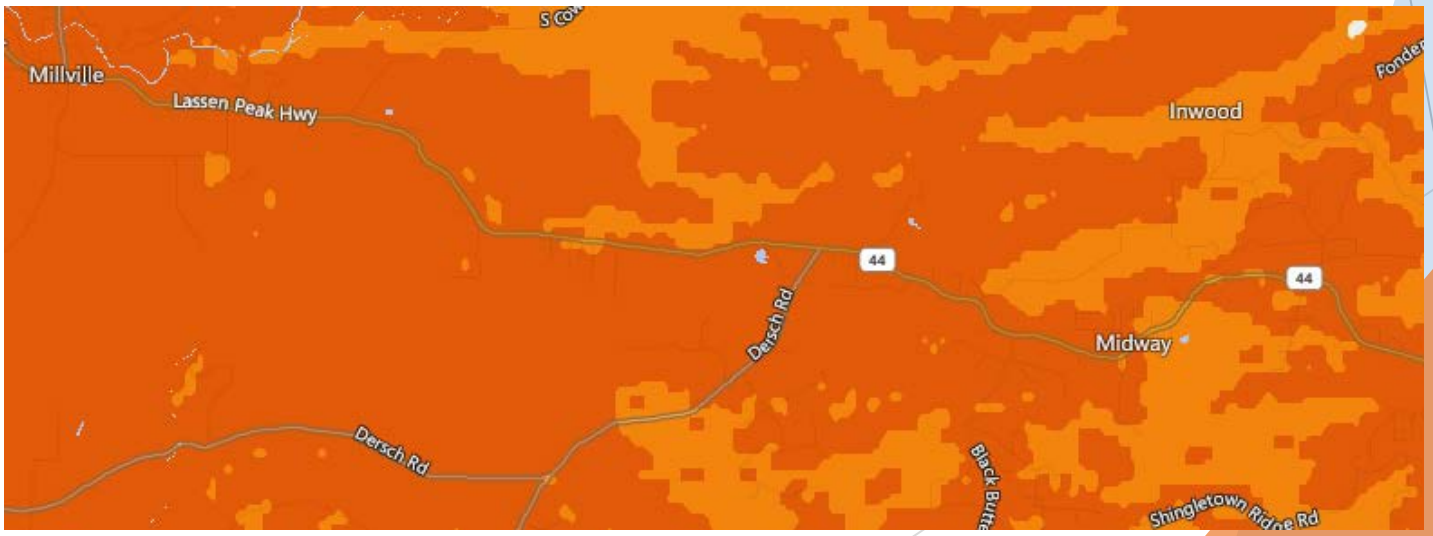
  - Example: AT&T 4G LTE





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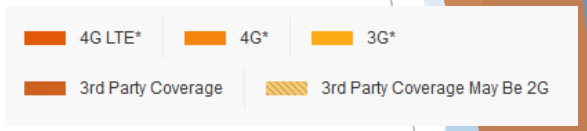

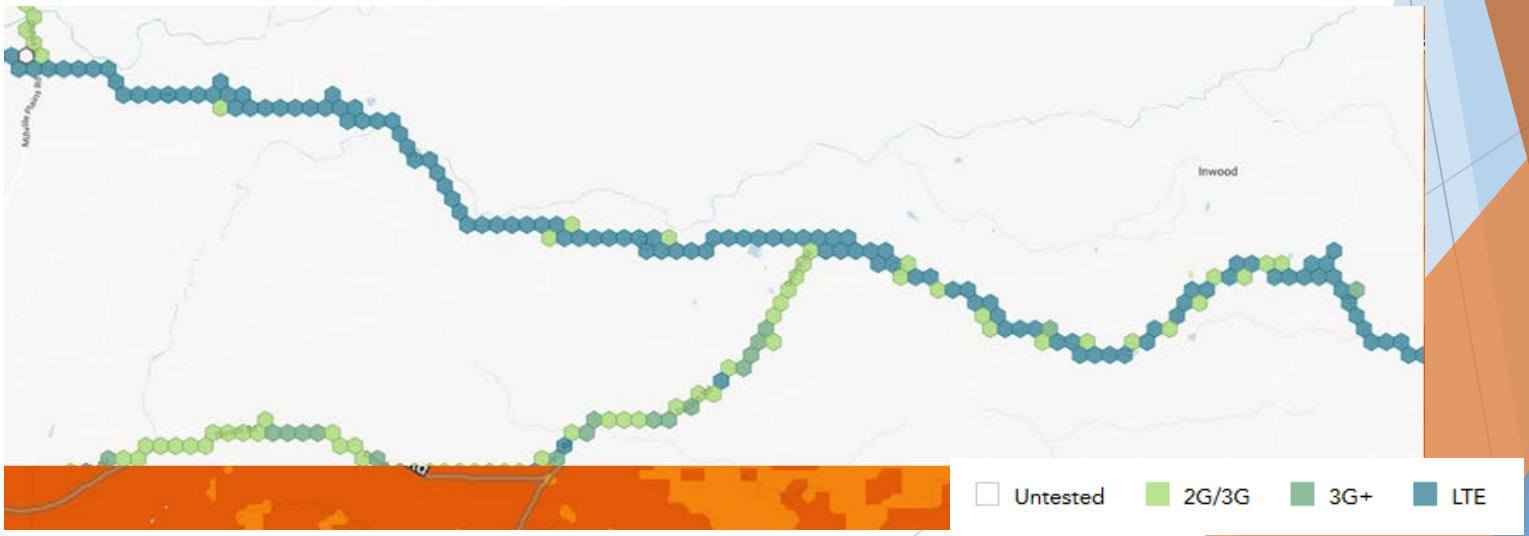

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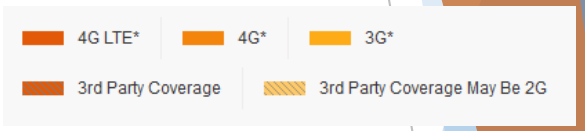

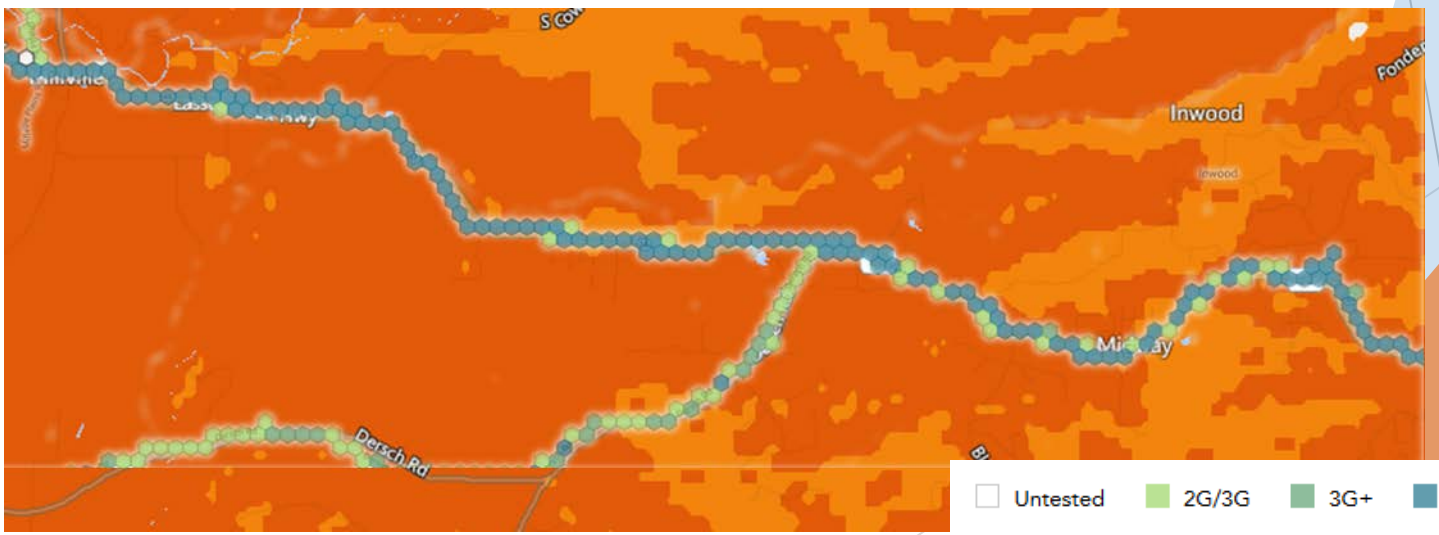

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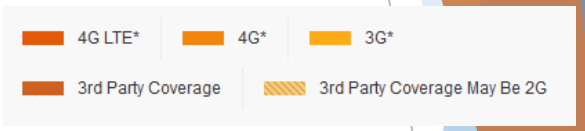

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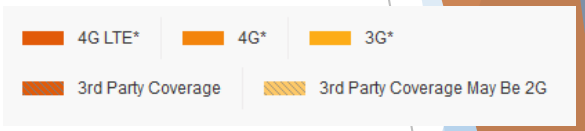

Cellular Network Deployment

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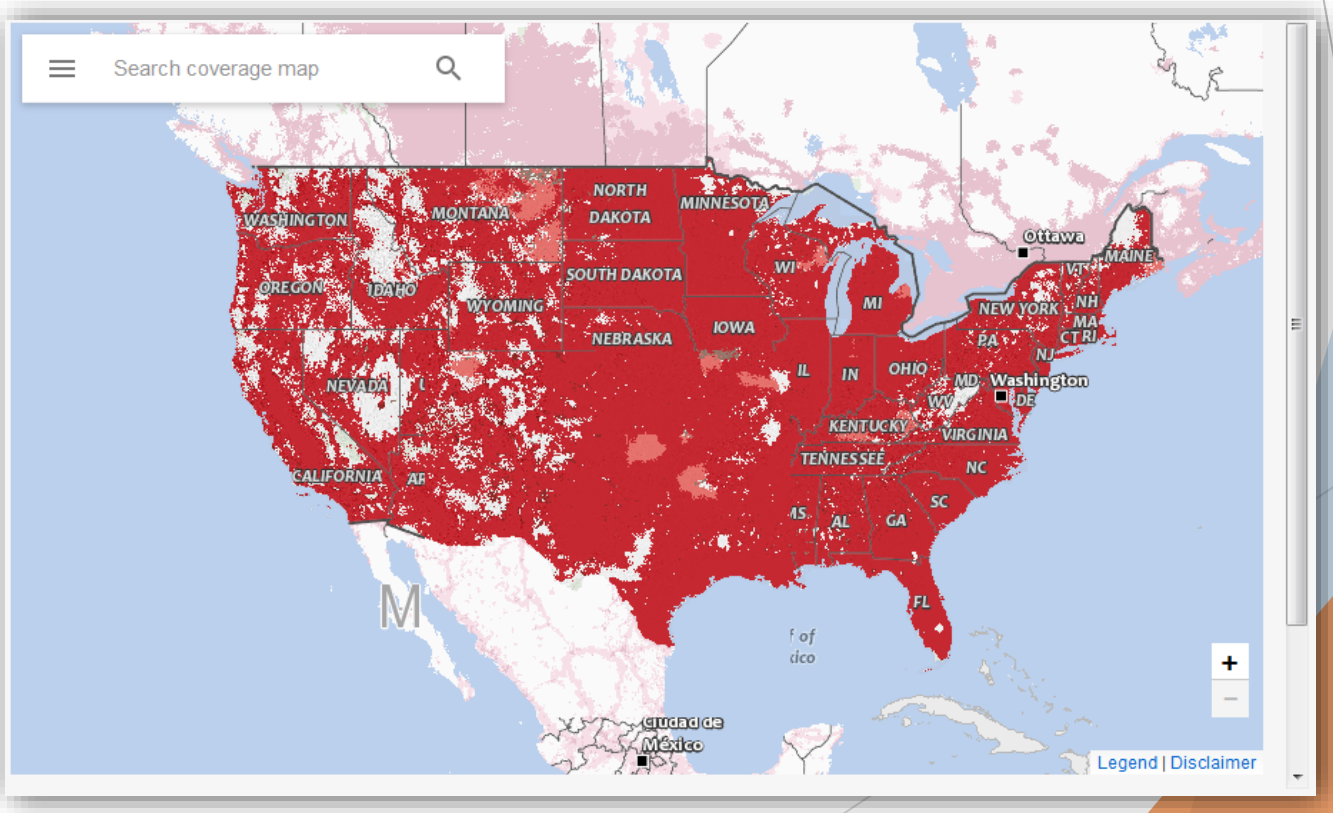

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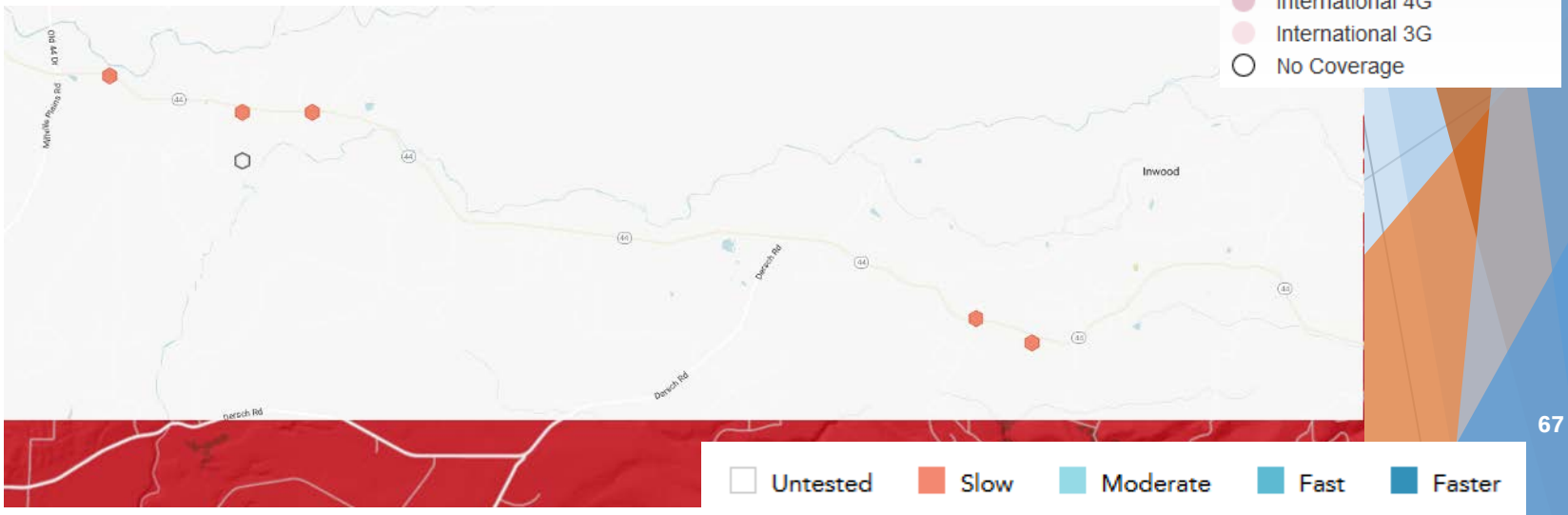

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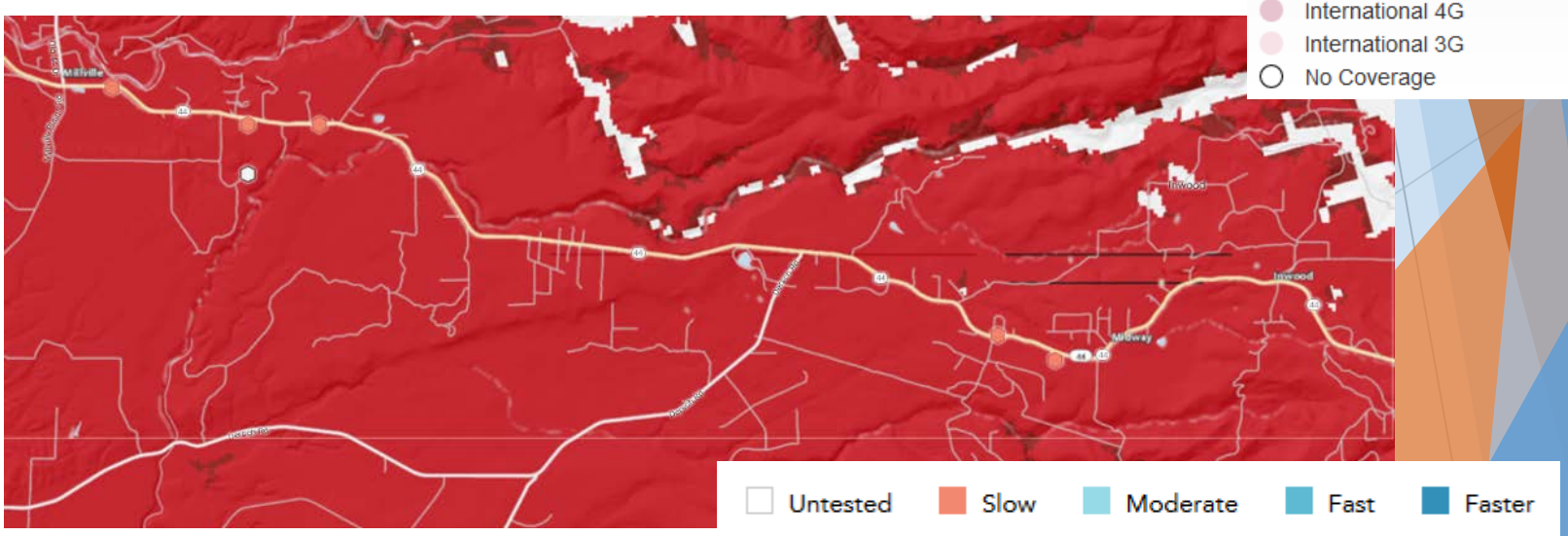

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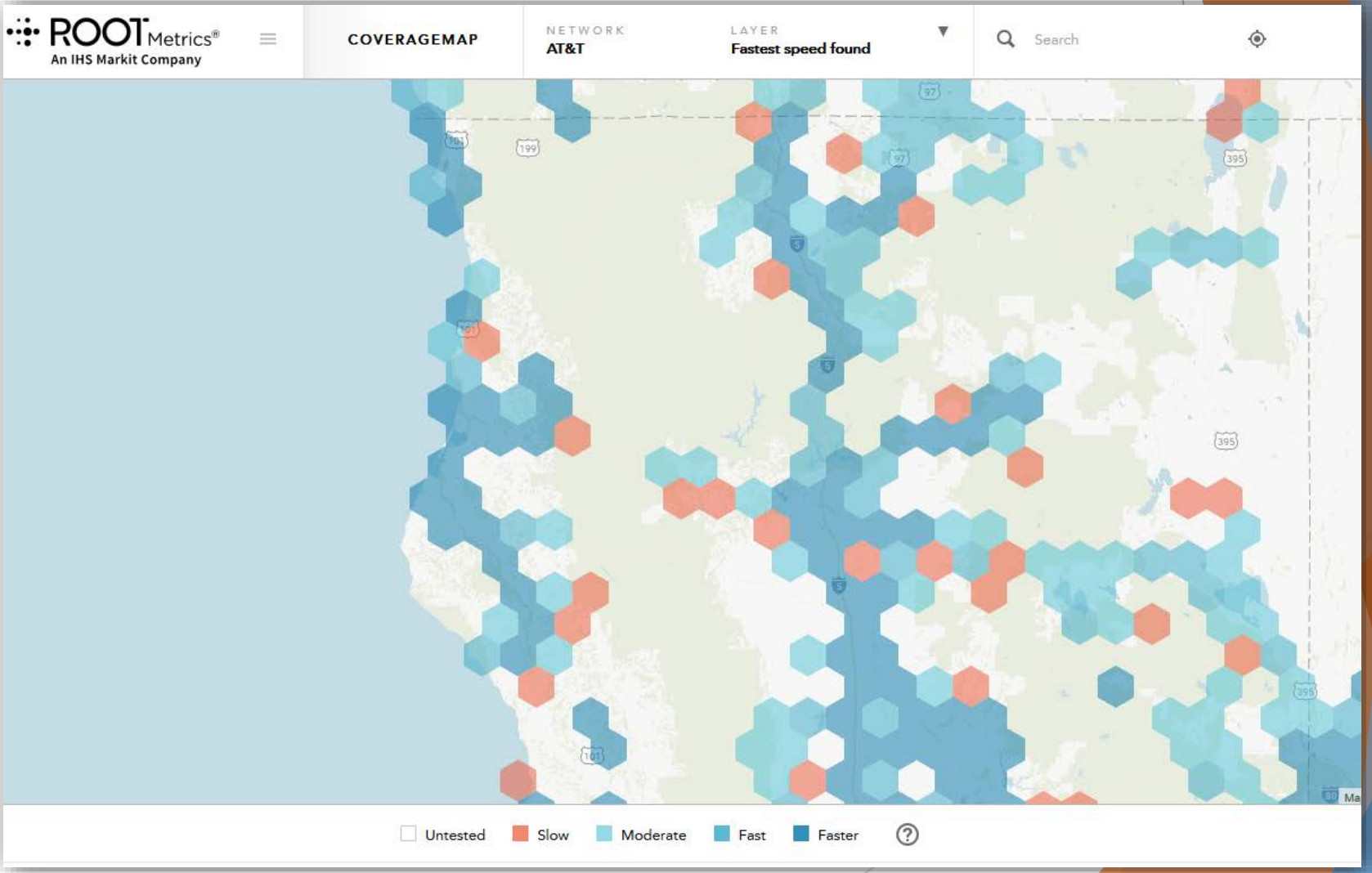

