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This report documents the research project "Mobile Real Time Information System for Snow Fighter Supervisors - System Design & Test." The primary goal of this research project was to investigate cost-effective and reliable communications in challenging environments. The target application is communications between Caltrans snowplows and supervisor vehicles. Messaging and mapping applications were designed based on a store-and-forward architecture to address intermittent data communications. The design included on-board processing and communications, human machine interface, and a variety of sensing. The sensing information was passed between vehicles, and displayed as vehicle state in the mapping application. The system was designed to leverage commercial-off-the-shelf components to the greatest possible extent. As part of the research, to evaluate the need for the store-and-forward architecture, a cellular signal coverage and strength survey was performed for California's snow-affected routes. The details of this survey, including app design and data collection results, are presented herein.

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Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
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Mobile Real-Time Information System for Snow Fighter Supervisors - System Design & Test

Stephen Donecker, Kin Yen, Bahram Ravani &
Ty A. Lasky (Principal Investigator)

Report Number: CA16-2299
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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
AB	Assembly Bill
ATIRC	Advanced Transportation Infrastructure Center
ATMS	Advanced Transportation Management System
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
CMS	Changeable Message Signs
COTS	Commercial Off–The-Shelf
DOE	Division of Equipment
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
DSRC	Dedicated Short Range Communication
ECU	Engine Control Unit
FCC	Federal Communication Commission
FIDAS	Fleet In-vehicle Data Acquisition Systems
FOT	Field Operational Test
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-ATD	GPS Automated Travel Diary
GSM	Global System for Mobile Communications
HMI	Human Machine Interface
HSE	High Sierra Electronics
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IRIS	Intelligent Roadway Information System
IT	Information Technology
LEO	Low Earth Orbit
LLC	Limited Liability Corporation
MAC	Media Access Control
MnDOT	Minnesota Department of Transportation
MRTIS	Mobile Real-Time Information System
MSU	Montana State University
OASIS	Operational Area Satellite Information System
OFDM	Orthogonal Frequency Division Multiplexing
OHS	Office of Homeland Security
OpenBTS	Open Base Transceiver Station
OS	Operating System
OSS	One-Stop-Shop
PC	Personal Computer
PCI	Peripheral Component Interconnect
PRN	Pseudo-Random Noise
R&D	Research & Development
RS	Recommended Standard
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SMS	Short Message Service

Acronym	Definition
SNR	Signal-to-Noise Ratio
SR	State Route
SSID	Service Set ID
SUV	Sport Utility Vehicle
TAG	Technical Advisory Group
VPN	Virtual Private Network
WGS84	World Geodetic System 1984
WTI	Western Transportation Institute
XML	Extensible Markup Language

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CHAPTER 1: INTRODUCTION

With increasingly constrained state budgets, Caltrans winter maintenance and snow removal operations must become more efficient to “do more with less”. Snow fighter supervisors are a crucial factor in this effort. Ideally, supervisors should be in two places at the same time—in the office and the field. In the office they have access to rapidly changing weather forecasts and radar, traffic conditions, satellite images, phones, and in some cases, Road Weather Information System (RWIS) terminals. In the field, supervisors can assist other snow fighter team members and have direct observations of fast-changing road and weather conditions to facilitate decision making. The goal of this research project is to provide snow fighter supervisors in the field with more information to make better decisions. Around-the-clock access to this crucial information and the supervisor's ability to stay in the field longer can improve resource allocation decisions, enhance efficiency, increase safety, minimize environmental impact, and enhance the Caltrans work environment.

Problem

Snow removal operations (also referred to as snow fighting or winter maintenance) are an important maintenance activity for Caltrans. It often must be done in communications-challenged areas. Snow fighting, for all but routine storms, is an unplanned incident requiring careful resource management and clear communications to effectively respond. As such, snow fighting has high communications and resource management requirements, but occurs in communications-challenged or deprived areas. There is a need for a mobile communications system that can meet these requirements under the challenging constraints faced.

Research Deliverables

The key deliverables of this research project include:

- Cellular coverage and signal strength data collection app
- Cellular coverage and signal strength maps for snow-affected areas
- System requirements
- Commercial Off–The-Shelf (COTS) component comparisons
- System design

The original proposal included the following two key additional deliverables:

- 2 supervisor vehicles and test results
- 2 snowplow vehicles and test results

These two deliverables were not provided, based on the project evolution discussed below.

Snow Fighter Information System Research Phases

In previous research, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center tested a prototype Mobile Real-Time Information System (MRTIS) for Snow Fighter Supervisors [16] (Phase 1), and wrote a high-level specification for a follow-up system for field testing and eventual deployment [17] (Phase 2). A brief summary of the previous and current research phases is provided in Table 1.1.

Table 1.1: Summary of Snow Fighter Information System research phases

Phase	Contract and Task Name	Dates	Purpose
1	65A0139 T.O. 06-12 Development and Field-Operational Testing of a Mobile Real-time Information System for Snow Fighter Supervisors [16]	6/05-12/06	Design, build, and test 1st-generation snow fighter information system.
2	65A0275 Task 1828 Research Planning for Caltrans Emergency Maintenance Response [17]	6/10–6/11	Review of existing research products, commercial systems, and Caltrans systems; and develop requirements for a research prototype for emergency maintenance response.
3	65A0416 Task 2299 Mobile Real Time Information System for Snow Fighter Supervisors - System Design & Test	6/12–9/15	The current research: investigation of reliable communications, system redesign to take advantage of the most current technology.

The current research (Phase 3) investigated cost-effective and reliable communications to assist Caltrans snow fighting activities. This included information to support situational awareness for snowplow operators and the supervisor, sensor data (e.g. snowplow location history, air and road temperature, plow blade status, and spreader status), and any coordinating information from the supervisor to the operators. The target application was communications between Caltrans snowplows and supervisor vehicles. Messaging and mapping applications were designed based on a store-and-forward architecture to address intermittent data communications. The sensing information would be passed between vehicles, and displayed as vehicle state in the mapping application. The research included migrating the original personal computer-based (PC-based) MRTIS system to use appropriate current technology, specifically using an Android-based tablet as the user interface, also called the Human Machine Interface (HMI), and developing targeted apps to provide the needed functionality. To clarify the need for the system, the researchers also surveyed and mapped all Caltrans snow–affected routes to determine cellular signal coverage. The detailed communications coverage maps generated from the survey influenced the subsequent system design update.

Snowplow Information System Research Project Evolution

The Phase 3 research project has evolved significantly since the original Phase 3 proposal. This has had a large effect on the course of the research, and the resulting deliverables. As such, it is important to document this evolution.

The Phase 1 research developed a first prototype snow fighter information system which was fully implemented and demonstrated in an AHMCT research vehicle. This was an on-board system that could track the research vehicle's location, measure air and road temperature, and communicate this information to a central location. Additionally, the vehicle was able to receive weather and other information from a central location [18]. As a first-generation prototype, the system implementation was a bit cumbersome; however, Caltrans was encouraged by the system design and features. This led to the Phase 2 effort, which included a review of existing research products, available commercial systems and existing Caltrans systems. Phase 2 also investigated the communication compatibility of the Phase 1 research with the larger emergency operations systems within Caltrans and across state agencies [17]. Finally, Phase 2 developed the initial requirements for a deployment-ready research prototype snow fighter information system to be developed in a Phase 3 effort.

The original intent of the Phase 3 research was finalization of system requirements, design and development of the next-generation snow fighter information system. During the research, AHMCT was to develop four instances of the system (two full capability, two sensing and communications only), and install the system on two supervisor vehicles, and two snowplow vehicles, to facilitate field testing and analysis. Testing was expected to occur in a communications-challenged district. An ideal location would manage frequent avalanches, such as the Caples Lake maintenance yard on SR 88.

The above scope was established by the Caltrans Division of Research, Innovation and System Information (DRISI) working in conjunction with its customer, Caltrans Maintenance. Caltrans was also looking beyond the Phase 3 research project to a larger deployment and field-operational test with more systems in multiple districts.

Based on this scope, AHMCT proceeded with finalizing system requirements in conjunction with the Technical Advisory Group (TAG), and developing the Phase 3 system design. AHMCT also investigated smartphone and tablet technologies for applicability in the system, and presented the results to the TAG. Based on the results and presentation, the TAG indicated that the design should use a tablet for the HMI. Along with these activities, AHMCT developed the software for the telecommunications survey, planned and executed the survey, and presented the results to the TAG.

In the first half of 2014, the Phase 3 project evolved in a different direction. Caltrans Maintenance began investigating COTS systems to see if they could realize a sufficient subset of the capabilities that would be provided by the snow fighter information system. Some COTS systems were identified that might be suitable. Based on information presented at a Clear Roads national research meeting, Caltrans Maintenance became interested in a COTS system from Vaisala. At Maintenance's request, AHMCT evaluated the features of the most capable COTS system, the Vaisala Condition Patrol DSP310, as documented in Table 5.1. The Vaisala system lacked a number of the important features listed in Table 5.1, yet its cost was comparable to the projected cost of the snow fighter information system. As part of this effort, AHMCT also attended meetings with Caltrans DRISI and Maintenance to discuss fleet management solutions with vendors, including Networkfleet (now owned by Verizon) and Delcan (now owned by Parsons). On February 21, 2014, Caltrans indicated that all Phase 3 design and development work on the snow fighter information system would be placed on hold until further notice. Based on this indication, AHMCT set aside its design and development work, and prepared to assist Caltrans in evaluation and a possible pilot study of a COTS system. AHMCT also, at this stage, prepared to redirect budget to procure hardware and services for a pilot study.

Based on identified needs of Caltrans Maintenance, system capabilities, and system cost, Caltrans began pursuing a pilot study with Verizon. This decision was at least in part based on an anticipated easy integration with the Verizon/Networkfleet system already being installed on the Caltrans heavy fleet vehicles. Since the Verizon/Networkfleet system has limited data gathering abilities compared to some other systems (both COTS and AHMCT-developed), Caltrans is also considering a separate future pilot study of the Delcan system. Both of these pilot studies would start after the end of this Phase 3 research effort. As such, no results of COTS pilot studies are reported herein.

Background

Available Technologies and Systems

Emerging technologies, systems, and trends will provide important components for an effective snow fighting communications system. These technologies include:

- Data over cellular networks (e.g. Short Message Service, or SMS, aka. "texting", Twitter[1], instant messaging), which is generally still available even when the cellular voice channel is not.

- GPS-enabled commodity smartphones, tablets, and similar mobile devices, and advanced operating systems that can support communications and user interfaces customized specifically for Caltrans' needs for snow fighting.

- Data over other existing Caltrans communications channels, e.g. 800 MHz voice radio, microwave radio systems (often the last working system in an emergency), Cal EMA OASIS (Operational Area Satellite Information System), etc.

- Emerging commodity communication technologies such as Wi-Fi, 4.9 GHz communication components, and other systems that may provide enhanced low-cost snow fighting communication.

[1] E.g. as used in the Bay Bridge closure and repair of October, 2009, at: http://twitter.com/baybridgeinfo

- Available or near-term research technologies that may be deployable in rural settings, such as the Responder system [5], WeatherShare[2], and Caltrans Earth[3].

- Commodity open-source software and collaboration methodologies that enable development of resource management systems. This can leverage existing software capabilities, increase customization, lower initial and ongoing costs, and reduce or eliminate vendor lock-in. This can lead to zero recurring licensing costs [2,3,13].

- General integrated asset tracking, communications, and resource management systems that provide robust capabilities and redundancies for maximum availability in challenging conditions and scenarios.

Research Approach

The Phase 3 research built on AHMCT's experience with winter maintenance, our Phase 1 and Phase 2 snow fighter research, our strength in sensing and system integration, and our established Mechatronic hardware and software base [4,7-9,16,17,21-23].

The Phase 3 research methodology included:

- User needs meeting with District 10 maintenance crews maintaining State Route 88 (SR 88)
- Regular meetings with DRISI project managers and Caltrans TAG
- Survey and map coverage for cellular signals along snow-affected routes
- Investigation of smartphone and tablet hardware and applications to determine the appropriate products for the user interface
- Requirements development
- System design
- Evaluation of commercial-off-the-shelf (COTS) systems for a Caltrans pilot study

Literature Review

Numerous vehicle-based technologies, including automatic vehicle location (AVL), surface temperature measuring devices, freezing point and ice-presence detection sensors, salinity measuring devices, visual and multi-spectral sensors, and millimeter wavelength radar sensors have been developed in recent years to improve winter maintenance efficiency and safety. A key consideration in implementing these technologies is communications, especially in rural

[2] http://weathershare.org/
[3] http://earth.dot.ca.gov/

areas [12]. Many of these technologies are candidates for integration with the snow fighter information system.

Watkins provides an overview of the Operational Area Satellite Information System (OASIS) satellite-based communications system [15]. Caltrans currently has several trailer-based systems and urban sites equipped with OASIS. Compatibility with OASIS may be an important component of the snow fighter information system, depending on customer need.

The National Traffic Incident Management Coalition's goals include interoperability of communications equipment used by different state agencies and entities in responding to incidents. They present strategies to achieve their goals, including Strategy 16 - Broadband Emergency Communications Systems [10]. This work, as it proceeds, will benefit the snow fighter information system.

A portion of Thomas and Piekarski's work on "through-walls" collaboration is relevant to the proposed system. Through-walls collaboration is a concept where users in the field work in real time with indoor users who have access to reference materials, a wider situational perspective, and advanced technology [14]. The concept leverages ubiquitous workspaces, augmented reality, and wearable computers. A portion of this work is relevant to the snow fighter information system.

Amann and Quirchmayr present a framework for knowledge management in context-aware and pervasive computing [1]. The focus is to enable adaptive, two-way interaction between context-aware systems and users in mobile settings.

CHAPTER 2: SNOW FIGHTER INFORMATION SYSTEM CONCEPT

The snow fighter information system would integrate perpetually changing information essential to the supervisor's decision-making and continuously provide it via in-vehicle access. The system maximizes communication options at the lowest cost by providing flexible support for 802.11 wireless, satellite, cellular, and future IP-based (Internet Protocol) communications. The system provides previously unavailable information from vehicle-based sensors, in particular temperature sensors providing ambient and road temperatures. GPS is used to provide vehicle location and speed. Figure 2.1 shows the central office architecture. The central office system collects weather data from all available sources (including vehicles in the field) and sends it to the supervisor's vehicle using the best currently available transmission method. The supervisor vehicle system includes a full communications package and user interface. Figure 2.2 shows the architecture of the equipment in the supervisor's vehicle, which includes:

- communications package and sensing systems (e.g. road temperature)
- GPS to support fleet management capabilities
- HMI for information display and supervisor input.

The snowplow systems can be a reduced system with:

- communications package and sensing systems (e.g. road temperature)
- GPS to support fleet management capabilities.

The reduced snowplow system architecture is shown in Figure 2.3. The overall snow fighter information system data flow is shown in Figure 2.4. Figure 2.5 illustrates the supervisor vehicle hardware architecture. Figure 2.6 provides an example snow fighter information system in-vehicle display integrating radar, weather forecasts, terrain, vehicle locations, traffic, and road surface condition.

