METEORCOMM LLC

ITCR Closed Track Test 1

Test Report

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Revision history

Revision	Date	Summary of Changes
1.0	10/12/2012	FRA document

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1. Executive summary

The first phase of closed track testing, referred to as CTT 1, of the PTC communication system entailed the installation and operation of the PTC communication system at the Transportation Technology Center (TTCI) located near Pueblo, Colorado. This facility was used to test the communication system under controlled field conditions using real locomotives and operating at speeds in excess of 100 mph.

The installation of the PTC communication system at TTCI included three base radio installations, eight wayside communication site locations, one mobile locomotive, one stationary locomotive site, a simulated local back office at TTCI, and a simulated remote back office located at the MCC facility in Renton, WA. All endpoints, which includes WIU, TMC, and back office applications were simulated.

After installation, basic functionality of the system elements was verified and pretest activities were completed. Pretesting included system configuration and debug, RF coverage measurements, basic messaging tests, and validation of basic radio network operation. Additionally, the test infrastructure was verified. This included the Test Executive SW, endpoint simulators, IP connectivity to test bed assets, and remote connections to MCC in Renton.

Basic RF measurements such as bit error rate (BER) established that there was little or no impact on RF link performance due to locomotive speeds of 80 mph and higher. Similar results were seen for message latency between the remotes and the back office. This result is due primarily to the benign RF environment surrounding the test bed, obviating the need for mitigation measures typically employed I the field.

During CTT 1 there were 108 test cases executed that directly tested system functionality. In addition there were numerous test runs to validate system operation and obtain performance benchmarks. Out of the 108 tests executed, 64 test cases passed, 24 failed, and 20 were blocked. Failures covered a variety of areas including latency, fragmentation, mobility, and QoS. Most of these failures were traced to messaging SW related defects. The blocked tests cases primarily covered latency, special handling, and mobility.

Analysis of requirements test coverage show that the test cases for CTT 1 directly cover 15.7% of the R1.0 radio requirements and 26% of the R1.0 messaging requirements. When radio requirements that are not tested but covered “by design” are included in the analysis, the R1.0 radio requirements coverage from CTT 1 goes up to 29%.

1.1 Overview

This template contains numbered section headers, a standard introduction section (section 1 and its subsections), a table of contents and footers with page numbers, and the required legal disclaimers. All text formats (section headings and subheadings, body text, table headers and contents, and lists) are pre-formatted Microsoft Styles.

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1.2 Introduction

The MCC PTC communication system contains three primary subsystems: 220 MHz PTC radios, messaging software, and systems management software. Integration testing of the communication system refers to a process under which two or more of these subsystems are combined together and tested.

There are two environments that MCC uses for integration testing. One is a lab environment containing multiple test beds and the other is a closed track environment. In closed track testing (CTT) the PTC communication system is tested in a controlled field environment with actual locomotives on a closed, non-revenue track.

For Release 1.0, closed track testing (CTT) is divided into two test phases referred to as CTT 1 and CTT 2. Each CTT phase runs approximately four weeks. Though it is tested in the lab, for Release 1.0, systems management is not included in CTT.

1.3 Purpose

This report serves as the document of record for the test activities and test results associated with the CTT 1 test phase.

1.4 Focus of closed track testing

Closed Track testing is not intended to revalidate features and functionality tested at the subsystem level. Rather, using system level test scenarios and appropriate KPIs, closed track testing is used to evaluate communication system performance in a controlled field environment.

Closed track testing focuses on the following:

- Mobility - locomotive radio hand off between base stations, base station selection
- PTC communication performance with locomotives travelling at high speeds
- General end to end message transport in a field environment

1.5 Objectives of closed track testing

The objectives for CTT 1 included

- Through a process of exploration and discovery, evaluate the PTC communication system functionality and performance
- Benchmark performance of some key performance indicators (KPIs) such as message latency
- Begin to develop an understanding of potential usability, logistical, and functional issues that may negatively impact future testing and deployment

1.6 Acronyms

Below is a list of acronyms that are commonly used in MCC test related documents. The following list contains definitions for various terms used in this document. The purpose of these tables is to improve clarity and provide a reference for the reader. The reader is encouraged to refer back to these tables as often as needed.

Acronym	Description
AAR	Association of American Railroads
BO	Back Office
CM	Connection Manager
CSMA	Carrier Sense Multiple Access
CT1	Closed Track 1
CT2	Closed Track 2
DHCP	Dynamic Host Control Protocol
DQPSK	Differential Quadrature Phase Shift Keying
DVT	Design Verification Test
ELM	External Link Manager
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
FW	Firmware
HRX	Host Radio Exchange
HW	Hardware
IP	Internet Protocol
ITC	Interoperable Train Control
ITCM	ITC Messaging System
ITCNet	PTC 220 MHz Radio Air Interface Protocol
KPI	Key Performance Indicator
Local	Generic term for base radio
MCC	MeteorComm LLC
OTA	Over the Air
PTB	Protocol Test Bed
PTC	Positive Train Control
RF	Radio Frequency
SBC	Single Board Computer
SM	System Management
SMS	System Management System

Acronym	Description
SNMP	Small Network Management Protocol
SSTB	Software Stress Test Bed
SW	Software

Term	Definition
Closed Track Testing	PTC communication system testing that takes place on non-revenue track at the TTCI test facility.
Corner Case Testing	Testing of a product or system under multiple simultaneous extreme conditions. For example, testing radio performance while operating the radio at the limits of specified operating conditions such as ambient temperature and supply voltage.
Customer	Refers to a railroad.
Direct Validation	Direct validation of a PTC communication system requirement is achieved when the expected result of test case execution ties to a specific ITC requirement.
Endpoint	Endpoints include WIUs, TMC, and back office applications
End to End Testing	Tests that encompass the delivery of messages between specified endpoints
Indirect Validation	Indirect validation of a PTC communication system requirement is achieved when the nature of a test is such that multiple elements of the system must be functioning properly to achieve a positive outcome.
Functional Testing	Testing to determine whether or not a specific product feature is operational or not. Functional tests are typically pass/fail.
Integration Test Strategy	A top level description of MCC's overall approach to integration testing.
Kit	Specific set of configuration data and/or software files that can be downloaded to assets within the PTC communication system.
Performance Testing	Testing to determine how well some aspect of a product or system behaves under a particular workload as compared to a defined set of metrics. Performance metrics are quantitative in nature. Some examples of performance metrics that apply during integration testing are message latency and throughput.
PTC Communication System	Includes PTC 220 MHz radios, Wi-Fi and cellular alternate messaging paths, messaging software, and system management software
Railroad	Refers to a Class I Railroad entity.
Remote	Generic term for locomotive and wayside radios
Scenario	A defined setup of product or system usage that approximates actual operation of the product in the field. Scenarios can be used to develop test cases. Typically multiple test cases are derived from each scenario.

Term	Definition
Segment	A subsystem of the PTC system. The subsystems pertinent to integration testing are Locomotive Office Wayside
Subsystem	With reference to MCC's development of the PTC communication system, in the context of integration testing, there are three subsystems: Messaging software System management software 220 MHz PTC radios
Test Bed	Refers to the specific hardware and software needed to test a product or system.
Test Case	Describes a specific test to be performed within a specified test environment and using a specific test configuration. The expected results of an executed test case support the validation of one or more requirements. The mapping of test cases to requirements can be one-to-one or one-to-many.
Test Configuration	Specific arrangement of test bed resources to facilitate execution of a specific test suite.
Test Cycle	A set of test suites grouped together for execution.
Test Environment	Generic term that refers to the nature of a test facility. Typically, a test environment includes one or more test beds. Environmental variables can include physical as well as operational parameters.
Test Procedure	Detailed description of how to execute a specific test case.
Test Scripts	A set of commands or SW elements that facilitate the execution of test cases.
Test Suite	A group of test cases executed to accomplish specific technical or business goals.
Use Case	A formalized scenario that identifies actors, stimulus, and responses within a system. A use case is made up of a set of possible sequences of interactions between systems and users in a particular environment and related to a particular goal.
Validation	A test process whereby specific product features, functionality, or performance levels are verified.
Witness Testing	Witness Testing (WT) is a designated portion of Closed Track Testing 2 (CTT2) when ITC members are invited to observe testing operations at TTCI. The Demonstration Days portion of WT includes 1-1.5 days. Test cases conducted during WT are selected by MCC to reflect ITC member input, but without disrupting the progress of CTT2. WT is not an acceptance test.
Work Stream	A development program within MCC's PTC communication system development project. There are four separate work streams as follows: 220 MHz PTC radio development Messaging SW development System management SW development PTC communication system integration

1.7 References

[1] Communication System Integration Test Strategy, MCC doc. TSP-PTC-00001093-A, October 27, 2010.

[2] ITC Scope and Requirements, MCC doc. REQ-PTC-00001007-C-1, December, 2010.

[3] ITC Messaging Requirements, MCC doc. REQ-PTC-00001041-B, August, 2010.

[4] Integrated Lab Test Plan, MCC doc. TSP-PTC-00001112-B, December 23, 2010.

[5] PTC Test Bed Overview, WCC presentation, March, 23, 2010.

[6] Closed Track Test Plan, MCC doc. TSP-PTC-00001163-B, March 2, 2011.

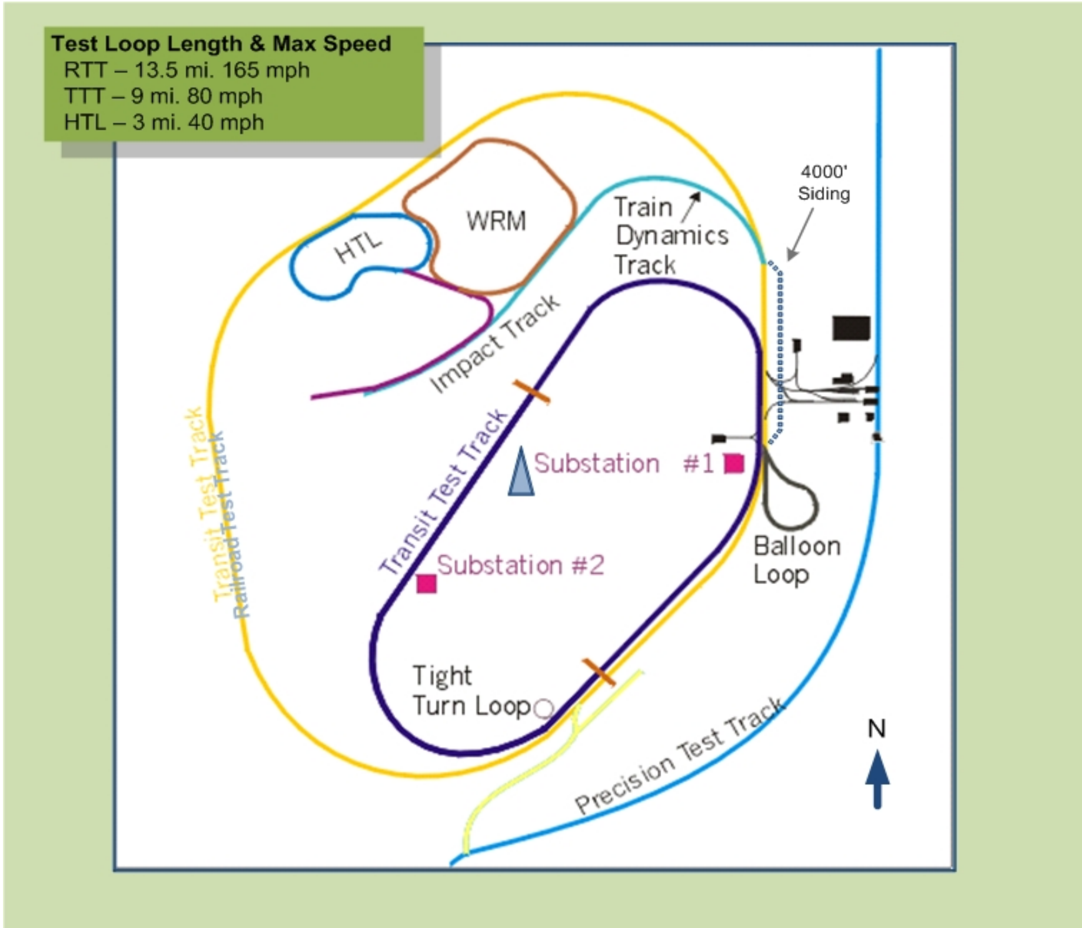
2. Closed track testing overview

CTT 1 entailed the installation, operation, and test of the PTC communication system at the Transportation Technology Center (TTCI) located near Pueblo, Colorado. The system included a complete PTC radio network, alternate messaging paths (cell and Wi-Fi) for all remotes, BO and remote messaging servers, and a test control system. All endpoints, which includes WIU, TMC, and back office applications were simulated.

2.1 Track test

TTCI has multiple tracks available for testing. An overview diagram of the TTCI test tracks [5] is shown in Figure 1.The test track used for CTT 1 is referred to as the Railroad Test Track (RTT). This is a 13.5 mile loop that can support locomotive speeds in excess of 110 mph.

Figure 1: TTCI test track diagram



2.2 RF environment

The RF propagation environment at the TTCI facility can be described as benign. The local topology is relatively flat, with the maximum elevation difference around the RTT being less than 170 feet. In the immediate vicinity of the RTT there is little vegetation and few trees. Much of the RTT is on a raised bed. All remotes used in the tests had line of sight to one or more of the base station antennas and there is minimal clutter.

2.3 Closed track test bed

This section provides an overview of the PTC communication system test bed configuration at TTCI.

2.3.1 CTT test bed component summary

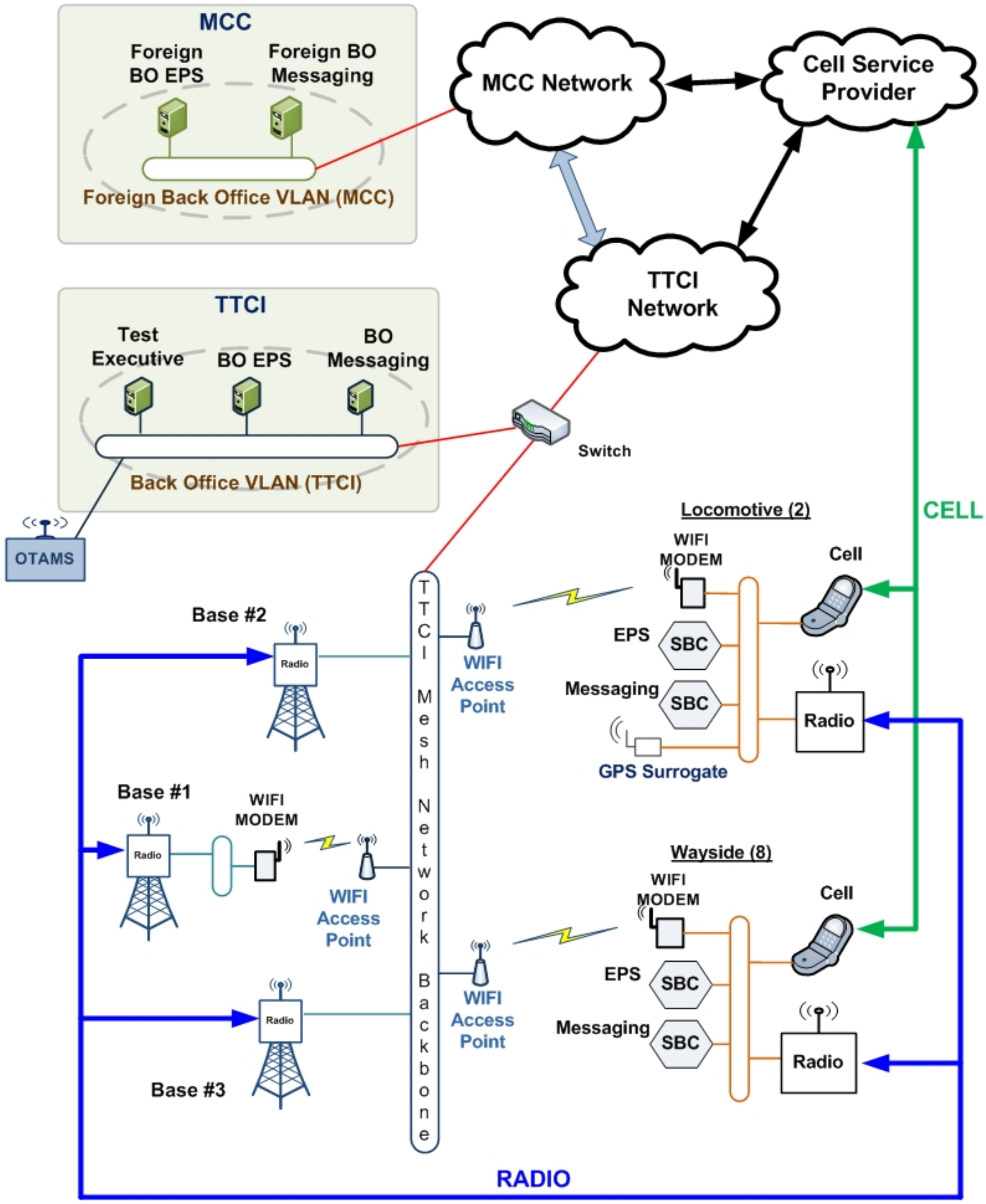
The test bed consisted of the following:

- 7 Wayside PTC communication sites
- 1 stationary locomotive PTC communication setup housed in a wayside bungalow
- 1 mobile locomotive equipped with a locomotive PTC communication setup
- 3 PTC base station radios sites
- Alternate messaging paths (cell and Wi-Fi) for all remotes
- Local BO server at TTCI to host BO messaging (ITCM) components and simulated BO applications
- Single board computers (SBCs) that host remote ITCM SW at waysides and on the locomotive (i.e. remote messaging servers)
- Simulated endpoints(EPSs)
  - WIU EPS – runs on an SBC that is collocated with the wayside messaging server
  - TMC EPS – runs on an SBC that is collocated with the locomotive messaging server
  - BO applications EPS – runs on a BO server
- IP connectivity to all test bed assets
- Test control system (Test Executive and EPSs)
- Over the air monitoring station (OTAMS) for monitoring the radio air interface (ITCnet)

2.3.2 CTT test bed interconnections

A diagram of the IP connections between test bed assets as well as the messaging transport paths is shown in Figure 2. Along with a 220 MHz PTC radio, each remote site had a cell modem and Wi-Fi modem that operated as alternate messaging transports. Additionally, the same Wi-Fi modem provided IP connectivity between each remote and the test control server.

Figure 2: CTT 1 PTC communication test bed connection diagram



2.4 Test bed communication sites

This section briefly describes the test bed communication sites (wayside and locomotive). Detailed connection diagrams, along with a bill of materials for each installation, are provided in 7.

2.4.1 Wayside PTC communication site

Each wayside PTC communication setup is housed in a weatherproof enclosure. Each site has 120VAC power and is adjacent to a pole suitable for antenna amounting. These enclosures are not climate controlled. The setup at each site includes

- DC power supply (powered by 120VAC)
- Wayside 220 MHz PTC radio
- Cell modem
- Wi-Fi modem
- Antennas for radios, cell modems, Wi-Fi, and GPS
- Ethernet switch
- SBC to host the remote ITCM components
- SBC to host the WIU simulator

The 220 MHz wayside radio antennas are pole mounted. The cell, Wi-Fi, and GPS antennas are attached to the outside of the enclosure on the top.

