TMC-TMS Communications: Overview and Demonstration

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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.
Disclaimer

This is a research study and the recommendations and viewpoints presented within do not necessarily represent those of the sponsor agency, the California Department of Transportation.
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.

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.
Kick-off Trip Site Visits: Collier’s Tunnel
Kick-off Trip Site Visits: Confusion Hill
Kick-off Trip Site Visits: Redwoods
Later Visits:
Redwood Forest Near CMS along US 101
Kick-off Trip Site Visits: D2 Bass Mountain
Kick-off Trip Site Visits: View to North from D2 Bass Mountain
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.
Three factors that determine communication capabilities:

- Environment
- Power
- Communications

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

**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

- **5.8 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)
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
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
Analysis of Communications Technologies

EXAMPLE:
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

EXAMPLE:
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.
EXAMPLE:
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.
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
“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.
SmartPhone CDMA Signal Strength Log - Summer 2007

Cell Towers as Identified from FCC Database
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
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 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

Colliers Tunnel

-75 dBm
-85 dBm
-95 dBm

-72 dBm
-82 dBm
-92 dBm
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
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
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.
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

- Focuses on methodology and tools.
  - ComStudy 2.2
  - MicroPath
  - MapPoint and Other GIS
  - Google Earth
  - Net Present Worth / Net Present Value
  - Friis Transmission Formula
Overall Conclusions

- There is no “silver bullet” solution.
- Sound engineering judgment and design are essential for developing a system that meets the needs of District 1.
- Strategies such as those used by District 2 to develop a hybrid, IP-based network with a clear migration plan are applicable and should be used.
- There will still be locations such as Collier’s Tunnel in which there are few if any viable options.
- The problem must be approached from a “systems” perspective, accounting for the entire system rather than isolated deployments.
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Questions?