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ADVANCED HIGHWAY MAINTENANCE
& CONSTRUCTION TECHNOLOGY
RESEARCH CENTER

Caltrans

Design, Development, and Field-Testing of the Caltrans Responder System

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List of Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
API	Application Programming Interface
BGAN	Broadband Global Area Network
BOM	Bill of Materials
BPF	Band Pass Filter
CAD	Computer-Aided Design
Caltrans	California Department of Transportation
CCTV	Closed-Circuit Television
CHP	California Highway Patrol
CMS	Changeable Message Sign
COTS	Commercial Off–The-Shelf
DRISI	Caltrans Division of Research, Innovation and System Information
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
InciWeb	Incident Information System

List of Acronyms and Abbreviations

Acronym	Definition
LOC	Lines of Code
LPF	Low Pass Filter
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
NDK	Native Development Kit
OS	Operating System
PRS	Portable Responder System
REST	Representational State Transfer
RF	Radio Frequency
RWIS	Roadway Weather Information System
SMTP	Simple Mail Transfer Protocol
TMC	Transportation Management Center
UI	User Interface
VDS	Vehicle Detection System
VRS	Vehicle Responder System
Wi-Fi	Wireless Fidelity
WTI	Western Transportation Institute

Problem

- An incident has occurred in an area with limited communication options. What do you do to accurately collect and communicate at -scene information to the TMC?
- Assuming there is someone nearby already in the field

1. Do they have cellular communications?
   – Take a picture of the incident and communicate additional information via voice/text/email to the TMC
2. Do they have radio communications?
   – Communicate information verbally to the TMC
3. Do they have a satellite phone nearby?
   – Transport sat phone from nearest location as soon as possible and communicate information verbally to the TMC

Problem

- Do they have what they need in their truck to adequately address the incident?
- In the case of additional equipment needs, has the incident information been accurately communicated with the TMC?
  - Resources take time to transfer to incident locations
  - Over/under scheduling resources will result in cost - overages/delays
- Wouldn't it be great if we had a complete mobile system to accurately/rapidly collect and communicate at-scene incident information?

History

- Prior work (great idea)
  - Hardware
    - Laptop
    - Camera
    - Cellular Phone/Modem
    - Satellite Phone/Modem
    - GPS System

History

Images provided by WTI-Caltrans, Previous Research

History

- Prior work (continued)
  - Software
    - OS
    - Responder application
      - Import photos
      - Annotate images
      - Display aerial photos
      - Display topographic maps
      - Obtain weather information by location
      - Obtain roadway information by location
      - Send message to TMC in email format
  - Field evaluated

History

Video provided by WTI-Caltrans Previous Research

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History

PHASE	DESCRIPTION	DATES
Responder Phase 1: Initial Design – WTI (Task ID 2079)	Objective was to develop a communication tool that will enhance the collection and sharing of incident, incident response and clearance information between first responders in the field and Traffic Management Center in District 2 Redding expeditiously.	2003-2005
Responder Phase 2: Enhancements and Field Test – WTI (Task ID 1004)	Objective was to further refine the prototype Responder system. Conducted further system development to “harden” the system, making it ready for field use. Software was finalized to accommodate hardware updates and to increase usability and robustness of the system. System was tested in multiple locations and with multiple crews in real use situations.	2006-2009
Responder Phase 3: Enhancements and Specifications – AHMCT (Task ID 1846)	Objective was to get Responder system updated to current technological standards and preparing a prototype system that is ready so the customer can begin the testing system.	2012-2016
Responder Study Phase 3: Testing and Support – AHMCT (Task ID 2927)	Objective was to pilot test the Responder system in Caltrans Districts 2, 3, 4, and 9 and revise Responder hardware and software as needed based on deficiencies identified in field testing.	2016-2018
Responder Phase 4: Transition Phase – AHMCT (Task ID 3098)	Objective of this task is to transition the prototype Responder system from AHMCT to a third-party vendor.	2017-2019
Responder Phase 5: Reproduction and Deployment Phase – IFB (Task ID 3613)	Objective of this task would be to enhance and upgrade Responder system that is not covered during transition phase, purchase the off-the-shelf equipment for additional Responder system units, reproduce the software and hardware for the additional Responder system, and deploy those Responder systems into Caltrans Districts.	2019-TBD
Responder Phase 6: Maintenance Phase – XXXX	Objective of this task would be the on-going maintenance of Responder system.	TBD

History

- User feedback
- Concerns
  - Communications
    - Cellular
      - Bandwidth
    - Satellite
      - Availability
      - Downtime
      - Bandwidth

Next Generation

- System Composition
  - Hand-held device
    - Tablet / phone
    - Responder application
    - Wireless communication with the vehicular or portable system
  - Vehicular system
    - Highly integrated
    - Self-contained operation
    - Automated services/managers

Next Generation

- Hand-held device
  - Tablet/phone with embedded camera/Wi -Fi
  - Responder application
    - Reporting (automation)
    - Pictures
    - Mapping (street, topographic, aerial)
    - Annotation (pictures, maps)
    - Mail (auto-formatted text, attachments)
    - Feeds
      - » Roadway (CCTV, CMS, Road Information, Chain Control, CHP Incident, VDS)
      - » Weather (Cal Fire, InciWeb, Stream Flow, Zone Alert, Zone Forecast, Daily Weather, RWIS)

Next Generation

- Vehicular system (hardware)
  - Highly integrated
    - Single compact enclosure
      - Embedded computer
      - Communication modems
      - Power management
    - Antennas
  - Wide operating temperature range
  - Communications
    - Multiple options (cellular, sat, etc.)
    - High bandwidth / availability

Next Generation

- Vehicular System (software)
  - Self-contained operation
  - Automated services/managers
    - Reports and meta-data
    - Mail and delivery
    - Mapping
    - Data feeds
    - Communication arbitration
  - Routing

Key System Requirements Summary

- The system shall
  - (1-1.4.3, 1.8) collect and store incident information and metadata as a collection
    - location (lat, lon, county, route, postmile)
    - infrastructure type
    - lanes blocked
    - vehicle type
    - special considerations
    - timestamps
  - (1.5) collect incident photographs
  - (1.6-1.7.4) facilitate annotation of photographs, and other snapshots
  - (1.9-1.10) allow incident information to be edited and deleted

Key System Requirements Summary

- The system shall
  - (1.12-1.12.2) identify and search for incidents by date, time, organization, name of responder, county, route, postmile
  - (3.1-3.2) be flexible in deployment to include the possibility of a briefcase, partially fixed within a vehicle, or entirely fixed within a vehicle
  - (3.4-3.4.2) use hardened equipment -20F to +120F (operation), -20F to +150F (storage)
  - (3.6) operable directly off vehicle power
  - (3.7) does not interfere with other work
  - (3.8-3.9) allow for antennas to be removable or permanently fixed
  - (3.10) modular hardware design

Key System Requirements Summary

- The system shall
  - (4.1) be usable up to 200 ft from the vehicle
  - (5.5–5.71) view and management of photographs
  - (5.10.1-5.10.1.1) store default contact information and allow override by selection or entry
  - (6.1) automatically geo-locate the responder
  - (7.2) automated transmission of incident information
  - (7.3) allow users to multitask while communications tasks are in progress
  - (8.2) preview messages prior to transmission
  - (8.3-8.3.2) automatically scale and compress photos and sketches for transmission with user override capability

Key System Requirements Summary

- The system shall
  - (8.5) transmit incident records as soon as possible
  - (8.6–8.8) allow the selection and transmission of incident information including selected sketches and photographs
  - (9–9.6) display information based on system's location
    - weather forecasts
    - fire information
    - RWIS data
    - chain control
    - stream flows
    - zone forecasts
    - CCTV
    - road, topo, and aerial maps
    - traffic volumes

Key System Requirements Summary

- The system shall
  - (9.10) use incident location to identify and expedite downloads
  - (9.11) display information within a user selectable radius
  - (10.1-10.2) operable in urban, rural, and mountainous areas
  - (10.3-10.3.1) attempt to mitigate communication failures and retry transmissions in the case of failure
  - (10.3.2) switch over to another communication device in the event of a failure
  - (10.4) notify the user if communication fails

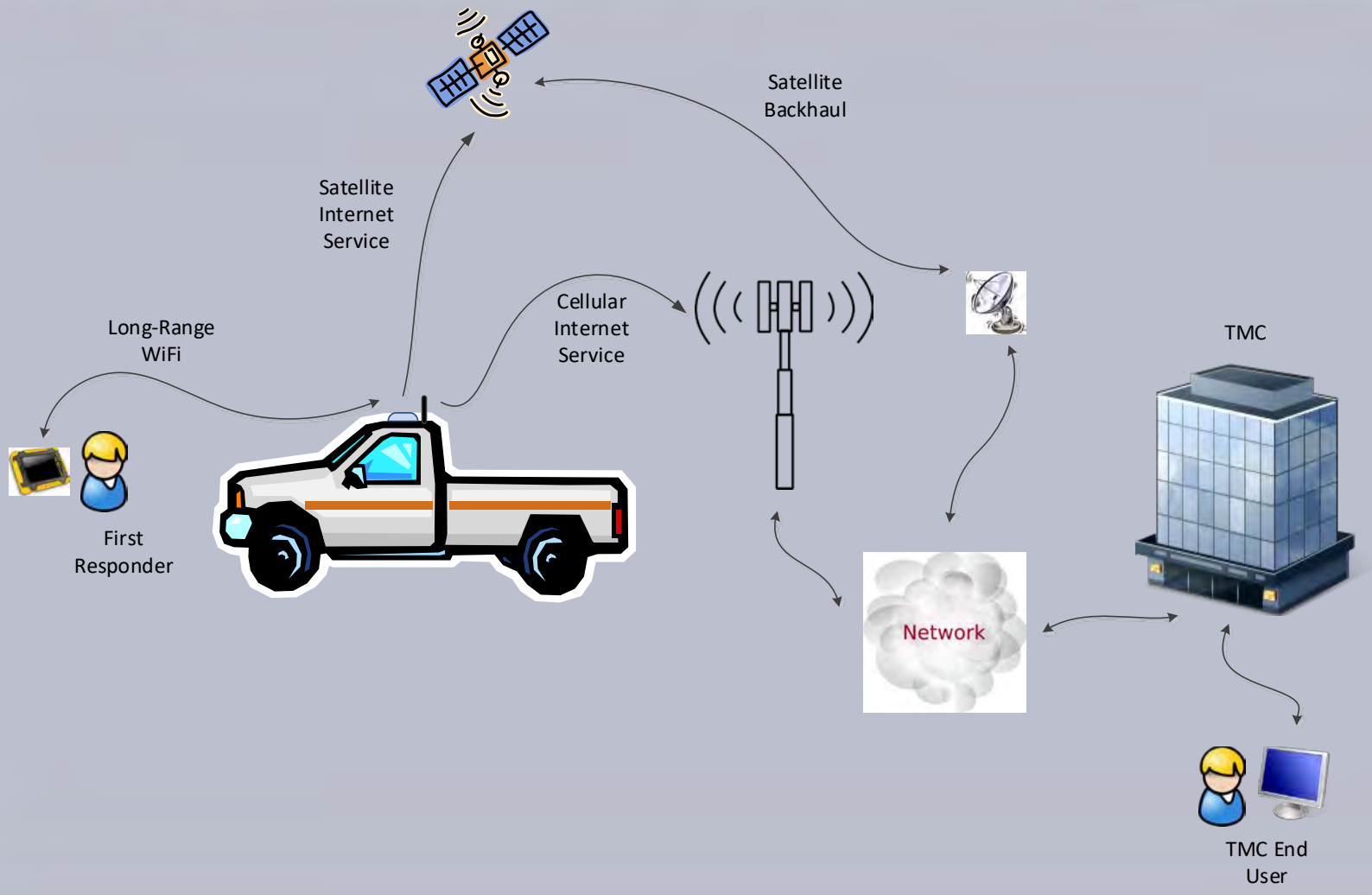
Additional System Requirements Summary

- Autonomous, no server connections required
- Geostationary, high-availability satellites only
- One-way email, send and forget

Subjective System Requirements

- Internal equipment location
  - end-user desired locations
    - under/behind seat for installed units
    - strapped in seat for portable units
- External equipment location
  - impact on end-users
    - truck bed is fully utilized
    - back rack space limited
    - full rack utilized for other purposes
    - antenna space above cab limited

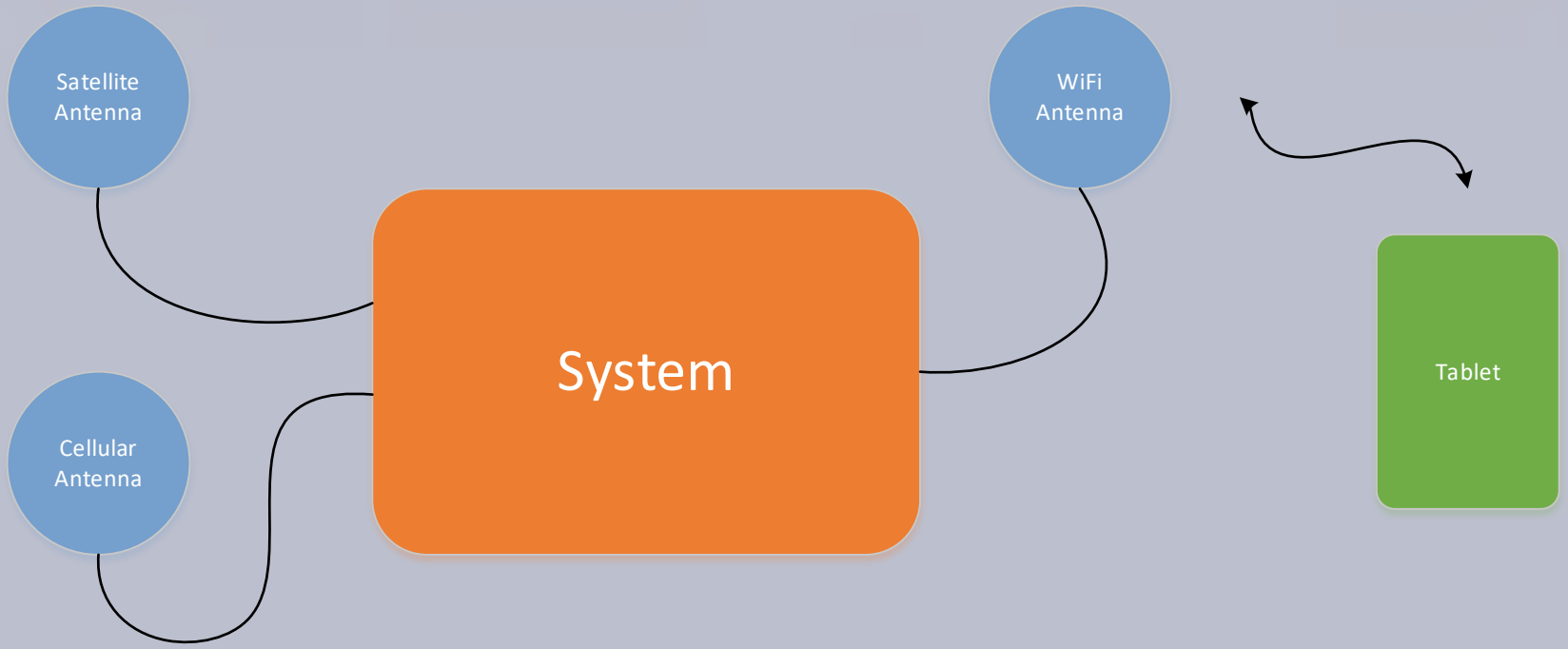
Overall Architecture



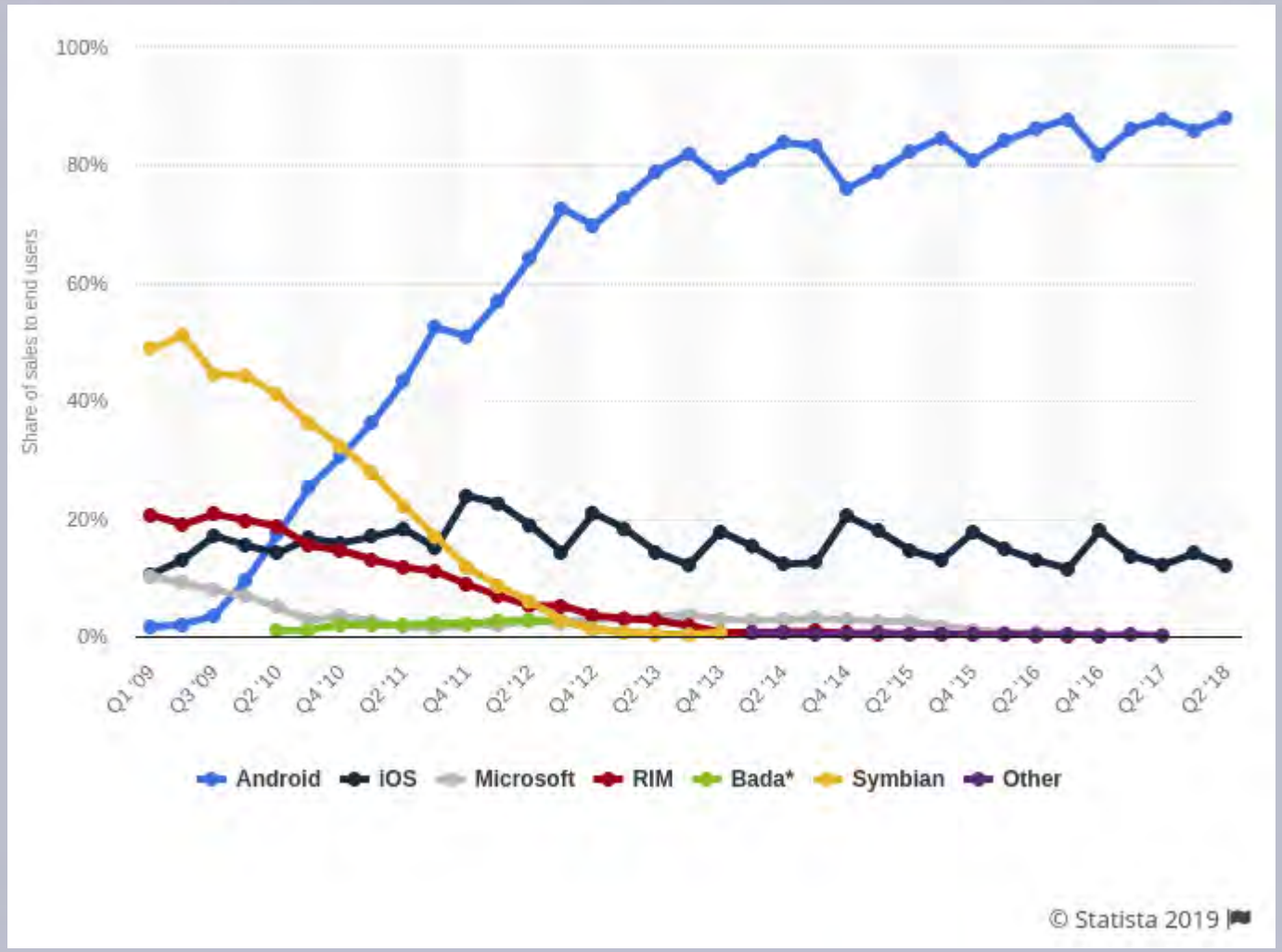
Typical Use Cases

- At location cellular access
- At location satellite access
- Move short distance to achieve satellite access
- Significant distance to achieve satellite or cellular access