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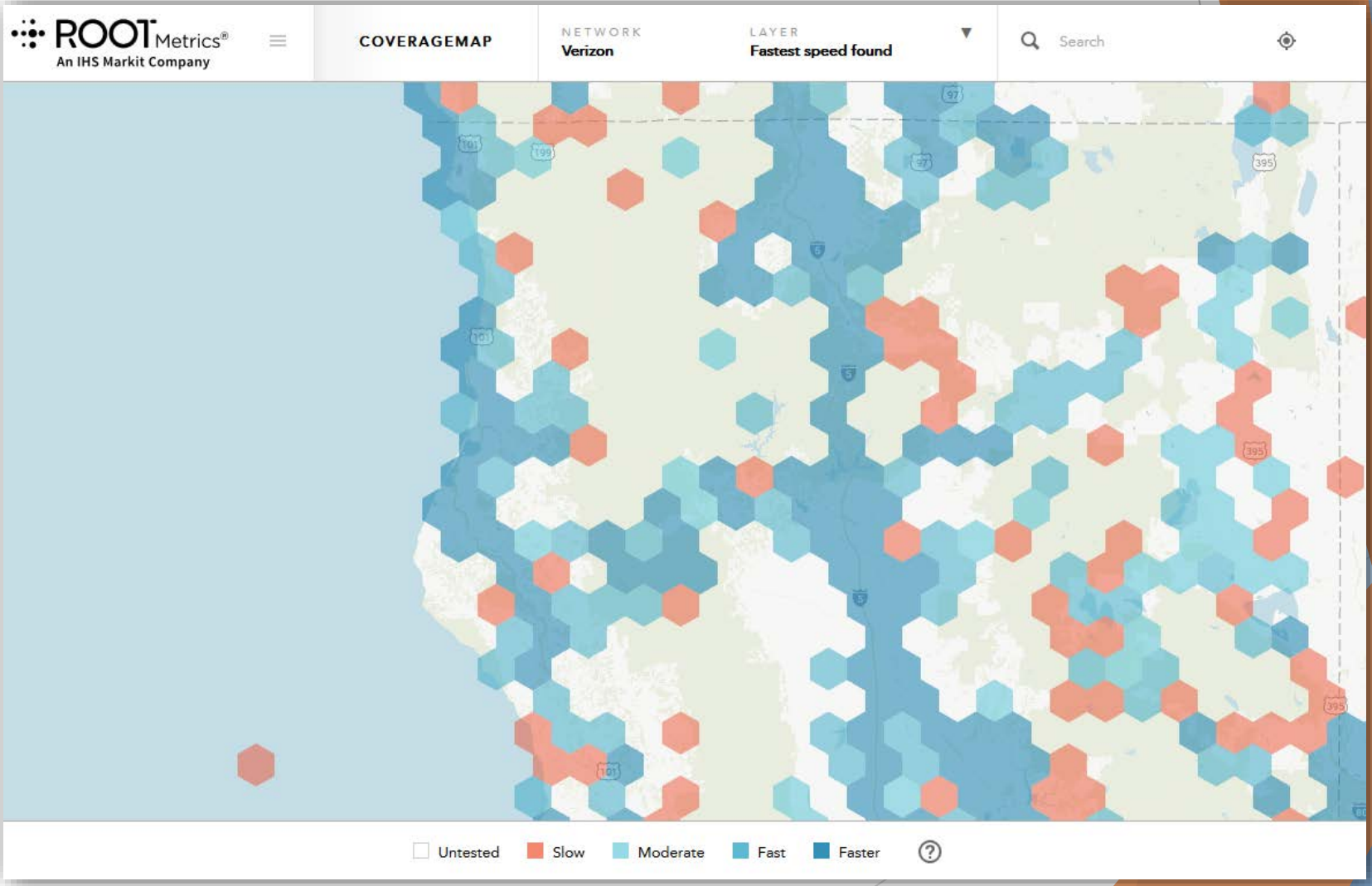


Cellular Network Deployment

Preselecting Sites

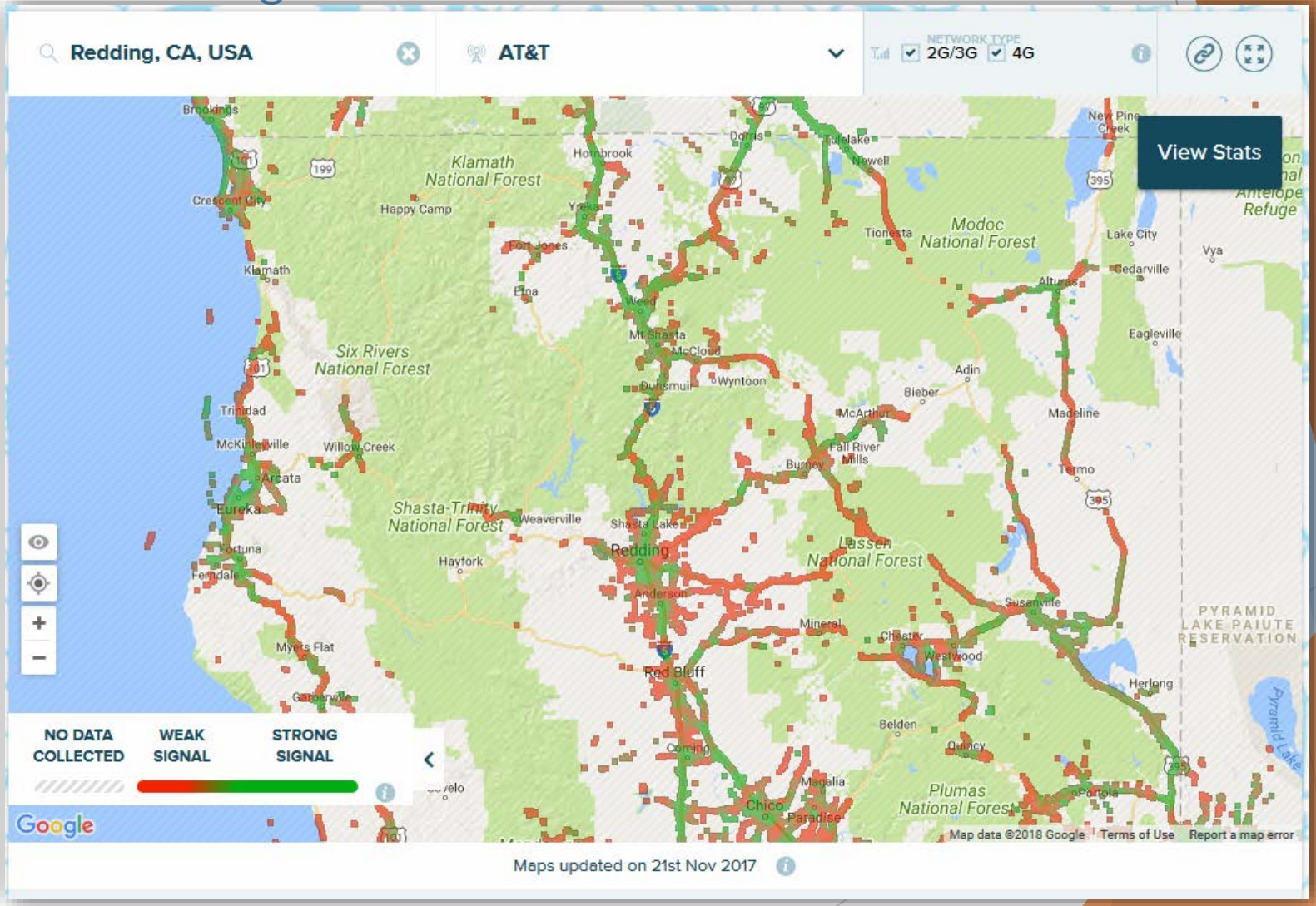
Does my site have cellular coverage?

Estimating Tools

- Wireless Carrier Maps – Generally shows better coverage than reality
- Third Party Tools
  - Root Metrics - http://webcoveragemap.rootmetrics.com/
    - Fairly accurate, but not perfect
  - OpenSignal - https://opensignal.com/networks
    - Show stats in “Signal Strength”
  - Sensorly - https://www.sensorly.com/en/map/

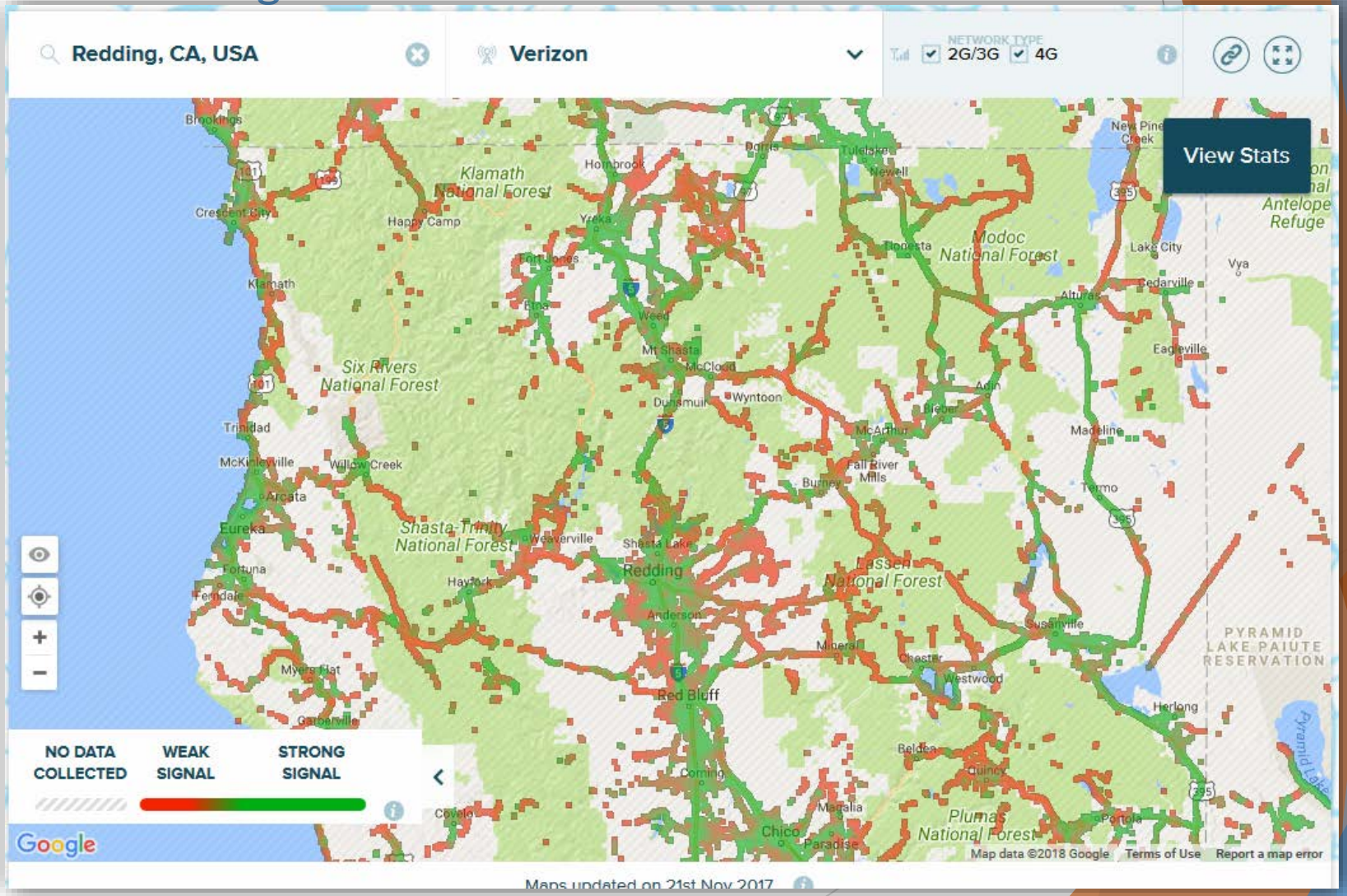
Cellular Network Deployment

Preselecting Sites



Cellular Network Deployment

Preselecting Sites



Cellular Network Deployment

Preselecting Sites

Does my site have cellular cc

Estimating Tools

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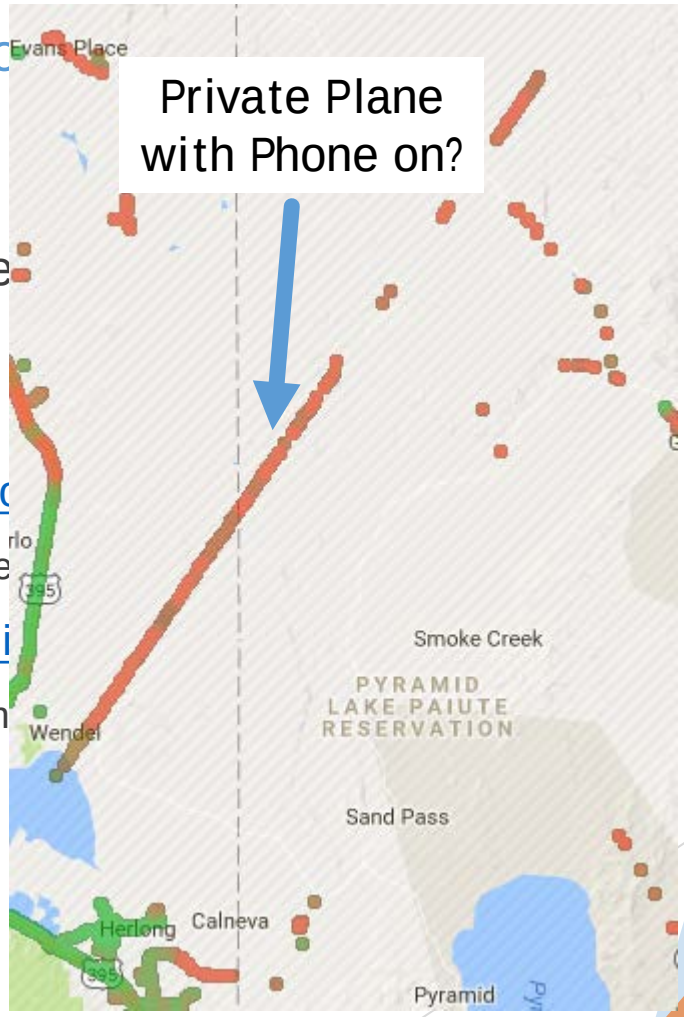
    - Show stats in “Signal Stren



Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Estimating Tools Demo?

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Contacting Cellular Providers

- Where is my nearest cellular site?
- What azimuth should I use for a directional antenna?
- Accurate coverage prediction maps (carrier generated)
- We don't' give out that information
  - Homeland Security
  - Proprietary Information
  - Irrelevant Information

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Contacting Cellular Providers

- Irrelevant Information Example
- “Where is the closest cellular site so I can use a directional antenna to get maximum signal?”

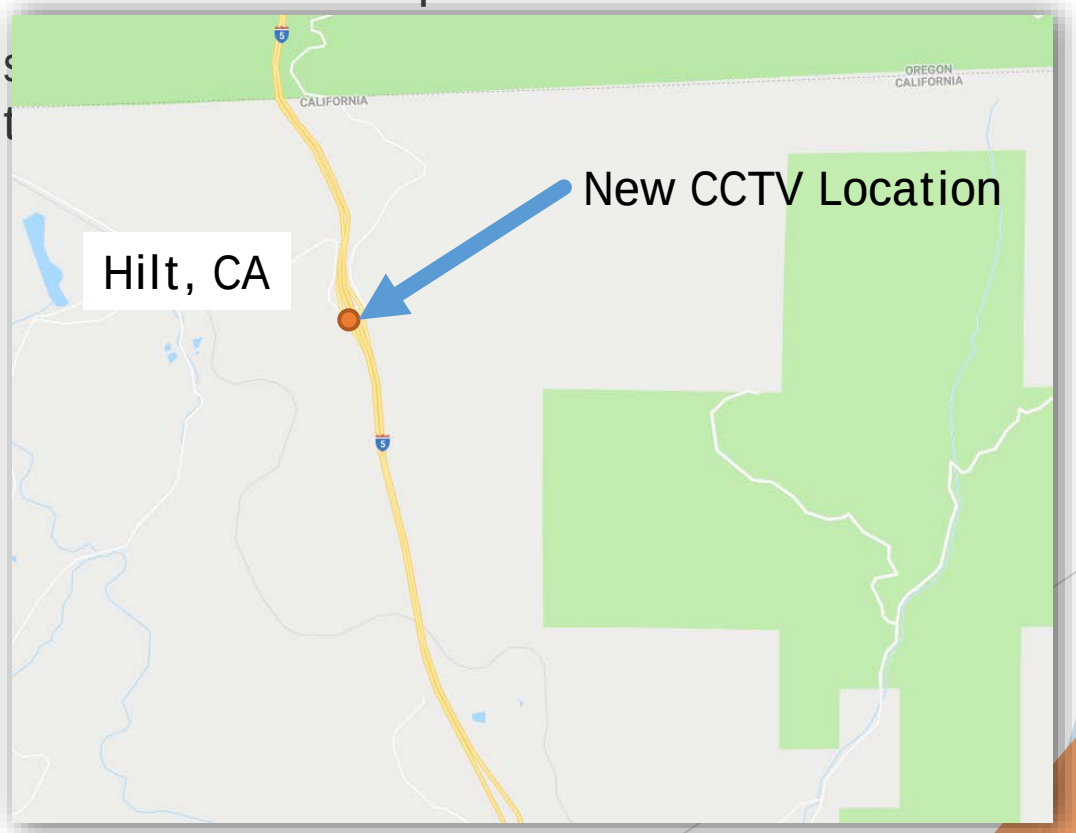
Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Contacting Cellular Providers

- Irrelevant Information Example
- "Where is
  antenna t



Cellular Network Deployment

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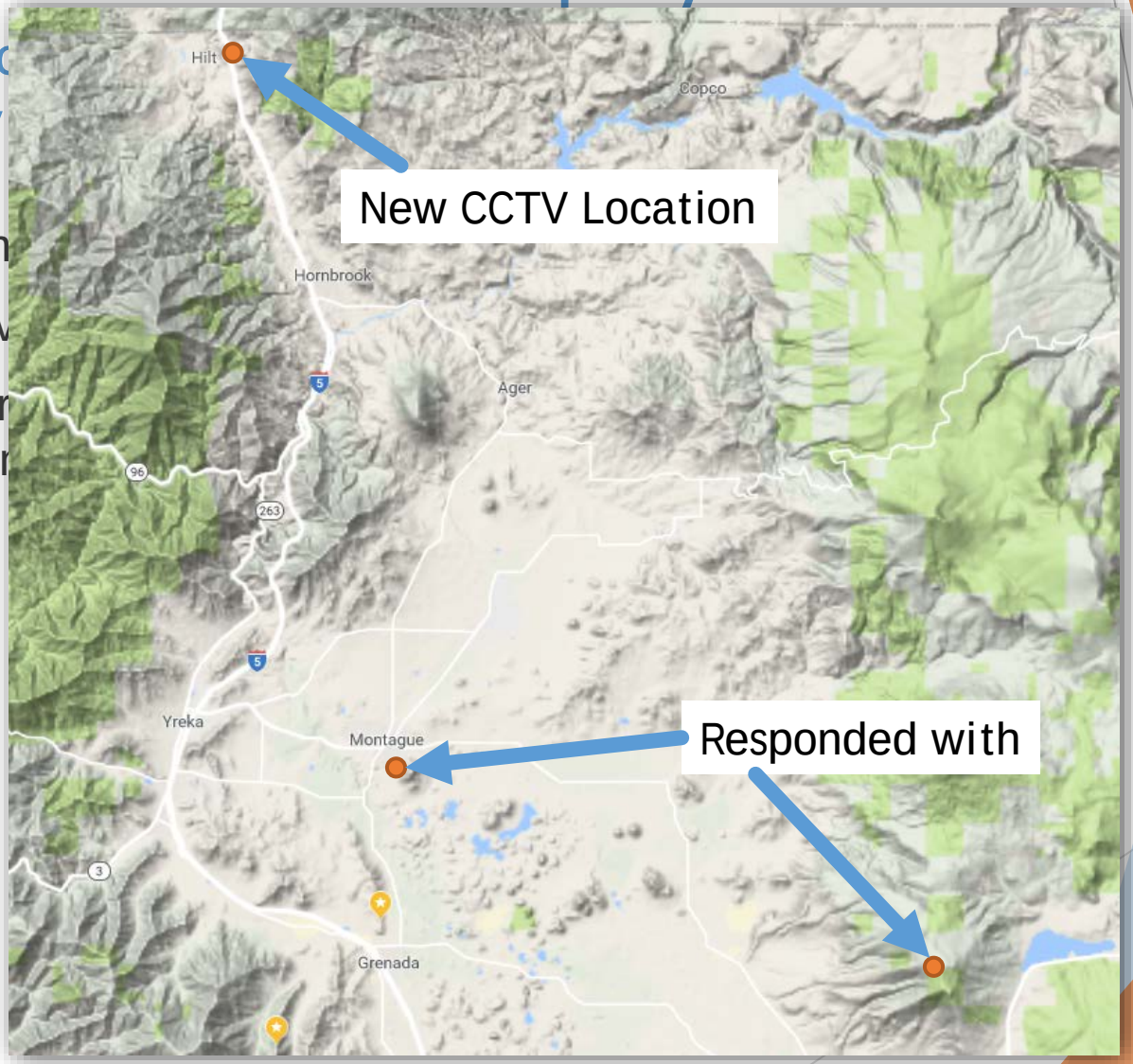

