METEORCOMM LLC

ITCR 1.1 System Architecture Specification

Document Revision: 4.0
Document Number: 00002542-A

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Document Number: 00002542-A

Revision history

Revision	Date	Summary of Changes
1.0	8/19/2011	Initial release - dnc 00001622-A
2.0	9/7/2011	Second release - dnc 00001622-B
3.0	11/17/2011	Third release - dnc 00001622-c
4.0	11/14/2012	Fourth release - FRA dcn 00002542-A change

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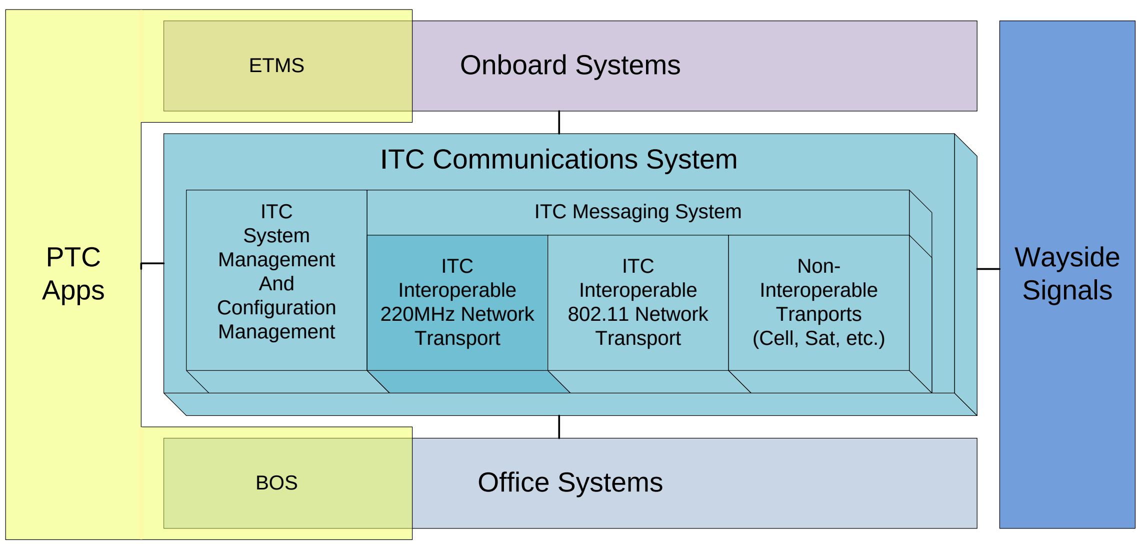
1. Introduction

1.1 Overview

This document is one of three documents in a set of specification documents that describe the ITC 220 MHz Radio Network. This network provides communications for Positive Train Control (PTC) and is composed of 220 MHz data radios designed specifically for this application.

The following diagram places the ITC 220 MHz Radio Network in the larger Interoperable Train Control (ITC) System context.

Figure 1: ITC system configuration



The 220 MHz Radio Network is the only nationwide interoperable transport within the ITC Messaging System. Interoperable transports allow direct communications between the remote asset of one railroad (for example, a locomotive) and a back office of another railroad. The other interoperable transport, 802.11, will only be available in limited coverage areas such as yards or terminals. Other message transport networks will be supported by the ITC Messaging System but will not be directly interoperable. Rather, they will be made effectively interoperable by routing messages through back offices to and from the target back office. As part of the messaging system, these transport networks provide data communication services between back office, locomotive, and wayside areas over any available

transport network. Their primary purpose is to transport PTC messages between these areas.

1.2 Purpose

These documents are primarily for use by Railroads as a description of the 220 MHz Radio Network functionality and the products that make up the network. They can be used:

- to provide information to support radio-frequency (RF) network engineering
- as a detailed description of what the products will do
- for customer review of the features and functionality
- to outline the parameters of acceptance tests

These documents will also be used internally by the Communications System Integrator and vendors to drive product development. Finally, they can be used to provide context to a radio manufacturer. By themselves, these specification documents are insufficient as test requirements or product design requirements and are not to be used as such.

1.3 Organization

- ITC 220 MHz Radio System Architecture Specification
- ITC 220 MHz Radio Functional Specification
- ITC 220 MHz Radio Hardware Specification

The System Architecture Specification document addresses system level aspects of the ITC 220 MHz Radio Network.

The Functional Specification document addresses the functionality provided by the radios and software that make up the 220 MHz Radio Network. The Hardware Specification document addresses the electrical, mechanical, and RF characteristics of the radios.

1.4 Scope

This document describes the system architecture-level features and functionality of the ITC 220 MHz Radio Network. It focuses on functionality that crosses the boundaries of individual system components, for example, by explaining interactions between the ITC 220 MHz Radio Network and parts of the larger ITC system, such as WIUs, onboard systems, and ITC Messaging System components.

In summary, this document describes:

- High-level system architecture that is relevant to the ITC 220 MHz radios
- Product features and interfaces of ITC 220 MHz radios and the ITC 220 MHz Radio Network
- Architecture and interface-related information that drive more detailed, lower-level product development

The following are out of the scope of this document:

- 220 MHz radio hardware, including mechanical, electrical, and packaging specifications
- 220 MHz radio functionality, including details of network connections, radio interfaces, boot processes, details of radio configuration and updates, and maintenance
- ITC system architecture (beyond the 220 MHz Radio Network), including details of the ITC Messaging System, ITC System Management System, Wayside Systems, Onboard Systems, Back Office Systems, or wired network architecture

The scope of this set of specification document is based on ITC requirements baseline documents [7], [8].

1.5 Assumptions

The following assumptions have helped to drive the specifications:

- A key driver of the 220 MHz Radio Network design is efficient use of the available spectrum for PTC message traffic. As such, the design is optimized with a focus on the specific needs of PTC.
- In order to deploy the initial product release, Release 1.0, in a timely manner, the initial release focuses on delivering critical and core functionality. Software functionality that was not deemed critical or core has been deferred to future releases.

- The follow-up release, Release 1.1, concentrates on providing core system management functionality to the existing Release 1.0 radio network. The most important aspect of system management at this point is to be able to perform software and configuration updates remotely. This will greatly reduce radio network operational expense, as updates to radios can be performed without having to visit radio locations. Other system-management functions are targeted to future releases.
- The ITC Communications system will be a single federated network shared across all participating railroads. This means that any railroad can have its remote assets connect and make use of any other railroad's base station assets over the 220 MHz Radio Network.
- To reduce unnecessary overlapping coverage, and to make the most efficient use of the available 220 MHz spectrum, some portions of the ITC 220 MHz Radio Network will have base stations that are shared among the railroads.

1.6 Acronyms

Acronym	Term	Description
	Address Resolution Table	A table in an ELM which is used to keep track of RF connections through attached radios.
AMQP	Advanced Message Queuing Protocol	A standard messaging protocol used by the ITC Messaging System.
AAR	American Association of Railroads	Industry association for North American rail industry. A major standards-generating body.
AG	Application Gateway	ITC Messaging System component which applications connect to and through which they send messages into the system and get messages from the system.
	Area	A subset of the Messaging System that has defined boundaries and physically hosts Messaging System components.
BO	Back Office	A facility containing network infrastructure for railroad operations.

Acronym	Term	Description
BOS	Back Office Server	Used in this document in a generic manner to mean the primary message handling service in the back office (especially for PTC messages). This term is not meant to refer to the ARINC BOS software package which is also known by that acronym.
	Beacon	Unsolicited, periodic, broadcast message. Currently two types of beacons are supported in the system. There is a base beacon which advertises information about a base station and there is a generic capability to send FTDMA beacons (e.g. used for wayside status beacons).
	Broker	Used synonymously with router and ITPR. A component of the ITC Messaging System which routes messages through the system and chooses the underlying networks to use.
CSMA	Carrier Sense Multiple Access	An air access technique where a transceiver senses activity on a channel before transmitting. See section 6.2.4.
CR	Change Request	An initiative that is submitted into a change control process in an organization.
	Class C	An AAR published protocol which is substantially based upon UDP/IP.
CBTC	Communication Based Train Control	Older terminology which can be considered to be synonymous with PTC or ITC.
CIM	Configuration Information Module	A removable device used primarily to store site-specific configuration information and log files. The CIM typically is associated with an installation location and can be transferred from one radio to another to maintain application continuity.
	Class D	A protocol that converts a stream based TCP protocol to a message or transaction based protocol. Class D also adds support for features such as connection monitoring/persistence and high availability. See section6.3.1.
DHCP	Dynamic Host Control Protocol	A computer networking protocol that dynamically assigns IP addresses to devices on a network.

Acronym	Term	Description
DTDMA	Dynamic Time Division Multiple Access	An air access technique where time is dynamically divided up into slots and assigned to a transmitter based upon traffic load. See section 6.2.4.
DQPSK	Differential Quadrature Phase-Shift Keying	A linear modulation waveform that relies on the difference between successive phases of a signal rather than the absolute phase position. The DQPSK modulation has 2 bits per symbol and a symbol rate of half the bit rate. See section 6.2.2.
EMP	Edge Message Protocol	An AAR published application level protocol.
ERP	Effective Radiated Power	A standardized theoretical measurement of RF energy using the unit watts.
ETMS	Electronic Train Management System	An application which runs onboard the locomotive on the TMC and which provides information to the crew as well as providing a safety backup by slowing or stopping the train if necessary.
ELM	External Link Manager	A software application that is the bridge between the ITC Messaging System and the ITC 220MHz Network.
FCC	Federal Communications Commission	Wired and wireless communications regulating body of the United States.
FTDMA	Fixed Time Division Multiple Access	An air access technique where time is statically divided up into slots and assigned to users or message sources through configuration. See section 6.2.4.
FEC	Forward Error Correction	A system of error control whereby the sender adds compressed redundant data to its messages that allow the receiver to detect and correct errors (within some bound) without the need to resend any data. See section 6.2.8.
FSU	FTDMA Slot Unit	An FTDMA frame is broken into units called FSUs. FTDMA slots are defined by a starting FSU and a length in FSUs. See section 7.5.2.
GPS	Global Positioning System	A space-based satellite system which provides position and time information at any location on a continuous basis.

Acronym	Term	Description
	GPS Timing Chip	A GPS chip developed with a focus on providing accurate time. With a good position (surveyed for example), these chips can generally provide accurate time even with a lock on only 1 satellite.
	Headroom	Capacity in the network planned for unanticipated PTC load peaks as well as for business load (lower priority) when not in use by PTC. See section 5.4.
HRX	Host/Radio eXchange (protocol)	An application level protocol used for communications between a radio and an ELM. See section 6.3.
	Inbound Messages	Messages which are travelling from a remote area (locomotive or wayside) into an office.
	Interoperable	Communications directly between the remote asset of one railroad and the office of another railroad.
ISMP	ITC System Management Protocol	An application level protocol that is used for all communication regarding ITC System Management (SMS). See section 6.5.
ITC	Interoperable Train Control	A communications-based method of controlling and monitoring train movement, permitting multiple Railroads to share track and facilities.
ITCSM	ITC System Management	A part of the ITC Communication System responsible for managing the network and devices connected to the network. This includes monitoring and managing alarms, log access, configuration management, and so on.
ITP	ITC Transport Protocol	A generic term for the protocol used by the ITC Messaging System to transport messages from one end of the messaging system to the other end (AG to AG). ITP will actually be implemented as AMQP.
	ITCnet	The air interface protocol used by the ITC 220 MHz radios to communicate with each other. See section 6.2.
ITPR	ITP Router	Used synonymously with broker and router. A component of the ITC Messaging System which routes messages through the system and chooses the underlying networks to use.

Acronym	Term	Description
	Link	A connection between two directly connected messaging components (for example, between an ELM and a router/broker).
MPLS	Multiprotocol Label Switching	A mechanism for creating high-performance "virtual links" between network nodes which can encapsulate packets of various network protocols. Used as the method of connecting the various railroad back office networks.
NMS	Network Management System	Used as a synonym for System Management in this document.
	OSI 7 Layer Model	A standard layered description for communications and computer network protocol design published as part of the Open Systems Interconnection (OSI) initiative.
	Outbound Messages	Messages which are travelling from an office to a remote area (locomotive or wayside).
	Peer to Peer	Communications directly between nearby remote areas (i.e. locomotives or waysides) without going through any back office components. Peer to peer communications are only supported over the 220 MHz Radio Network and will work when there is no base coverage.
	π/4 DQPSK	A variation of DQPSK waveform with phase transitions rotated by 45 degrees. See section 6.2.2.
PTC	Positive Train Control	An umbrella term that refers to technology focused on preventing train-to-train collisions, over-speed derailments, and casualties or injuries to roadway workers. See section 2.1.
PA	Power Amplifier	A device in the radio that changes, usually increases, the amplitude of an RF signal.
	Preemption	Stopping/deferring the processing of a lower priority message in order to quickly process a higher priority message. See section 3.
	PTC 220, LLC	An organization which owns 220 MHz spectrum for use in the ITC Communications System.

Acronym	Term	Description
QoS	Quality of Service	Information used by an application to give specific instructions to the Messaging System about how to handle a message. See section 7.4.1.
RF	Radio Frequency	
RSIA	Rail Safety Improvement Act	A law from 10/16/2008 requiring an interoperable PTC system to be implemented by the end of 2015. See section 2.2.
RX	Receive	Refers to either a receiver or reception.
	Remote	Used to refer to an area or asset which is not an office (that is, locomotive or wayside). Also used to refer to a radio on the other side of an RF connection from the radio under discussion.
	RF Connection	A connection between two radios.
RRC	Root Raised Cosine	The square root of the raised cosine function used as a transmit/receive filter. See section 6.2.2.
	Router	Used synonymously with broker and ITPR. A component of the ITC Messaging System which routes messages through the system and chooses the underlying networks to use.
SNMP	Simple Network Management Protocol	A standard UDP-based network protocol which will be used as part of the ITC System Management solution between managed devices or components and the SM Agents managing them.
	Slotted CSMA	An air access technique similar to CSMA but organizing the channel into slots and then only starting a transmission at the beginning of a slot. See section 6.2.4.
	SM Agent	A component of the ITC System Management System which will manage devices and components on the same local network on which it is running and which will use the ITC Messaging system to communicate to a System Management Server or Console as necessary.
SDR	Software Defined Radio	A radio technology where components that have typically been implemented in hardware are instead implemented using software.

Acronym	Term	Description
TDD	Time Division Duplex	Emulation of full duplex over a half-duplex communication link by having designated time allocations for traffic in each direction.
TTL	Time to Live	The amount of time that a message should live before being discarded by the messaging system. See section 7.4.1.
	Track Database	A database onboard a locomotive with information about the track and waysides along a route. This information is used by the ETMS/TMC to implement PTC functionality.
TMC	Train Management Computer	A vital computer onboard a locomotive that implements PTC functionality. The ETMS application runs on the TMC. See section 2.2.
TX	Transmit	Refers to either a transmitter or transmission.
	Transport	A term used to designate a network (usually RF)
VDU	Video Display Unit	A non-vital display onboard a locomotive used by the TMC to display PTC information to the crew. See section 2.2.
	Vital	A term used to indicate that something requires fail-safe operation as part of a critical safety system.
WIU	Wayside Interface Unit	Devices alongside the track that gather and pass along signal status, switch position, and track status information.

1.7 References

[1] Radio Hardware Specification, “ITC 220 MHz Radio Hardware Specification”, ver1.3, 6/15/2011, HWD-PTC-00001040-C

[2] Radio Functional Specification, “ITC 220 MHz Radio Functional Product Specification”, ver1.0.1, 6/6/2011, PRS-PTC-00001056-B

[3] Rail Safety Improvement Act, “Public Law 110-432 Federal Rail Safety Improvements,” 10/16/2008

[4] EMP Specification, “EMP Message Format Specifications”, ver2.0, 9/23/2009

[5] Class C Specification, “Class C Messaging Specifications”, ver1.6, 3/1/2010

[6] ITCM System Architecture, “ITC Messaging System Architecture”, SWD-PTC-00001004-A, 1/20/2011

[7] ITCC Release 1.0 Requirements Baseline, “ITCC Release 1.0 Requirements Baseline”, REQ-PTC-00001174-I, 7/6/2011

[8] ITCC Release 1.1 Requirements Baseline, “ITCC Release 1.1 Requirements Baseline”, REQ-PTC-00001174-E, 5/19/2011

[9] PTC Demand Study, “PTC_Demand_Study”, ver0.4, 3/13/2009

[10]Wayside Status Comm Use Cases, “ITCC Wayside Status Communication Use Cases”, 10/27/2009

[11]ITCSM Architecture, “ITCSM Architecture”, v1.4, SYS-PTC-00001149-A, 7/19/2011

[12]Class D specification, “Class D Messaging Specification”, v.3.2, ITC Messaging Team, 3/1/2010

2. ITC system background

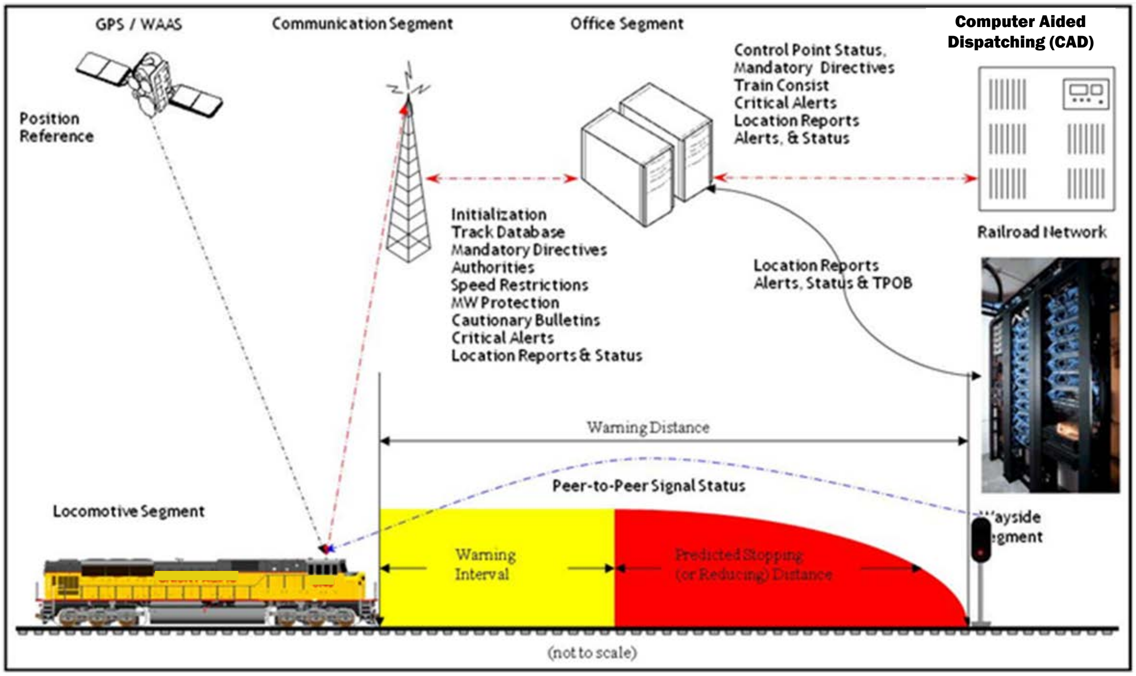
This section provides background on PTC and the ITC System for readers who are not familiar with these concepts. Major portions of the material in this section were pulled from the ITC Messaging Architecture document (Reference [6]).

2.1 Positive Train Control (PTC)

Rail systems, whether freight or passenger rail, are complex systems, requiring the management of the movement of thousands of pieces of equipment over many miles of rail. Signal systems assist with coordinating these movements by providing instructions to locomotive engineers and feedback to dispatchers about vehicle movement. However, as human beings are inherently “human,” mistakes can be made, leading to accidents. Signal systems are also not perfect, and although systems are designed to downgrade to a stop or restricting signal in the event of failures, system failures are still possible.