2.4.2 Locomotive PTC communication system setup

The locomotive PTC communication installation includes

- Locomotive 220 MHz PTC radio
- Cell modem
- Wi-Fi modem
- Roof-mounted antennas for radios, cell, Wi-Fi, and GPS. For the radio, a single antenna was used for both transmit and receive
- Ethernet switch
- SBC - hosts remote ITCM and SMS agent
- GPS information packet generator. This provides the GPS information that will come from the TMC in a live field application.

In addition to the PTC communication system equipped mobile locomotive, one locomotive communication setup was installed at one of the wayside enclosures. This provided an additional, but stationary "locomotive" to be used during testing.

2.4.3 PTC base station site

Each 220 MHz PTC base station site consists of the following

- 220 MHz PTC base radio
- DC power supply (powered by 120VAC)
- Tower mounted 220 MHz VHF antenna used for both transmit and receive
- Antenna for GPS
- Backhaul IP connection to the local BO ITCM server. Depending on the tower location, this was either a direct connection or via Wi-Fi.

2.4.4 Over the air monitoring station

The over the air (OTA) monitoring station is used to monitor the PTC radio air link protocol known as ITCnet. The heart of the monitoring system is a Radio Platform Unit (RPU) connected to an antenna. The RPU consists of the same receiver signal processing circuitry as in the base and locomotive PTC radios. Additionally, numerous test points are supplied to a connector in the housing. This system allows the slot timing of up to eight RF signals to be observed simultaneously.

2.5 Software loads tested during CTT 1

There two SW entities of interest when looking at test results for CTT 1. These are the radio SW load and the messaging system SW load. Table 1 below summarizes the radio and messaging SW loads tested during CTT 1. The date indicates the last day of the week that the SW was introduced into the test bed. Also noted in Table 1 is the Test Executive SW used for testing.

Table 1: Radio and messaging software loads tested during CTT 1

CTT 1 Week	Date	Radio SW Load	Messaging	Test Executive
Week 1	8/5/2011	18.09	1.0.3.2	0.37.4
Week 2	8/12/2011	18.10	1.0.3.2	0.37.4
Week 3	8/19/2011	18.10	1.0.3.3	0.37.4
Week 4	8/26/2011	18.10	1.0.3.3	0.37.11

2.6 RTT system installation

Figure 3 shows the installation locations of the base station, wayside, and stationary locomotive communication sites around the RTT. There are three antenna towers that were used for base station antenna installations. These are identified as BASE 1, BASE 2, and BASE 3. The wayside locations are identified as WAY 1, WAY 2, etc. and the stationary locomotive site is identified as LOCO 3. Along with antenna and transmit power information, the corresponding TTCI nomenclature for each of these installations is listed in Table 2.

Figure 3: TTCI site plan showing CTT 1 test bed asset installation locations

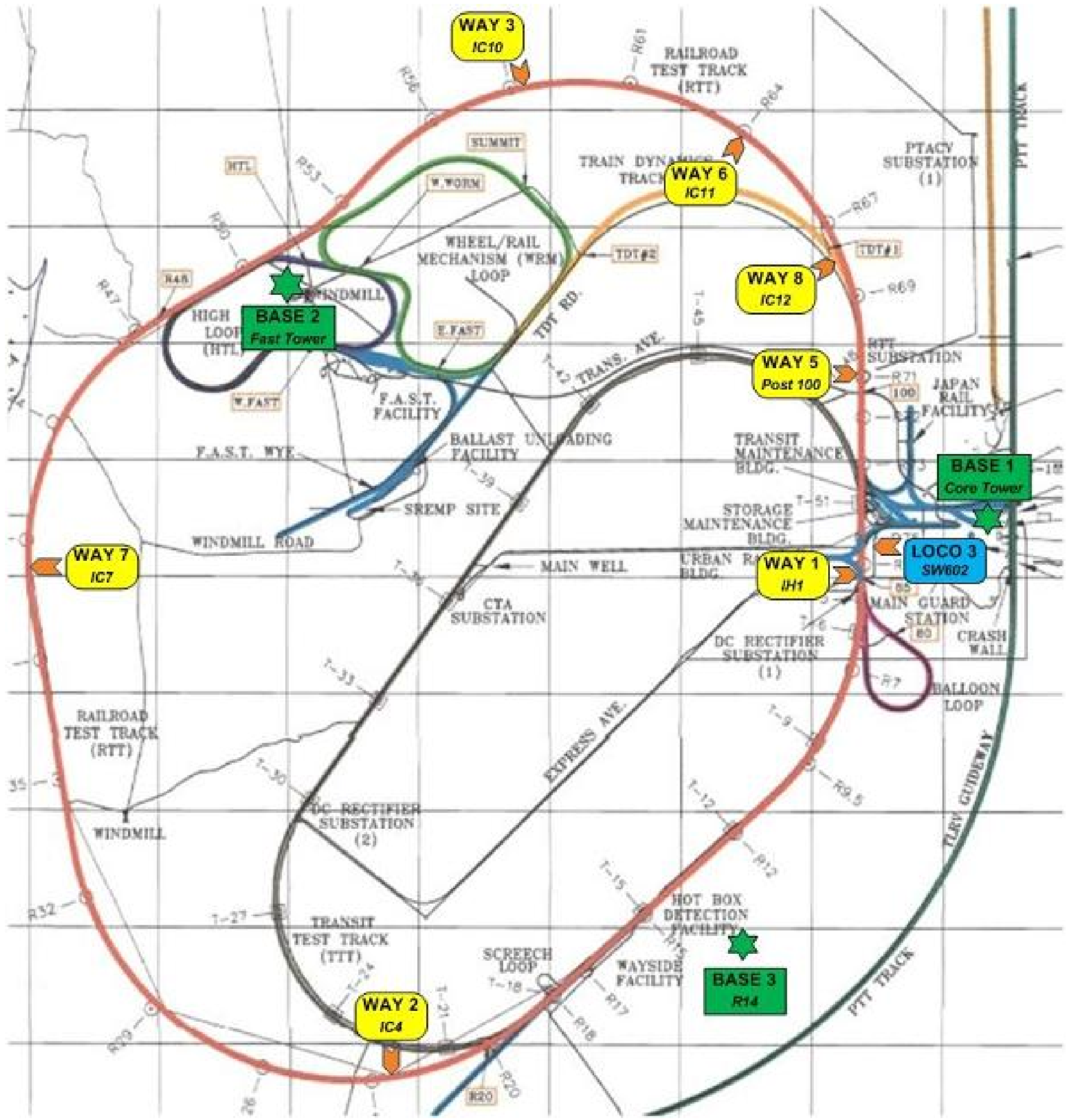


Table 2: TTCI site designators and corresponding transmit site information

Installation Type	TTCI Designator	Avg TX Power (watts)	Radio to Antenna Loss[1] (dB)	Antenna Gain (dBi)	Antenna Height (ft)	EIRP (watts)
BASE 1	Core Tower	37.5	11.9	7.00	60	12.1
BASE 2	Fast Tower	37.5	12.1	7.00	80	11.6
BASE 3	R14 (Tall) Tower	37.5	11.6	7.00	60	13.0
LOCO 1	'203' GP40 Locomotive	25.0	1.35	2.15	21	30.0
LOCO 3	SW602	25.0	11.1	2.15	12	3.20
WAY 1	IH1 (R4)	15.0	10.9	7.00	30	6.10
WAY 2	IC4 (R23)	15.0	1.69	7.00	30	50.9
WAY 3	IC10 (R58)	15.0	1.68	7.00	30	51.1
WAY 5	POST100	15.0	1.12	7.00	12	58.1
WAY 6	IC11 (R64)	15.0	1.38	7.00	30	54.7
WAY 7	IC7 (R40)	15.0	2.03	7.00	30	47.1
WAY 8	IC12 (R70)	15.0	1.12	7.00	16	58.1
OTAMS	WLF Radio Lab	n/a	5.49	7.00	37	n/a

[1]Includes losses from cables, couplers, and external attenuation

2.7 Summary of test case categories

A summary of the types of testing performed during CTT 1 is given in Table 3. The test areas in Table 3 are further broken out in Section 5 where pass/fail results are summarized. A list of CTT 1 test cases is provided in Appendix C.

Table 3: Summary of closed track testing areas

Test Area	**Description/Conditions**
Radio Network	Basic RF link validation RF link performance as a function of locomotive speed (BER) Base station RF coverage along the test track Wayside signal level as a function of locomotive position
Confidence Tests	Basic validation tests of system operation
Inbound and Outbound Messaging	Message latency under a variety of scenarios QoS (message priority tests) Fragmentation Special handling Rerouting
WIUStatus	Status request and response Beacon On and GetWIUStatus
Mobility	Base selection process Message delivery during locomotive radio handoffs
SW Upgrades	Remote upgraded of remote message server SW Remote upgrade of PTC radio SW
System Level KPIs	Latency Radio transport bandwidth

3. CTT 1 test results – RF system measurements

Prior to the start of CTT 1, as part of the system checkout, measurements of RF signal levels and bit error rates (BER) for a locomotive moving around the RTT were made. At the time of these measurements, along with LOCO 1 and LOCO 3, two base stations and five wayside radios were operational in the test bed.

3.1 RF measurement methodology

Measurements were made of signal level (RSSI) and BER for RF links between the radio in a moving locomotive and the stationary radio sites around the RTT. The mobile locomotive radio was the transmit signal source for all of these measurements. The PTC radios at the stationary site locations were operating in multichannel receive mode.

At the time the measurements were made the PTC 220 radio SW did not support RSSI or BER measurement. As such, a special developmental SW load was used to collect the RF data. The SW allowed the transmitting radio to output a pseudo-random sequence of bits, referred to as a PN9 sequence. This is a known bit pattern that the receiving radio attempts to synchronize with and decode.

3.2 RF measurement signal setup

The operational parameters for the RF measurements are listed in Table 4.

Table 4: RF measurement parameters

Parameter	Value
Modulation	Half Rate DQPSK
PN Sequence Packet Length	512 bits
Transmit Rate	quasi-continuous, 4 sec TX signal off time every 32.5 seconds
RX Sample Rate	1 RSSI sample every 2 sec

Baseline measurements of RF signal levels were made at each stationary radio site. LOCO 1 was the transmitter, traveling at various speeds around the RTT. The base radio designated as BASE 1 was configured as shown in Table 5.

Table 5: BASE 1 receiver configuration

RX Channel	RX Frequency	Notes
1	220.0000 MHz	Noise floor monitor
2	220.4125 MHz	LOCO 1 TX frequency
3	220.4125 MHz	Redundant LOCO 1 TX frequency
4	220.4375 MHz	Noise floor monitor
5	220.4375 MHz	Redundant noise measurement
6	221.0000 MHz	Noise floor monitor
7	220.7625 MHz	Noise floor monitor
8	220.7625 MHz	Redundant noise measurement
9	222.0000 MHz	Unknown Interferer

Things to note about the configuration of the RX channels on BASE 1:

- The signal of interest is the LOCO 1 TX frequency on channel 2
- Some channels (1, 4-8) were set to other frequencies for monitoring the noise floor
- Redundant RX channels were used to provide a cross check of measurement accuracy
- Though the operational design for the base radio provides for 8 RX channels, the special PN9 SW load, designed for RF testing, provided 9 RX channels.

3.3 Baseline RF measurements

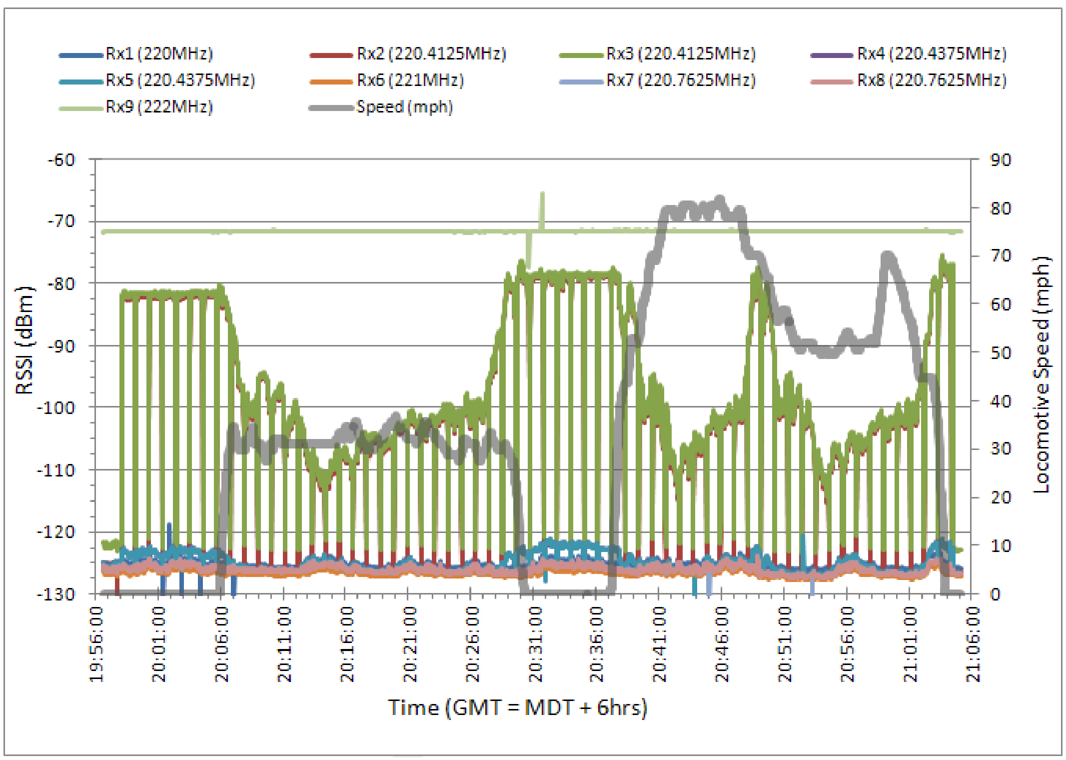
Figure 4 shows typical RF signal level results as seen at BASE 1. The signal levels are plotted as a function of time and overlaid with the locomotive speed.

RX2 and RX 3, which were set to the transmit frequency of LOCO 1, provided essentially identical results. The periodic signal dropouts seen on RX2 and RX3 are a result of the TX off time mentioned earlier. The speed of LOCO 1 is also included on the graph. As expected, when the locomotive speed drops to 0 mph the signal levels remain constant.

RX9 was tuned to 222 MHz to monitor an interferer discovered during an initial RF spectral sweep. The source of this interferer was never identified, but appeared to be coming from outside of the TTCI facility.

As indicated in Table 5, noise floor measurements of BASE 1 were made using RX1 and RX4 through RX8. With the exception of RX4 and RX5, the noise floor measurements are almost identical. RX4 and RX5 are set to an adjacent channel of RX3, the signal of interest, and present a noticeable rise in signal level, with corresponding higher levels of the signal of interest. This is discussed in more detail in the next section.

Figure 4: RF signal level at BASE 1 from a locomotive radio. Locomotive speed varied between 0 and 80 mph



3.4 Adjacent channel performance

Adjacent channel performance of the base, locomotive, and wayside radios used for CTT 1 can be estimated using the RSSI data captured during pre-testing. Figure 5, Figure 6, and Figure 7 below present

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received signal levels obtained while the locomotive was stationary. The signal level difference between the signal of interest and the signal level of an adjacent channel are indicated in each figure. These are summarized in Table 6.

Table 6: F2 radios at CTT 1 - Adjacent channel signal level comparison

Radio	RX Frequency	Adjacent Channel	RSSI Delta (dB)
Base	220.4125 MHz	220.4375 MHz	44
Locomotive	220.4125 MHz	220.4375 MHz	47
Wayside	220.4125 MHz	220.4375 MHz	48