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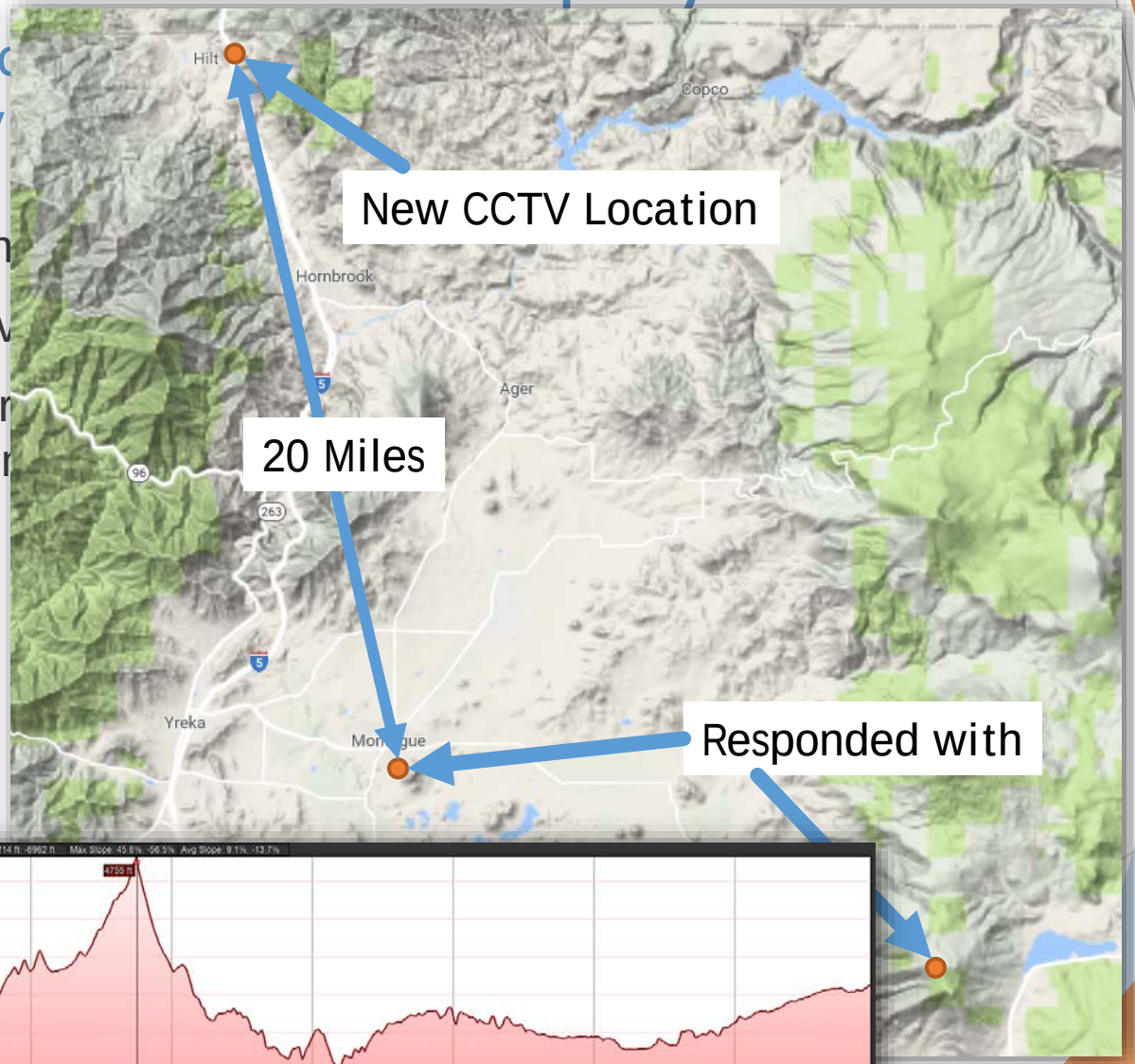

Cellular Network Deployment

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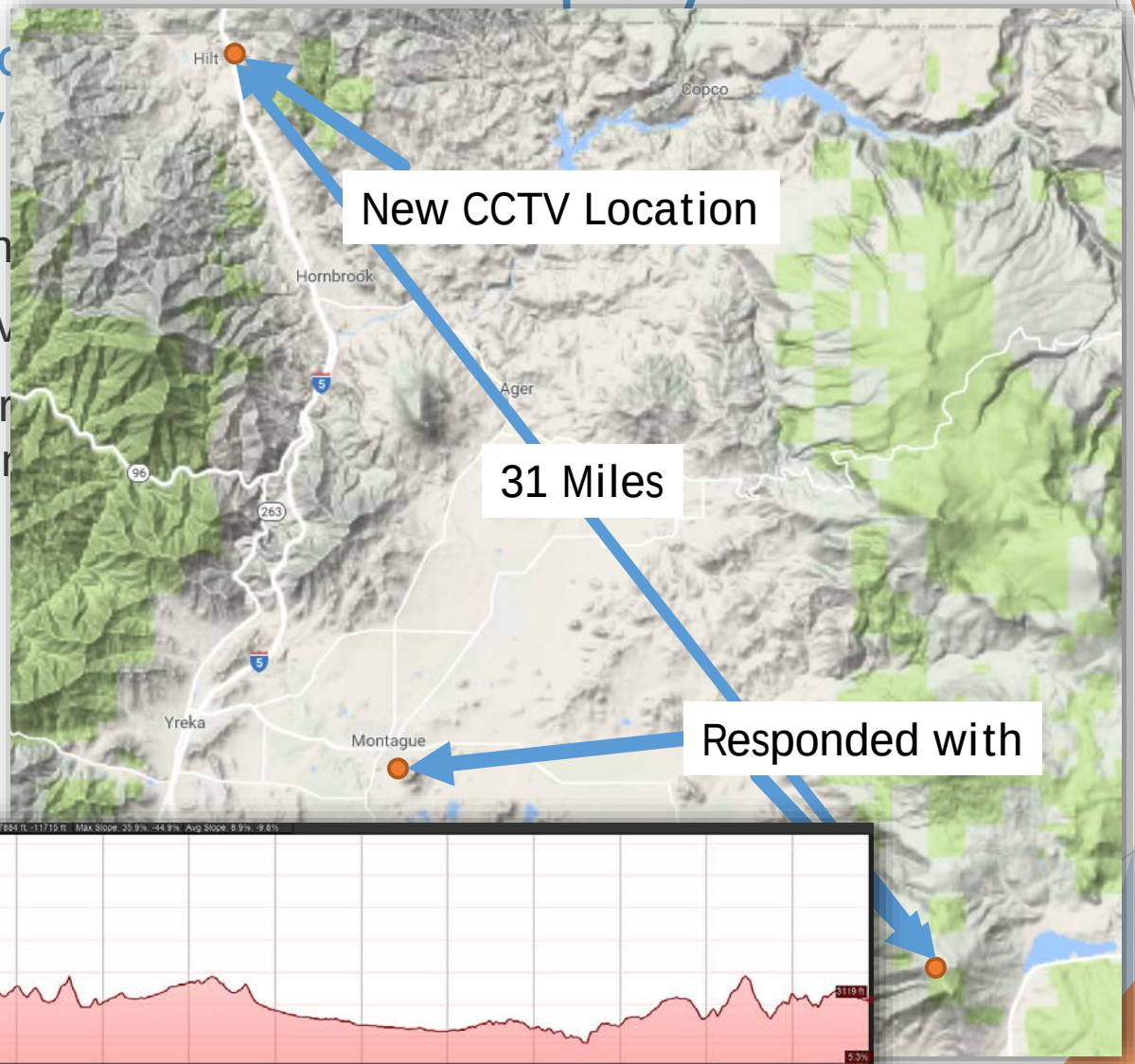


Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Contacting Cellular Providers

- Irrelevant Information Example
- “Where is the closest cellular site so I use a directional antenna to get maximum signal?”
- Obviously wouldn’t work and not all of the carrier’s sites in the area
- Typical response is “Why don’t you go out and try it?”

Cellular Network Deployment

Preselecting Sites

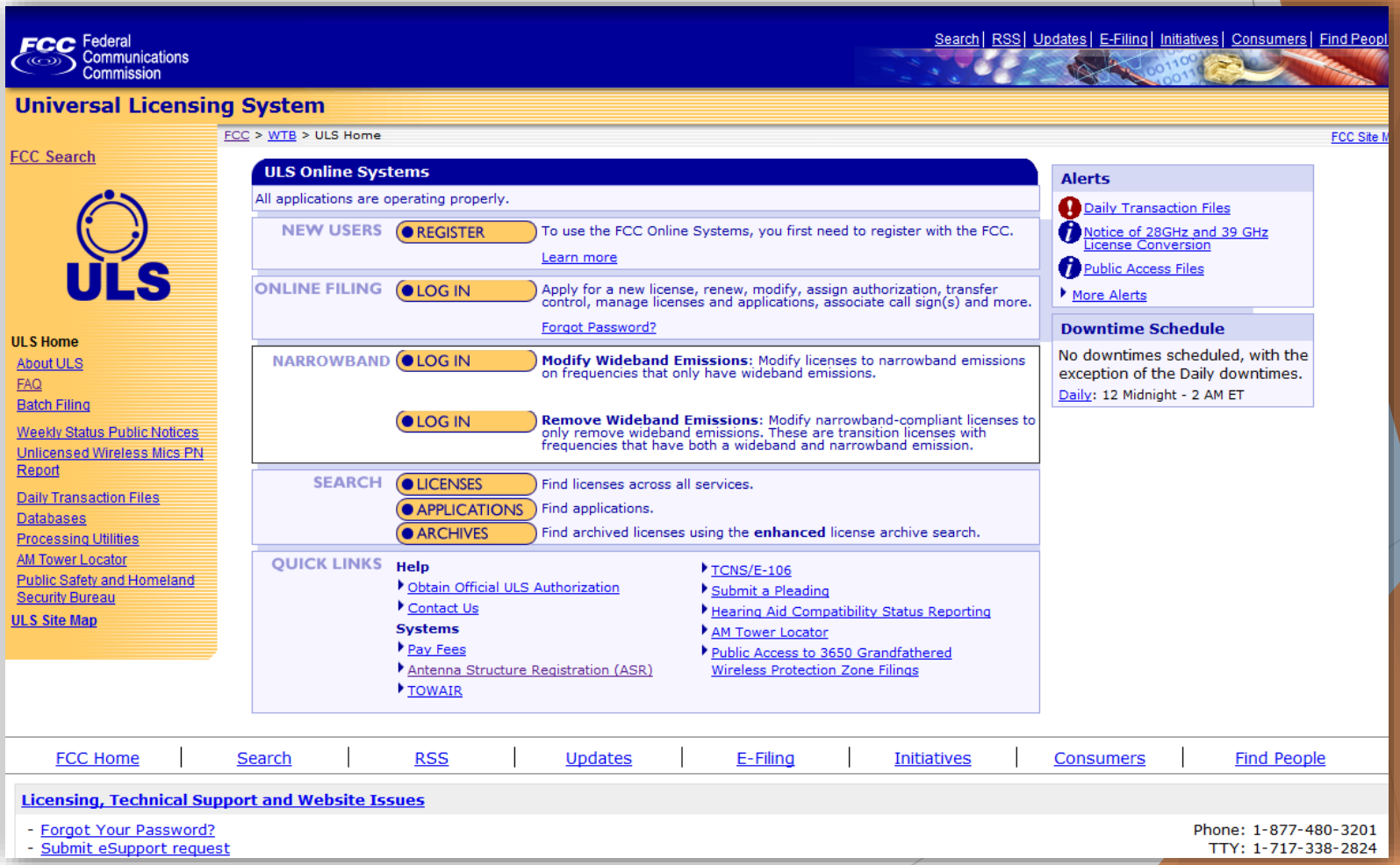
Does my site have cellular coverage?

Use of FCC ULS database to help identify cellular sites

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?



Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Use of FCC ULS database to help identify cellular sites

- Requires a lot of “poking around” and educated assumptions
- Typical Search Results for Cellular-Like licenses

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Use of FCC ULS database to help identify cellular sites

License Search

Search Results

New Search | Refine Search | Printable Page | Query Download | Map Licenses

Specified Search

State = **California**
County = **SHASTA**
Radio Service = **CL, CW, CY, GR, GX, YC, YD, YS, YX**

Matches **1- 10** (of **137**)

PA = Pending Application(s)
TP = Termination Pending
L = Lease

Page 1 2 3 4 5 6 7 8 9 10 NEXT

	Call Sign/Lease ID	Name	FRN	Radio Service	Status	Expiration Date
1	KNCR536	NEXTEL OF CALIFORNIA, INC.	0003293511	YX	Active	01/23/2019
2	KNEC722	NEXTEL OF CALIFORNIA, INC.	0003293511	GX	Canceled	04/30/2012
3	KNKA540	AT&T Mobility Spectrum LLC	0014980726	CL	Active	10/01/2018
4	KNKA751	REDDING MSA LIMITED PARTNERSHIP	0001723964	CL	Active	01/22/2028
5	KNLF208 L	Sprint Spectrum L.P.	0005072970	CW	Active	06/23/2025
6	KNLF740	T-Mobile License LLC	0001565449	CW	Active	01/22/2027
7	KNLG524	AT&T Mobility Spectrum LLC	0014980726	CW	Active	04/28/2027
8	KNLH765	AT&T Mobility Spectrum LLC	0014980726	CW	Active	04/28/2027
9	KNNX230 L	PDV Spectrum Holding Company, LLC	0023948573	YD	Active	08/12/2026
10	KNNX231	PDV Spectrum Holding Company, LLC	0023948573	YD	Active	08/12/2026

Call Sign/Lease ID	Name	FRN	Radio Service	Status	Expiration Date

Page 1 2 3 4 5 6 7 8 9 10 NEXT

* Please note search results do not return licenses that contain geometry data issues.

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

Use of FCC ULS database to help identify cellular sites

- Requires a lot of “poking around” and educated assumptions
- Typical Search Results for Cellular-Like licenses
  - Some carriers are easy to identify

    Nextel of California

    AT&T Mobility Spectrum LLC
  - Others not so much

    Redding MSA Limited Partnership

    PDV Spectrum Holdings Company, LLC

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Cellular-Like licenses (cont.)

  Example: PDV Spectrum Holding, LLC call sign KNNX231

  General Info – Band Auctioned 896-901/935-940 MHz

ULS License

SMR, 896-901/935-940 MHz, Auctioned License - KNNX231 - PDV Spectrum Holding Company, LLC

New Search | Refine Search | Return to Results | Printable Page | Reference Copy

MAIN | ADMIN | MARKET | MAP

Call Sign	KNNX231	Radio Service	YD - SMR, 896-901/935-940 MHz, Auctioned
Status	Active	Auth Type	Regular
Rural Service Provider Bidding Credit			
Is the Applicant seeking a Rural Service Provider (RSP) bidding credit?			
Reserved Spectrum			
Reserved Spectrum			
Market			
Market	MTA004 - San Francisco-Oakland-San Jose	Channel Block	J
Submarket	0	Associated Frequencies (MHz)	000898.25625000-000898.38125000 000937.25625000-000937.38125000
Dates			

Cellular Network Deployment

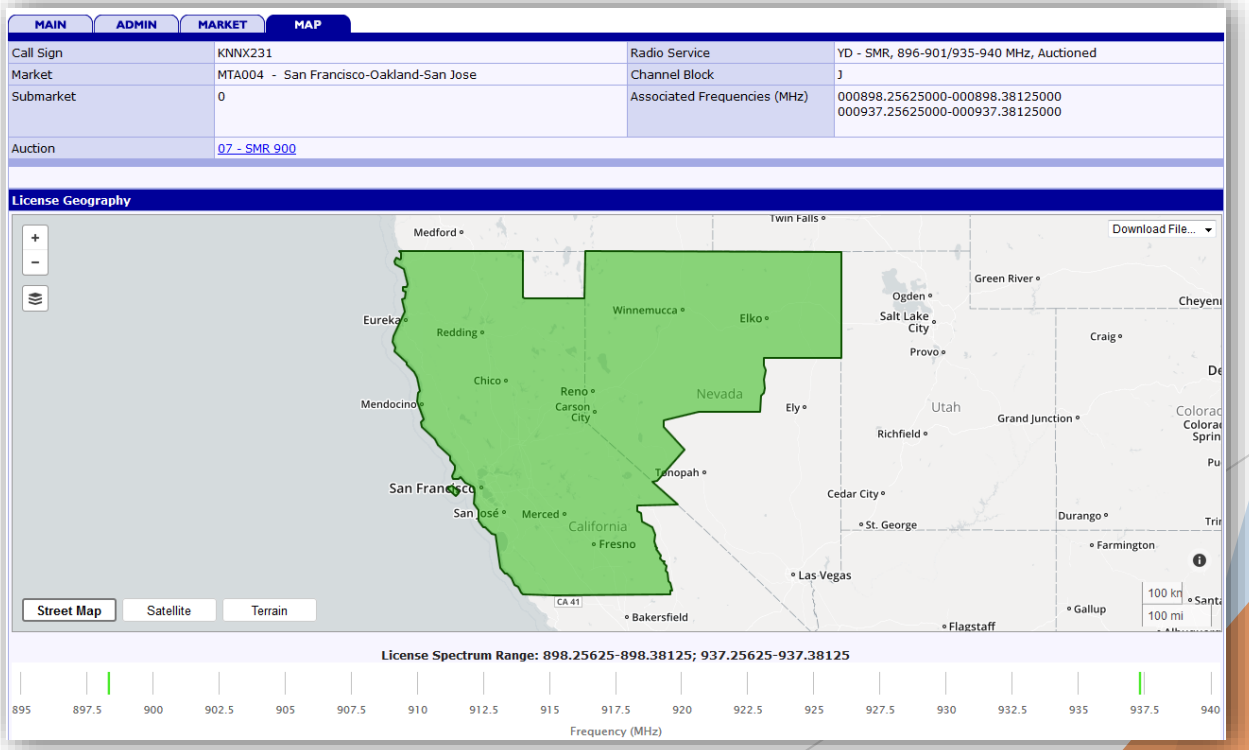
Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Cellular-Like licenses (cont.)

  Example: PDV Spectrum Holding, LLC call sign KNNX231

  Licensed Area



Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

Specified Search

Latitude='**41-59-34.9 N**' Longitude='**122-36-36.9 W**' Radius = **10 Kilometers**
Radio Service = **AB, AI, AS, CE, CF, CT, MG, MM, MW, NN, PE, TB, TI, TP, TS, TT, TZ, WA, WM, WR**

Matches **1**- **10** (of **15**)

PA= Pending Application(s)
TP= Termination Pending
L= Lease

Page 1 2 NEXT

	Call Sign/Lease ID	Name	FRN	Radio Service	Status	Expiration Date
1	KOR60	AT&T COMMUNICATIONS OF THE PACIFIC NORTHWEST INC		CF	Canceled	02/01/2000
2	KOR61	Qwest Corporation	0003746757	CF	Active	08/01/2020
3	WMM431	AT&T Mobility Wireless Operations Holdings Inc.	0020078887	CF	Active	02/01/2021
4	WMQ301	Qwest Corporation	0003746757	CF	Active	08/01/2020
5	WPTY584	New Cingular Wireless PCS, LLC	0003291192	CF	Canceled	01/14/2022
6 PA	WQFX322	New Cingular Wireless PCS, LLC	0003291192	CF	Active	10/26/2026
7	WQGF215	UNITED STATES CELLULAR OPERATING COMPANY OF MEDFORD	0002844801	CF	Canceled	12/28/2016
8	WQGF216	UNITED STATES CELLULAR OPERATING COMPANY OF MEDFORD	0002844801	CF	Canceled	12/28/2016
9	WQHJ446	Sacramento Valley Limited Partnership	0002972149	CF	Active	08/14/2027
10	WQIJ300	CALIFORNIA RURAL SERVICE AREA #1, INC.	0002703700	CF	Canceled	02/26/2018
	Call Sign/Lease ID	Name	FRN	Radio Service	Status	Expiration Date

Page 1 2 NEXT

* Please note search results do not return licenses that contain geometry data issues.

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: CALIFORNIA RURAL SERVICE AREA #1, INC.; WQIJ300

ULS License

Common Carrier Fixed Point to Point Microwave License - WQIJ300 - CALIFORNIA RURAL SERVICE AREA #1, INC.

New Search | Refine Search | Return to Results | Printable Page | Reference Copy | Map License

MAIN | ADMIN | LOCATIONS | PATHS | MAP

Call Sign	WQIJ300	Radio Service	CF - Common Carrier Fixed Point to Point Microwave
Status	Canceled	Auth Type	Regular
Dates			
Grant	02/26/2008	Expiration	02/26/2018
Effective	05/27/2016	Cancellation	12/06/2017
Control Points			
None			
Licensee			
FRN	0002703700 (View Ownership Filing)	Type	Corporation
Licensee			

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: CALIFORNIA RURAL SERVICE AREA #1, INC.; WQIJ300

Common Carrier Fixed Point to Point Microwave License - WQIJ300 - CALIFORNIA RURAL SERVICE AREA #1, INC.