Positive Train Control (PTC) is an umbrella term that refers to technology that is capable of preventing train-to-train collisions, over-speed derailments, and casualties or injuries to roadway workers (for example, maintenance-of-way workers, bridge workers, signal maintainers) operating within their limits of authority as a result of unauthorized incursion by a train. PTC is also capable of preventing train movements through a switch left in the wrong position.

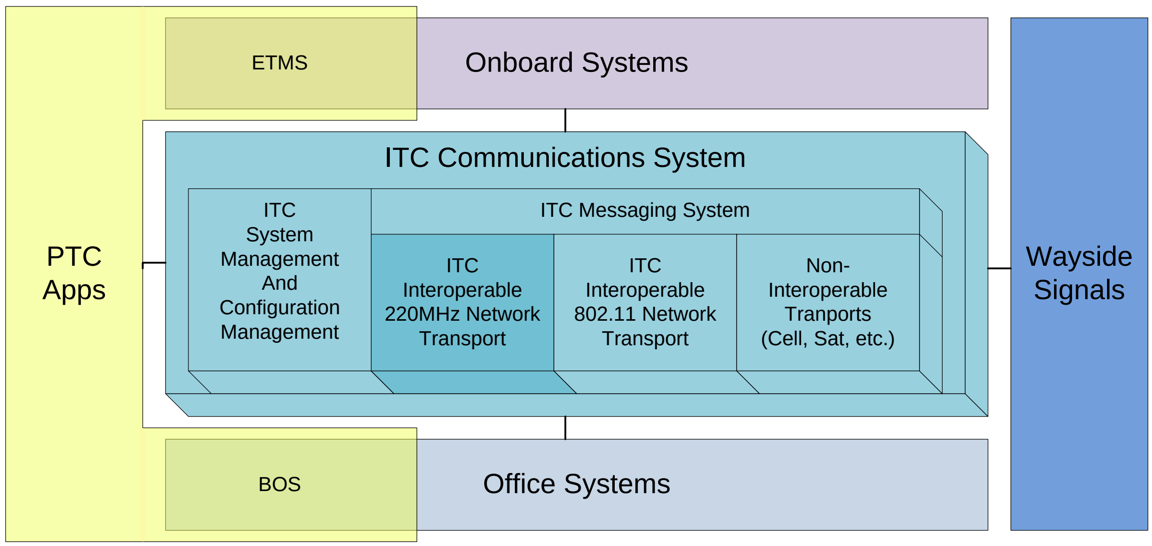
Figure 2: PTC overview



PTC systems generally consist of equipment on the rail vehicle, equipment in the control center, equipment on the rail wayside, and wireless communication between all three elements. Global positioning systems (GPS) provide location information of each vehicle to the control center. The PTC system essentially reviews speeds, track conditions, and vehicle locations and determines braking curves for each vehicle. The system alerts the vehicle crew if a condition presents itself that requires the train to slow or stop. If the crew does not respond, emergency braking is automatically applied.

2.2 ITC system overview

Figure 3: ITC system components



The ITC System is a locomotive-centric train control system designed to be overlaid on existing methods of operation and provide a high level of railroad safety through enforcement of a train's authority limits, enforcement of permanent speed restrictions, and enforcement of temporary speed restrictions. The ITC System includes a non-vital in-cab Video Display Unit (VDU), a safety-critical Train Management Computer (TMC) with redundant processors, and cross-checking capabilities running an Electronic Train Management System (ETMS), including a vital locomotive brake interface and a vital CAB Signal Monitor (CSM-1200) as well as a non-vital Back Office Server (BOS).

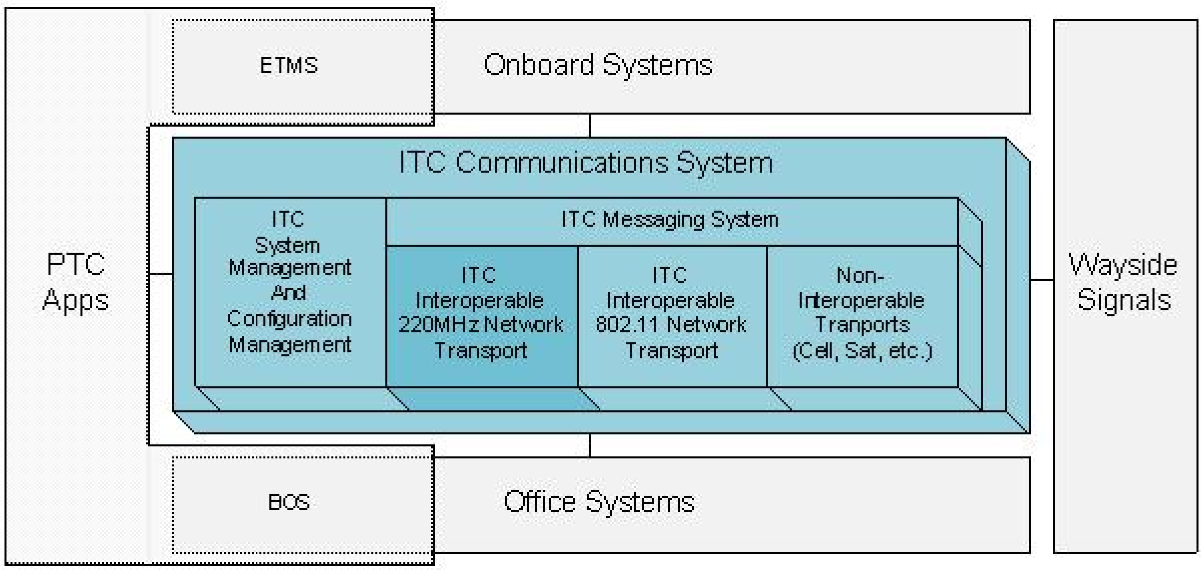
The communications logic and messages used in the ITC system are designed in a vital manner to provide a safety-critical message delivery process and ensure safety while operating with non-vital communications systems. The design and implementation of communications protocols provides the ITC system with multiple, redundant communications circuits for communications between the locomotive On-board system and the Back Office Server (BOS). The design and implementation of the peer-to-peer communications system provides the ITC system with a fail-safe or vital method of communicating wayside switch and signal state to the locomotive on-board system over a non-vital communications circuit.

The overall system relies on vital components in the field to monitor and provide the status of the current block to the on-board system via CAB

Signal, the switch state in non-signaled territory, or the signal state via a peer-to-peer radio network. CAB Signal indications are monitored by the CAB Signal Monitor (CSM-1200) in a vital, non-intrusive manner. The CAB Signal indications are conveyed by the CSM-1200 to the Train Management Computer (TMC) in a fail-safe or vital manner. The locomotive engineer is provided feedback when specific operating thresholds are exceeded. Feedback provided to the locomotive engineer is logged and downloaded to the Back Office Server (BOS) for internal distribution, recordkeeping, and potential follow-up.

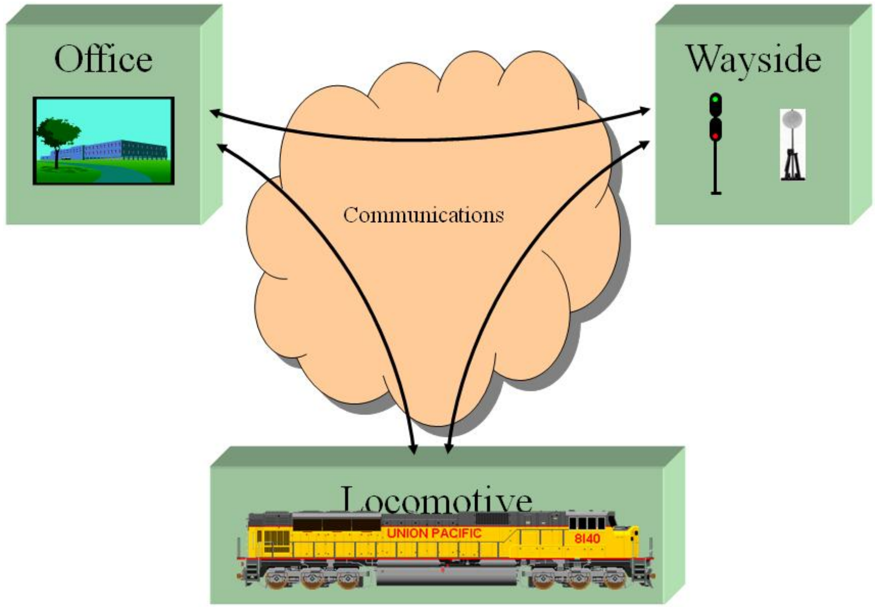
2.3 Communications system overview

Figure 4: ITC communication overview



The ITC system consists of components physically and logically divided into four subsystems or segments: Office, Locomotive, Wayside, and Communications. The communications segment provides connectivity between each of the other segments. It includes everything involved in communications over both wired and wireless networks.

Figure 5: ITC system segment relationships



The wireless networks are made up of narrowband networks (low-data throughput and high coverage such as 220 MHz) and broadband networks (high-data throughput and low coverage such as 802.11). These wireless networks are connected to wired networks at physical access points (that is, 220 MHz base station locations, 802.11 access points, and so on) for backhaul. The broadband networks are primarily used for initial bulk data downloads to the identifying unit of a train that is preparing to use ITC in its operations. The narrowband network is primarily used in continuous position reporting, data updates, and wayside status communications. The narrowband network can serve as a secondary network for initial bulk-data download.

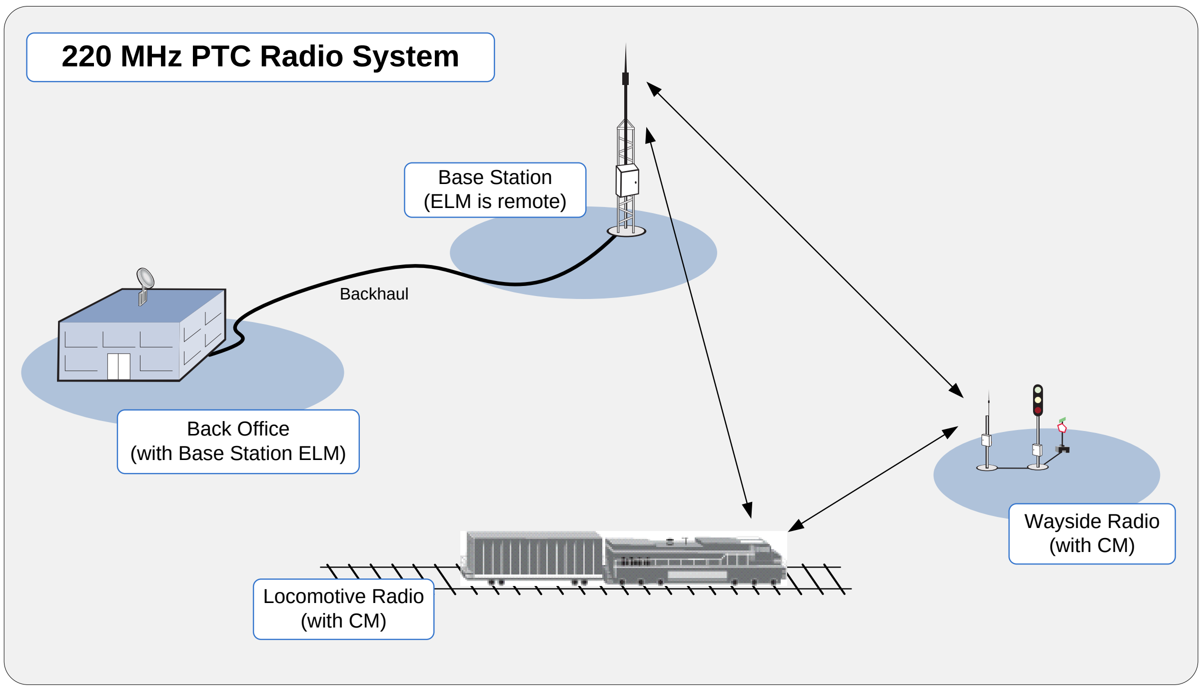
The communications segment also provides data communications and messaging functions between Office segments. It includes MPLS networks interconnecting the Back Office segments of each of the Class 1 railroads or other participating rail organizations.

3. 220 MHz radio network overview

Figure 6 shows a diagram of the ITC 220 MHz Radio Network. This network connects three (3) different types of areas: Locomotives (mobile remote areas), Waysides (static remote areas), and Back Offices (office areas). In order to make the most cost-effective and efficient use of available 220

MHz bandwidth, a different type of radio will be used for each of these different areas. An office will make use of many base station radios. Each locomotive will have a radio. A single radio will serve one or more waysides through a single CM. These different radios will address different operational environments and RF link requirements for each of the different areas. Due to the radios' architecture and design, these radios are commonly referred to as software-defined radios (SDRs).

Figure 6: High level 220 MHz radio network system diagram



The base stations run in an office area and the waysides and locomotives are called remote areas. Communications from an office to a remote are called outbound communications. Communications from a remote to an office are called inbound communications. Inbound and outbound communications are controlled by the Base radio. The network also supports peer-to-peer communications between two nearby remotes. Initially, the peer-to-peer communications will only be used for wayside to locomotive communications (more detail in section 7.5).

Following are some of the key goals and concepts that apply to this architecture:

- The radios communicate over the air in half-duplex (or TDD) mode using a combination of FTDMA, DTDMA, and CSMA. A more detailed description of the air interface can be found in section 6.2.

- Due to the limited bandwidth available and the desire to make optimal use of the available spectrum, minimizing overhead is a primary goal of the architecture.
- Due to a mix of high-priority PTC messages and lower priority messages, it is critical that every component in the system support quick preemption of servicing of lower-priority messages in favor of servicing higher-priority messages. This will allow an important (PTC) message to flow through the system quickly, even when the system is heavily loaded with low-priority messages.
- There is an architectural goal (and a requirement) of having no direct dependencies between the communications system and the PTC system. In other words, although the communications system is optimized to carry PTC traffic, the system and components should work fine carrying message traffic for systems other than the PTC system (given the limits of functionality built into the system). As an example of this principle, 220 MHz Radio Network data (for example, frequency info) has not been added to the Track Database. This avoids the need for the communications system to have data from an application in order to operate. It also avoids operational complexity in keeping the Track Database up to date with 220 MHz Radio Network updates.

The following are specifications related to types of communications that the system will support.

Table 1: Communications type specifications

Function	Description	Value	Conditions
Wayside-to-Office Messaging	Communications will be supported between a wayside and a base	Both directions	Wayside is covered by a base
Network engineered with sufficient signal strength between base and wayside			
Locomotive-to-Office Messaging	Communications will be supported between a locomotive and a base	Both directions	Locomotive is covered by a base
Network engineered with sufficient signal strength between base and locomotive			

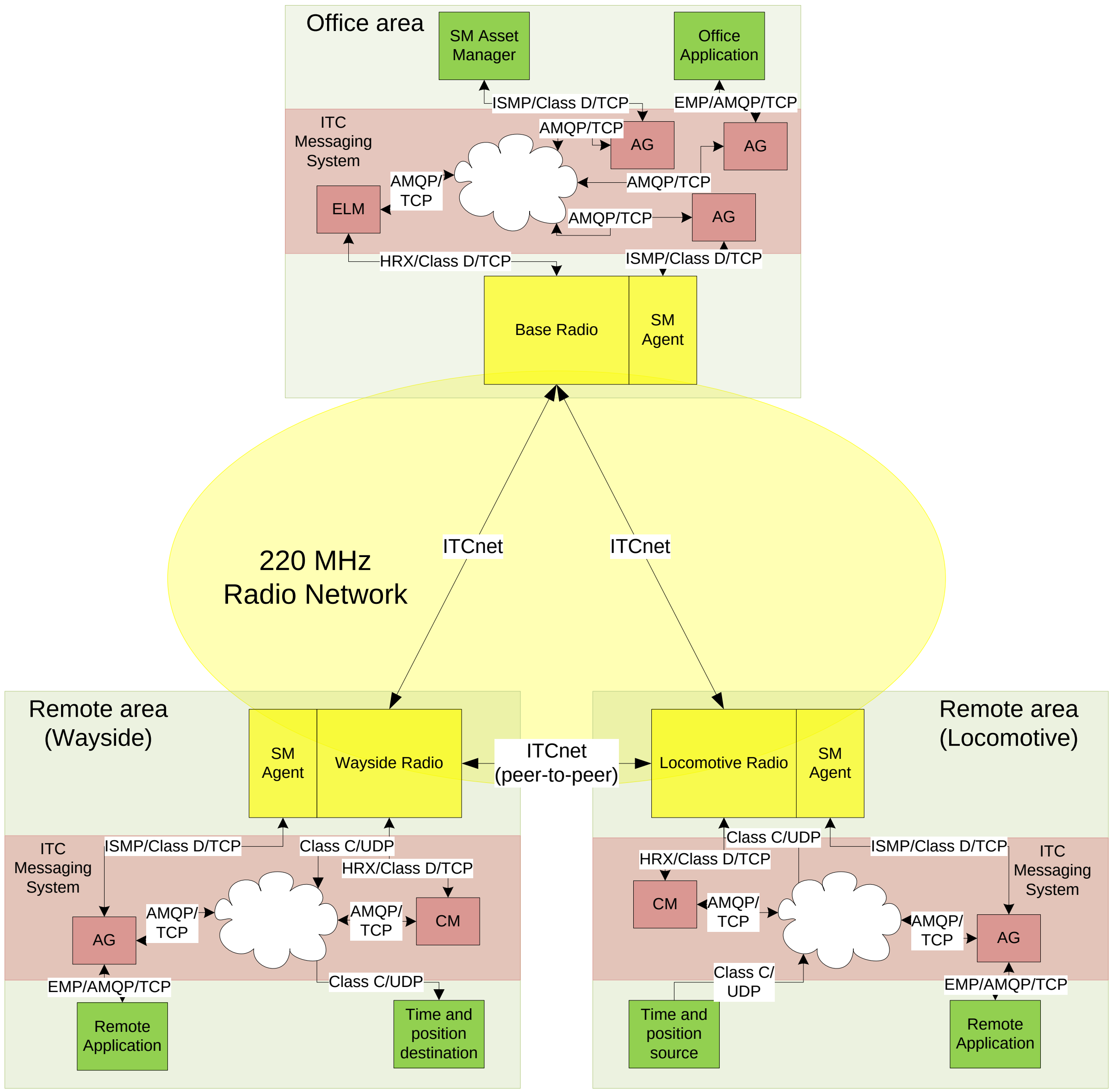
Function	Description	Value	Conditions
Locomotive-to-Wayside Messaging	Communications will be supported between a locomotive and a wayside	Both directions	Base coverage not required
Network engineered with sufficient signal strength between wayside and locomotive			

4. 220 MHz radio network component overview

In Figure 7, you can see the components of the ITC 220 MHz Radio Network in yellow. The ITC messaging system components, some of which are connected to radio network components, are designated in red. The endpoint applications are marked in green.

The network is comprised of four major components. The first three are the radios for each area type (Base, Locomotive, and Wayside). The fourth component is either an External Link Manager (ELM) or a Connection Manager (CM) that bridges from the 220 MHz Radio Network to the outside world and is in fact considered to be part of the ITC messaging system. The message flow primarily goes through the ELM or CM. One exception is that the system management agent, which is an embedded part of the ITC radios, communicates directly with a messaging system AG using ISMP protocol.

Figure 7: ITC 220 MHz radio network components



The following sections give a high-level overview of each of these components.