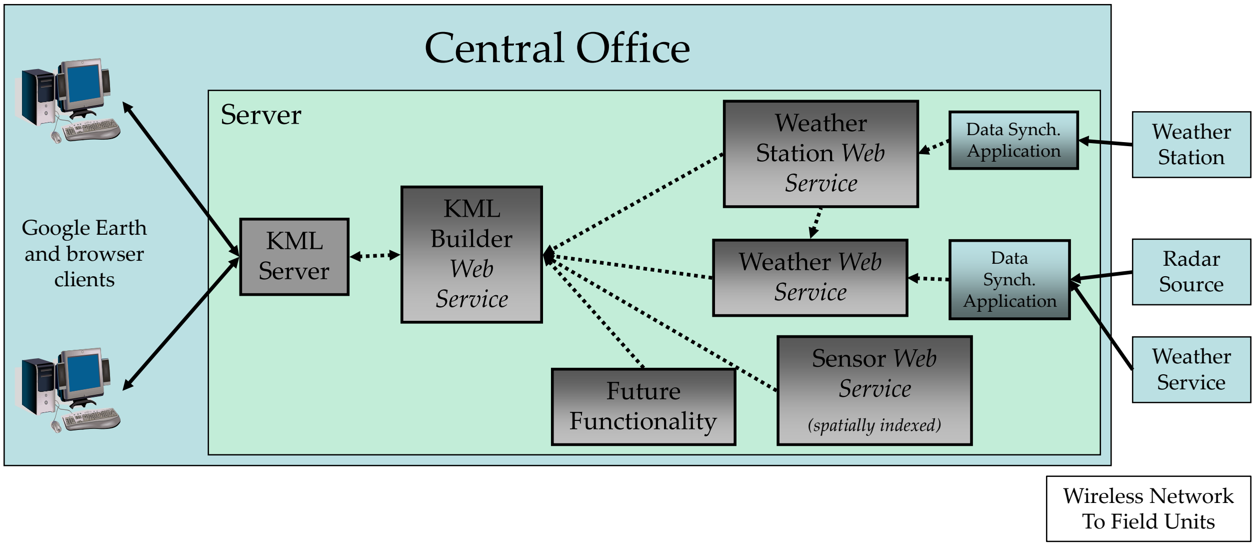

Figure 2.1: Central office architecture

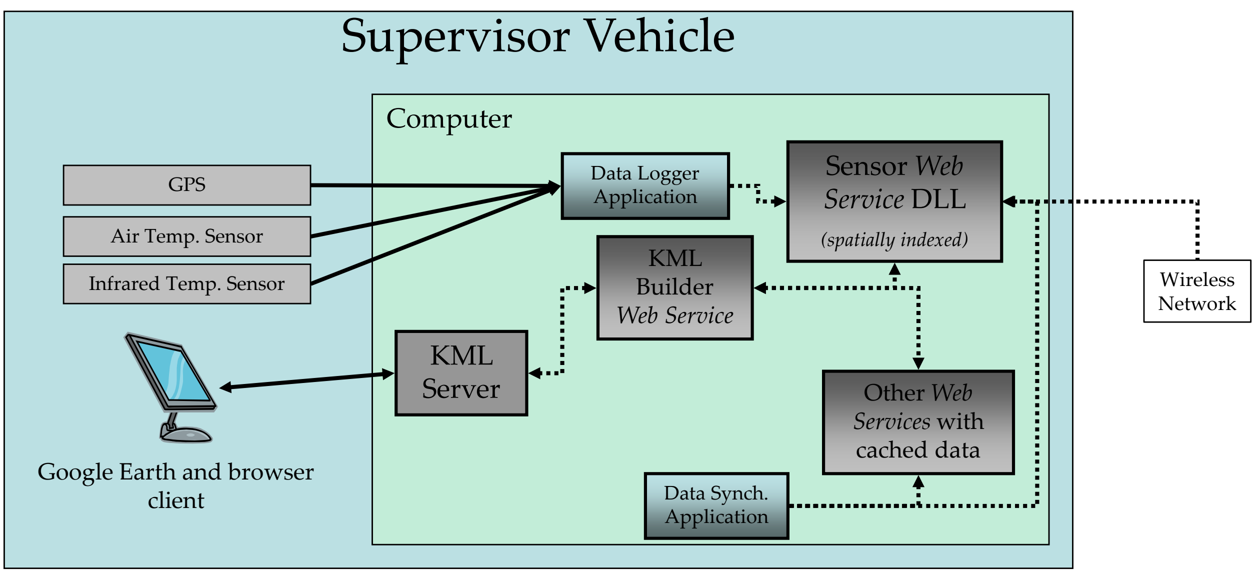

Figure 2.2: Supervisor vehicle architecture

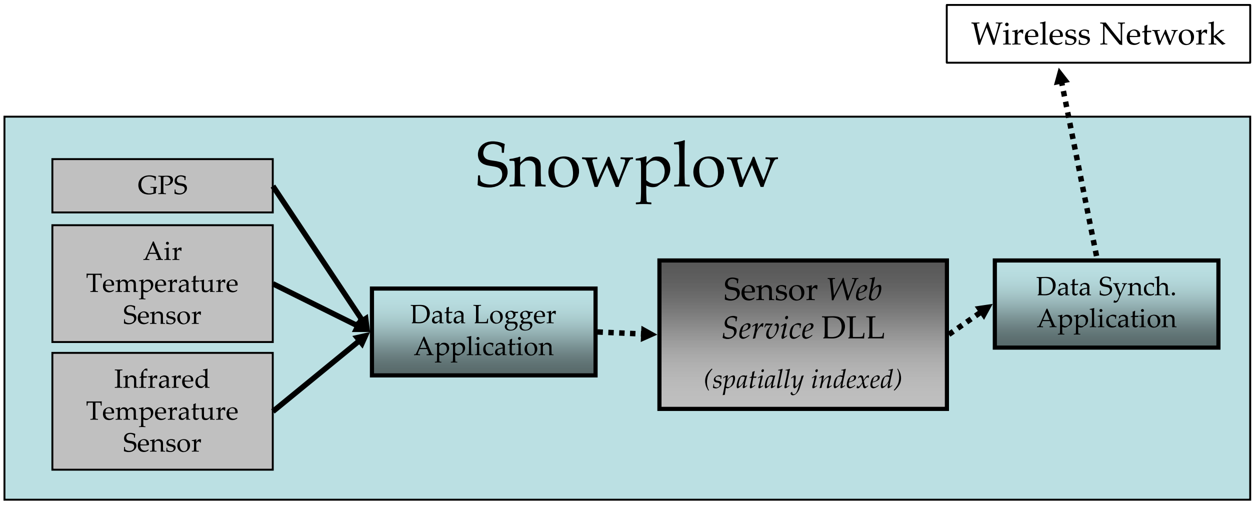

Figure 2.3: Snowplow vehicle reduced architecture

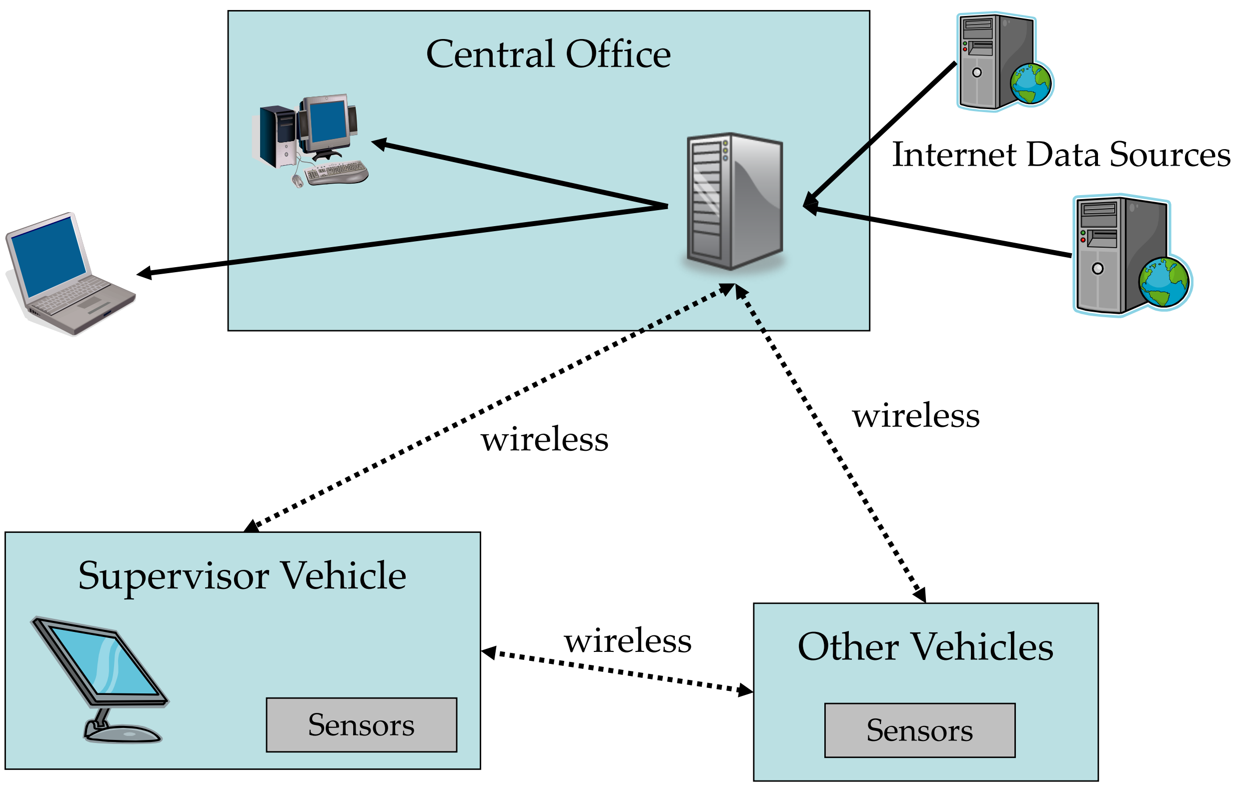

Figure 2.4: Overall snow fighter information system data flow

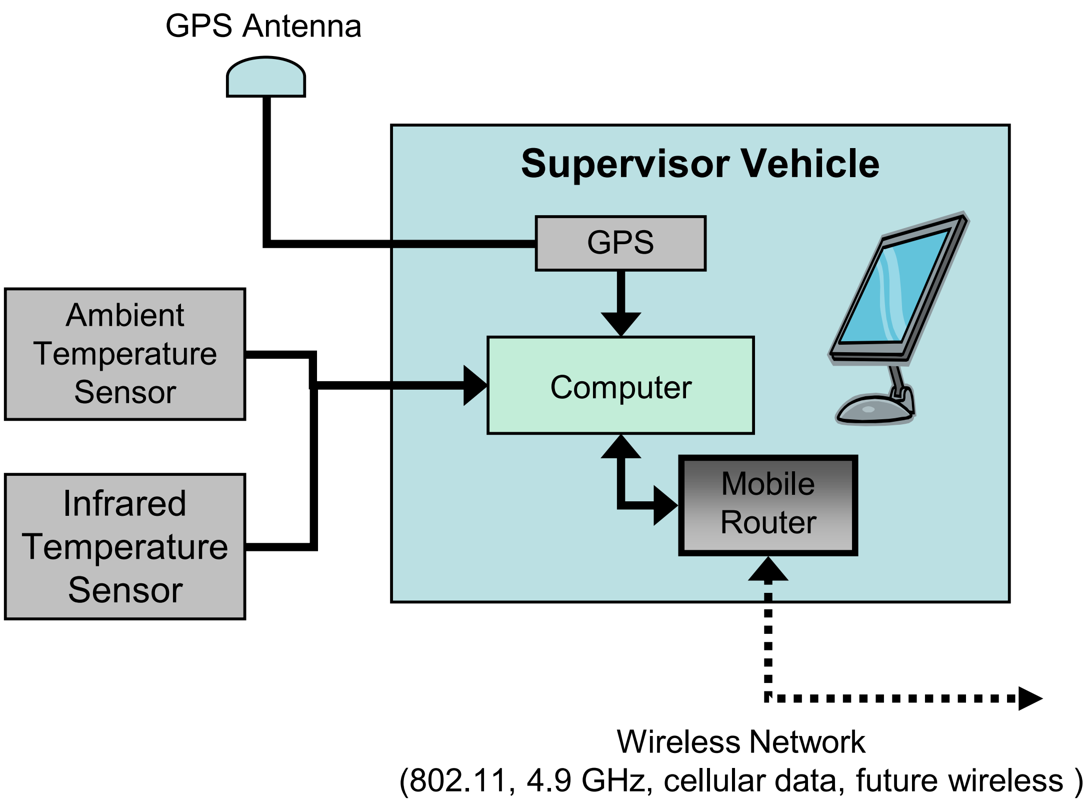

Figure 2.5: Supervisor vehicle hardware architecture

Figure 2.6: Example snow fighter information system in-vehicle display integrating radar, weather forecasts, terrain, vehicle locations, traffic, and road surface condition. This is a prototype display from Phase 1 research[18].

RWIS data is targeted to be included in the system. RWIS environmental sensors provide real-time temperature, wind direction, speed, humidity, and precipitation data. One-Stop-Shop (OSS) is a recently developed DRISI web site that gathers weather forecasts, radar images, traffic camera images, terrain maps, and sensor data and makes available in one place. OSS is included in the system, and uses a pictorial presentation for easier interpretation. Figure 2.7 shows one of the many OSS screens available, here providing current wind speed and direction.

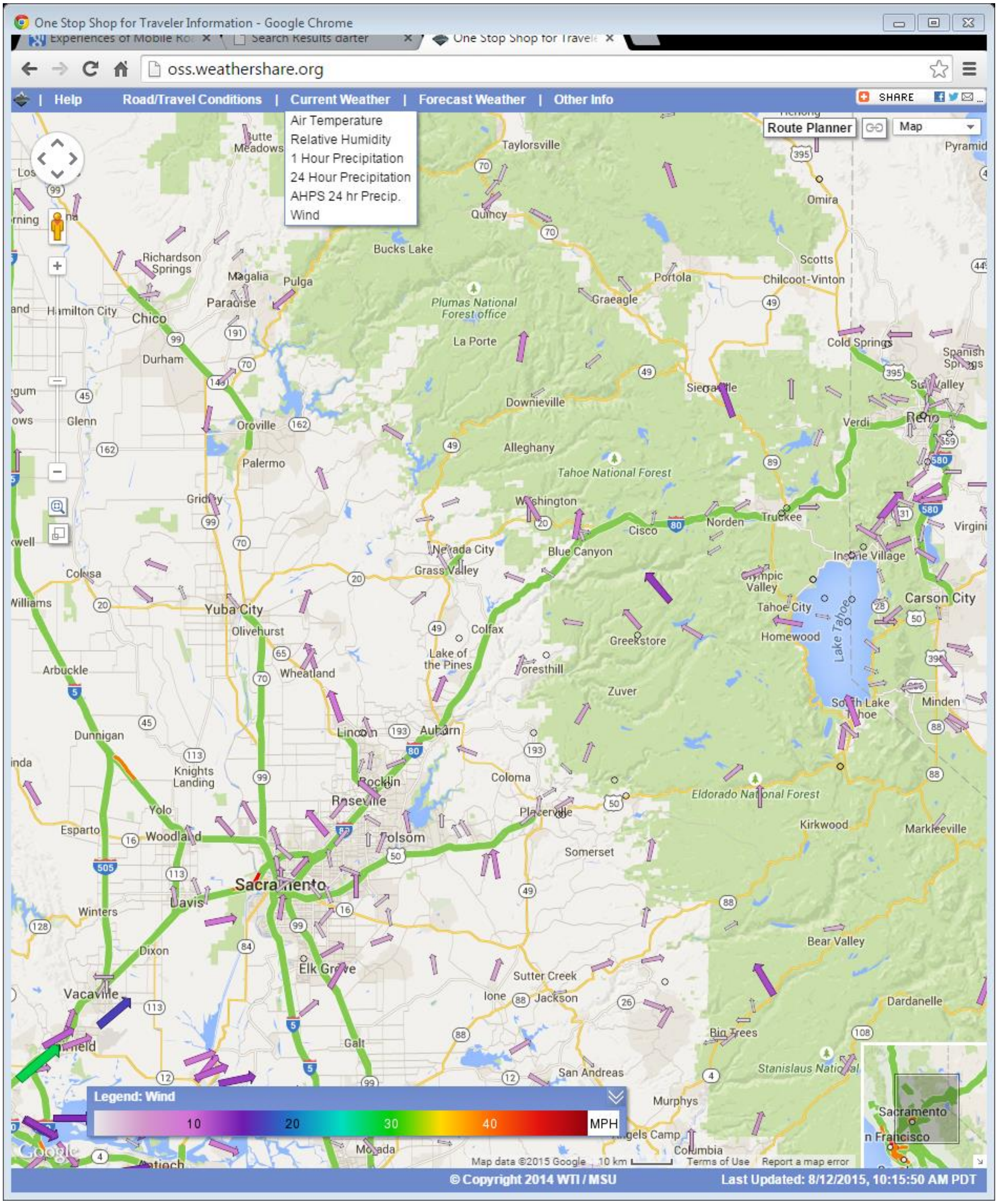

Figure 2.7: One-Stop-Shop example screen shot (courtesy of WTI)

Caltrans vehicles routinely operate in challenging communications environments with discontinuous wireless network coverage and limited transmission range in mountainous areas. Integrating a commercial mobile wireless router into the vehicle solves many of these problems and provides a transparent IP connection as the vehicle moves between various wireless networks (802.11, cellular, satellite, future IP-based wireless). System data such as radar images are cached locally and updated after a lost connection is reestablished. In addition to this design's value for the snow fighter system, the advanced communications system and the array of sensors also make this system a prime candidate for future use in tracking other Caltrans vehicles and equipment.

CHAPTER 3:
COTS COMPONENTS

To the extent possible, the intent was to develop the snow fighter information system using COTS system components. This is important in terms of system cost, implementation, deployment, and maintainability. Some of the key components, including comparisons, are detailed in this chapter. This chapter does not consider COTS systems that might serve as a partial replacement for the snow fighter information system. One such partial replacement is considered in Chapter 5. The focus in this chapter is on COTS components that could be used to implement the snow fighter information system.

There are two main types of COTS systems that are suitable: wireless communication systems/components, and mobile information display systems. Example COTS wireless communication components and systems include cellular communications, 802.11abgn, satellite communications (one-way or both ways), 802.11s mesh network, and 4.9 GHz and 5.8 GHz Dedicated Short Range Communication (DSRC) components and systems. Example mobile information display systems include light-weight rugged laptops, tablets (running iOS, Android, or Windows operating systems), and smartphones.

COTS Communication Components and Systems

Cellular wireless data communication

Mobile cellular wireless data communication is one of the most widely available and economical high-speed communications options. AT&T and Verizon are the two major service providers with large coverage area in California. However, cellular services are usually very limited in rural areas despite efforts by all carriers to set up cellular communication towers along the major highways. SR 88 near Caples Lake, SR 108 near Sonora Pass, and SR 299 near Burney are example areas with limited cellular service. Users often have to drive more than an hour to reach a location with cellular service. Thus, a sole commercial cellular communication link would not be viable for data communication in rural areas.

As part of this research, AHMCT performed a cellular communications survey for all of California's snow-affected areas. This cellular communications survey is discussed in Chapter 6, with the app developed to implement it presented in Appendix C and the survey results presented in Appendix D.

OpenBTS – open source 2G GSM implementation

OpenBTS (Open Base Transceiver Station), a Linux application, uses a software radio to provide a 2G GSM (Global System for Mobile Communications) air interface to 2G GSM-compatible handsets to make voice phone calls or send SMS messages[4]. OpenBTS can provide a low-cost private GSM cellular base station in remote areas where commercial GSM service is not available, and highway workers can communicate with each other via voice or SMS using low-

[4] http://openbts.org/

cost GSM phones or smartphones. An OpenBTS development kit[5] is available for under $5,000. OpenBTS base station hardware, as shown in Figure 3.1, is compact and low power. AHMCT set up an OpenBTS base station and evaluated it at the Advanced Transportation Infrastructure Center (ATIRC) test site, as well as surrounding parts of Yolo County. It works well in the tested conditions, providing voice and SMS communication for a radius of about 0.6 mi. These tests were in very flat areas with excellent line of sight; additional testing in more challenging mountainous is needed. The base station was located at ATIRC, and the smartphone test unit and range extender were moved about the surrounding environment, taking note of range, bandwidth and link characteristics at each location. The base station antennas height was 6.6 ft (2 m), and the smartphone antenna height was 4.9 ft (1.5 m).

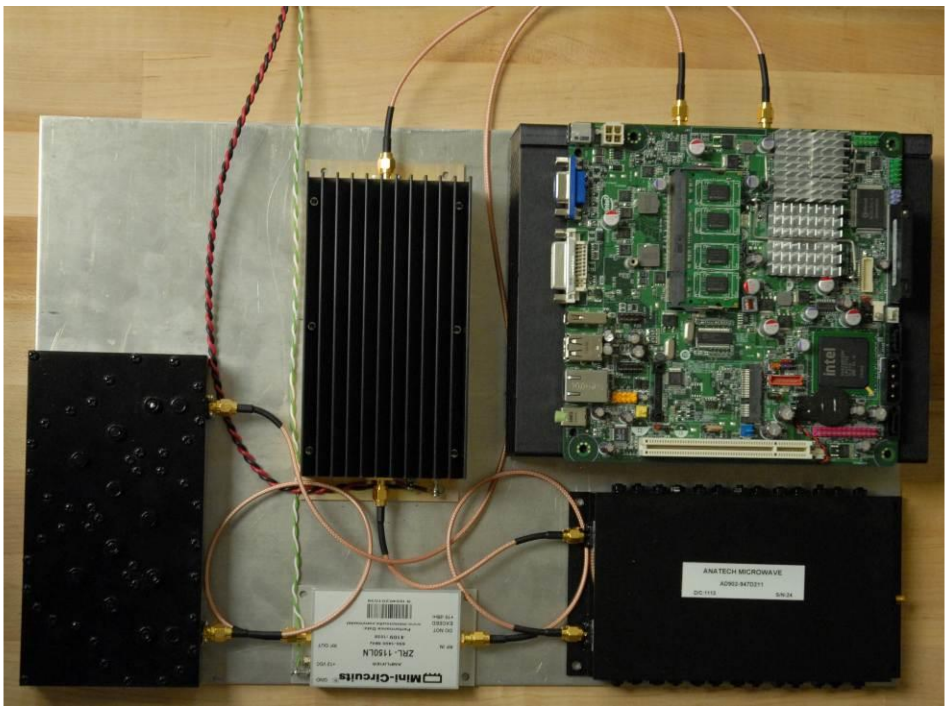

Figure 3.1: OpenBTS base station hardware implementation at AHMCT

[5] http://www.rangenetworks.com/store/development-kit

Figure 3.2: ATIRC and surrounding wireless test environment

Satellite Communication

Satellite communication provides coverage for the entirety of California. There may be some localized dead zones caused by signal blockage by local mountainous terrain or buildings in urban settings. Popular two-way satellite communication providers are Inmarsat and Iridium. Inmarsat employs 11 satellites flying in a geosynchronous orbit. The Iridium constellation is composed of 66 cross-linked Low Earth Orbit (LEO) satellites. User's line of sight to geosynchronous satellite can sometimes be blocked by local terrain or buildings. In addition, geosynchronous satellite communication has higher latency. On the other hand, the blockage to user's line of sight to LEO satellites caused by local terrain is often only temporary as the LEO satellites position move over time away from the terrain blockage.

Recently, low-cost one-way satellite simplex uplink-only connection (one-way data transmission) has become available. This service allows users at remote locations to reliably send short text messages in a rural area. These messages can be geo-location of mobile asset, sensor readings, or SOS (varyingly defined as "Save Our Ship", "Save Our Souls", and "Send Out Succor") messages[6]. SPOT LLC provides products and services for one-way satellite simplex uplink-only connection[7]. SPOT Satellite GPS Messenger is a small portable unit that allows a user

[6] https://en.wikipedia.org/wiki/SOS
[7] http://www.findmespot.com/en/

to send its geo-location periodically, SOS, or pre-formed custom messages in remote area within 20 minutes. The SPOT Connect enables smartphone user to send custom email or text messages out via satellite through a Bluetooth connection between the SPOT Connect and the smartphone. It enables a worker to send critical messages out without delay for $99 a year plus 10 to 50 cents per message. With the reduction of work force, highway workers are often working along rural highways with no other means communication. SPOT products would allow them to call for help in an emergency such as an avalanche or a vehicle breakdown. The current Gen 3 SPOT Messenger includes the capability to send a pre-programmed custom message. SPOT also offers the Connect system which pairs with smartphone via Bluetooth, supporting satellite transmission of messages typed on the smartphone. This system could be leveraged to send simple data such as snow depth and avalanche alert back via satellite.

Figure 3.3: SPOT Satellite GPS Messenger

Figure 3.4: SPOT Connect

Terrestrial wireless components

The commercial success of the IEEE 802.11abgn Wi-Fi standard and its components has led to development of low-cost OFDM (Orthogonal Frequency Division Multiplexing) wireless radio in other radio frequencies (700 MHz, 900 MHz, 4.9 GHz, and 5.8 GHz) based on 802.11 technology. These radios use the Qualcomm Atheros AR91xx chipset or AR54xx chipset originally developed for 802.11abgn. AHMCT researchers have experimented with these low-cost radios in the 5.8 GHz and 900 MHz frequencies for point-to-point communication. Using the 5.8 GHz radio, a high-speed reliable point-to-point connection was achievable in the tested conditions over 3.1 mi using COTS sector antenna mounted on a vehicle at about 12 feet off the ground. Longer range can be achieved using higher antenna height and optimizing radio operational parameters such as bandwidth and timeout timing. The 4.9 GHz radio should achieve similar performance. The experiments were done at the ATIRC test site, as well as surrounding parts of Yolo County. The test area was very flat with excellent line of sight; additional testing in challenging mountainous areas is needed.

Figure 3.5: AHMCT 5.8 GHz point-to-point communication experimental setup

In 2002, the Federal Communication Commission (FCC) designated the 4.9 GHz band for use in support of public safety. The FCC has allocated 50 MHz of spectrum in the 4940-4990 MHz band (4.9 GHz band) for fixed and mobile wireless services and designating the band for use in support of public safety. This allocation and designation will provide public safety users with additional spectrum to support new broadband applications such as high-speed digital technologies and wireless local area networks for incident scene management. The spectrum also can support dispatch operations and vehicular or personal communications. Specific FCC rules[8] are covered in Subpart Y of 47CFR part 90. Caltrans is eligible to use the allocated 4.9 GHz spectrum. Currently, Caltrans District 2 is using the 4.9 GHz frequency for point-to-point data link in a few locations. The expanded used of the allocated 4.9 GHz frequency by Caltrans and other DOTs would ensure that FCC would not reallocate the 4.9 GHz spectrum to other applications or commercial uses. The 4.9 GHz frequency is currently underutilized and thus it is not subjected to interference issue that often happen when using 2.4 GHz and 5.8 GHz frequencies. 4.9 GHz provides a prime opportunity for Caltrans to build a wireless data network similar to the 800 MHz voice network.

Figure 3.6 shows an example of a 4.9 GHz mini-PCI (Peripheral Component Interconnect) card based on the Atheros 802.11 chipset made by Doodle Labs[9]. It is well-supported by the open source MadWifi Linux kernel driver[10] and open-source router software OpenWrt[11]. The open-source nature of the driver and software provide maximum flexibility for user to configure the radio parameters to optimize for range and bandwidth. In conjunction with open 802.11s[12], an open-source implementation of the recently ratified IEEE 802.11s wireless mesh standard, a 4.9 GHz mesh data network can be implemented with COTS components and open-source software at low cost. AHMCT researchers have set up a 5.8 GHz mesh network using open-source software and evaluated it used for network backhaul application. Figure 3.7 shows a group of small

8 http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title47/47cfr90_main_02.tpl
9 http://www.doodlelabs.com/
10 http://madwifi-project.org/
11 https://openwrt.org/
12 http://open80211s.org/open80211s/

mesh node and single mesh node hardware with two 5.8 GHz 802.11 radios. The 5.8 GHz 802.11 radio cards can be easily changed to 4.9 GHz radio. Since these radio share the same software driver, the reconfiguration is minimal. The open-source firmware allows users to make changes to best suit their applications. AHMCT researchers envision a 4.9 GHz data network backbone can be built using mesh network technology and installing 4.9 GHz mesh network nodes on light poles along the highway. However, further development and experimentation is required to evaluate the envision mesh network performance in mountainous terrain found typical in many snow routes.