Locations Summary

New Search | Refine Search | Return to Results | Printable Page | Reference Copy | Map License

MAIN | ADMIN | LOCATIONS | PATHS | MAP

Call Sign	WQIJ300	Radio Service	CF - Common Carrier Fixed Point to Point Microwave
2 Total Locations 10 Locations per Summary Page			
Fixed Transmit Location 1: R RANCH			
SISKIYOU County		Coordinates	41-55-47.0 N, 122-33-29.0 W
Site Elevation (AMSL)	933.3m	Height w/o Appurtenances	45.7m
ASR #/File #	N/A	Height w/ Appurtenances	53.3m
Support Structure Type	GTOWER - Guyed Structure Used for Communication Purposes		
NEPA Required	No		

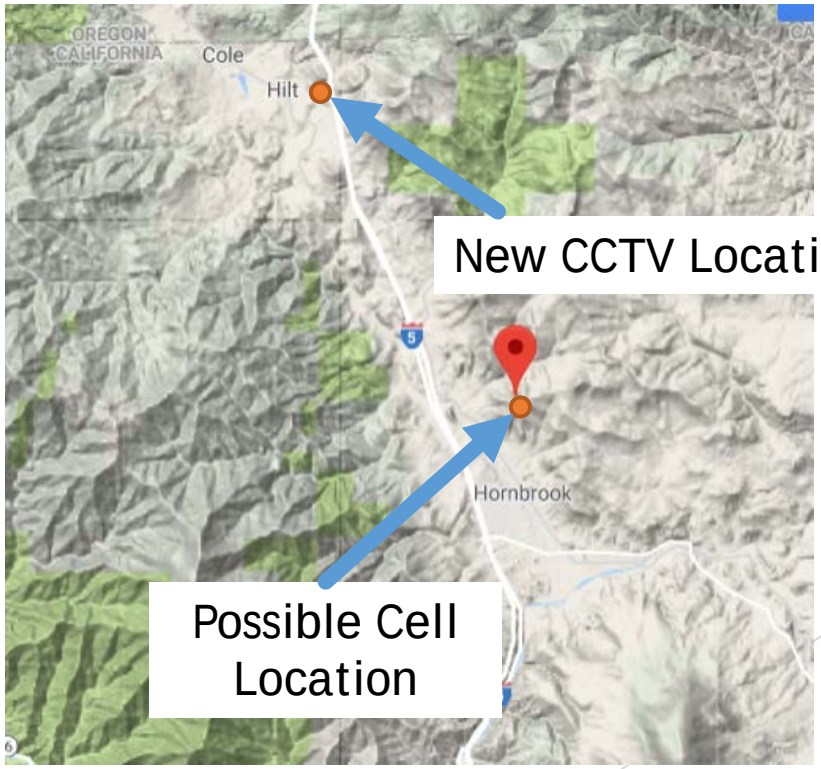
Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: CALIFORNIA RURAL SERVICE AREA #1, INC.; WQIJ300



Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: CALIFORNIA RURAL SERVICE AREA #1, INC.; WQIJ300

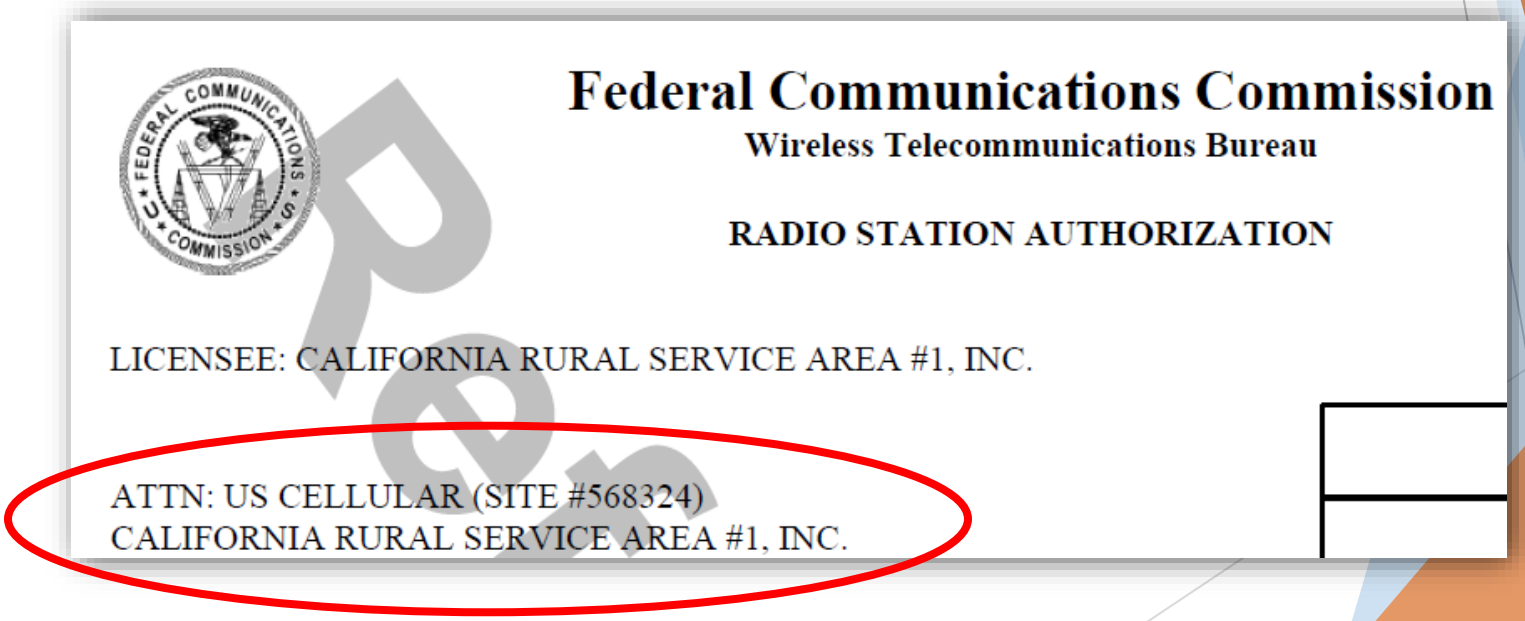
Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: CALIFORNIA RURAL SERVICE AREA #1, INC.; WQIJ300



Federal Communications Commission

Wireless Telecommunications Bureau

RADIO STATION AUTHORIZATION

LICENSEE: CALIFORNIA RURAL SERVICE AREA #1, INC.

ATTN: US CELLULAR (SITE #568324)
CALIFORNIA RURAL SERVICE AREA #1, INC.

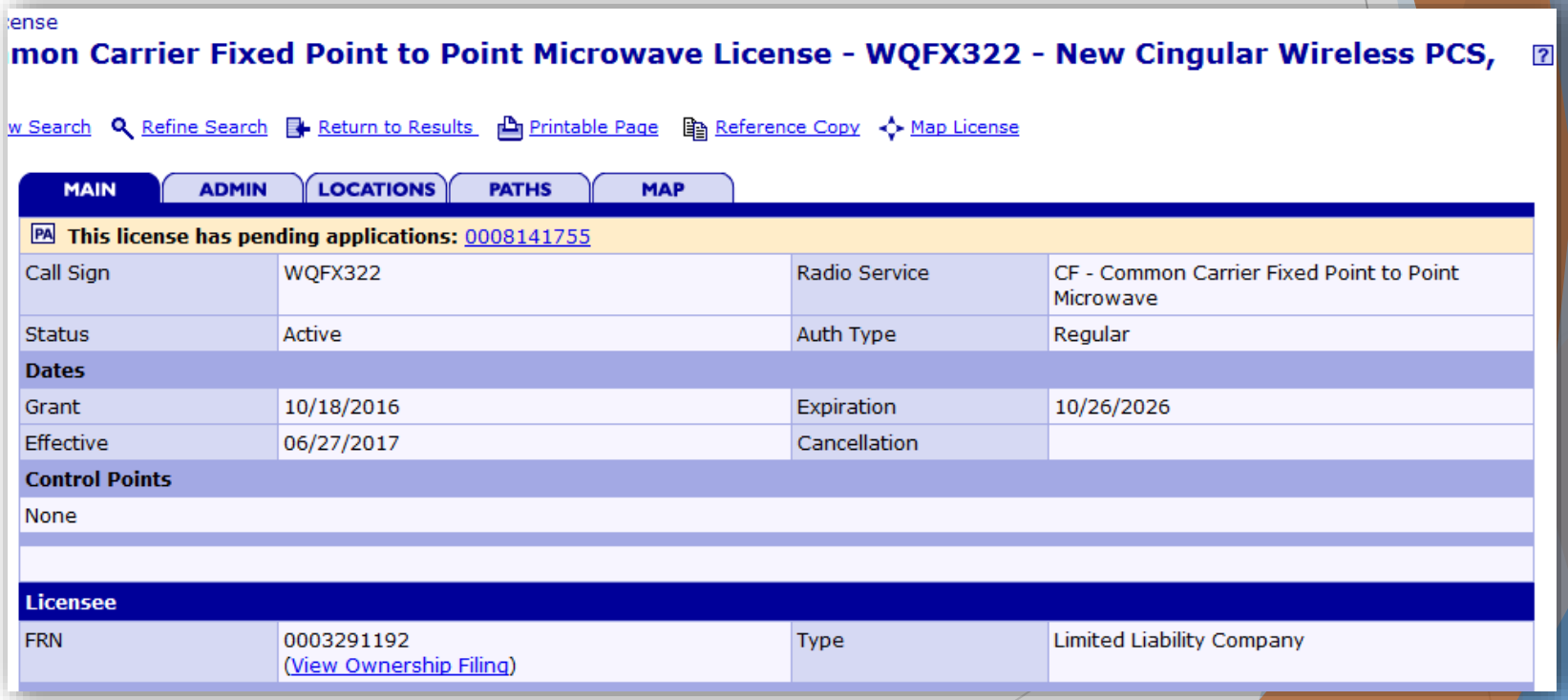
Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: New Cingular Wireless PCS; WQFX322



ense

mon Carrier Fixed Point to Point Microwave License - WQFX322 - New Cingular Wireless PCS,

w Search | Refine Search | Return to Results | Printable Page | Reference Copy | Map License

MAIN | ADMIN | LOCATIONS | PATHS | MAP

PA **This license has pending applications:** 0008141755

Call Sign	WQFX322	Radio Service	CF - Common Carrier Fixed Point to Point Microwave
Status	Active	Auth Type	Regular
Dates			
Grant	10/18/2016	Expiration	10/26/2026
Effective	06/27/2017	Cancellation	
Control Points			
None			
Licensee			
FRN	0003291192 (View Ownership Filing)	Type	Limited Liability Company

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: New Cingular Wireless PCS; WQFX322

Common Carrier Fixed Point to Point Microwave License - WQFX322 - New Cingular Wireless PCS, LLC

Paths Summary

New Search | Refine Search | Return to Results | Printable Page | Reference Copy | Map License

MAIN | ADMIN | LOCATIONS | PATHS | MAP

Call Sign	WQFX322	Radio Service	CF - Common Carrier Fixed Point to Point Microwave
Transmitter	Vista	Coordinates	41-47-37.8 N , 122-35-03.1 W
3 Total Paths 10 Paths Per Summary Page		Path: 2 - To HORNBROOK 1 GO	

Define View: **General** | Buildout | COSER | IRAC

Path 2 - Fixed Point-to-Point

Path Details	**Rec. Call Sign**	
Location Name	**Coordinates**	
HORNBROOK 1	41-55-47.4 N , 122-33-26.6 W	

Path Frequencies	**Tolerance**	**EIRP**	**ATPC**	**Emission Designators**
010855.00000000	0.00100%	62.7dBm	No	40M0D7W Baseband Digital Rate (kbps): 221000.0 Digital Modulation Type: 128 QAM

Transmitter Manufacturer: Alcatel-Lucent USA, Inc. Model: 95MPR11-C128F40-221

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: New Cingular Wireless PCS; WQFX322

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: New Cingular Wireless PCS; WQFX322

Fixed Location Address or Area of Operation:
5510 Anderson Grade Road
City: Yreka **County:** SISKIYOU **State:** CA

Loc No.	Location Name	Latitude	Longitude	Elevation	Antenna Structure Registration No.
001	Vista	41-47-37.8 N	122-35-03.1 W	1028.7	
002	Butcher Hill	41-43-29.0 N	122-37-49.0 W	966.2	
003	HORNBROOK 1	41-55-47.4 N	122-33-26.6 W	935.4	

FREQUENCY PATHS

Frequency (MHz)	Tol (%)	Emission Desig	EIRP (dBm)	Constr Date	Path No	Seg	Emit Loc No	Ant Hgt (m)	Gain (dBi)	Beam (deg) Reflector Ht(m)xWd(m)	POL	AZIM (deg)	Rec Loc No	Rec Call Sign
10855.0	0.00100	40M0D7W	62.700	06-29-2016	002	1	001	27.4	43.8	1.1	H	8.4	003	
10895.0	0.00100	40M0D7W	62.700	06-29-2016	003	1	001	27.4	43.8	1.1	V	8.4	003	
19345.0	0.00100	30M0D7W	54.000	02-10-2017	004	1	001	14.0	43.5	1.1	H	206.5	002	WPTY615

Cellular Network Deployment

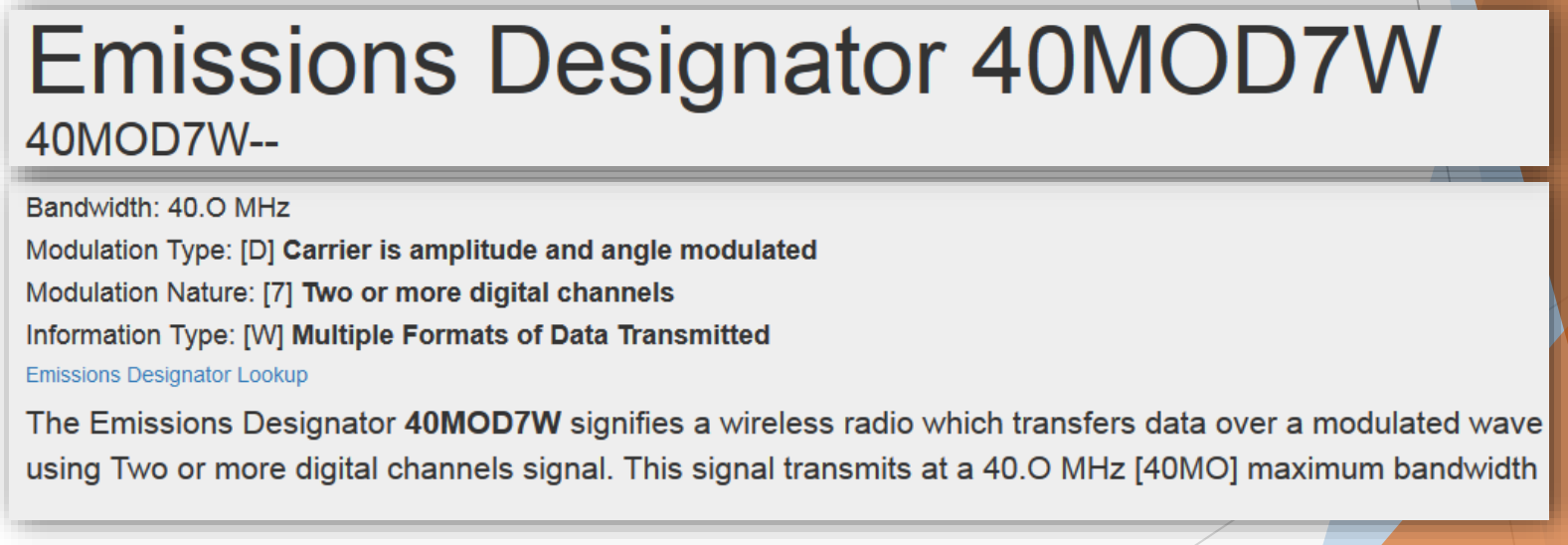
Preselecting Sites

Does my site have cellular coverage?

- Typical Search Results for Common Carrier Fixed P2P Microwave

  Example: New Cingular Wireless PCS; WQFX322

  Base assumption is back haul is licensed to AT&T so may be a cell site



Emissions Designator 40MOD7W

40MOD7W--

Bandwidth: 40.0 MHz

Modulation Type: [D] **Carrier is amplitude and angle modulated**

Modulation Nature: [7] **Two or more digital channels**

Information Type: [W] **Multiple Formats of Data Transmitted**

Emissions Designator Lookup

The Emissions Designator **40MOD7W** signifies a wireless radio which transfers data over a modulated wave using Two or more digital channels signal. This signal transmits at a 40.0 MHz [40MO] maximum bandwidth

Cellular Network Deployment

Preselecting Sites

Does my site have cellular coverage?

- Field Verification (not fancy)
  - Basic means of field verification
    - AT&T Cell phone
    - Verizon Mifi
  - Check to see if either device attaches to 4G or 4G LTE network
  - If it does – Attempt to do a internet "Speed Test"
    - Coverage Map App (Root Metrics)
    - Speedtest.net – http://speedtest.net
    - Fast.com – http://fast.com
  - If able to pass data at reasonable speed – Site *may* be a candidate for upgrade

Cellular Network Deployment

Field Installation

At District Office

- Configure Cisco 1921 Integrated Service Router per District's Cellular template in Lab
  - Local LAN interface to match test site's current addressing scheme – Drop-in replacement
- Make Field Trip!

Cellular Network Deployment

Field Installation

At Field Location

- Remove cabinet lifting eye

Cellular Network Deployment

Field Installation

At Field Location

- Remove cabinet lifting eye
- Replace with antenna and custom bracket

Cellular Network Deployment

Field Installation

At Field Location

- Remove cabinet lifting eye
- Replace with antenna and custom bracket
- Add drip-loop in cabinet and seal hole
  - Duct seal
  - Silicone

Cellular Network Deployment

Field Installation

At Field Location

- Remove cabinet lifting eye
- Replace with antenna and custom br
- Add drip-loop in cabinet and seal hol
  - Duct seal
  - Silicone
- Rack router and test configuration

Cellular Network Deployment

Field Installation

At Field Location

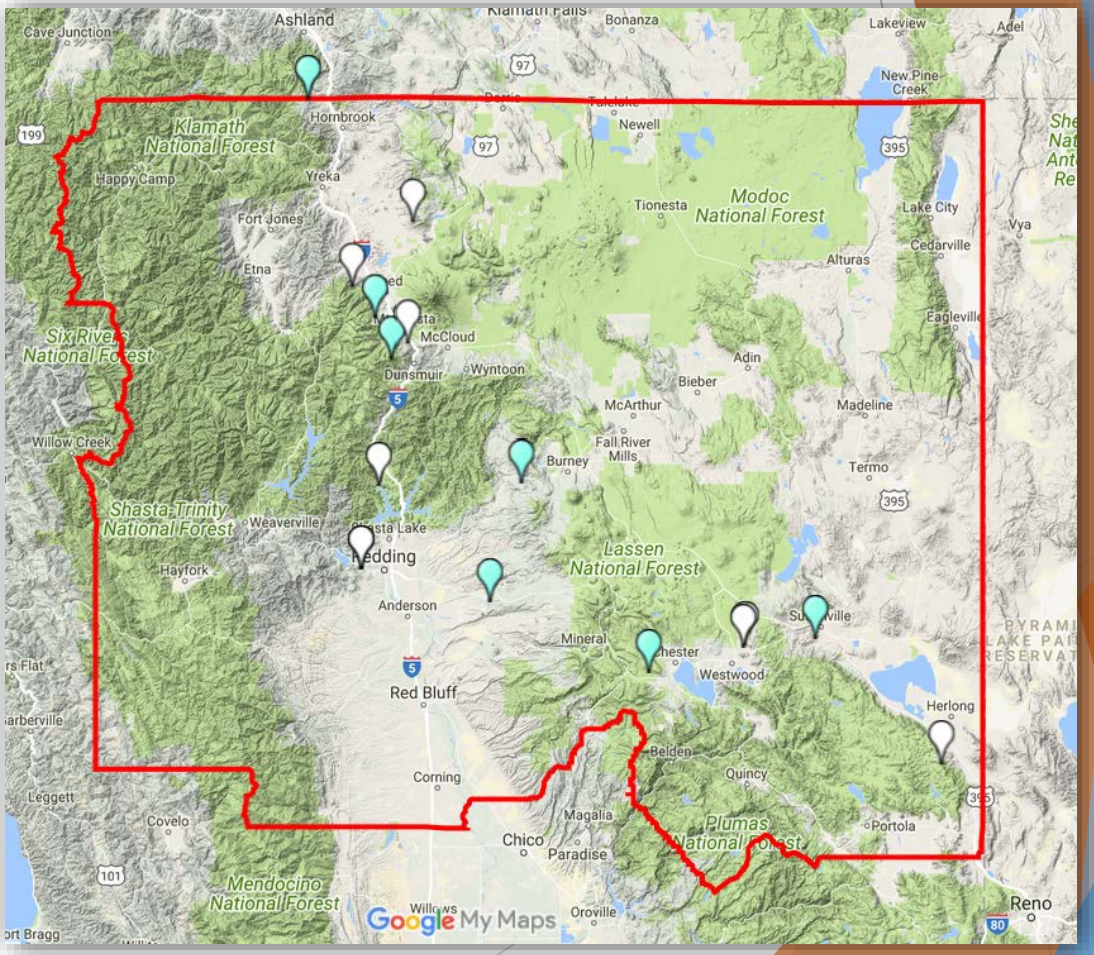
- Remove cabinet lifting eye
- Replace with antenna and custom bra
- Add drip-loop in cabinet and seal hol
  - Duct seal
  - Silicone
- Rack router and test configuration
- Make changes to Core Router