4.1 ITC 220 MHz radio summary

Table 2 provides a quick summary of the three ITC 220 MHz software-defined radios.

Table 2: 220 MHz radio summary

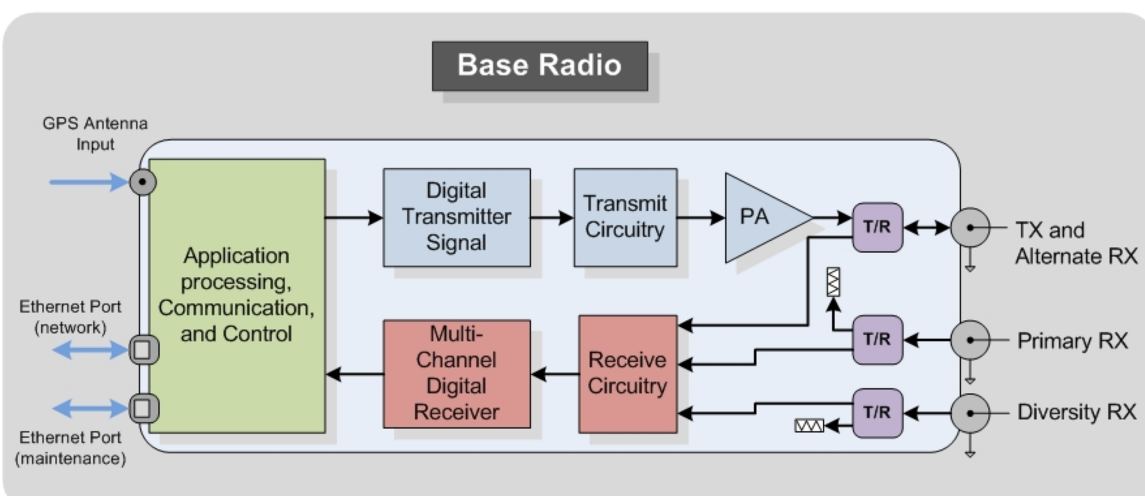
	Wayside	Locomotive	Base
Application of Device	Fixed remote installations	Mobile remote installations	Base Station installations
Frequency Band	217.6-222.0 MHz	217.6-222.0 MHz	217.6-222.0 MHz
Channel spacing	25kHz	25kHz	25kHz
Simultaneous Transmit Channels	1	1	1
Primary Receive Channels	2	8	8
Diversity Receive Channels	0	8	8

4.2 Base radio

Base radios are installed at fixed locations and provide RF connectivity between Back Office (BO) applications and applications running in remote areas (Locomotives and Waysides). The backhaul between the Base radio and the BO is typically in the throughput range 56 kbps to 1 Mbps, depending on traffic load and radio configurations. The Base radios also use the pulse per second (PPS) from an onboard GPS timing chip for channel synchronization.

Base radio sites, TX power levels, and antenna characteristics are designed to provide radio coverage to all waysides and operational locomotives in the system.

Figure 8: High level radio block diagrams



4.3 Locomotive radio

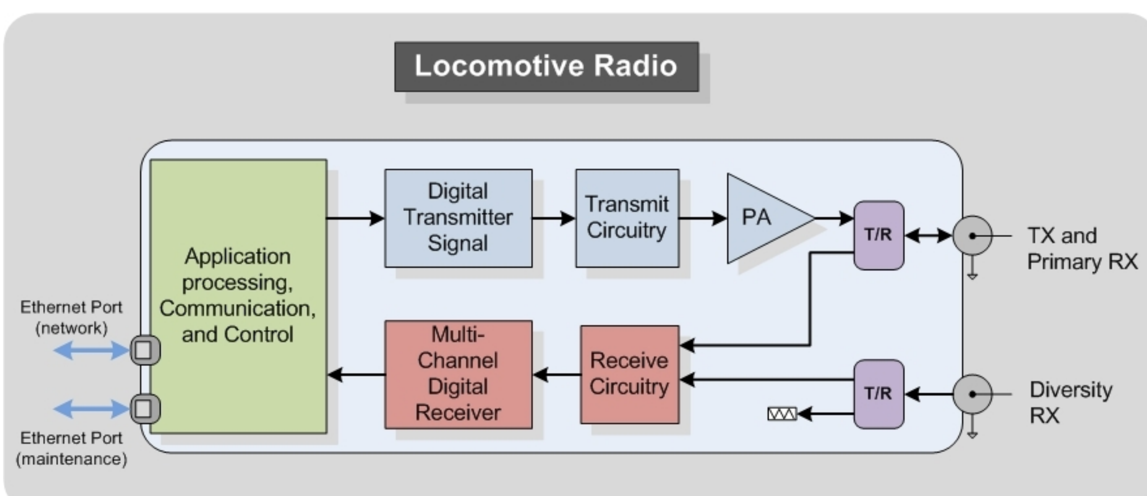
Locomotive radios are remote radios installed in the cab of locomotives and are the mobile radio element of the ITC 220 MHz Radio Network. For normal operation within the system, a locomotive communicates with the BO through a Base radio over a 220 MHz RF link. To establish this link, a Locomotive radio registers with a Base radio. As long as the base is the best one available for that locomotive, the locomotive will continue to communicate with the BO through that base.

As a locomotive moves along the track, it moves out of the RF coverage of one base and into the RF coverage of another. As this happens, the locomotive registers with the new base. As much as possible, the system is designed with overlapping base coverage along the tracks. Under this condition, as the locomotive moves down the track, the Locomotive radio will decide when to drop communication with one base and register with the next. This decision is based on a number of criteria and is discussed in more detail later in the document.

Locomotive radios also communicate directly with waysides and must do so even when there is no base coverage. There could be no base coverage due to a failure at the Base radio site or simply because providing base coverage to a particular section of track is cost prohibitive.

The Locomotive radios do not have onboard GPS like the Base and Wayside radios. Rather, they are controlled by the Base radio for channel synchronization.

Figure 9: High level locomotive radio block diagrams

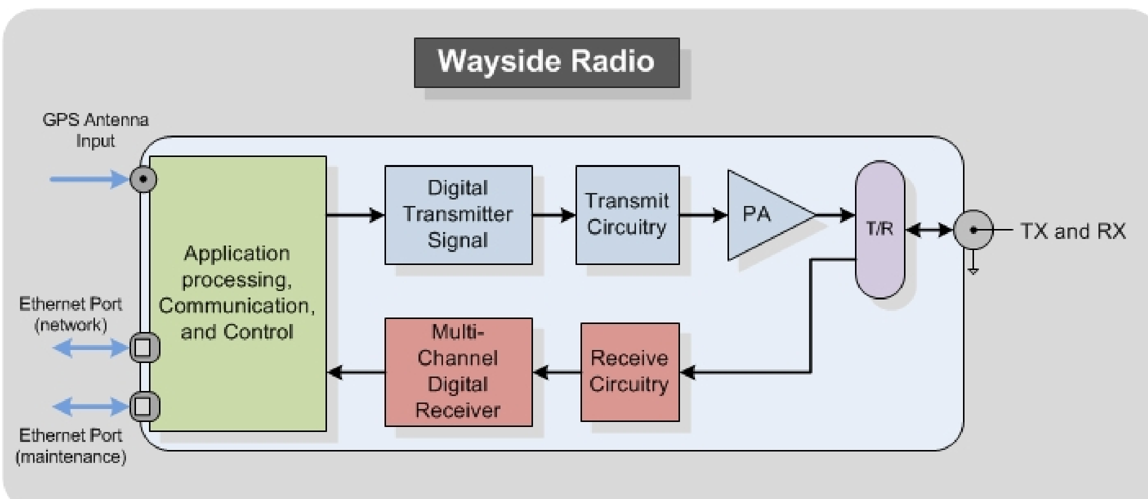


4.4 Wayside radio

Wayside radios are remote, fixed-location radios installed at waysides. These radios provide wayside signal status, switch position, and track integrity information to locomotives. Wayside radios will also provide the ability for the wayside to communicate with the BO for maintenance and other purposes. Some waysides may have access to the BO through a broadband connection. The Wayside radios use the pulse per second (PPS) from an onboard GPS timing chip for channel synchronization of transmissions that are not controlled by the Base radios.

Wayside radios also communicate directly with locomotives and must do so even when there is no base coverage. There could be no base coverage due to a failure at the Base radio site or simply because providing base coverage to a particular section of track is cost-prohibitive.

Figure 10: High level wayside radio block diagrams



4.5 External link manager

The External link manager (ELM), or Connection Manager (CM) in the case of a remote radio, is a messaging component that is the bridge between the ITC Messaging System and the ITC 220 MHz Radio Network. The ELM and CM present consistent interfaces to the ITC messaging system, which hide the details of the underlying transport.

The ELM or CM will not run on the radio. Rather, it will run on the same hardware platform as the rest of the ITC Messaging System in an area. In the

BO, that would be on a BO server on the office side of the backhaul. On the locomotive and wayside, the Connection Manager (CM) will run on a computer that is on the same local subnet as the radio. For the ITC 220 MHz Radio Network, all normal message traffic related communications to and from the radios will be through an ELM or a CM. System management (SMS)-related communication will be established by direct communication with a messaging system application gateway (AG), and will not operate via the ELM/CM. Time/position synchronization-related communications will also not require the ELM/CM.

The ITC 220 MHz radios will always connect to an ELM or a CM through an Ethernet connection and will use a published proprietary MCC protocol (HRX) for the wire communications to the radio. Since this protocol for communicating with a radio will be published, it will be possible to use an ITC 220 MHz radio for non-ITC communications without using an ELM or a CM, if desired. Alternatively, it is also possible to develop ELMs that support messaging systems or application messaging other than that used by the ITC System, if desired.

The ELM will support the following three primary functions:

- Protocol Transformation – Bridge and transform messages between the ITC Messaging protocol and the Radio wire protocol.
- Routing – Route messages that are incoming from the ITC Messaging components to multiple radios (mostly used for cases where you have each office ELM managing multiple base station radios).
- Mobility – When a mobile moves from one base to another under a single ELM, update routing tables for the new path and flush the old path without having to notify the ITC Messaging components. Otherwise an ELM handles active connection updates from Base radios that occur due to mobility, and notifies other messaging system components about route updates to remotes.

A connection manager (CM) will handle the same protocol transformation as an ELM.

With regards to routing, CM's task is a lot simpler than ELM's, since on the remote area the messages received from the messaging system side have only one destination. Connection manager's task is mostly to choose between different available transports, such as 220 MHz radio, cell, satellite, Wi-Fi, and so on, rather than doing actual routing.

A connection manager handles mobility in such a way that it receives the connection updates from the 220 MHz radio and keeps track of the currently active base connection.

5. Network loading, performance, and reliability

5.1 Message types

5.1.1 PTC messages

The 220 MHz Radio Network has been designed with the primary goal of carrying PTC messages. To ensure the scalability of the system, headroom has been also built into the capacity of the network. This headroom is meant to be used to accommodate future growth in PTC traffic, provide capacity for low-priority non-PTC traffic, and handle unanticipated spikes in PTC message traffic. Examples of PTC messages are:

- WIU Status – from a wayside to a locomotive
- Beacon On (to turn on a WIU Status beacon) – from a locomotive to a wayside
- Position Report – from a locomotive to an office
- Speed Restriction – from an office to a locomotive
- Initialization – from an office to a locomotive

5.1.2 Business messages

When the network capacity is not being fully used for PTC messages, it will be used for other types of messages called business messages. Business messages are expected to have a different class of service and lower priority than PTC messages but will have a wide variety of priorities relative to each other. Examples of business messages are:

- Fuel Status Reports
- Log Uploads

The 220 MHz Radio Network is not expected to be the primary method of data communications in yards or terminals or other very high-density areas.

As such, it is not expected to support the full business traffic loads in those areas.

5.1.3 System management messages

The final type of messages that the network is expected to carry are messages that are used to manage the system. Examples of System Management messages are:

- Health Status Reports
- Alarms
- Configuration Parameter Queries
- Configuration Parameter Updates
- Firmware Downloads

In this document, wherever business messages or business traffic is discussed, it would include system management messages. Although those are not necessarily lower priority messages than PTC messages, those are generally grouped into the business message category.

5.2 Loading model overview

A demand study for PTC has been done to evaluate how much load the PTC application is likely to put on the 220 MHz Radio Network. The study simulated a 30-mile linear section of triple track with a high density of waysides (about one wayside per mile). The simulation then ran trains as close together as possible along all three tracks. It simulated 25 trains, but at its peak, it managed to get 21 trains connected to a same base station at the same time. As the trains were moving, the study simulated the office and trains sending the seven most common PTC messages to each other (requests and responses for each). It also simulated the waysides sending out status beacon messages to the locomotives. The results of this study can be found in the PTC Demand Study document (Reference [9]).

For this high-load scenario of one base station covering 30 miles of track with 30 waysides and 21 locomotives under the base, the study created raw data about how many messages were sent and how many bits of data that added up to in each second of the simulation.

The initial result of this study was to establish that the wayside status messages make up in excess of 60% of the bits over the air. As a result, the air interface for the network has been designed to highly optimize the wayside status message traffic and to make it as deterministic in its behavior as possible. The design has also separated the wayside message traffic from the inbound (remotes to office) and outbound (office to remotes) traffic. Due to this design approach, the key metric from this study that is most important is capacity required for inbound and outbound PTC traffic. Wayside status traffic is handled separately and is more sensitive to geographic wayside density than it is to simulated message volume.

5.3 Peak averaging analysis

Since the loading model looked at message traffic on a second-by-second basis. Analysis determined that when looking for useful peak averages, using the peak second of traffic in the model would not be realistic. This is because seconds near peak seconds of traffic tend to have much lower levels (or no) traffic. Given that the latency requirements for the system are around 15 seconds, it is not necessary to engineer the system to support the peak 1-second load every second. Rather, it is reasonable that the system will have time to recover from a 1-second peak in the next few seconds. Therefore, the model was also analyzed using 3-second, 15-second, and 1-minute moving windows and averaging the load across those windows. These moving window peaks are more realistic to consider as useful averages.

The following table shows the results from that analysis.

Table 3: Loading model peak averages

Kbps/Second	**Office->Loco**	**Loco->Office**	**Total**
1-Second Moving Window Peak	5.06	2.57	5.58
3-Second Moving Window Peak	2.53	1.46	3.64
15-Second Moving Window Peak	1.31	0.84	2.04
60 Second Moving Window Peak	0.94	0.53	1.45
Messages/Second	Office->Loco	Loco->Office	Total
1-Second Moving Window Peak	5.00	4.00	6.00

3-Second Moving Window Peak	2.33	2.00	4.00
15-Second Moving Window Peak	1.27	1.20	2.33
60-Second Moving Window Peak	0.90	0.80	1.68

The above information is useful when working with peak averages from the loading model. Yet, this network has been designed to meet at least all latency and performance requirements given the actual loads put onto the network by exactly executing this loading model in a lab simulation.

5.4 Loading, performance, and reliability specifications

The following are specifications that the system will meet related to loading and performance.

Table 4: Loading and performance specifications

Function	Description	Value	Conditions
Wayside Status Age	Locomotive must receive wayside status beacon messages such that they are no more than 12 seconds old to avoid false enforcements	< 12 sec, with 99.9999% reliability	Locomotive in braking distance+buffer (< 3.5 miles) + 12 seconds Network-engineered with sufficient signal strength between locomotive and wayside Base coverage not required Wayside status is the highest priority message type
OTA PTC Messages	Radio Ethernet port to radio Ethernet port max allowable message latency	< 15 sec, with 99.9% reliability	Applies to inbound and outbound messages only Network engineered with sufficient signal strength between base and remotes Messages no more than 256 bytes in size
Communication at Speed	Support latency requirements when traveling at speed	See above	Locomotive traveling at speeds up to 110 mph A
Messaging Throughput	PTC (high priority) message traffic supported per	PTC demand study loading	PTC_Demand_Study_Version_04.xls

Function	Description	Value	Conditions
	loading model	model	
	Headroom message traffic supported from a base to remotes B	≥ 4 kbps	Does not include link level overhead
	Headroom message traffic supported from remotes to a base B	≥ 4 kbps	Does not include link level overhead
Operational PTC Trains	Operational trains under a single base	≥ 24 trains	Only one locomotive on each train is cut in and sending/receiving PTC messages
Operational Waysides	Number of waysides supported under the coverage of a base	≥ 30 waysides	All waysides may be actively sending wayside status messages
Wayside Density	Number of waysides supported within an area	≥ 250 waysides	All waysides actively sending wayside status messages within a 5-mile radius circle
Train Initialization	Number of simultaneous train initializations supported under a base C	≥ 2 trains	Lower priority than PTC message

Notes:

[A] Higher speeds may be challenging until spatial diversity is fully implemented.

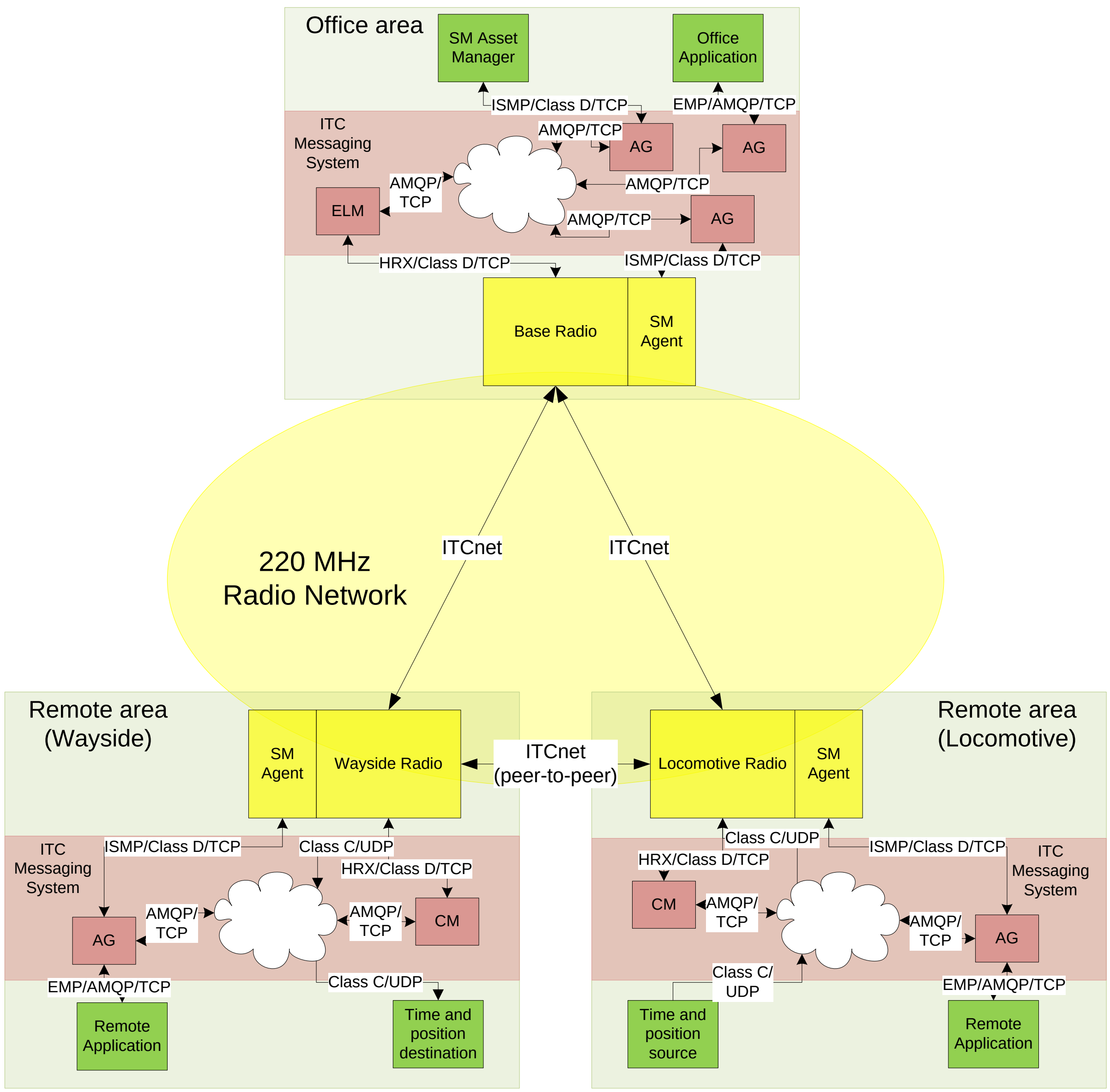
[B] Headroom is for unanticipated PTC load peaks and for business load (lower priority) when not in use by PTC.

