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Methodology for Initial Assessment of Spectrum Requirements and Required Numbers of Base Stations in a Multi-railroad, Dense Traffic Area

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This report is intended to provide a methodology for performing an initial assessment of spectrum requirements related to deployment of a 220 MHz RF network for handling of Positive Train Control (PTC) messaging in a multi-railroad, dense traffic area. It also identifies how to determine the number of radio base stations required to support the projected messaging load in a territory.

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Methodology for Initial Assessment of Spectrum Requirements and Required Numbers of Base Stations in a Multi-railroad, Dense Traffic Area

Sponsorship of Report

This report has been prepared as a part of Grant No. FR-TEC-0004-11-01-00, issued by the Federal Railroad Administration (FRA) to Southern California Regional Rail Authority (SCRRA) under the Railroad Safety Technology Grant Program.

Focus of Report

This report is intended to provide a methodology for performing an initial assessment of spectrum requirements related to deployment of a 220 MHz RF network for handling of Positive Train Control (PTC) messaging in a multi-railroad, dense traffic area. It also identifies how to determine the number of radio base stations required to support the projected messaging load in a territory.

The radio network is intended to serve the needs of the PTC systems being deployed concurrently by multiple railroads in accordance with the requirements of the Rail Safety Improvement Act (RSIA) of 2008, and the corresponding implementing rules promulgated by the FRA. The methodologies explored and documented during the performance of this work is intended to assist other railroad entities with their deployment strategies as they develop their own PTC radio network deployment strategies for multi-railroads in dense urban areas.

Format of the Report

This report follows a sequential process that can be used when performing the initial assessment for requirements of an RF network and in developing the final RF network configuration. Where appropriate, this report will provide a case study of how the development team for SCRRA actually addressed a specific step in the assessment/development process and will provide lessons learned of what worked and what did not.

One should note that this report provides a roadmap for a sequence of steps that can lead to a final RF network deployment, but it is not the only road available, nor is it a "cookbook" for the design of an RF network. Each operating area will have its own unique set of conditions, requirements and restrictions that will need to be factored into the design process. These unique conditions can be driven by technical constraints, business necessities, or both. No one design will satisfy all urban areas.

For security purposes, details concerning the precise locations and configuration of RF network components or the content of assets included therein are omitted from this report.

A companion report will be issued at a later date that provides a methodology for cost apportionment in a shared RF network.[1]

Background

In accordance with the requirements of the Rail Safety Improvement Act (RSIA) of 2008, passenger railroads and most freight railroads, shall install and have operational an interoperable Positive Train Control System (PTC) by no later than December 2015.

PTC is a predictive collision avoidance system that provides a first warning to train operators and then intervenes to stop a train before a collision or other hazardous train movement can occur through use of an “integrated command, control, communications, and information system.” The four (4) core requirements of a PTC System that it shall reliably and functionally prevent are:

- Train-to-train collisions
- Over speed derailment
- Incursions into established work zone limits
- The movement of a train through a main line switch in an improper position

To meet the requirements of the RSIA 2008, SCRRA is designing and installing an interoperable PTC system in the Los Angeles, California, in coordination with Union Pacific Railroad (UPRR), BNSF Railway (BNSF), and the National Passenger Railroad Corporation (Amtrak), which all operate in the region. Under PTC, high-density rail traffic, combined with multiple main tracks, with numerous control points and three or more different host railroads, equates to high-density radio traffic. Coordination of frequency allocation, reuse, and propagation present both technological challenges and commercial implications. SCRRA’s efforts to resolve these issues through its design and implementation of a PTC system in the Los Angeles basin were used as the basis of this report.