Cellular Network Deployment

Total Field Installation

Initial Deployment

- Carriers
  - AT&T
  - Verizon
- Field Sites
  - CCTV – 7
  - CCTV/RWIS - 5
  - CMS - 1
  - RWIS – 1
- District Office - 2



Cellular Network Testing

Network “Stress Test”

- Stress Test the network
  - Test end to end throughout
    - Internet speed test
    - Single site (Test single site uplink speed)
    - All sites (Test Zero Point Tunnel entry point)
  - Free run encoder/decoder negotiated speed
    - Run Statistical analysis for consistent end user experience
  - Total data used

Cellular Network Testing

Network “Stress Test”

Internet Speed Test

- Test method
  - Personal Cell phone (iPhone, AT&T)
  - Work Assigned Verizon MiFi
  - Speed Tests – top of cabinet
    - SpeedTest.net
    - Fast.com
    - Coverage Map App by Root Metrics
  - Speeds varied by location

Cellular Network Testing

Network “Stress Test”

Single Site Uplink Speed

- Test method
  - Configure Encoder to MJPEG, unlimited frame rate, unlimited bandwidth
  - Stream in to Traffic Management Center 24/7
  - Use custom logging script to monitor decoder connection and connected speed
  - Let run for a full week

Cellular Network Testing

Network “Stress Test”

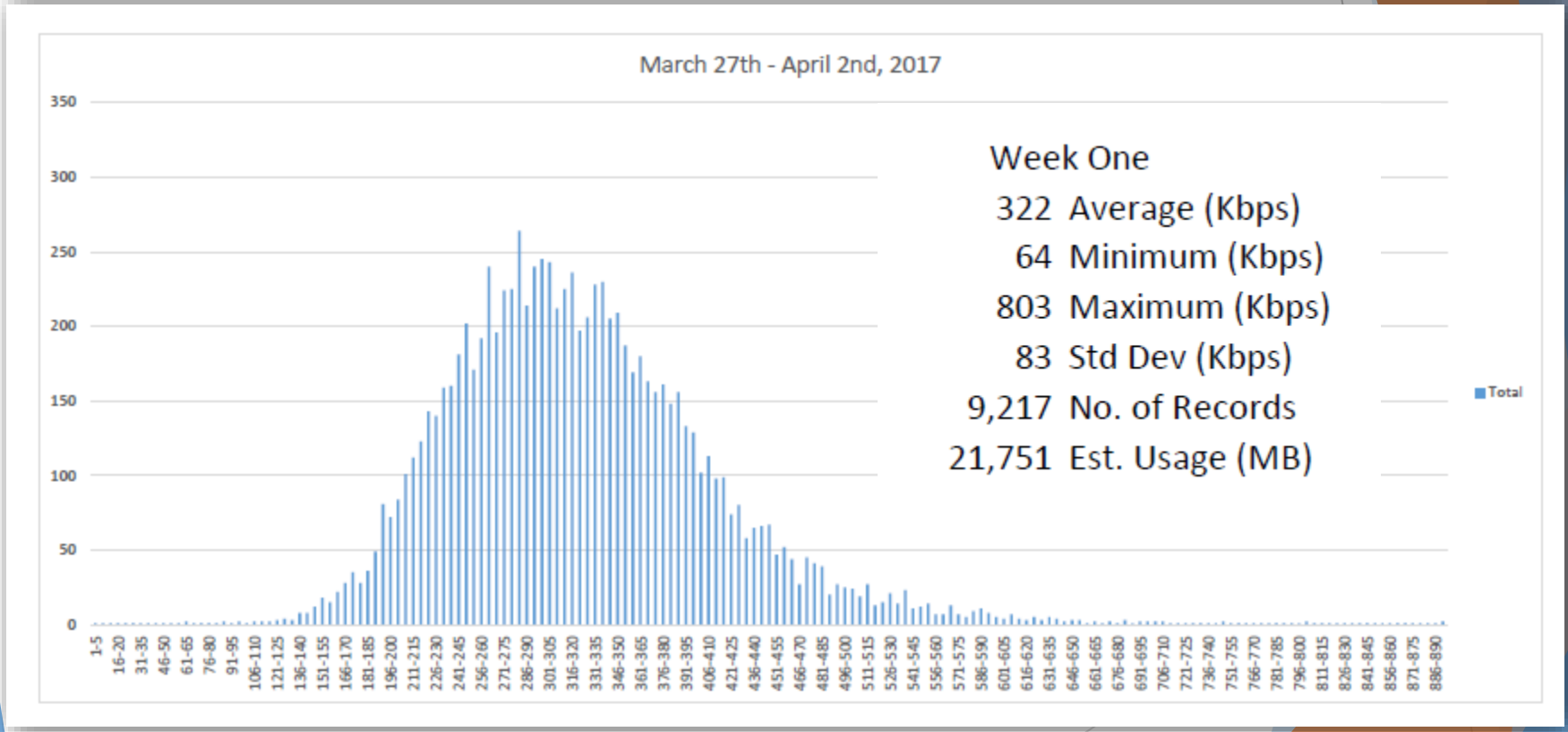
All Sites District Office Downlink Speed

- Test method
  - Configure Encoder to MJPEG, unlimited frame rate, unlimited bandwidth
  - Stream all sites to respective wireless providers into Traffic Management Center 24/7
  - Use custom logging script to monitor decoder connection and connected speed
  - Let run for a full week

Cellular Network Testing

Results

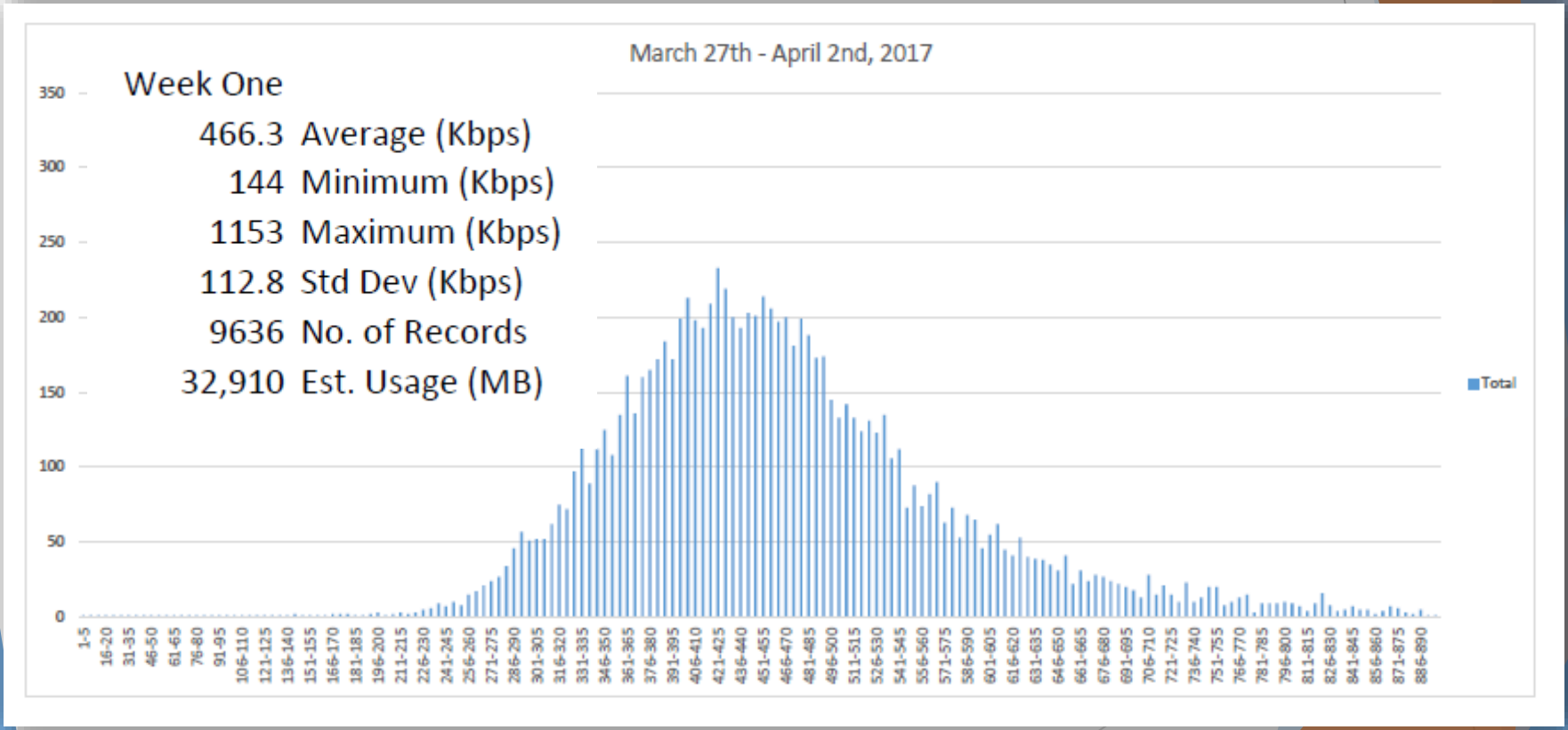
AT&T, Doyle



Cellular Network Testing

Results

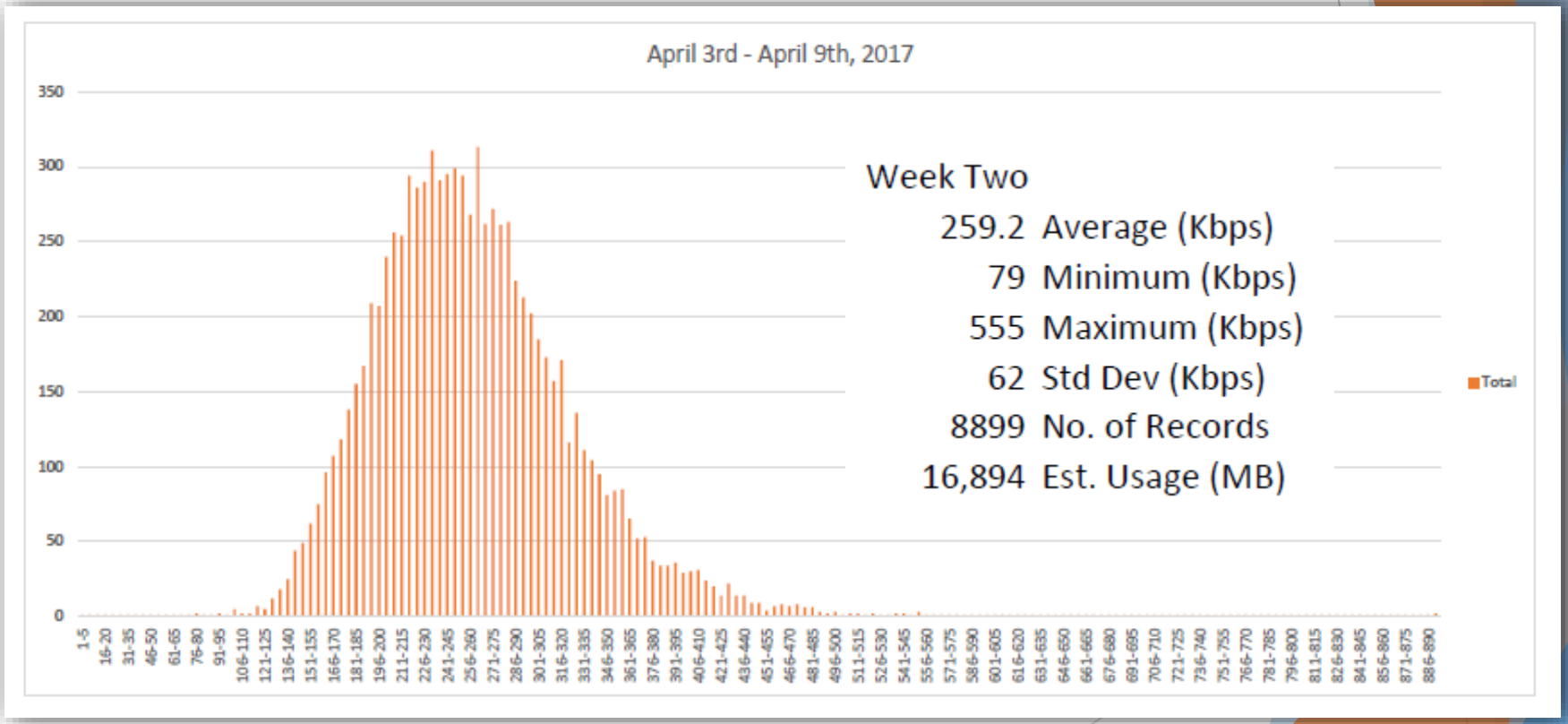
Verizon, North HIlt



Cellular Network Testing

Results

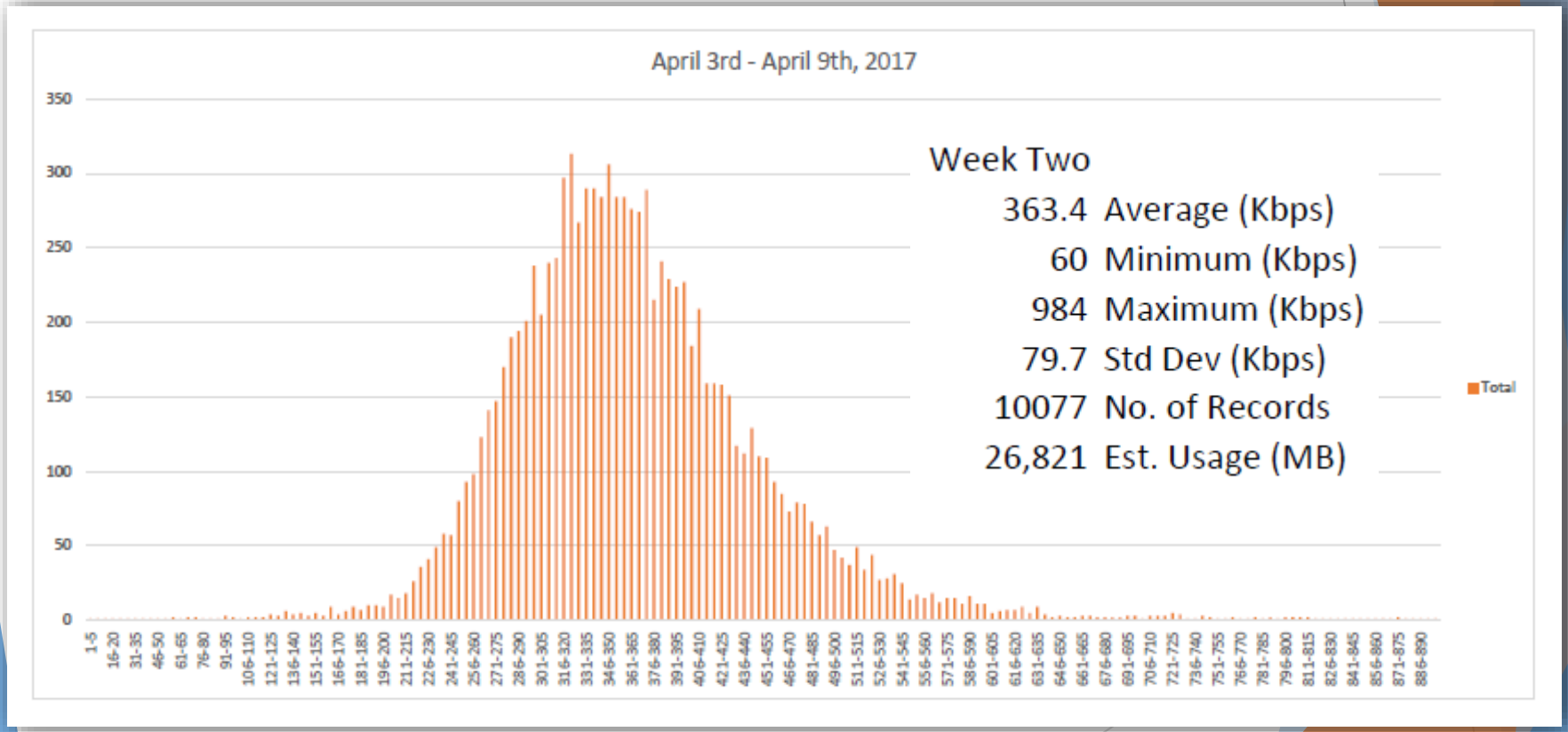
AT&T, Doyle, All Sites Streaming



Cellular Network Testing

Results

Verizon, North HIlt, All Sites Streaming



Cellular Network Testing

Results

AT&T

Average DO Downlink Speed			Average Minimum		
	Week 1	1,071 Kbps		Week 1	40 Kbps
	Week 2	1,386 Kbps		Week 2	68 Kbps
	Delta	315 Kbps		Delta	28 Kbps
Average Speed per site			Average Maximum		
	Week 1	357 Kbps		Week 1	845 Kbps
	Week 2	277 Kbps		Week 2	574 Kbps
	Delta	-80 Kbps		Delta	-271 Kbps
Estimated Data Usage at the DO			Average Std Dev		
	Week 1	74,457 MB		Week 1	92 Kbps
	Week 2	96,539 MB		Week 2	70 Kbps
				Delta	-22 Kbps

Cellular Network Testing

Results

Verizon

Average DO Downlink Speed		
Week 1	1,485	Kbps
Week 2	2,457	Kbps
Delta	972	Kbps
Average Speed per site		
Week 1	495	Kbps
Week 2	351	Kbps
Delta	-144	Kbps
Estimated Data Usage at the DO		
Week 1	104,813	MB
Week 2	174,545	MB

Average Minimum		
Week 1	180	Kbps
Week 2	51	Kbps
Delta	-129	Kbps
Average Maximum		
Week 1	1,150	Kbps
Week 2	889	Kbps
Delta	-261	Kbps
Average Std Dev		
Week 1	117	Kbps
Week 2	88	Kbps
Delta	-29	Kbps

Cellular Network Testing

Bandwidth Considerations

AT&T

Prob. of Streaming at Conf. Speed			Simultaneous
Config. Speed Kbps	Week 1	Week 2	Streaming Cameras
32	99.98%	99.98%	43
64	99.93%	99.88%	21
96	99.77%	99.51%	14
128	99.36%	98.34%	10
160	98.39%	95.27%	8
192	96.36%	88.77%	7
224	92.59%	77.55%	6
256	86.39%	61.79%	5
288	77.34%	43.76%	4
320	65.62%	26.95%	4
352	52.17%	14.20%	3
384	38.46%	6.32%	3
416	26.07%	2.35%	3

1,400 Kbps
Assumed Downlink at the DO based on Week 2 average usage

Cellular Network Testing

Bandwidth Considerations

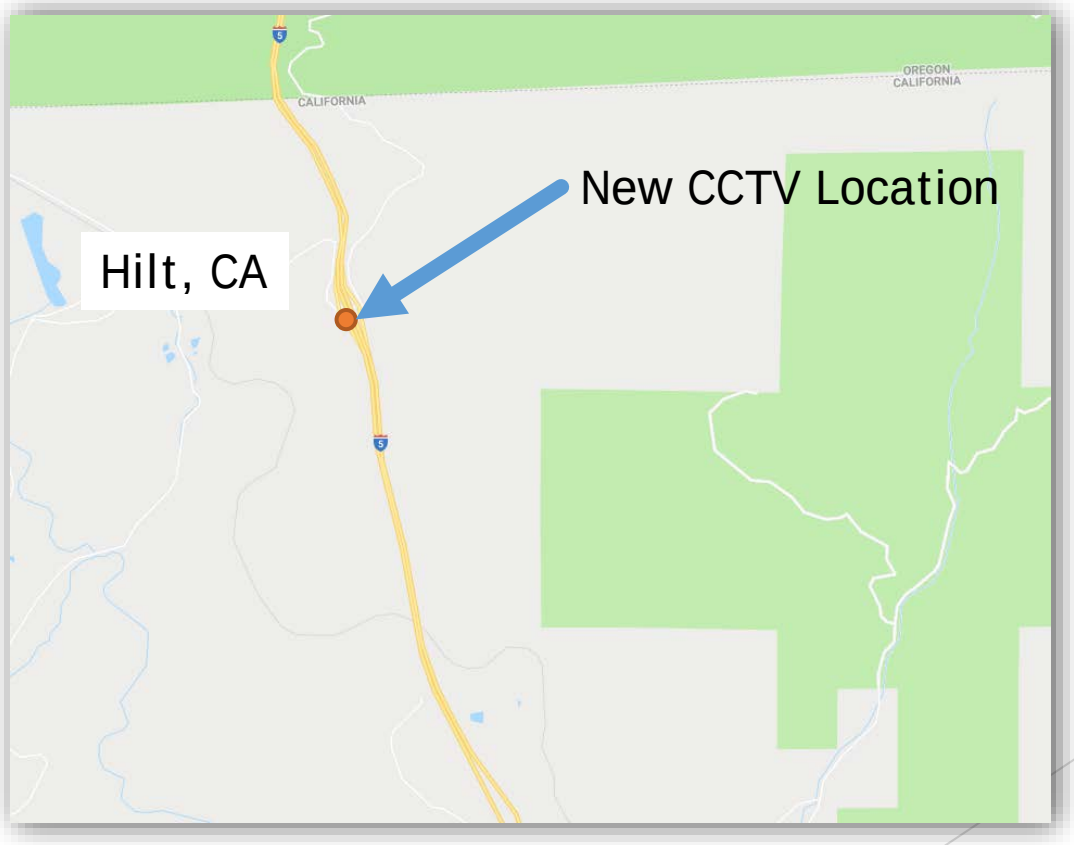
Verizon

Prob. of Streaming at Conf. Speed			Simultaneous
Config. Speed Kbps	Week 1	Week 2	Streaming Cameras
32	100.00%	99.99%	78
64	99.99%	99.94%	39
96	99.97%	99.81%	26
128	99.91%	99.44%	19
160	99.79%	98.50%	15
192	99.52%	96.46%	13
224	98.97%	92.55%	11
256	97.95%	85.98%	9
288	96.16%	76.30%	8
320	93.26%	63.77%	7
352	88.92%	49.55%	7
384	82.86%	35.38%	6
416	75.02%	23.01%	6