[C] Supported within the headroom capacity. System-wide, broadband IP networks are expected to support the majority (about 80%) of train initializations.

6. Interfaces

As can be seen in Figure 11, the 220 MHz radios have two primary interfaces between network components. One is over the air between radios and the other is over a wire between the radio and an ELM or a CM. The air interface is implemented with an MCC proprietary protocol known as ITCnet covering from the physical to the network layer. The wire interface is implemented with a published MCC protocol known as HRX, which is carried over Class D and TCP/IP and covers the application layer.

Figure 11: ITC 220 MHz radio network interfaces



The network also supports several interfaces to components outside of the 220 MHz Radio Network. The primary interface for the flow of PTC and business messages between an ELM or a CM and its messaging system components will be implemented using the messaging system specified protocol AMQP over TCP/IP. Locomotive radios will require that a Time and Position message be broadcast via Class C so that they can tell where they are for base selection and can have a time to use in marking log entries, alarms, etc. For waysides, the radio will be able to send a periodic time broadcast message over Class C to allow a WIU to keep its clock synced. In all environments, an ISMP over Class D/TCP interface will support centralized configuration management functions.

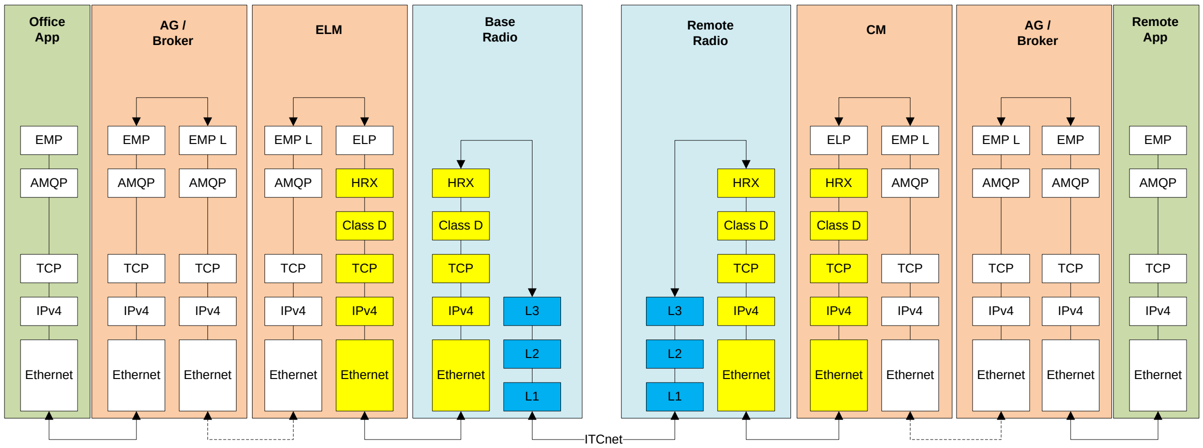
The remainder of this section covers an overview of each of these interfaces and the protocols that define them with the exception of the ISMP interface for configuration management, which will be covered in the section 9 System, and Configuration Management.

6.1 Protocol Architecture

The protocol stack lineup on the various ITC radio interfaces is different. Figure 12 shows the path of the EMP application protocol message, which is transmitted from the Office Application to the Remote Application, through various protocol stacks.

The green blocks represent Back Office or Remote Applications. The red blocks indicate messaging system components. The blue blocks are the radios. L3, L2, and L1 designate various layers in the ITCnet 220 MHz air-interface protocol that will be discussed in the next section.

Figure 12: ITC system protocol architecture



6.2 Radio-to-radio interface (ITCnet)

This section discusses the interface between radios. This interface uses the 220 MHz radio spectrum to provide data communications by using the ITC 220 MHz radios. These radios use a protocol called ITCnet to provide communications over the air. ITCnet has been specifically designed to solve Interoperable Train Control communications needs as efficiently as possible within the available ITC spectrum.

6.2.1 Frequencies and channelization

A channel in the 220 MHz frequency band consists of a combination of a base and mobile transmit frequency. Each base transmit frequency is taken from the 220-221 MHz range and is paired with a mobile frequency in the 221-222 MHz range. According to original FCC regulations, a mobile can transmit or receive on either the mobile or base frequency, while a base can transmit only on the base frequency. In October 2008, a waiver to FCC 220 MHz rules was submitted by PTC-220, LLC. The waiver has since been granted and allows a base to transmit in the mobile frequency. However, the base transmitting in the mobile frequency has to follow the antenna height and power restrictions for the mobile frequencies. Specifically, a base transmitting in the mobile frequency cannot have a combination of an antenna higher than 7 meters and power above 50 Watts ERP. Therefore, bases transmitting on mobile frequencies will typically achieve a smaller coverage range than those operating on base frequencies.

In CFR Title 47 §90.715, the FCC channel plan describes 5 kHz channels. However, where a licensee is authorized on adjacent channels, the 5 kHz channel can be aggregated over the contiguous spectrum. For ITC, 25 kHz channels (five adjacent 5 kHz channels) will be used.

The ITC 220 MHz Radio Network is a half-duplex (or TDD) system, where each 25-kHz channel provides a communication path in both directions between two connected radios, but in only one direction at a time.

The ITC 220 MHz Radio Network will use one of the available channels as a common channel. This common channel will be at a single frequency across the entire nation and will be shared by all radios in the network. The remaining channels will be used as local channels. Each local channel is controlled by a base in a master/subordinate architecture when it comes to the dynamic use of the channel. Each base station will control only a single local channel. Each remote radio can listen to multiple base stations but will select only one base at a time to be its master. Other base stations are referred to as neighbors of the selected base.

As in a cellular network, different local channels will be assigned to adjacent base stations to prevent interference. The same local channel can be re-used by other base stations that are far enough apart to avoid interference.

A set of 25-kHz local channels (in the base frequency) will be designated as primary local channels. Since bases can transmit with higher power and antenna heights in the base frequency, these primary local channels will provide greater coverage than the local channels that are in the mobile frequency. Based on the currently available channels for ITC, at least six 25-kHz channels in the base frequency can be set as primary local channels. In high-density areas where six primary local channels are not sufficient to support the traffic, other local channels can be used. One 25-kHz channel in the base frequency is reserved for the common channel.

Table 5 shows the currently available 220 MHz ITC nationwide channels that are held by PTC-220, LLC.

The ITC radios will use an extended channel numbering scheme that includes the whole 217 – 222 MHz frequency band. This ITC radio channel numbering is defined by a center frequency formula

$$F_c = 217.587500 + Ch*0.025 \text{ (in MHz)}$$

where Ch is the ITC radio channel number.

Table 5: Frequencies and channel types

25 kHz Frequency Channel	Center Frequency	ITC Radio Channel #	Channel Type
220.125-220.150 MHz	220.1375 MHz	102	Base
220.400-220.425 MHz	220.4125 MHz	113	Base
220.425-220.450 MHz	220.4375 MHz	114	Base
220.700-220.725 MHz	220.7125 MHz	125	Base
220.725-220.750 MHz	220.7375 MHz	126	Base
220.750-220.775 MHz	220.7625 MHz	127	Base
220.975-221.000 MHz	220.9875 MHz	136	Base
221.125-221.150 MHz	221.1375 MHz	142	Mobile
221.400-221.425 MHz	221.4125 MHz	153	Mobile
221.425-221.450 MHz	221.4375 MHz	154	Mobile
221.700-221.725 MHz	221.7125 MHz	165	Mobile
221.725-221.750 MHz	221.7375 MHz	166	Mobile
221.750-221.775 MHz	221.7625 MHz	167	Mobile
221.975-222.000 MHz	221.9875 MHz	176	Mobile

6.2.2 Waveforms and bit rates

The ITC 220 MHz Radio Network uses Differential Quadrature Phase Shift Keying (DQPSK), which is a linear modulation.

According to FCC regulations, signal waveforms transmitted in the 220 MHz band need to fit FCC Mask F (defined in 47 CFR 90.210 (f)). In 25-kHz channels, the requirement is to fit FCC Mask 5xF[1].

The ITC radios use only one modulation type for their transmissions, $\pi/4$ DQPSK.

The $\pi/4$ DQPSK modulated signal is a DQPSK waveform with phase transitions rotated by 45 degrees. The $\pi/4$ DQPSK waveform uses an RRC pulse-shaping

[1] Defined in FCC Part 90.733d-e.

filter with a roll-off factor of 0.35. It achieves a channel bit rate of 32 kbps in a 25 kHz channel under emission Mask 5xF.

A half-bit rate version of the $\pi/4$ DQPSK waveform is also being used that achieves 16 kbps in a 25-kHz channel under the same emission mask. This alternative waveform type is used primarily with wayside radio transmissions. The wayside radio is currently only able to transmit the half-bit rate version of the DQPSK waveform. The benefit of using the 16 kbps otherwise is that due to its lower noise bandwidth, it offers better radio link performance than 32 kbps. Better link performance can translate either to larger coverage areas or more reliable quality of service with the same radio link distance.

Table 6 shows the waveforms transmitted by each type of radio in each type of channel. HR means half-rate modulation (16 kbps) and FR indicates full-rate modulation (32 kbps).

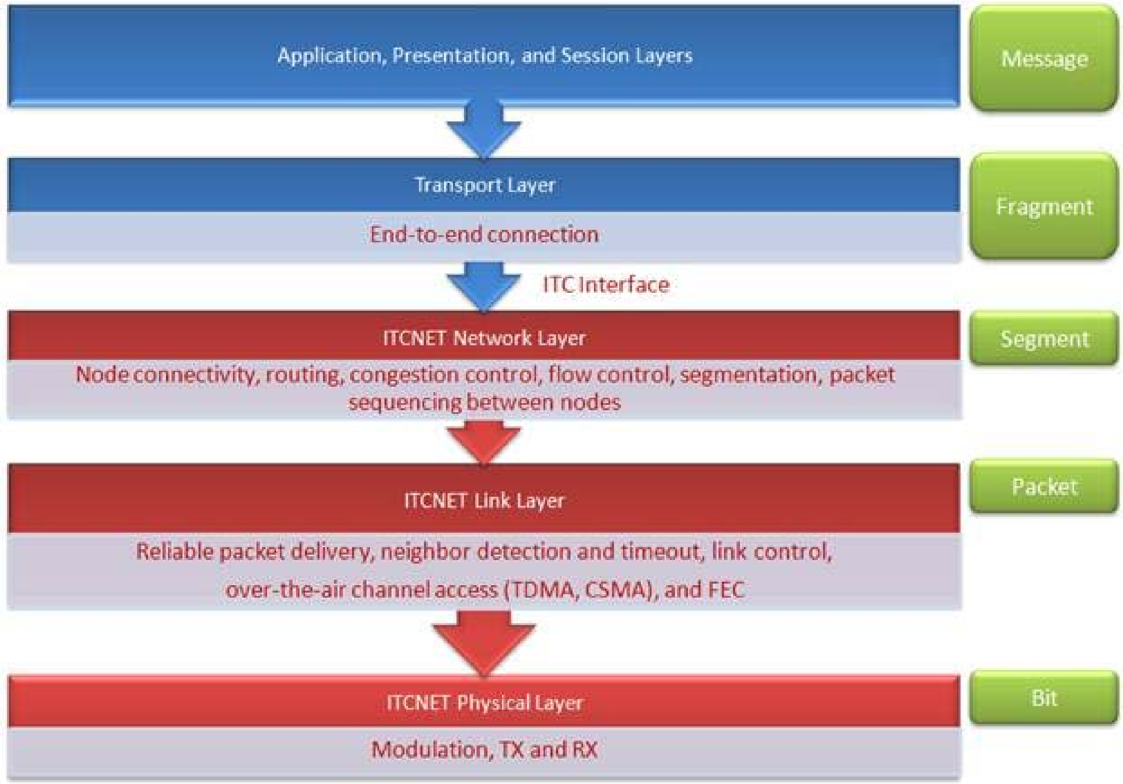
Table 6: Radio transmit waves and channels

Radio	Transmit Waveform	Channel
Wayside	π/4 DQPSK HR	Common
	π/4 DQPSK HR	Local, FTDMA
	π/4 DQPSK HR	Local, DTDMA
Locomotive	π/4 DQPSK HR	Common
	π/4 DQPSK HR	Local, FTDMA
	π/4 DQPSK HR or FR	Local, DTDMA
Base	π/4 DQPSK HR	Common
	π/4DQPSK HR	Local, FTDMA
	π/4 DQPSK HR or FR	Local, DTDMA

6.2.3 Protocol layers

As can be seen in Figure 13, ITCnet provides functionality in the first three layers of the OSI seven layer model. This includes the physical layer, link layer, and network layer.

Figure 13: ITCnet protocol layers



The remainder of this section focuses mostly on the link layer functionality, as other sections in this document describe the network layer functionality.

6.2.4 Channel access methods

ITCnet makes use of multiple access schemes for base and remote radios to share channel resources. The schemes used are fixed time division multiple access (FTDMA), dynamic time division multiple access (DTDMA), and carrier sense multiple access (CSMA).

FTDMA

In FTDMA, the channel is time slotted. The FTDMA slot size can be different from one slot to another, but the allocation of the channel time to each user is fixed. FTDMA is used to support constant periodic traffic from users. A fixed number of FTDMA slots, each having a fixed (preconfigured) slot size, are periodically reserved for a user at a fixed repetition rate. One FTDMA slot is used to support one FTDMA packet. Each user can get assigned multiple FTDMA slots to transmit multiple FTDMA packets. The FTDMA configuration is done in advance by a network engineer, who predetermines the channel capacity and channel frequency required to send FTDMA data for each user in the network.

DTDMA

DTDMA is a centralized access scheme where the channel is time slotted and the base station controls the allocation of time slots to users. Several TDMA slots are grouped into a DTDMA cycle of variable length. Each slot in the DTDMA cycle can be allocated for the transmission of an RF packet (also referred to as a packet) from the base or remote. A slot for remote transmission could be assigned to a particular remote or set as a contention slot. The contention slots are not assigned to specific remotes but allow remotes to get access to the channel through a slotted CSMA scheme (described below). Slots in the DTDMA cycle could have different length.

The DTDMA slot assignment, including slot size and the user that the slot is assigned to, is controlled by a base station. Specifically, DTDMA slot assignment is performed by a scheduler at the base station, based on transmit queue information from the base and the remotes. The DTDMA slot assignment is broadcast by the base in a DTDMA control packet, which is sent at the beginning of the DTDMA cycle.

In order for the scheduler to get knowledge of the remote transmit queue, each remote sends an update of its transmit queue information to the base station when necessary. The remote can transmit its queue information in the assigned DTDMA slot or in the contention slot. At the end of each DTDMA cycle, the scheduler uses the currently available queue information of every user to determine the allocation of slots in the next DTDMA cycle.

CSMA

CSMA is a contention-based access scheme that enables the physical channel to be shared by users and has a mechanism to prevent collisions among multiple users trying to access the channel at the same time. The CSMA scheme requires the users to listen to the channel before starting to transmit, to avoid possible collisions with other ongoing transmissions. The basic principle of the CSMA scheme is that when a user has a packet to transmit, the user waits for a random period of time during which the channel is sensed. If the channel is idle, the user transmits the packet. If the channel is busy, the user reschedules the packet transmission to some other time in the future (chosen with some randomization), at which time the same operation is repeated.

Slotted CSMA

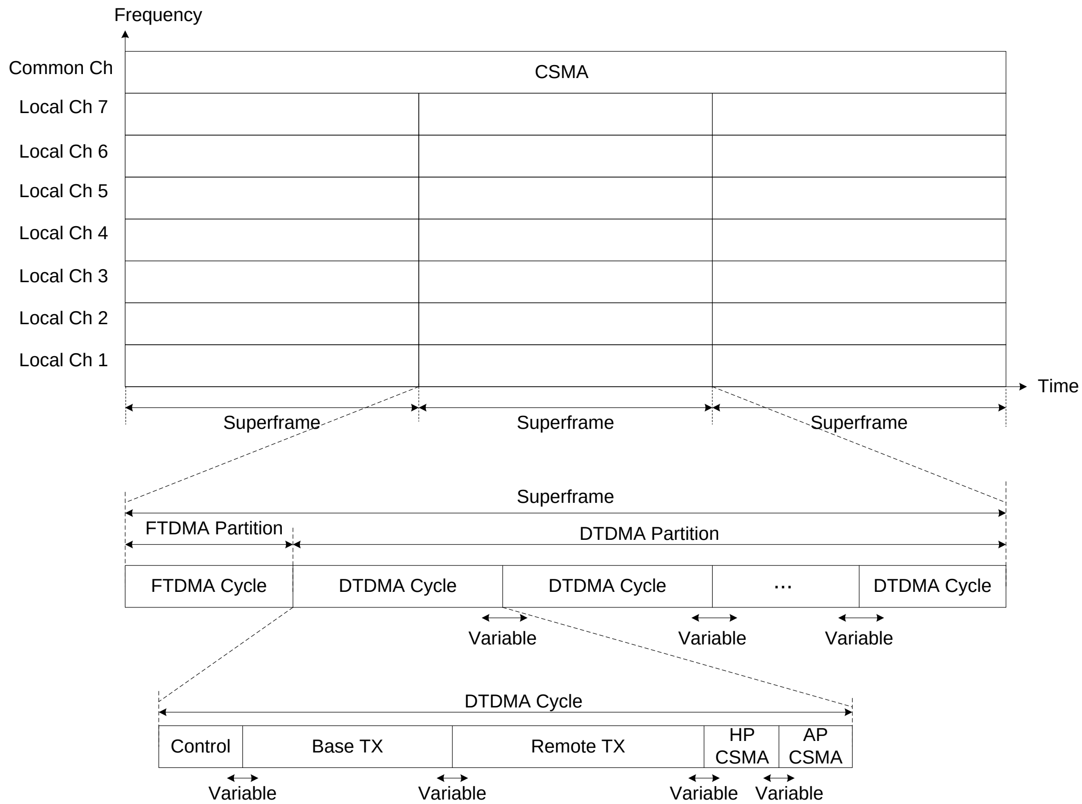
A variation of the CSMA scheme that is also used in this application is slotted-CSMA. Slotted-CSMA is similar to CSMA except that any packet transmission in a slotted-CSMA scheme has to start at the beginning of a time slot. The slot size can be shorter than the time required to transmit the packet. When a user has a packet to transmit, the user picks a random integer and waits for that number of slots before transmission. The user senses the channel. If the channel is idle, the user transmits the packet at the beginning of the slot. If the channel is busy, the user picks another random integer and reschedules the packet transmission, as in a CSMA scheme.

The maximum back off time or the range of random integers is configurable by priority.

6.2.5 Channel structure

Each local channel is divided in time into periodically repeated superframes of fixed duration. The superframe duration is the same for all local channels, and is set to the wayside broadcast interval of 3 seconds.