Figure 5: BASE 1 adjacent channel signal level

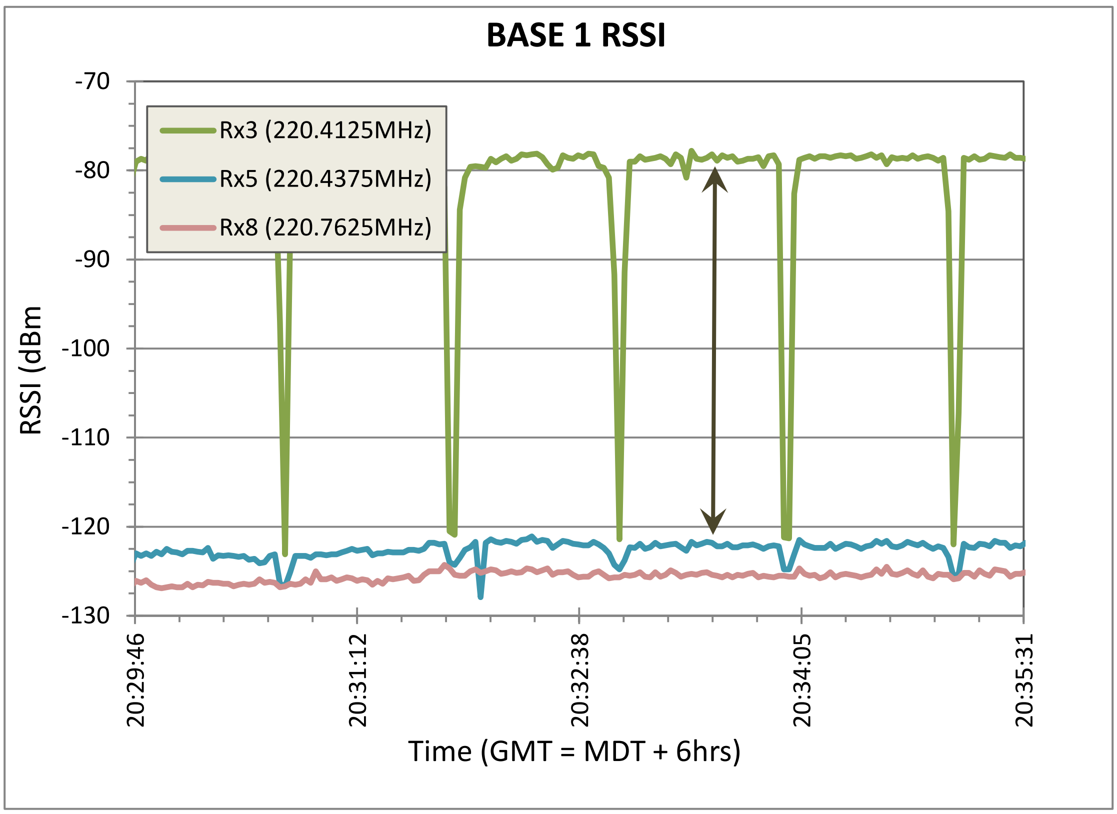


Figure 6: LOCO 3 adjacent channel signal level

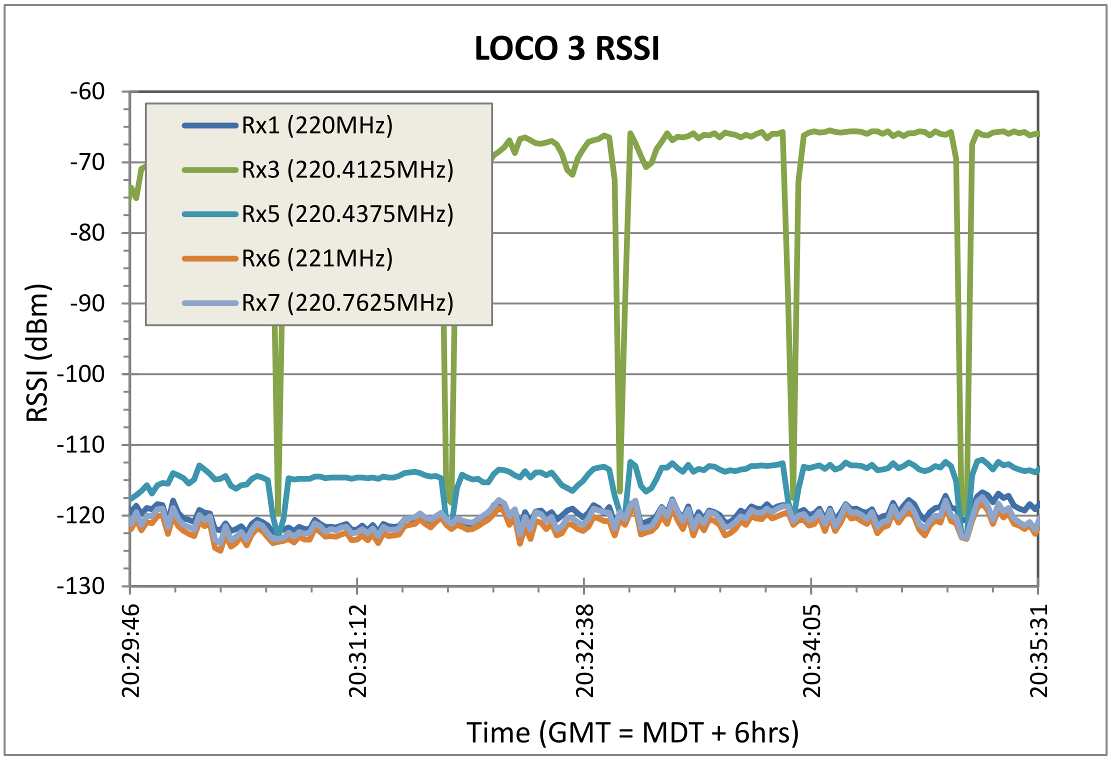
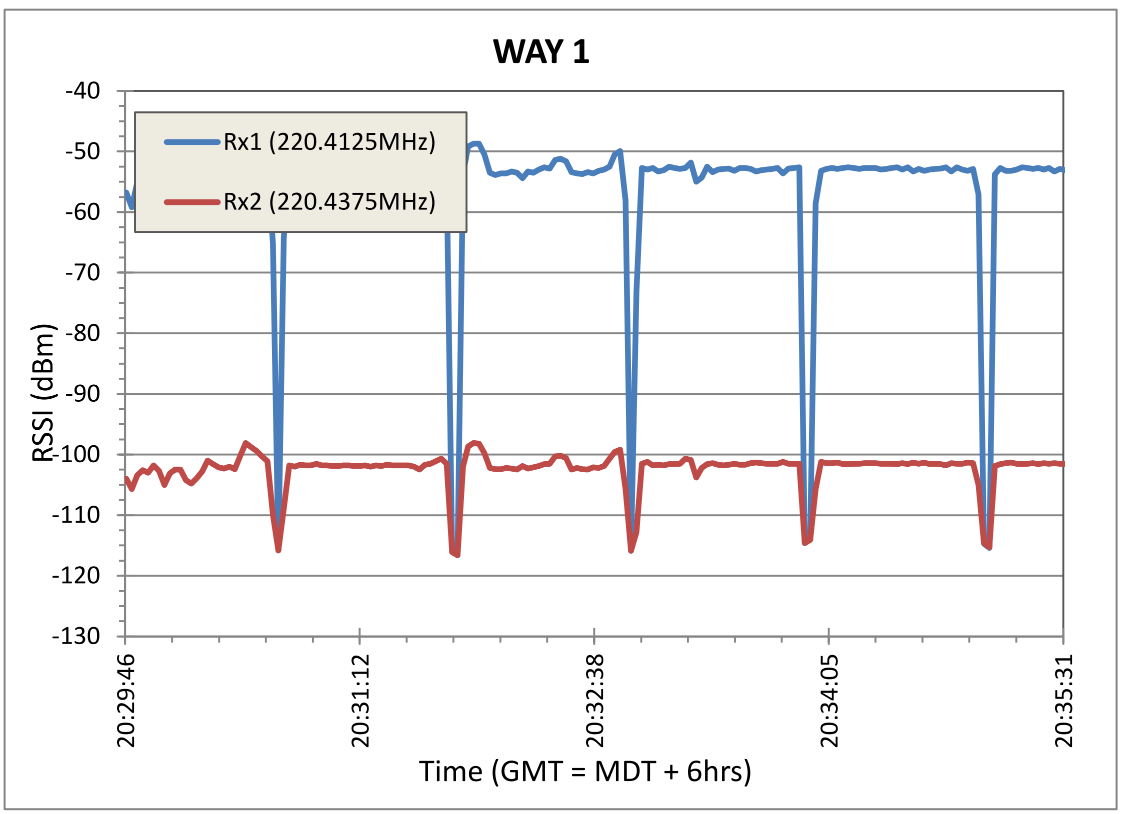


Figure 7: WAY 1 adjacent channel signal level

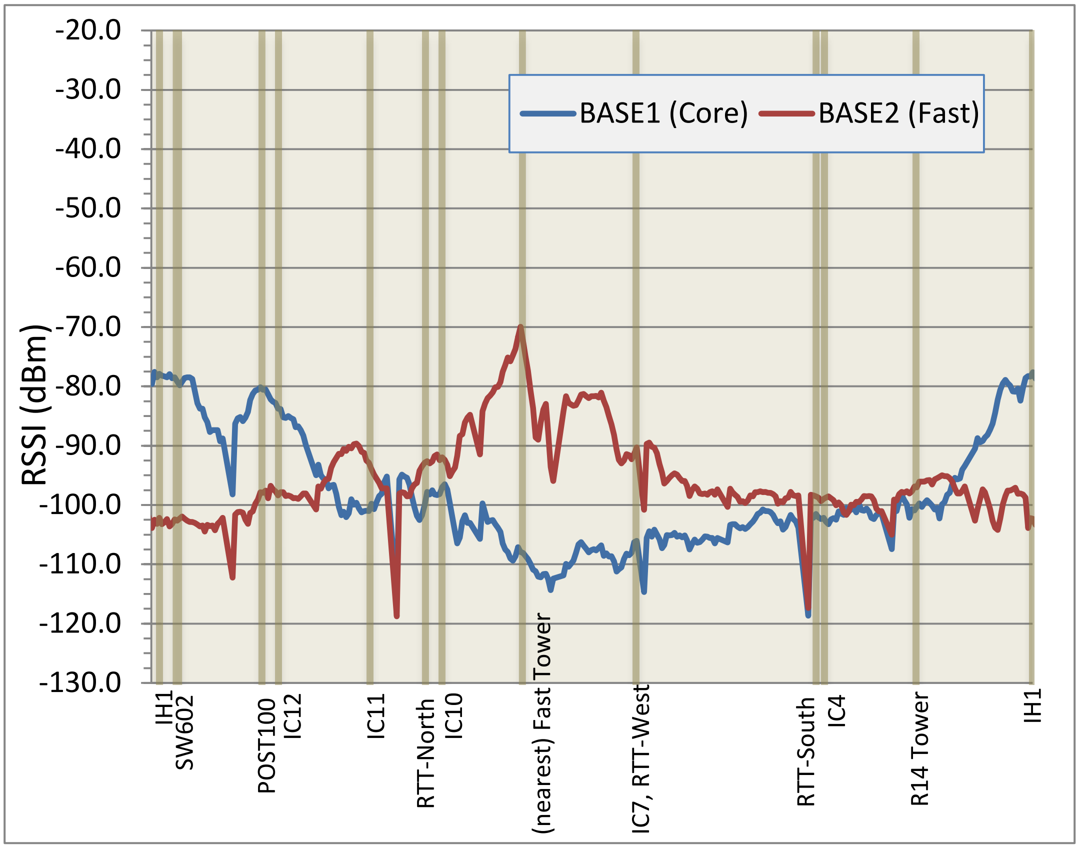


The results presented here are indicative of the adjacent channel performance that can be expected using F2 radios with developmental radio SW. However, these results are not representative of the expected operational performance of the radios. The primary reasons for this are 1) the next iteration of the radios (F3) uses a higher performance oscillator, significantly decreasing adjacent channel cross talk and 2) the SW and FW used during CTT 1 was not optimized for RF performance.

3.5 Base radio RF coverage

The RF coverage from BASE 1 and BASE 2 around the RTT is shown in Figure 8. As noted earlier, all RF measurements were made using a single transmit source – the locomotive radio on LOCO 1. Since the RF propagation paths between the locomotive and base station antennas are assumed to be reciprocal, this data also represents the relative RF coverage provided by BASE 1 and BASE 2 to a locomotive on the RTT. As the locomotive moves around the RTT, the signal level from each base increases and decreases accordingly. The occasional signal dropouts are an artifact of the receive signal level sampling process.

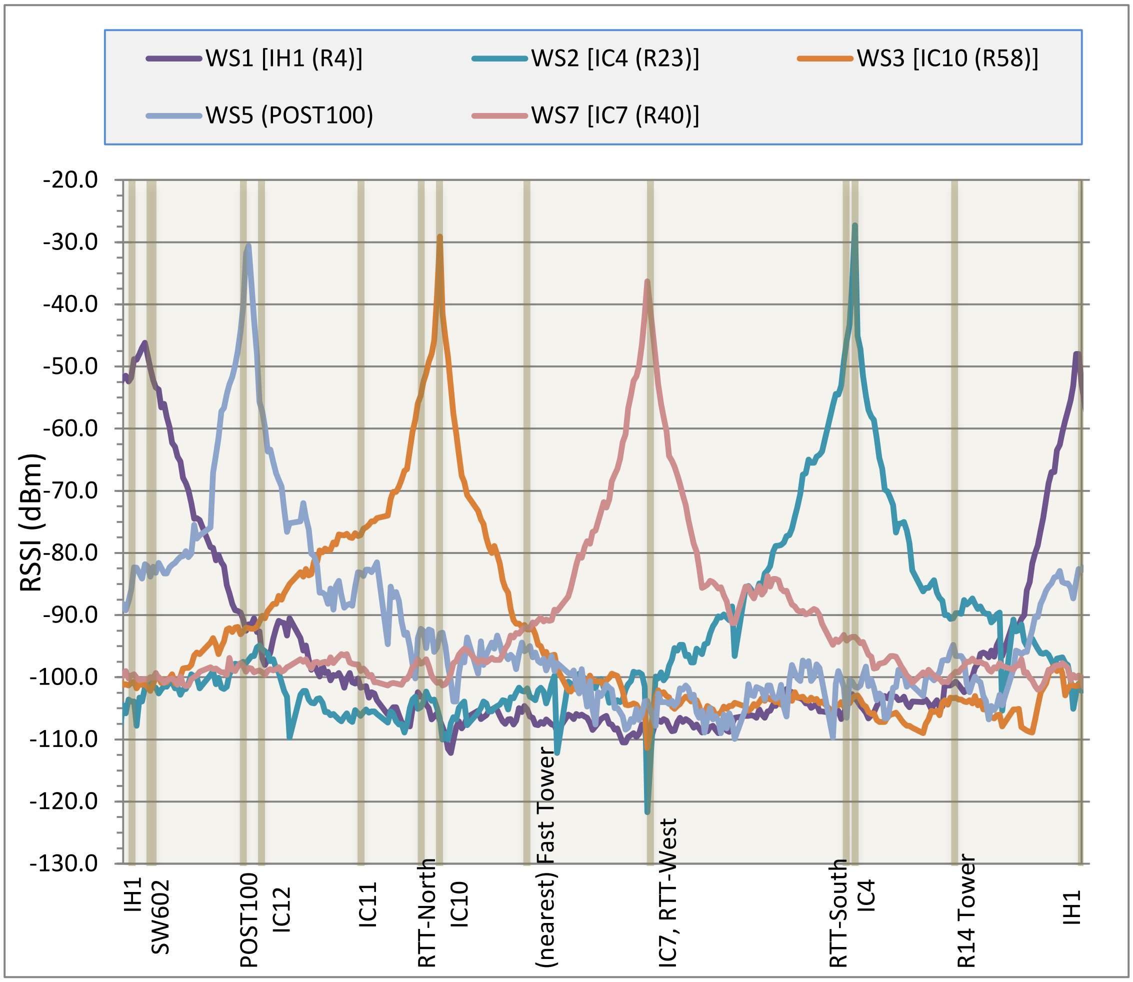
Figure 8: RF coverage for BASE 1 and BASE 2 as a function of locomotive position on the RTT



3.6 Wayside radio RF coverage

Similar to the RF coverage measurement for BASE 1 and BASE 2, RF signal level measurements for the wayside radios are presented in Figure 9. This data indicates that as the locomotive moves around the RTT, the locomotive radio will see about a 75 dB signal level change for each wayside transmitter.

Figure 9: RF signal level at wayside radios as a function of locomotive position on the RTT



3.7 Bit error rate measurements

Along with signal level measurements, bit error rate (BER) measurements were also performed. One purpose of the BER measurements was to evaluate RF link performance under mobile conditions with the locomotive traveling at speeds in excess of 80 mph. BER measurements were made simultaneously with the RSSI measurements using the same developmental radio SW load with LOCO 1 operating as the transmit source.

3.7.1 Base radio BER vs. signal level

Figure 10 shows the BER observed at BASE 1 while LOCO 1 was in motion around the RTT. The results indicate a BER curve that is consistent with the expected sensitivity level of the base radio. The metric that has been adopted by MCC is a BER of 10^{-4}. As can be seen, due to the measurement variability inherent in open air RF performance measurements, it is not possible to determine at what RSSI level this BER occurs.

3.7.2 Base radio BER vs. locomotive speed

Figure 11 shows the same data as seen in Figure 10 except that the data has been binned and color coded according to locomotive speed. This data represents locomotive speeds between 0 and 84 mph. The measurements indicate no discernable difference in BER performance as a function of locomotive speed. This was an unexpected result as the radios were operating without the benefit of forward error correction (FEC). The likely reason for this result is two-fold. First, as noted earlier in this report, the RF environment at TTCI for 220 MHz is benign. Second, though all the radios were padded down to reduce transmit power, there was still a significant signal level around the RTT. As such, there was minimal need for fade margin.

Figure 10: BER vs. signal level at BASE 1

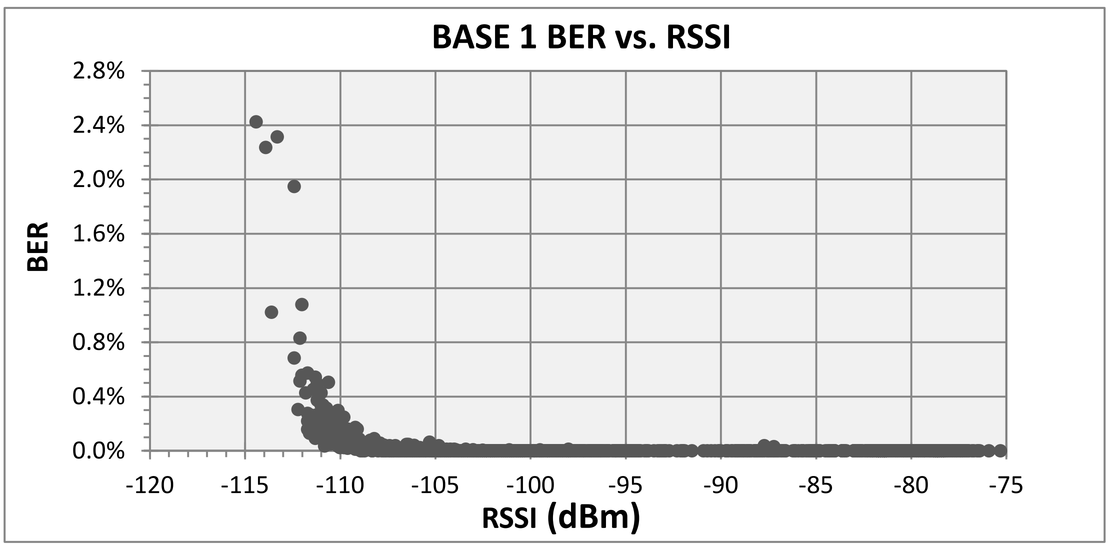
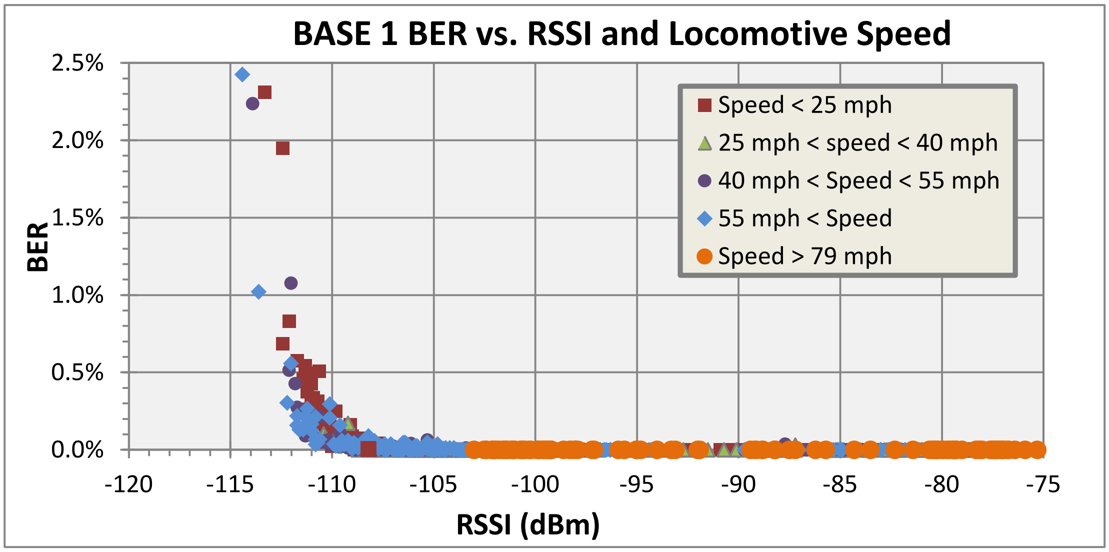


Figure 11: BER vs. signal level and locomotive speed at BASE 1



3.7.3 Remote radio BER

The data presented in Figure 11 and Figure 12 indicates similar results for BER measurements at LOCO 3 and WAY 2 as for BASE 1.