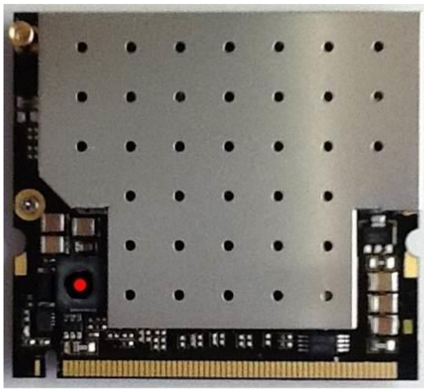

Figure 3.6: 4.9 GHz wireless radio (www.doodlelabs.com)

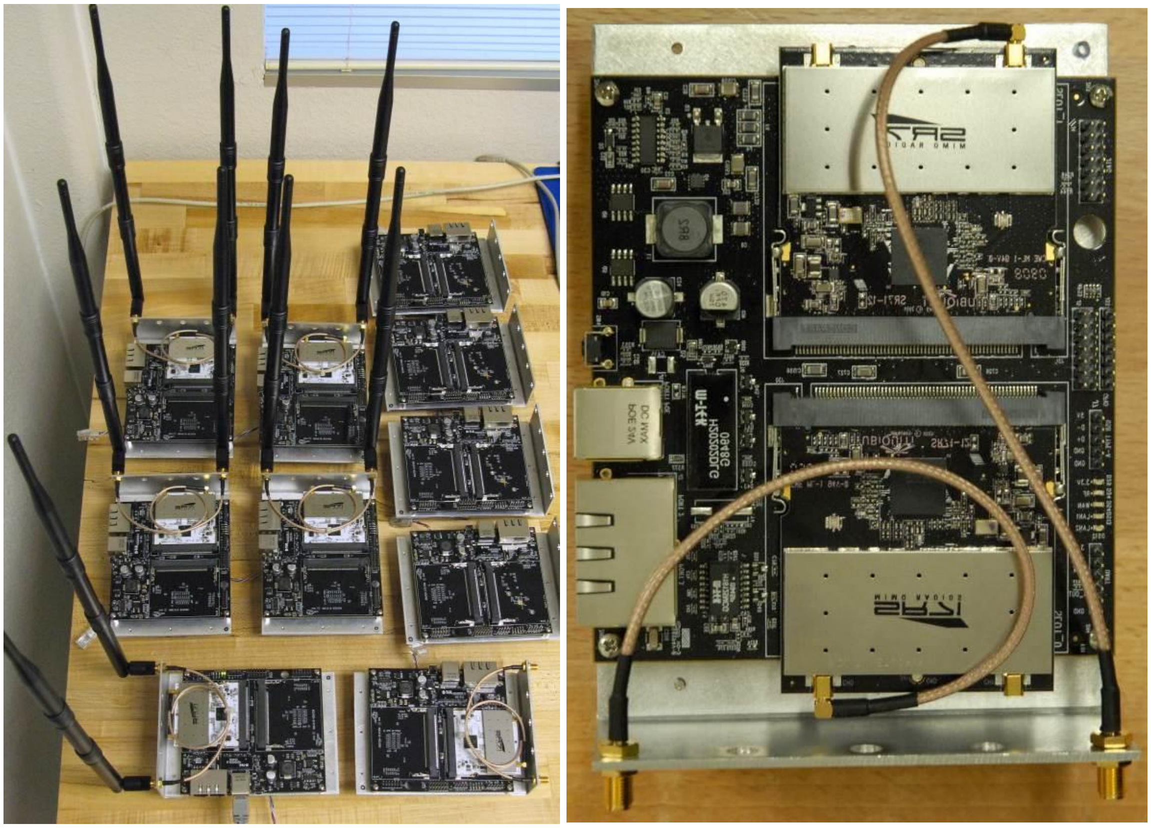

Figure 3.7: AHMCT 5.8 GHz mesh network experiment setup

Human Machine Interface

For the snowplow operator or the supervisor, the Human Machine Interface (HMI) represents the entire system. Thus, the selection of the hardware for the HMI is a critical issue in the system development.

Previously, rugged laptops with high-resolution display and processing power were the only viable choice. However, they were large and bulky with short battery life. Recently, powerful light-weight smartphones and tablets with high-resolution displays and long battery life have been developed and are well-accepted by consumers. These devices are a viable alternative to laptops. The snow fighter information system application does not require extensive use of keyboard input. On the other hand, the majority of existing research projects and Caltrans software were designed to run on a PC or a laptop. Nevertheless, a new generation ultra-light notebook remains a viable choice. While recent advances such as Google Glass[13] (recently discontinued) and Microsoft HoloLens[14] are promising, head-mounted displays remain in their infancy and are not expected to be ready for field deployment for at least several years.

Apple iOS, Google Android, and Windows Phone are the three major operating systems of current smartphones and tablets[15]. Apple iOS and Google Android are the most popular platforms and have larger communities of software developer support and third party software available, as well as accessories such as rugged protective cases. The open-source nature of the Android platform is well-supported by the open-source community. There are many software libraries developed for and compatible with the Android operating system. Android devices are produced by several manufacturers. Apple iOS devices are only produced by Apple. As a result, the choice of IOS devices is very limited. On the other hand, software testing and validation on iOS devices is simpler since the number of devices required for testing is much less compared to Android devices. For example, in the testing of AHMCT GPS Automated Travel Diary (GPS-ATD) app, the app was tested on over fifteen different models of smartphone with different versions of Android operating system and multiple manufacturers' custom user interfaces.

The tablet form factor is better-suited for information intensive applications and viewing websites that were originally designed for desktop computers, due to its larger and higher resolution screen. The majority of the available tablets have either a 7" or 10" display. Two models of 7" and 10" tablets were evaluated for usability by AHMCT researchers. The 7" tablet can be held securely in one hand while inputting data with the virtual keyboard. It is difficult to hold a 10" tablet securely with one hand without having a thumb on the display area, which interferes with the touch screen interface. The conclusion is that the 7" tablet has a large enough screen for information display and input. In addition, the 7" tablet has advantages in the portability and usability categories. There are too many Android and Windows Mobile devices to review as a list.

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[13] https://www.google.com/glass

[14] https://www.microsoft.com/microsoft-hololens/en-us

[15] http://www.apple.com/ios
https://www.android.com
http://www.windowsphone.com/

Tables 3.1 and 3.2 list some of the suitable devices for snow operations. More details on some of the more promising systems are provided in Appendix A.

Table 3.1 Suitable information display and input devices

Company	Model	Details
Apple	iPad	10” tablet on IOS platform http://www.apple.com/
Apple	iPhone	Smartphone on IOS platform http://www.apple.com/
Samsung	Galaxy Tab	7” and 10” tablets on Android platform http://www.samsung.com/us/mobile/galaxy-tab/
TerreStar	GENUS Smartphone	Window mobile smartphone with both GSM (AT&T) and satellite communication. (~$800) http://www.terrestar.com/
WinMate	Rugged PDA and Tablet	WinMate makes various Rugged PDA and tablet that run either Android or Window Mobile operating system thttp://www.winmate.com.tw/
Google	Galaxy Nexus	Android smartphone with high resolution display http://www.google.com/nexus/#/galaxy
Google	Nexus 7	7” Android tablet http://www.google.com/nexus/#/7
Panasonic	Toughpad B1	http://www.panasonic.com/business/toughpad/US/secure-tablet-specs.asp#
Panasonic	Toughpad A1	10” rugged Android tablet http://www.panasonic.com/business/toughpad/US/secure-tablet-specs.asp
Trimble	Yuma	Rugged Window 7 tablet computer with Intel processor http://www.trimble.com/
Trimble	Juno	Rugged Window Mobile PDA with build in GPS and cellular voice and data. http://www.trimble.com/

Table 3.2 Suitable information input devices

Company	Model	Details
Delorme	Earthmate PN-60W	GPS (u-blox) plus text messaging via SPOT satellite Communicator (GPS World 8/2010), http://www.delorme.com
EMS Global Tracking	Osprey Personal Tracker	GPS (u-blox) plus Inmarsat communications of up to 450 predefined messages (GPS World 8/2010), http://www.emsglobaltracking.com
GeoPro Solutions	GeoPro Messenger	Satellite text-messaging and integrated GPS, coupled to secure hosted web application for workplace safety in disaster zones (GPS World 8/2010), http://www.geoprosolutions.com/geopro-messenger

Surface Condition Monitoring Sensing

AHMCT began investigating surface condition monitoring sensors in November of 2013 for use in the snow fighter information system. Surface condition monitoring sensing provides real-time surface conditions from a moving snowplow or supervisor vehicle, including surface and air temperature, relative humidity, surface condition indicator (hazardous ice, snow, or wet conditions), and a surface friction coefficient. Several COTS systems are available, with pricing from about $5,000 to about $16,000. These are sensor systems that could be integrated into the snow fighter information system.

Vaisala

The Vaisala DSC111 costs approximately $16,000. For the snow fighter system, or any mobile application, this system would require custom firmware, likely at increased price. We did not discuss the price increase with Vaisala.

Contact: Mark Feldman, 314-705-0522 (in Sacramento)

High Sierra Electronics (HSE)

The HSE Model 5435-00 Surface Sentinel costs approximately $5,000. It is designed for mobile use on a vehicle. They have not used it on a snowplow, but have done some related vibration testing. It is typically mounted on the driver's side of a vehicle. HSE can provide a hitch mount for preliminary testing on a truck or SUV (Sport Utility Vehicle) at a cost in the low $100s.

The system uses an easy, open communications protocol, basically a space delimited ASCII (American Standard Code for Information Interchange) stream. For serial communication via RS485 (recommended standard), the system can stream data or provide it when or polled. For Ethernet, the system streams data.

The HSE 5435 provides dew point and frost alert. The HSE update rate is about once every five seconds, i.e. 0.2 Hz. The system includes a one-year warranty.

HSE was willing to do a demonstration, and is a local company.

Contact: Main number: 800-275-2080 (Grass Valley)

Brett Hansen (HSE), Cell: 801-834-3583, bhansen@highsierraelectronics.com, www.highsierraelectronics.com

Rep: Stewart Wilkerson, 209-304-3517 (Stockton), swilkerson@westernsystems-inc.com

Innovative Dynamics, Inc.

The IceSight-2020S costs approximately $5,000. It is the same as the High Sierra Electronics system discussed above. High Sierra Electronics has secured manufacturing rights from Innovative Dynamics

Contact: Kumar Seetharam, 607-591-1742 (New York), kseetharam@icingdynamics.com, www.icesight.com

Teconer

The Teconer Road Condition Monitor RCM411 costs about 7,590 Euros ($8,365 on 8/11/15) + transportation costs from Finland.

The package includes an absolute friction meter (μTec), and a temperature option.

Contact: Phone1: +358 40 592 3396 (Finland), taisto.haavasoja@teconer.fi, http://www.teconer.fi

See also (Haavasoja, Nylander, and Nylander, 2012) [6].

CHAPTER 4: SYSTEM REQUIREMENTS

The first-generation snow fighter information system requirements (Phase 1 research) [16] received major updates in the Phase 2 research [17]. This was done because of advances in technology and improved understanding of functional needs. Phase 3 research provided additional requirements updates and refinement, for much the same reasons. Phase 3 system requirement are presented here, along with Phase 2 system requirements for reference.

Phase Two Requirements

General scope

Provide pertinent Winter Maintenance information to field personnel to improve winter maintenance capabilities.

Focus

Develop a system to provide real-time information to snow fighter supervisor personnel in the field. Target is information to supervisor, sander truck, and lead snowplow operator. Use Caples Lake needs to provide focus for Phase 2 effort.

Primary project customer

Caltrans District 10, SR 88, Caples Lake Maintenance Yard.

Additional customers

Caltrans Districts 1, 3, 9.

Guiding principles

- Use COTS or other existing research prototype systems where available.
- Leverage and harmonize with other research and deployment efforts, including Responder, WeatherShare, One Stop Shop, and CT-Earth.
- For deployed research products, we will need to consider their current evolution, availability, and the evolving commercial landscape (e.g. emerging smartphone and similar communications capabilities).
- Use open standards and interfaces to enhance capability to obtain data from and feed data to existing or future systems, e.g. fleet and material management systems.

Main information

- Weather data (temperature, precipitation, wind, pressure, etc.)

- Avalanche information in support of prediction, control, and monitoring. E.g. if instrumentation were available to confirm snow movement in the chute, this would greatly facilitate control and operator safety.
- Similar information for winter landslides, where instrumentation is available
- Chain control
- Changeable Message Sign (CMS) status
- Incident status

Additional features

These may be of interest for HQ and some districts. Note that most of these are available in existing COTS systems or emerging fleet management prototypes. Also, some of these capabilities may need to be user-configurable at the appropriate level within Caltrans (district or maintenance yard, for example).

- Automated logging for spreading of materials (sand, salt, etc.)
- Automated logging of snowplow locations
- Road temperature logging

Constraints

- Communications-challenged environment
- Restricted bandwidth, if available at all
- Limited cellular signal availability, strength
- Limited range for radio communications, and line-of-sight issues
- Cost (often fixed, annual) for alternative communications channels, e.g. satellite
- Some availability issues even for satellite-based options, depending on service provider or type of satellite
- Ability to support the system after deployment.

Updated Requirements for Phase 3 Research

The Phase 2 requirements were updated and expanded upon for this Phase 3 research. This included additional detail on the exact information to be collected for each vehicle type, as well as details for the applications, messaging, and mapping. Unless otherwise noted, the Phase 2 requirements are incorporated by reference.

Communications

- Use a “store and forward” system architecture to address communication system limitations typical in mountainous terrain.

Specific vehicle information to collect from the snowplow vehicles

- Nose Plow Blade Up/Down
- Wing Plow Blade Up/Down
- Sander on/off
- Air Temperature
- Road Temperature
- Chemical application on/off
- Road Wet/Dry/Snow/Ice
- Vehicle stopped for more than a prescribed amount of time, such as five minutes. If the time is exceeded, a message is sent to the lead worker, supervisor, manager, and maintenance station. More about messages follows.
- Emergency Notification (Panic button) to the supervisor vehicle, and perhaps other locations such as the supervisor cell phone, closest maintenance station, or district maintenance dispatch. Also see the Message section below.
- During research, cell signal strength versus location, as was done in the survey, to add to our survey maps
- GPS location will be logged for all vehicles. Geo fencing is an option.
- Include three axis accelerometers (or other sensor) to capture:
    - Sudden impact such as the plow blade hits a large rock and is stopped
    - Sudden impact such as being hit by another vehicle
    - Pitch, roll or yaw beyond TBD degrees (snowplow wheel into ditch, snowplow leaves the road, snowplow rolls over)
    - These events would generate an automatic message to the lead worker, supervisor, and maintenance station. See Message section below.

Specific vehicle information to collect from the supervisor's vehicles

- Rock plow blade up/down (if installed on supervisor vehicle)
- Air Temperature
- Road Temperature
- Road Wet/Dry/Snow/Ice
- Emergency Notification (Panic button) to other supervisor vehicles, closest maintenance station, or district maintenance dispatch. Also see the message section below.
- During research, cell signal strength versus location, as was done in the survey, to add to our survey maps
- GPS will be logged for all vehicles. Geo fencing is an option.

Information availability

- Available in the supervisor vehicle, in snowplows (limited information, mapping and messaging only) at the maintenance station, and for managers in HQ. In Phase 2, information was limited to supervisor vehicle, sander truck, and lead snowplow. In

Phase 3, information will be provided to any instrumented snowplow; however, the level of information is less than that available to the supervisor vehicle.

Information consumption format

- Information available in real time to supervisor and snowplow vehicles via the HMI (tablet), subject to communication system availability.
- Information available in real time to workers in an office environment using a Windows workstation, subject to communication system availability. Supervisors and managers can monitor vehicle locations including telemetry information and send and receive messages to/from vehicles in the field.
- Build a repository to archive collected data - consider compatibility with any existing fleet management systems.

Supervisor vehicle applications

- Real-time mapping for user location and other vehicle last-known locations. See In-vehicle mapping discussion below.
- Messaging. See messaging discussion below.
- Browser for World Wide Web (One Stop Shop and other browser applications). See last bullet in this subsection.
- VPN (Virtual Private Network) to Caltrans network and Caltrans Web Applications. See last bullet in this subsection.
- Note: Browser and VPN functions will only function when continuous communication system access is available. They will not function under the "store and forward" architecture. If a specific software application is a 'must have', it must be evaluated first to determine if it can be used under store and forward.

Snowplow vehicle applications

- Real-time mapping. See In-vehicle mapping discussion below.
- Messaging. See messaging discussion below.

Messaging

- The system shall include a messaging system (similar to cell phone text messages or Twitter messages in appearance) with the following characteristics:
    - Messages can be addressed by vehicle or operator
    - Messages can be sent to specific users or broadcast to all
    - Menu with canned common messages to minimize typing
    - Operator entered messaging disabled if vehicle is moving

    - Panic button activation sends an automatic message to all vehicles that are instrumented and logged in, plus the maintenance station. This function is not disabled if moving.
    - Each vehicle is assigned a specific tablet, and each tablet includes a unique identifier. This is used for tracking location and other data.
    - At the start of a shift, the operator enters their ID, which allows the system to know who the driver is. The user must log out at the end of the shift. Properly logging into and out of the system must be addressed as part of snow fighter information system training.
    - Available pull-down menu of staff logged into the system with name and ID, for easy message addressing. This is dependent on store and forward

In-vehicle mapping

- Display real time information (subject to communication system availability) of snowplow locations, supervisor vehicle locations, maintenance stations, and salt/sand/cinders refill locations. Touching a vehicle Icon should open a window with:
    - Vehicle speed (or highlighted stopped message if vehicle is not moving)
    - Nose plow blade up/down (if a snowplow)
    - Wing plow blade up/down (if a snowplow)
    - Sander on/off (if a snowplow)
    - Chemical application on/off (if a snowplow)
    - Rock plow blade up/down (if a supervisor vehicle)
    - All available temperatures from the selected vehicle
    - Latitude/Longitude location for the selected vehicle
- Activation of the panic button in any vehicle enlarges or flashes that vehicle icon in all vehicles that are instrumented and logged in, and displays the canned message that includes the vehicle's Latitude/Longitude location.

CHAPTER 5:
SYSTEM DESIGN

System Features

The system as designed would have substantially more features than any available COTS system, as of the end of the Phase 3 research project. Table 5.1 provides a feature comparison matrix of snow fighter information system capabilities as represented by the Phase 3 system requirements discussed in Chapter 4 versus the most feature-rich COTS system currently available, the Vaisala Condition Patrol DSP310.

Table 5.1: Feature comparison for the AHMCT snow fighter information system versus the most advanced COTS system, the Vaisala Condition Patrol DSP310

	AHMCT Snow Fighter Info System	COTS system
Weather Sensor Features		
Road condition: Dry	X	X
Road condition: Moist	X	X
Road condition: Wet	X	X
Road condition: Snow	X	X
Road condition: Ice	X	X
Surface temperature	X	X
Grip	X	X
Dew point temperature	X	X
Air temperature	X	X
Humidity	X	X
Soiled optics indicator	X	
Vehicle Sensor Features		
Nose plow up/down	X	
Wing plow up/down	X	
Rock plow up/down	X	
Sander on/off	X	
Chemical on/off	X	
Communication Features		
Cellular communications	X	X
Satellite communications	X	
WiFi communications	X	
Vehicle-vehicle communications	X	
Store-and-Forward for intermittent communications	X	
In-Vehicle Display Features		
Weather data only		X
Mapping of fleet locations	X	
Mapping of sensor data	X	X
Vehicle-to-vehicle messaging	X	
Vehicle-to-office messaging	X	
Safety Features		
Vehicle stopped alert	X	
Panic button alert	X	
Vehicle location	X	
Impact detection	X	
Roll-over detection	X	
Enterprise Features		
Remote viewing of weather data only		X
Mapping of fleet locations and sensor data	X	
Office-to-vehicle messaging	X	
Data repository	X	X
Installation Compatibility		
Supervisor Vehicle	X	X
Snowplow	X	

HMI Design

As noted elsewhere, the HMI represents the complete system for the end user. Thus, the design and implementation of the HMI is essential for a successful system. The AHMCT-designed HMI mapping application is shown in Figure 5.1 Here, location of four snowplows is provided along

SR 88 near Caples Lake. Each snowplow is labeled with its ID number, in addition to being color-coded for easy at-a-glance identification. In the image shown, the user has clicked on snowplow truck #19, which brings up a window providing that truck's location (latitude / longitude), speed (or highlighted stopped message if vehicle is not moving), direction of travel, nose and wing plow blade up/down, sander on/off, road condition, and road and air temperature. The map allows zoom in/out via the upper left slider. In addition, a period of historical data can be displayed using the video animation controls at the bottom of the map. The system would also display last update date and time for each vehicle, so it is clear whether or not the information is current. Note that some of these features exceed those in the requirements.

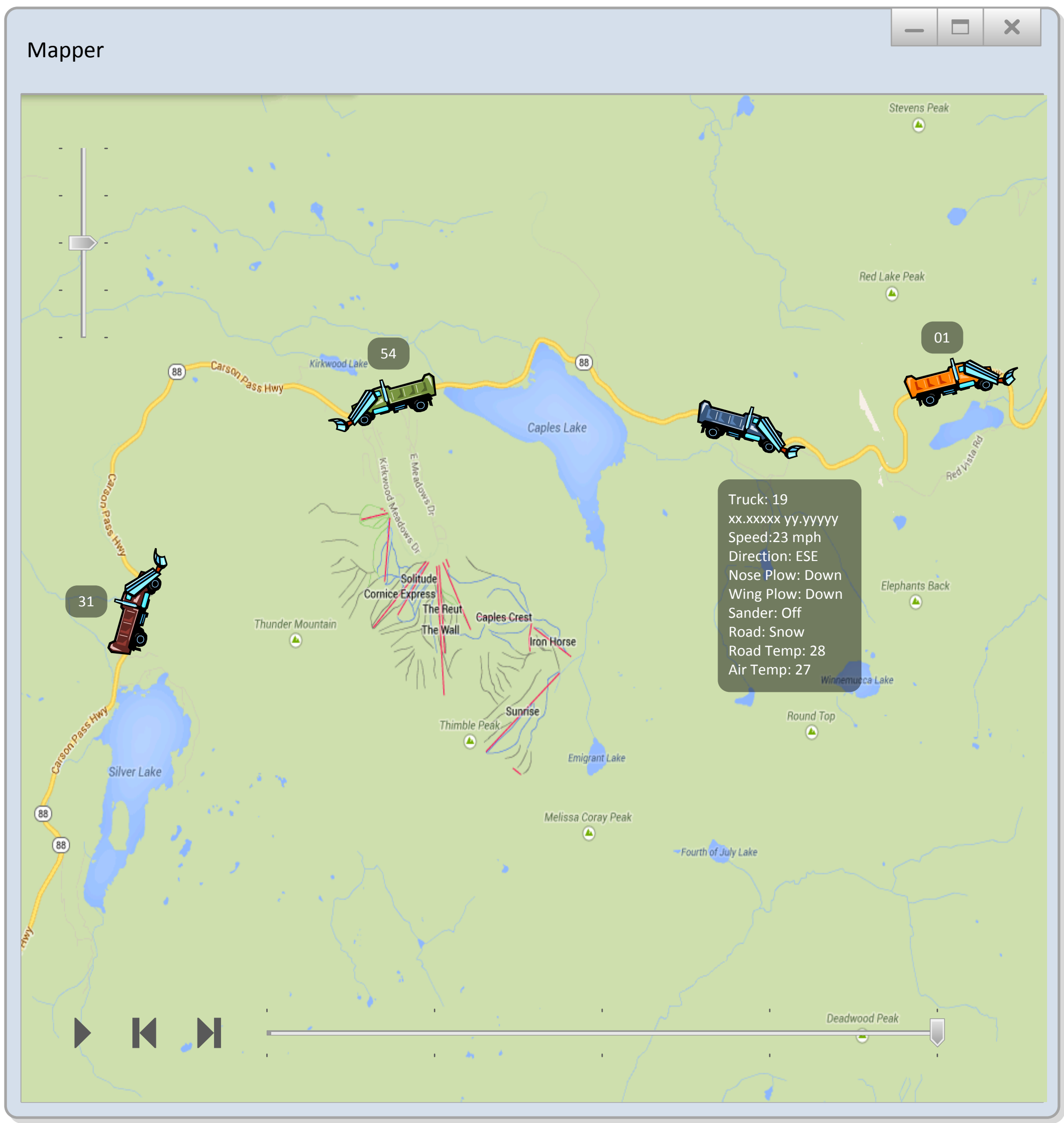

Figure 5.1: Mapping application HMI

The AHMCT-designed HMI messaging application is shown in Figure 5.2 Here, the core of the HMI is the messaging dialog in the main upper right panel. This shows the most recent messages to and from this vehicle. Free-form messages are entered via the bottom panel. Pre-programmed ("canned") messages are available in the panel above the free-form panel. These canned messages can be configured by the site administrator. Some canned messages will be fairly universal across many sites, while others will be site-specific, such as “Avalanche at Carson Pass.” The left pane provides the available contacts (individual trucks, supervisors, and plowing groups) that can be targeted for a given message via one click. Groups are set up by an administrator, and would typically represent a group of snowplow trucks at, for example, Caples Lake. Alternatively, at a site like Kingvale, a group might be a snowplow echelon configuration. Finally, there is a search field to allow an operator to search available messages for a specific word or phrase. The design could be revised to support other organization techniques, e.g. by radio channels.