Figure 14: Channel structure



Superframes are synchronized across all local channels. Each superframe consists of one FTDMA cycle and one or multiple DTDMA cycles. The superframe starts with the FTDMA cycle, followed by the DTDMA cycles.

The common channel is shared by every user through the use of CSMA. RF packets transmitted in the common channel are typically short packets that are very high priority (such as the Get WIU Status message). The common channel is also used to support base beacon signals, which carry information necessary for remotes to identify and select a base as well as to set up their receive frequencies.

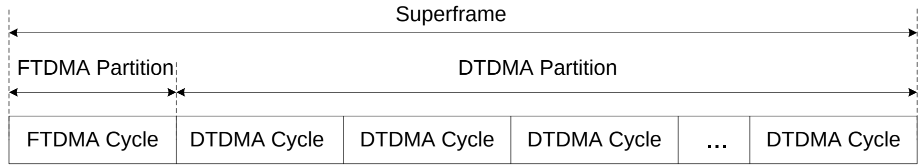
6.2.6 Superframe structure

This section describes the structure of the superframe, including the partition between FTDMA and DTDMA, the structure of the FTDMA cycle, and the structure of the DTDMA cycle.

FTDMA/DTDMA Partition

The superframe is divided into FTDMA and DTDMA partitions. The superframe starts with the FTDMA partition followed by the DTDMA partition.

Figure 15: FTDMA and DTDMA partitions in a superframe



The DTDMA partition consists of one or multiple DTDMA cycles. Each DTDMA cycle is controlled by one base station. The DTDMA cycle is used to support traffic between remotes and the base connected to those remotes. The length of DTDMA cycle depends on the amount of traffic, which can vary from one cycle to the next.

The start of a DTDMA partition and the duration of the DTDMA partition are configurable parameters that can be set in the Base radio.

The DTDMA partition in a channel can be controlled by one base or shared by multiple base stations:

- In the case where the local channel is controlled by one base station, the base station has the control of the entire DTDMA partition.
- In the case where the local channel is shared by other base stations, the DTDMA partitions in each sharing base stations are configured to be at different non-overlapping times during the superframe. The entire duration of the DTDMA partition during each superframe is divided among the shared base stations.

FTDMA Cycle

The FTDMA cycle is used to support periodic traffic that is repeated every superframe. The FTDMA cycle comprises multiple FTDMA slots which can have different slot sizes. One FTDMA slot is used to support one RF packet. The size of each FTDMA slot can be set by the network engineer according to the packet length that will be transmitted in that slot. The FTDMA cycle repeats every superframe, and the size of each slot remains the same in every superframe.

The length of the FTDMA cycle in a local channel depends on the amount of FTDMA traffic in the channel. As different local channels could have different amounts of FTDMA traffic, the FTDMA cycles could have variable lengths across all local channels. However, the FTDMA cycles in all local channels start at the same time, which is at the beginning of the superframe.

To transmit a message in an FTDMA slot, the transmit radio needs to know that the message is for FTDMA transmission and which FTDMA slot to transmit the message in. This information is driven by the special handling functionality described in section 7.4.2. Section 7.5.2 also discusses how the variable-size FTDMA slots are configured.

DTDMA Cycle

The DTDMA cycle is controlled by a base station. The DTDMA cycle is used to support traffic from the base and remotes that are connected to the base. At the beginning of each DTDMA cycle, the base station broadcasts a DTDMA control packet that organizes the transmissions in the DTDMA cycle. Following the DTDMA control packet is the data traffic from the base and remotes. The duration of a DTDMA cycle can be varied, depending on traffic in the cycle. The DTDMA cycle is typically about 1-second long.

The DTDMA cycle consists of five variable-length fields:

- **Control** field, which specifies the DTDMA cycle structure
- **Base transmit (B-TX)** field, which is used to carry outbound data traffic from the base station to remotes
- **Remote transmit (R-TX)** field, which is used to carry inbound data traffic, and peer-to-peer data traffic from remotes if some future communication types require it
- **High-priority CSMA (HP-CSMA)** field, which is reserved for remotes with high-priority data to get access on the local channel
- **All-priority CSMA (AP-CSMA)** field, which is used for any remotes to get access on the channel

6.2.7 Packet type summary

Messages received by a radio for delivery are segmented into ITCnet packets. Packets are then delivered over the air from one radio to another. A message that is awaiting delivery in queue, or that has had some but not all of its packets delivered, can be preempted by a higher priority message.

Once the higher priority messages have been taken care of, then processing will resume on the preempted messages.

Table 7 lists the key packet types exchanged between radios that will be supported by the ITCnet protocol.

Table 7: ITCnet packet summary

Type	Dir [A]	Trigger	Description
DTDMA Control	B->R	Beginning of DTDMA Cycle	Information about slot sizes and assignments for that DTDMA cycle
Queue Status	R->B	Data to be sent	Information about the status of the remote radio's transmit queue, including the priority and amount of data for the highest priority packet waiting in the queue
Base Beacon	B->R	Periodic	Broadcast of base information. Used at the remote to select the base and set up local receive channels. The base beacon includes: Base ID Location Channel – Channel number of the base local channel Bit rate – Transmit bit rate for DTDMA cycles (16 or 32 kbps) Utilization – Ratio of channel in use to channel available Neighbor Channels – Channel numbers of neighbor bases (defined by network engineer)
Ack	R->B	Receipt of a packet	Acknowledges success or failed reception of packets from the base
Acquire	R->B	Startup or mobility or periodic	Request to initiate a connection or to keep a connection alive
Short Data Broadcast	*	Data received with special handling code [B]	FEC coded broadcast of a packet without a transmit or receive ID
Long Data Broadcast	*	Data received with special handling code [C]	FEC coded broadcast packet with a transmit ID but no receive ID
Unicast	*	Data received [D]	FEC coded packet with transmit and receive IDs

Notes:

[A] Direction; B = Base, R = Remote.

[B] Used for WIU Status beacon messages.

[C] Used for WIU Beacon On and Get WIU Status messages.

[D] Used for normal messaging.

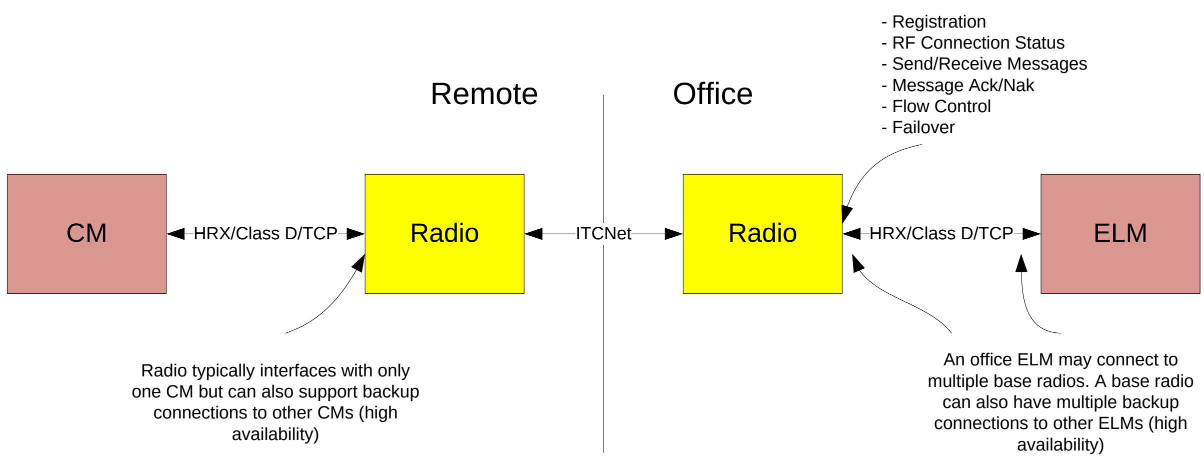
6.2.8 Forward error correction

A Reed-Solomon code RS(16,12) on 8-bit symbol is used for the FEC. The RS encoder takes a data block (DB) of 12 bytes and outputs an encoded block (EB) of 16 bytes containing 12 bytes of original data and 4 redundancy bytes.

6.3 Radio to ELM or CM interface (HRX)

The interface between a radio and an ELM or a CM primarily supports the passing of data messages to and from the radio. It also supports service messages to control the flow of information across the interface. This interface is defined by the Host/Radio eXchange (HRX) Protocol. HRX is an application level protocol which is transported over Class D and TCP/IP.

Figure 16: Radio to ELM interface (HRX)



To support multiple waysides with one radio, all of the waysides communicate through a single ITC Messaging stack to a single CM that is connected to the radio. This means that all of the waysides that share a radio will have to be in a single remote area.

The HRX connections support high availability, which means that the radios can have multiple simultaneous ELM/CM HRX connections. Only one of the HRX connections is going to be active at the time, and the other ones are backup connections.

6.3.1 Underlying class D transport

The Class D protocol (Reference [12]) provides some important additional features to basic TCP/IP transport. It is intended for applications requiring reliable point-to-point message delivery. Class D converts a stream-based TCP/IP connection to a delimited, message exchange-based one. Message delivery is guaranteed by an additional layer of acknowledgement-based retransmissions that can be configured to be either on or off.

Many of the Class D protocol features are optional. Table 8 lists Class D protocol features that are implemented in ITC 220 MHz Radios.

The radio is the server for the underlying Class D data connection, and the ELM or the CM is the client.

Table 8: Class D features in ITC 220 MHz radios

Class D Protocol Layer	Feature (category)	Required by Class D specification	Required in ITC radio Class D implementation
Protocol Layer	Link initialization	Yes	Yes
Protocol Layer	Security	Optional	Yes
Protocol Layer	Message formatting / transport	Yes	Yes
Protocol Layer	Message framing and delivery	Yes	Yes
Protocol Layer	Message ACK	Yes	Yes
Protocol Layer	Error feedback (NACK)	Yes	Yes
Protocol Layer	Link management	Yes	Yes
Protocol Layer	Link monitoring (keep-alive)	Yes	Yes

Class D Protocol Layer	Feature (category)	Required by Class D specification	Required in ITC radio Class D implementation
High Availability Layer	Link initialization	Optional	No
High Availability Layer	Link management	Optional	No
High Availability Layer	Link monitoring	Optional	No
Persistence Layer	Link initiation	Optional	No
Persistence Layer	Message transport	Optional	No
Management Layer	Remote configuration	Optional	No
Management Layer	Remote statistics reporting	Optional	No
Management Layer	Remote reset	Optional	No
Management Layer	Remote link state	Optional	No
Management Layer	Alerts	Optional	No
Test Layer	Test message	Optional	Yes
Test Layer	Test message logging	Optional	Yes
Test Layer	Echo request message and response	Optional	Yes

6.3.2 Underlying TCP/IP transport

The ITC radios will only support Ethernet connections for wire-side data communications. Across those Ethernet connections, the radios will require TCP/IP to be supported, because HRX/Class D will expect TCP/IP as its underlying transport. Similarly, the ELM or the CM will expect to have an available TCP/IP connection to the radios for which it is configured.

Regarding this connection, the radio is always the TCP server and will be waiting for a connection request. The ELM or the CM will be the TCP client and will always initiate connections to the radios. In the case of an ELM in a back office, it will potentially be initiating and managing connections to several radios.

The following are specifications that the system will meet to support TCP/IP between the radio and ELM.

Table 9: TCP/IP addressing specifications

Function	Description	Value	Conditions
ELM/CM IP Addressing	ELM/CM will support the following types of IP address assignment	Static or Dynamic via DHCP	For Dynamic addressing, DHCP server is available on the local network
Radio IP Addressing	Radio will support the following types of IP address assignment	Static	Applies to data connections (not maintenance connections) Address manually set in the radio configuration

6.3.3 Message summary

Table 10 lists the key messages between the radio and ELM that will be supported by the HRX protocol.

Table 10: HRX message summary

Type	Dir [A]	Trigger	Description
Registration Request	E->R	Completion of TCP connection	Communicates the address and class of service supported by the area that the ELM represents to the radio for use in ITCnet connections.
Registration Response	R->E	Receipt of Registration Request	Changes status of the ELM to radio connection to active.

Type	Dir [A]	Trigger	Description
RF Connection Available	R->E	RF connection to another radio established	Update address resolution table for the new RF connection. If a route was previously available via another radio under the same ELM, then notify the previous radio to flush its pending messages and delete its RF connection to that other radio. If a route was not previously available via another radio under the same ELM, then notify the messaging system that a route to the area received from the other radio is available (passing along the most restrictive class of service between the local area's class of service and the class of service received from the other radio).
RF Connection Unavailable	R->E	RF connection to another radio lost	Update address resolution table for the lost RF connection. Notify the messaging system that a route to the area received from the other radio is no longer available.
ELM Connection Status	R->E	Other radio loses or re-establishes its connection to its ELM	Update address resolution table for the RF connection. If the radio-to-ELM connection on the other side of the RF connection was lost, then notify the messaging system that the route to the area for the other radio is not available. If the radio-to-ELM connection on the other side of the RF connection was re-established, then notify the messaging system that the route to the area for the other radio is available.
Message Send	E->R	ELM receives data message from router/broker	If message priority is less than flow control priority filter, then NAK the message. Store the message in a transmit queue and transmit the message to the other radio based on special handling, priority, and scheduling algorithm.
Message Receive	R->E	Radio receives data message over RF connection	Apply special handling logic as appropriate. Send the message to the router/broker if not filtered out by special handling.

Type	Dir [A]	Trigger	Description
Message Ack	R->E	Message successfully transmitted over RF connection	Notify the router/broker that the message has been sent, and it can remove the message from its queues.
Message Nak	R->E	Message failed to be transmitted over RF connection	Notify the router/broker that the message has not been sent and that it can re-evaluate the available transports for the message and route it again (this could cause the message to be returned to the 220 MHz Radio Network again for another try).
Flow Control [B]	R->E	Radio has a temporary problem in its message processing or RF transmission and is not at the moment able to process its message queue.	The ELM/CM stops sending messages to the radio.
Flow Control [B]	R->E	Radio clears its temporary message queue related issue, and is again able to send air interface packets.	The ELM/CM can resume sending data messages again to the radio.
Failover Service	R->E	Radio loses its primary host connection.	The message is sent in the backup host connection to inform that it now must become the primary connection.
Failover Confirmation	E->R	Host receives a Failover Service Message.	The message informs the radio that the backup host has received the previous Failover Service message and is in agreement that it has become the new primary connection.

Notes:

[A] Direction; E = ELM, R = Radio.

[B] For more information, see section 7.1.

6.3.4 Notes

Since the HRX interface will be published, it will be possible to connect an application or messaging component other than an ELM to a radio in order to make use of 220 MHz Radio Network functionality, although this capability has not been explicitly tested. Testing of this interface has only focused on radio-to-ELM/CM interactions.

6.4 Time and position interfaces (Class C)

Table 11 shows how each component of the 220 MHz Radio Network will get and use time and position information.

Table 11: Component time and position summary

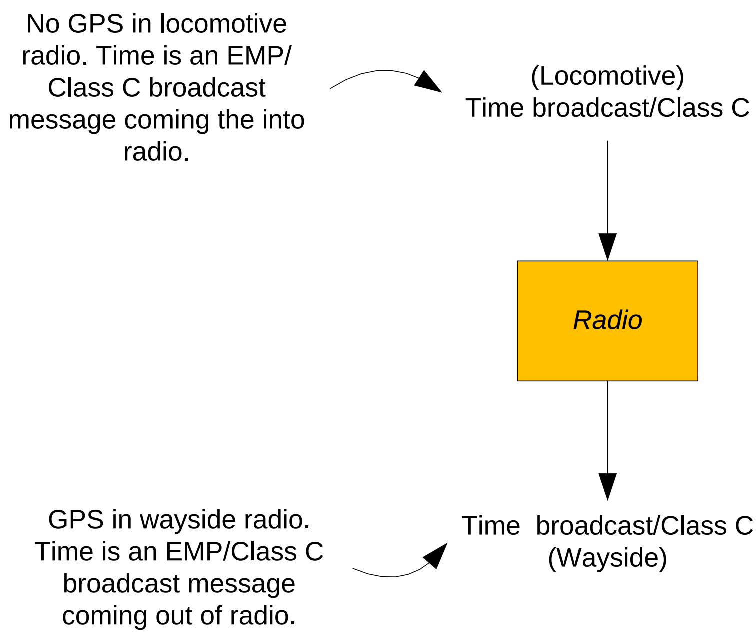
Component	Type	Need	Source
Base	Timing	ITCnet for all RF timing	GPS in radio
	Time	Logging	
	Position	ITCnet base beacon to support mobile selection of a base	Manually configured surveyed position
		Quick setting of GPS position to get accurate time from 1 satellite	
Locomotive	Timing	ITCnet for all RF timing	Base (via control of time through ITCnet)
	Time	Logging	Onboard component via local Class C interface
	Position	ITCnet to support base selection	
Wayside	Timing	ITCnet for FTDMA beaconing A	GPS in radio
	Time	Logging	
	Time	Publish time +/- 1 second via local Class C interface (for WIU)	
	Timing	ITCnet for non-FTDMA timing	Base (via control of time through ITCnet)
	Position	Quick setting of GPS position to get accurate time from 1 satellite	Manually configured surveyed position
ELM	Time	Logging	Local processor time, NTP, or Class C broadcast

Note:

[A] Supports accurate FTDMA timing without coverage of a base.

As can be seen in Table 11 above and in Figure 17 below, there are two interfaces over the Class C protocol supported by the 220 MHz Radio Network for time and position related messages.

Figure 17: Time and position interfaces (Class C)



The first interface is required by the Locomotive radio so that it can get time and position information to support logging (time) and base selection (position). This interface is made up of a single EMP message broadcast over the local network via Class C. The radio will listen for this message and use it to keep its local clock synchronized and to keep track of its position.

The second interface is supported by the Wayside radio, which will broadcast an EMP message over the local network via Class C every TBC (configurable number) of seconds. The WIU will listen for this message and use it to keep its local clock synchronized.

The following are specifications that the system will meet related to the wayside radio time broadcast interface.

Table 12: Wayside time broadcast specifications

Function	Description	Value	Conditions
Wayside Time Accuracy	Wayside radio will broadcast time with an accuracy of	+/- 1 second	GPS has a lock on one satellite
GPS Satellites	Number of satellites Wayside or Base radio GPS requires to be locked in order to get time	≥ 1 satellite	

6.4.1 Underlying UDP/IP transport

Both of these interfaces will make use of Class C (UDP) messages which will be broadcast over the same local IP network to which the radio data port is connected.

6.4.2 Message summary

Table 13 lists the key messages between the radio and external components that will be expected or supported by the time interfaces.

Table 13: Time and position message summary

Type	Dir [A]	Trigger	Description
Time and Position Broadcast	LN->R	Received Class C message, with minimum 1-second interval	EMP message containing position in the body and using the time from the EMP header for the time. Per the EMP specification, time will be in UTC expressed as the absolute number of seconds since midnight, January 1, 1970, including leap seconds.
Time Broadcast	R->WN	Configurable interval, minimum 1 second	EMP message using time from the EMP header for the time (could be the same as above with position just not being used by the WIU). Per the EMP specification, time will be in UTC expressed as the absolute number of seconds since midnight, January 1, 1970, including leap seconds.

Note:

[A] Direction; LN = Locomotive Network (a component on the network will be the source of the time and position message), WN = Wayside Network (expected that the message will be used by the WIU), R = Radio.