Figure 12: BER vs. signal level and locomotive speed at LOCO 3

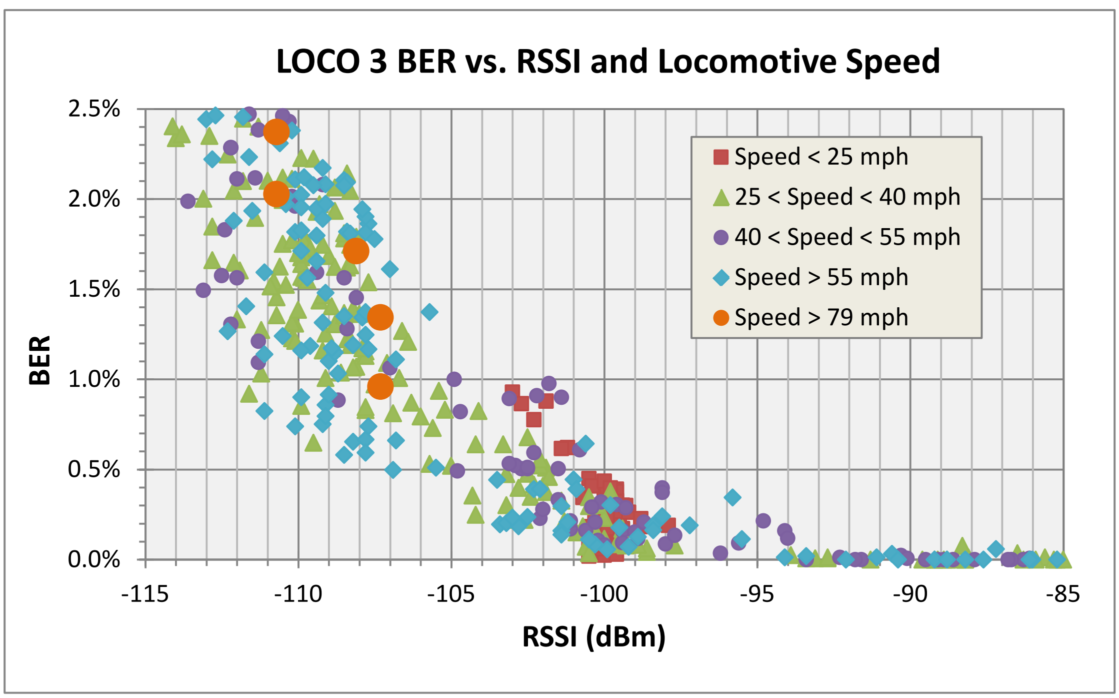
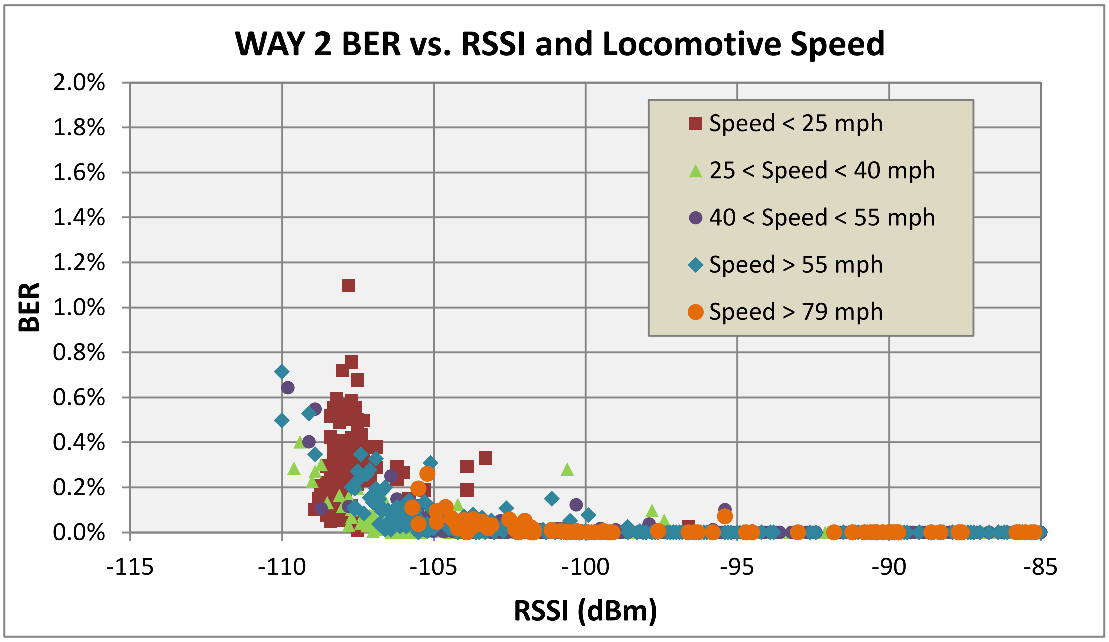


Figure 13: BER vs. signal level and locomotive speed at WAY 2



4. End to end system tests

The bulk of testing during CTT 1 involved testing message delivery between various endpoints in the system. In this context endpoints are either a WIU, TMC, or BO application. For CTT 1 all endpoints were simulated. Also, for the discussion of messaging tests in this document, the terms wayside and locomotive are used interchangeably with WIU and TMC, respectively.

4.1 Message paths

The available messaging paths are listed in Table 7 along with the corresponding shorthand notation that is used in this document.

Table 7: End to end testing messaging paths

Source	Destination	Shorthand
Locomotive	Wayside	L -> W
Locomotive	Back Office	L -> BO
Wayside	Locomotive	W -> L
Wayside	Back Office	W -> BO

Source	Destination	Shorthand
Back Office	Wayside	BO - > W
Back Office	Locomotive	BO - > L

Additionally, for some of the tests, bidirectional message flow is defined. For example, if the test case calls for messages to simultaneously be sent from the BO to a locomotive and from the locomotive to the BO, the message path is designated as BO <-> L.

4.2 Message transports

Messaging transports of cell, Wi-Fi, and radio were available to all remotes in the test bed as well as the BO. Depending upon the nature of any particular test case, one or more of these three transports could be used.

Diagrams of the CTT 1 test setup indicating the messaging paths over each transport are provided in Appendix B.

4.3 Latency measurements

4.3.1 BO <-> Remotes latency benchmarks

To establish a baseline, measurements of message latency over radio between the BO and remotes were made with the locomotive stationary. The message size was 64 bytes and the message rate was 1 Msg/s. The results are presented in Figure 14 and the average latency for each message path is summarized in Table 8.

Figure 14: Baseline message latency between remotes and back office over radio

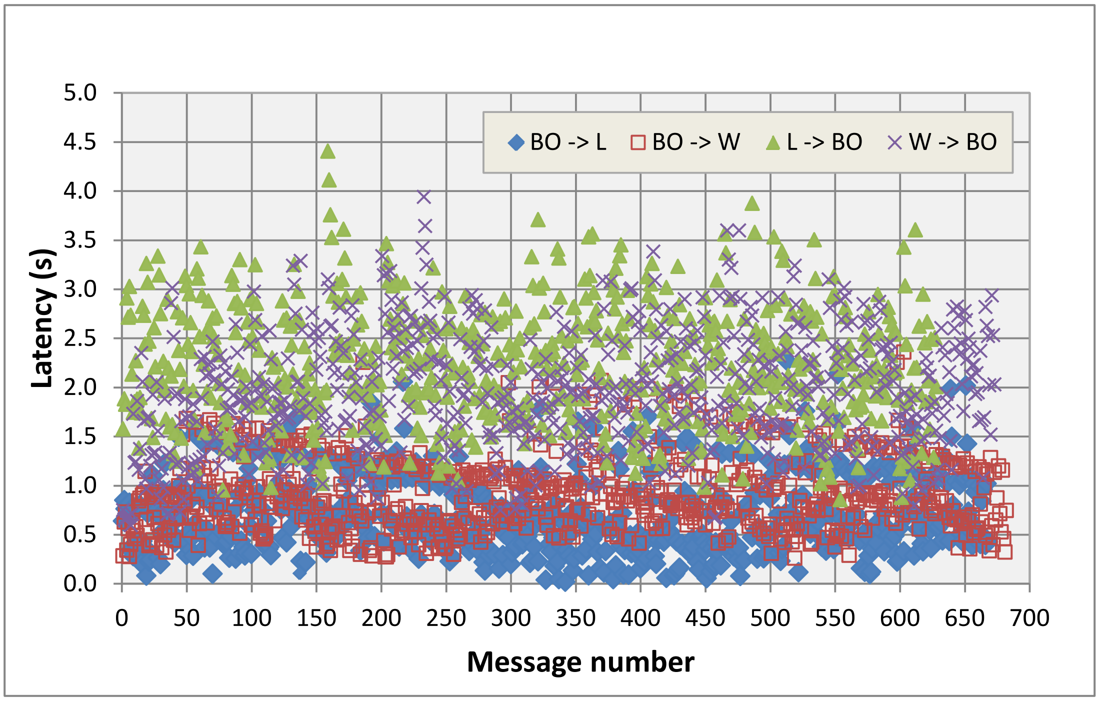


Table 8: Average message latency for messages between remotes and the back office

Path	Average Latency (sec)
BO->L	0.72
BO->W	0.92
L->BO	2.22
W->BO	1.96

4.3.2 Latency vs. message size

Message latency between the back office and the locomotive over radio for various message sizes is shown in Figure 15 and Figure 16. As can be seen, there is no appreciable difference in message latency until the message size gets large, which for these measurements is 512 bytes. Though not fully understood, the increased latency with larger message sizes is due in part to data throughput limitations of the radio SW under test.

Figure 15: Baseline message latency between back office and locomotive over radio

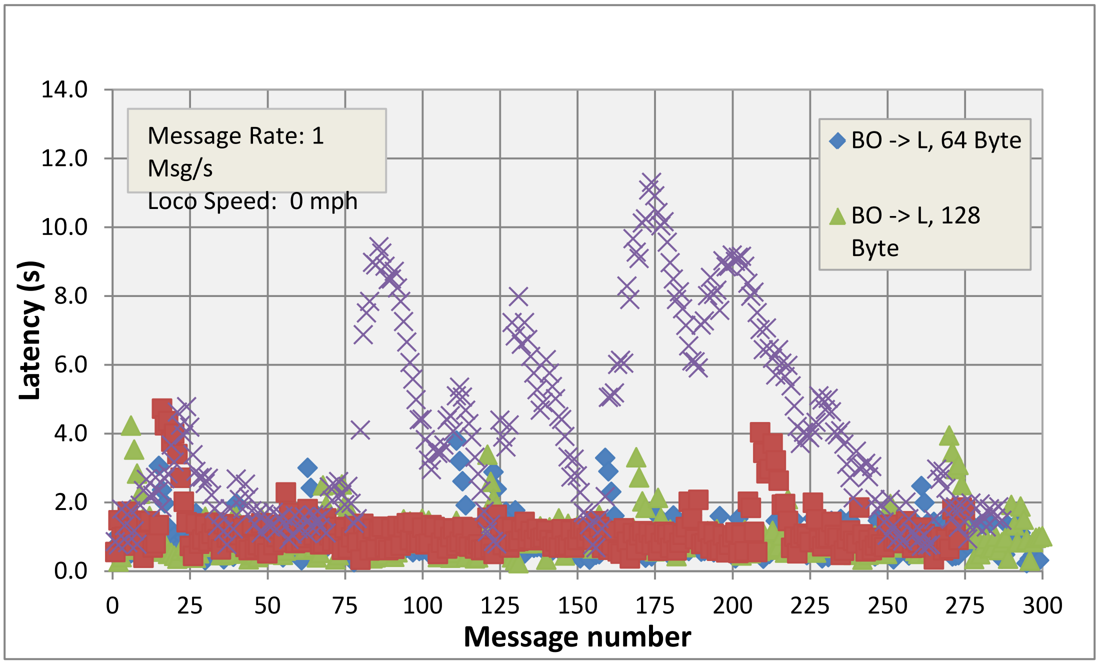
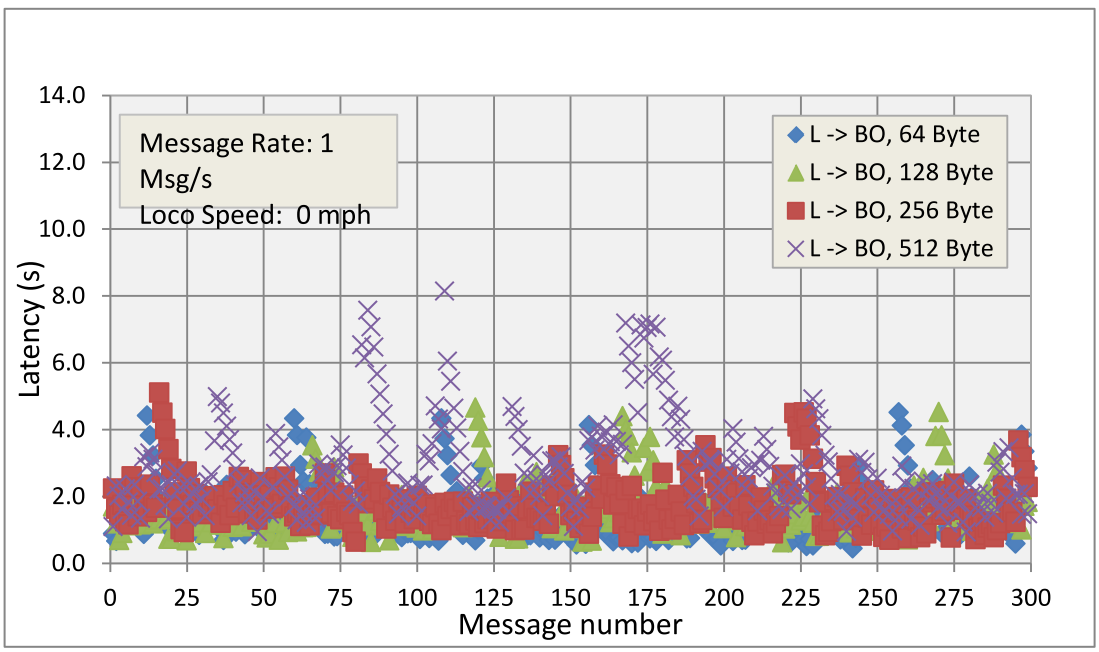


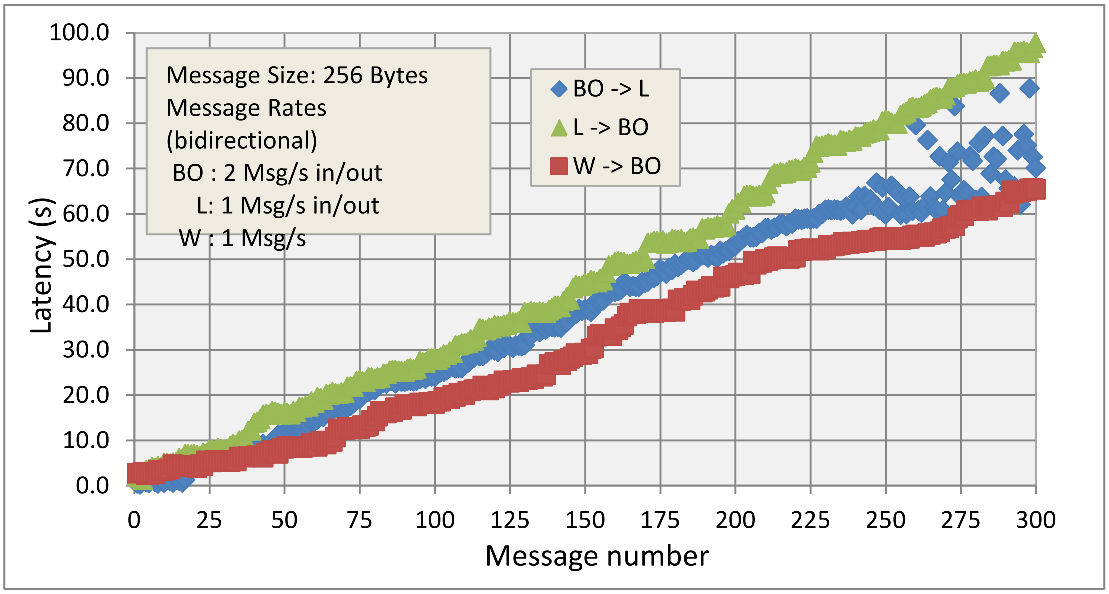
Figure 16: Baseline message latency between locomotive and back office over radio



4.3.3 Message latency over radio with bottleneck

When the data rate or message rate exceeds the capability of the radio the message latency increases with each succeeding message. A typical example is shown in Figure 17. This behavior is due to the radio not being able to empty transmit or receive queues fast enough.

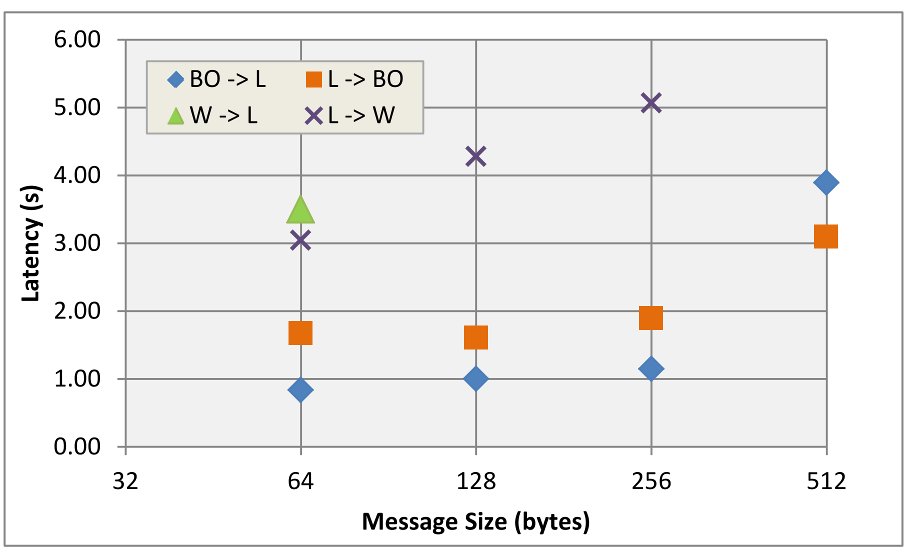
Figure 17: Excessive message latency over radio



4.3.4 Comparison of message latency over cell and radio

Figure 18 presents of summary of typical average latency for various messages sizes over radio. For message sizes larger than 256 bytes there is a noticeable increase in latency.

Figure 18: Average message latency over radio vs. message size. Message rate is 1 Msg/s



Typical values of average message latency over cell are shown in Table 9. Latency over radio for 1024 byte messages, highlighted in yellow, is included for comparison.

Table 9: Average message latency over cell. Latency over radio is highlighted for comparison

Message Size	BO -> L	L -> BO	BO -> W	W -> BO
1024	303	200	0.29	0.42
4096	0.48	1.3		

5. CTT 1 test case results

There were a total of 108 test cases executed during CTT 1. These test cases covered a variety of system features as well as multiple aspects of system performance. Additionally, numerous tests, designed to determine a basic level of system operational confidence, were executed.

5.1 Test case pass/fail summary

A summary of test categories, the number of tests that apply to a particular category, and the success rate of test execution are presented in Table 10. Of the 108 test cases executed, due to various defects, 20 test cases were blocked from testing. Out of the remaining 88 test cases 64 passed and 24 failed.

Table 10: CTT 1 test case pass/fail summary

Area	Description	Executed	Passed	Failed	Blocked
Baseline	Benchmark tests of basic system performance	7	7	0	0
Confidence	Basic validation tests of system operation	27	23	4	0
Fragmentation	Test system operation with messages that are fragmented	8	4	4	0
KPI	Test of one or more key performance indicators as	0	0	0	0

Area	Description	Executed	Passed	Failed	Blocked
	defined in the test plan				
Latency	Test message latency under a variety of scenarios	20	7	9	4
Mobility	Test system operation during locomotive radio handoffs	14	6	4	4
PTC	Various tests the involve WIU status	18	6	3	9
QoS	Various message priority tests	7	7	0	0
Rerouting	Rerouting of messages to different transports due to various failures	2	2	0	0
Special Handling	Various tests that include use of special handling codes	4	1	0	3
SW Upgrade	Validate remote upgrade of radio and messaging server SW.	1	1	0	0
	Totals	108	64	24	20

5.1.1 Defects causing blocked tests and failures

The Blocked and failed test cases were due to only 7 defects. These are summarized in Table 11. Defects 1641 and 1709 are tied together because fixes for both were required to unblock the test cases.