Hardware System Architecture



Mobile OS Market Share



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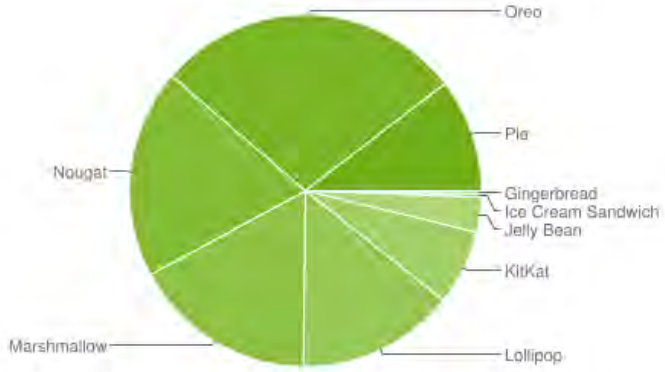
Android Version Market Share

Version	Codename	API	Distribution
2.3.3 - 2.3.7	Gingerbread	10	0.3%
4.0.3 - 4.0.4	Ice Cream Sandwich	15	0.3%
4.1.x	Jelly Bean	16	1.2%
4.2.x		17	1.5%
4.3		18	0.5%
4.4	KitKat	19	6.9%
5.0	Lollipop	21	3.0%
5.1		22	11.5%
6.0	Marshmallow	23	16.9%
7.0	Nougat	24	11.4%
7.1		25	7.8%
8.0	Oreo	26	12.9%
8.1		27	15.4%
9	Pie	28	10.4%

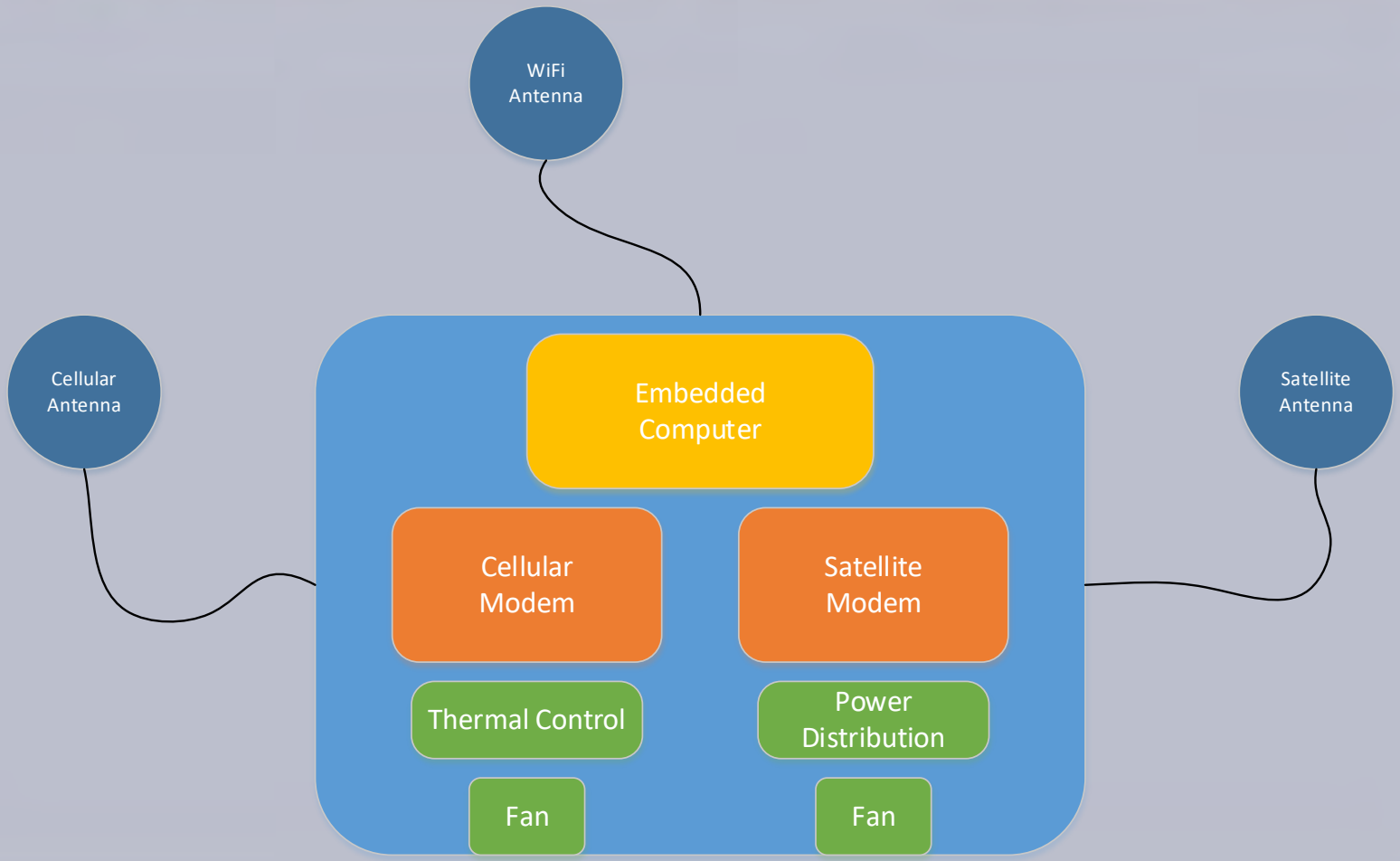


Data collected during a 7-day period ending on May 7, 2019
Any versions with less than 0.1% distribution are not shown.

Target Devices

- Android 7.0+
- OS open source (secure, extensible, etc.)
- Supported development languages
  - Java
  - Kotlin
  - C and C++ support through native development kit (NDK)

Hardware Enclosure System Architecture



Considered Satellite Hardware

- AVL 1078
  - –Cost ~ $20k
  - –Ku band
  - –3 Mbps x 1 Mbps
  - –IntelSat
  - –$250/mo for 3 GB $0.12/MB
  - –Antenna 61.5” L x 40” W x 13.5” H stowed
  - –Possible operator input required depending on selection

Considered Satellite Hardware

- KVH TracPhone V3 mini VSAT
  - Cost ~ $17k
  - Ka band
  - 2 Mbps x 128 Kbps
  - ViaSat
  - $1.99/MB
  - Antenna15.5" D x 17.6" H
  - Note: Available, but not intended for land-mobile installations

Considered Satellite Hardware

- Hughes 9450-C11 BGAN
  - Cost ~ $6k
  - Ka band
  - 464 kbps
  - Inmarsat
  - $6.00/MB
  - -13F to +131F
  - Antenna 10” diameter
  - No operator setup required (mobile, auto-positioning)

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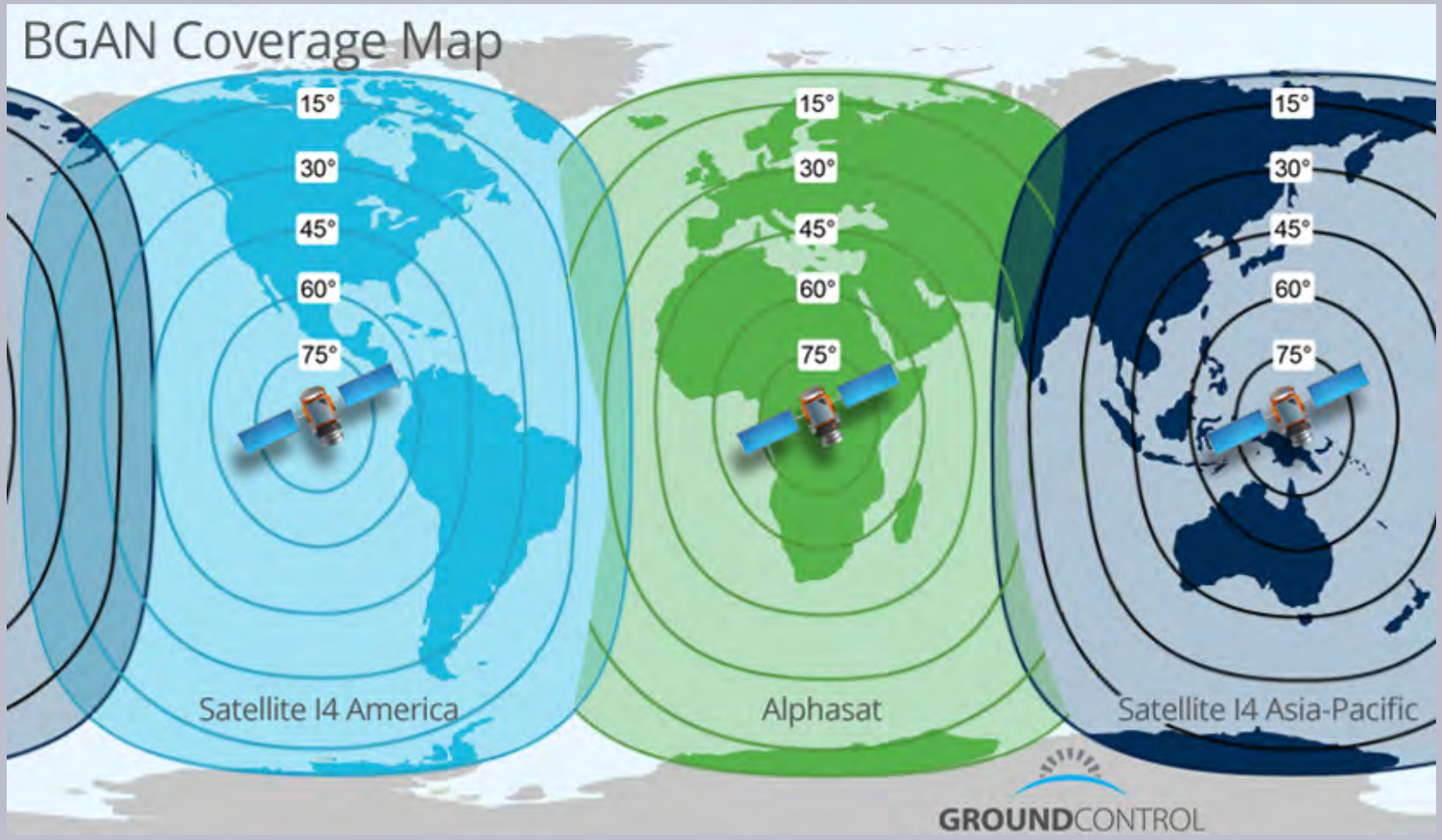
Inmarsat Coverage Map



Selected Satellite Hardware

- Hughes 9450-C11
- Rationale
  - Smallest of satellite systems
  - Least intrusion into vehicle workspace
  - Although more costly per MB required, typical operational use cases in light of estimated bandwidth consumption is acceptable to lower impact on real -world available workspace

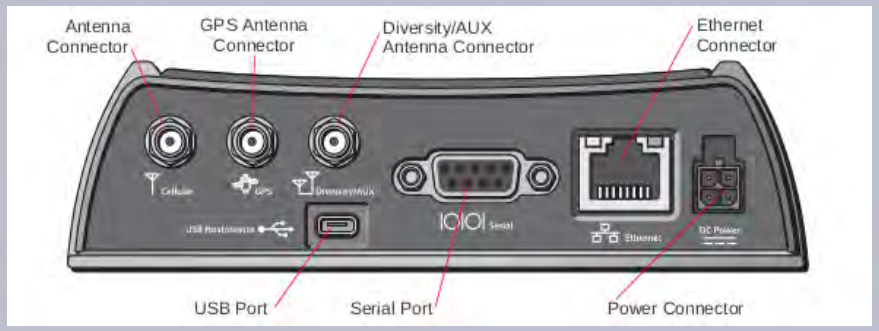
Selected Embedded Computer

- Neousys Technology Nuvo-3100VTC
- -13F to +131F
- Rugged
- Low Power

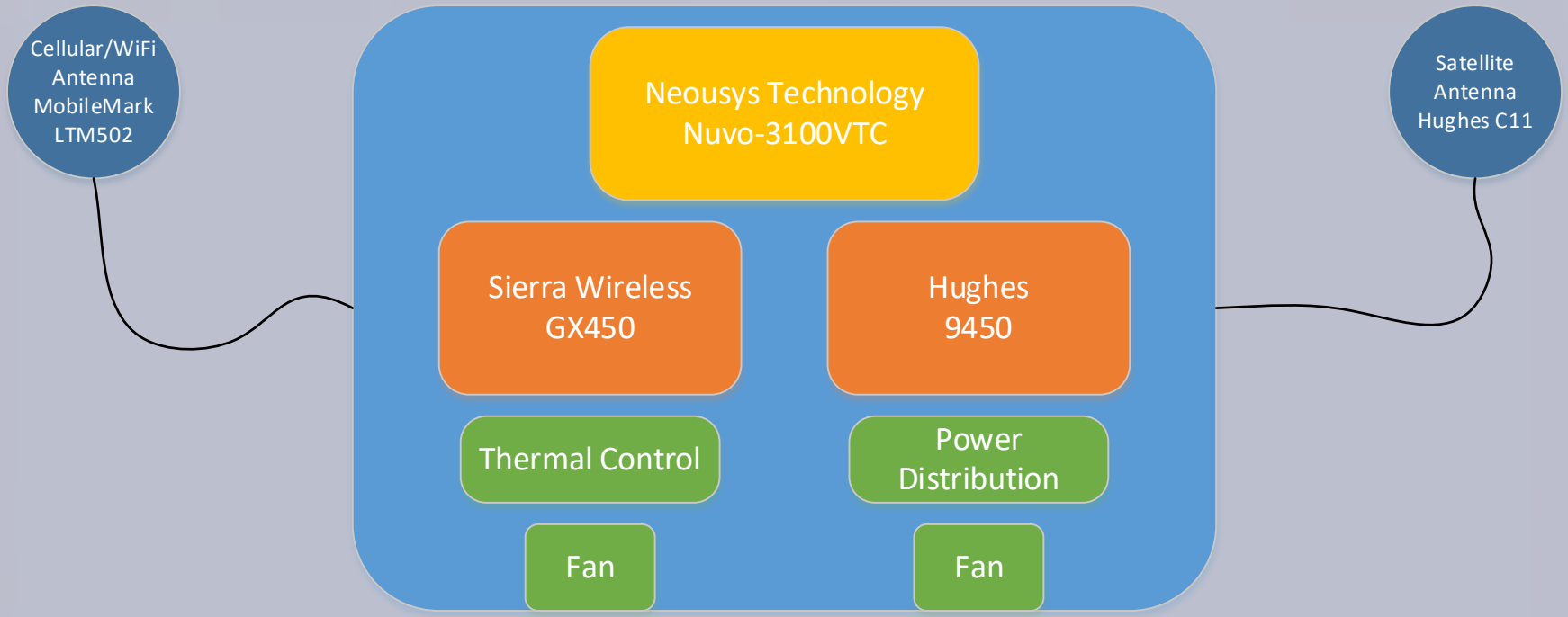
- CPU: Intel i7-3610QE 2.3 GHz
- RAM: Transcend Wide-Temp SO-DIMM DDR3 1600 8 GB
- SSD1: InnoDisk 3ME2 128 GB (mSATA)
- SSD2: Samsung 850 PRO 1 TB
- WIFI: Compex WLE600VX 802.11ac/n/b/g 2x2 MIMO QCA9882
- NET0: Intel 82579LM Gigabit Network Connection
- NET1: Intel I210 Gigabit Network Connection
- NET2: Intel I210 Gigabit Network Connection
- NET3: Intel I210 Gigabit Network Connection