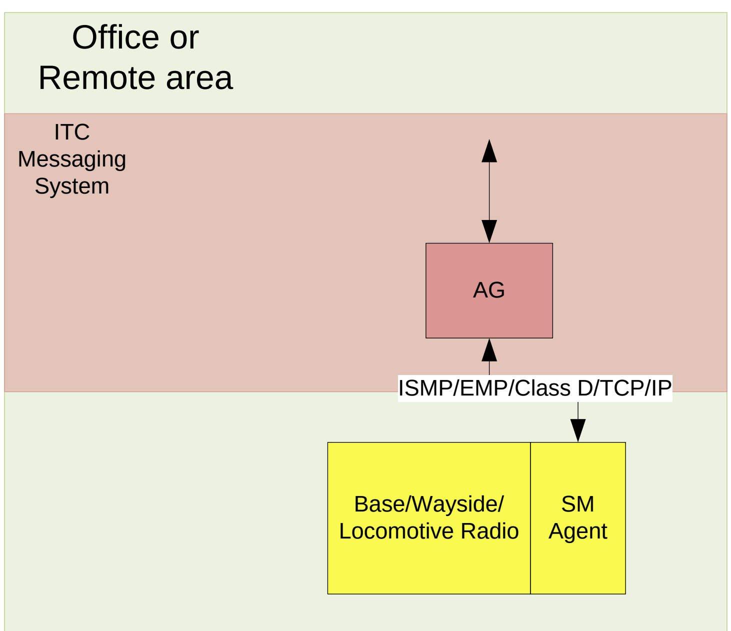
6.5 System management interface

The system management communication to the radio is handled by a separate interface, which bypasses the ELM or the CM and connects directly to an application gateway (AG) on the messaging system side. The communication with this network connection is done by using the ISMP/EMP protocol.

The ISMP messages are transported as a normal payload inside standard EMP messages. The ISMP/EMP protocol has Class D and TCP/IP as its lower-level transport protocols in the system management interface.

On the radio side, this system management connection is handled by a specific embedded code that is a separate entity in the overall radio software. This part of the software is called System Management Agent (SMA). Figure 18 shows this system management interface in the form of a block diagram.

Figure 18: System management interface



6.5.1 Underlying class D transport

The system management communication utilizes Class D as its underlying transport protocol.

When it comes to the system management-related Class D connection, the radio is the client and the application gateway the radio is connected to acts as a server.

A description of Class D and its feature is included in the section 6.3.1. Every Class D connection can be configured differently as far as it features are concerned. The system management connection can have different features and configuration than what the connection to the ELM/CM is using with regards to Class D.

6.5.2 Underlying TCP/IP transport

The underlying TCP/IP transport for the system management connection will utilize the same Ethernet connection as the wire -side data communication, but the communication end points are different. The system management connection has different IP destination address (IP address of the AG), and the connection will use different TCP port numbers than what the data connection is using. Class D will expect TCP/IP as its underlying transport.

Regarding the system management connection, the radio is the TCP client, and it will establish an initial connection, and it will re-establish the connection in case the connection fails. The AG will be the TCP server and will take care of connection requests. The AG will likely be handling system management connections to multiple radios, while the radio itself has only one system management connection.

As far as the IP addressing goes, the system management connection will use the same IP interface and addressing as the data connection. The addressing scheme related to the data connection is described in Table 9.

6.5.3 Message summary

Table 14 summarizes the key system management messages that are relevant for the current radio software. The Release 1.1 software will only implement file transfer, configuration update, and software update related system management functionalities. In future radio software releases, the number of supported system management ISMP messages will be extended.

Table 14: System management message summary

Type	Dir	Trigger	Description
File Transfer Request (10255)	AM->R	Software or configuration kit ready to be transferred to the radio.	ISMP/EMP message that contains a binary file to be transferred. The message also contains a file ID and other properties of the file.
File Transfer Response (10256)	R->AM	Reception of File Transfer Request.	ISMP/EMP message that confirms a successful transfer of a file fragment.
Kit Management Request (10263)	AM->R	Previous file transfer complete. Time to update radio configuration or software using the previously transferred file.	ISMP/EMP message that instructs the radio to load a previously transferred configuration or software kit file.
Kit Management Response (10264)	R->AM	Reception of Kit Management Request.	ISMP/EMP message that confirms loading a kit file with Kit Management Request.

6.5.4 Notes

System management capabilities will be expanded with future software releases. The description above reflects only to what the system management capability is with the radio regarding Release 1.1.

6.6 Maintenance port interface (XtermW)

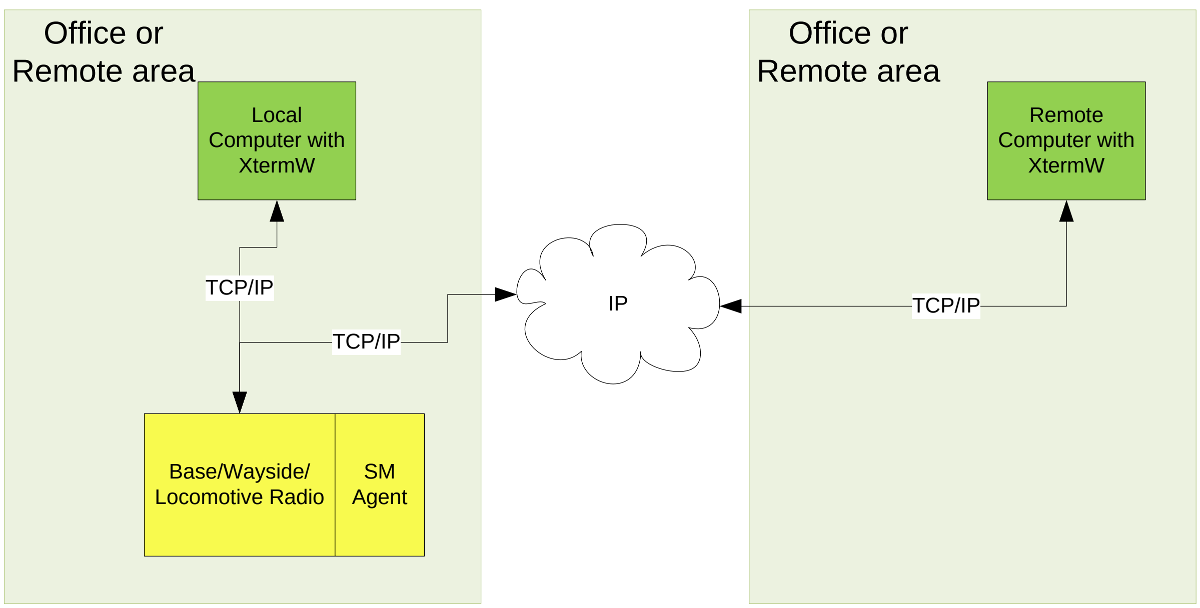
ITC radios support maintenance port connections via either one of their Ethernet ports. The maintenance connection provides text terminal input and output plus some special functions related to file transfers. The radio is the server for the maintenance port connection.

XTermW is a proprietary Windows-based program that is used for remote maintenance of ITC radios. XTermW operates on the client side of each maintenance connection.

The maintenance port connection can be established with a direct cable connection to one of the ITC radio Ethernet ports. Since the maintenance connection is a normal TCP/IP connection, it can be also routed through multiple networks or operated via cell or satellite radio-based remote IP connectivity. Figure 19 describes the maintenance port interface.

The ITC radio management and maintenance can be performed either with the system management interface (section 6.5) or via the maintenance port interface. The maintenance port interface has its own radio specific command line interface commands for controlling radio operation and changing configuration parameters.

Figure 19: Maintenance port interface



6.6.1 Underlying TCP/IP transport

The maintenance port connection operates on a normal TCP/IP socket-based connection. The connection provides bidirectional text transport similar to telnet. Special transmitted and received binary sequences trigger file transfer functions.

The XTermW program takes care of necessary terminal emulation, which is required for text-based input and output.

By default, the Ethernet port for maintenance port connections has a DHCP server, which provides IP addresses from a private network address subnet.

7. Special topics

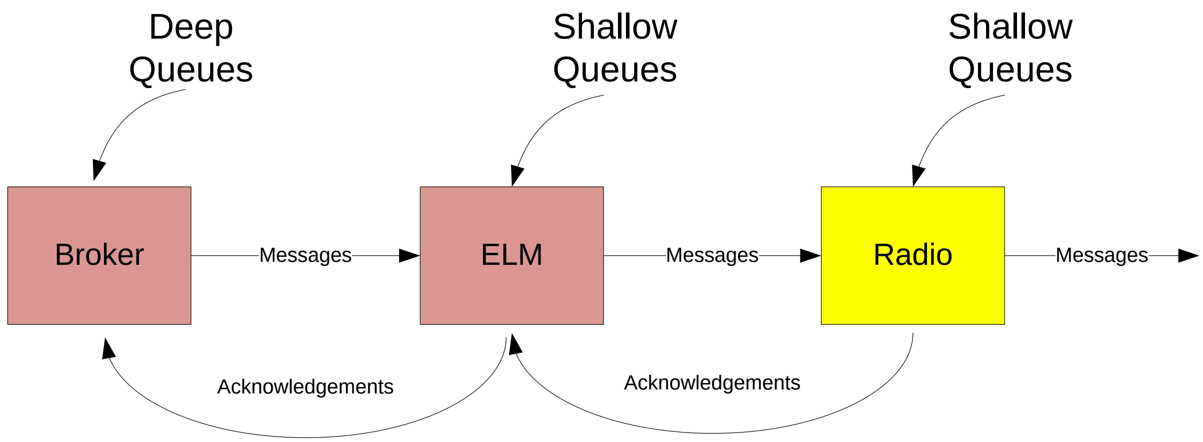
7.1 Flow control and queue management

Messages flowing to the radio to be sent out over the RF will get backed up behind a scarce resource (the available spectrum managed by a base station). One possible way of dealing with this backup is to have huge queues in the radio to hold the messages until they can be sent. From a hardware perspective, given the low cost of memory, this is a viable approach. However, the problem with this approach is that it keeps the ITC Messaging System’s router/broker from having the opportunity to easily select alternate paths for messages when other paths become available, if those messages have already been handed off to the 220 MHz Radio Network for delivery.

So, rather than having deep queues in the ELM or the radio, those components will have shallow queues, and instead the deep queues will be in the broker. This allows for messages that are queued in the broker for a slow or busy 220 MHz connection to be quickly re-routed quickly through another transport network (for example, 802.11) when it becomes available, leaving only the small queue’s worth of messages in the radio for it to finish sending.

The size of the radio’s queue will be configurable. Configuring the radio queue size to be smaller will help with the rerouting challenge mentioned above. Yet, it will also tend to make less efficient use of the airtime, for example, if the queues in the radio are not deep enough to give the base enough knowledge to make good slot assignment decisions, or if slow backhaul keeps messages from flowing into the radio fast enough to keep a continuous stream of messages flowing over the air. So, if the backhaul connecting the radio through the ELM to the broker is slow, then it will lead to a larger configured queue size to ensure that bursts in message activity are smoothed out and the airtime can be used to the fullest extent possible. The ideal queue size that will be configured for the radios will be determined during performance testing of the system.

Figure 20: Flow control and queue management



To support this model and keep from overloading the radio's queues, there is a flow control mechanism that is based on knowing the status of a radio's queues and the feedback from acknowledgements. As can be seen in Figure 20, this mechanism feeds information upstream about the ability of the radio to accept more messages into its queue for delivery. Since this is a mixed-priority system with requirements for very quick preemption of low-priority messages in favor of high-priority messages, this flow control mechanism will work based on a priority-filtering approach. In other words, when the radio's primary queues are full, the ELM will know the lowest priority message in a radio's primary queues. The idea is that even if the radio's primary queues are full, it should still preempt that lowest priority message with any higher priority message that is waiting to be sent. In this case, when a higher priority message is sent through, the radio will drop the preempted message from its primary queue and send a negative acknowledgement back to the ELM, which can re-send the message at a later time.

The details around flow control messaging can be found in Section 6.3.

7.2 Addressing

The address (or ID) used by the radio for node identification over the air is an arbitrary three-byte number that is stored on the CIM and represents the site where a radio is installed. Translation between these addresses and the ITC Messaging System addresses is handled in the ELMs and the CMs.

The following are specifications that the system will meet to support addressing.

Table 15: Addressing specifications

Function	Description	Value	Conditions
Number of Addresses Supported [A]	Number of addresses supported by the 220 MHz Radio Network	≥ 16 million addresses	Addresses are managed to avoid duplication across multiple CIMs

Note:

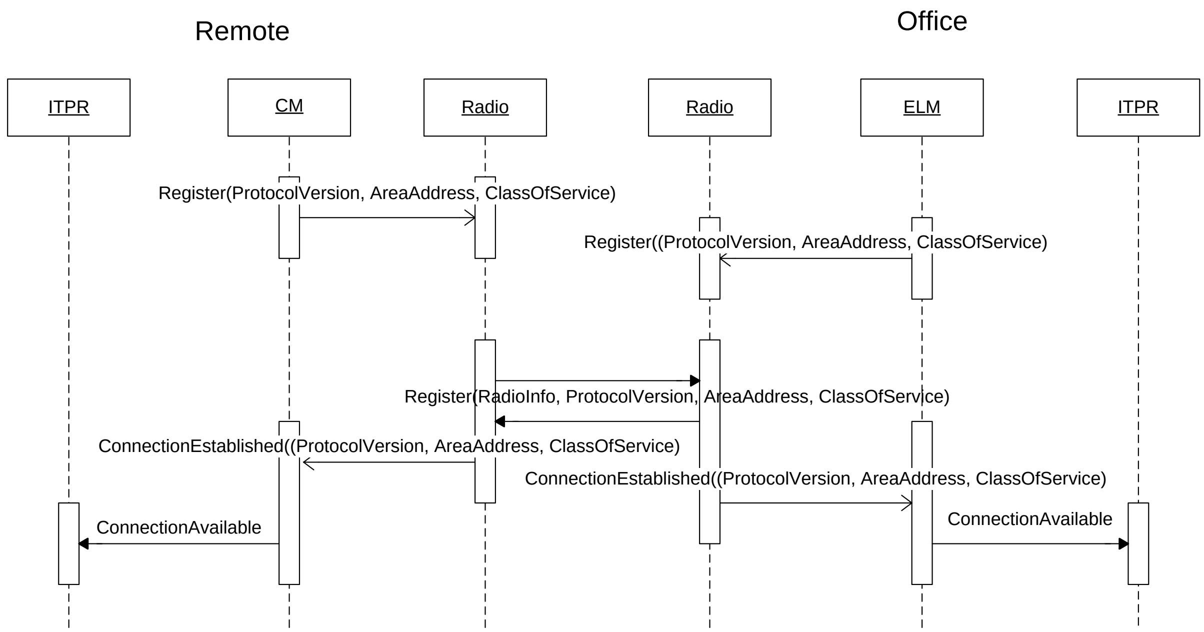
[A] Required to support 7,000 bases, 30,000 locomotives (10,000 active at a time), and 300,000 waysides with an ongoing growth rate of 0.5%/year.

7.3 Connection management

Sections 6.2 and 6.3 discuss how connections are made and advertised between each individual component in the 220 MHz Radio Network. To provide a comprehensive understanding of these separate interactions, this section provides an overview of how changes to RF connections are communicated out to the broader network. For details of each interaction, see the previously mentioned sections.

Figure 21 shows the interactions that prepare for a new RF connection and the interactions that happen when a connection is made.

Figure 21: End-to-end connection



The following describes each step involved in making an RF connection. In these steps, the terms “local” and “remote” are used in a relative manner:

1. To prepare for a new RF connection, when each ELM or CM registers with its radio, it passes its local area address and supported class of service as part of the HRX registration request. The radio stores that information for use when making RF connections.

2. When two radios establish a connection via ITCnet, they pass their local area address and supported class of service to the remote radio.

3. Once the RF connection is successfully established, the radios both notify their local ELM/CM of the connection via HRX, passing the remote radio’s area address and supported class of service.

4. The ELM checks to see if it is already connected to that same remote radio (potentially via a different local radio). If it is, then it processes it as an existing connection. If it isn’t, then it processes it as a new connection.

5. If it is an existing connection, the ELM updates its address translation tables with the new route information and is done.

6. If it is a new connection, the ELM adds an entry to its address translation table. It then compares the local class of service to the

remote class of service and chooses the most restrictive class of service to use for that connection. It then notifies the router via AMQP about the remote area and supported class of service for the new connection.

7. The router is responsible for letting the rest of the ITC Network know (as appropriate) about the new path to the remote area.

8. The router also gets an update from an ELM that previously had the connection that it has lost the connection. The old ELM will flush its message queues as soon as it is notified by its radio that the remote connection has been closed. If the router does not get the old connection closure update in time, the newer timestamp associated with the new connection will cause it to override the old route.

When an RF connection is lost, the radios will let their local ELM/CM know about the loss of the connection. If the ELM doesn't already have a new connection recorded for that remote area, then it will notify the router, which will let the rest of the network know about the loss of the connection.

If a radio loses its primary ELM connection, but has a backup connection to another ELM available, the radio performs a failover procedure to change its backup connection to become a new primary connection.

Finally, if a radio has an RF connection but loses its connection to its ELM/CM, including all backup connections, it will change its node state status to reflect its loss of ELM/CM connection. If the radio is a Base radio, the node state will be broadcast as part of the periodic base beacon packet to inform the remote radio about the loss. If the radio is a remote radio, the node state will be part of an Acquire packet that will need to be specifically sent when the connection loss happens, in order to inform the connected Base radio. Depending upon its situation, that radio will either drop the connection and attempt to connect to a different radio, or it will notify its ELM/CM of the issue. For example, if a base loses its connection to its ELM, it lets connected remotes know.

If the connected remotes have the option to connect to a different base, they drop their RF connection to the first base and attempt to connect to a different base. If they did not have any other options, they will instead let their CM know that the remote connection was not complete. The CM sends a connection status message to tell the router that the connection was not complete so that it will not send messages that cannot be delivered. Then the CM continues to track the connection in case the issue is resolved and the remote sends another connection status message indicating that it has resumed its CM connection so that the entire connection can be brought back online.

7.4 QoS and special handling

7.4.1 QoS

The ITC Messaging system will support a standard set of QoS fields. These fields are used by an application to give specific instructions to the Messaging System about how to handle a message. Table 16 indicates how those fields are used within the 220 MHz Radio Network.

Table 16: QoS specifications

QoS Field	220 MHz Radio Network Behavior
Priority	Passed through the 220 MHz Radio Network with each message. Used by ELMs/CMs and radios. A measure of the message's importance, with a range from zero to nine. Higher numbers indicate higher priorities. Priority is used by both the ELM or the CM and the radios. Higher priority messages are always serviced first. If the sending of a lower priority message is preempted by a higher priority message, the sending of the lower priority message will be resumed once it is again the highest priority message. Within a priority, messages will be serviced in a FIFO order.
Class of Service	Passed through the 220 MHz Radio Network as part of establishing an RF connection. The ELM selects the most restrictive class of service (out of the values from each side of the connection) to communicate to the router/broker for the connection[A]. Passed through on each message to the other side of the 220 MHz Radio Network. Not used within the 220 MHz Radio Network on a message by message basis. Used by the router/broker to restrict the messages that are routed across that connection[A].

QoS Field	220 MHz Radio Network Behavior
Time to Live (TTL)	Passed transparently through the 220 MHz Radio Network with each transported EMP message. Used by the ELMs/CMs and the sending radio. TTL value for each message is communicated to the sending radio separately by ELMs/CMs, as the radio does not parse message contents. Once the TTL has expired, the sending radio will send a negative acknowledgement to the ELM/CM and remove the message from its queue.
Network Preference	Not passed to the other side of the 220 MHz Radio Network with a message. Not used within the 220 MHz Radio Network. This field is used before a message reaches the 220 MHz Radio Network and does not need to be used again in any area on the other side of the RF connection.
Special Handling Code[B]	Passed through the 220 MHz Radio Network with each message. Used by the ELMs/CMs and sending radios. Translated into transport combination used by the sending radio.