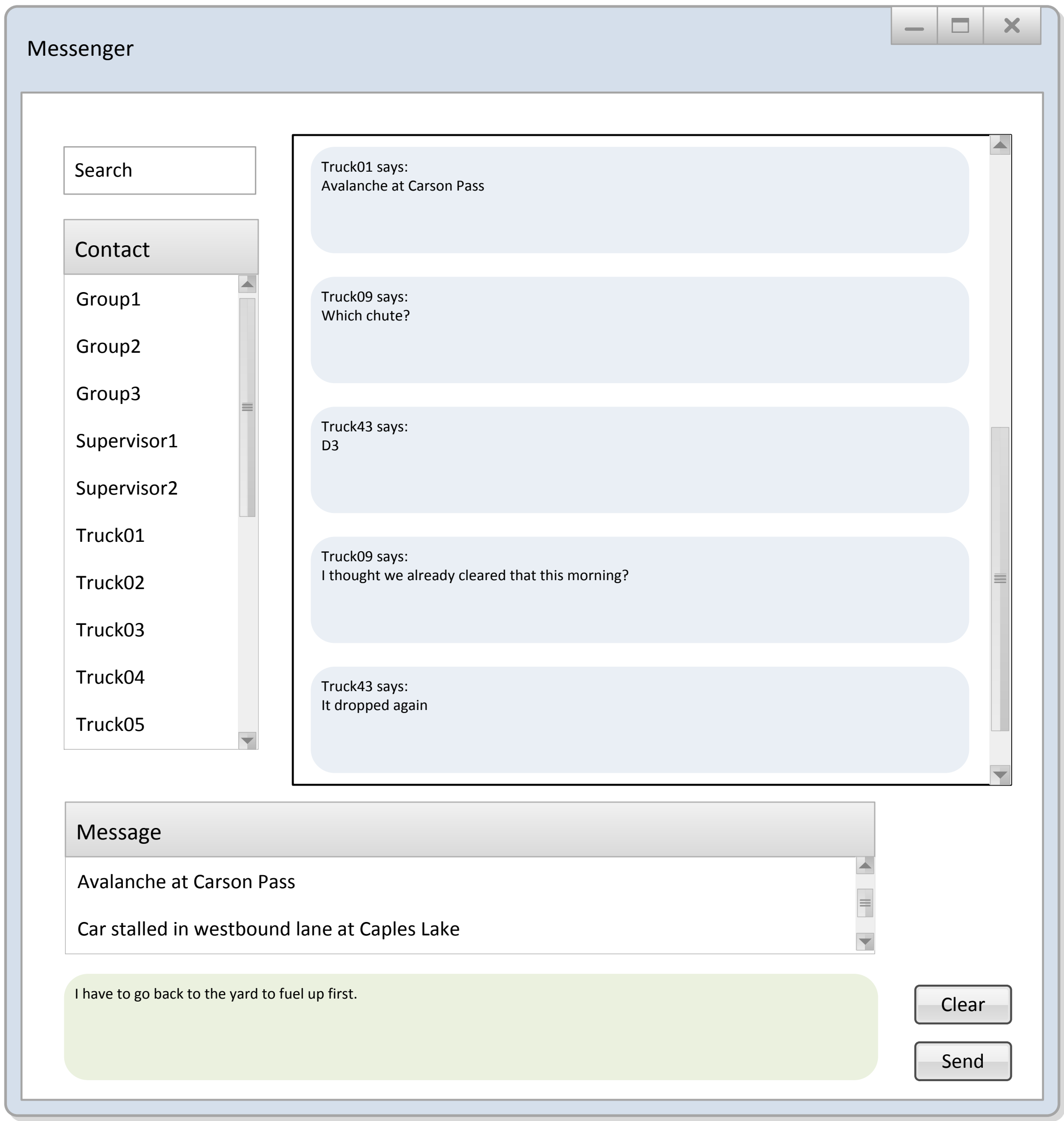

Figure 5.2: Messaging application HMI

The remainder of the HMI consists of screens providing information to the snowplow operator or the supervisor. This information includes weather, leveraging One-Stop-Shop. These screens are omitted here for conciseness.

System Hardware Components

The system hardware was selected based on ability to meet requirements, performance, robustness with respect to the winter maintenance environment, prior application in winter maintenance, and, finally, cost. The system electronics were designed to be incorporated inside the snowplow or supervisor vehicle cab. The details of the system electronics are omitted here for conciseness. The GPS receiver is an integrated and hardened unit, as shown in Figure 5.3. The RoadWatch air and road temperature sensor is shown in Figure 5.4.

Figure 5.3: GPS sensor

Store-and-Forward Architecture

The key aspect of the computation and communications architecture for the snow fighter information system is the use of store and forward. As discussed in the introduction and the system requirements in Chapter 4, and as clearly illustrated in the cellular survey results of Chapter 6, snow fighters often operate in areas where cellular communications is intermittent, including large areas where no signal is available. To accommodate this constraint, the system implements a store-and-forward architecture. Under normal conditions wherein cellular signal is available, the system transmits and receives as would any other cellular data-equipped system, e.g. a smartphone. However, when there is no cellular signal available, the system then stores up any messages, data, and requests. The system then monitors for cell signal availability. Upon detecting cell signal with sufficient strength, the system then forwards all stored messages, data, and requests, and receives responses from the server.

Figure 5.4: RoadWatch air and pavement temperature sensor

The system can also use Wi-Fi to transmit and receive data. The same store-and-forward architecture will work for Wi-Fi as well. In a future scenario, the system could also use DSRC to provide communication, i.e. in a Connected Vehicle environment (vehicle-to-roadside communications). Finally, satellite communications can also be used. Satellite was not used here due to the relatively high cost of satellite communications equipment and data plans. Satellite communications is used in the Responder system [5]. Note that all of these communications modes are subject to non-availability, so the store-and-forward architecture must be applied even if all of them are used. As is done in Responder, an arbiter routine can select which communications channel is used based on cost, bandwidth, signal strength, or other criteria.

CHAPTER 6:
CELLULAR SURVEY

The snow fighter information system is designed to work in any snow-affected area, through the inclusion of Wi-Fi, cellular, and satellite communications systems. The system is most valuable in areas with degraded or no cellular reception. Such cellular-challenged areas are not uncommon in the more rural snow-affected areas in Caltrans. To better understand the level of need and the expected benefit from the additional communications systems, AHMCT performed a cellular survey on all snow-affected routes in California. This survey determined cellular coverage and signal strength along all state routes where Caltrans performs winter maintenance. The area to cover was based on Caltrans chain control stations, which are provided in Appendix D.

To determine cellular coverage and signal strength for multiple cellular providers, AHMCT developed a survey strategy, cellular data collection hardware, and an Android app to sample and record signal strength. The service providers do have coverage maps; however, their maps do not provide the level of detail and resolution necessary to inform the snow fighter information system design process. The data collection hardware and software are discussed in the next section. The survey results in the form of coverage maps are provided in the section following that. The data was collected using an AHMCT research vehicle. The process consisted of driving each snow-affected route while capturing the providers' (AT&T, Verizon, and T-Mobile) signal strength as measured by the detection system. Location coordinates were also recorded using the smartphone's built-in GPS receiver. To perform the full survey, AHMCT spent three full working weeks on the road, logging approximately 5000 total miles. The signal strength and coverage data collected in this survey has provided key information for other AHMCT research efforts, including evaluation research for a head-up display snowplow driver assistance system [19], and the Phase III Responder system [5] discussed in Appendix B.

Cellular Coverage and Signal Strength Survey Results

The cellular signal strength survey was performed in 2013 for all California snow-affected routes. Heat maps for a small portion of the collected data are provided in Appendix D. Data is available for the entire length of the California snow-affected areas, and heat maps can easily be generated for any area within the survey. The results are shown only for AT&T and Verizon, for conciseness. T-Mobile signal strengths were typically lower in the rural areas of the survey. The AT&T data was collected on a Nexus 4 3G smartphone, while the Verizon data was collected on a Samsung Galaxy S4 4G smartphone. From the results for Interstate 80 (I-80) at both the general and detailed zoom levels, it is fairly clear that Verizon provides better coverage and signal strength than AT&T in this semi-rural area. At the detailed zoom level, it becomes much clearer that Verizon provides better coverage with higher signal strength and fewer coverage gaps.

Interstate 80 has some of the best coverage of all California snow-affected areas. The snow fighter information system is designed to work well in any snow-affected area. However, its key features and capabilities, particularly its store-and-forward architecture, were designed to provide the best possible function in areas with the worst cell signal coverage and strength. With these capabilities, the system can bridge areas of zero coverage, storing all data and requests. Upon entering an area with cell coverage, the system then forwards data and requests to the server, and downloads any responses. The system was explicitly designed with this capability so that the snow fighter information system could support snow operations in Caltrans' most rural and isolated areas. The target for field testing was near the Caples Lake maintenance yard on SR 88 in Caltrans District 10. Appendix D provides the cell signal coverage and strength along SR 88 for AT&T and Verizon, respectively. As with the semi-rural I-80, the highly rural SR 88 has far better coverage and signal strength than AT&T. This pattern was seen for essentially all snow-affected routes in California. One clear conclusion is that for the semi-rural to rural areas where Caltrans must perform winter maintenance, Verizon would be a good vendor for cellular data transmission. Note that even with its superior coverage and signal strength, Verizon does exhibit areas with low signal strength as well as coverage gaps. Thus, one can also conclude that the use of the store-and-forward architecture is justified for either carrier.

CHAPTER 7:
CONCLUSIONS AND FUTURE RESEARCH

Key contributions of this Phase 3 research included:

- Development of cost-effective and reliable communications in challenging environments
- Design of a store-and-forward architecture to address intermittent data communications
- Design of the HMI for a snow fighter information system
- Assessment of available COTS systems for winter maintenance fleet applications.

Implementation of a snow fighter information system would enhance winter maintenance operations through improved communications and situational awareness, leading to increased safety for Caltrans Maintenance personnel, and improved safety and mobility for the traveling public. Unfortunately, the system under development by AHMCT did not reach an implementation stage due to changes in the Phase 3 project focus, as discussed in Chapter 1. However, some of the benefits inherent in the snow fighter information system are still achievable through judicious application of a COTS snow fighter system. The benefits will be lower, and the system will provide fewer capabilities, but the systems are commercially available now, and could be widely deployed in the Caltrans fleet.

Future research in this area may include a pilot study of one or more commercial systems in a small portion of the Caltrans winter maintenance fleet. This would be expected to include at a minimum fleet tracking including GPS location, interfacing to ECUs (Engine Control Units), and sensing of front plow blade and spreader status. Additional sensing may include spreader rate. Ideally, such a pilot would also investigate mobile surface condition monitoring on at least one snowplow. Such a pilot study is under consideration for the winter of 2015-2016. One COTS system has been identified, and another is under consideration.

Farther into the future, based in part on the results of any pilot study, Caltrans may want to reconsider the development and deployment of the snow fighter information system as envisioned and designed in this Phase 3 project. As shown in Table 5.1, this system is much more capable than existing COTS systems and was designed to be easily supportable after deployment. Based on current commercial trends, it is anticipated that this would remain true for many years to come.

Future work should consider the use of winter maintenance vehicles as sensor probes. This could include integration of data from snow fighter information systems into a Transportation Management Center (TMC). The vehicles, wirelessly connected to the Internet, provide a form of mobile RWIS combined with traffic sensing probe. Thus, the connected winter maintenance vehicles would become additional roving network nodes that can provide real-time data to the TMC. Future sensors could include video, additional weather functions, etc. This combination could provide added efficiency and novel operational capabilities.

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APPENDIX A: COTS HARDWARE EVALUATION FOR HMI

AHMCT performed an extensive survey and detailed comparison of available COTS hardware that could serve as the snow fighter information system HMI. This comparison is provided in Tables A.1 – A.2. The COTS systems are grouped into ruggedized (Table A.1), non-ruggedized (Table A.2), and Windows 8 tablets (Table A.3). While ruggedized tablets have an intuitive appeal in the harsh snow plowing environment, it is important to evaluate cost and capabilities versus non-ruggedized systems. Ruggedized tablets can be as much as ten times the price of non-ruggedized systems. In addition, they are often quite far behind in terms of operating system and corresponding capabilities and programming API (Application Programming Interface). Generally, a non-rugged tablet can be incorporated into a ruggedized case, providing a good level of protection. Finally, with the price differential, an agency can replace five to ten broken non-ruggedized tablets for the cost of a single ruggedized system. Operating system (OS) choice, including version, may be important in terms of the supported API, and in terms of existing custom applications. The final trade-off analysis is left to the end-user agency, as there may be other agency-specific constraints to factor in, such as IT (Information Technology) and procurement requirements.

Table A.1: Ruggedized commercial-off-the-shelf system comparison for HMI

Model	OS	Display Size	Resolution	Screen Brightness	IP Rating	Drop	MicroSD	Camera	GPS	WiFi	Ethernet	wwan	BT	size	weight	Op. Temp.	Battery Life	Cost	
T70H	Android 4.2	7"	1024x600	400 nit	IP67		yes	5 MP	yes	802.11b/g/n	no	GSM CDMA	4					$759	
Xplore Technologies RangerX	Android 4.0.4	10.1"	1366x786	500 nit	MIL–STD–810G & IP65	4'	yes	5 MP		802.11a/b/g/n	Optional	CDMA 4G LTE	4	182x183 x21.5 mm	2.2 lbs	-20 to 60C			
Getac Z710	Android 4.1	7"	1024x600	Sunlight Readable	IP65		Yes	5MP	Yes	802.11b/g/n	no	3.5G GSM	2.1	8.85x5.6x1.06"	1.77 lbs	-20 to 50C		$1,500	
Panasonic Toughpad JT-B1	Android 4.0	7"	1024x600	500 nit Sunlight Readable	IP65		Yes	13MP	Yes	802.11a/b/g/n	via Docking Station	Optional 4G LTE	4.0	8.7x5.1 x0.7"	1.2 lbs		8 hrs	$1,500	
Panasonic Toughpad FZ-A1	Android 4.0	10.1"	1024x768	500 nit Sunlight Readable	IP65		yes	5MP	Yes	802.11a/b/g/n	via Docking Station	Optional 4G LTE	2.1	10.5x8.4x0.7"	2.1 lbs		10 hrs	$1,500	
Fieldbook FBD1	Android 4.0	7"	1024x600		IP54		yes	5MP	Yes	802.11b/g/n	no	3.5 G	2.1	132x220 x17 mm	580g		7 hrs		
Juniper Systems MESA	CE6.5 (Android possible)	5.7"	640x480		IP67		yes	3.2MP	yes	802.11b/g	no	3.5G		5.3x8.6 x2"	2.2lbs	-20 to 60C		$4,000	
SDG Rampage6	Android 2.3	5.7"	640x480		IP67		yes	3.2MP	yes	802.11b/g	no	3.5G	2.0	5.3x8.6 x2"	2.2lbs	-20 to 60C		$4,000	
Armor X7ad	Android 3.2	7"	1280x800	400 nit	MIL–STD–810G & IP65	4	yes	5MP		802.11b/g/n		GSM / CDMA	2.1	8.4" x 5.2" x 0.8" / 214 x 132 x 21 mm	1.3 lbs	-20 to 60C		$1,199	

Table A.2: Non-ruggedized commercial-off-the-shelf system comparison for HMI

Model	OS	Display Size	Resolution	Screen Brightness	IP Rating	Drop	MicroSD	Camera	GPS	WiFi	Ethernet	wwan	BT	size	weight	Op. Temp.	Battery Life	Cost	
Google Nexus 7	Android 4.3	7"	1280x800		non		no	1.2MP	Yes	802.11b/g/n		no		198.5 x 120 x 10.45 mm	340g			$230	
Google Nexus 7 2013	Android 4.3	7.02"	1920x1200		non		no	5 MP	Yes	802.11a/b/g/n	no	GSM	4	114 x 200 x 8.65 mm	0.64 lbs				
Google Nexus 10	Android 4.2	10"	2560x1600				no	5MP	Yes	802.11b/g/n		no		263.9 x 177.6 x 8.9 mm	603g			$499	
Samsung Note 8"	Android 4.1	8"	1280x800				Yes	5MP	??	802.11b/g/n		no		8.3" X 5.35" x 0.31"	12oz			$399	
Samsung Note 10"	Android 4.1	10.1"	1280x800		NA		Yes	5MP	??	802.11b/g/n		optional	4.0	7.1" x 10.3" x 0.35"	1.31lbs			$499	
Lenovo Ideatab A2109	Android 4.0	9"	1280x800		NA		Yes	3MP	no	802.11b/g/n		no	3.0	9.3" x 6.5" x 0.46"	1.3lbs			$230	
Lenovo Ideatab A2107	Android 4.0	7"	1024x600		NA		Yes	3MP	no	802.11b/g/n		optional	4.0	7.6" x 4.8" x 0.45"	0.9lbs			$180	

Table A.3: Windows 8 commercial-off-the-shelf system comparison for HMI

Model	OS	Display Size	Resolution	Screen Brightness	IP Rating	Drop	MicroSD	Camera	GPS	WiFi	Ethernet	wwan	BT	size	weight	Op. Temp.	Battery Life	Cost	
Panasonic Toughpad FZ-G1	Win 8	10.1"	1920x1200	800 nit Sunlight Readable	IP65		yes	3MP	optional	802.11a/b/g/n	yes	Optional 4G LTE	4.0	10.6x7.4x0.8"	2.5 lbs		8 hrs	$2,500	
Dell Latitude 10	Win 8	10"	1366x768				yes	8MP	optional	802.11b/g/n	no	Optional 3G HSPA					10 hrs	$700	

APPENDIX B:
RELATED EXISTING RESEARCH

There are several existing research projects or products that can be leveraged to benefit the snow fighter information system. The key existing projects and products are reviewed here, including the context for their use with the snow fighter information system.

One-Stop-Shop and WeatherShare

The One-Stop-Shop[16] (OSS) web application provides travelers in California with comprehensive, real-time data. This information consists of both traditional information (routing, imagery, weather, wind speed, etc.), as well as points of interest and other route-specific information (elevations, rest areas, etc.). Specifically for weather, WeatherShare[17] presents weather data for California in a map-based format (see zoomed partial screen shot in Figure B.1).

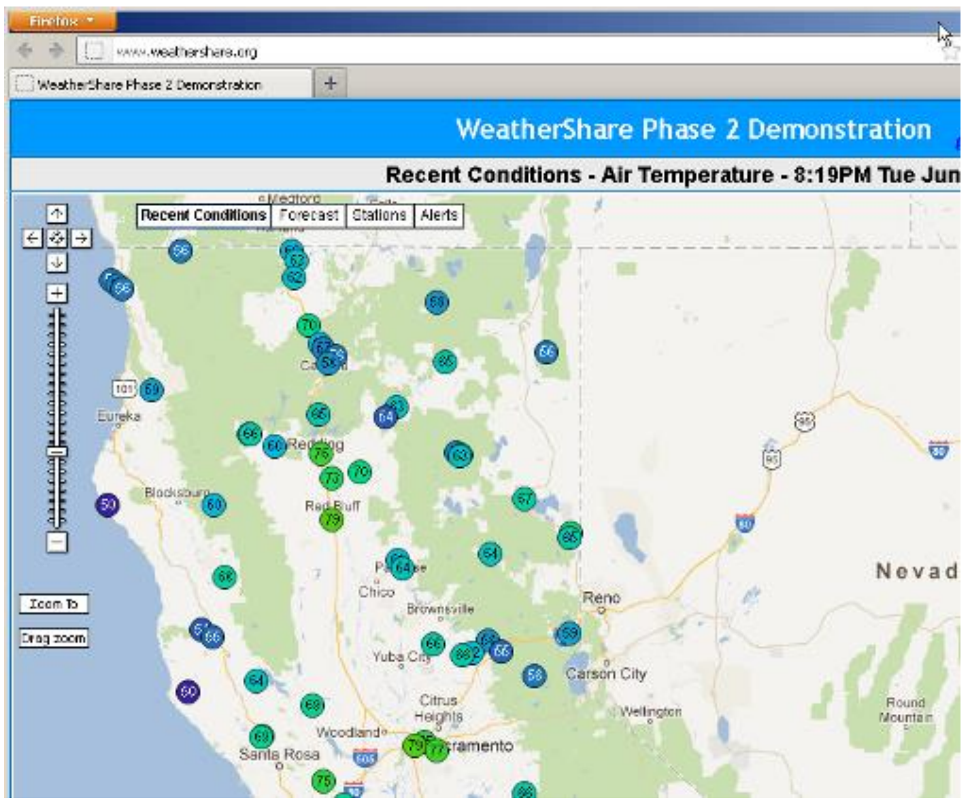

Figure B.1: WeatherShare.org website zoomed partial screenshot (courtesy of WTI)

OSS and WeatherShare, both developed by the Western Transportation Institute (WTI) at Montana State University (MSU), could serve as information feeds to the snow fighter information system, fulfilling a key information need.