Interoperability Requirements

In order to comply with the federal RSIA mandate for interoperability[2], the PTC system must be configured so that all trains can operate over tracks that are owned and operated by various host railroads. A key factor in assuring interoperability is the development of a coordinated communications network where all operating railroads can reliably send and

[1] The report titled “Methodology for Cost Apportionment in a Shared 220 MHz RF Network for a Multi-railroad, Dense Traffic Area” will examine the factors involved in apportioning cost sharing among the host and tenant railroads that will operate under the RF umbrella. Among the factors to be considered in making the apportionment will be spectrum contribution, shared base station assets, backhaul connectivity, message utilization, and maintenance.

[2] Interoperability as defined under 49CFR Part 236.1003: Definitions as “the ability of a controlling locomotive to communicate with and respond to the PTC railroad's positive train control system, including uninterrupted movements over property boundaries”.

receive compatible PTC control and status messages over the single communication network, even though parts of the network are constructed and operated by different railroads. The 220 MHz RF communications system is structured to handle tri-fold data traffic amongst the on-board PTC equipment, wayside signaling equipment, and strategically located radio base stations.

A core requirement for PTC to be interoperable is that all participating railroads in an area must be able to communicate seamlessly between the on-board PTC system and the wayside signal system, as well as access up-to-date geographic databases and directives through the governing Back Office Server (BOS). To meet interoperability requirements, the communications networks must provide seamless and continual links to trains from participating railroads when they traverse an area and transition from one host railroad's territory to another host railroad's territory.

The interoperable PTC communications network is being designed to utilize radio spectrum in the 220 MHz band. Spectrum is a finite resource that must be managed so that the PTC messages reach the intended train, and only the intended train. A significant portion of the design effort for PTC implementation is centered upon the establishment of criteria for PTC data handling. Much of this work is being undertaken by the Interoperable Train Control (ITC) Committee, which is composed of the four largest U.S. freight railroads - BNSF, CSX, NS, and UPRR. However, each host railroad must provide significant additional effort to design, deliver, and test the databases and communications networks that will process the message streams.

CASE STUDY #1: *SCRRA has chosen to proactively engage itself in the implementation of its PTC program and is targeted to have its rail network under PTC protection by early 2013, three years prior to the mandated date. BNSF, UPRR and AMTRAK, the other railroads servicing or passing through the LA basin area, have committed to support the SCRRA initiative and are also targeting an early 2013 completion of PTC on their own rolling equipment and rail properties within the area. Refer to Figure 1 for a map of the LA basin Area that identifies the various railroad holdings in the area.*

PTC is a locomotive-centric system overlaid on existing methods of control and operation that provides an enhanced level of safety through enforcement of train authority limits, permanent speed restrictions and temporary speed restrictions. The SCRRA PTC program as a whole, will design, furnish, install, test, and commission a FRA certified PTC system at the same pace as the BNSF, UPRR and Amtrak in the LA basin area. This PTC system will be designed and implemented as an ITC compliant interoperable safety critical system and will provide a fail-safe response to system vulnerabilities, such as the loss of communication of vital data.

SCRRA has chosen to implement PTC by deploying the I-ETMS software, hardware and associated components that are compatible with the PTC systems being deployed by BNSF and UPRR.

To assure the integrity and reliability of the portion of the communications data transmission link between the base stations and the operations back office, SCRRA has undertaken a program to upgrade the backhaul portion of the communications network. These upgrades will include a best-fit between fiber optics and packet-digital microwave radio configured as a SONET/Ethernet network. Network architecture will use a ring topology in order to provide improved reliability of data transmission. BNSF and UPRR are likewise upgrading their own communications networks to accommodate their own PTC programs.

In response to the mandate for use of the 220 MHz radio spectrum as the interoperable data channel for PTC, SCRRA is attempting to purchase spectrum in the 220 MHz band and obtain the necessary FCC licenses. The spectrum is needed to support PTC data communication over SCRRA owned trackage, thereby providing the required communication links between the On-Board system, the EIC units, and WIUs. SCRRA recognizes that the success of the PTC system relies on the availability and reliability of the communications system. If the communications system is unreliable, there will be a resulting incidence of train delays. SCRRA considers the hardening of its backhaul communications network as a critical component of PTC implementation. To this end, SCRRA is in the process of upgrading and hardening the data transfer links between the various wayside base station locations and the operations control center. This upgrade program is discussed in more detail below.