Selected Cellular Modem

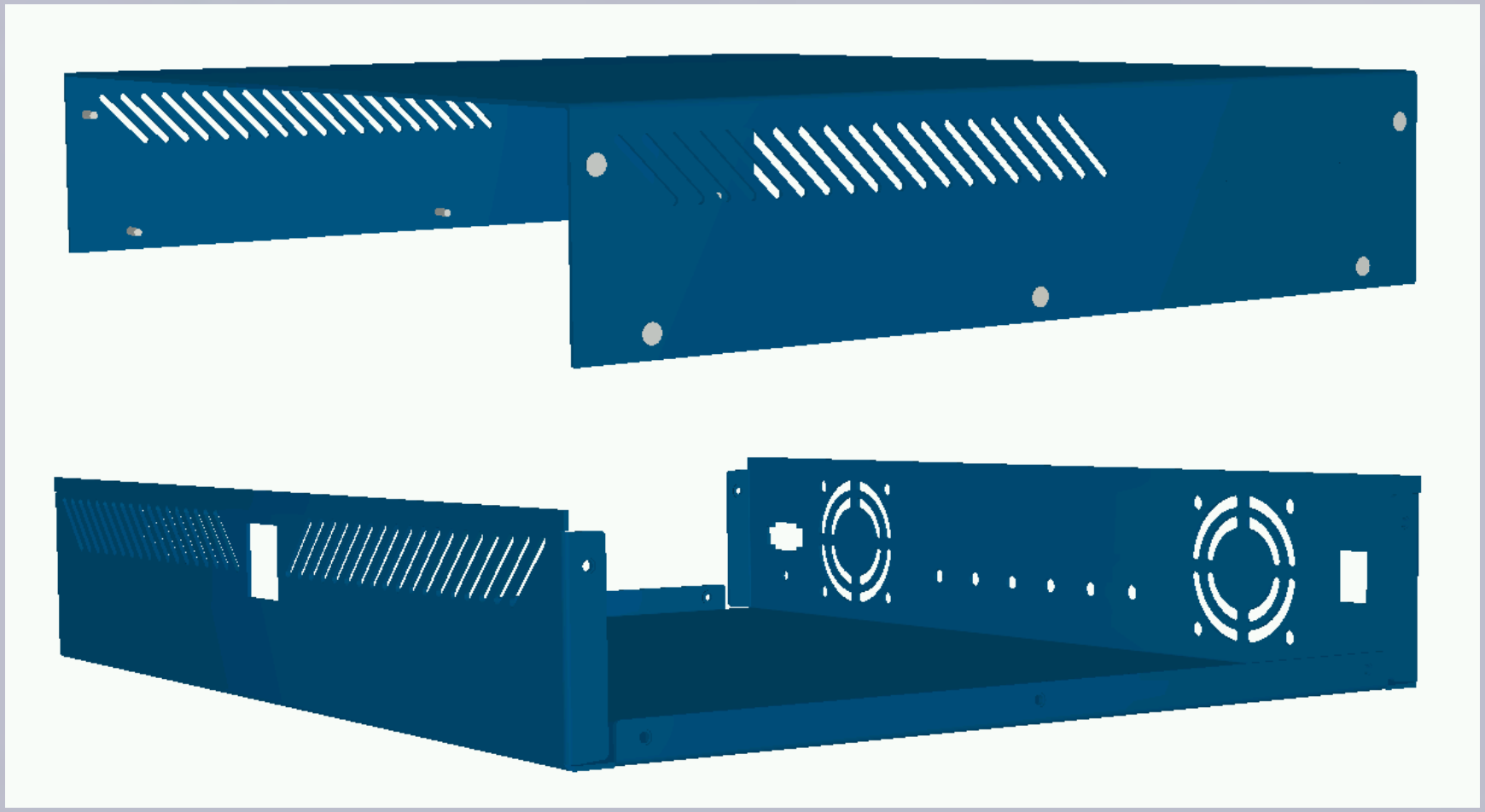
- Sierra Wireless GX450
  - Verizon LTE
  - -40F to +185F
  - Rugged
  - Low power



Detailed Enclosure System Architecture

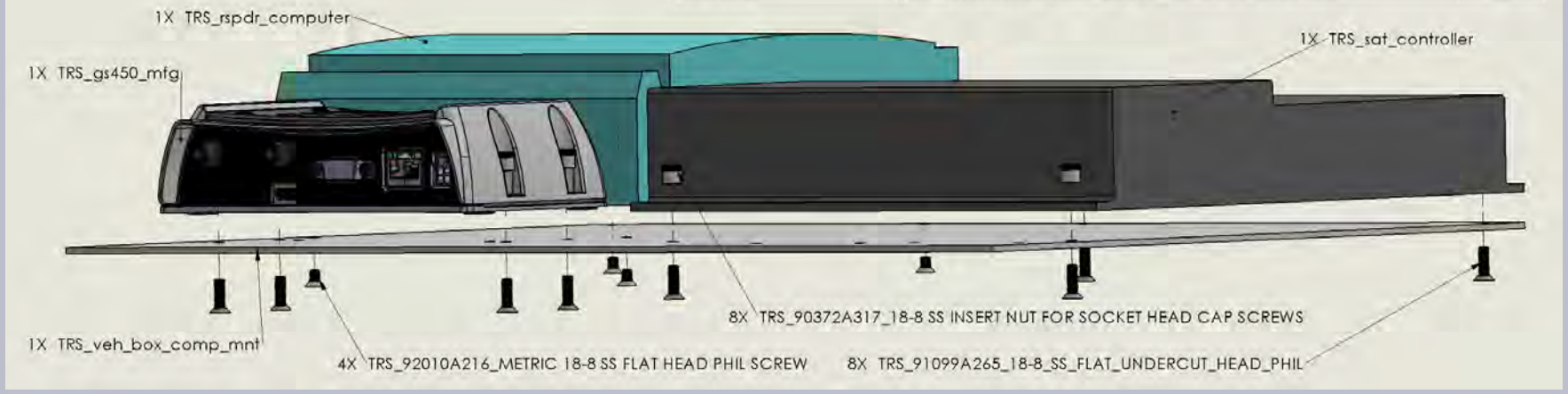


Vehicle Responder Hardware Design



Vehicle Responder Hardware Design

PART NUMBER	File Name	QTY.
TRS_veh_box_comp_mnt	TRS_veh_box_comp_mnt	1
TRS_sat_controller	TRS_sat_controller	1
TRS_rspdr_computer	TRS_rspdr_computer	1
TRS_gs450_mfg	TRS_gs450_mfg	1
90372A317	TRS_90372A317_18-8 SS INSERT NUT FOR SOCKET HEAD CAP SCREWS	8
91099A265	TRS_91099A265_18-8_SS_FLAT_UNDERCUT_HEAD_PHIL	8
92010A216	TRS_92010A216_METRIC 18-8 SS FLAT HEAD PHIL SCREW	4



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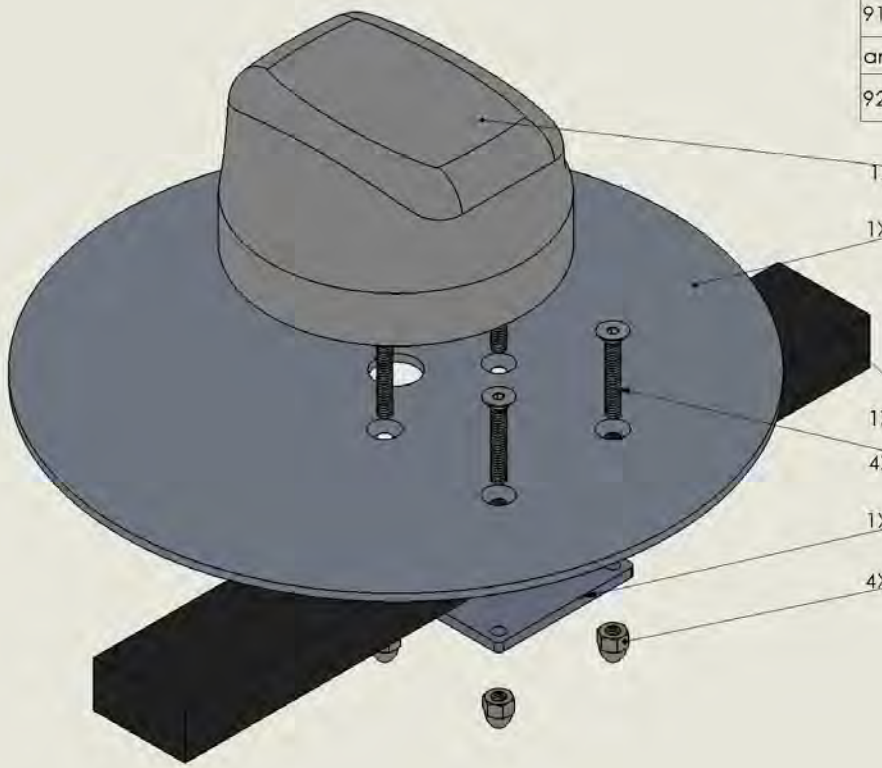
Vehicle Responder Hardware Design

PART NUMBER	File Name	QTY.
LTE_mobile_ant	LTE_mobile_ant	1
2in_bar	2in_bar	1
12in_gnd_plane	12in_gnd_plane	1
91855A360	91855A360_18-8 STAINLESS STEEL CAP NUT	4
ant_mount_bottom	ant_mount_bottom	1
92210A547	92210A547_18-8 STAINLESS STEEL FLAT-HEAD SCKT CAP SCREW	4



Vehicle Responder Hardware Design

PART NUMBER	File Name	QTY.
TRS_sat_ant	TRS_sat_ant	1
TRS_sat_ant_ss_washer	TRS_sat_ant_ss_washer	3
TRS_sat_ant_washer	TRS_sat_ant_washer	6
91831A411	TRS_91831A411_TYPE 18-8 STAINLESS STL NYLON-INSERT LOCKNUT	3
sat_ant_mount_plate_final	sat_ant_mount_plate_final	1
2in_bar	2in_bar	1
ant_mount_bottom	ant_mount_bottom	1
92949A838	92949A838_18-8 SS BUTTON-HEAD SOCKET CAP SCREW	4
91855A360	91855A360_18-8 STAINLESS STEEL CAP NUT	4
92196A279	92196A279_18-8 STAINLESS STEEL SOCKET HEAD CAP SCREW	3

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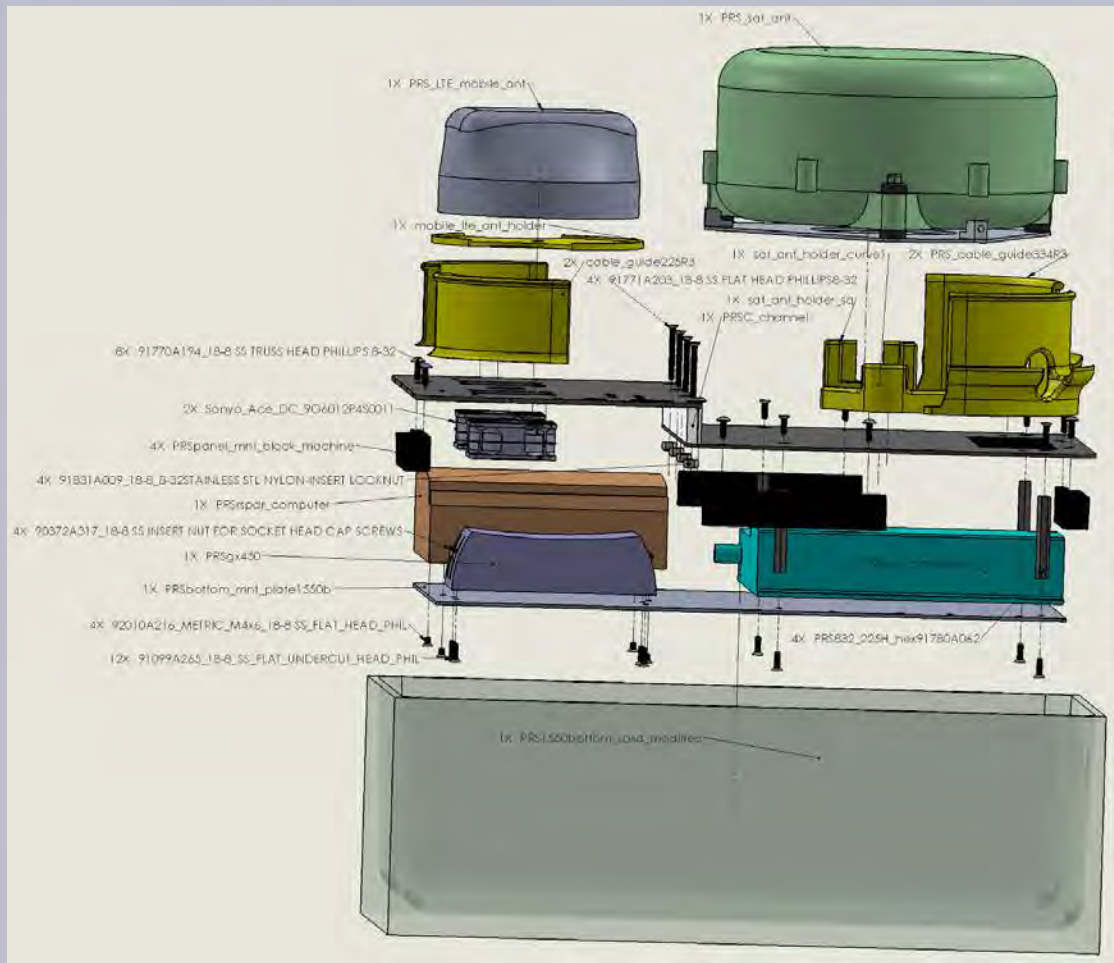
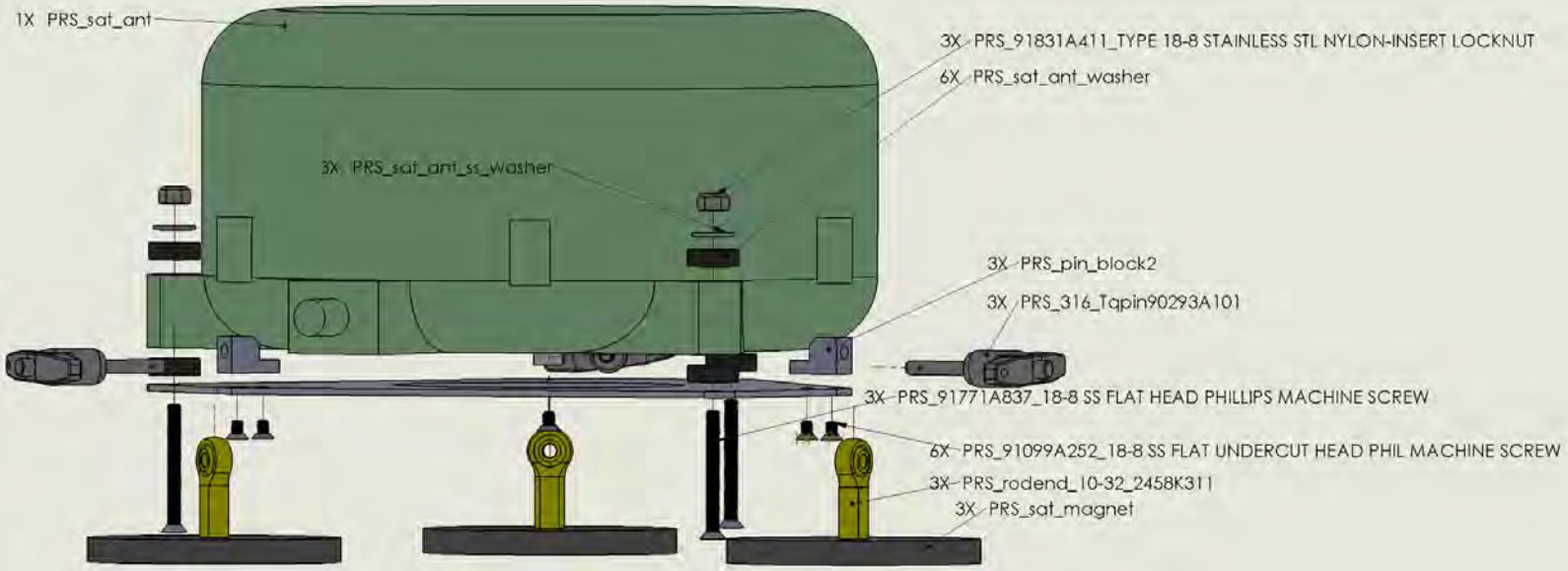
Portable Responder Hardware Design