Table 11: Summary of defects causing failed or blocked test cases

Defect ID	Description	Number of Failed Test Cases	Number of Blocked Test Cases
1486	Flood Messages sent from Wayside to BO creates multiple copies of the message @ the back office	2	0
1641,	1641: Slot keys show up as zero in messaging	0	11

1709	1709: SH Code 3 messages not sent to Radio. Attempts fail precondition with Error: Owning organization not found key=XX		
1664	After hand-off (Base1 --> Base2), ELM ignores the TNQ update for Base2, erroneously reports update as duplicate of Base1 TNQ	4	3
1690	Once the Base radio loses the connection to the ELM it is never restored until the ELM is restarted	2	0
1722	SHC 1, 2 and 6 doesn't work when the Base Station is offline	3	0
1728	250 millisecond delay in Class D Acks Limits message throughput	9	4

5.2 Test case prioritization

As a guide during test execution, per reference [6] closed track test cases were prioritized to the three levels indicated in Table 12. This information is reiterated here as it has a bearing on the exit criteria discussed in the next section of this report.

Table 12: Closed Track test case priority guidelines

Priority	Attributes
P1	Tests an essential product feature Tests a basic element of functionality Tests functionality or performance that has not been tested in prior integration phases.
P2	Supports testing of important usage scenarios Tests features or functionality not well tested elsewhere
P3	There was extensive like testing at the subsystem level P3 test cases do not directly address core functionality

5.3 Test case pass/fail vs. test case priority

An examination of the CTT 1 test cases for Pass/fail as a function of test case priority is summarized in Table 13. The corresponding percentages for each priority level are listed in Table 14.

Table 13: Test case pass/fail results summary

Test Case Priority	Number of Test Cases	Executed	Pass	Fail	Blocked
1	49	34	26	8	15
2	50	43	31	12	7
3	11	11	7	4	0
TOTALS	110	88	64	24	22

Table 14: Test case percentage pass, fail, and blocked

Priority	Test Cases	% Executed	% Pass	% Fail	% Blocked
1	100.0%	69.4%	53.1%	16.3%	30.6%
2	100.0%	86.0%	62.0%	24.0%	14.0%
3	100.0%	100.0%	63.6%	36.4%	0.0%

Since some of the test cases were blocked, it is useful to also look at the pass/fail percentages as compared to the actual number of test cases executed. Additionally, these are the percentages that apply to exit criteria. These results are summarized in Table 15.

Table 15: Pass/Fail as a percentage of test cases executed during CTT 1

Priority	% Pass (of executed)	% Fail (of executed)
1	76.5%	23.5%
2	72.1%	27.9%
3	63.6%	36.4%

5.4 CTT 1 KPI measurements

Measurements of performance metrics from CTT 1 are summarized in Table 16.

Table 16: CTT 1 KPI results

Category	Description	Requirement	Actual results
Message Rate	Mobile message rate	33 messages/sec (32 in, 1 out)	Radio: 3 Msg/sec (Msg. size: 64 byte, Class D ACKs on) Cell: 2 Msg/sec
Message Rate	Wayside Message Rate	6 messages/sec (5 in, 1 out)	Radio: 3 Mgs/sec (Msg. size: 64 byte, Class D ACKs on) Cell: 2 Msg/sec
Message Latency	Locomotive segment	TBD (not defined for R1.0)	Radio: 2.2 sec (Msg. size: 64 byte, Class D ACKs on) Cell: 0.42 sec
Message Latency	Wayside segment	TBD (not defined for R1.0)	Radio: 2.0 sec (Msg. size: 64 byte, Class D ACKs on) Cell: 1.3 sec
Radio Network Traffic Load	Base to the Locomotive message traffic bit rate.	4 Kbits/sec of traffic over and above the PTC traffic load	
Radio Network Traffic Load	Locomotive to the Base message traffic bit rate.	4 Kbits/sec of traffic over and above the PTC traffic load	

6. Closed track testing exit criteria

The exit criteria along and some corresponding results for CTT 1 are listed in Table 17. As can be seen, the results of CTT 1 are not passing the established exit criteria. The impact of this is discussed below.

Table 17: CTT 1 exit criteria

Dependency	Exit Criteria	Result
Test Coverage	All priority 1 and priority 2 test cases have been executed	Priority 1 Test Cases Executed: 52 Not Executed: 1 Priority 2 Test Cases Executed: 42 Not Executed: 1
Test Coverage	Priority 1 test case pass rate: 90% Priority 2 test case pass rate: 75%	Priority 1 Pass Rate: 75.7% Priority 2 Pass Rate: 68.6%
Product Quality	All critical and major defects have been resolved	Radio Defects Critical: 6 Major w/o work around: 25 Messaging Defects Critical: 1
KPIs	Applicable system level KPIs meet or exceed required levels to a 75 % [1]confidence level	Insufficient data to make an assessment
Results Reporting	Test results have been documented and archived	In work

[1]A confidence level of 75% means that KPI measurements will likely meet required levels 75% of the time.

6.1 Exit criteria waiver for CTT 1

Exit criteria were established well in advance of CTT 1. A primary purpose of these criteria was to provide completion targets to the development team and allow anticipated levels of available functionality to be estimated for test planning. Additionally, the exit criteria are intended to establish an internal review point for the project. Though, the exit criteria listed above are being missed by a wide margin in a number of areas, a decision was made to move forward for the following reasons:

- Testing at TTCI is costly in both dollars and resources. Until a number of defects were resolved, testing at TTCI had reached a point of diminishing return. As such, resources could be more effectively used in the lab.
- The original CTT exit criteria were estimated based on past experience melded with subsystem development plans. Over the course of the program, plans and schedules morphed to accommodate new information and address various challenges. This made the exit criteria of some intermediate program stages, such as CTT 1, less relevant.
- A considerable amount was learned about testing in a non-lab environment. Closed track testing could be made more effective by updating tools and processes prior to continuing testing.

7. Requirements coverage analysis

As defined in [6] and reiterated in section 1.2 of this document, CTT is not intended to test and validate all requirements. Tests performed during CTT directly validate only a small percentage of the release 1.0 requirements. The remainder of the requirements validation tests are expected to be completed within the radio, messaging, and systems management work streams. None the less, it is helpful to understand the level of requirements validation that was achieved during CTT 1.

7.1 Release 1.0 requirements tested at CTT 1

A requirements traceability matrix is provided in Appendix C. This matrix maps a subset of Release 1.0 requirements to one or more CTT 1 test cases.

7.1.1 Radio requirements coverage

For Release 1.0 there are a total of 115 radio requirements. Test cases for CTT 1 directly apply to a total of 18 of these requirements. This results in test coverage of 15.7% of the radio requirements. However, as summarized in Table 2, a number of these radio requirements can be excluded from closed track testing.

Table 18: Radio requirements that can be excluded from CTT

Requirement Categories	Reason to Exclude	Number of Requirements
Connector	As designed	9
Extensibility	Not testable	10
Packaging	As designed	3
Standards	As designed	26
Ethernet	As designed	4
Negative requirement (R111.1)	Not testable	1

When the requirement numbers listed in Table 2 are taken into account, which excludes 53 of the radio requirements, the CTT 1 radio requirements test coverage goes up to 29%.

7.1.2 Messaging requirement coverage

For R1.0 there are a total of 127 messaging requirements. Test cases for CTT 1 directly apply to a total of 33 messaging requirements. (See Appendix C for details.) This results in test coverage of 26% at CTT 1 for the R1.0 messaging requirements.

Appendix A - Test bed communication site details

This Appendix contains details of the wayside and locomotive communication sites, base station radios installations, and over the air monitoring station.

Connection diagrams

Figure 19: Wayside communication site connection diagram

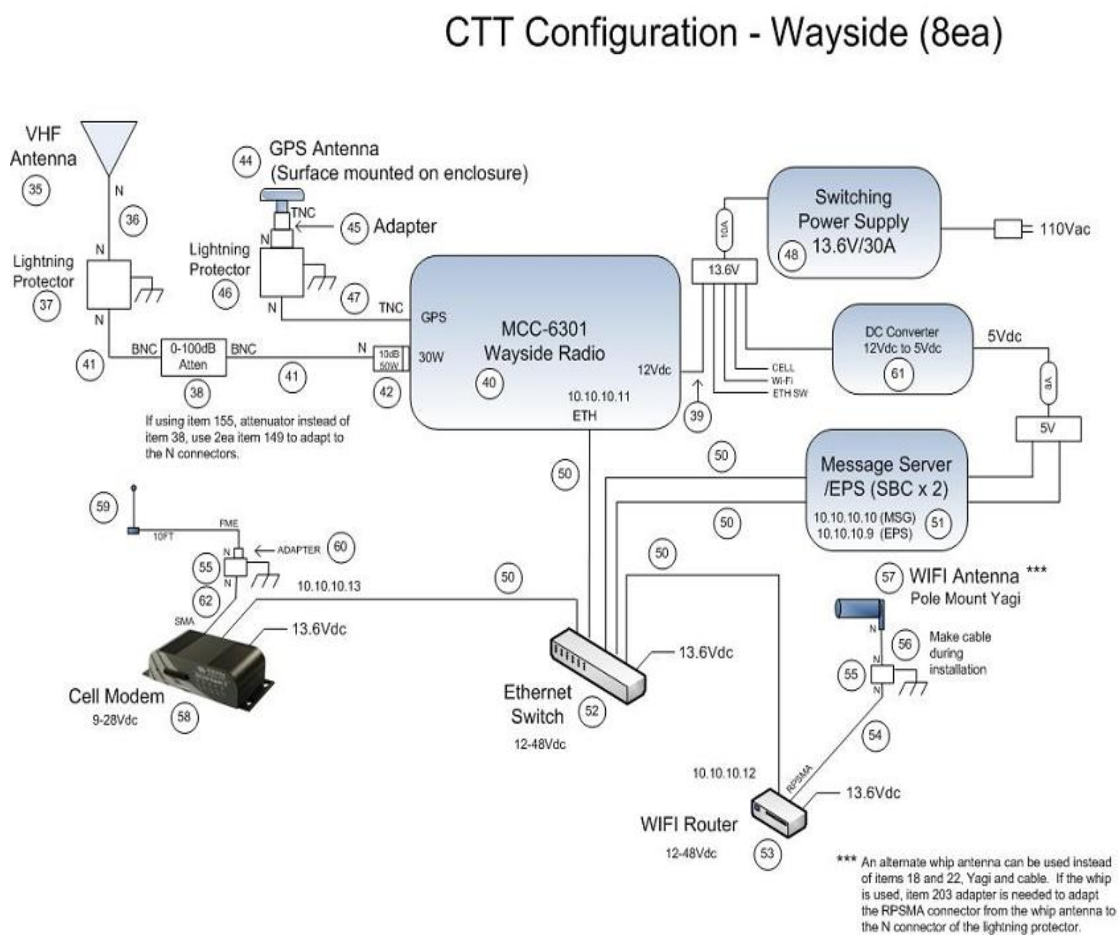


Figure 20: Locomotive communication site connection diagram

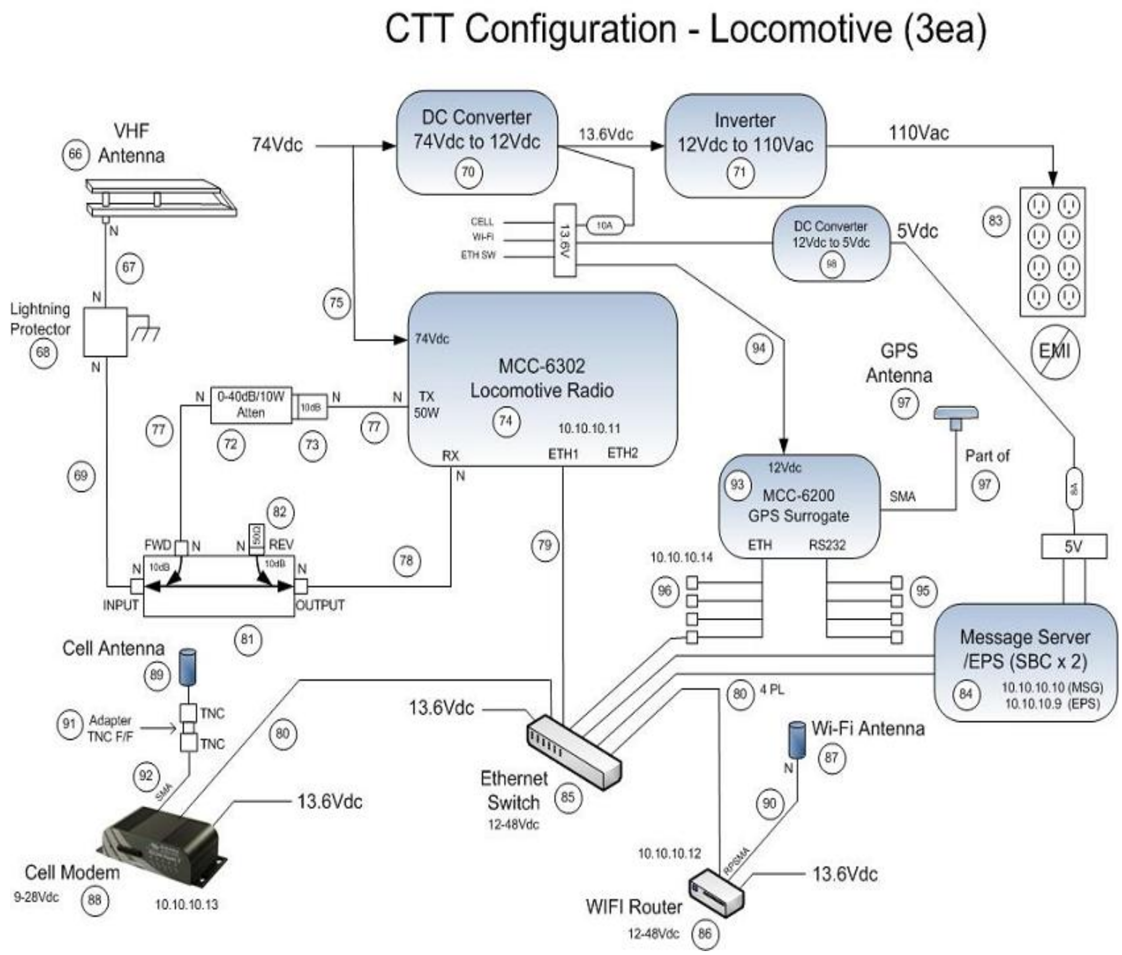


Figure 21: Base station communication site connection diagram

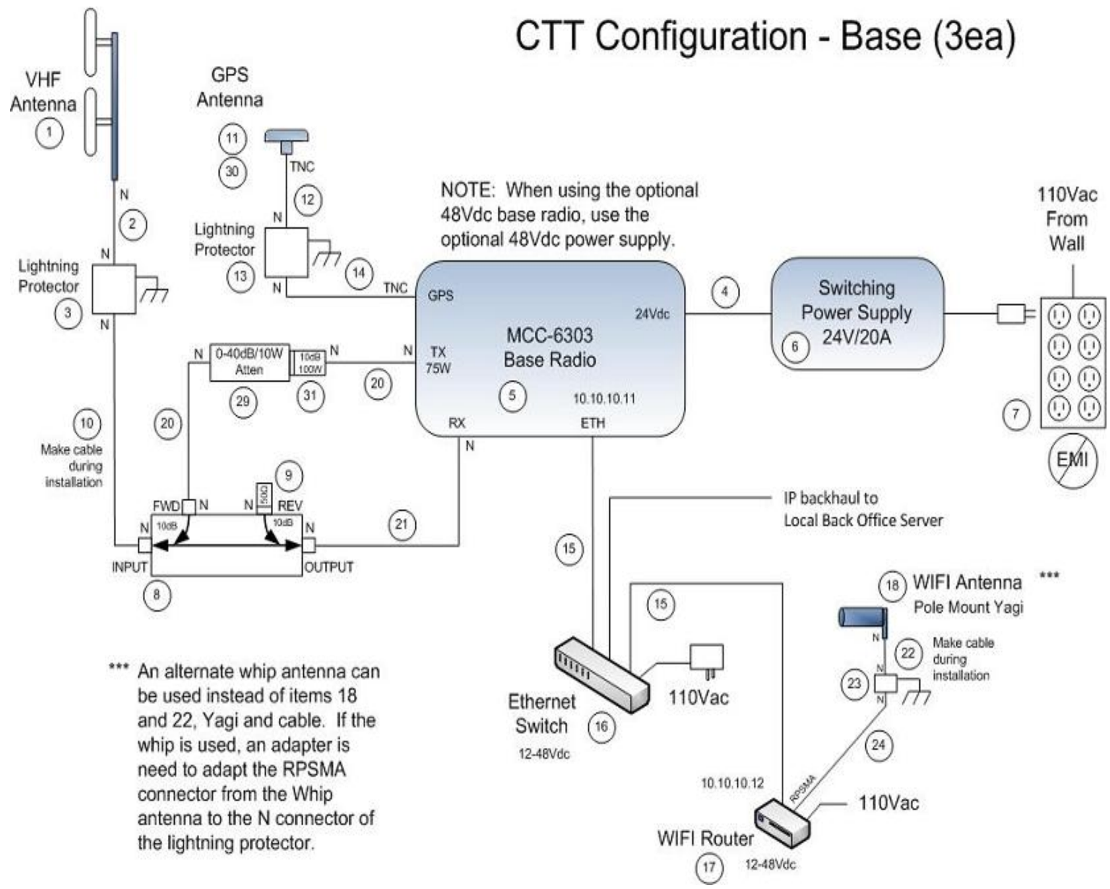
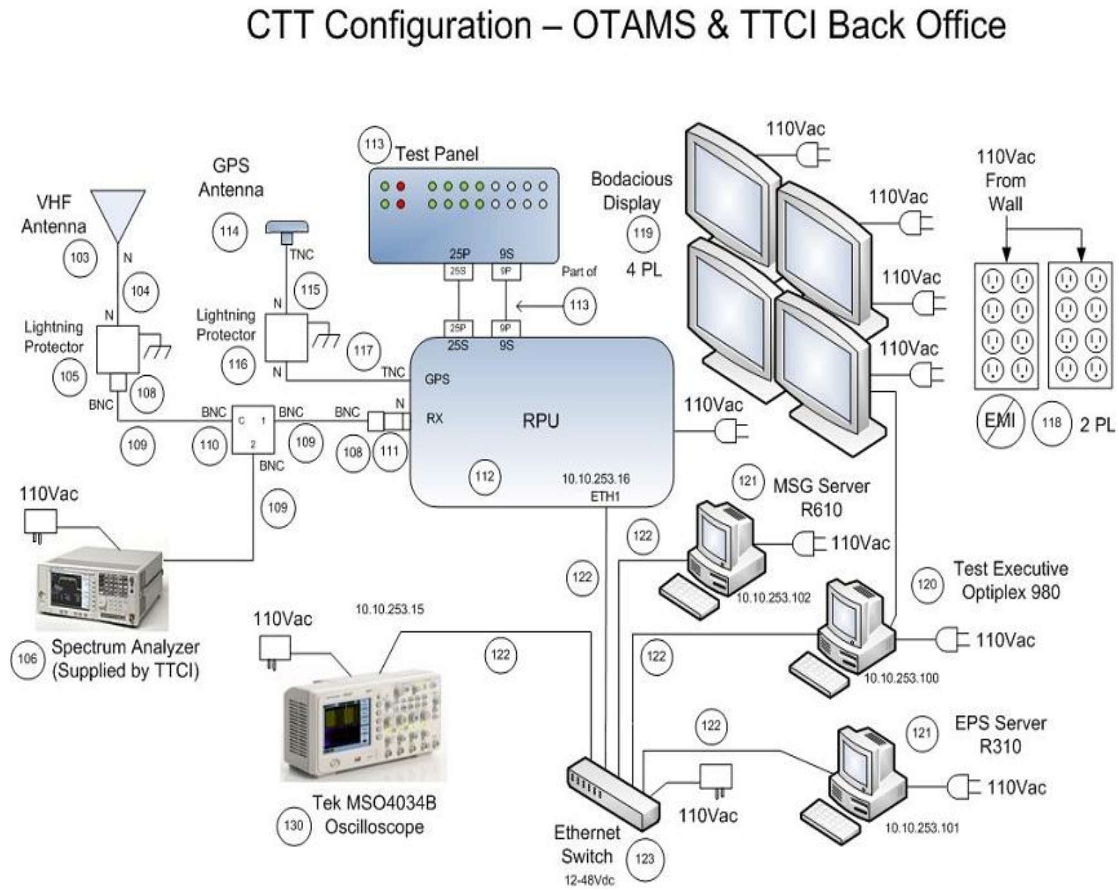