2,500 Kbps
Assumed Downlink at the DO based on Week 2 average usage

Deployment Problems

Hilt Sandhouse



Deployment Problems

Hilt Sandhouse

- Could make voice call on AT&T

Deployment Problems

Hilt Sandhouse

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- Cell towers located across the street

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  - Router would not attach to AT&T's network

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- Regrouped and contacted AT&T

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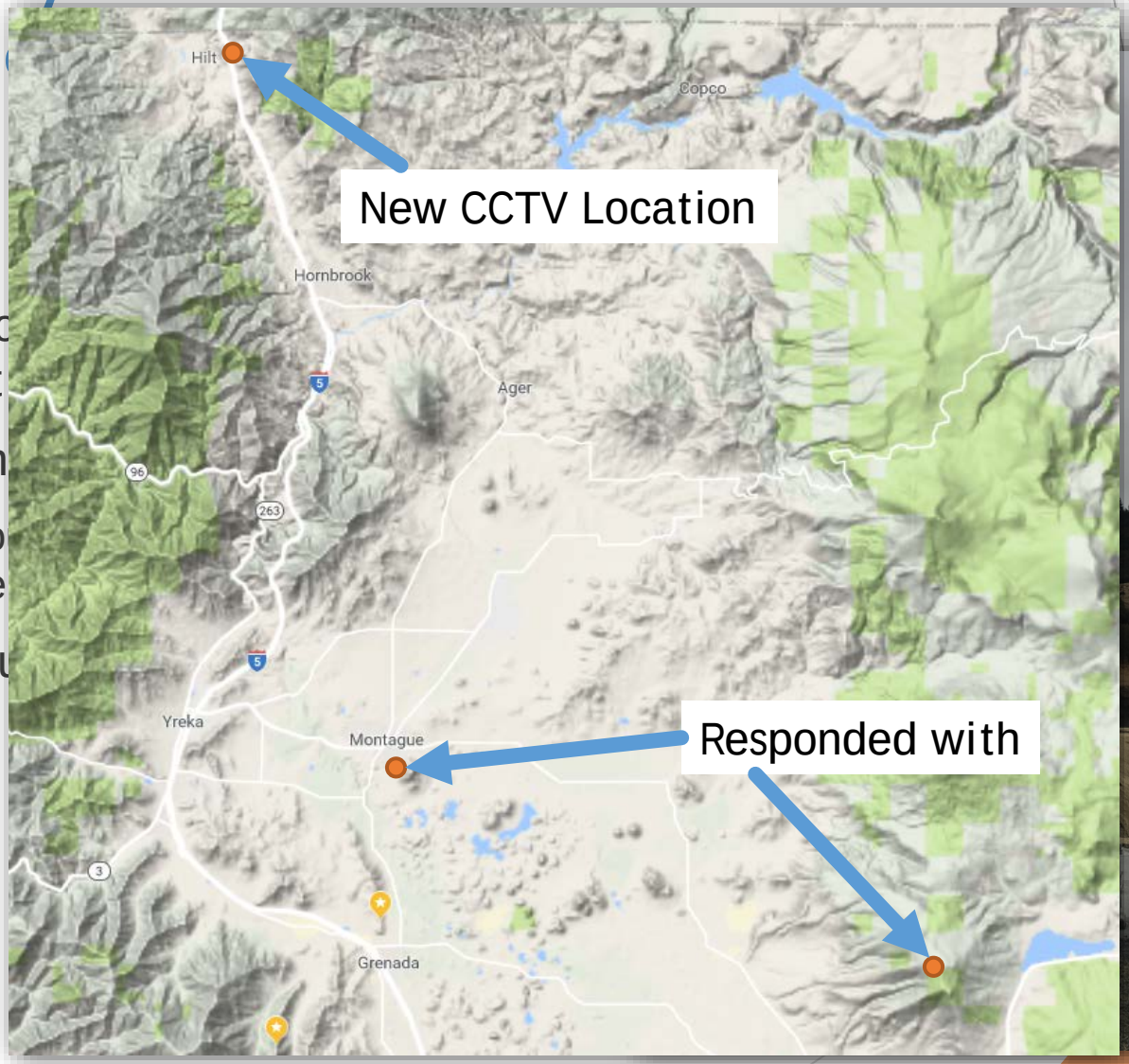

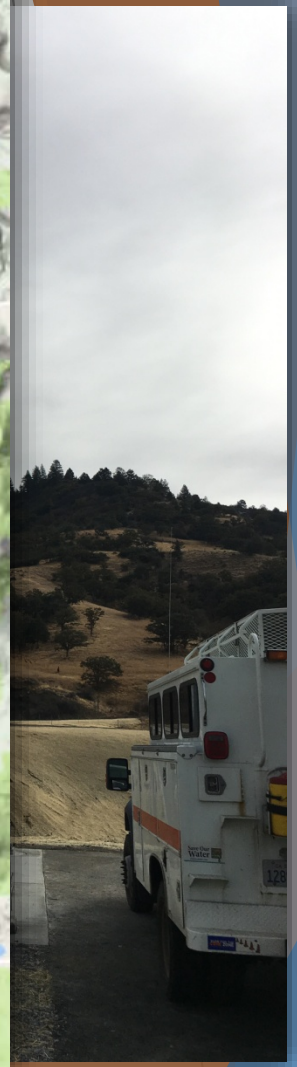

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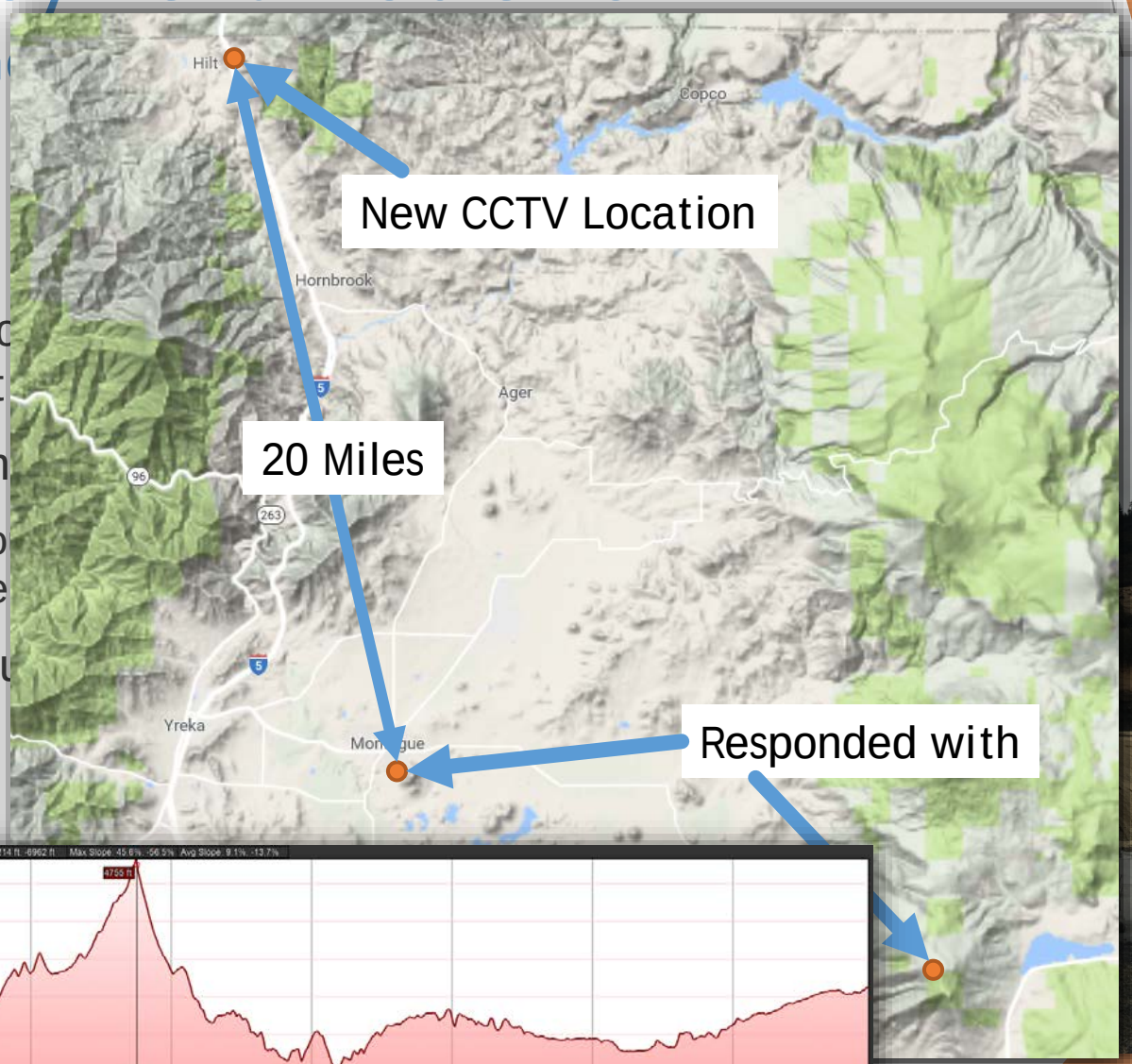

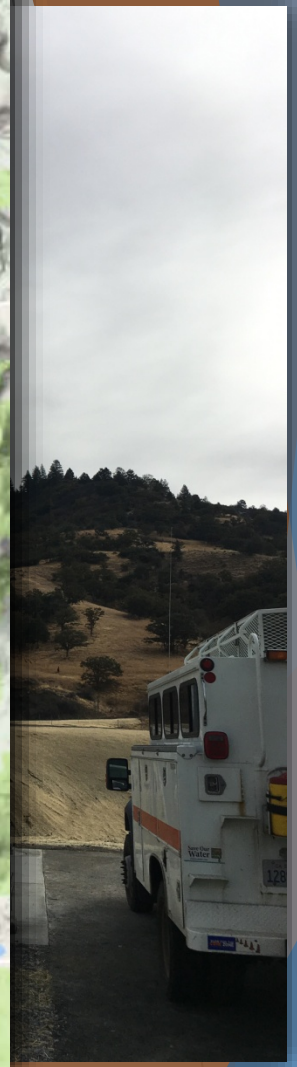

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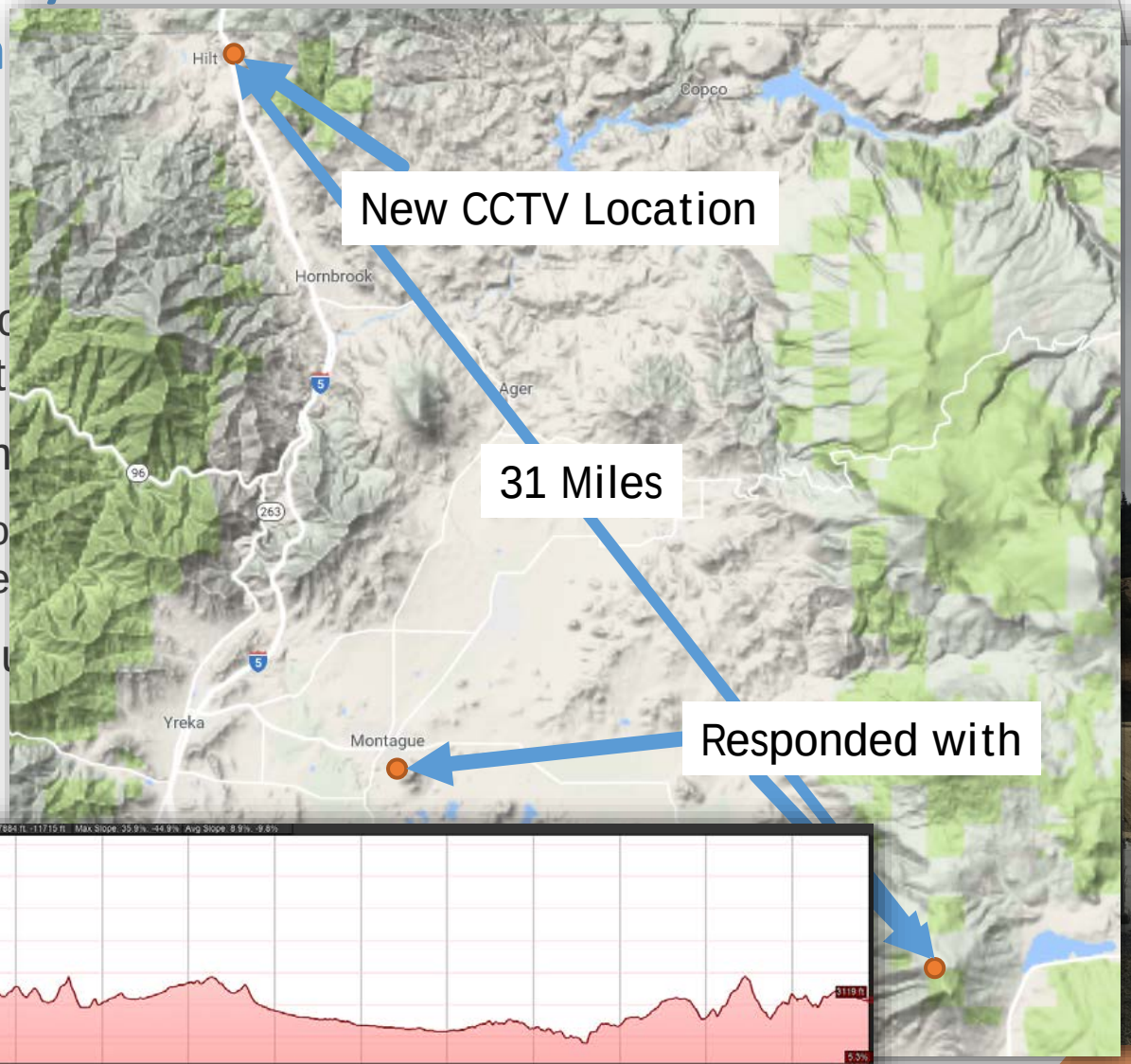

Deployment Problems

Hilt Sandhouse

- Could make voice call on AT&T
- Cell towers located across the street
- Attempted to deploy AT&T
  - Router would not attach to AT&T's network
- Regrouped and contacted AT&T
- Found with reasonable certainty where the nearest AT&T site was located via FCC ULS searching

Deployment Problems

Hilt Sandhouse

- Could make voice call on AT&T
- Cell towers located across the street
- Attempted to
  - Router wou
    network
- Regrouped an
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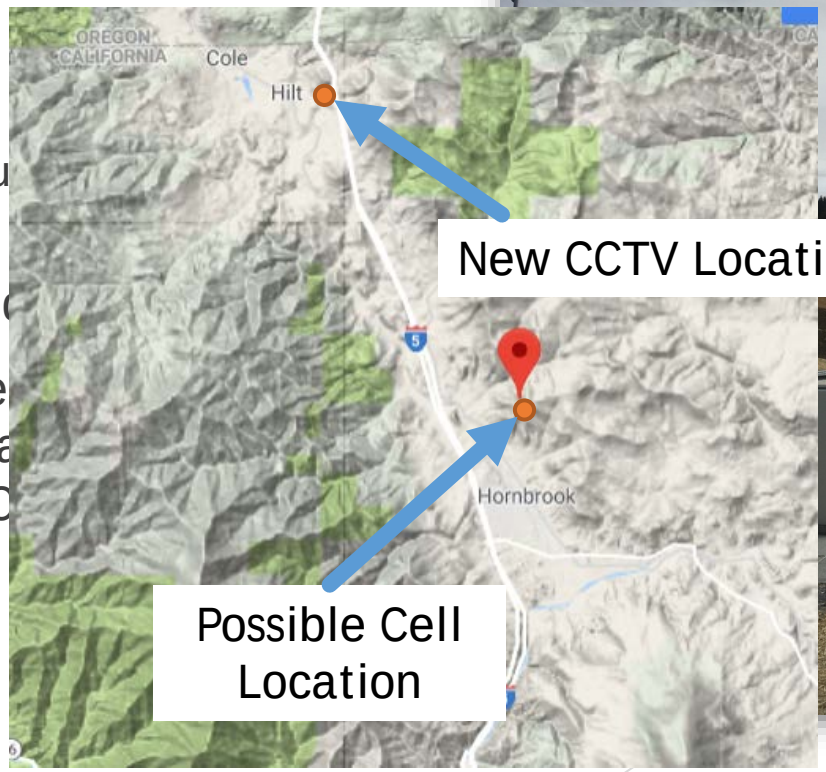

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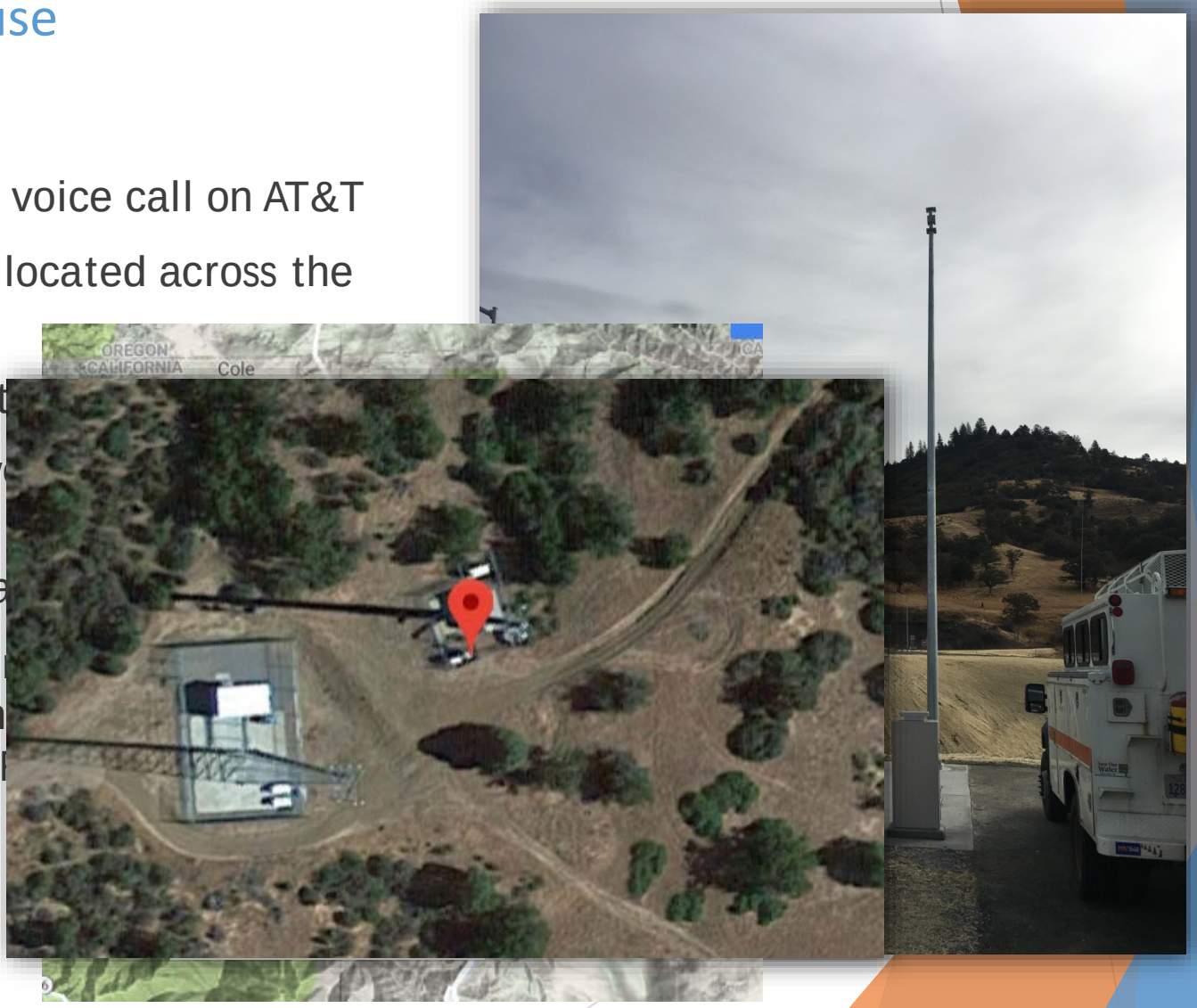