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16 http://www.westernstates.org/Projects/OSS/ and http://oss.weathershare.org/
17 http://www.weathershare.org/

Figure B.2: Responder communications briefcase from Phase II effort (courtesy of WTI)

Responder

The Responder[18] system facilitates communication and documentation of incidents in rural areas [11]. Incident responders use the Responder system to describe an incident and convey details back to a traffic management center. The Responder system consists of a tablet PC, an optional communications briefcase (see Figure B.2), and purpose-built software. The briefcase houses cellular and satellite phone communication equipment. While it was developed with a focus on communications-challenged rural areas, the system can also provide benefit in urban areas, as communications, particularly cellular, are often degraded in more severe incidents. Responder was originally designed and developed by WTI. At Caltrans' request, AHMCT performed research and development to move the system to a deployable design for Caltrans to use in urban and rural emergencies [5].

The Responder communications briefcase could serve as a component of the snow fighter information system. This would depend on a number of factors, particularly the state of related commercial technologies, and the specific requirements as dictated by the TAG. Considerations should be made so that the snow fighter information system would be able to share and run on the same platform to facilitate deployment of both systems and reduce duplication of hardware and services costs.

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[18] http://www.westernstates.org/Projects/Responder/

Light and Heavy Vehicle Fleet Tracking

Recently, Caltrans Division of Equipment (DOE) and Division of Maintenance have explored the use of vehicle tracking systems to improve overall fleet management. DOE assessed the use of cost-effective fleet in-vehicle data acquisition systems (FIDAS) for fleet management [20]. DOE and AHMCT completed this assessment which targeted light fleet vehicles (less than ¾ ton) that typically allow more uniform installations, require less customization, and have reduced per vehicle costs. In conjunction, the Division of Maintenance is planning to evaluate FIDAS for heavy duty vehicles. The objective is to improve fleet management, reduce fuel use, and produce accurate fuel use reporting. Improvements will be accomplished by automating trip-related data collection and report generation, and improving communications to equipment managers. COTS components (hardware and software) will be procured, tested, and evaluated for heavy fleet vehicles. The results could provide vehicle asset location data that can greatly enhance resource allocation decisions in an emergency. Note that real-time location information may not be available for mobile assets, depending on communications status; however, location for stored vehicles and equipment will generally be available.

IRIS (Intelligent Roadway Information System)

AHMCT deployed, maintained, and enhanced IRIS for Caltrans Districts 1, 2, 5, and 10. A Feasibility Study Report (FSR) was completed for full deployment, and IRIS is now deployed and being maintained by a third-party contractor [13]. IRIS, as illustrated by the example screens in Figures B.3 and B.4, is an Advanced Transportation Management System (ATMS) that was developed and released as open-source software by the Minnesota Department of Transportation (MnDOT) in 2007. Caltrans is the first agency to adopt and enhance IRIS, contributing numerous improvements back to the open-source project. The system provides significant capabilities, improved safety, lower personnel maintenance needs, and higher reliability than previously employed systems. For example, IRIS provides changeable message sign libraries and fonts, as well as system logging, error checking, and configuration flexibility. The system provides traffic flow data from traffic detectors in the district, video from traffic cameras, traffic incident data, and changeable message sign status as well as data from weather stations. These data are crucial for effective emergency management. Consideration is being given to incorporating information from the snow fighter information system or from similar sensors to provide a sort of mobile road weather information system (RWIS) data feed to IRIS.

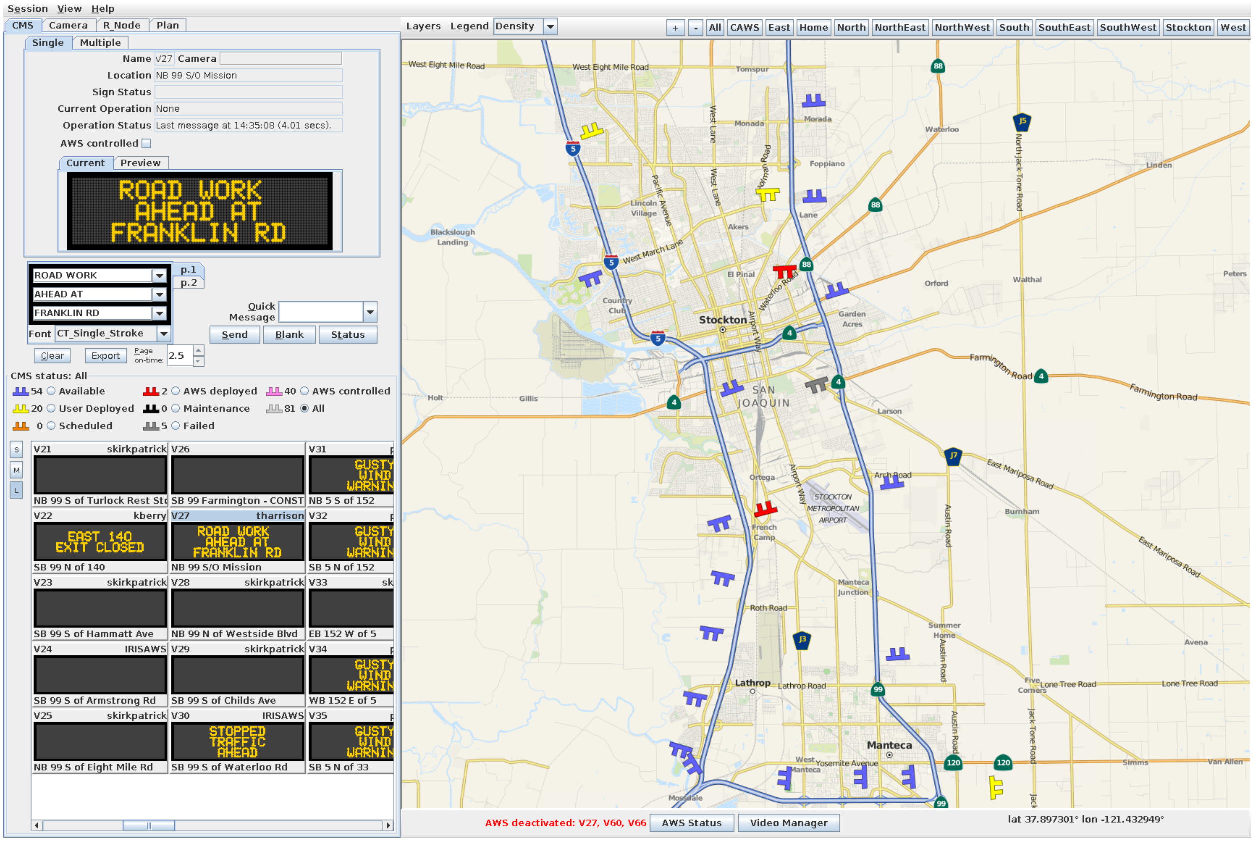

Figure B.3: IRIS ATMS example full screen for Changeable Message Signs (CMS) including control pane and map

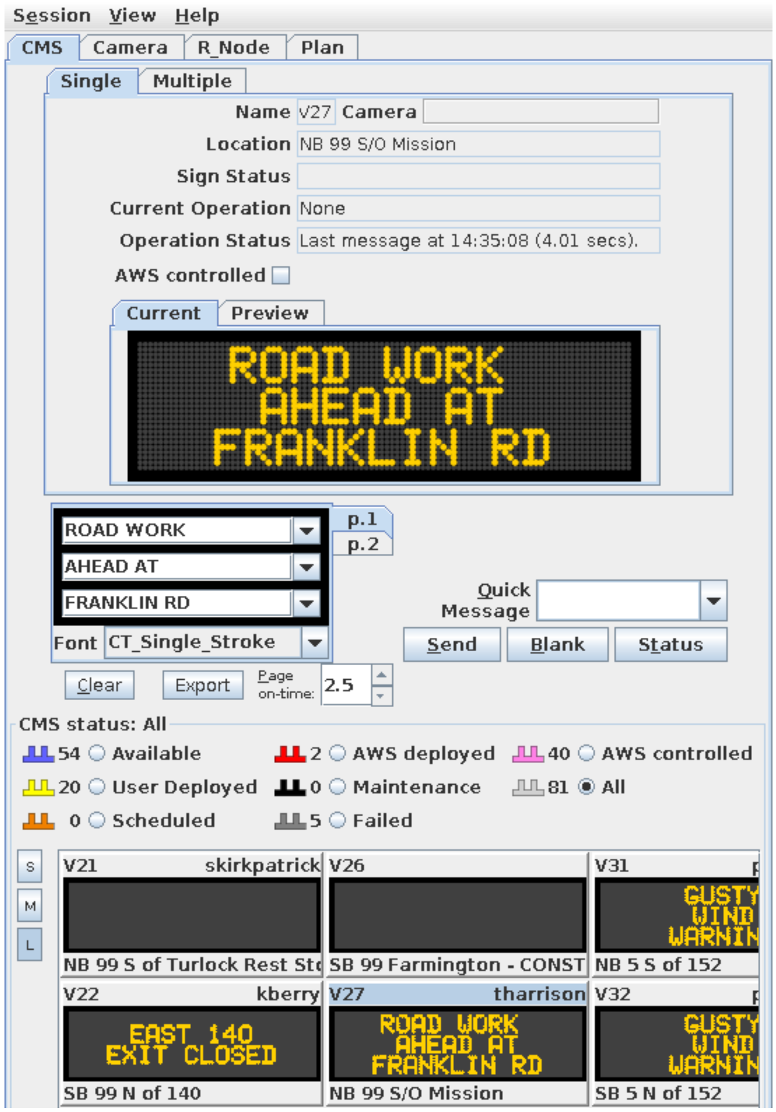

Figure B.4: IRIS ATMS zoomed image of part of the CMS control pane

APPENDIX C: POWERMETER APP DETAILS

The Android PowerMeter data collection app was designed to be highly reliable and intuitive to use. The app is best described in reference to screen shots. Figure C.1 shows the launch icon for the PowerMeter app. The app uses "swipe" gestures to navigate between the available screens, as can be seen by the menus visible near the top of the app in Figure C.2. For example, to move from the Main screen to the Mobile screen, the user would swipe across the screen from right to left. Navigation by swipe gestures is quite familiar for Android users. The app makes use of a unified color scheme to organize and present data. All mobile cellular signal information is green, while all GPS information is blue. To make the app more generally useful, Wi-Fi signal strength can also be recorded. Wi-Fi information is all presented in orange. Storage information is colored red.

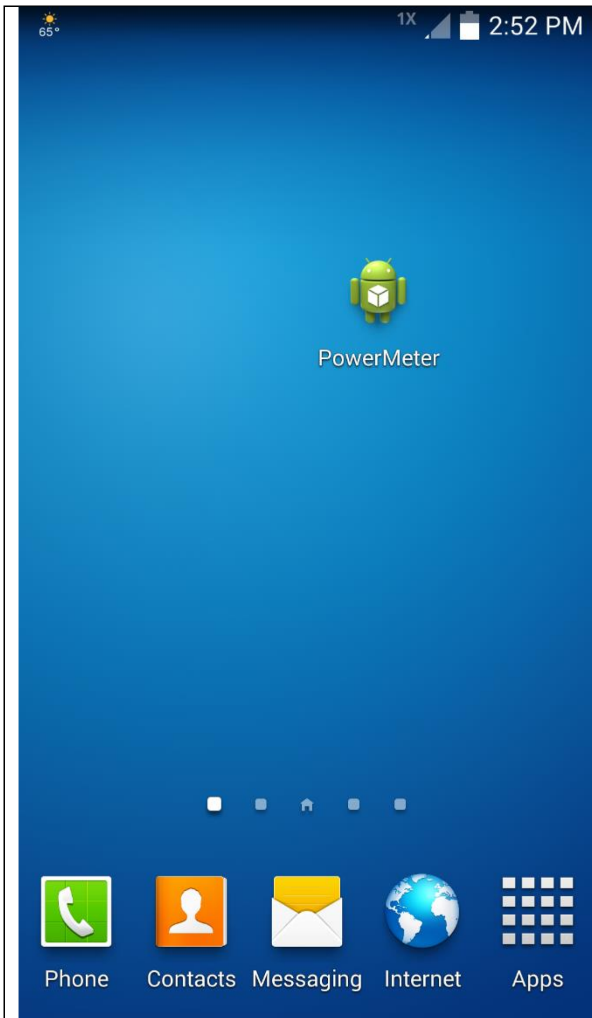

Figure C.1: Launch icon for the PowerMeter app

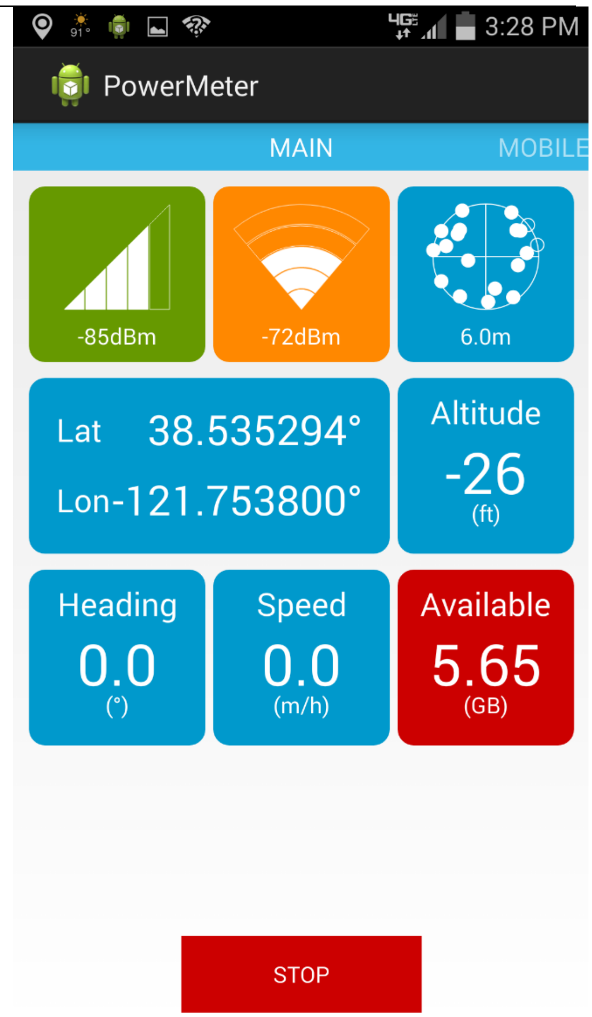

Figure C.2: Main screen for PowerMeter app

Figure C.2 shows the PowerMeter app's Main screen. This is the screen that appears when the app is first launched. The images on this screen are active information providers; they are not buttons. The images provide an overview of the current sensing status, including cell signal strength (green), Wi-Fi signal strength (orange), and various GPS / location sensing status indicators (blue). The GPS indicators include estimated accuracy, current latitude and longitude, altitude, heading, and speed. Finally, the amount of storage remaining is shown in red. Data collection begins immediately when the app is launched, and continues until the user presses the "STOP" button on the Main page.

Figure C.3 provides the Mobile screen. This screen presents all currently sensed cell towers (here, only one), and provides the tower ID and the sensed signal strength. This signal strength, along with current location via GPS, is the core data collected by the app.

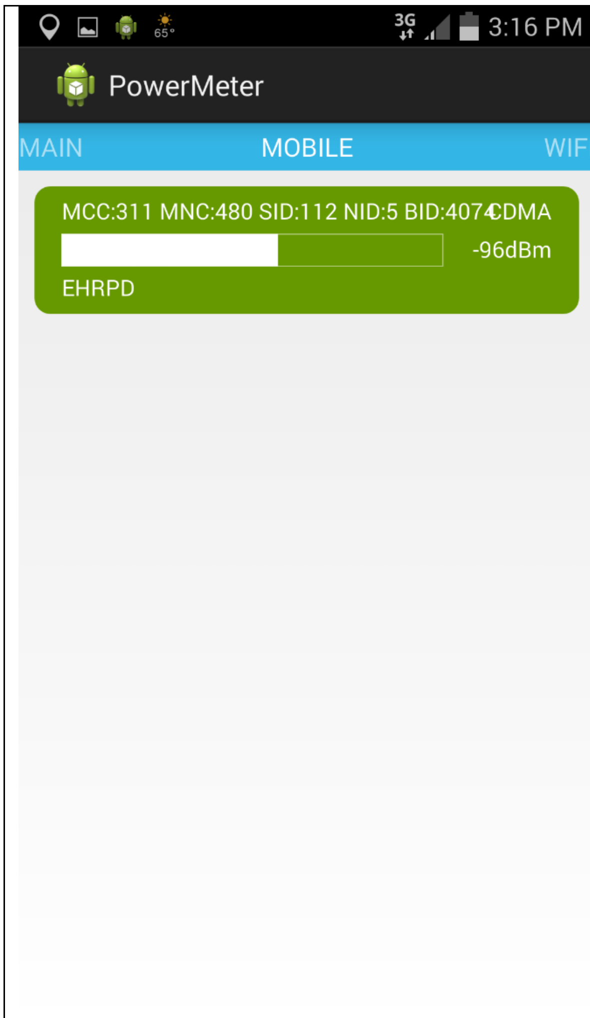

Figure C.3: Mobile screen for PowerMeter app

Figure C.4: Wi-Fi screen for PowerMeter app

While the focus in this research was on cell signal strength, the app is more general purpose, in that it can also sense, collect, and map Wi-Fi signal strength. Figure C.4 shows the Wi-Fi screen. Here, information is shown for each Wi-Fi router detected, including name, MAC address, frequency, signal strength, and security method(s) supported or enabled.

Figure C.5 shows the Wi-Fi Map screen. This screen provides a graphical presentation of the Wi-Fi signal strength for all detected routers at 2.4 GHz and 5 GHz. The routers are plotted based on their channel. The 2.4 GHz frequency supports 11 overlapping channels in the United States. The 5 GHz frequency supports at least 23 non-overlapping channels.

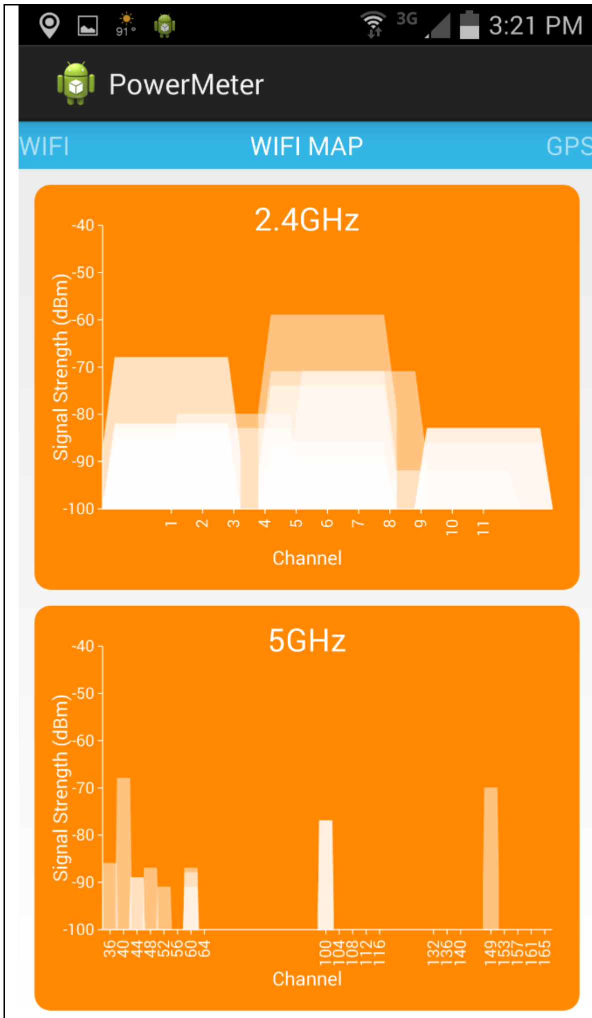

Figure C.5: Wi-Fi Map screen for PowerMeter app

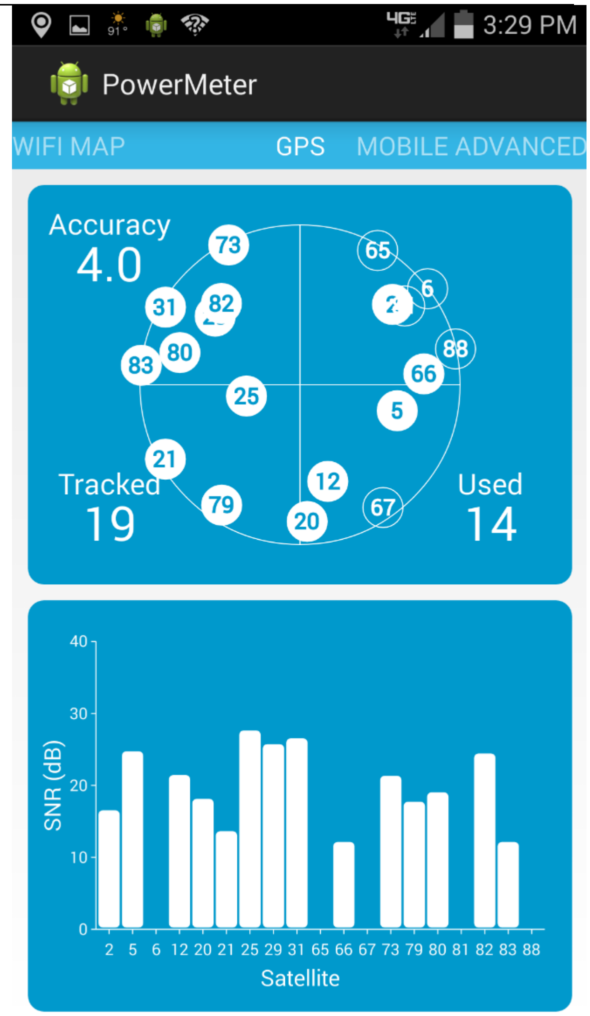

Figure C.6: GPS screen for PowerMeter app

Figure C.6 provides the GPS receiver status screen. More accurately, this is the GNSS (Global Navigation Satellite System) status. The top panel plots the satellite geometry. This includes the satellite number, and whether the particular satellite is used (solid white) or not (transparent) in the location solution. This panel also indicates the current solution accuracy level, the number of satellites being tracked, and the number of satellites being used in the location solution. All of these indicators are useful in evaluating the quality of the location solution. The bottom panel plots the received signal strength for each of the tracked satellites.