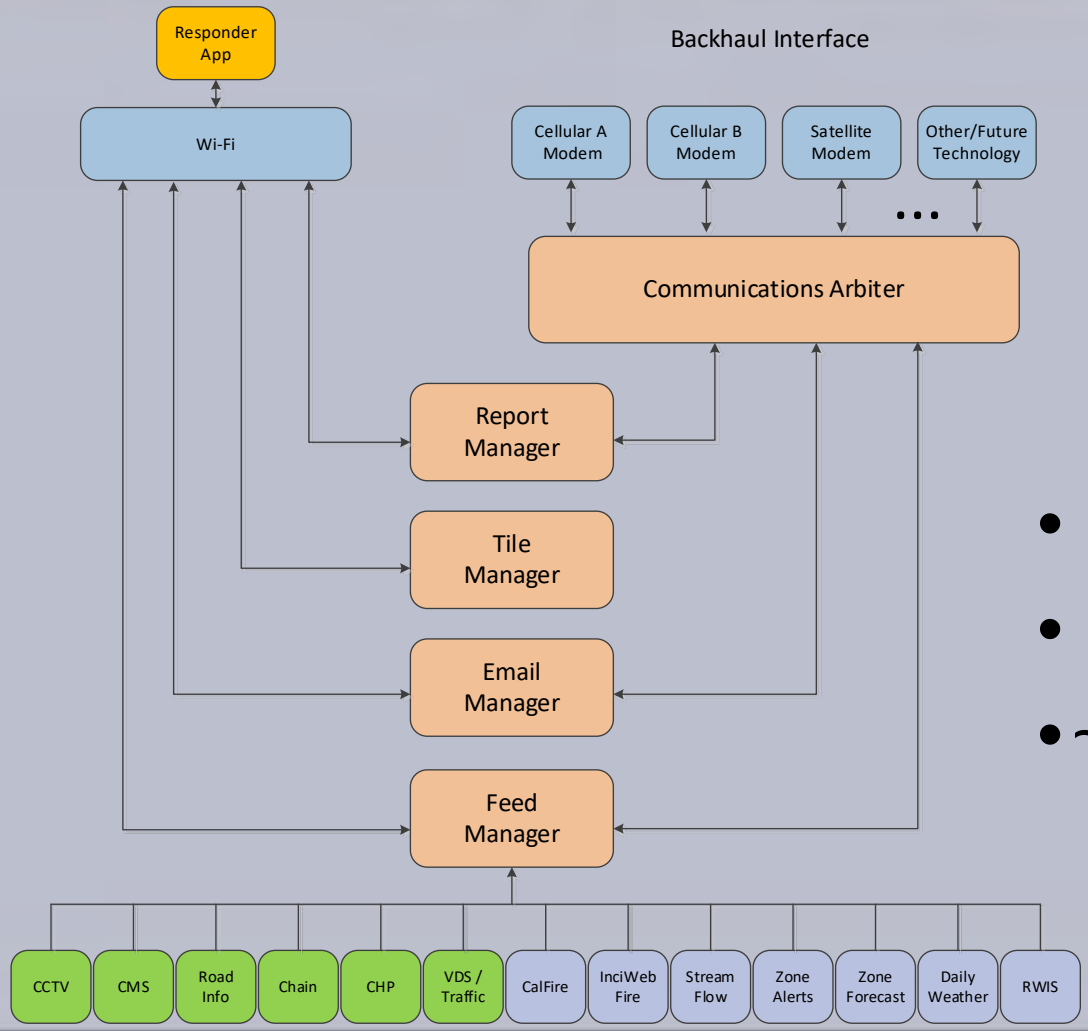
PART NUMBER	File Name	QTY.
PRS1550bottom_solid_modified	PRS1550bottom_solid_modified	1
PRSbottom_mnt_plate1550b	PRSbottom_mnt_plate1550b	1
PRSsat_controller	PRSsat_controller	1
PRSspdr_computer	PRSspdr_computer	1
PRSgx450	PRSgx450	1
91780A062	PRS832_225H_hex91780A062	4
PRSsat_topcover_1550a	PRSsat_topcover_1550a	1
PRScomptr_topcover_1550a	PRScomptr_topcover_1550a	1
PRSC_channel	PRSC_channel	1
PRSpanel_mnt_block_machine	PRSpanel_mnt_block_machine	4
fangguard_20150614-25888_body	fangguard_20150614-25888_body	2
91099A265	91099A265_18-8_SS_FLAT_UNDERCUT_HEAD_PHIL	12
91770A194	91770A194_18-8 SS TRUSS HEAD PHILLIPS 8-32	8
91771A203	91771A203_18-8 SS FLAT HEAD PHILLIPS8-32	4
90372A317	90372A317_18-8 SS INSERT NUT FOR SOCKET HEAD CAP SCREWS	4
91831A009	91831A009_18-8_B-32STAINLESS STL NYLON-INSERT LOCKNUT	4
92010A216	92010A216_METRIC_M4x6_18-8 SS_FLAT_HEAD_PHIL	4
cable_guide225R3	cable_guide225R3	2
PRS_cable_guide334R3	PRS_cable_guide334R3	2
PRS_sat_ant	PRS_sat_ant	1
PRS_sat_ant_ss_washer	PRS_sat_ant_ss_washer	3
PRS_sat_ant_washer	PRS_sat_ant_washer	6
PRS_sat_ant_mag_mount_plate2	PRS_sat_ant_mag_mount_plate2	1
91099A252	PRS_91099A252_18-8 SS FLAT UNDERCUT HEAD PHIL MACHINE SCREW	6
91831A411	PRS_91831A411_TYPE 18-8 STAINLESS STL NYLON-INSERT LOCKNUT	3
91771A837	PRS_91771A837_18-8 SS FLAT HEAD PHILLIPS MACHINE SCREW	3
PRS_pin_block2	PRS_pin_block2	3
sat_ant_holder_sq	sat_ant_holder_sq	1
sat_ant_holder_curve1	sat_ant_holder_curve1	1
mobile_lte_ant_holder	mobile_lte_ant_holder	1
lte_ant_holder_steelplate	lte_ant_holder_steelplate	1
lte_ant_holder_alignment	lte_ant_holder_alignment	1
PRS_LTE_mobile_ant	PRS_LTE_mobile_ant	1
Sanyo_Ace_DC_9G6012P4S0011	Sanyo_Ace_DC_9G6012P4S0011	2

Portable Responder Hardware Design

PART NUMBER	File Name	QTY.
PRS_sat_ant	PRS_sat_ant	1
PRS_sat_ant_ss_washer	PRS_sat_ant_ss_washer	3
PRS_sat_ant_washer	PRS_sat_ant_washer	6
PRS_sat_ant_mag_mount_plate2	PRS_sat_ant_mag_mount_plate2	1
2458K311	PRS_rodend_10-32_2458K311	3
PRS_sat_magnet	PRS_sat_magnet	3
92196A269	92196A269_18-8 STAINLESS STEEL SOCKET HEAD CAP SCREW	3
91099A252	PRS_91099A252_18-8 SS FLAT UNDERCUT HEAD PHIL MACHINE SCREW	6
91831A411	PRS_91831A411_TYPE 18-8 STAINLESS STL NYLON-INSERT LOCKNUT	3
91771A837	PRS_91771A837_18-8 SS FLAT HEAD PHILLIPS MACHINE SCREW	3
PRS_pin_block2	PRS_pin_block2	3
90293A101	PRS_316_Tqpin90293A101	3