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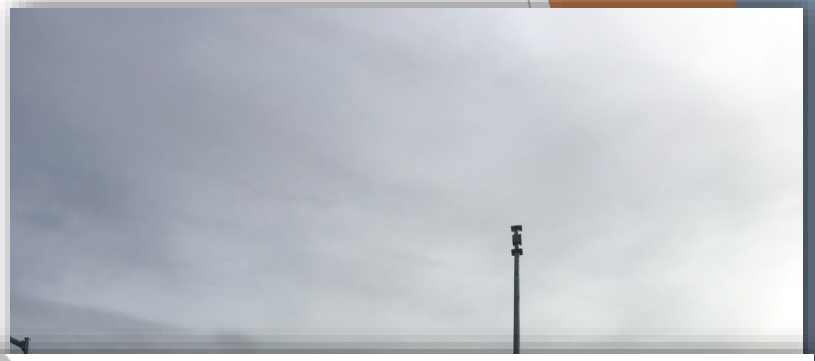


Fixed Location Address or Area of Operation:
5510 Anderson Grade Road
City: Yreka **County:** SISKIYOU **State:** CA

Loc No.	Location Name	Latitude	Longitude	Elevation	Antenna Structure Registration No.
001	Vista	41-47-37.8 N	122-35-03.1 W	1028.7	
002	Butcher Hill	41-43-29.0 N	122-37-49.0 W	966.2	
003	HORNBROOK 1	41-55-47.4 N	122-33-26.6 W	935.4	

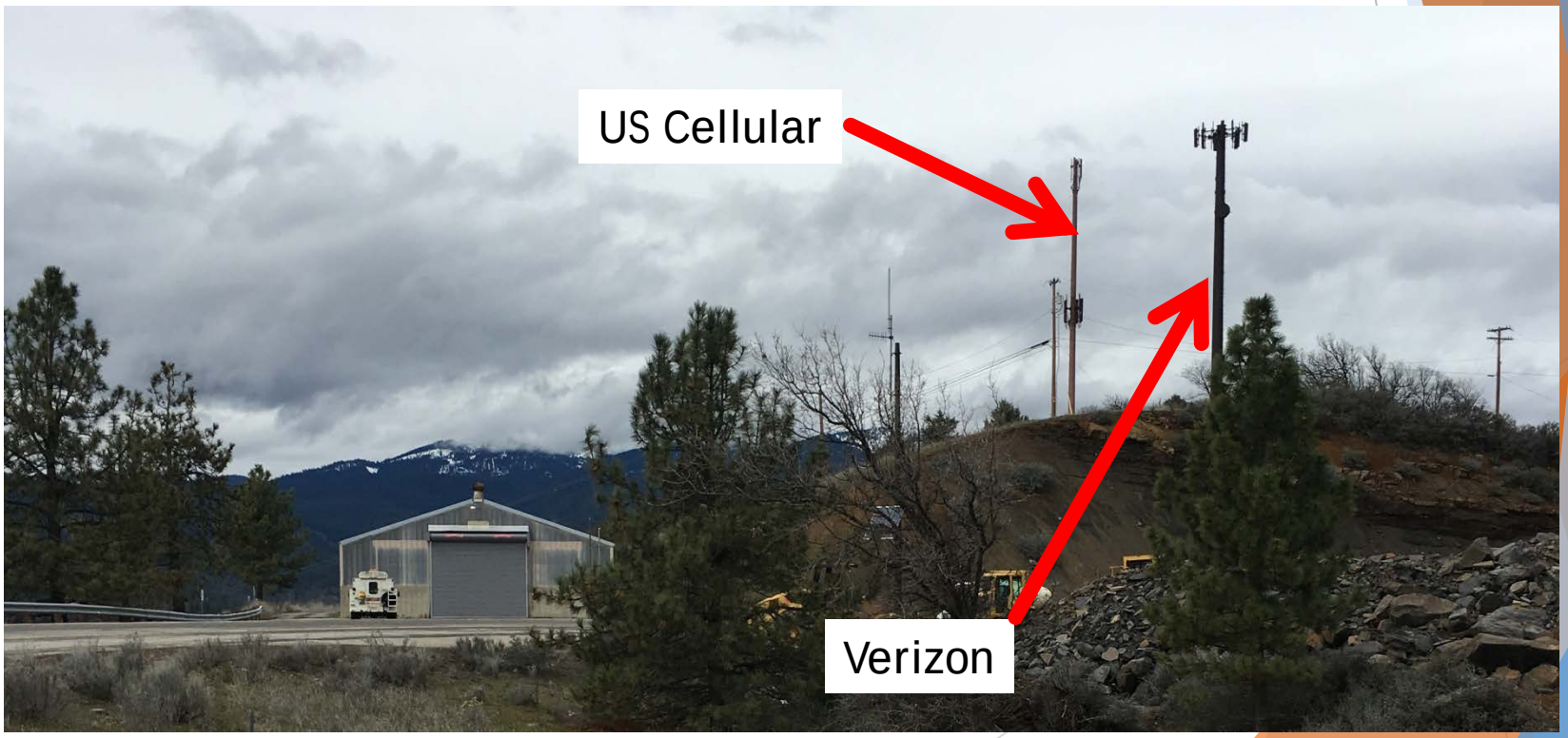
FREQUENCY PATHS

Frequency (MHz)	Tol (%)	Emission Desig	EIRP (dBm)	Constr Date	Path No	Seg	Emit Loc No	Ant Hgt (m)	Gain (dBi)	Beam (deg) Reflector Ht(m)xWd(m)	POL	AZIM (deg)	Rec Loc No	Rec Call Sign
10855.0	0.00100	40M0D7W	62.700	06-29-2016	002	1	001	27.4	43.8	1.1	H	8.4	003	
10895.0	0.00100	40M0D7W	62.700	06-29-2016	003	1	001	27.4	43.8	1.1	V	8.4	003	
19345.0	0.00100	30M0D7W	54.000	02-10-2017	004	1	001	14.0	43.5	1.1	H	206.5	002	WPTY615

Deployment Problems

Hilt Sandhouse

- Found that cellular towers were US Cellular and Verizon



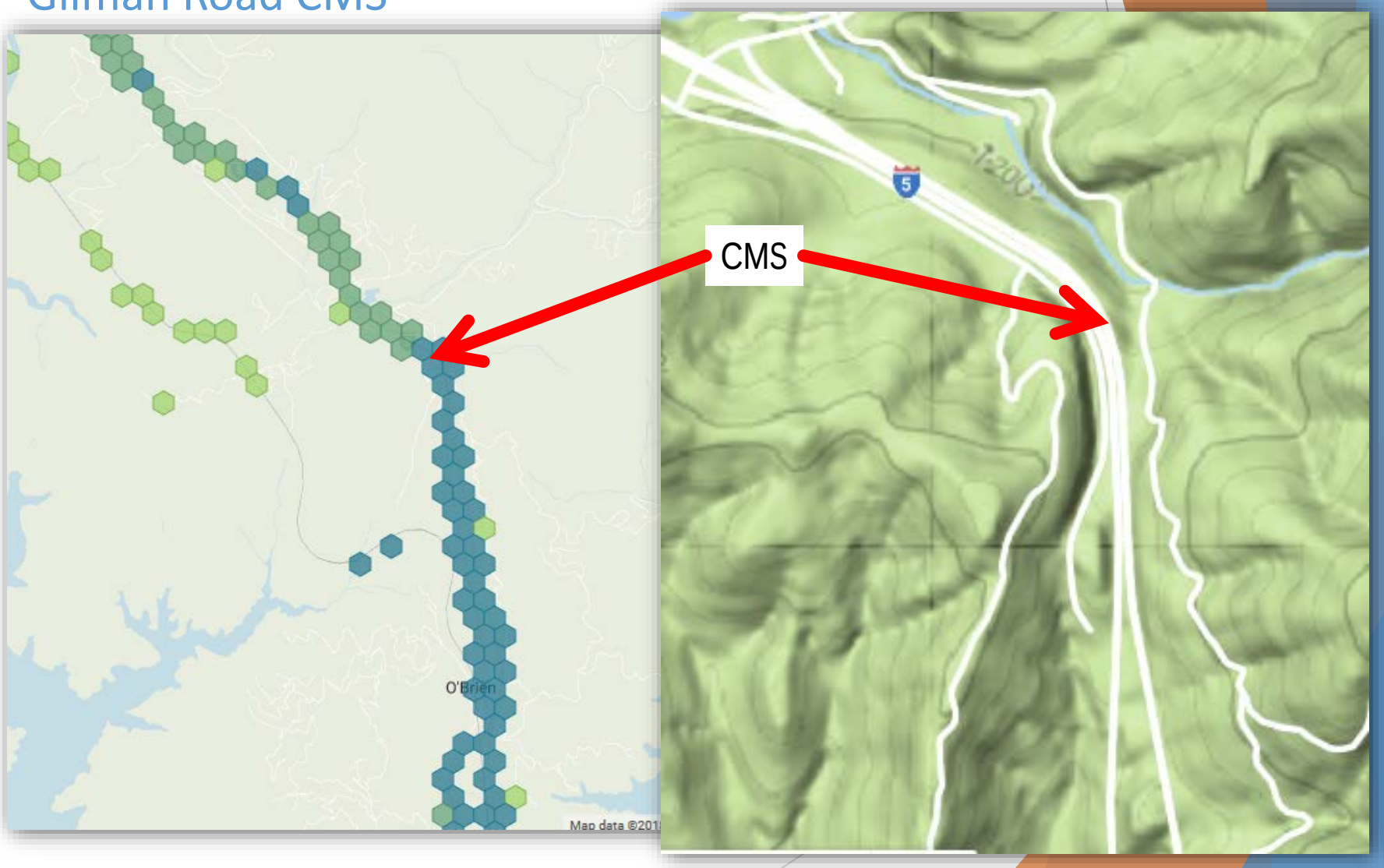
Deployment Problems

Gilman Road CMS

- 2G cellular network at CMS location with only power
  - Installed in the dark ages before office was established
- AT&T announced end of support of 2G cellular network
- Decided the only upgrade path was cellular
- Preformed a “drop-in” replacement upgrade
- Found that the location would not attached to AT&T with anything but 3G (OK for CMS applications)

Deployment Problems

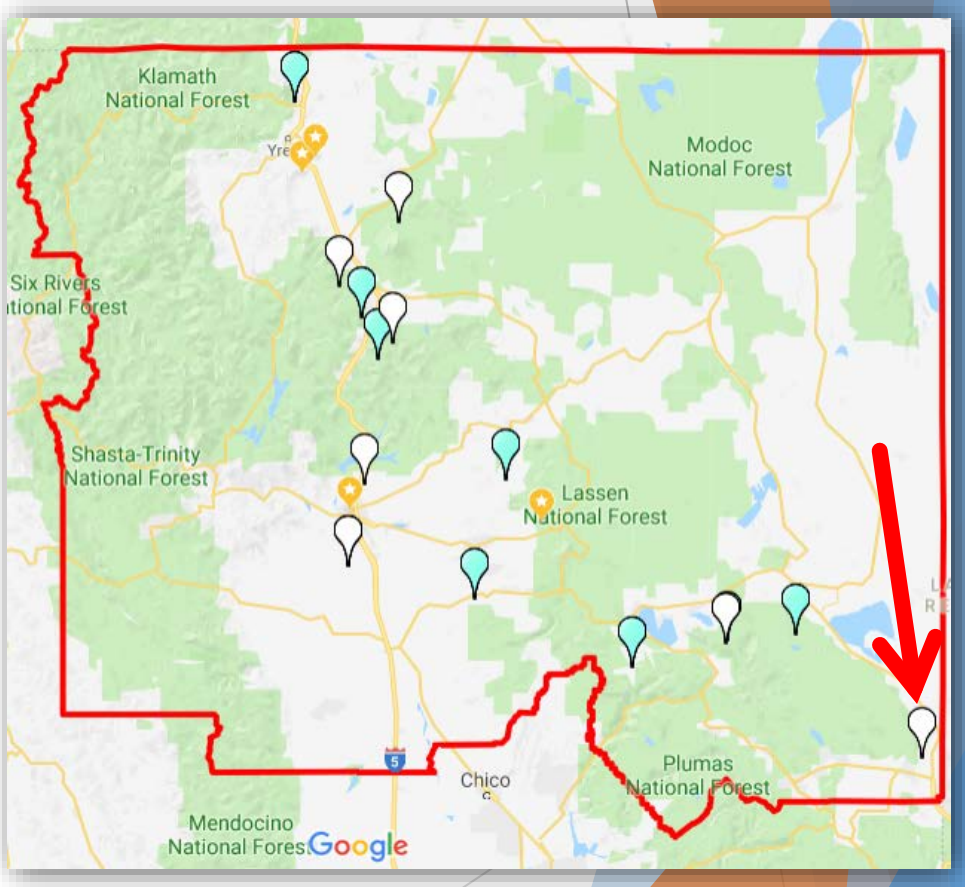
Gilman Road CMS



Deployment Problems

Doyle

- Remote location on US-395 near Nevada border



Deployment Problems

Doyle

- Remote location on US-395 near Nevada border
- Site went down in the middle of the night
- Checked router logs
  - Showed site was up for several weeks
  - Showed site was “connected” to mobility network
- Contacted wireless company
  - Was told there was a widespread power outage in the area

Deployment Problems

Doyle

- Contacted wireless company (cont.)
  - Was told they were dispatching a snow cat to refuel on site generator
- There was no other site for cellular modem to fail over to

Deployment Problems

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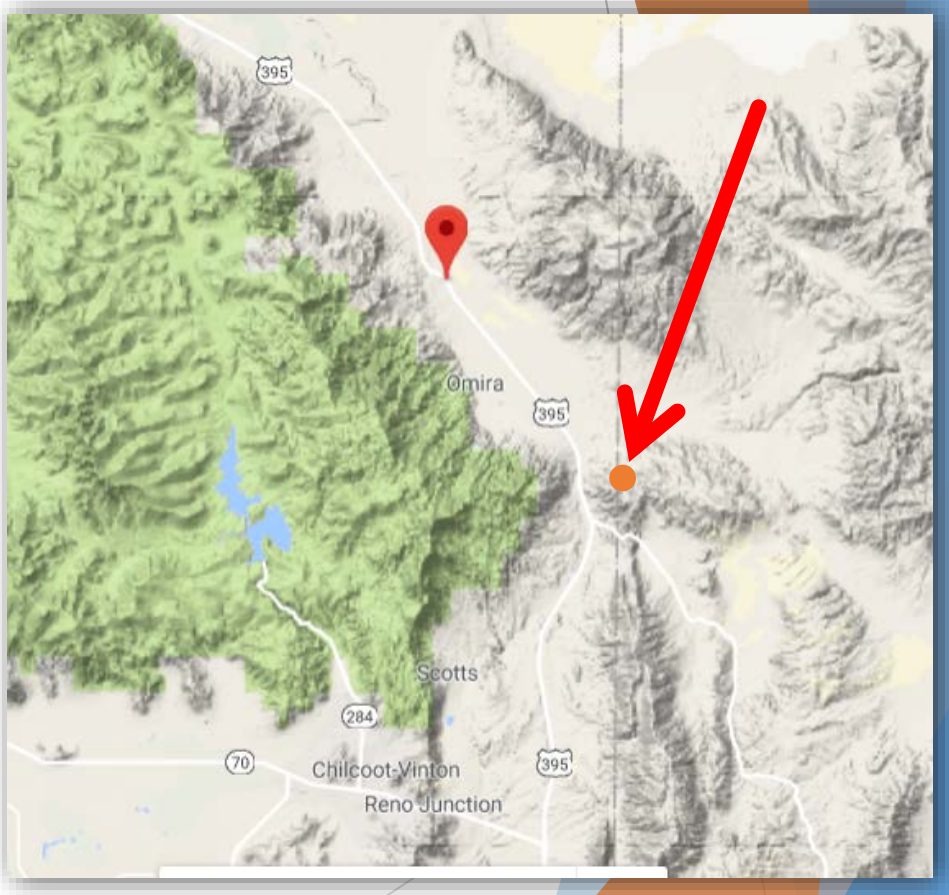
- Poking around found the site



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Deployment Problems

Doyle

- Contacted wireless company (cont.)
  - Was told they were dispatching a snow cat to refuel on site generator
- There was no other site for cellular modem to fail over to
- Poking around found the site
- Could not positively identify another site
- During outage events the site could see another cellular tower, but could not attach to the network

Deployment Problems

Doyle

- Similar outage events happened three separate times in 2017

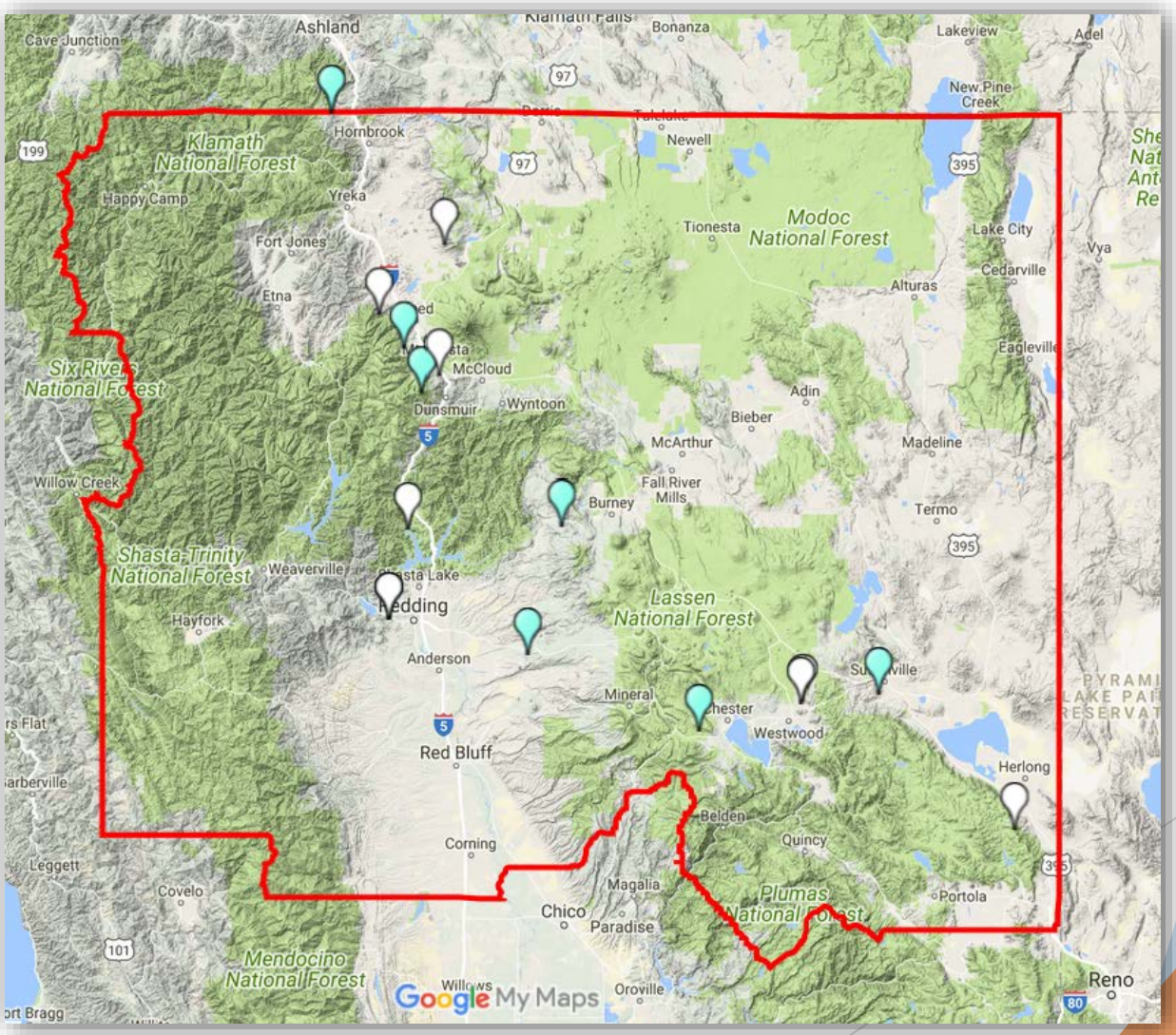
Deployment Conclusions

- Generally good coverage, but still very difficult to predict service and quality at an exact location
  - “Try it and see if it works” approach
  - Hard to engineer a large system over a large geographical area without extensive field time

Deployment Conclusions

- “Salt and Pepper” deployment strategy
  - Alternate carriers along corridors
    - Helps with potential corridor outage
  - Multiple carrier zero point tunnels
    - Helps with centralized entry point failures effecting single carrier
  - Multiple geographical locations for zero point hubs
    - Helps with overloading and hub failures effecting all carriers at single hub location