The app's Mobile Advanced screen is shown in Figure C.7. This screen is most useful for app debugging and testing purposes. It provides very detailed information about the mobile cellular signal, including current time, signal strength, cell tower location, base station ID, network ID, system ID, network operator, and phone type. All of this data is in Extensible Markup Language (XML) format. As such, it is easily human readable, and can be imported into many standard applications (e.g. Excel, Firefox, etc.), as well as custom-developed analysis applications. The data is provided for each cell transmitter in range.

Figure C.7: Mobile Advanced screen for PowerMeter app

Figure C.8: Wi-Fi Advanced screen for PowerMeter app

The app's Wi-Fi Advanced screen is shown in Figure C.8. Again, this screen is most useful for app debugging and testing purposes. It provides very detailed information about the Wi-Fi signal, including current time, SSID, supported authorization algorithms and ciphers, supported protocols, and network ID. All of this data is in Extensible Markup Language (XML) format. As such, it is easily human readable, and can be imported into many standard applications (e.g. Excel, Firefox, etc.), as well as custom-developed analysis applications. The data is provided for each Wi-Fi router in range.

Figure C.9: GPS Advanced screen for PowerMeter app

Figure C.9 provides the GPS Advanced screen. Again, this screen is most useful for app debugging and testing purposes. It provides very detailed information about the GNSS state, including current time, latitude/longitude location solution, altitude, provider (GPS, GLONASS, etc.), solution accuracy, speed, time to first fix, and maximum number of satellites. For each satellite being tracked, it also provides azimuth and elevation to satellite, satellite ID (PRN), signal-to-noise ratio (SNR), almanac availability, ephemeris availability, and whether that satellite is used in the location solution. All of this data is in Extensible Markup Language (XML) format. As such, it is easily human readable, and can be imported into many standard applications (e.g. Excel, Firefox, etc.), as well as custom-developed analysis applications. The data is provided for each satellite being tracked.

APPENDIX D: CELLULAR COVERAGE AND SIGNAL STRENGTH SURVEY

The snow fighter information system is designed to work in any snow-affected area, through the inclusion of Wi-Fi, cellular, and satellite communications systems. The system is most valuable in areas with degraded or no cellular reception. Such cellular-challenged areas are not uncommon in the more rural snow-affected areas in Caltrans. To better understand the level of need and the expected benefit from the additional communications systems, AHMCT performed a cellular survey on all snow-affected routes in California. This survey determined cellular coverage and signal strength along all state routes where Caltrans performs winter maintenance. The area to cover was based on Caltrans chain control stations, which are shown in Figures D.1 – D.4.

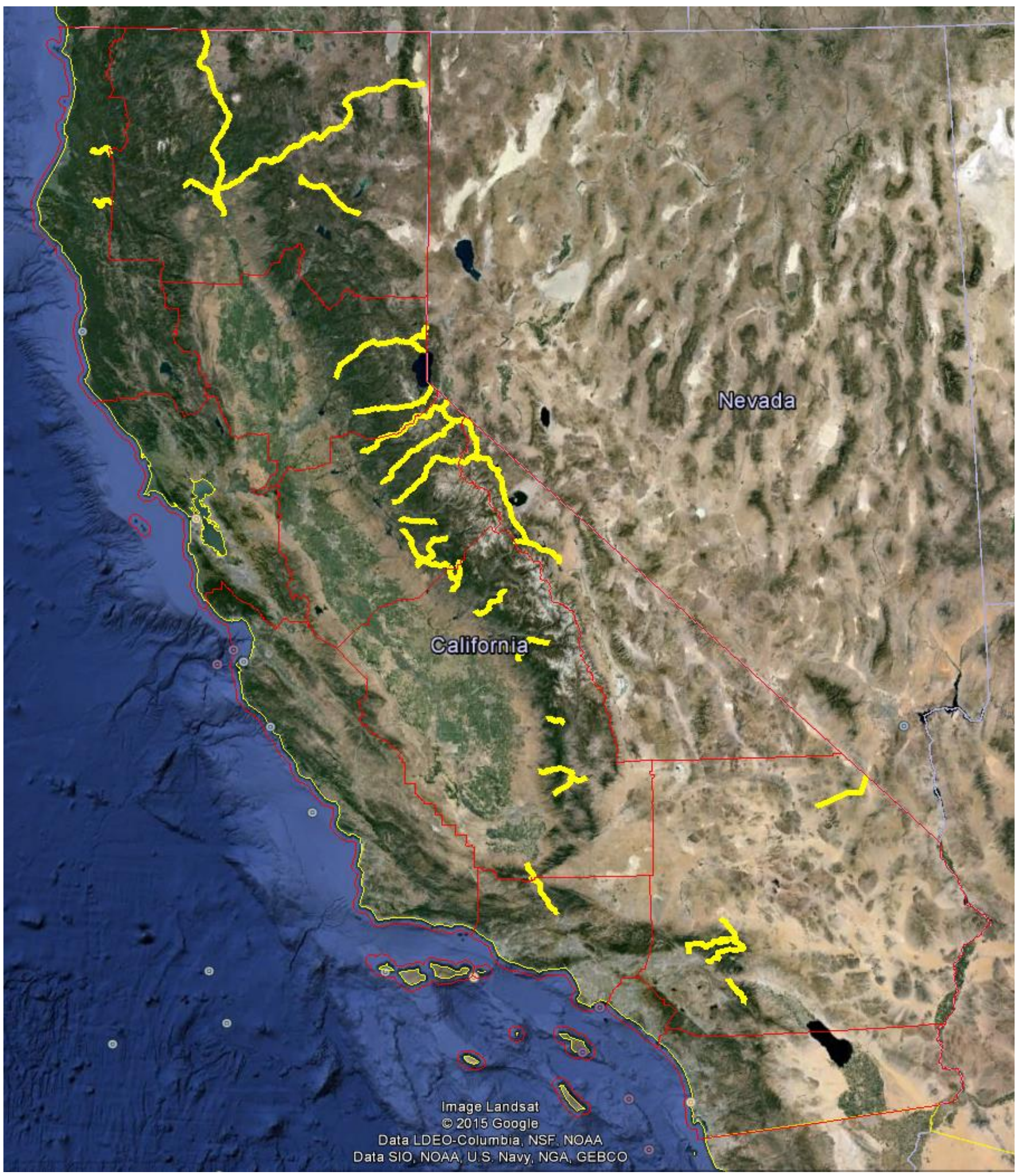

Figure D.1: Snow-affected routes (yellow) for California. Red boundaries represent Caltrans districts.

Figure D.2: Snow-affected routes (yellow) for northern California. Red boundaries represent Caltrans districts.

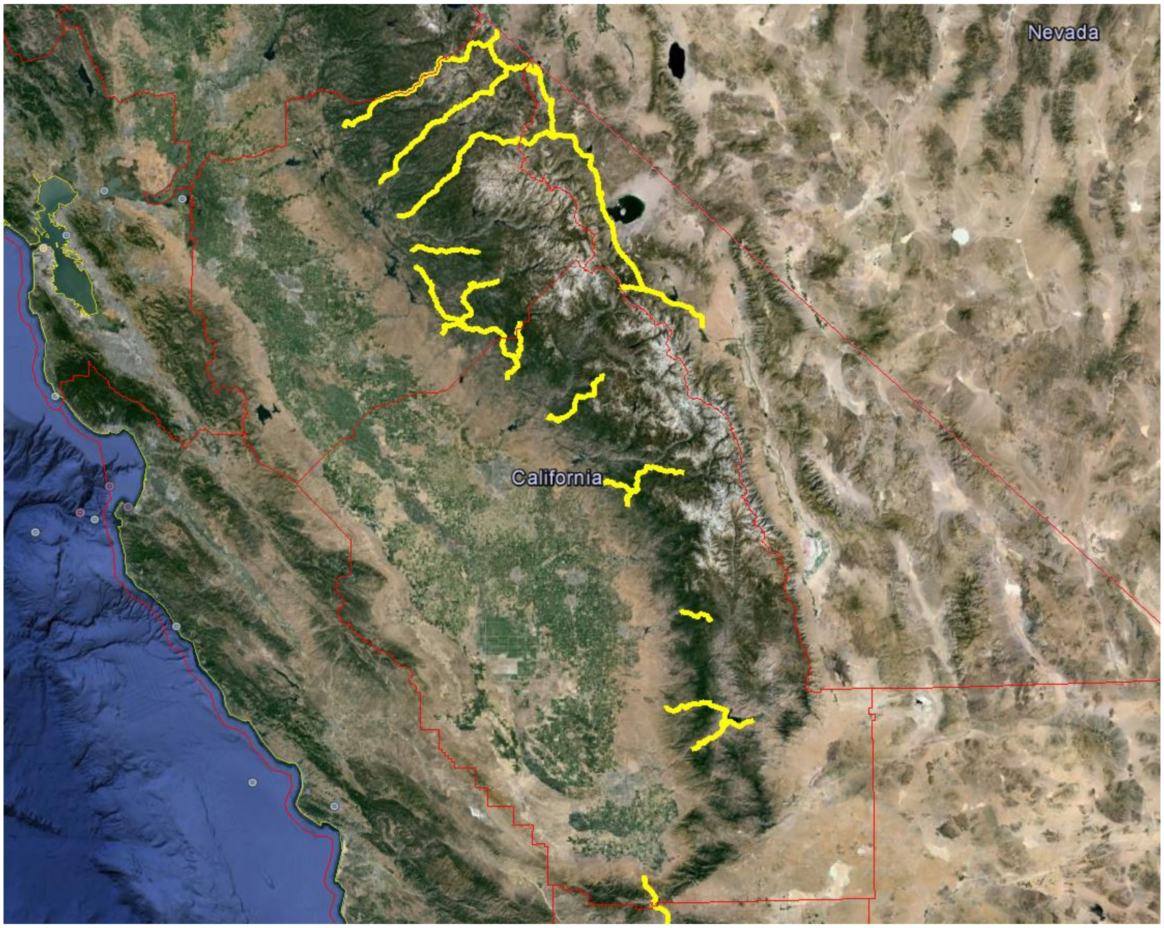

Figure D.3: Snow-affected routes (yellow) for central California. Red boundaries represent Caltrans districts.

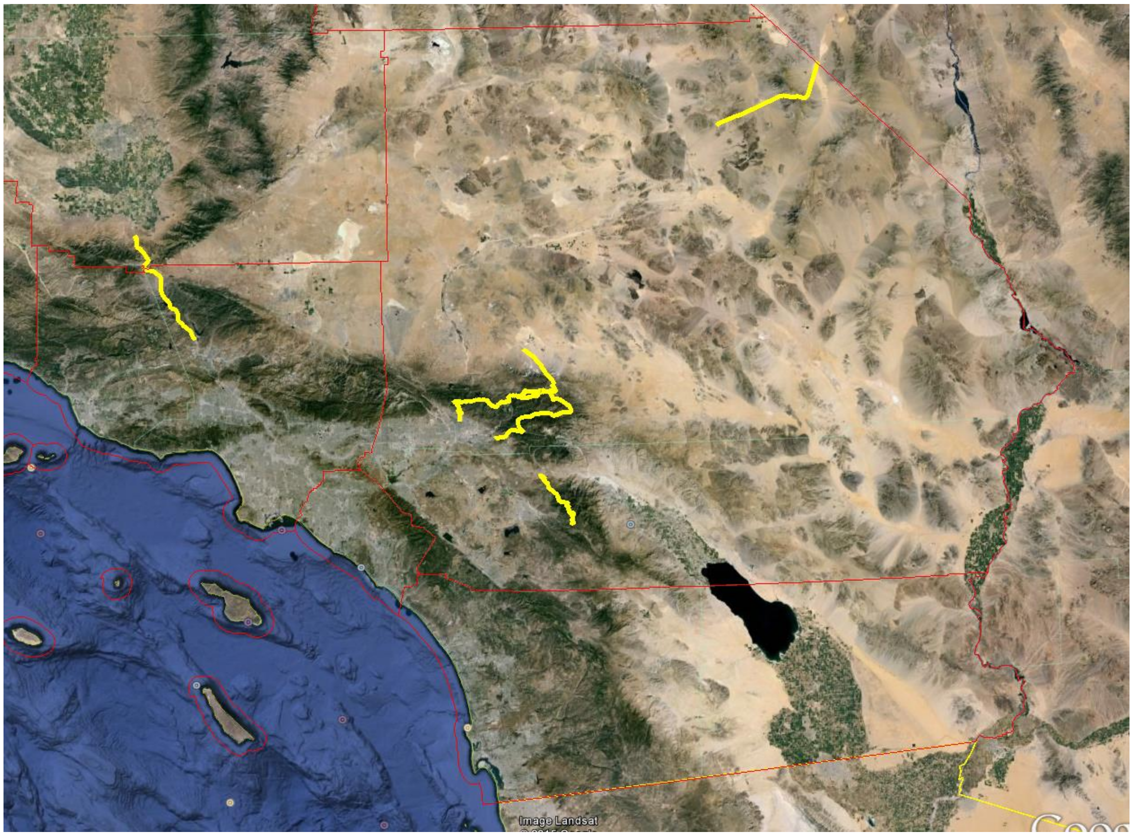

Figure D.4: Snow-affected routes (yellow) for southern California. Red boundaries represent Caltrans districts.

To determine cellular coverage and signal strength for multiple cellular providers, AHMCT developed a survey strategy, cellular data collection hardware, and an Android app to sample and record signal strength. The service providers do have coverage maps; however, their maps do not provide the level of detail and resolution necessary to inform the snow fighter information system design process. The data collection software is discussed in Appendix C. The survey results in the form of coverage maps are provided in the section following that. The data was collected using an AHMCT research vehicle. The process consisted of driving each snow-affected route while capturing the providers' (AT&T, Verizon, and T-Mobile) signal strength as measured by the detection system. Location coordinates were also recorded using the smartphone's built-in GPS receiver. To perform the full survey, AHMCT spent three full working weeks on the road, logging approximately 5000 total miles. The signal strength and coverage data collected in this survey has provided key information for other AHMCT research efforts, including evaluation research for a head-up display snowplow driver assistance system [19], and the Phase III Responder system [5] discussed in Appendix B.

Cellular Coverage and Signal Strength Data Collection System

The data collection system consisted of a custom designed and developed Android app named "PowerMeter", and three Android cell phones running the app to collect data. The details of the PowerMeter app are provided in Appendix C. The specific test phone information is provided in Table D.1. The phone provided the measure of signal strength, as well as latitude and longitude

(WGS84) position coordinates. Data was stored locally on each phone. After the survey, the data for each carrier was post-processed to convert it into a heat map, a useful way to visualize three-dimensional data on a two-dimensional medium. The heat maps can be viewed in a web page using associated JavaScript programs[19].

Table D.1: Data collection system phone information

Phone Model	Communications Generation	Carrier	Note
Nexus 4	3G	AT&T	
Samsung Galaxy S4	4G	Verizon	
Nexus 3	3G	T-Mobile	
HTC One	4G	AT&T	Had some stability issues, replaced by Nexus 4

Cellular Coverage and Signal Strength Survey Results

The cellular signal strength survey was performed for all California snow-affected routes note above, shown in Figures D.1 – D.4. Heat maps for a small portion of the collected data are provided in this section. Data is available for the entire length of the California snow-affected areas, and heat maps can easily be generated for any area within the survey. The results are shown only for AT&T and Verizon, for conciseness. T-Mobile signal strengths were typically lower in the rural areas of the survey. The AT&T data was collected on a Nexus 4 3G smartphone, while the Verizon data was collected on a Samsung Galaxy S4 4G smartphone. Throughout the results, red areas represent the highest signal strength ("hot"), while orange, yellow, green, turquoise, and blue represent decreasing ("cooler") signal strength. If an area is not colored, no signal was detected for that carrier in that particular area. Table D.2 provides a key mapping color to strength.

[19] http://www.patrick-wied.at

Table D.2: Heat map key relating color to signal strength

Color	Signal Strength
Red	-75 dBm
Orange	-81 dBm
Yellow	-87 dBm
Green	-93 dBm
Turqoise	-99 dBm
Blue	-105 dBm
None	No signal detected

Figures D.5 and D.6 show the signal strength for AT&T and Verizon, respectively, on Interstate 80 from about Heather Glen to the California-Nevada state line. Even at this zoom level, it is fairly clear that Verizon provides better coverage and signal strength than AT&T in this semi-rural area. Figures D.7 – D.22 show finer detail along this section of I-80 for both providers. At the finer zoom level, it becomes much clearer that Verizon provides better coverage with higher signal strength and fewer coverage gaps. This pattern was repeated in essentially all of the California snow-affected roadways. The clear conclusion is that for the semi-rural to rural areas where Caltrans must perform winter maintenance, Verizon would be a good vendor for cellular data transmission.

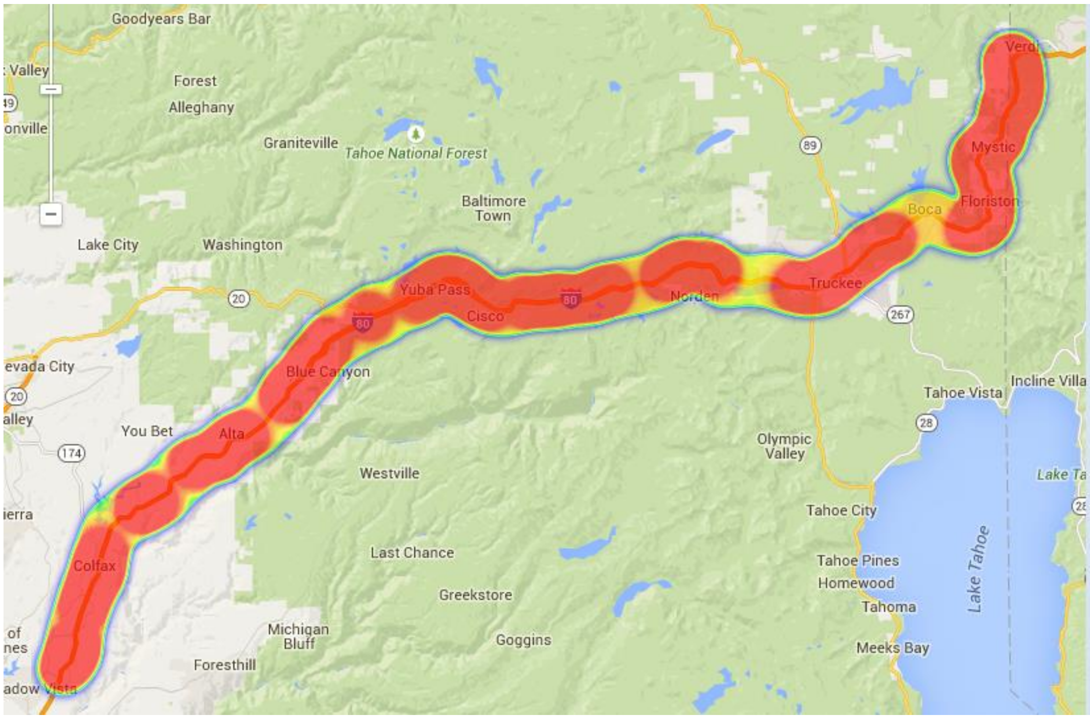

Figure D.5: AT&T signal strength for Interstate 80 near Kingvale (survey: June 21, 2013 from 10:30 – 11:45)

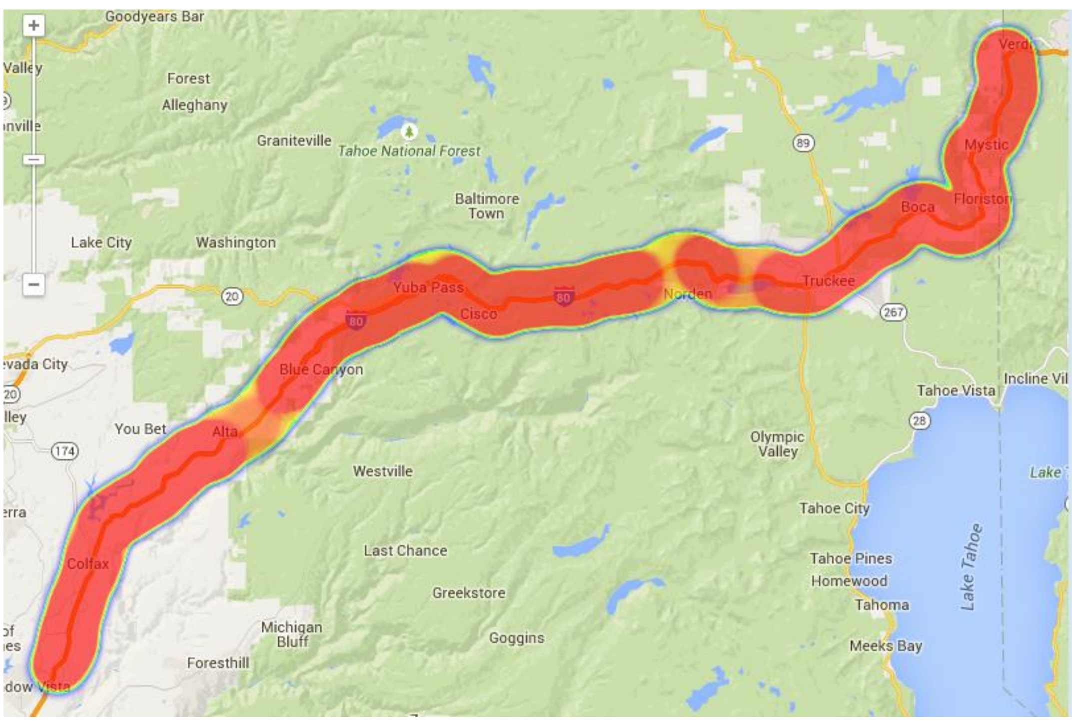

Figure D.6: Verizon signal strength for Interstate 80 near Kingvale (survey: June 21, 2013 from 10:30 – 11:45)