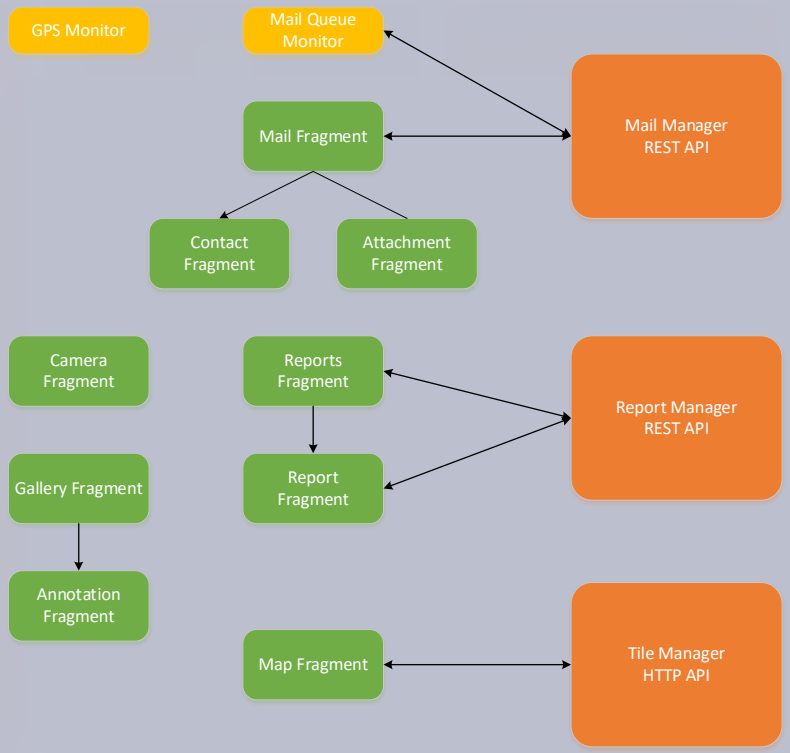


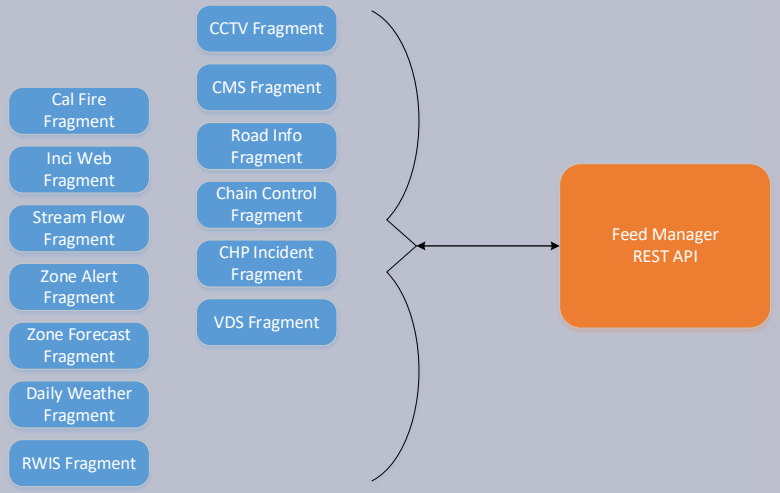
Software System Architecture



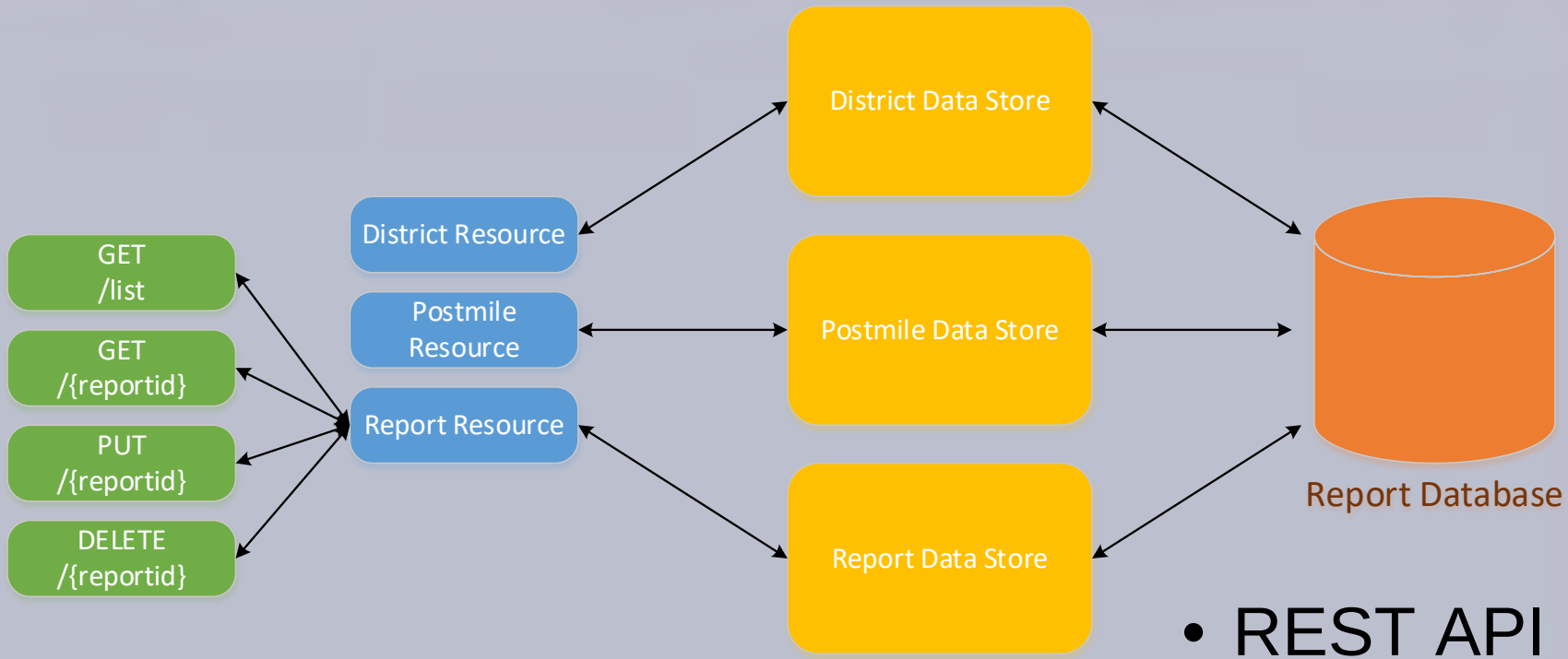
- Java
- Python
- ~100k LOC

Responder Software Architecture



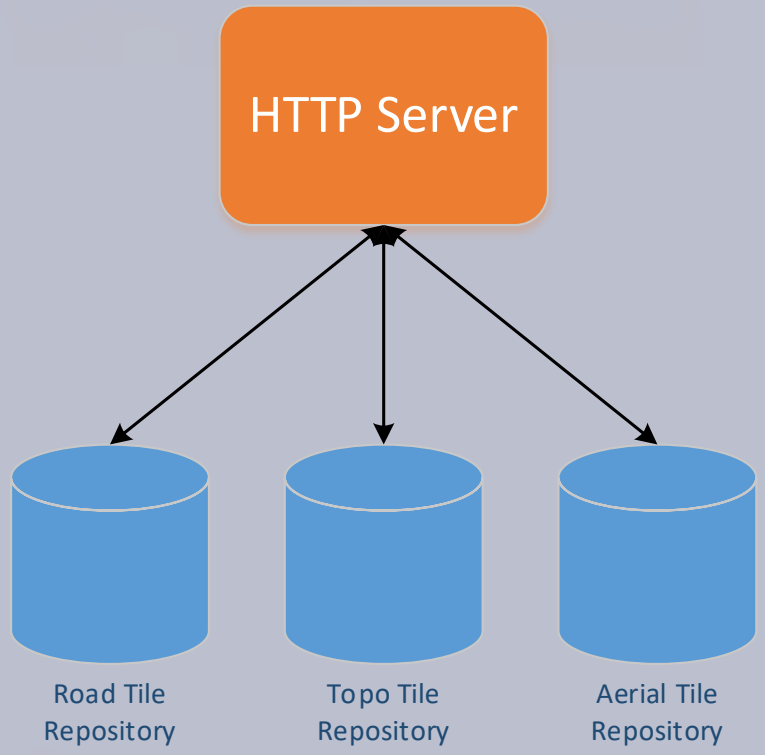


Report Manager Software Architecture



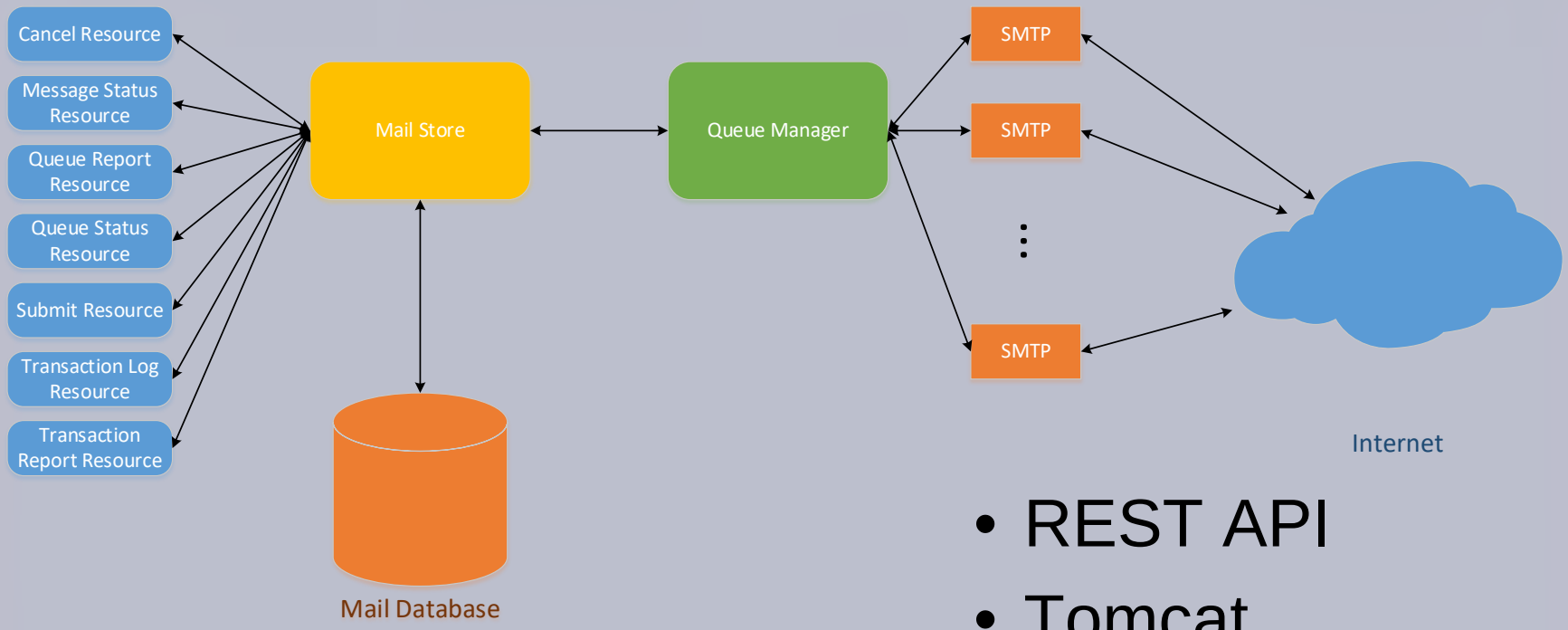
- REST API
- Tomcat
- Postgresql

Tile Manager Software Architecture



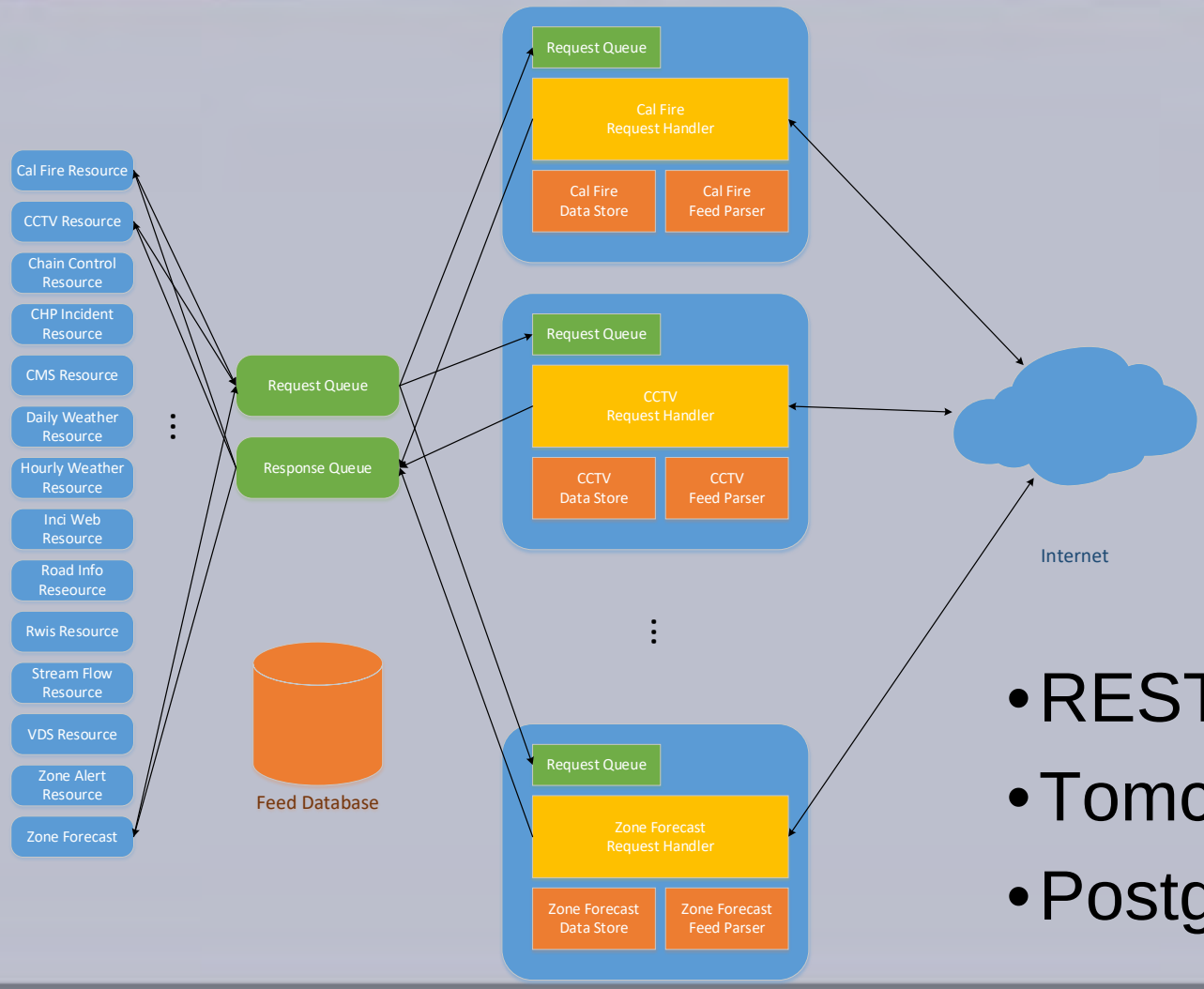
- Tile levels 9-17
- 800 GB total
- Mercator projection tile organization

Mail Manager Software Architecture



- REST API
- Tomcat
- Postgresql

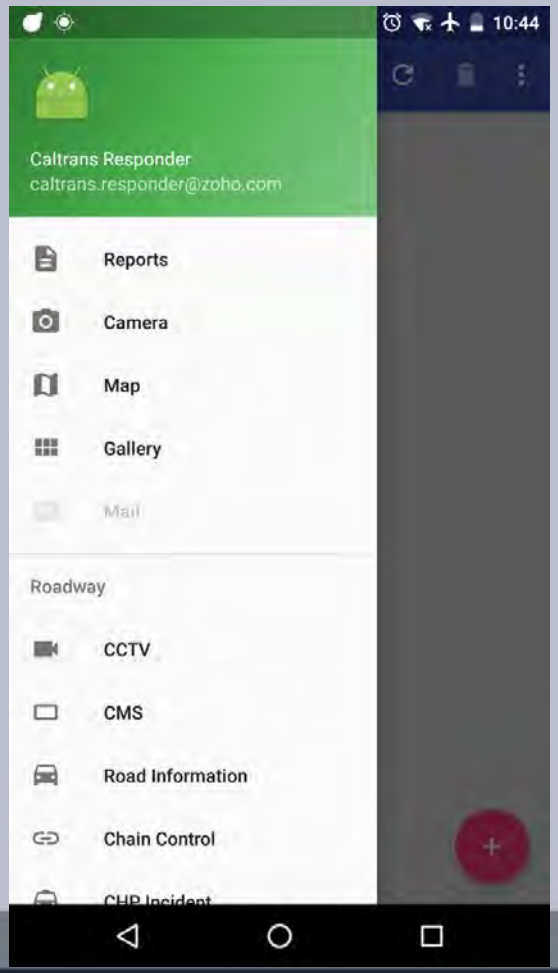