Deployment Conclusions



Deployment Conclusions

Cellular Technology appears to be a reasonable interim soliton to sunsetting circuit-switched and TDM services

- Caveats and Risks
  - Radio channel congestion
    - Depending on how carriers configure and deploy cellular radios, each radio will only be able to support a maximum amount of concurrent uses for both voice and data needs
    - Typical numbers found on the Internet vary widely
  - Back haul congestion
    - Rural areas lend themselves to daisy chain and star network topologies

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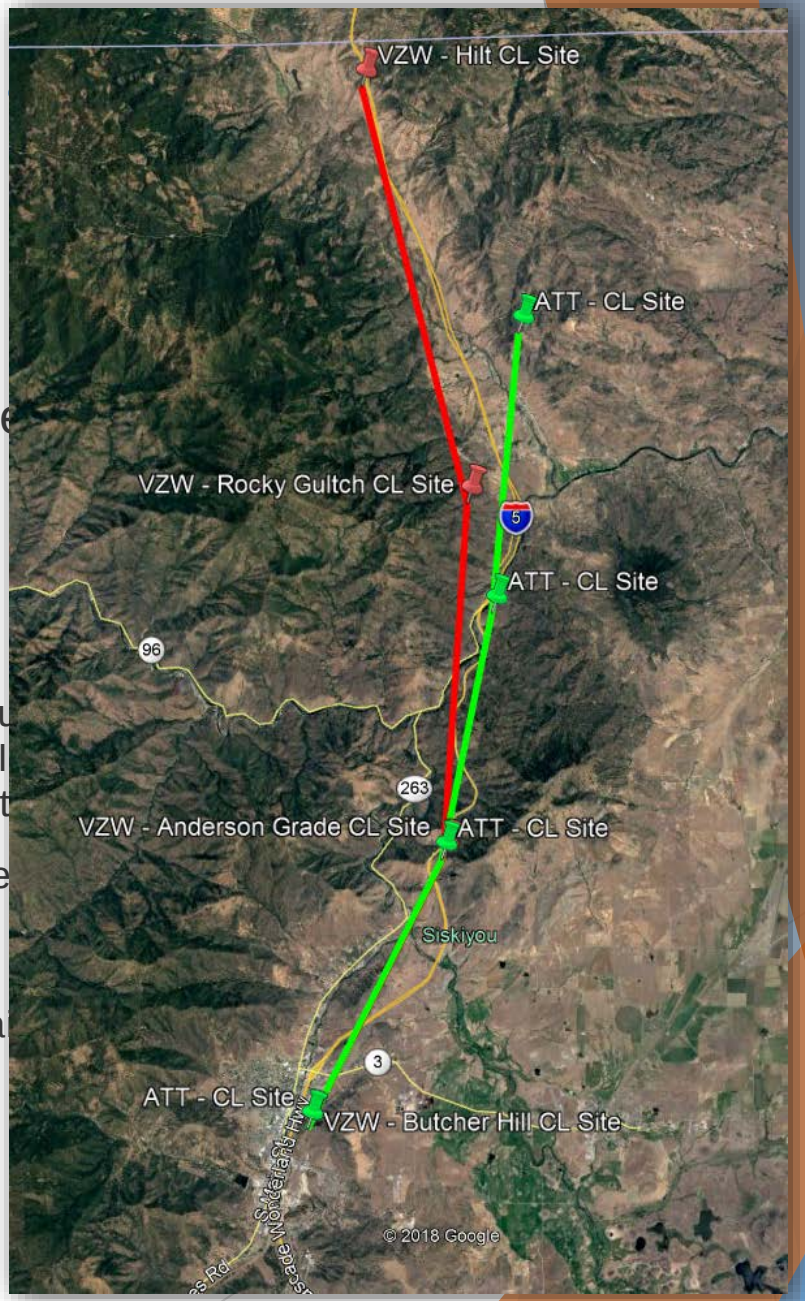

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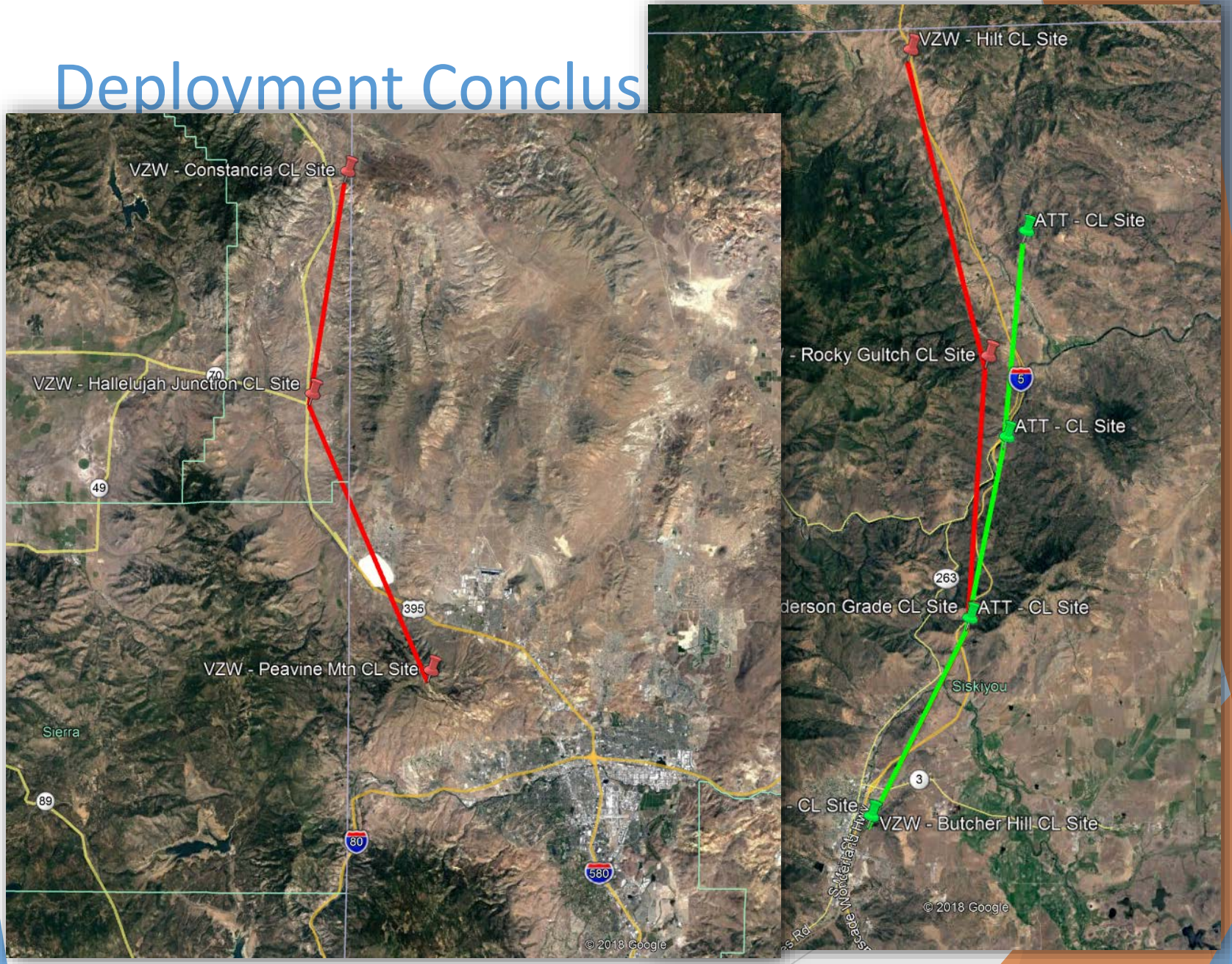

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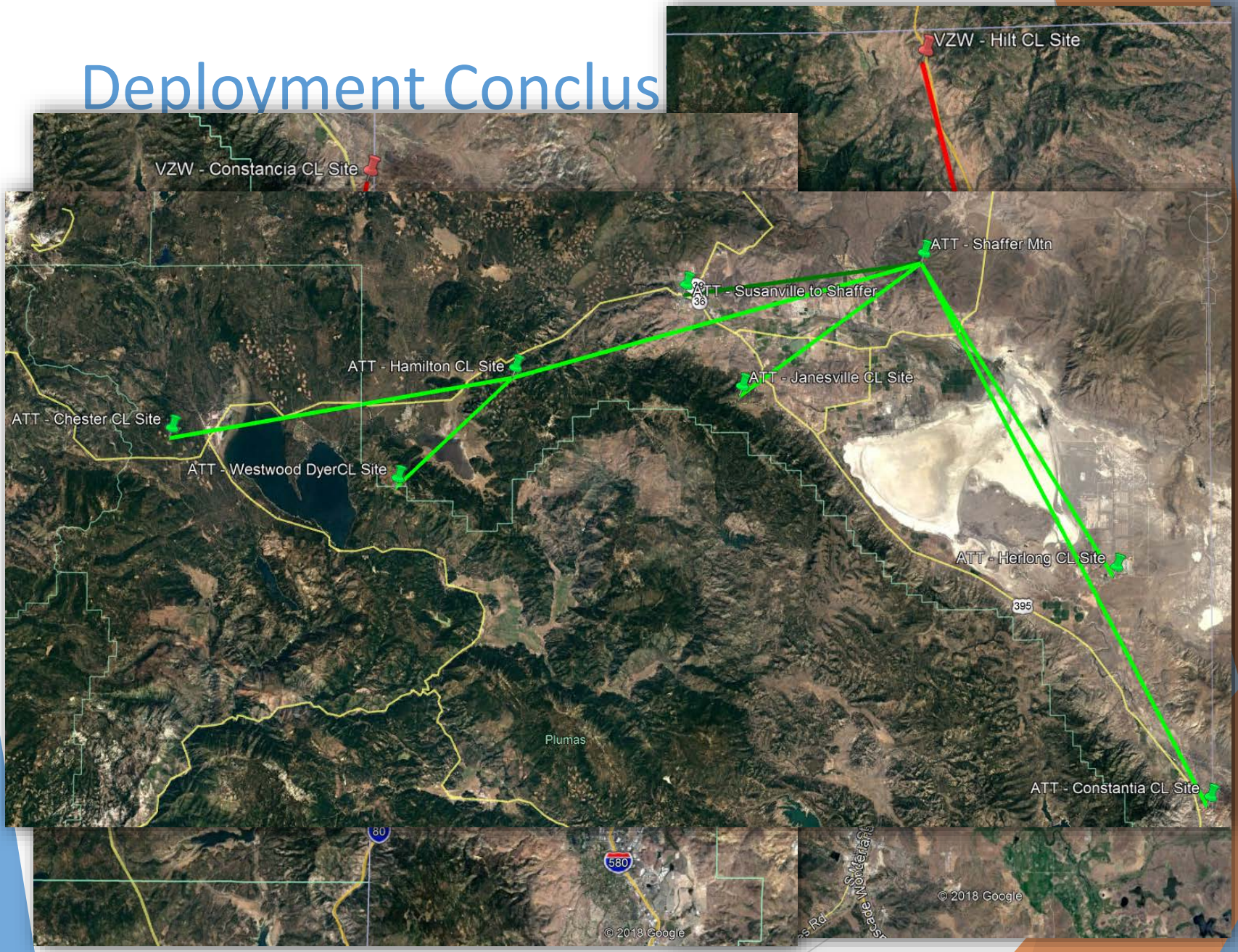


Deployment Conclusions

Cellular Technology appears to be a reasonable interim soliton to sunsetting circuit-switched and TDM services

- Caveats and Risks (cont.)
  - Back haul congestion (cont.)
    - Aviat Networks White Paper

    "LTE BACKHAUL REQUIREMENTS: A REALITY CHECK"

    "Because LTE handsets are statistically distributed within the three radio sectors and not downloading at maximum peak rates all the time, backhaul capacity can be split and overbooked among individual sectors."

    - Because of overbooking there may not be enough backhaul capacity to service all users in extreme loading conditions

Deployment Conclusions

Cellular Technology appears to be a reasonable interim soliton to sunsetting circuit-switched and TDM services

- Rural Cellular Network Studies
  - CT Initiated Preliminary Investigation and found nothing
  - No known study found

Deployment Conclusions
Data Usage

- Current contract with AT&T and Verizon allow for Government Unlimited usage for general use
  - Roughly $40/month
  - No radio channel priority
  - No backhaul QoS priority
- Both carriers offer Machine to Machine plans with various tiered pay per usage options
  - Cost depends on plan and actual usage
  - Radio channel priority IF PUBLIC SAFTEY
  - Backhaul QoS priority for a fee

Deployment Conclusions
Data Usage

- Carriers have expressed a desire to have our equipment transitioned to M2M data plans
- Current contract may change when up for negotiations
- M2M Usage example:
  - Typical field site data usage
    - Encoders are set at 2CIF, 50% Compression, MJPEG
    - 8hrs, 5 working days, approx. 20-25 GB/month
    - 12hrs, 5 working days, approx. 30-35 GB/month
    - 24/7 operations, approx. 90-100 GB/month
    - Image Grab every 5 mins approx. 0.5 GB/month

Deployment Conclusions
Data Usage

- M2M Usage example (cont.):
  - Typical District Office usage (Aggregate of all streaming sites)
    - Worse case, 15 simultaneous streams
    - 8hrs, 5 working days, approx. 340-350 GB/month
    - 12hrs, 5 working days, approx. 500-520 GB/month
    - 24/7 operations, approx. 1.4-1.5 TB(1,400-1,500 GB)/month
    - Image Grabs every 5 mins approx. 4-4.5 GB/month

Deployment Conclusions
Data Usage

- M2M Usage example (cont.):
  - Prices quoted for M2M data plans, and cost estimates
    - $99/month with 20GB of M2M data, $8/GB over
    - Field Sites (each)
      - 8hrs, 5 working days, approx. $120-130/month
      - 12hrs, 5 working days, approx. $200-220/month
      - 24/7 operations, approx. $700-750/month
    - Central Office
      - 8hrs, 5 working days, approx. $2500/month
      - 12hrs, 5 working days, approx. $4K/month
      - 24/7 operations, approx. $10K/month

Deployment Conclusions

Moving Forward

- Cell is an additional tool that can be used for backhaul communications
- However, there may be unforeseen issues in a major crises
- Left unchecked operating cost may skyrocket

Deployment Conclusions

Moving Forward

- Installation Methods
  - Pole Mounted antenna

Deployment Conclusions
Moving Forward

- Installation Methods
  - Pole Mounted antenna

    Omnidirectional

Deployment Conclusions

Moving Forward

- Installation Methods
  - Pole Mounted antenna
    - Omnidirectional
    - Directional

Deployment Conclusions
Moving Forward

- Installation Methods
  - Pole Mounted antenna
    - Omnidirectional
    - Directional
  - Lightning Protection

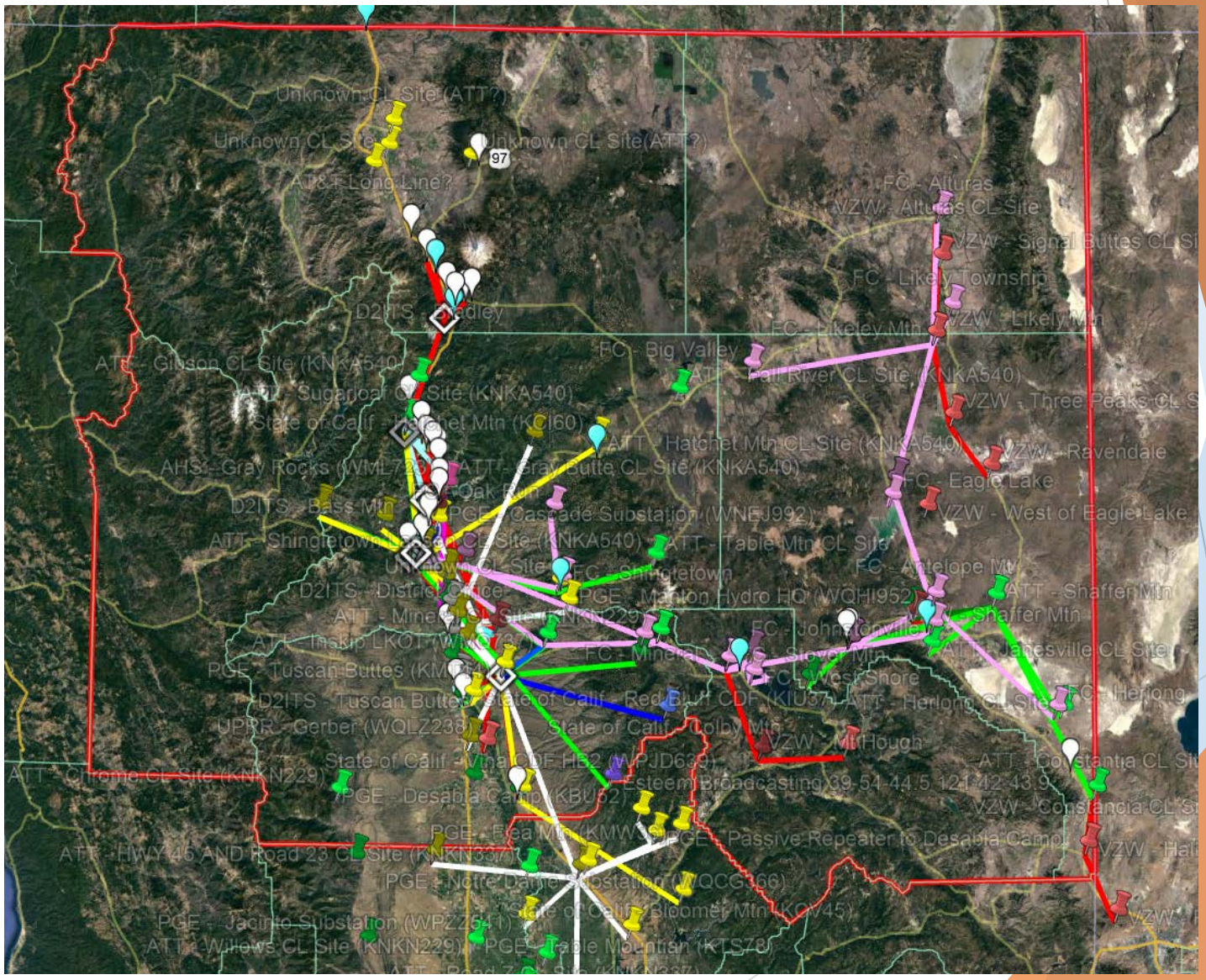
Deployment Conclusions
Moving Forward

- Install more zero point tunnel network entry points at different physical locations
  - Minimize potently for single points of failure
  - Deploy routing protocol on routers
    - OSPF, RIP

Deployment Conclusions
Moving Forward

- Install more zero point tunnel network entry points at different physical locations
  - Minimize potently for single points of failure
  - Deploy routing protocol on routers
    - OSPF, RIP
- Develop robust testing method for field verification
  - Test devices (multiple carriers)
  - Use of directional antennas mounted on pole
    - Fox Hunting Amateur Radio

Questions


Unknown CL Site (ATT?)
Unknown CL Site
Unknown CL Site(ATT?)
AT&T Long Line?
97
FC - Alturas
VZW - Alturas CL Site
VZW - Signal Buttes CL Si
FC - Likely Township
FC - Likely Mtn
VZW - Likely Mtn
D2ITS - Ladley
FC - Big Valley
ATT - Gibson CL Site (KNKA540)
ATT - Sugarloaf CL Site (KNKA540)
ATT - Hat River CL Site (KNKA540)
VZW - Three Peaks CL Si
State of Calif - Hatchet Mtn (KCI60)
ATT - Hatchet Mtn CL Site (KNKA540)
AHS1 - Gray Rocks (WIML7
ATT - Gray Butte CL Site (KNKA540)
VZW - Ravendale
D2ITS - Bass Mtn
Oak Run
FC - Eagle Lake
PGE - Cascade Substation (WNEJ992)
VZW - West of Eagle Lake
ATT - Shingletown
CL Site (KNKA540)
ATT - Table Mtn CL Site
FC - Shingletown
FC - Antelope Mtn
D2ITS - District Office
PGE - Manton Hydro HQ (WQHI952)
ATT - Shaffer Mtn
ATT - Mine
Shaffer Mtn
FC - John
ATT - Janesville CL Site
FC - Mine
Tuscan Buttes (KM
West Shore
D2ITS - Tuscan Butte
State of Calif - Red Bluff CDF (KIU37)
ATT - Herlong CL Site
FC - Herlong
UPRR - Gerber (WQLZ238)
State of Calif - Colby Mtn
VZW - Mt Hough
State of Calif - Vina CDF HB2 (WPJD639)
ATT - Constantia CL Sit
ATT - Chrome CL Site (KNKN229)
Esteem Broadcasting 39 54 44.5 121 42 43.9
PGE - Desabla Camp (KBU52)
VZW - Constancia CL S
PGE - Fea Mtn (KMW
PGE - Passive Repeater to Desabla Camp
ATT - HWY 45 AND Road 23 CL Site (KNKN33
VZW - Hat
PGE - Notre Dame Substation (WQCG366)
State of Calif - Bloomer Mtn (KCV45)
PGE - Jacinto Substation (WPZZ541)
ATT - Willows CL Site (KNKN229)
PGE - Table Mountain (KTSZ8)

Questions