Notes:

[A] See section 7.3, for details on how class of service is used during connection setup and during message routing.

[B] See section 7.4.2, Special Handling, for details on special handling.

7.4.2 Special handling

One of the QoS fields is called the Special Handling Code. This code indicates some special or nonstandard behavior that should be performed for a message. In the 220 MHz Radio Network, the ELM/CM will translate the special handling code into a set of behaviors. Some of those behaviors will be performed by the ELM/CM. The same special handling code will be communicated to the radio and some other special behavior is performed by the radio based on the special handling code. The translation of the code into behaviors will be table driven, based upon configuration data. This allows the behaviors that are mapped to a code to be modified or for new codes to be added in the future, resulting in new combinations of behaviors. This translation also takes into account the direction of the message (send vs. receive) so that the same code can cause different behaviors on the sending side than on the receiving side. The radios will only perform special handling on the sending side.

The code will be transported across the 220 MHz Radio Network with each message, so that the radio and ELM/CM on the receiving side can perform special handling, just like the radio and ELM/CM on the sending side may have done. This functionality is critical for the WIU Status-related messages discussed in section 7.5.

Table 17 describes behaviors that are supported in the 220 MHz Radio Network for various special handling codes. The component column indicates the component that implements the behavior.

Table 17: Special handling specifications

Behavior	Component	Description
Broadcast	Radio	Causes the message to be broadcast over the RF to all nearby radios, instead of it being unicast to a specific destination. Used for peer-to-peer messages (for example, WIU Status and WIU Beacon On).
Message Filtering	Radio or ELM/CM	Used on the receive side. Cleans up broadcast messages from being passed on through to the messaging system when they are not applicable. Can filter out all messages with a certain code (for example filtering out WIU Status messages received at a wayside). Can filter out messages with a code where the message is addressed to an area address that does not match the ELM's or CM's local area address.
RF Channel Selection	Radio	Indicates the RF channel that the message should be sent on. When not specified, the default behavior is always to send a message via DTDMA on the local channel. Codes can map to sending via DTDMA on the local channel, FTDMA on the local channel (for periodic beacon messages), or CSMA on the common channel.

Behavior	Component	Description
Periodic Beaconing	Radio and ELM	When periodic beaconing is selected, the ELM or the CM will get the LLLGGG:SS part of the source address from the higher level network headers and will send that to the radio as a slot key. The radio will have a slot mapping table in its configuration data which will map from the slot key to a slot using an FSU range. Once the slot time comes up, the message will be put into that slot. This behavior goes along with an RF Channel Selection of FTDMA on the local channel. [A] If a message with the same slot key is received before the previous message with that same slot key is transmitted, the newer message will overwrite the older message. Once a FTDMA beacon message is transmitted, it will be erased and will not be transmitted again. If no message is available to transmit when a slot time comes up, the nothing will be transmitted.
Header Stripping	ELM	ITC Transport headers will be stripped by the sending ELM or CM before the message is passed to the radio. The priority and special handling code will generally be carried separately through the network in ITCnet so that they can be used by the radio and ELM/CM on the other side of the RF connection whether or not the headers were stripped. It is expected that application headers will be stripped by other components in the ITC Messaging System (i.e. the AG).
Header Replacement	ELM	ITC Transport headers will be replaced by the receiving ELM or CM when the message is received from the radio. The headers will be looked up in the ELM/CM's configuration data based on the special handling code. It is expected that application headers will be replaced by other components in the ITC Messaging System (i.e. the AG).
Header Modification	ELM	The receiving ELM or CM will be able to replace the ITC Transport header destination address for the message from configuration data based on the special handling code.

Note:

[A] See section 8.5.3, Beaconed Wayside Status Message Configuration, for details on slot mapping and FSUs.

7.4.3 Base filtering of wayside status beacon messages

One other type of functionality that will be supported is a special case of filtering of FTDMA beacon messages. This is a special case because it is in response to something caused by special handling behavior, but it is not configured based on a special handling code.

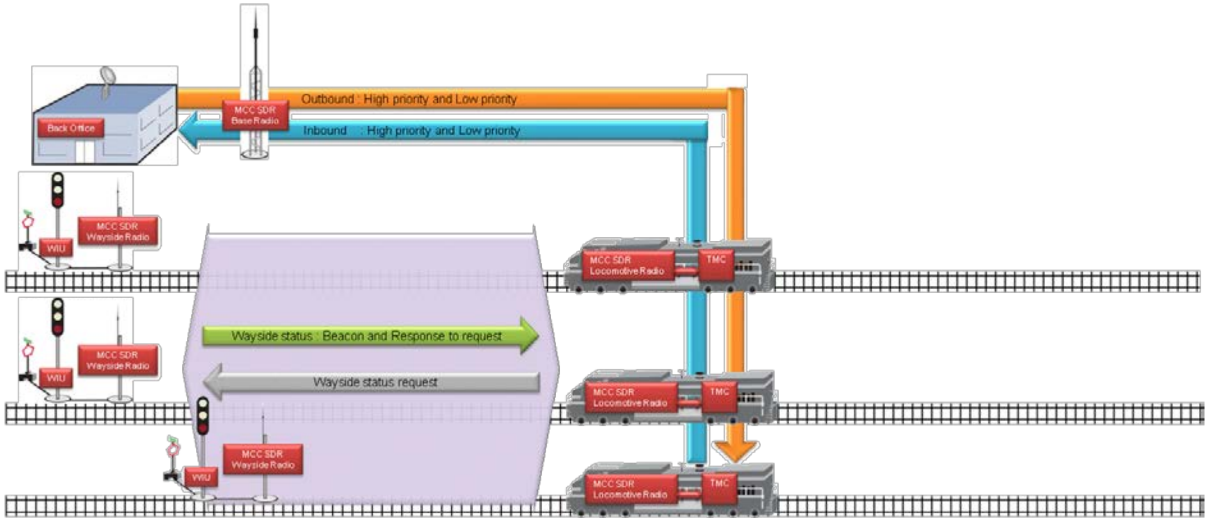
Both the Base and Locomotive radios listen to many local channels. A locomotive needs to receive and pass on to the wayside status messages from all of those channels, since there is no telling which channel will contain the wayside messages the locomotive cares about. Yet, nearby bases mostly connect to the same office. So, if all bases pass on all wayside status messages that they receive, there will be many duplicate wayside status messages passed along into the office. This duplication may be desirable and viewed as making the system more robust and reliable. Or, it may just be viewed as a waste of resources.

To help with this situation, a network engineer can, on a per channel basis, configure FTDMA beacon traffic to be blocked from passing through to the ELM/CM.

7.5 Wayside status message

As mentioned in the section 3, there are inbound and outbound messages going between the office and remotes. There are also peer-to-peer messages sent directly between remotes. The primary type of peer-to-peer messages supported is wayside status-related messages. As can be seen in Figure 22, a wayside status message is broadcast directly from a Wayside Interface Unit (WIU) to a locomotive, to communicate indications and switch positions for the wayside.

Figure 22: Wayside status message



By having these messages be supported as peer-to-peer messages over the 220 MHz Radio Network, it avoids additional latency from going through a base or other Back Office components. It also allows for these messages to work in areas engineered with no base coverage or where a base has failed.

7.5.1 Messages

The core concept supported is having an unsolicited wayside status beacon message that is sent periodically. If the network is correctly configured, this message should be heard by approaching trains before they need it as well as during their entire approach to the wayside. The message will be sent as a broadcast message in the 220 MHz Radio Network. It will also have its EMP and ITC Transport headers stripped off when it is sent over the air (and reconstructed on the other side) to make the most efficient possible use of the available airtime.

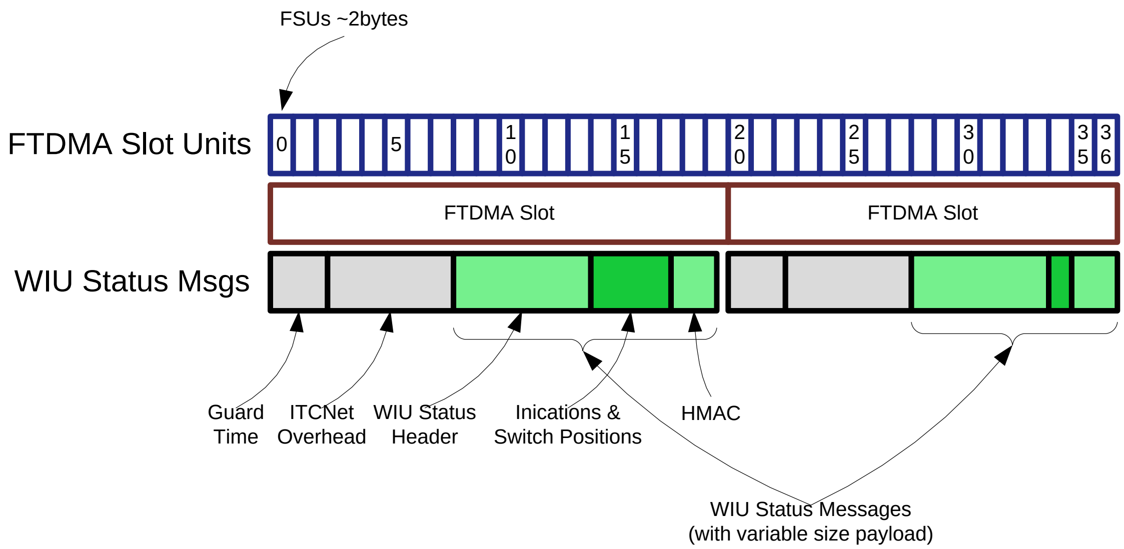
The basic assumption is that most waysides will continuously send out their periodic status beacon messages (constant beaconing). But, there is also the ability to configure a wayside to turn their status beacon messaging on and off (intermittent beaconing) in order to save power and/or to control approach lighting. When an intermittent beaconing wayside is not sending out status messages, then an approaching train will need to send a “beacon on” message to the wayside to request that it turn on its status beacon. This “beacon on” message is sent as a broadcast packet in the link layer but is only passed through the receiving CM if its application level EMP address matches the wayside area. When a wayside receives a “beacon on” message, it will start sending its status beacon for a configurable period of time. It will also light approach lighting if not already lit. As the configurable period of time gets close to the end, the wayside status beacon messages will include an expiration bit to tell trains that are listening to it that the period of time where it is sending its status beacon will expire soon. This will let the train know to re-send a “beacon on” message which will cause the wayside to reset its status beacon timer once again.

Finally, there is a “get status” message that can be sent by a locomotive in the case of an emergency. This message is sent in a similar manner to the “beacon on” but is only sent in the case where the train is in imminent risk of going into restricted operation if it does not receive a wayside status within the next few seconds. When a wayside hears this message, it will send an immediate response to the train and will also start its status beacon if not already on. If the network is well configured, this message should never need to be sent. Every time that this message is sent, it is expected that the locomotive will log the event so that a network engineer can evaluate what went wrong and take corrective action.

7.5.2 Beaconed wayside status message configuration

As mentioned above, the wayside status beacon messages will be sent on a fixed cycle in pre-defined FTDMA slots. Given that the wayside status message is a variable-size message, the slot configuration for these messages will use an approach of mapping a range of small FTDMA Slot Units (FSUs) to each message. As can be seen in Figure 23, the first message is mapped to FSU 0-19, the second to FSU 20-36, and so on. This example shows how they are mapped for an area with a high density of waysides, where they have to be fitted together as tightly as possible to fit all of the wayside beacon messages into the available FTDMA frame. In a lower density area, some space may be left between FTDMA slots to allow for changes in the size of the wayside status messages, without having to change the FTDMA slot mapping for the entire channel in that location.

Figure 23: variable size message to FTDMA slot map example



This mapping is done in the radio configuration data (centrally managed as a part of the configuration management system). In the configuration, there will be a mapping from a "slot key" to a start FSU and a length in FSUs. This indicates that messages that come into the radio with that slot key should be put into the slot defined by the mapped FSU range. The slot key will be set by the ELM or the CM from the source address on the message before it is sent to the radio. More details about how this mechanism works can be found in the section 7.4.2.

7.5.3 Specifications

Full details of how messaging related to wayside status functionality works can be found in the Wayside Status Comm Use Cases document (Reference [10]).

The following are specifications that the system will meet for functionality related to wayside status messaging.

Table 18: Wayside status messaging specifications

Function	Description	Value	Conditions
FTDMA Message Cycle Time	Time between beaconing of each FTDMA message from a single source	3 seconds	A message is given to the radio at least once every 3 seconds (ideally more often like every 1 second to avoid timing issues)

Function	Description	Value	Conditions
FTDMA Message Size Supported	Size of beaconed FTDMA messages supported	1-2040 bits	Enough airtime is available in the FTDMA frame to support the message size. A minimum size for the originating message will be 104 bits in the case of WIU Status.
FTDMA Message Timeliness	When multiple messages have been received by the radio between beacon cycles, which message will be sent	Last message only	Other messages received will be discarded
FTDMA Message Uniqueness	How often will a message received by the radio be sent as an FTDMA beacon per beacon cycle	Once	If no messages have been received by the radio since the last one was sent, no message will be sent

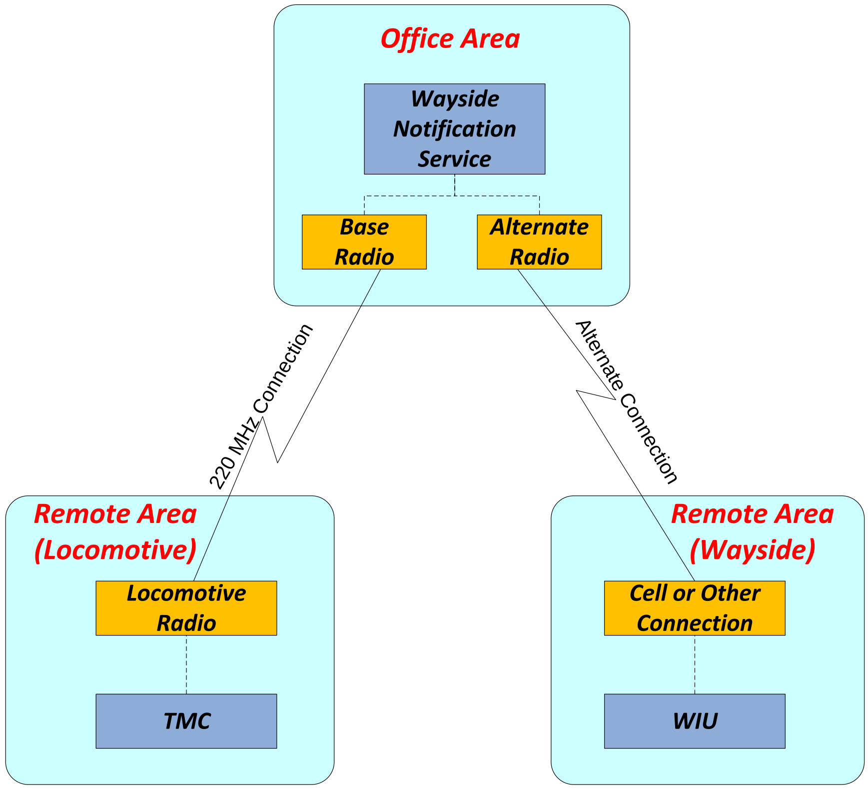
Note:

See section 6.2 for more information on FTDMA frames.

7.6 Virtual wayside radios

There is a desire in some cases to support a virtual wayside radio concept. The idea is that if a wayside already has reliable high-speed backhaul, either via a wired or a wireless connection (cell, microwave, and so on), then there may be an opportunity to save money by not installing a 220 MHz Wayside radio at that wayside. Although this concept is not explicitly supported by the 220 MHz Radio Network, the 220 MHz Radio Network is believed to have the functionality necessary to support this concept.

Figure 24: Virtual wayside radio



In the simplest variation of this concept, the base radio acts as a virtual wayside radio. This allows for wayside beacons to be routed via a non-220 MHz path to a service in the back office (or directly to the base). From there, the service can reset the destination address and QoS to get them to the appropriate base radios and to cause them to be sent as an FTDMA beacon (using the same special handling functionality that is described in section 7.4.2). Depending upon coverage patterns, a single wayside beacon may need to be sent from more than one base adjacent to the wayside's physical location. To get these wayside beacon messages to a base, functionality in the ELM allowing a static remote address to be configured will be used. This allows a wayside status message to be delivered to a base by addressing it to a static remote area address. The fact that the remote area matching the address does not actually exist will not matter for these wayside status messages. Because they are marked to be broadcast and at the radio, the remote address will be ignored and the headers will be stripped.

Similarly, using special handling functionality, it is possible to configure a base that receives a "beacon on" or get status message to route that message to the back office service that manages this functionality. This allows both the intermittent beaconing as well as the emergency functionality described in section 7.5.

There are also numerous other ways that the virtual wayside radio functionality can be achieved. Some of these alternatives may or may not be supported by the current 220 MHz Radio Network functionality. Additional analysis is required before pursuing any other variation on this type of functionality.

Finally, it is important to note that this approach requires aggressive system engineering to ensure that latencies do not add up to a level that causes problems.

7.7 Wayside Status Relay Service (WSRS)

Wayside Status Relay Service is fundamentally very similar to the Virtual Wayside concept that is described in the previous section. The basic idea for this service is to fulfill and mitigate gaps that otherwise can occur in Wayside radio coverage areas. In some cases, providing fixes to Wayside radio coverage problems can be cost prohibitive, in which case WSRS provides a better solution. Also, WSRS can help in increasing the overall reliability in wayside status messaging.

Figure 25 has a conceptual diagram about WSRS.