Feed Manager Software Architecture



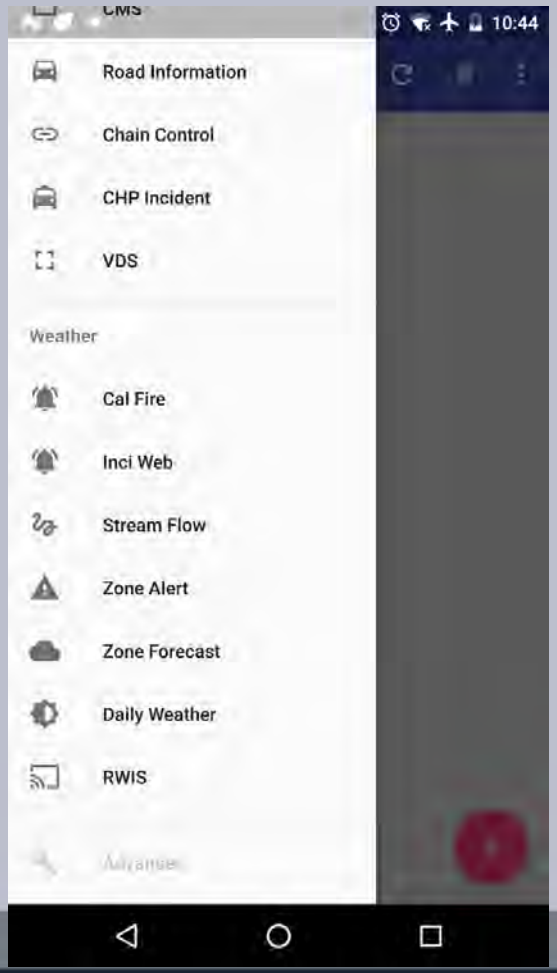
- REST API
- Tomcat
- Postgresql

Primary Screenshots

Navigation

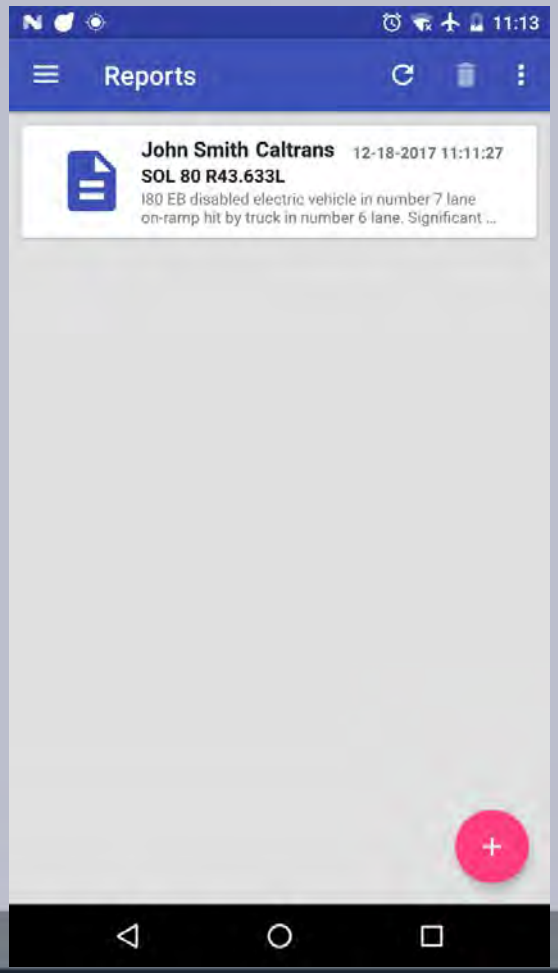


Navigation



Primary Screenshots

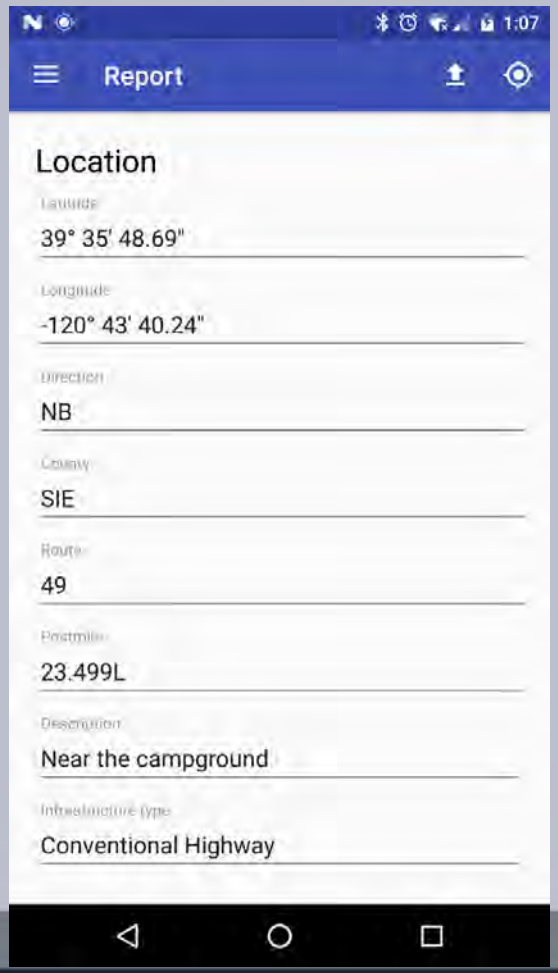
Reports



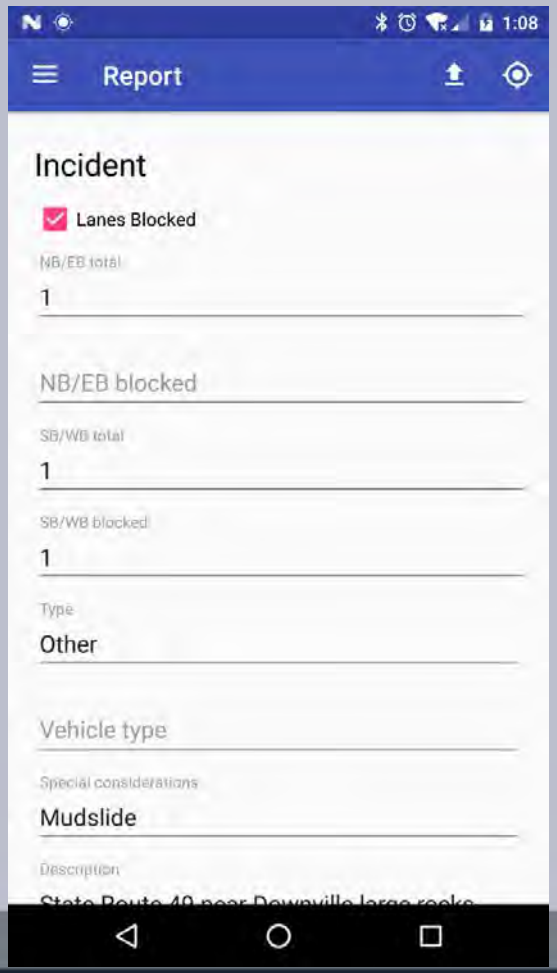
Report

Primary Screenshots

Report Location

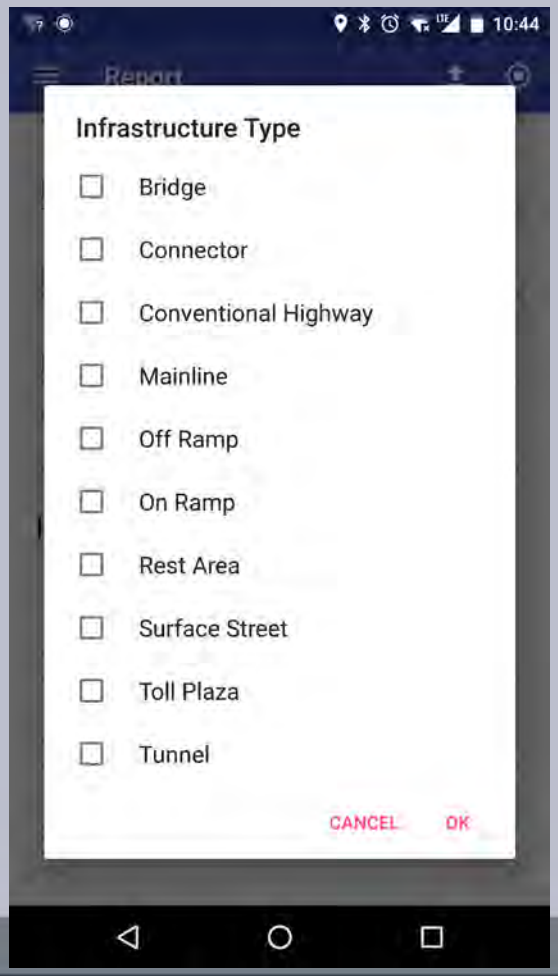


Report Incident

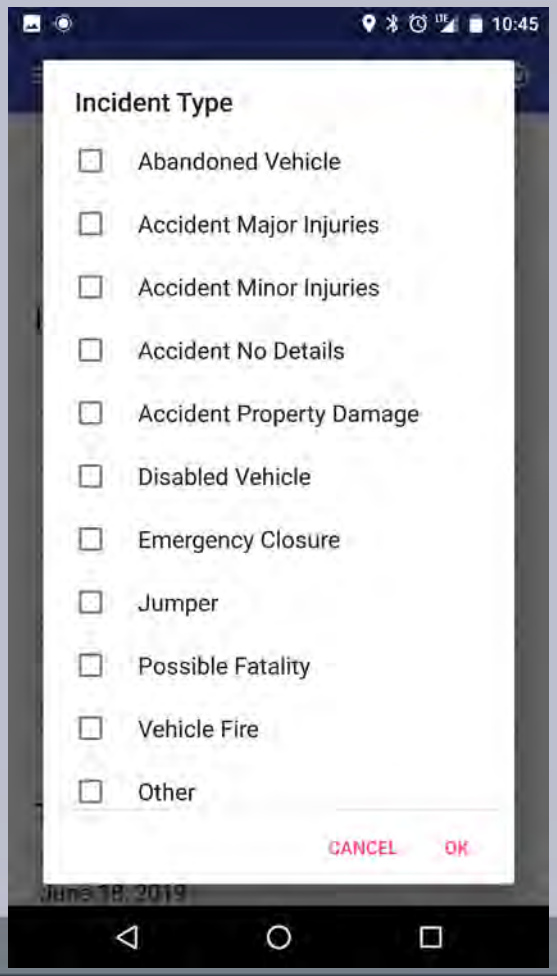


Primary Screenshots

Infrastructure Type



Incident Type



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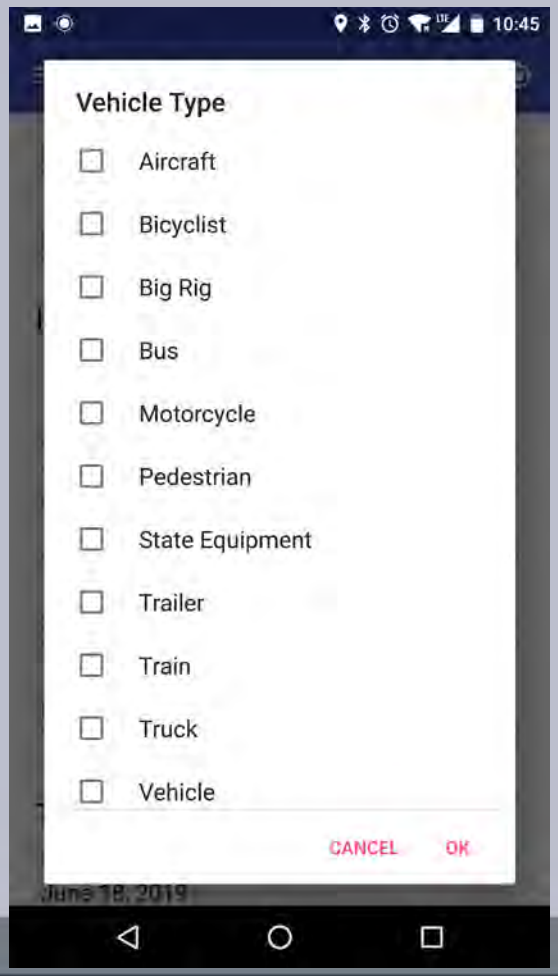
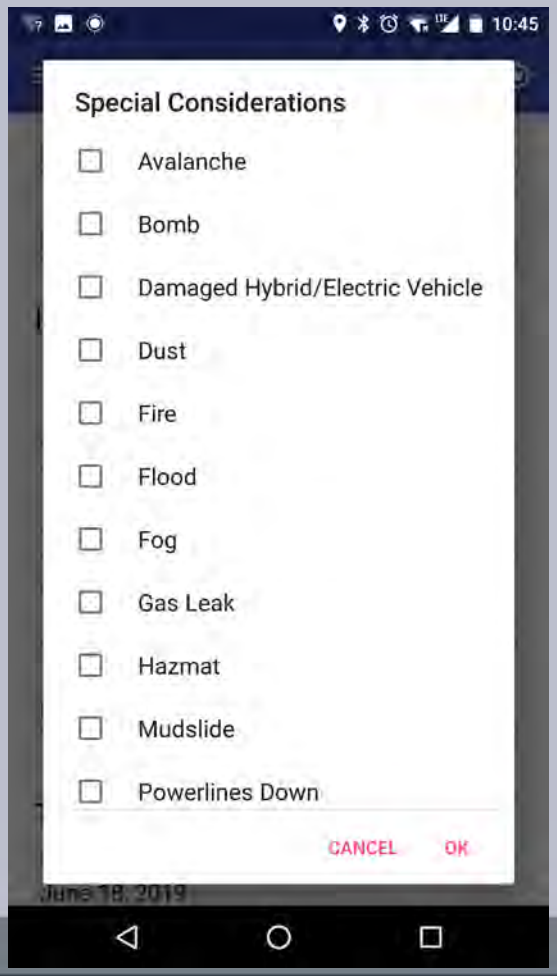
Primary Screenshots