Figure 22: OTAMS back office connection diagram



Bill of Materials

Table 19: Wayside communication site bill of materials

Item #	Wayside Station (8 sites)	Comments
35	VHF Antenna	Sinclair SD212-SF3P2SNM(D008)
36	VHF Antenna Cable, N/N	LMR400 or better with type N connectors
37	Lightning Protector (N/N) for VHF	Polyphaser IS-B50LN-C0 or equivalent
38	Step Attenuator, BNC Connectors, 2W	
39	Power Cord for radio	MCC 14001577-01
40	Wayside Radio	

Item #	Wayside Station (8 sites)	Comments
41	Coax Cable, 6FT, RG-223, N/BNC	Pasternack PE3476-72
42	Attenuator, 50W,10dB, NM/NF, 1.5" Diameter	Fairview Microwave SA3N511-10
44	GPS Antenna	Mobile Mark NT-1575
45	Adapter, TNC Plug/N Plug	Fairview Microwave SM4153
46	Lightning Protector for GPS, N/N	Polyphaser DGXZ+06NFNF-A (MCC# 051-031-0015)
47	Cable from LP to Radio, N/TNC, 6FT	Pasternack PE3665-72
48	Power supply, 13.6V, 30A	Astron SS-30
50	Ethernet Cable, CAT-5E, RJ-45 (3 FT)	L-COM TRD855SCR-3
51	Computer - SBC & Pwr Supply in an enclosure	SIP SIP-11-MTC-PS02
52	Ethernet Switch, 6 to 8-port	Ethernet Direct HUE-800SE
53	WiFi Router	Axxeon APR-2000T
54	Cable, RP-SMA/N, 20FT, RG-223	TCA
55	Lightning Protector, N/N, For Cell & Wi-Fi	L-COM AL-NFNFB-9
56	Cable, LMR400, N/N, Make during installation	LMR400 + 2ea N Connectors
57	WiFi Antenna, Pole Mount, 15dB, Yagi	L-COM HG2415Y-NF
58	Cell Modem	Raven X PN# V2221E-VA
59	Cell Antenna with cable & FME female connector	Wilson 301103
60	Adapter, N Male/FME Male	Fairview Microwave SM6107
61	DC Converter, 12Vdc to 5Vdc	CUI Inc. VHK50W-Q24-S5
62	Cable, SMA/N, 20FT, RG-223	TCA

Table 20: Locomotive communication site bill of materials

Item #	Locomotive (3 sites)	Comments
66	VHF Antenna	Sinclair Excaliber or Sti-Co HDLP-NB-220
67	VHF Antenna Cable, N/N	LMR400 or better with type N connectors
68	Lightning Protector (N/N) for VHF	Polyphaser IS-B50LN-C0 or equivalent
69	Cable, N/N from VHF LP to Radio	LMR400 or RG-223
70	DC Converter, 72Vdc to 12Vdc	Wilmore 1620H-74-13-30
71	Inverter, 12Vdc to 110Vac	
72	Step Attenuator, 0-40dB,N Connectors, 10W	RF Lambda RKT10G3A40
73	Attenuator, 50W,10dB, NM/NF, 1.5" Diameter	Fairview Microwave SA3N511-10
74	Locomotive Radio	
75	Power Cord for Radio	MCC 14001578-01
77	Cable, 1FT, RG-223, N/N	Pasternack PE3447-12
78	Coax Cable, 6FT, RG-223, N/N	Pasternack PE3447-72
79	M12 Ethernet Cable, 10FT	Turck RSS RJ45S 841-3m
80	Ethernet Cable, CAT-5E, RJ-45 (3 FT)	L-COM TRD855SCR-3
81	Directional Coupler, 200W,10dB, N Connectors	Werlatone C7126-10
82	Termination, 50 Ohm, 2W, N Connector	Fairview Microwave STN0610
83	AC Power Strip, 8 outlet, EMI Protected	TrippLite TLP808TELTV
84	Computer - SBC & Pwr Supply in an enclosure	SIP SIP-11-MTC-PS02
85	Ethernet Switch, 8-port	Ethernet Direct HUE-800SE

Item #	Locomotive (3 sites)	Comments
86	WiFi Bridge	Axxeon APR-2000T
87	Antenna, WiFi, Stub, N Conn Mount	005-179-0301 in Stock at MCC
88	Cell Modem	Raven X PN# V2221E-VA
89	Antenna, Cell, Stub, 5/8 Stud Mnt,TNC Male Conn	Mobile Mark RM3-900/1900
90	Cable, WiFi Antenna, N Male/RPSMA Male, 30FT	TCA RG223-N-RPSMA-30FT
91	Adapter, TNC F/F Barrel	Pasternack PE9099
92	Cable, Cell Ant, TNC Male/SMA Fem, 30FT	TCA RG223-TNC-SMA-30FT
93	MCC-6200 Radio	For GPS surrogate
94	Power Cord for MCC-6200	For GPS surrogate
95	ComPort Cable	For GPS surrogate
96	Ethernet/USB Cable	For GPS surrogate
97	GPS Antenna, Stud Mount, with Cable	For GPS surrogate
98	DC Converter, 12Vdc to 5Vdc	CUI Inc. VHK50W-Q24-S5

Table 21: Base station installation bill of materials

Item #	Base Station (3 sites)	Comments
1	VHF Antenna	Sinclair SD212-SF3P2SNM(D008)
2	VHF Antenna Cable, N/N	LMR400 or better with type N connectors
3	Lightning Protector (N/N) for VHF	Polyphaser IS-B50LN-C0 or equivalent
4	Power Cord for radio	MCC 13000374-01
5	Base Radio, 24V, with Power Cord	
6	Power Supply, 24V, 20A	Acopian W24MT25

Item #	Base Station (3 sites)	Comments
7	AC Power Strip, 8 outlet, EMI Protected	TrippLite TLP808TELTV
8	Directional Coupler, 200W,10dB, N Connectors	Werlatone C7126-10
9	Termination, 50 Ohm, 2W, N Connector	Fairview Microwave STN0610
10	Cable, LMR400, N/N, Make during installation	LMR400 + 2ea N Connectors
11	GPS Antenna	Mobile Mark NT-1575
12	GPS Antenna Cable, TNC/N, 30FT	TCA
13	Lightning Protector for GPS, N/N	Polyphaser DGXZ+06NFNF-A (MCC# 051-031-0015)
14	Cable from LP to Radio, N/TNC, 20FT	TCA
15	Ethernet Cable, CAT-5E, RJ-45 (3 FT)	L-COM TRD855SCR-3
16	Ethernet Switch, 6 to 8-port	Ethernet Direct HUE-800SE
17	WiFi Router	Axxeon APR-2000T
18	WiFi Antenna, Pole Mount, 15dB, Yagi	L-COM HG2415Y-NF
20	Cable, 1FT, RG-223, N/N	Pasternack PE3447-12
21	Coax Cable, 6FT, RG-223, N/N	Pasternack PE3447-72
22	Coax Cable, Wi-Fi, LMR400, N/N	LMR400 + 2ea N Connectors
23	Lightning Protector, N/N, For Wi-Fi	L-COM AL-NFNFB-9
24	Cable, RP-SMA/N, 20FT, RG-223	TCA
29	Step Attenuator, 0-40dB,N Connectors, 10W	RF Lambda RKT10G3A40
30	Bracket for GPS Antenna	Mobile Mark NT-MK
31	Attenuator, 10dB, 100W, Nm/Nm	

Table 22: OTAMS back office bill of materials

Item #	TTCI Back Office / OTAMS Monitoring Station (1 site)	Comments
103	VHF Antenna	Sinclair SD212-SF3P2SNM(D008)
104	VHF Antenna Cable, N/N	LMR400
105	Lightning Protector (N/N) for VHF	Polyphaser IS-B50LN-C0 or equivalent
106	Spectrum Analyzer	
108	Adapter, N/BNC	Pasternack PE9002
109	Coaxial Cable, 6FT, RG-223, BNC Plug/BNC Plug	Pasternack PE3087-72
110	RF Power Splitter, 2-Way, BNC Connectors	Pasternack PE2000
111	BLANK	
112	RPU with Power Cord	
113	Test Panel with test points & LEDs	
114	GPS Antenna	Mobile Mark NT-1575
115	GPS Antenna Cable, TNC/N, 20FT	TCA
116	Lightning Protector for GPS, N/N	Polyphaser DGXZ+06NFNF-A (MCC# 051-031-0015)
117	BLANK	
118	AC Power Strip, 8 outlet, EMI Protected	TrippLite TLP808TELTV
119	Monitor, 27" Flat Panel	Dell U2711
120	Computer, Mini-Tower	Dell Optiplex
121	Computer, Rack Mount Server	Dell R310 & R610
122	Ethernet Cable, CAT-5E, RJ-45 (3 FT)	L-COM TRD855SCR-3
123	Ethernet Switch, 6-port	Ethernet Direct HUE-800SE
124	Oscilloscope, 4 Analog, 16 Digital, 350MHz	Agilent MSO7034B

Appendix B - CTT message paths

This appendix contains diagrams of the CTT 1 test setup showing the messaging paths using Radio, Cell, and Wi-Fi transports. Brief descriptions of each message path are given below.