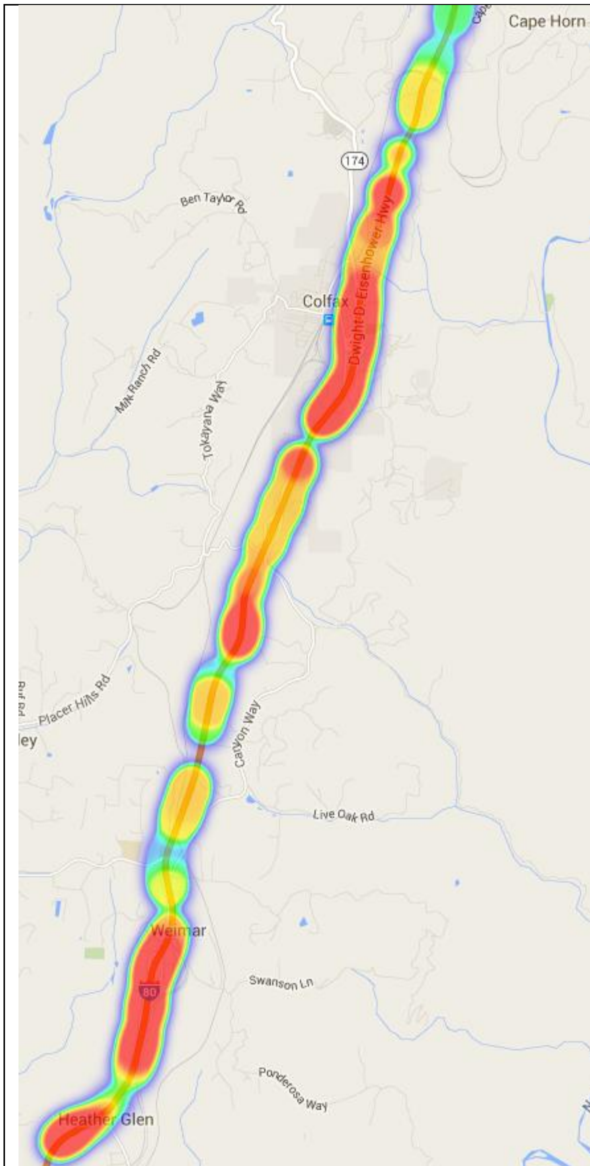

Figure D.7: AT&T signal strength for Interstate 80, Heather Glen to Cape Horn (survey: June 21, 2013 from 10:30 – 11:45)

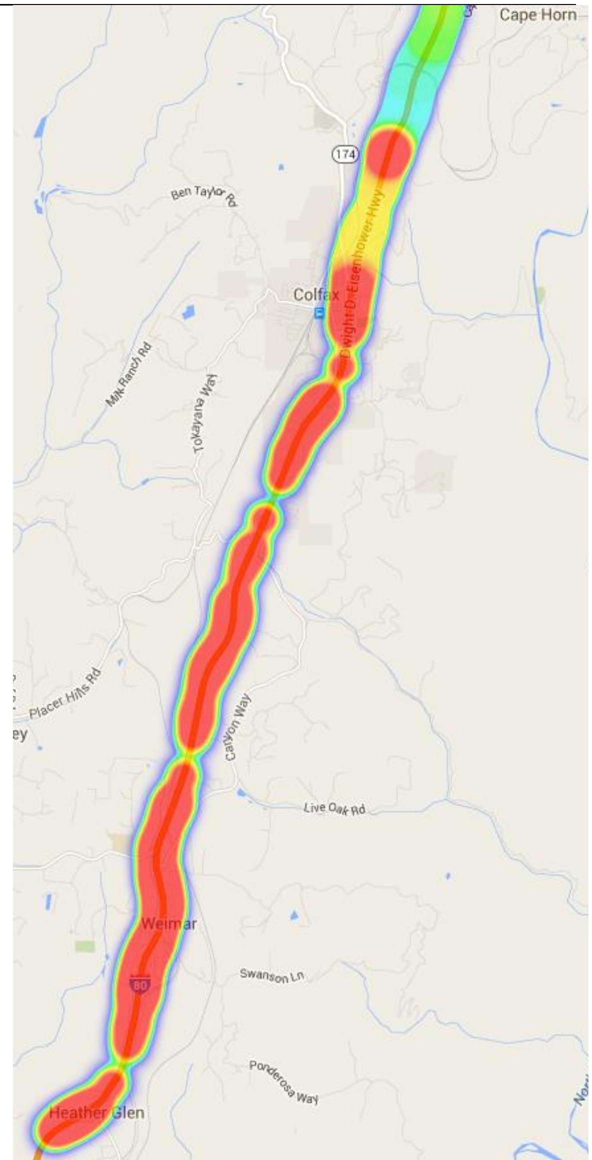

Figure D.8: Verizon signal strength for Interstate 80, Heather Glen to Cape Horn (survey: June 21, 2013 from 10:30 – 11:45)

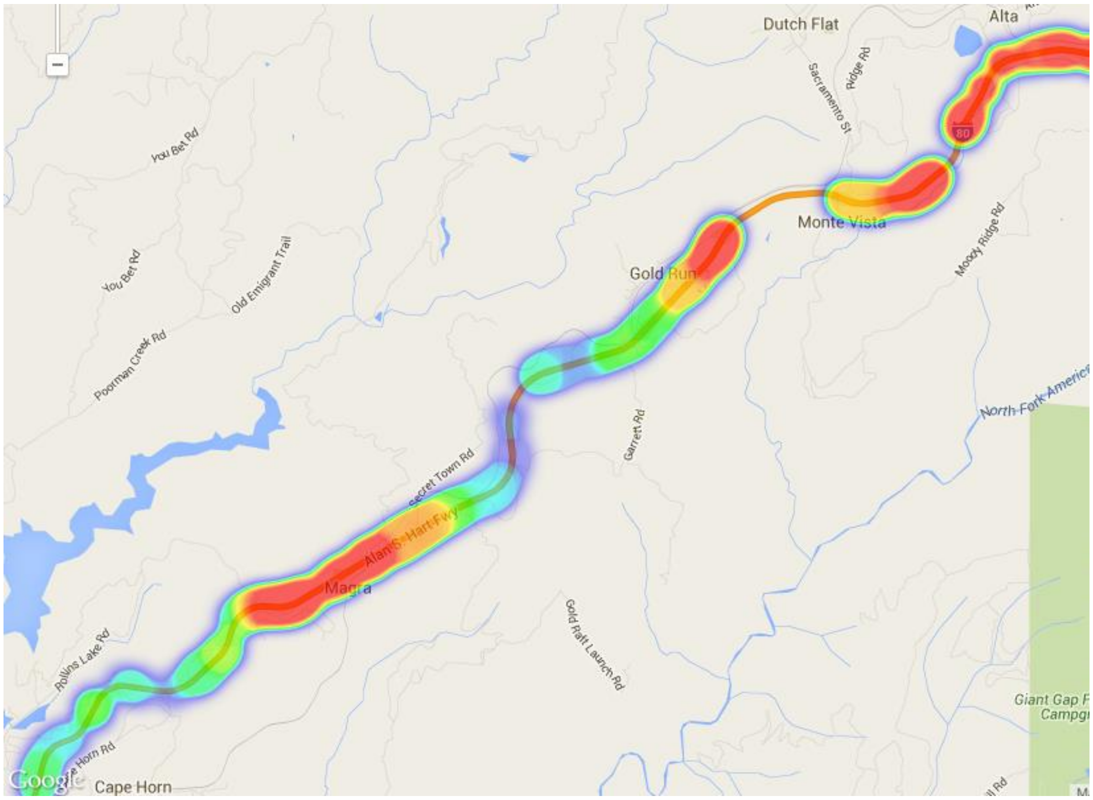

Figure D.9: AT&T signal strength for Interstate 80, Cape Horn to Alta (survey: June 21, 2013 from 10:30 – 11:45)

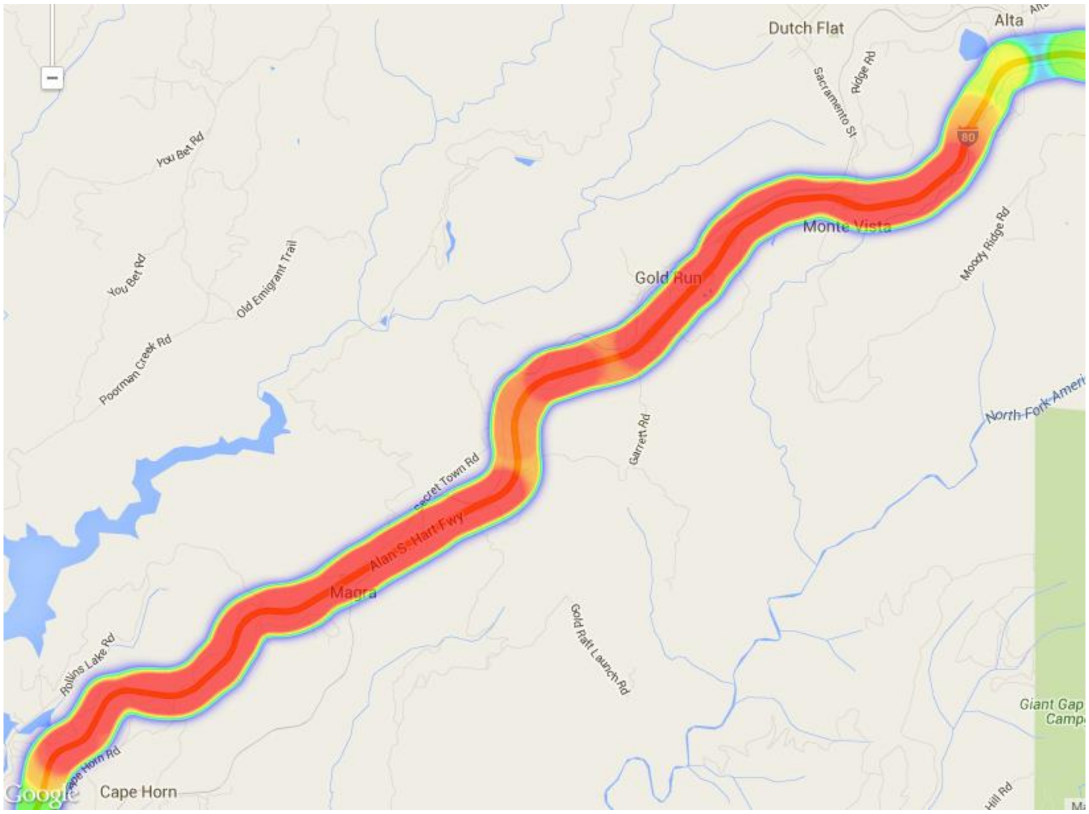

Figure D.10: Verizon signal strength for Interstate 80, Cape Horn to Alta (survey: June 21, 2013 from 10:30 – 11:45)

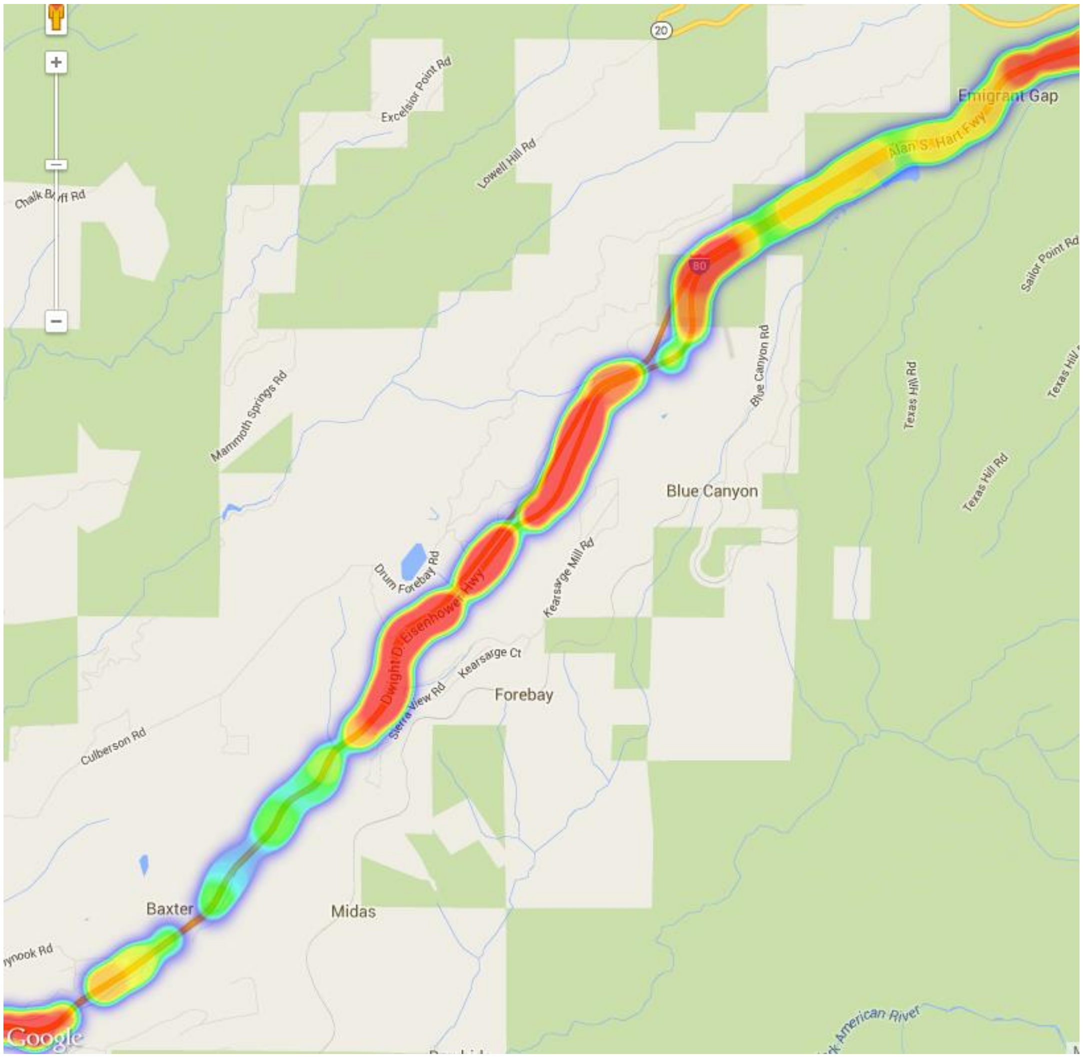

Figure D.11: AT&T signal strength for Interstate 80, Alta to Emigrant Gap (survey: June 21, 2013 from 10:30 – 11:45)

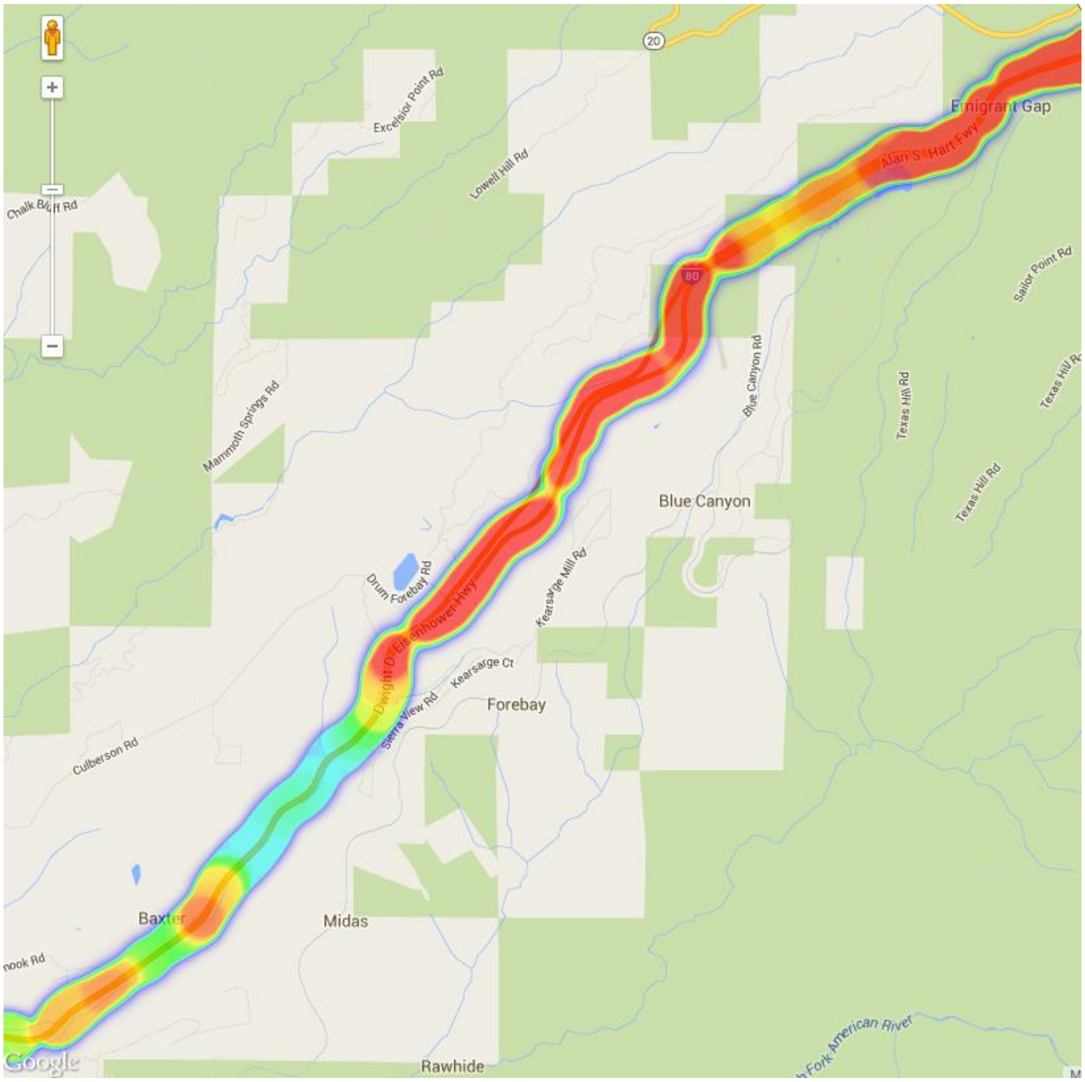

Figure D.12: Verizon signal strength for Interstate 80, Alta to Emigrant Gap (survey: June 21, 2013 from 10:30 – 11:45)

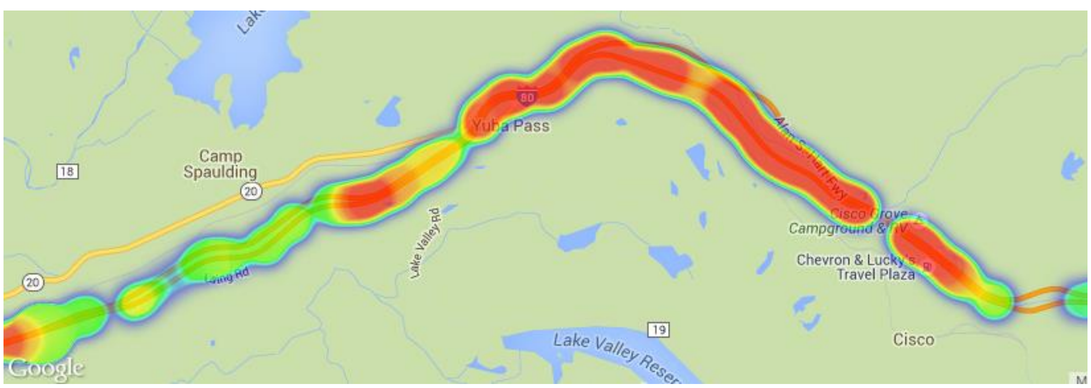

Figure D.13: AT&T signal strength for Interstate 80, Emigrant Gap to Cisco (survey: June 21, 2013 from 10:30 – 11:45)

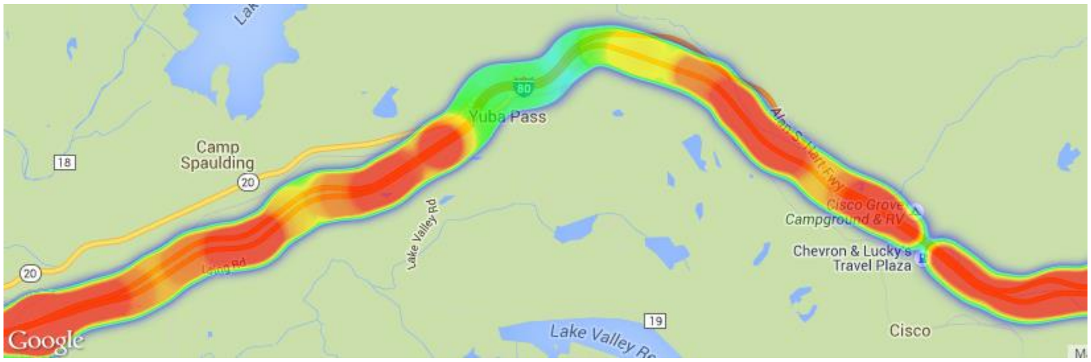

Figure D.14: Verizon signal strength for Interstate 80, Emigrant Gap to Cisco (survey: June 21, 2013 from 10:30 – 11:45)

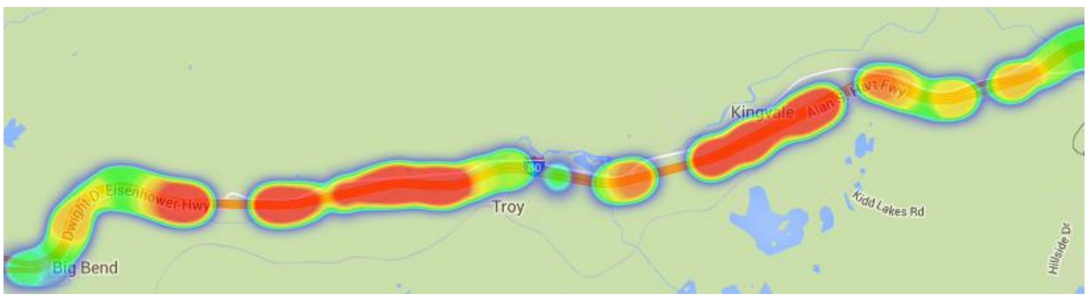

Figure D.15: AT&T signal strength for Interstate 80, Cisco to Kingvale (survey: June 21, 2013 from 10:30 – 11:45)