Vehicle Type

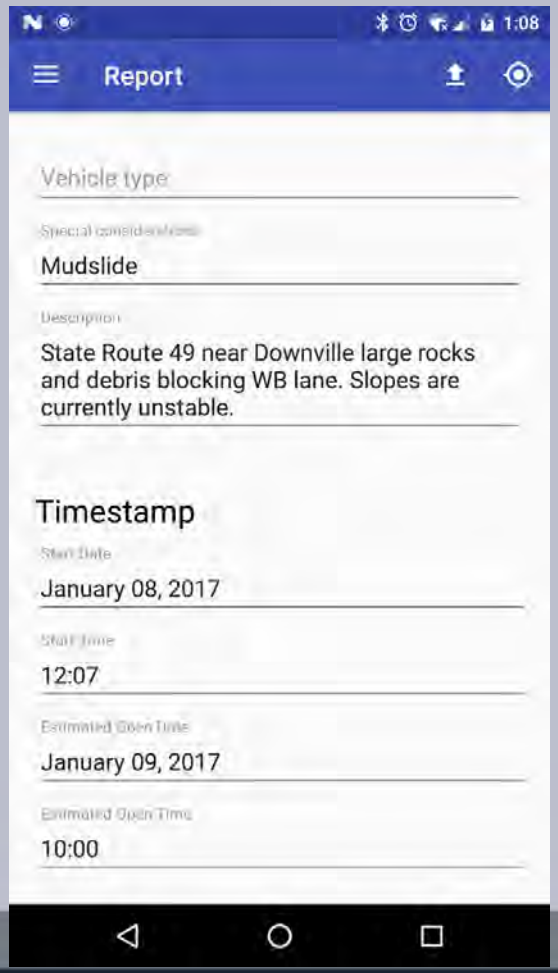


Special Considerations



Primary Screenshots

Report Timestamp



Camera

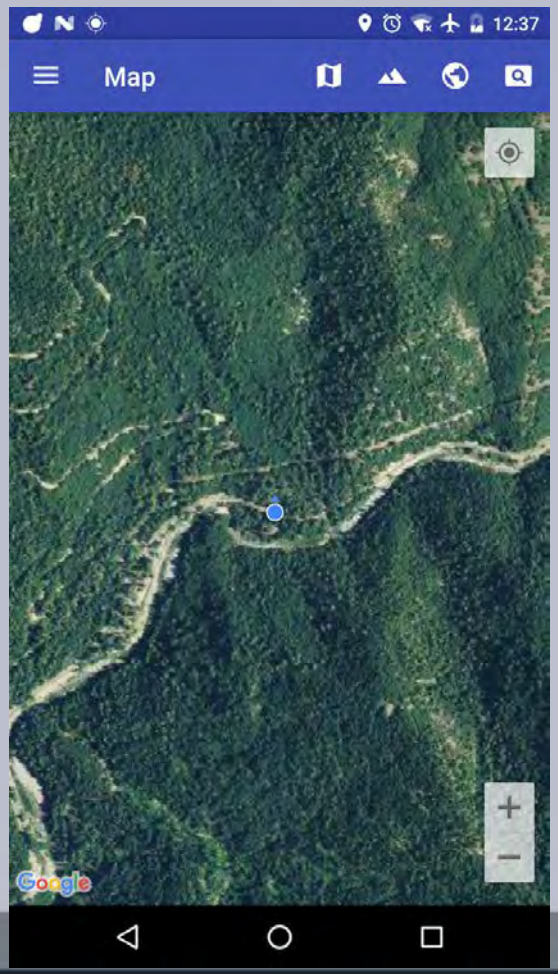
Primary Screenshots

Road Map

Topo Map

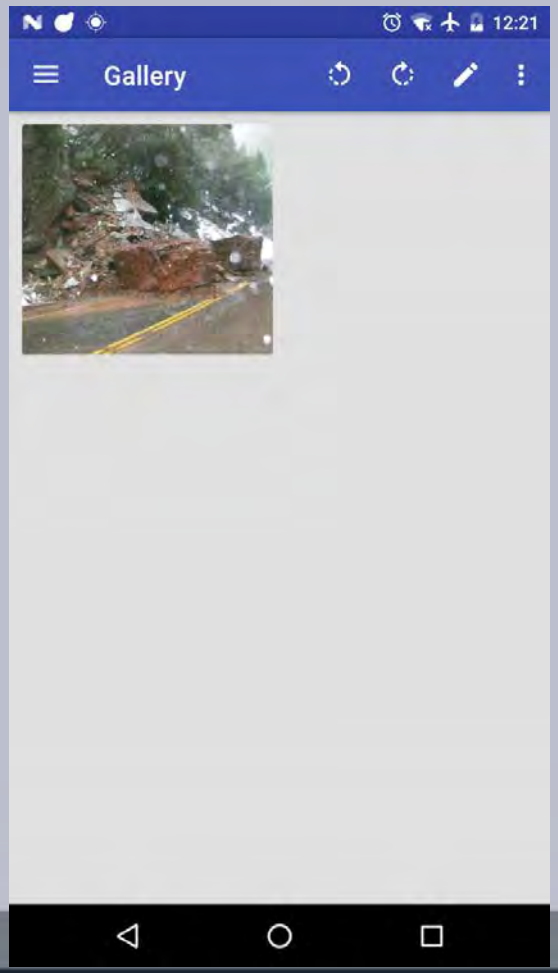
Primary Screenshots

Aerial Map



Primary Screenshots

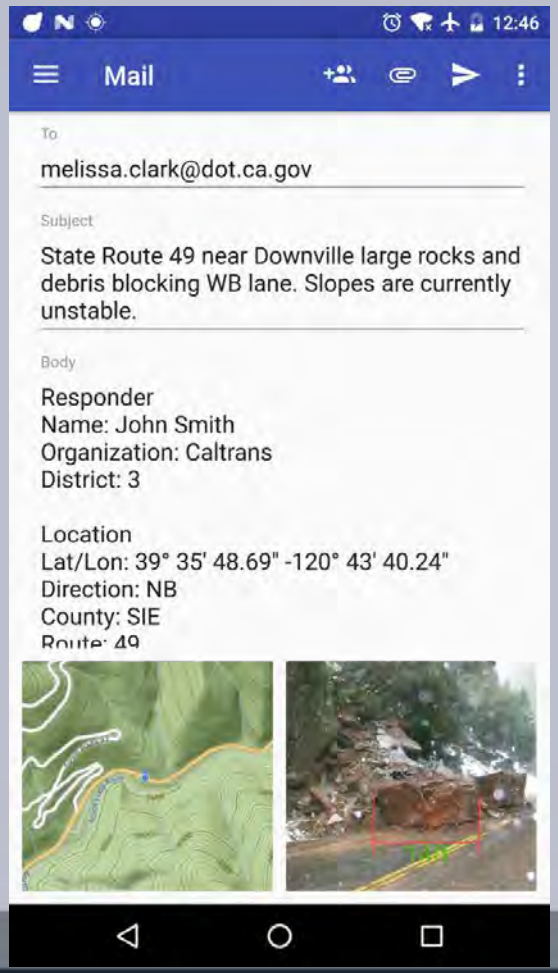
Gallery



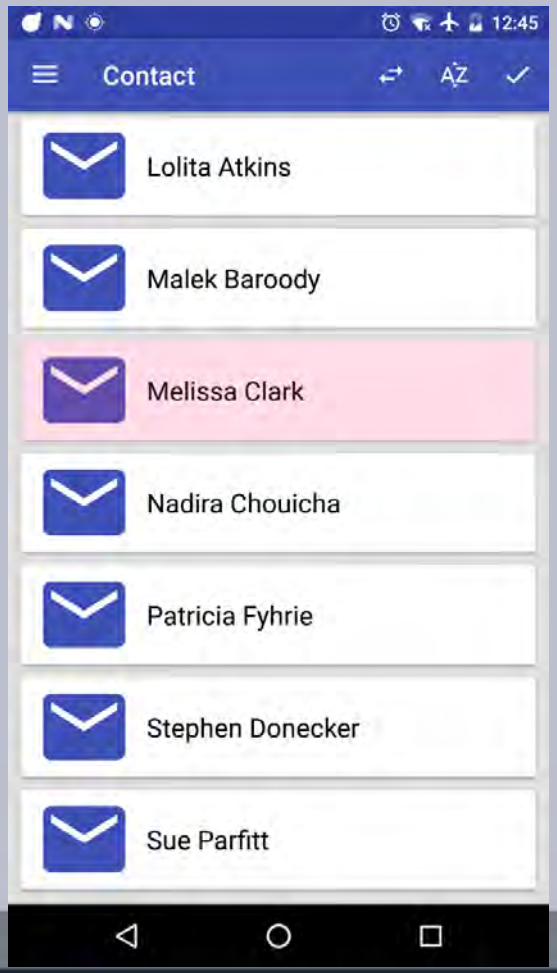
Annotation

Primary Screenshots

Mail



Contact



Primary Screenshots

Attachment

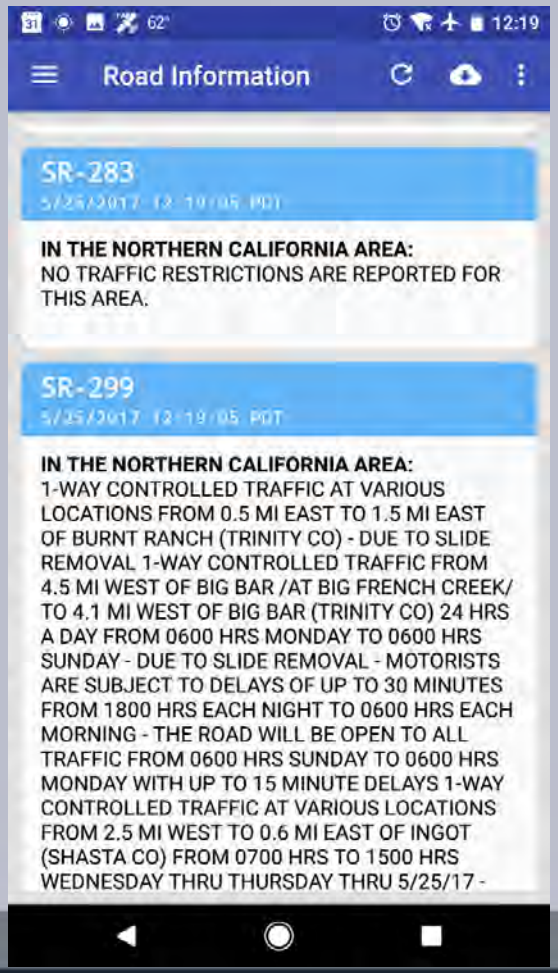
Information Screenshots

CCTV

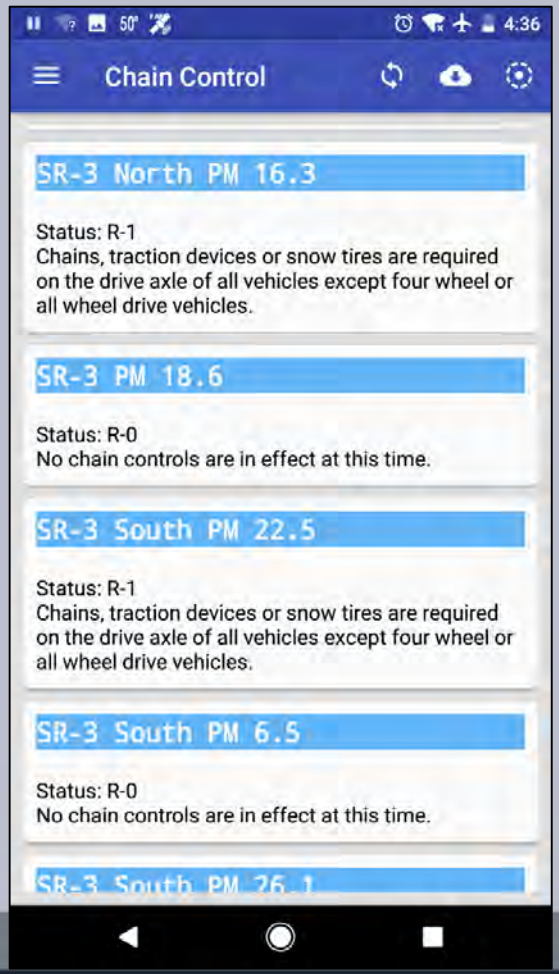
CMS

Information Screenshots

Road Information

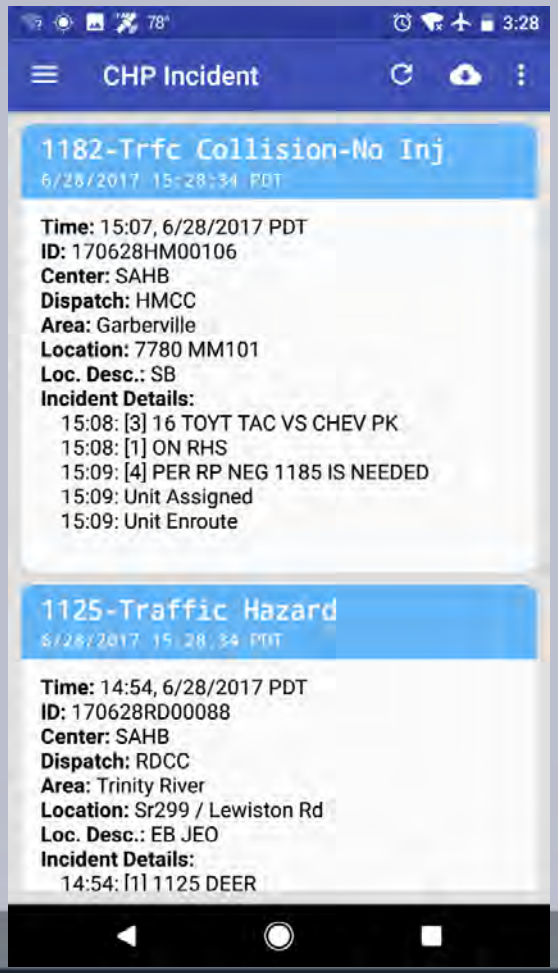


Chain Control



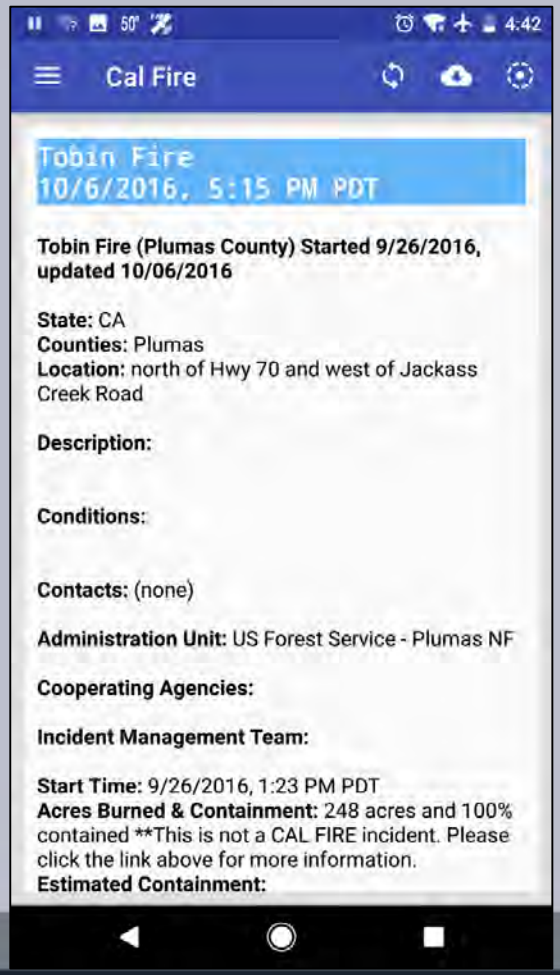
Weather Screenshots

CHP Incident

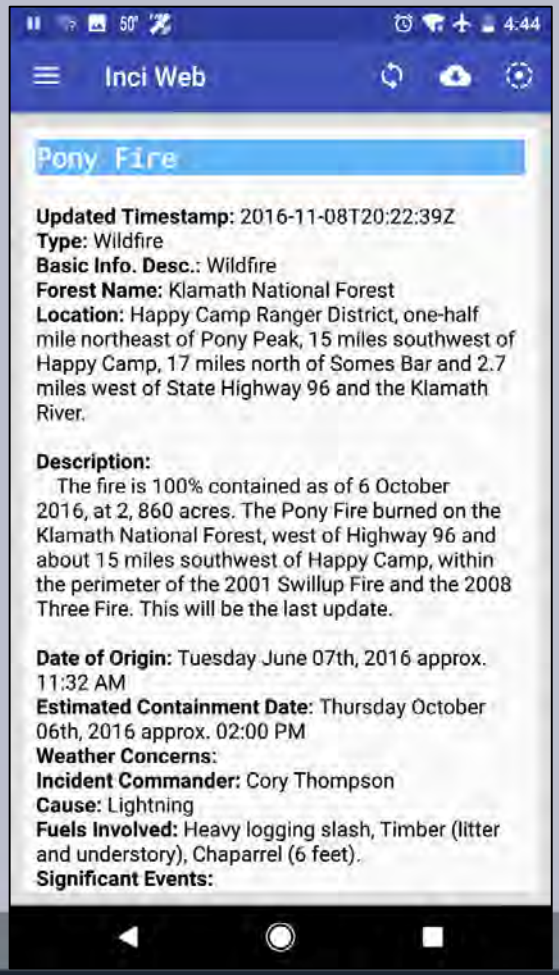


Weather Screenshots

Cal Fire

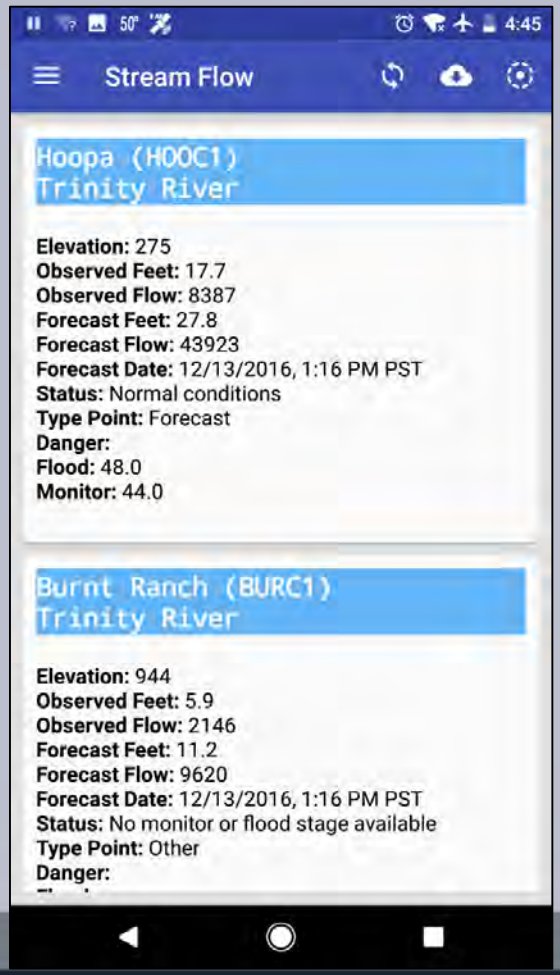


InciWeb

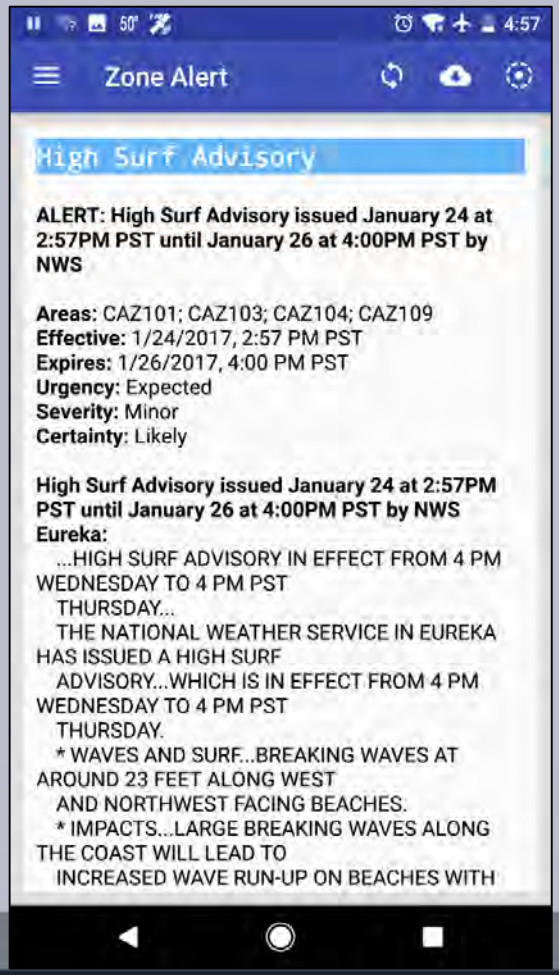


Weather Screenshots

Stream Flow



Zone Alert



Weather Screenshots

Zone Forecast

Daily Weather

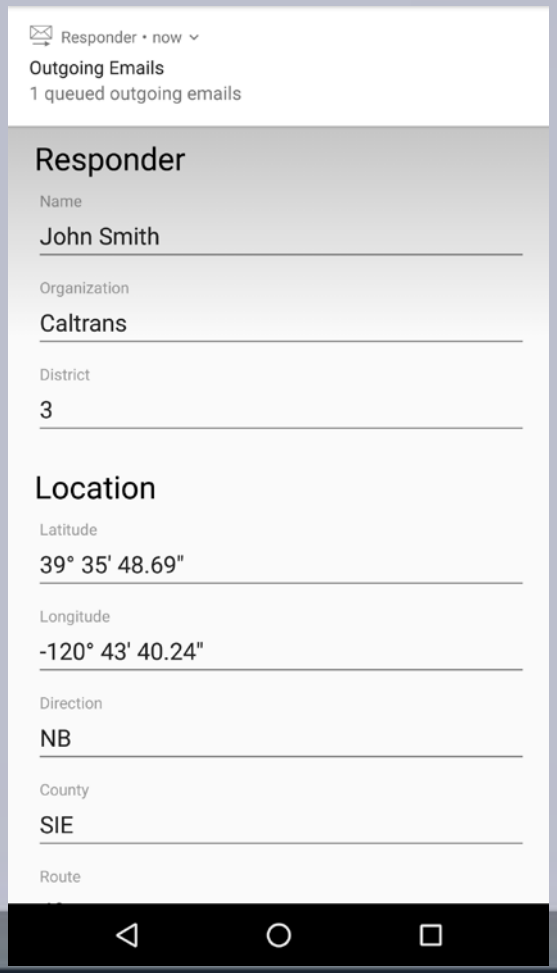
Weather Screenshots

RWIS

Notification Screenshots

Queueing

Outgoing Email



Notification Screenshots

Successful Email

Notification Screenshots

Notification Icons

Received Responder Message

From: caltrans.responder@zoho.com
To: caltrans.responder@zoho.com
Cc: Siddiqui, Asfand Y@DOT; Lomeli, Carlos@DOT; Esquivil, David@DOT; Pearce, Jeremiah C@DOT; Baltazar, Joseph@DOT; Mcneely, Joseph D@DOT; Koeppen, Keith B@DOT; Clark, Melissa L@DOT; smdonecker@ucdavis.edu; talasky@ucdavis.edu
Subject: test unit at 7500+ feet in sub-freezing weather powered by solar generator
Date: Thursday, December 27, 2018 11:34:20 AM

```
Responder
Name: James province
Organization: tb region
District: 6

Location
Lat/Lon: 37° 12' 23.44" -119° 12' 50.93"
Direction:
County: FRE
Route: 168
Postmile: 59.867L
Description: test communications for snowfighter and first responders
Infrastructure Type: Conventional Highway

Incident
Lanes Blocked: No
Type: Other
Vehicle Type: Other
Special Considerations: Other
Description: test unit at 7500+ feet in sub-freezing weather powered by solar
generator

Timestamp
Start: December 27, 2018 11:13
Open: December 27, 2018 11:13
```

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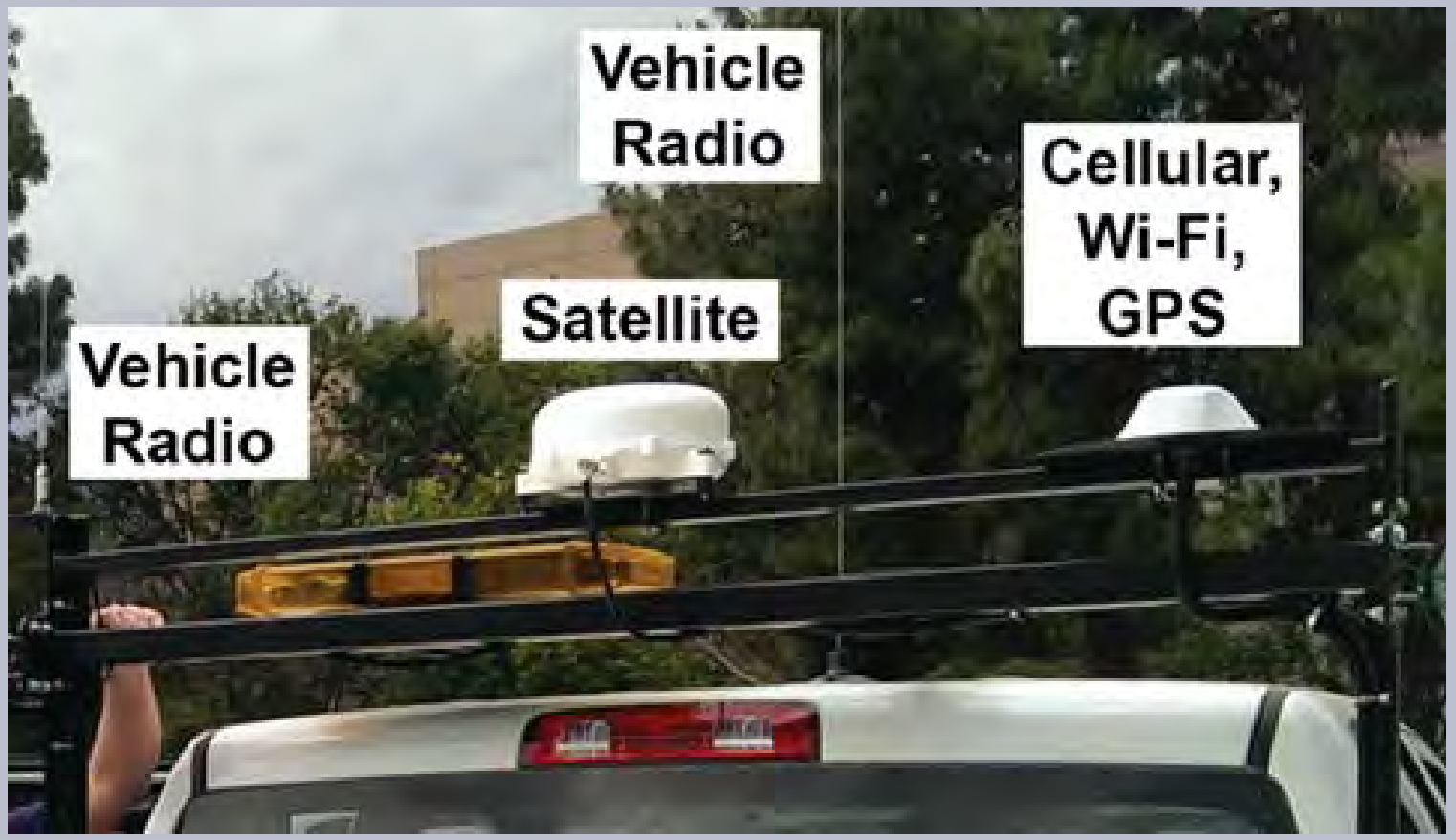
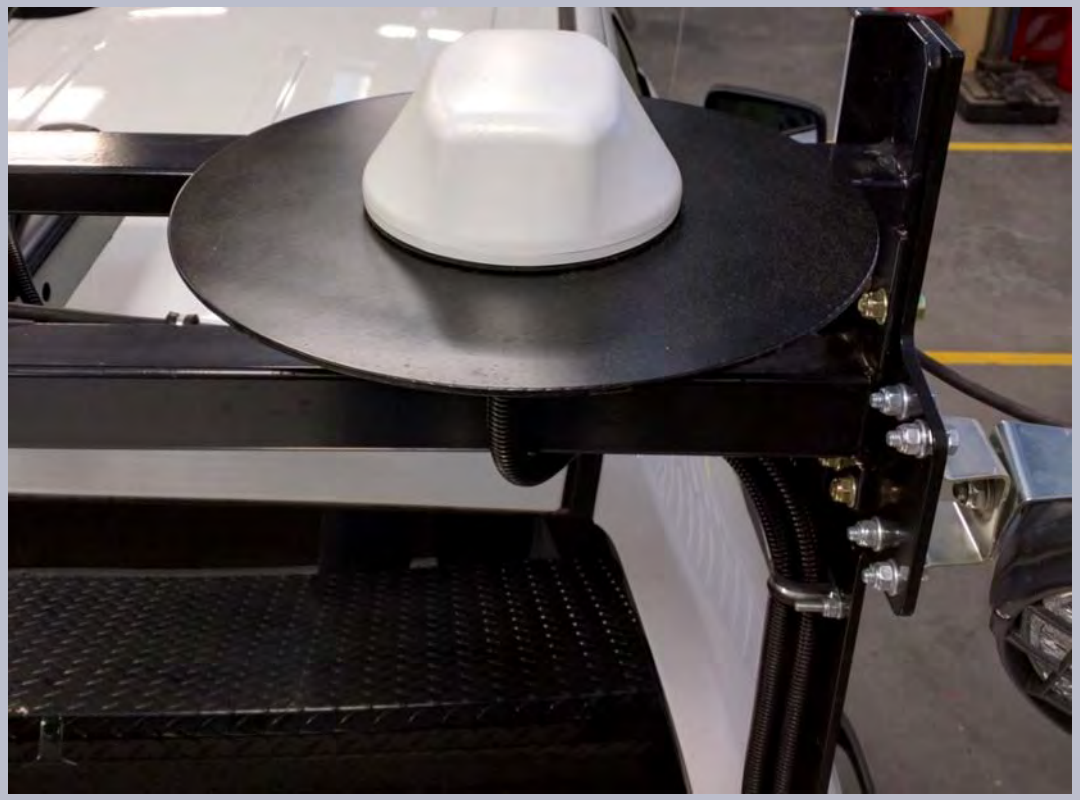
Vehicle Responder Hardware Implementation



Vehicle Responder Hardware Implementation



Vehicle Responder Hardware Implementation

Vehicle Responder Hardware Implementation

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Vehicle Responder Hardware Implementation