Message over radio path

1a) Test Exec sends message command to Remote EPS

1b) EPS reports transmit of message to Test Executive

2) EPS sends message to Messaging SW

3) Messaging SW sends message to Remote Radio

4) Remote Radio sends message to Base Radio

5) Base Radio sends message to Back Office

6) Back Office sends message to EPS

7) EPS reports receipt of message to Test Executive

Message over cell path

1a) Test Exec sends message command to Remote EPS

1b) EPS reports transmit of message to Test Executive

2) EPS sends message to Messaging SW

3) Messaging SW sends message to Cell Modem

4) Cell Modem sends message to Cell Service Provider

5) Cell Service Provider sends message to TTCI Corpnet

6) TTCI Corpnet routes message to Back Office

7) Back Office sends message to EPS

8) EPS reports receipt of message to Test Executive

Message over Wi-Fi path

1a) Test Exec sends message command to Remote EPS

1b) EPS reports transmit of message to Test Executive

2) EPS sends message to Messaging SW

3) Messaging SW sends message to Back Office over WIFI

4) Back Office sends message to EPS

5) EPS reports receipt of message to Test Executive

Figure 23: Messaging path over radio transport

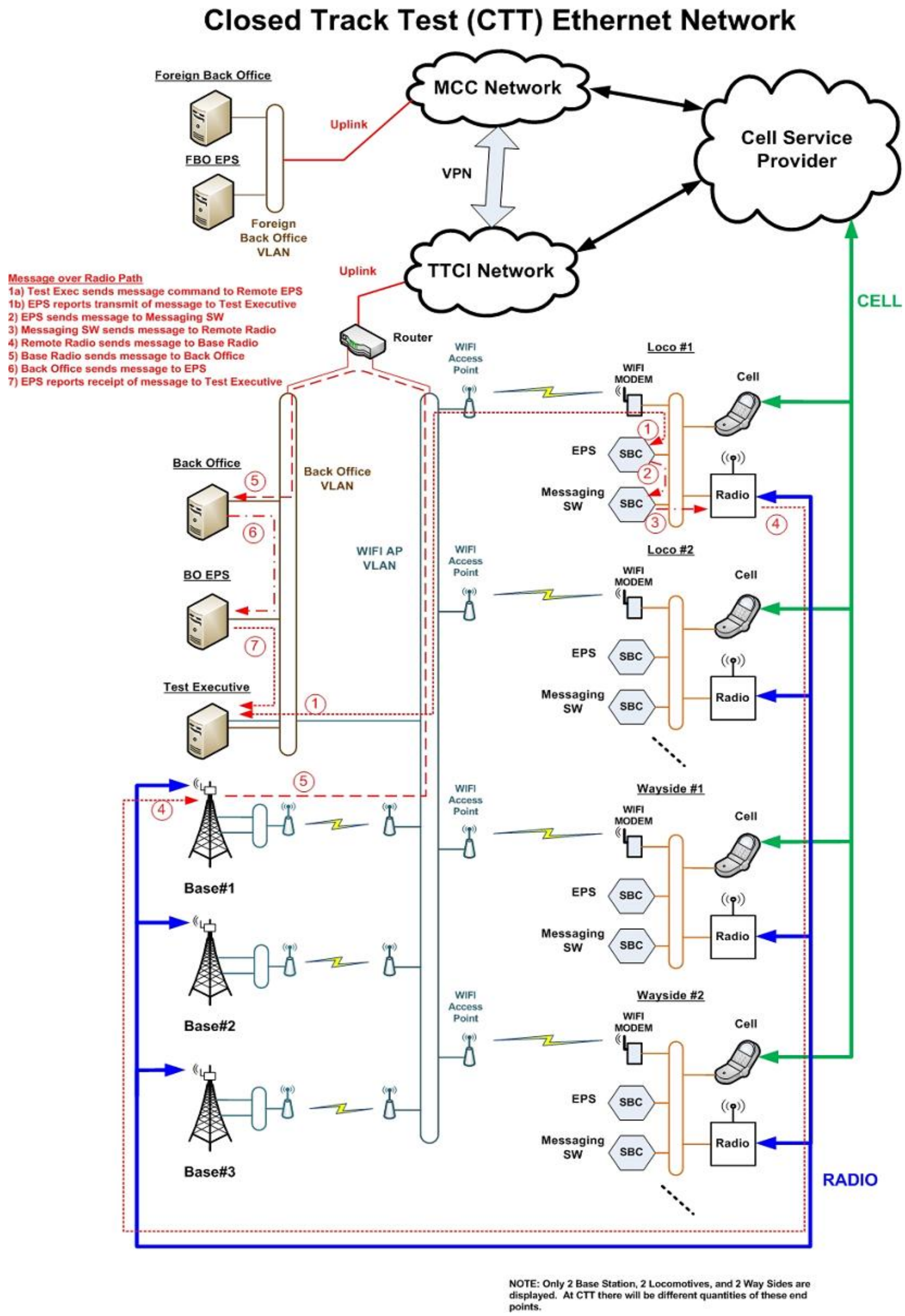


Figure 24: Messaging path over cell transport

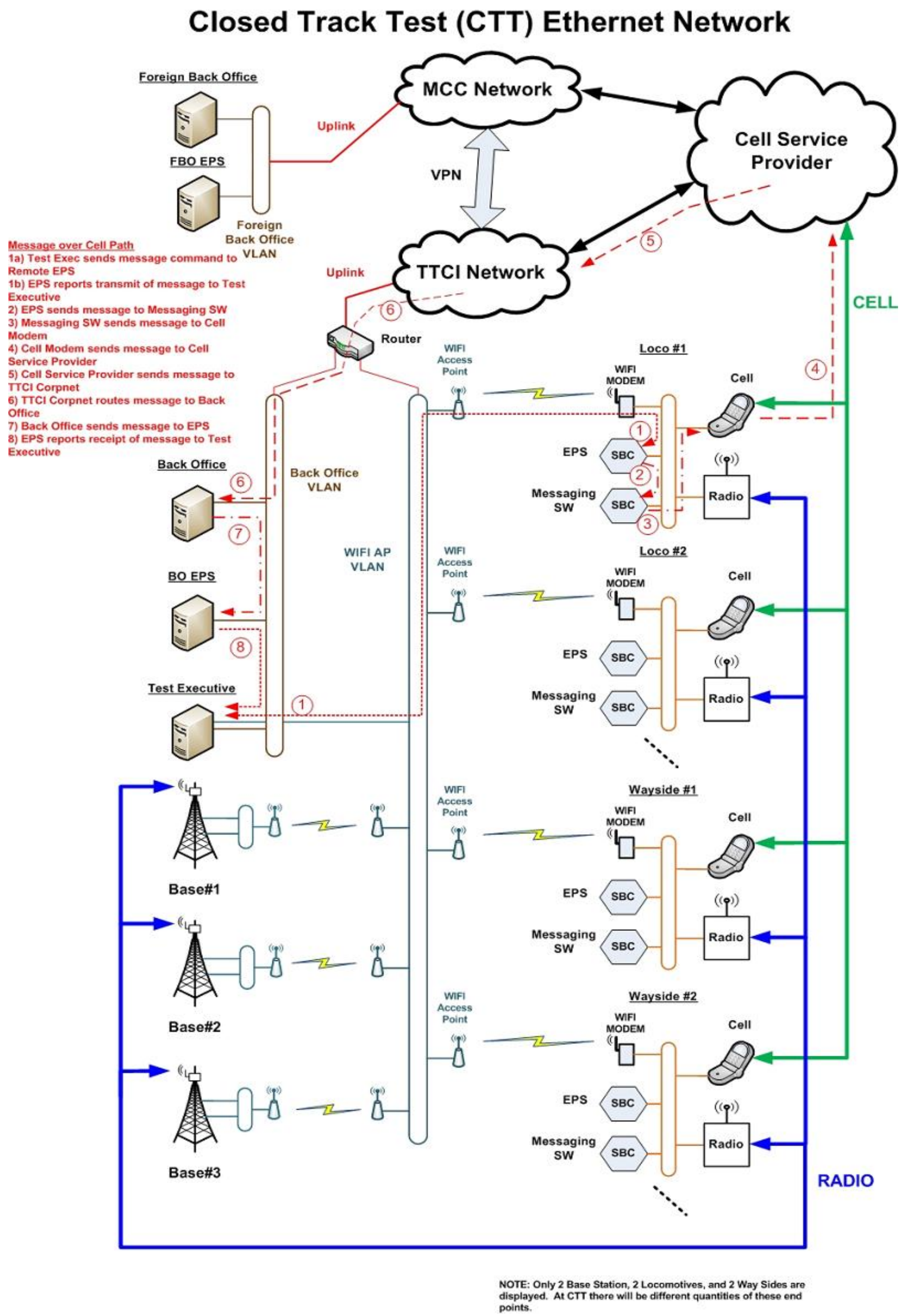
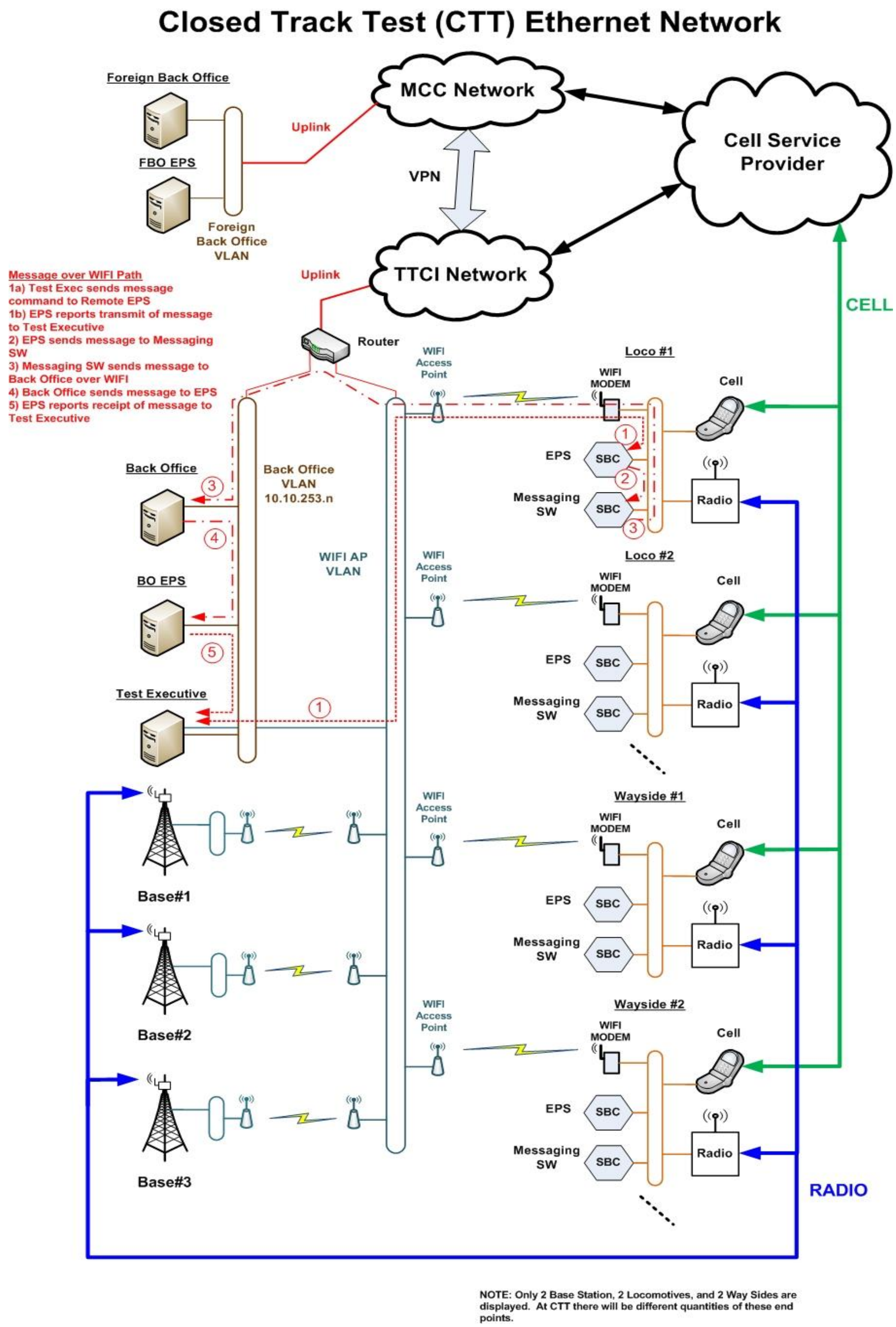


Figure 25: Messaging path over Wi-Fi transport



Appendix C - CTT 1 test cases

Test Case Identifier	Description	Status	Defect ID	Priority
CTT_Mob_Radio104_TC05_Cond5	Locomotive switches base at 30 miles per hour with overlapping coverage. Single ELM topology is used. Locomotive sends 64 byte messages the Back Office at a rate of 1 msg / sec.	Failed	1664	1
CTT_ConfCN_SR-009_TC001_Cond0	Send a class 0 messages to each and every endpoint. Class 0 is accepted among all transports.	Passed		1
CTT_ConfCN_SR-009_TC006_Cond0	Send a class 1 messages to each and every endpoint. Class 1 is accepted by radio transport.	Passed		1
CTT_ConfCN_SR-009_TC008_Cond0	Send a class 2 messages to each and every endpoint. Class 2 is accepted by WIFI transport.	Passed		1
CTT_ConfCN_SR-009_TC009_Cond0	Send a class 3 messages to each and every endpoint. Class 3 is accepted by Cell transport.	Passed		1
CTT_ConfCN_SR-144_TC001_Cond0	Remote Radio is rebooted. Verify remote radio connects to Base without manual intervention.	Passed		1
CTT_ConfCN_SR-145_TC001_Cond0	Locomotive radio is disconnected then reconnected to host (CM)	Failed	1690	1
CTT_ConfCN_SR-145_TC002_Cond0	Base radio is disconnected then reconnected to host (ELM)	Failed	1690	1
CTT_ConfRL_SR-049_TC001_Cond0	Messages with Network Preference 7 (flood) are sent from remotes to Back Office.	Failed	1486	2
CTT_ConfRL_SR-049_TC002_Cond0	Messages with Network Preference 7 (flood) are sent from Back Office to remotes.	Passed		2
CTT_ConfRL_SR-049_TC003_Cond0	Messages with Network Preference 7 (flood) are sent from remotes to remotes.	Failed	1486	2
CTT_ConfFR_SR-014_TC001_Cond0	Class 0 messages just over the fragmentation limit are sent from remotes to Back Office. Class 0 is accepted among all transports.	Passed		3
CTT_ConfFR_SR-014_TC002_Cond0	Class 0 messages just over the fragmentation limit are sent from Back Office to remotes. Class 0 is accepted among all transports.	Passed		3
CTT_ConfFR_SR-014_TC003_Cond0	Class 0 messages just over the fragmentation limit are sent from Back Office to remotes. Class 0 is accepted among all transports.	Passed		3
CTT_ConfRL_SR-041_TC001_Cond0	Messages with network preference set to radio are sent from Back Office to locomotive.	Passed		2
CTT_ConfRL_SR-040_TC002_Cond0	Messages with Cell designated class will be allowed only over Cell	Passed		2

Test Case Identifier	Description	Status	Defect ID	Priority
CTT_ConfRL_SR-040_TC003_Cond0	Messages with Radio designated class will be allowed only over Radio	Passed		2
CTT_ConfRL_SR-041_TC002_Cond0	Messages with network preference set to cell are sent from Back Office to locomotive	Passed		2
CTT_ConfRL_TC001_Cond0	Messages are sent over IP transports simultaneously from remotes to Back Office	Passed		2
CTT_ConfRL_TC003_Cond0	Messages are sent over Radio and IP transports simultaneously from remotes to Back Office	Passed		2
CTT_ConfRL_SR-127_TC001_Cond0	Class 0 messages are sent from remotes to Back Office. Verify messages use lowest cost transport. Class 0 is accepted among all transports.	Passed		2
CTT_ConfPRI_TC001_Cond0	Messages of priorities 0 through 7 are sent across the network.	Passed		2
CTT_ConfRL_TC002_Cond0	Messages are sent over IP transports simultaneously from Back Office to remotes.	Passed		2
CTT_ConfRL_TC004_Cond0	Messages are sent over radio and IP transports simultaneously from Back Office to remotes.	Passed		2
CTT_Conf_Msg_Restart_DR	Restart Messaging and verify all endpoints can send and receive messages	Passed		1
CTT_Mob_Radio104_TC02_Cond5	Locomotive switches base at 70 miles per hour with non-overlapping coverage. Single ELM topology is used. No messages are sent.	Blocked	1664	1
CTT_Mob_Radio104_TC03_Cond5	Locomotive switches base at 70 miles per hour with overlapping coverage. Single ELM topology is used. Locomotive sends 64 byte messages the Back Office at a rate of 1 msg / sec.	Passed		1
CTT_Mob_Radio104_TC04_Cond5	Locomotive switches base at 70 miles per hour with overlapping coverage. Back Office sends 64 byte messages to the locomotive at a rate of 1 msg /sec.	Failed	1664	1
CTT_Frag_SR-014_TC001_Cond5	Locomotive sends 2048 byte messages to the Back Office over radio while traveling at 20 miles per hour. 2048 bytes is over the fragmentation limit.	Passed		3
CTT_Frag_SR-014_TC002_Cond5	Locomotive sends 2048 byte messages to the Back Office over cell while traveling at 20 miles per hour. 2048 bytes is over the fragmentation limit.	Passed		3
CTT_Frag_SR-014_TC003_Cond5	Locomotive sends 2048 byte messages to the Back Office over WIFI while traveling at 20 miles per hour. 2048 bytes is over the fragmentation limit.	Failed		3
CTT_Frag_SR-014_TC004_Cond5	Locomotive sends 2048 byte messages to the Back Office over radio while traveling at 70 miles per hour. 2048 bytes is over the fragmentation limit.	Passed		3
CTT_Frag_SR-014_TC005_Cond5	Locomotive sends 2048 byte messages to the Back Office over cell while traveling at 70 miles per hour. 2048 bytes is over the fragmentation limit.	Passed		3

Test Case Identifier	Description	Status	Defect ID	Priority
CTT_Frag_SR-014_TC006_Cond5	Locomotive sends 2048 byte messages to the Back Office over WIFI while traveling at 70 miles per hour. 2048 bytes is over the fragmentation limit.	Failed		3
CTT_Mob_Radio104_TC01_Cond5	Locomotive switches base at 70 miles per hour with overlapping coverage. Single ELM topology is used. No mssages are sent.	Passed		1
CTT_Frag_SR-014_TC007_Cond5	Locomotive sends 2048 byte messages to the Back Office with a network preference of cell while traveling at 70 miles per hour.	Failed		3
CTT_Frag_SR-014_TC008_Cond5	Locomotive sends 2048 byte class 0 messages to the Back Office while traveling at 70 miles per hour. Class 0 messages are accepted over any transport.	Failed		3
CCT_ConfRL_SR-041_TC003_Cond0	Messages are sent from Back Office to Locomotive with network preference set to WIFI, when WIFI is not available.	Passed		2
CCT_ConfRL_SR-040_TC001_Cond0	Messages with WIFI designated class will be allowed only over WIFI	Passed		2
CCT_ConfLST_TC004_Cond4	Verity stability of radio message completion rate. 99 % of class 1 messages should be received during a 1 hour test.	Passed		1
CTT_SL-010_TC01	64 byte bi-directional messages are sent between Back Office, locomotive, and wayside over radio. Messages are sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_SL-010_TC02	256 byte bi-directional messages are sent between Back Office, locomotive, and wayside over radio. Messages are sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_SL-010_TC03	512 byte bi-directional messages are sent between Back Office, locomotive, and wayside over radio. Messages are sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_SL-010_TC04	1024 byte bi-directional messages are sent between Back Office, locomotive, and wayside over radio. Messages are sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_DL-032_TC01	64 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 30 miles per hour. Messages are sent at a rate of 1 msg / sec.	Passed		2
CTT_DL-032_TC02	256 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 30 miles per hour. Messages are sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_SR-020_TC01	Validate stationary base location when position of the base's are changed prompting a handoff.	Passed		2
CTT_ML-060_TC01	Locomotive switches base while traveling at 30 miles per hour. 64 Byte messages are sent at a rate of 1 msg / sec.	Passed		2

Test Case Identifier	Description	Status	Defect ID	Priority
CTT_ML-060_TC02	Locomotive switches base while traveling at 30 miles per hour. 256 Byte messages are sent at a rate of 1 msg / sec over radio.	Blocked	1664	2
CTT_DL-032_TC03	512 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 30 miles per hour. Messages sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_DL-032_TC04	1024 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 30 miles per hour. Messages sent at a rate of 1 msg / sec.	Blocked	1728	2
CTT_DL-032_TC05	64 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 80 miles per hour. Messages sent at a rate of 1 msg / sec.	Passed		2
CTT_DL-032_TC06	256 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 80 miles per hour. Messages sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_DL-032_TC07	512 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 80 miles per hour. Messages sent at a rate of 1 msg / sec.	Failed	1728	2
CTT_DL-032_TC08	1024 byte Bi-directional messages are sent between locomotive and Back Office over radio while traveling at 80 miles per hour. Messages sent at a rate of 1 msg / sec.	Blocked	1728	2
CTT_ML-060_TC03	Locomotive switches base while traveling at 80 miles per hour. 64 Byte messages are sent at a rate of 1 msg / sec over radio.	Failed	1664	2
CTT_ML-060_TC04	Locomotive switches base while traveling at 80 miles per hour. 256 Byte messages are sent at a rate of 1 msg / sec over radio.	Blocked	1664	2
CTT_DL-032_TC09	Locomotive switches base while traveling at 80 miles per hour. 64 Byte messages are sent at a rate of 2 msgs / sec over radio.	Failed	1728	2
CTT_DL-032_TC10	Locomotive switches base while traveling at 80 miles per hour. 256 Byte messages are sent at a rate of 2 msgs / sec over.	Passed		2
CTT_DL-032_TC11	Locomotive switches base while traveling at 80 miles per hour. 512 Byte messages are sent at a rate of 2 msgs / sec over radio.	Blocked	1728	2
CTT_DL-032_TC12	Locomotive switches base while traveling at 80 miles per hour. 1024 Byte messages are sent at a rate of 2 msgs / sec over radio.	Blocked	1728	2
CTT_BRL_TC01	Locomotive sends 64 byte messages to the Back Office over radio at a rate of 1 msg / sec.	Passed		1
CTT_BRL_TC02	Back Office sends 64 byte messages to the locomotive over radio at a rate of 1 msg / sec.	Passed		1

Test Case Identifier	Description	Status	Defect ID	Priority
CTT_BRL_TC03	Wayside sends 64 byte messages to the Back Office over radio at a rate of 1 msg / sec.	Passed		1
CTT_BRL_TC04	Back Office sends 64 byte messages to the wayside over radio at a rate of 1 msg / sec.	Passed		1
CTT_BRL_TC05	64 byte bi-directional messages are sent between Back Office and locomotive over radio. Messages are sent at a rate of 1 msg / sec.	Passed		1
CTT_BRL_TC06	64 byte bi-directional messages are sent between Back Office and wayside over radio. Messages are sent at a rate of 1 msg / sec.	Passed		1
CTT_BRL_TC07	64 byte bi-directional messages are sent between locomotive and wayside over radio. Messages are sent at a rate of 1 msg / sec.	Passed		1
CTT_MHO_SL-025_TC05	Locomotive switches base while traveling at 50 miles per hour. 64 byte messages are sent at a rate of 1 msg / sec.	Failed	1664	1
CTT1_Lat-070_TC01	Locomotive sends 64 byte messages to the Back Office over radio at a rate of 1 msg / sec. Class D acks are turned off.	Passed		2
CTT1_Lat-070_TC02	Locomotive sends 256 byte messages to the Back Office over radio at a rate of 1 msg / sec. Class D acks are turned off.	Passed		2
CTT1_Rout_SR-022_TC001	64 byte bi-directional class 0 messages with a network preference of cell are sent between locomotive and Back Office. Locomotive is traveling at 30 miles per hour. Messages re-route to Radio or WIFI based on radio and cell transport availability.	Passed		2
CTT1_Lat-075_TC01	Locomotive sends 64 and 128 byte messages to the Back Office over radio while traveling at 30 miles per hour. Messages are sent a rate of 1 msg / sec. Class D acks are turned off.	Passed		2
CTT1_Lat-075_TC02	Locomotive sends 64 and 128 byte messages to the Back Office over radio while traveling at 80 miles per hour. Messages are sent a rate of 1 msg / sec. Class D acks are turned off.	Passed		2
CTT1_SH-Lat-070_TC01	Wayside sends 64 byte status response messages to the locomotive.	Blocked	1641, 1709	1
CTT1_SH-Lat-070_TC02	Wayside sends 64 byte status response messages to the locomotive while the locomotive is traveling at 30 miles per hour.	Blocked	1641, 1709	1
CTT1_SH-Lat-070_TC03	Wayside sends 64 byte status response messages to the locomotive while the locomotive is traveling at 80 miles per hour.	Blocked	1641, 1709	1
CTT1_Rout_SR-022_TC002	64 byte bi-directional class 0 messages with a network preference of cell are sent between locomotive and Back Office. Locomotive is traveling at 30 miles per hour. Messages re-route to	Passed		2

Test Case Identifier	Description	Status	Defect ID	Priority
	WIFI based on cell transport availability.			
CTT1_KPI-130	Locomotives 1 and 2 send 64 byte messages to the Back Office over radio at a rate of 10 msgs / sec.	Blocked		2
CTT_QosPRI_SR-047_TC002_Cond4	Queues are filled with messages of varying priorities then released.	Passed		2
CTT_QosPRI_SR-048_TC002_Cond0	Verify messages with high priority get serviced first when absolute priority algorithm is configured in messaging.	Passed		2
CTT_QosPRI_SR-052_TC001_Cond0	50 / 50 mix of low and high priority class 0 messages are sent from Back Office to locomotive at a high rate.	Passed		2
CTT_QosTTL_SR-056_TC001_Cond0	Verify messages will be kept alive as long as their TTL has not expired.	Passed		2
CTT_QosTTL_SR-056_TC002_Cond4	Verify message load does not affect the handling of TTL in the messaging system.	Passed		2
CTT_QosTTL_SR-056_TC003_Cond4	Verify messages die when their TTL has expired.	Passed		2
CTT_QosTTL_SR-057_TC001_Cond0	Mix of messages with different TTL's will not affect the handling of TTL in the messaging system.	Passed		2
CTT_SHC-1_TC02	Locomotive sends a 64 byte beacon on message to a target WIU while traveling at 30 miles per hour.	Passed		1
CTT_Mob_SR-076_TC02_Cond0	Locomotive switches from Base A to Base B when Base A's signal is attenuated.	Blocked	Handoff Algorithm	1
CTT_Mob_SR-076_TC03_Cond0	Locomotive switches from Base A to Base B when Base A's signal is attenuated in the middle of a large message.	Blocked	Handoff Algorithm	1
CTT_Mob_Radio_104_TC001_Cond0	Locomotive switches from Base A to Base B when base B loses power. Locomotive is sending 64 byte messages to the Back Office at a rate of 1 msg / sec.	Passed		1
CTT_Radio_075_TC001_Cond0ND-	Locomotive switches from Base A to Base B when Base A's transmitter is turned off. Locomotive is sending 64 byte messages to the Back Office at a rate of 1 msg / sec.	Passed		1
CTT_PTC-Cap_065_TC01_Cond3	Two periodic beacon messages are sent to the wayside radio with preconfigured slots. Messages are sent in the same FTDMA frame.	Blocked	1641, 1709	1
CTT_PTC-SH_71_TC01_Cond0	WIU sends periodic beacon messages to the Wayside at a high rate (3/sec)	Failed	1722	1
CTT_PTC-SH_R-71_TC001_Cond0	Locomotive sends a wayside status request message to the wayside while connected to a base.	Passed		1

Test Case Identifier	Description	Status	Defect ID	Priority
CTT_PTC-SH_SR049_TC01_Cond0	Wayside send a periodic beacon message every 3 seconds while registered to a base.	Blocked	1641, 1709	1
CTT_PTC-SH_SR049_TC04_Cond0	Wayside sends a status response message to the locomotive while connected to a base.	Passed		1
CTT_PTC-SpclHdlng_068_TC01_Cond3	Periodic beacon is sent to the wayside while low priority traffic is present.	Blocked	1641, 1709	1
CTT_PTC-Load_DR_TC001_Cond0	Locomotive receives periodic beacon messages on different channels simultaneously.	Blocked	1641, 1709	1
CTT_PTC-Load_R-75_TC001_Cond0	Locomotive can gain access to a loaded channel.	Blocked	1641, 1709	1
CTT_PTC-SH_R-xxx_TC001_Cond-0	Locomotive sends a wayside status request to the wayside while not connected to a base.	Passed		1
CTT_PTC-SH_R-xxx_TC002_Cond-0	Locomotive sends a beacon on message to reset a target WIUs timer.	Blocked	Application Response	1
CTT_PTC-SH_R-71_TC002_Cond0	Locomotive sends a wayside status request to the wayside while not connected to a base.	Failed	1722	1
CTT_PTC-SH_SR049_TC02_Cond0	Wayside sends a periodic beacon message every 3 seconds while not connected to any base.	Blocked	1641, 1709	1
CTT_PTC-SH_SR049_TC05_Cond0	Wayside sends a status response message to the locomotive while connected to a base.	Blocked	1641, 1709	1
CTT_PTC-SH_SR049_TC06_Cond0	Wayside sends a status response message to the locomotive while not connected to a base. Radio is only available transport.	Blocked	1641, 1709	1
CTT_PTC-SH_SR049_TC07_Cond0	Wayside sends a status response message to the locomotive while connected to a base. IP transports are available; Verify messages are flooded across all transports.	Failed	1722	1
CTT_PTC-SH_R-71_TC003_Cond0	Verify non target WIUs do not receive status request messages.	Passed		1
CTT_PTC-SH_R-71_TC004_Cond0	Locoomotive sends a wayside status request message to the wayside while connected to a base. IP transports are available; Verify messages are flooded across all transports.	Passed		1
CTT_PTC-SH_R-xxx_TC003_Cond-0	Locomotive sends beacon on messages to multiple WIUs.	Passed		1
CTT_RemoteSWUpgrade_TC01	Verity software can be downloaded remotely over 220 Mhz channel.	Passed		1

Appendix D - Requirements traceability

This appendix contains a requirements traceability matrix that maps a subset of radio and messaging requirements to one or more CTT 1 test cases.