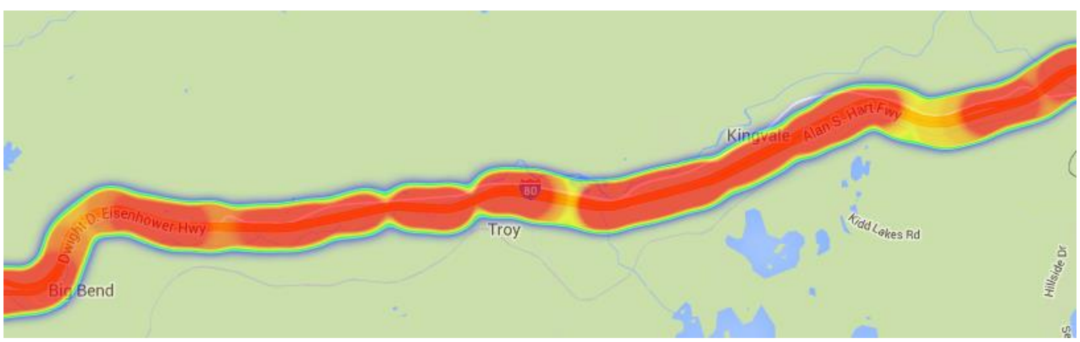

Figure D.16: Verizon signal strength for Interstate 80, Cisco to Kingvale (survey: June 21, 2013 from 10:30 – 11:45)

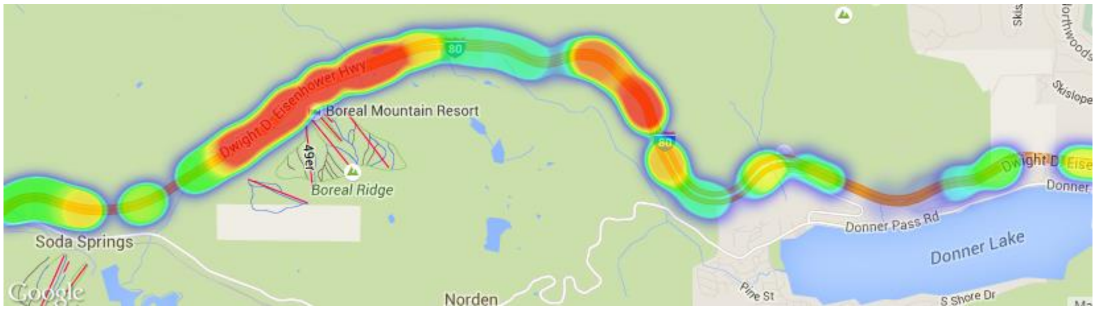

Figure D.17: AT&T signal strength for Interstate 80, Kingvale to Donner Lake (survey: June 21, 2013 from 10:30 – 11:45)

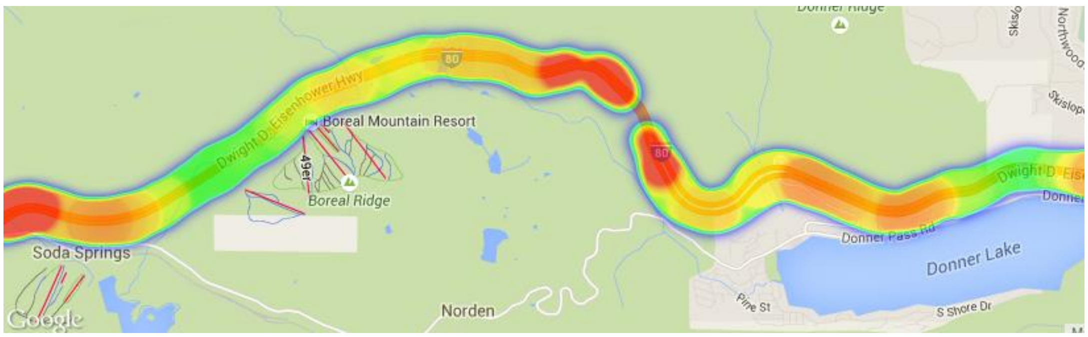

Figure D.18: Verizon signal strength for Interstate 80, Kingvale to Donner Lake (survey: June 21, 2013 from 10:30 – 11:45)

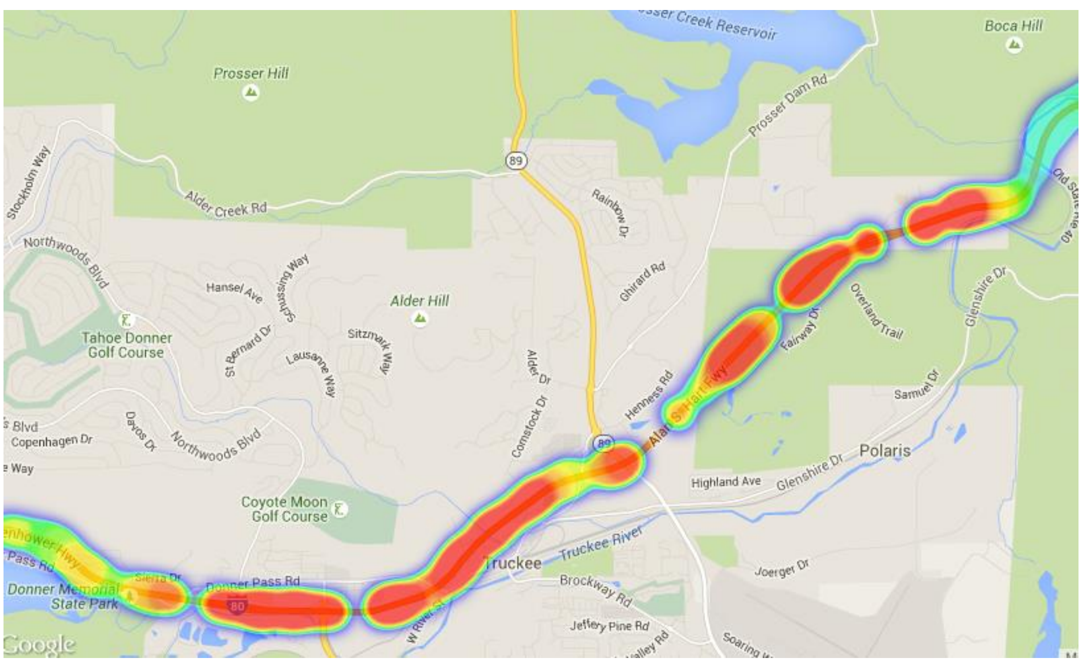

Figure D.19: AT&T signal strength for Interstate 80, Donner Lake to Old SR 40 (survey: June 21, 2013 from 10:30 – 11:45)

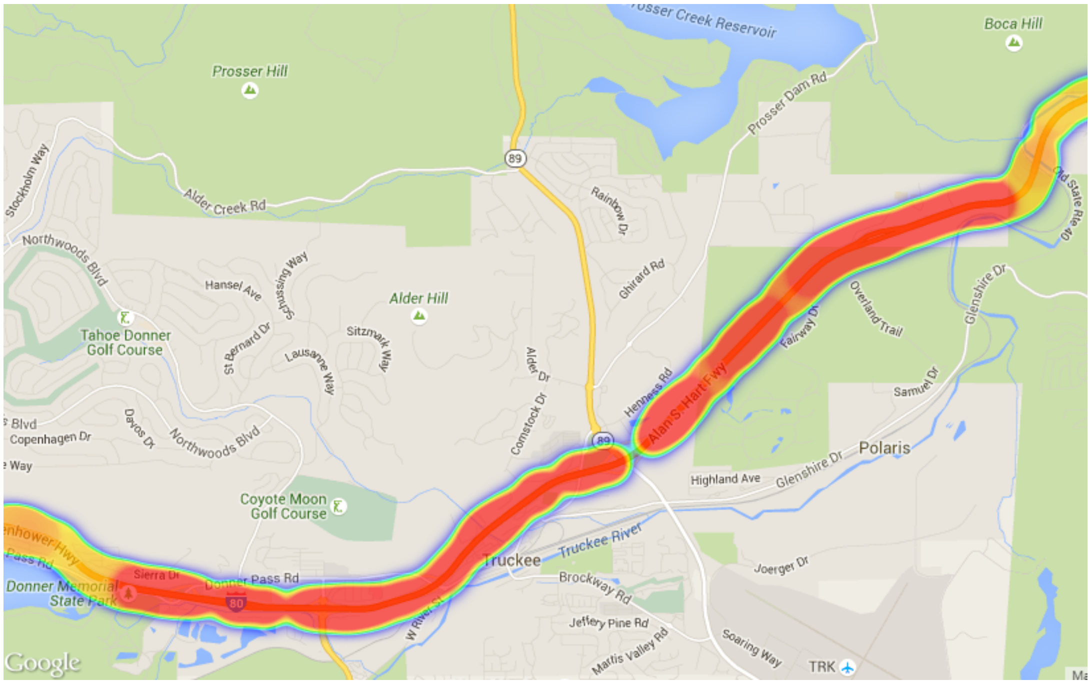

Figure D.20: Verizon signal strength for Interstate 80, Donner Lake to Old SR 40 (survey: June 21, 2013 from 10:30 – 11:45)

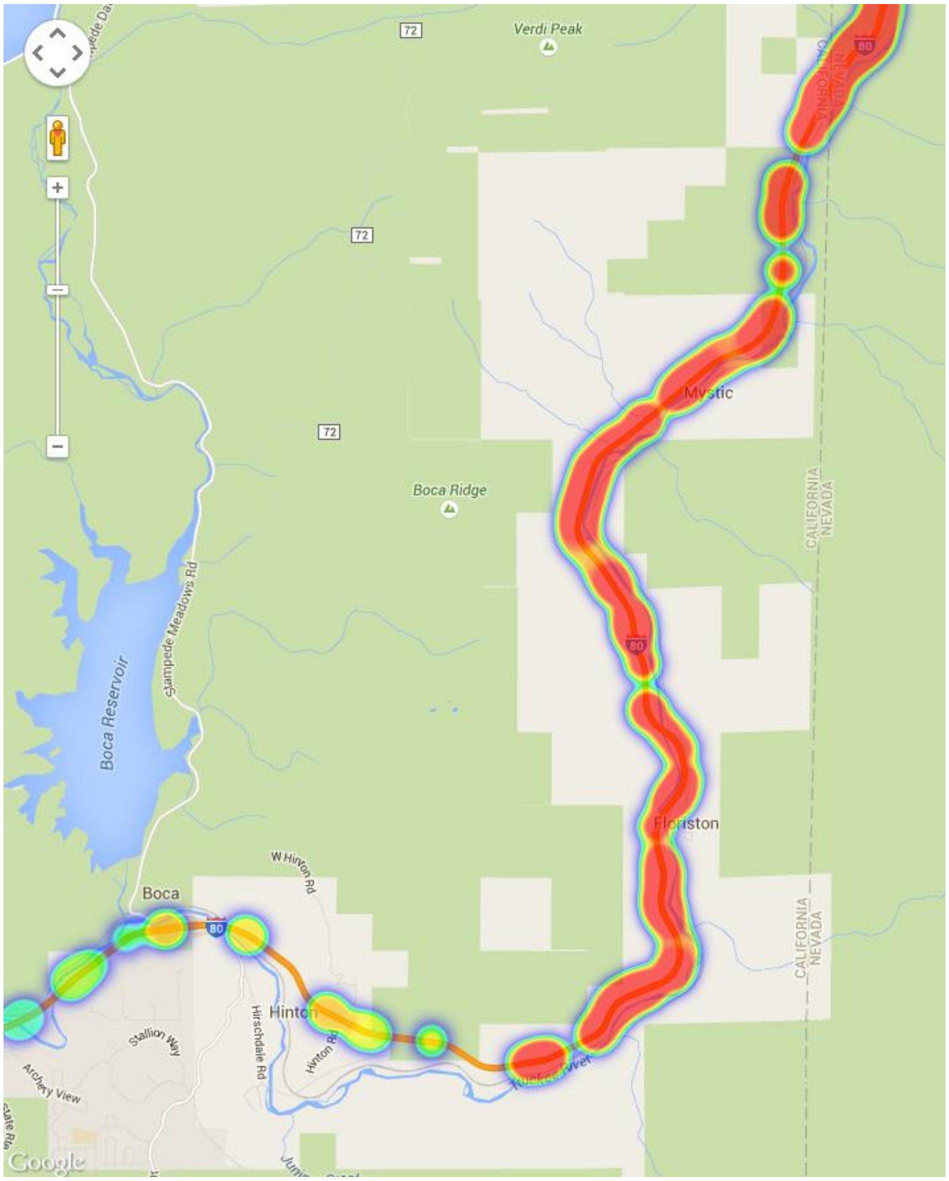

Figure D.21: AT&T signal strength for Interstate 80, Old SR 40 to Stateline (survey: June 21, 2013 from 10:30 – 11:45)

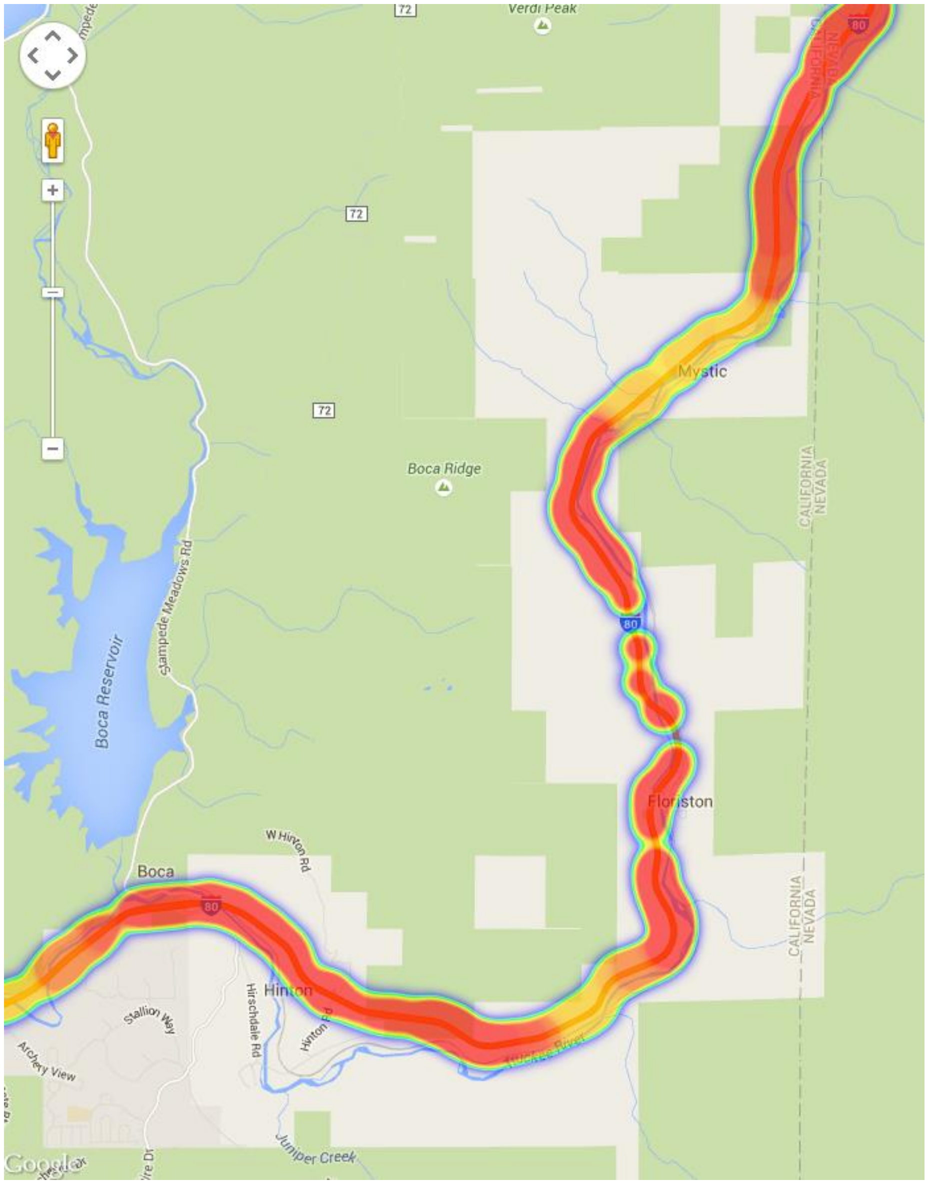

Figure D.22: Verizon signal strength for Interstate 80, Old SR 40 to Stateline (survey: June 21, 2013 from 10:30 – 11:45)

The above figures illustrate the signal strength for I-80, which has some of the best coverage of all California snow-affected areas. The snow fighter information system is designed to work well in any snow-affected area. However, its key features and capabilities, particularly its store-and-forward architecture, were designed to provide the best possible function in areas with the worst cell signal coverage and strength. With these capabilities, the system can bridge areas of zero coverage, storing all data and requests. Upon entering an area with cell coverage, the system then forwards data and requests to the server, and downloads any responses. The system was explicitly designed with this capability so that the snow fighter information system could support snow operations in Caltrans' most rural and isolated areas. The target for field testing was near the Caples Lake maintenance yard on SR 88 in Caltrans District 10. Figures D.23 and D.24 illustrate the cell signal coverage and strength along SR 88 for AT&T and Verizon, respectively. As with the semi-rural I-80, the highly rural SR 88 has far better coverage and signal strength than AT&T. This pattern was seen for essentially all snow-affected routes in California. Note that even with its superior coverage and signal strength, Verizon does exhibit areas with low signal strength as well as coverage gaps. Thus, the use of the store-and-forward architecture is justified for either carrier.

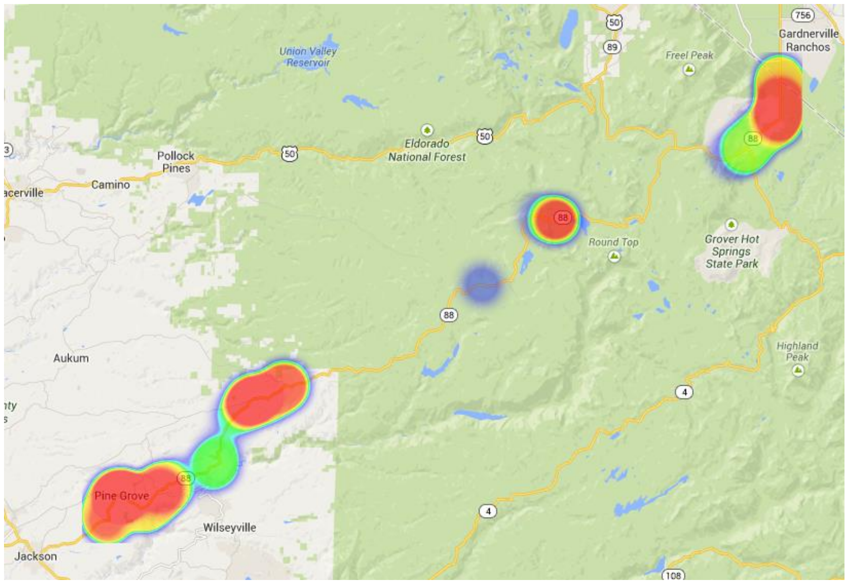

Figure D.23: AT&T signal strength for State Route 88 near Caples Lake maintenance yard (survey: August 3, 2013 from 12:25 – 13:52)

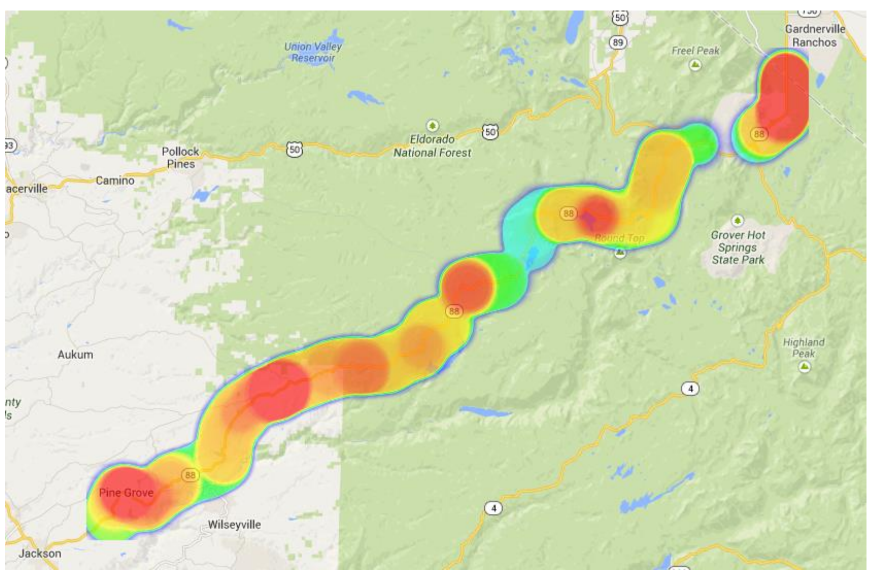

Figure D.24: Verizon signal strength for State Route 88 near Caples Lake maintenance yard (survey: August 3, 2013 from 12:25 – 13:52)

APPENDIX E:
COTS SYSTEM CANDIDATES FOR CALTRANS PILOT STUDY

Short summary for Networkfleet:

- Heavy vehicle telematics solution
- GPS (Global Positioning System) tracking of vehicle location, start/stop time, geo-fencing
- Inputs that can support plow blade up/down and spreader on/off monitoring
- Connection to the SAE (Society of Automotive Engineers) J-Bus (J1939 and J1708) interfaces. This allows the telematics device to collect vehicle operating data from the vehicle on-board electronic control units (ECU). Most modern heavy trucks have J1708 and/or J1939 J-bus. The system can report engine data, including odometer, speed, fuel level, temperature, run and idle time, RPM, oil pressure, and battery voltage.
- Cellular modem to transmit data to a server at regular interval.
- Verizon has indicated ability to develop custom reports based on Caltrans needs.

Short summary for Delcan:

- Heavy vehicle telematics solution
- GPS tracking of vehicle location, start/stop time, geo-fencing
- Inputs that can support plow blade up/down and spreader on/off monitoring
- Material application rates (solid and liquid). Target rate, i.e. current spreader setting. Actual rate, i.e. what is being applied to the road.
- Type of material being applied
- Air and road temperature
- Camera images
- In-cab viewing of local and regional radar weather
- Connection to the SAE (Society of Automotive Engineers) J-Bus (J1939 and J1708) interfaces. This allows the telematics device to collect vehicle operating data from the vehicle on-board electronic control units (ECU). Most modern heavy trucks have J1708 and/or J1939 J-bus. The system can report engine data, including odometer, speed, fuel level, temperature, run and idle time, RPM, oil pressure, and battery voltage.
- Cellular modem to transmit data to a server at regular interval.

- Wi-Fi to transmit data to a server at regular interval.
- Parsons has indicated ability to augment existing ATMS systems, particularly the Delcan ATMS in use by several Caltrans districts, to incorporate telematics from snowplows.