Vehicle Responder Hardware Architecture

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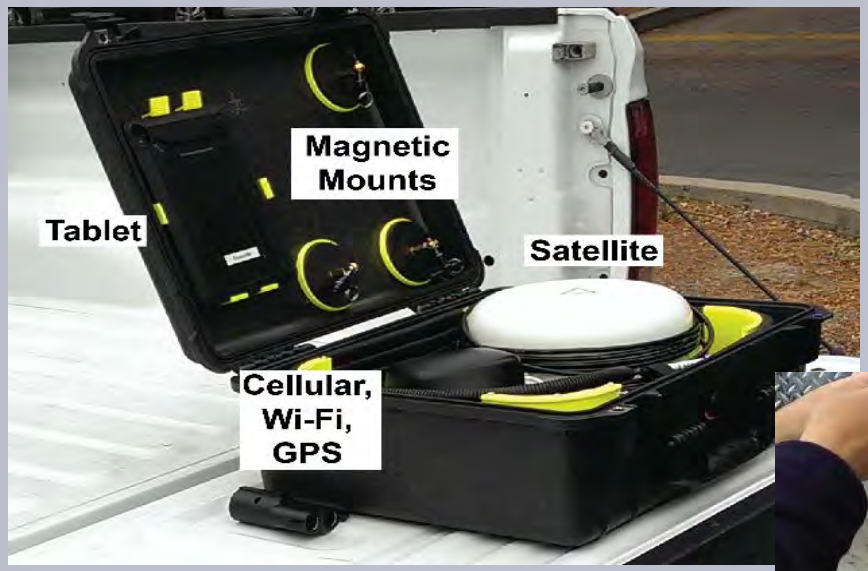
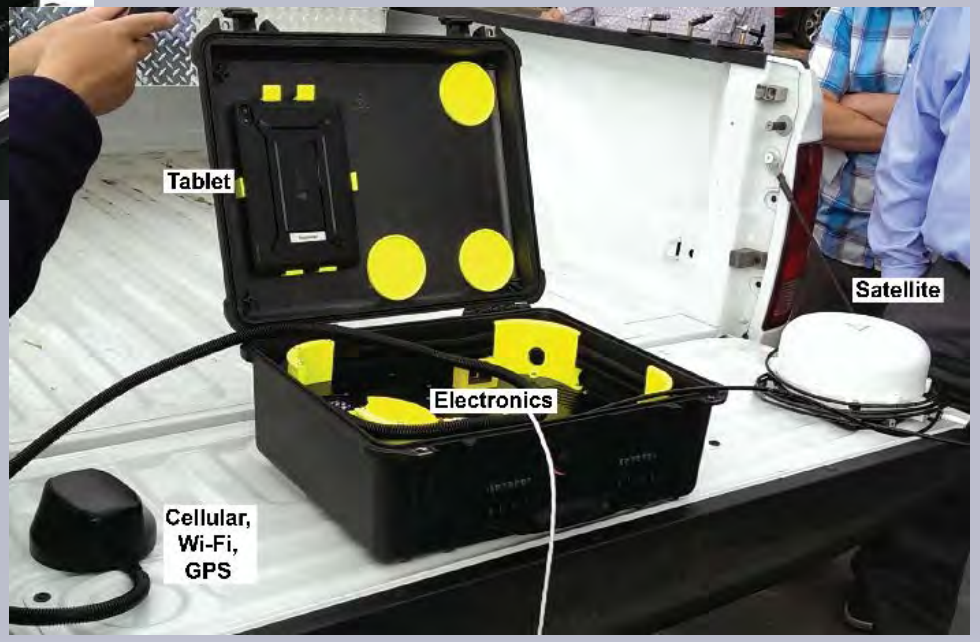
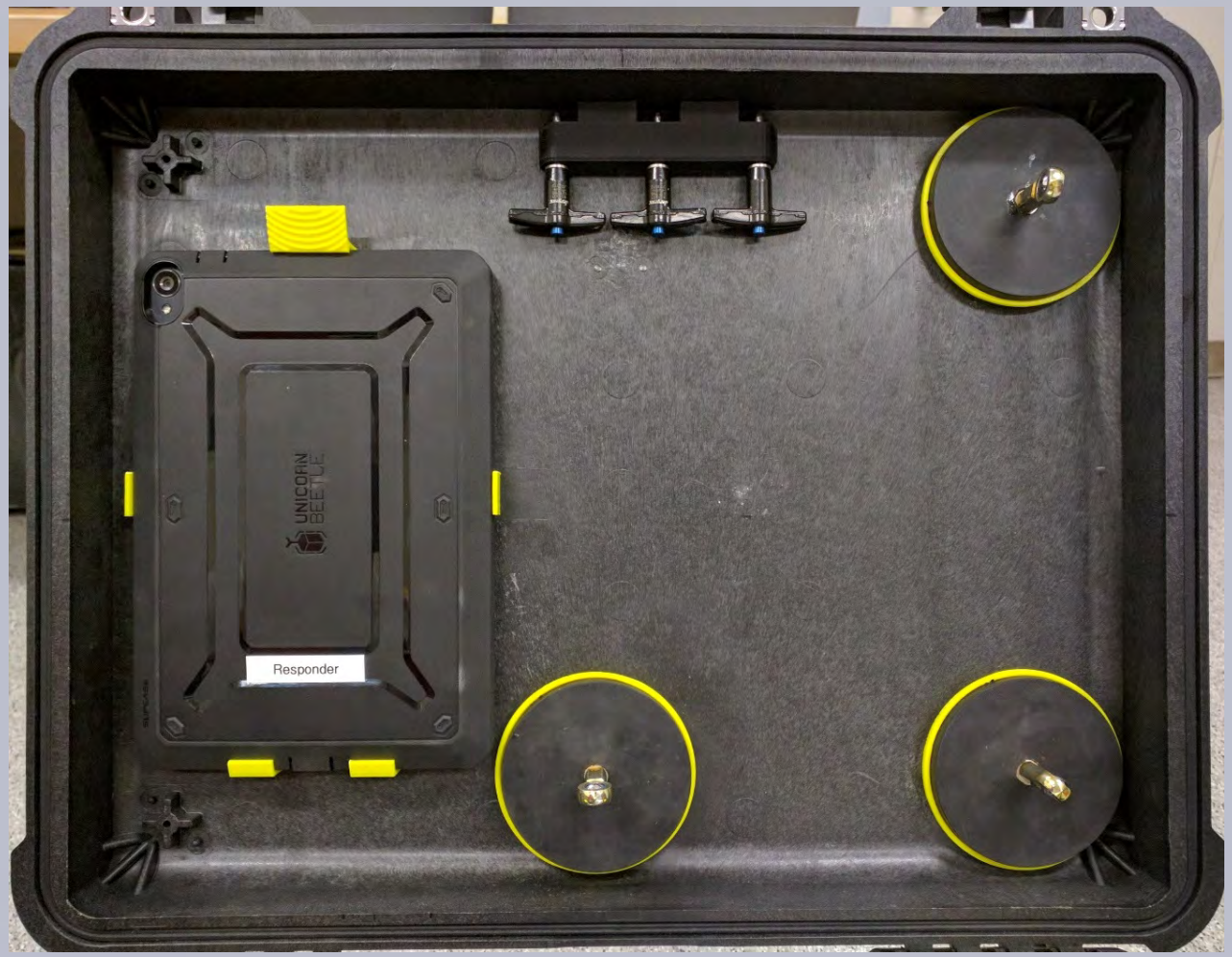
Portable Responder Hardware Implementation





Portable Responder Hardware Implementation

Portable Responder Hardware Implementation



Portable Responder Hardware Implementation

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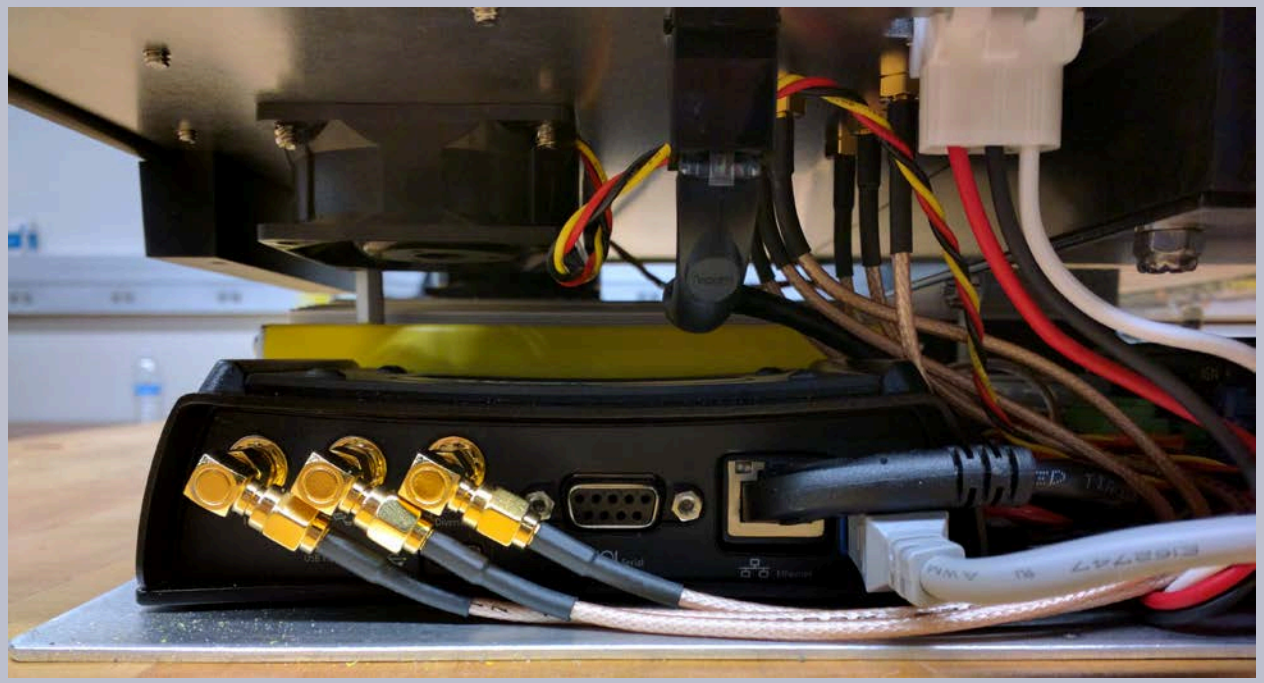
Portable Responder Hardware Implementation

Portable Responder Hardware Implementation

Portable Responder Hardware Implementation



Portable Responder Hardware Implementation

Field Testing

- Conducted in D2, D3, D4, D6, D7, D9, D10, D11
- Rural and urban
- Over land and water
- Temperature extremes
- Mountains, bridges, urban canyons

Field Testing Plan

- Responder system transferred from AHMCT to district
- On-site operational tutorial
- One month testing commences
  - Actual/mock incidents
  - Maintenance reporting
  - Testing typically performed in challenging locations
- On-site debrief of one or more district staff
- End users complete questionnaire
- Transfer vehicle back to AHMCT for system prep for next district

Field Testing

- Satellite constellation
  - –The Responder system supports Inmarsat BGAN I-4 series of satellites
  - – Inmarsat 4-F1 Asia
  - – Inmarsat 4-F2 Europe
  - – Inmarsat 4-F3 Americas
- Satellite pointing
  - –Look angles for the Inmarsat 4-F3 from each district's headquarters

District	Elevation (degrees)	Azimuth (degrees)
1	35.5	128.0
2	36.6	130.3
3	38.9	130.9
4	39.2	129.5
5	42.3	130.7
6	41.4	132.8
7	44.7	133.9
8	45.1	135.5
9	41.5	135.1
10	39.5	131.0
11	46.5	135.0
12	45.2	134.5

Field Testing D2

Report 2 generated and sent from TRI 299 33.296L

This actual incident report lists the incident as a big rig over the bank in the river below. The purpose of this image is to show the unobstructed view of the sky, although a reasonably tall mountain is just ahead. The report was successfully sent over the satellite communications system.

Field Testing D2

Report 3 generated and sent from SHA 299 1.780L

The purpose of this image is to show the partially obstructed view of the sky due to the nearby foliage and the reasonably tall mountain in the background. The report was successfully sent over the satellite communications system.

Field Testing D2

Report 4 generated and sent from TRI 299 26.356R

The purpose of this image is to show the partially obstructed view of the sky due to the nearby foliage, the adjacent hill, and the reasonably tall mountain in the background. The report was successfully sent over the satellite communications system.

Field Testing D2

- Key Results (Weaverville Maintenance)
  - Improves ability to communicate incidents to the TMC
  - Would use Responder system 75% of the time to respond to incidents
  - Would definitely use the Responder system for other maintenance work
  - Need two-way communication (i.e., notification of report receipt and response from recipient)
  - Long message transmission times

Field Testing D3

- The VRS was delivered to District 3
- However, evaluation was not conducted due to district resource issues

Field Testing D9

Report 1 generated and sent from MNO 395 102.793R

The purpose of this image is to show the view of the sky with a pair of mountains in the background. The report was successfully sent over the satellite communications system.

Field Testing D9

Report 3 generated and sent from INY 168 28.968R

The purpose of this image is to show the view of the sky and the mountains in the background. The report was successfully sent over the satellite communications system.

Field Testing 9

- Key Results (District Management)
  - Well done, very intuitive
  - Improves ability to communicate incidents to the TMC
  - Typically use the Responder system to respond to incidents 50% of the time
  - The Responder system would be used for other maintenance activities where other forms of communication are unavailable
  - Need to be able to conduct two-way communications as satellite is the only communications option

Field Testing D4

- D4 Oakland Bay Bridge deck and surrounding water
  - existing cell communication periodic
- D6 near Huntington Lake
  - existing no cell, no radio
  - 7500ft snow
  - run from solar power
- D7 Vincent Thomas Bridge LA Harbor deck

Field Testing D4

- D11 San Diego harbor
- D11 Pacific Ocean near Coronado
  - existing cell signals did not work, Mexico hijacked service

Field Testing D4

- Key Results
  - Quite impressive
    - On bridges
    - Water around bridges
    - San Diego Harbor
    - Los Angeles Harbor
    - Pacific Ocean
    - Central Valley
    - Sierra Nevada
    - Runs on solar power
  - Communications are stressed between bridge towers

Field Testing Data Analysis

- Round 1 testing
  - noticed a variety of issues in the logs from the TCP/SMTP communication stack
  - resulted in many failed attempts and retries
  - primarily short connection timeouts (< 10 sec)
- Made changes to various timeouts, rural communications need long timeouts (30 - 60 sec)

Field Testing Data Analysis

- Round 2 testing
  - increased timeouts
  - average send times, 0-4 attachments
    - D2 5.3 seconds, sat
    - D4 2.7 seconds, cell/sat
    - D6 2.8 seconds, cell/sat
    - D7 2.4 seconds, cell/sat
    - D9 14.3 seconds, sat
    - D10 1.5 seconds, cell
    - D11 3.0 seconds, cell

Field Testing Data Analysis

- Remaining issues
  - add recipient failures due to malformed email addresses
    - name.company.com (malformed)
    - should be handled by remote mail server, but results in failure
  - Found a single failure upon finalization of SMTP DATA command event (rare)
  - Found a single message stuck in the send queue event (> 2hrs) (rare)

Field Testing Summary

- Operational concerns
  - Time to complete transmission in challenging environments is key
  - Message retries/attempts typically require moving vehicle
- Significant feature requests
  - Disable visibility of select feeds
  - Two-way communications
- Conclusions
  - Well received, all would like a Responder system
  - Really like the automation at all levels (i.e. district, postmile, etc.)
  - Very useful in a variety of environments

Additional Observations

- Pulga Maintenance Station (VRS) D2
- Poor nearby geostationary satellite communications due to geography
- Works to the North of Belden and the South of Pulga (*Paradise, Magalia, Concow Fire*)

Problems

- Long transmission times
  - Bandwidth issues due to obstructions
  - Possible failures on multiple levels in transmission stack
  - Automated transmission retry assumptions (i.e. late vs. early failure)
- Discuss details regarding antenna interference concerns
- Discuss details from antenna lead engineer

Problems

Problems

High-Band Specifications

- K&L Microwave 4FV50-838/H64-N/N
- BPF
- Center 838.8 MHz
- 0.5 dB Bandwidth 70.4 MHz
- Insertion Loss 0.31dBa
- Stop-band Atten (1525 MHz) 113 dBc

High-Band Filter

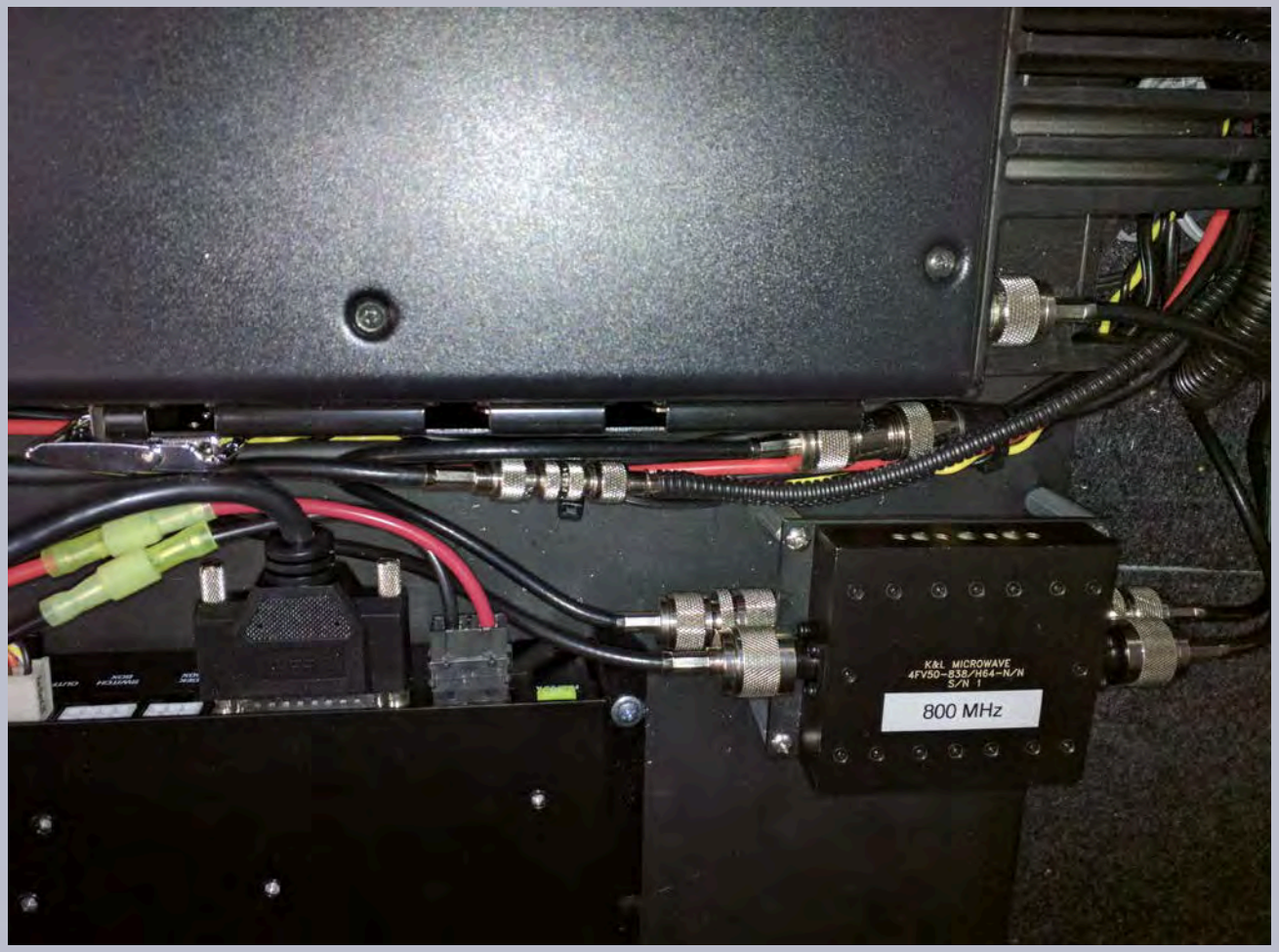
Problems

Low-Band Specifications

- Microwave Filter Company 191141-400
- 400 MHz LPF
- 100 W Max
- 50 dB rejection 1.3 Fc to 6.0 Fc

Low-Band Filter

Problems



Lessons Learned

- Mobile radio interference appears to be a non - issue
- Send email failure modes, optimize timeouts and retry intervals to match use cases
- You can never have too much application UI feedback, and backend logging
- Two-way communication is strongly desired
- Use case locations, i.e. sheer cliffs to the south, consider additional satellite system

Looking Ahead

- Detailed manufacturing hardware/software documentation
- Manufacture and deployment of 12 portable Responder systems
- Enhance software based on test feedback, and new feature requests