Normally, the wayside status message goes across the Wayside and Locomotive radios in peer-to-peer fashion according to the following communication path:

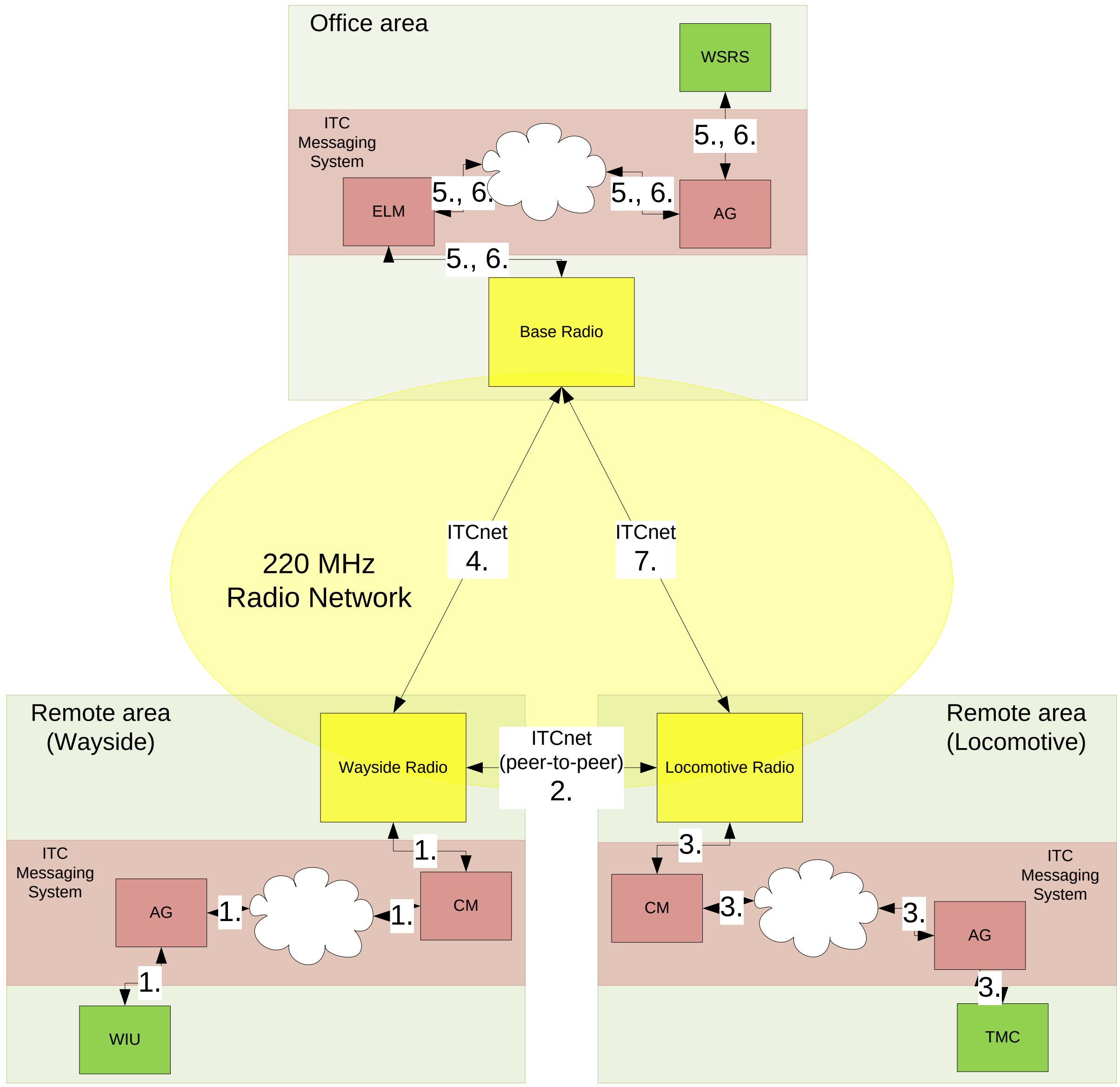
- The wayside status message is generated by a WIU, and will be sent to a wayside radio (1)
- The Wayside radio broadcasts the message peer-to-peer to a Locomotive radio (2)
- The Locomotive radio forwards it to a locomotive TMC that is connected to it through the locomotive messaging system network.

In case the Wayside radio has limited or otherwise problematic coverage areas, the Locomotive radio will not be able to receive the message and the communication path (2) is not available.

Assuming that the Base radio has a reliable connection to the Wayside radio, the wayside status message travels with a help of the WSRS the following communication path:

- The wayside status message is generated by a WIU, and will be sent to a Wayside radio (1)
- The wayside broadcasted message that was intended to go peer-to-peer to the Locomotive radio will be received by a Base radio (4)
- The Base radio will forward the message to a WSRS server located in the office area (5)
- The WSRS will relay the message, by designating it to a new destination, and by sending it back to one or more Base radios (6)
- The Base radio, which could either be the same that received the message or a different Base radio, will transmit the message to the intended Locomotive radio (7)
- The Locomotive radio will forward the message to its TMC via the locomotive messaging system network (3)

Figure 25: Wayside status relay service architecture



There are multiple ways how the WSRS can handle the message redirection, which affects how the Base radio will relay the message to the Locomotive radio (7). The options are:

- Broadcast the wayside status message in the FTDMA section similar to the original wayside transmission.
- Send the message with a unicast packet in the DTDMA section to a designated Locomotive radio.
- Broadcast the message with a broadcast packet on the common channel (CSMA).
- Send the message as a broadcast packet in the DTDMA section.

The current radio software supports only the first three options.

The wayside status relay service can also operate in only one of the following ways:

- in a static fashion, where certain waysides are configured to be relayed by certain base radios as stated by a static WSRS configuration
- dynamically as a subscription based service

In the latter case, the wayside status relay service will not operate continuously but rather in a demand based fashion. The locomotives need to subscribe or inform the WSRS beforehand about the waysides they need to monitor, and the subscription may time out after a specified time in order to reduce radio network load.

The dynamic subscription occurs with a specific message from the locomotive to a back office, where the TMC informs the WSRS about the waysides it needs to receive status from.

8. System Management

The 220 MHz ITC radios support two different management interfaces. First of all, ITC radios can be managed via the maintenance port connection, which is described in section 6.6. The maintenance port connection operates as a TCP/IP connection through one of the radio Ethernet ports by using a proprietary text terminal and file transfer program (XTermW) as a client. More information about available ITC radio configuration parameters and management commands that are related to the maintenance port connection can be found in the Functional Specification document (Reference [2]).

The maintenance port connection can provide both local and remote management of ITC radios. The maintenance port connection can be established with a direct connection between an ITC radio and a local laptop computer running XTermW. The maintenance port connection can also be remotely operated with any available remote IP-based link, for instance, via cell or satellite radios.

In Release 1.0 of the 220 MHz Radio Network, the only system management interface to ITC radios is the maintenance port connection.

The other supported approach to radio management is called centralized management. This approach is supported with the ITC system management (ITCSM), which operates over the ITC Network. The Release 1.1 software will include first implementation of end-to-end centralized remote management features that will be part of the ITC System Management System (ITCSM). The supported ITCSM features include remote file transfer and loading of new configuration and software kit files to the radio.

Table 19 describes the two different local and remote management alternatives of ITC radios. The following sections describe the ITCSM based system management option.

Table 19: System management interfaces for ITC radios

System Management Mode	Description	Mode	Release	Operations
Maintenance Port Connection	Command line interface over TCP/IP terminal connection. Operates with radio specific commands	Local or Remote	1.0, 1.1	Individual parameter, configuration script, and firmware updates. Full ability to control the radio operation.
ITCSM	System management interface that operates over ISMP protocol. The interface is standard over all ITC assets.	Remote	1.1	Configuration script and firmware updates. Supports separate download vs. activation of changes. Downloads and activations are sent through the ITC Network to an embedded SM Agent in the radio.

8.1 ITC System Management system (ITCSM)

The ITC System Management solution (ITCSM) introduces additional system management components that are either part of the managed assets (which also includes ITC radios) or are located in back offices. From radio or messaging system communication point of view the system management related communication is transparent.

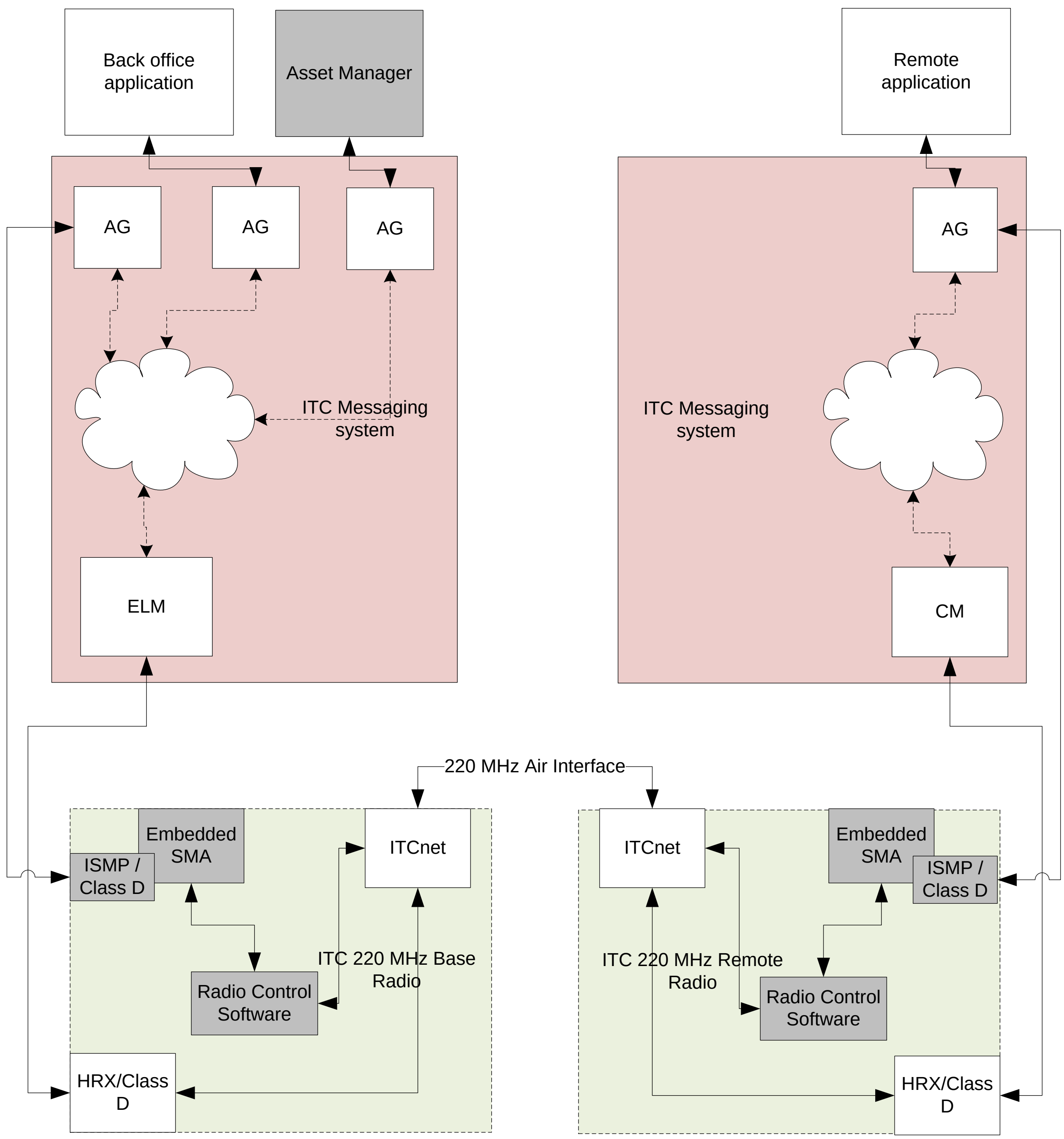
Figure 26 presents the overall system architecture where radio centric ITCSM components are highlighted.

The ITC System Management System includes the following components:

- Asset Manager (AM), which is the communication endpoint in the back office from the radio perspective
- System Management Agent (SMA), which will be integrated into the radio software and is the other communication endpoint

The SMA further consists of ISMP/Class D protocol implementation to handle required communication with the messaging system components. The SMA interfaces with the radio control software in order to perform actual management of radio functionality and features.

Figure 26: ITCSM centric radio architecture



8.2 ITCSM interfaces and protocols

The embedded SMA in the radio establishes the system management connection with the messaging system Application Gateway (AG) by using one of the radio Ethernet ports. The protocol architecture that is used in the system management connection is ISMP/EMP/Class D/TCP/IP.

ISMP is a system management protocol that utilizes EMP messaging as a wrapper. Reference [11] includes a description about the protocol and how related EMP messages are constructed.

Class D protocol is described in Section 6.3.1 and the Class D specifications are in Reference [12].

8.3 ITCSM messages

Section 6.5.3 has a list of ISMP system management messages that are supported in Release 1.1.

8.4 ITCSM communication paths

System management related communication paths are slightly different for base and remote radios. The first leg of ITCSM communication for all radios is the connection to the messaging system AG, but from there on the communication paths differ.

Base radios (as illustrated in Figure 27):

- Send system management messages directly by using ISMP/Class D/TCP to its messaging system AG. (1)
- From there the messaging system routes the messages to the Asset Manager (AM) that is also connected to one of the messaging system AGs. (2)

Remote radios (as illustrated in Figure 28):

- Send system management messages similarly with ISMP/Class D/TCP to their local messaging system AG. (1)
- From there the messaging system routes the messages by using some available transport path to the office area. If the transport is the 220 MHz radio, the messages will be transparently routed through the same radio using its regular HRX host data connection. (2)
- From the office area the messaging system routes the messages to the Asset Manager that is also connected to one of the messaging system AGs. (3)

The system management communication paths in the opposite directions are the same.

Figure 27: ITCSM communication path for base radio

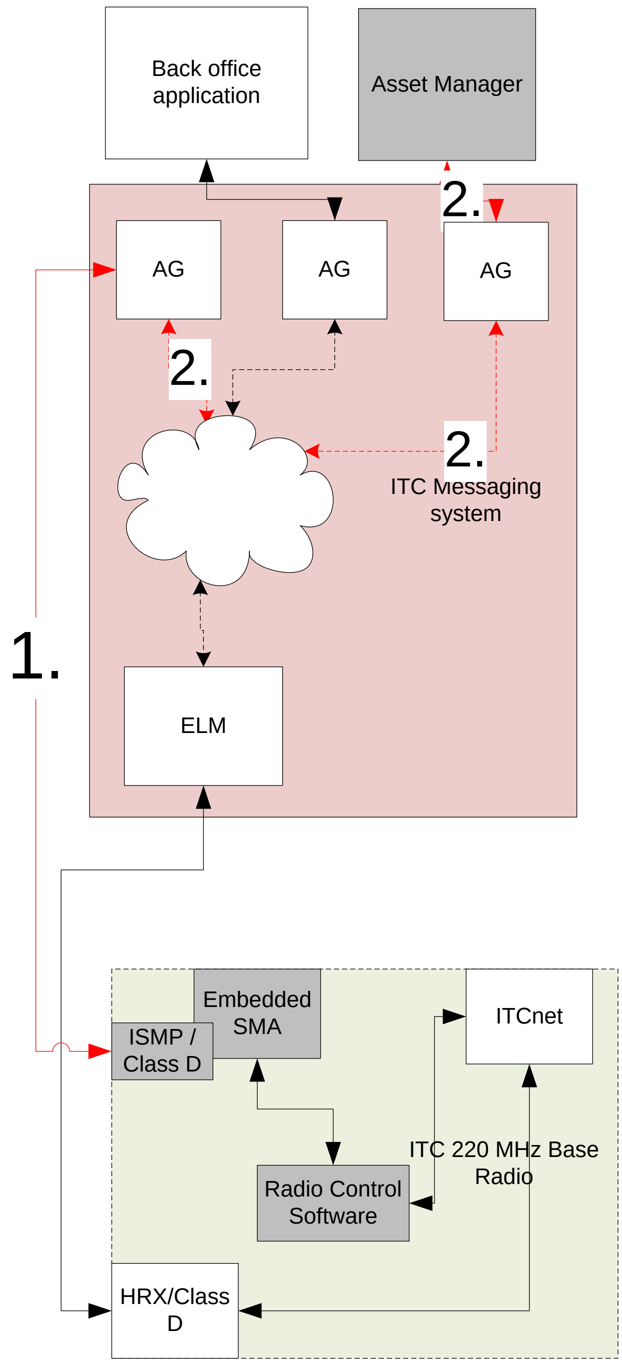
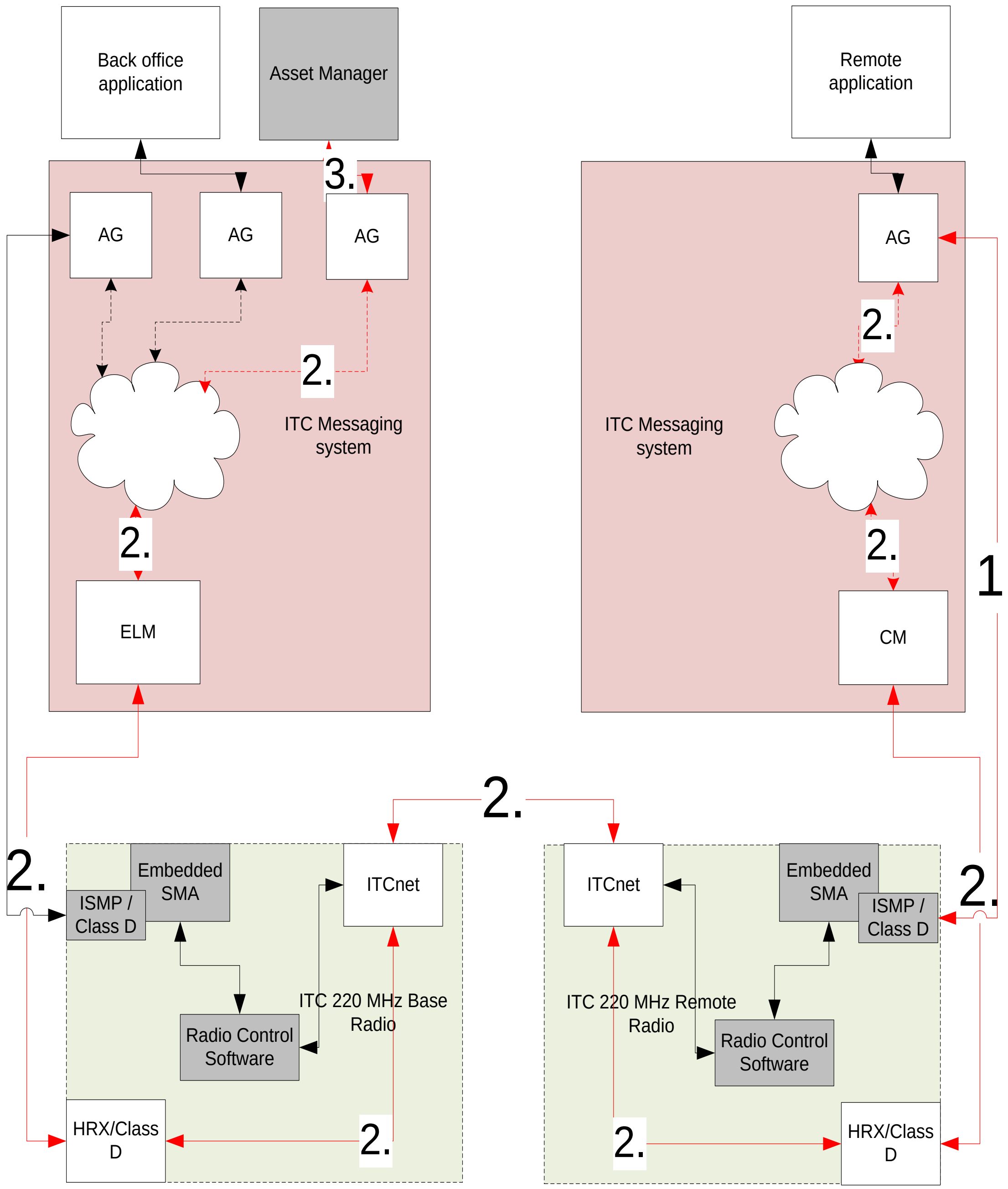


Figure 28: ITCSM communication path for remote radios



8.5 Remote file transfer

Release 1.1 will support file transfers from the Asset Manager to the embedded SMA in the radio. The file transfers will essentially be applicable to software and configuration kit transfers.

The Embedded SMA in the radio will have to support file transfer commands:

- File Transfer Request
- File Transfer Response

The software and configuration kits that radios are using are below the EMP message size limitation of 16 Mbytes. Therefore fragmentation support is not needed and the radio can expect to receive its software kits with a single received ISMP message.

Security features are not targeted to Release 1.1 for the radio, and this applies also to file transfers.

8.6 Kit management

Release 1.1 will support software and configuration management via kit transfers. This includes the following supported items:

- The radio will accept new software and/or configuration in files that are packaged and transferred as kits.
- The radio will know based on a received kit file how to extract and interpret its contents. The radio will know how to update its software and/or configuration based on the kit file contents. This action is referred to as "loading a kit."
- The ITCSM based software and configuration management is integrated with the native maintenance port connection based software and configuration management in the radio. Both maintenance port connection and ITCSM based methods of updating either configuration or software are available in the radio.

The Embedded SMA in the radio will have to support the following kit / configuration management commands:

- Kit Management Request, with actions
  - Load
- Kit Management Response