Req ID	Category	Description	Test Status	Associated Test Case IDs
56	HA	The radio must be able to communicate with a Locomotive in the absence of a Base.	X	CTT_PTC-SH_R-xxx_TC003_Cond0 CTT_PTC-SH_R-xxx_TC004_Cond0 CTT_PTC-SH_SR049_TC07_Cond0 CTT_PTC-SH_SR049_TC02_Cond0 CTT_PTC-SH_R-71_TC003_Cond0
57	Latency	The system design and implementation must ensure that a Locomotive receives an updated Wayside status message in no more than 12 seconds with a reliability of 99.9999% when the Locomotive is within braking distance plus 12 seconds.	PARTIAL: Further analysis and testing Needed	CTT_SHC-2_TC01 CTT_SHC-2_TC02 CTT_SHC-6_TC01 CTT_SHC-6_TC02
58	Latency	The radio must support a latency for high priority messages (of up to 256 bytes) sent over the air between the wired side of one radio and the wired side of another radio which is not greater than 15 seconds for at least 99.9% of messages. This applies to all in-bound and out-bound messages and does not include Wayside status related messages.	PARTIAL: Passed Application to Application for certain Message Rates	CTT_SL-010_TC01 - CTT_SL-010_TC04 CTT_SL-012_TC01 - CTT_SL-012_TC04 CTT_DL-032_TC01 - CTT_DL-032_TC12 CTT_BRL_TC01 - CTT_BRL_TC07 CTT1_Lat-070_TC01 - CTT1_Lat-070_TC02 CTT1_Lat-075_TC01 - CTT1_Lat-075_TC04
59	Latency	The system must support a latency for high priority messages (application to application) which is not greater than 60 seconds for at least 99.9% of messages. This applies to all in-bound and out-bound messages and does not include Wayside status related messages.	FAIL: Does not Pass for handoffs known Defect in 1.0.3.4	All test cases where messages were sent excluding those where messages are much greater than the fragmentation limit
62	Latency	The system must support all latency requirements when a Locomotive, travelling up to 110 MPH, is transitioning from one Base Station to another Base Station.	Fail: Does not Pass for handoffs known Defect in 1.0.3.4	CTT_ML-060_TC01 - CTT_ML-060_TC05 CTT1_Mob-025_TC01 - CTT1_Mob-025_TC02 CTT_Mob_Radio104_TC02_Cond5
65	Load	The radio must support one or more beacon/status messages each beacon cycle from each WIU.	Blocked	CTT_PTC-Cap_065_TC01_Cond3
68	Load	The radio must give preference to transmitting beaconed status messages over any other type of message.	Blocked	CTT_PTC-SpclHdlng_068_TC01_Cond3

Req ID	Category	Description	Test Status	Associated Test Case IDs
80	Load	The system design must support two way communications from the Locomotive to the Wayside.	X	CTT_SL-010_TC01 - CTT_SL-010_TC04 CTT_SL-012_TC01 - CTT_SL-012_TC04CTT_PTC-SH_R-xxx_TC003_Cond0 CTT_PTC-SH_R-xxx_TC004_Cond0 CTT_PTC-SH_SR049_TC07_Cond0 CTT_PTC-SH_SR049_TC02_Cond0 CTT_PTC-SH_R-71_TC003_Cond0
80.1	Load	The system design must support a message from the Locomotive to the Wayside to turn on a sleeping beacon.	X	CTT_SHC-1_TC02
80.2	Load	The system design must support a message from the Locomotive to the Wayside to reset a beacon's timer.	X	CTT_SHC-1_TC02
81	Load	The system design must support two way communications from the Back Office to the Wayside.	X	CTT_SL-012_TC01 - CTT_SL-012_TC04
104	Mobility	The system design must support the ability for a Locomotive to detect and transition to a different Base Station without a dependency on information in a track database.	X	CTT_ML-060_TC01 - CTT_ML-060_TC05 CTT1_Mob-025_TC01 - CTT1_Mob-025_TC02 CTT_Mob_Radio104_TC02_Cond5
108	Network	The system must support prioritization of message delivery based upon the ITP QoS:Priority as defined in the ITP specification.	X	CTT_QosPRI_SR-048_TC002_Cond0 CTT_PTC-SpclHdlng_068_TC01_Cond3
111	Network	The radio must be provided with an ELM (External Link Manager) which provides a gateway into the 220MHz communication network, follows the ITP ELM specification, and runs on the standard ITP platforms.	X	All test carried out in either single or multi-ELM topolgy
111.1	Network	There is no requirement for a particular protocol to be used over the Ethernet for wired communications between the radio and the 220MHz ELM.	X	Testing with Acks / Keep Alives OFF CTT1_Lat-070_TC01 - CTT1_Lat-070_TC01 CTT1_Lat-075_TC01 - CTT1_Lat-075_TC02
114	Network	The 220MHz ELM must use QoS to indicate when it should or should not strip ITP and EMP headers off of a message before sending it on to the radio.	X	All Special Handling Tests CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02

Req ID	Category	Description	Test Status	Associated Test Case IDs
115	Network	The 220MHz ELM must use QoS to indicate when it should or should not add back ITP and EMP headers to a message where they were stripped off after receiving it from the radio.	X	All Special Handling Tests CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02
116	Network	The radio must use QoS to make necessary decisions about what RF Channel a message should be transmitted on.	X	All Special Handling Tests CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02
SR-009	App	The ITC Messaging System shall accept EMP messages from applications, and deliver EMP messages to applications.	X	CTT_ConfCN_SR-009_TC001_Cond0 CTT_ConfCN_SR-009_TC006_Cond0 CTT_ConfCN_SR-009_TC008_Cond0 CTT_ConfCN_SR-009_TC009_Cond0
SR-012	App	The messaging system shall accept or deliver messages from an application via the Class D protocol.	X	CTT_ConfCN_SR-009_TC001_Cond0 CTT_ConfCN_SR-009_TC006_Cond0 CTT_ConfCN_SR-009_TC008_Cond0 CTT_ConfCN_SR-009_TC009_Cond0
SR-013	App	The messaging system shall accept or deliver messages from an application via AMQP	X	CTT_ConfCN_SR-009_TC001_Cond0 CTT_ConfCN_SR-009_TC006_Cond0 CTT_ConfCN_SR-009_TC008_Cond0 CTT_ConfCN_SR-009_TC009_Cond0
SR-014	App	The messaging system shall only deliver complete messages to the destination application.	X	CTT_ConfFR_SR-014_TC001_Cond0 - CTT_ConfFR_SR-014_TC003_Cond0 CTT_Frag_SR-014_TC001_Cond5 - CTT_Frag_SR-014_TC008_Cond5
SR-019	Addr/Rtng	The messaging system shall support the delivery of peer-to-peer messages (between nearby remotes without going through a back office) over the 220MHz network.	X	CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02
SR-020	Addr/Rtng	The messaging system shall support the delivery of peer-to-peer messages over the 220MHz network whether or not there is a connection from the remote to a base station.	X	CTT_PTC-SH_R-xxx_TC003_Cond0 CTT_PTC-SH_R-xxx_TC004_Cond0 CTT_PTC-SH_SR049_TC07_Cond0 CTT_PTC-SH_SR049_TC02_Cond0 CTT_PTC-SH_R-71_TC003_Cond0

Req ID	Category	Description	Test Status	Associated Test Case IDs
SR-021	Addr/Rtng	If the messaging system cannot send a message to its destination, it shall retain the message until conditions support sending the message and then the messaging system shall again attempt to send the message to its destination.	X	CTT_Frag_SR-014_TC001_Cond5 - CTT_Frag_SR-014_TC006_Cond5
SR-022	Addr/Rtng	The messaging system shall update the routing information as the destinations lose and reestablish connections to the system.	X	CTT_Frag_SR-014_TC001_Cond5 - CTT_Frag_SR-014_TC008_Cond5 CTT1_ReR-090
SR-023	Addr/Rtng	The messaging system shall support the routing of messages over multiple communication paths (IP and non-IP, wired and wireless as underlying transports) simultaneously, in all segments.	X	CTT_ConfRL_TC001_Cond0 - CTT_ConfRL_TC004_Cond0
SR-024	Addr/Rtng	The messaging system shall accept messages from an application when there is no current path to the message destination.	X	CTT_QosPRI_SR-048_TC002_Cond0
SR-028	Addr/Rtng	The messaging system shall route messages around lost connections to the destination where the routing policy allows the use of other transport paths.	X	CTT1_ReR-090 CTT_Frag_SR-014_TC007_Cond5 CTT_Frag_SR-014_TC008_Cond5
SR-032	Addr/Rtng	The messaging system shall reconsider the appropriate path for a message whenever a new path becomes available for that message.	X	CTT1_ReR-090 CTT_Frag_SR-014_TC007_Cond5 CTT_Frag_SR-014_TC008_Cond5
SR-033	Addr/Rtng	The messaging system shall reconsider the appropriate path for a message whenever the selected path for that message becomes unavailable.	X	CTT1_ReR-090 CTT_Frag_SR-014_TC007_Cond5 CTT_Frag_SR-014_TC008_Cond5
SR-034	Addr/Rtng	The messaging system shall deliver messages to the application as specified by the destination address information in the message unless special handling applies.	Blocked	CTT_PTC-SH_SR049_TC01_Cond0
SR-037	Addr/Rtng	The messaging system shall respond to stable link up events (presence information) from each wireless transport network (WiFi, Cell or 220) and cause the routing information to be updated appropriately.	X	CTT1_ReR-090 CTT_Frag_SR-014_TC007_Cond5 CTT_Frag_SR-014_TC008_Cond5
SR-038	Addr/Rtng	The messaging system shall respond to link down events (presence loss information) from each wireless transport network (WiFi, Cell or 220) and cause the routing information to be updated appropriately.	X	CTT1_ReR-090 CTT_Frag_SR-014_TC007_Cond5 CTT_Frag_SR-014_TC008_Cond5

Req ID	Category	Description	Test Status	Associated Test Case IDs
SR-040	QoS-MC	The messaging system shall only allow a message to use a transport network if the message class of the message is among the transport network's allowable message classes, regardless of any other Routing Request parameters associated with the message.	X	CTT_ConfRL_SR-040_TC001_Cond0 - CTT_ConfRL_SR-040_TC003_Cond0
SR-041	QoS-NP	When the messaging system is unable to satisfy a network preference route request for specific transport preference, it should handle the message as if the transport preference was unspecified.	X	CCT_ConfRL_SR-041_TC001_Cond0 - CCT_ConfRL_SR-041_TC003_Cond0
SR-042	QoS-NP	The messaging system shall provide a mechanism for an application to request special handling for messages.	X	All Tests Involving special handling demonstrate this is satisfied
SR-047	QoS-P	Absolute Priority: The messaging system shall service higher priority messages prior to servicing lower priority messages.	X	CTT_QosPRI_SR-048_TC002_Cond0
SR-049	QoS-NP	The messaging system shall support a network preference route request attribute on a message that would instruct the system to transmit the message using every network transport which the configured message classes allow.	PARTIAL: Receiving Duplicates	CTT_ConfRL_SR-049_TC001_Cond0 - CTT_ConfRL_SR-049_TC003_Cond0 CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02
SR-052	QoS-P	The messaging system shall use the message priority to determine the order in which messages are sent.	X	CTT_QosPRI_SR-048_TC002_Cond0
SR-057	QoS-TTL	The messaging system shall discard messages that have not been delivered and whose TTL is expired.	X	CTT_QosPRI_SR-052_TC001_Cond0
SR-060	Qos-SH	The messaging system shall support sending messages over an underlying transport where connections are not established and routing policies are not exchanged when specifically requested by the application's routing request (i.e. special handling, network preference).	X	All Special Handling Tests (SHC 1,2 and 6) CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02
SR-064	Qos-SH	The messaging system shall communicate to the underlying transport the special handling that was requested by the application.	X	All Special Handling Tests (SHC 1,2 and 6) CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02
SR-127	Addr/Rtng	If two or more network transports meet criteria of class and network preference QOS values, the ITCM shall select the network transport with the lowest cost.	X	CTT_ConfRL_SR-127_TC001_Cond0

Req ID	Category	Description	Test Status	Associated Test Case IDs
SR-133	Addr/Rtng	The messaging system shall react to changes in routing information by re-determining the best path for a message at the next available routing decision point.	X	CTT1_ReR-090 CTT_Frag_SR-014_TC007_Cond5 CTT_Frag_SR-014_TC008_Cond5
SR-134	Addr/Rtng	The messaging system shall support the delivery of messages to 220mhz base stations for the purpose of broadcast out of that base station.	X	All Special Handling Tests (SHC 1,2 and 6) CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02 CTT_PTC-SH_SR049_TC01_Cond0
SR-144	Config.	After a new remote asset is provisioned, configured and activated it shall immediately function within the messaging system without the need for manual intervention.	X	CTT_ConfCN_SR-144_TC001_Cond0
SR-145	Addr/Rtng	All remote assets which come into coverage of the interoperable transport network supported by the messaging system , even for the first time, shall immediately be able to register their presence and exchange messages with the back office system without the need for manual intervention.	X	CTT_Mob_Radio104_TC01_Cond5 CTT_ConfCN_SR-144_TC001_Cond0
SR-178	Addr/Rtng	The messaging system on remote areas shall support a configurable filter on incoming wireless messages so that it can filter out and drop messages whose destination area does not match that remote area.	X	All Special Handling Tests (SHC 1,2 and 6) CTT_SHC-2_TC01 - CTT_SHC-2_TC02 CTT_SHC-6_TC01 - CTT_SHC-6_TC02 CTT_SHC-1_TC02
SR-200	Qos-P	The messaging system shall implement preemption so as to not delay the servicing of higher priority messages due to the servicing of lower priority messages.	X	CTT_QosPRI_SR-048_TC002_Cond0 CTT_PTC-SpclHdlng_068_TC01_Cond3

Req ID	Category	Description	Test Status	Associated Test Case IDs
SR-211	Configuration	The Messaging system shall support the immediate application of configuration changes in the following scenarios: - Adding a radio to an External Link Manager (ELM) - Adding an application to an Application Gateway (AG) - Changing the logging level of a component Immediate means the added configuration is available without requiring a restart of the component. The specific parameters to support these scenarios are provided in Application Parameter Characteristics (MCC DCN REQ-PTC-00001226-A, published 3/9/2011). All other parameter changes shall require a restart of the affected component(s) to take effect.	Fail: Class D / Connection, Defect in 1.0.3.4	CTT_ConfCN_SR-145_TC002_Cond0

Appendix E - Key performance indicators

Key performance indicators (KPIs) are quantifiable metrics that reflect certain performance levels of the PTC communication system. KPIs provide a metric to compare various system configurations, software releases, and hardware versions. Additionally, KPI measurements are used to validate some requirements. A list of PTC communication System KPIs and their associated performance requirements are given in Table 23.

Category	Description	Requirement	Req. Ref.	Applicable to CTT 1	Notes
Message Rate	Back office message rate	7500 messages/sec (6900 to remotes, 600 from remotes)	SR-086		Minimum measurement time is 8 hrs
Message Rate	Mobile message rate	33 messages/sec (32 in, 1 out)	SR-087	X	Minimum measurement time is 8 hrs
Message Rate	Wayside Message Rate	6 messages/sec (5 in, 1 out)	SR-088	X	Minimum measurement time is 8 hrs
Message Routing	Message routing updates	Process 50 routes/sec	SR-149		
Message Routing	Path updates	Respond to new paths and update routing info < 1000ms	SR-084		
Message Routing	Message path updates between offices	propagate addition/removal of paths < 3 sec	SR-085		
Message Latency	Locomotive segment	TBD	SR-185	X	
Message Latency	Wayside segment	TBD	SR-186	X	

Radio Network Latency	Latency for high priority over the air messages.	<15 s, 99.9% of high priority messages (<=256 bytes)	R58		Over the air: wired side of one radio to the wired side of another radio.
Radio Network Latency	Latency for high priority over the air messages, Locomotive travelling <=110 MPH	<15 s, 99.9% of high priority messages (<=256 bytes)	R62		Locomotive is transitioning from one Base Station to another Base Station.
Radio Network Traffic Load	System must support a minimum number of wayside beacon/status messages.	30 beacon/status messages per cycle	R69	X	Under the coverage of a single base. Loading model: PTC_Demand_Study_Version_03.xls
Radio Network Traffic Load	Base to the Locomotive message traffic bit rate.	4 Kbits/sec of traffic over and above the PTC traffic load	R82.1	X	Not including link level overhead
Radio Network Traffic Load	Locomotive to the Base message traffic bit rate.	4 Kbits/sec of traffic over and above the PTC traffic load	R82.2	X	Not including link level overhead
Radio Network Traffic Load	Operational PTC trains under a single Base Station.	>= 24	R85		