Organizational Relationships

The first step in approaching the assessment and design of an area-wide RF network is to identify the key participants. These include the system development partners and any second tier users. All host railroad entities within the immediate RF coverage area and any other railroads operating strictly as tenants on one of the host railroad properties must be identified. In addition, any organizations that have either direct ownership or control of potential assets and any entities that may exercise governance over these assets must be identified.

Case Study #2: *In the LA basin area, the three host railroads – SCRRA, BNSF and UPRR – have mutual host/tenant relationships. A fourth railroad, NCTD, also owns and operates trackage in the Southern California area for commuter passenger service. However, NCTD is not on the same accelerated PTC implementation schedule as the other LA basin area service providers, so their network relationships will need to be factored into the area network allocation process at a later date.*

Amtrak is a tenant on various portions of the trackage owned by either SCRRA, BNSF or UPRR. Though not a host railroad in Southern California, Amtrak's level of service was factored into the overall traffic density calculations when the RF requirements list was developed for the area.

Another important participant in the area RF design process (though not a host railroad), was PTC-220, LLC. PTC-220, LLC is an entity created by four of the major Class 1 railroads (BNSF, CSX, NS and UPRR) to manage shared spectrum consisting of eighteen (18) frequency blocks in the 220 MHz Bandwidth area.

Another significant participant in the design of the area wide RF network was MeteorComm LLC (MCC). MCC, as a designer/vendor wholly owned by the four (4) Class 1 railroads, was tasked with development, design and licensing of the 220 MHz PTC compliant radios. MCC has established the protocols that will be used for over-the-air interoperable data messaging transmission between the on-board, wayside, and base stations.[3]

Though not a direct participant in the RF design process, the FRA holds governance over the final PTC deployment. SCRRA has chosen to engage the local and national FRA representatives throughout the RF design process to assure them that their statute requirements are being factored into the design.

The FCC also holds governance over the final RF design and its statute requirements were factored into the design.

The secondary spectrum market is also an indirect participant in the RF design process. This part of the equation will be addressed in more detail when we explore the spectrum acquisition portion of the RF process.

Develop an RF Design Development and Coordination Team

Given the number of interested parties and their sometimes diverse agendas, it is critical when developing an area-wide RF design, that there be a clear understanding of the criteria and responsibilities of each of the parties participating in the design process. After identifying the various parties, it is important to establish the lines of communication for fact gathering and for actual design development.

***Case Study #3**: SCRRA's V/I took the technical lead in organizing and chairing weekly working group teleconferences with key representatives of the rail users and communications vendors. In addition to SCRRA and V/I staff, this included representatives of BNSF, UPRR, PTC-220, LLC, and MeteorComm.*

As a result of these coordination meetings, it was decided that the V/I would take the lead in developing the area wide radio coverage studies and coordination of shared asset utilization. Additionally, each participating railroad was responsible for the procurement and design of its own wayside and base station sites.

[3] Alternate over-the-air messaging utilizing the ITC messaging protocol can be realized via Wi-Fi, commercial cellular or commercial satellite systems. However, the 220 MHz band will be the primary message carrier for PTC data traffic.

As expected, this area-wide design effort has been an iterative process with significant give-and-take between the parties.

Identify and Execute NDA's

One of the realities that needs to be faced early on by an agency is that much of the information required to design a large area RF network for PTC radio coverage is either still in development or sheltered under the cover of formal non-disclosure agreements (NDAs). For what appears to be a combination of technical and business reasons, the only avenue currently available for obtaining detailed insight into the 220 MHz band radio hardware performance parameters is to enter into NDAs with various parties, including the developers of the actual radio design.

Case Study #4: *It has been necessary for SCRRA and its V/I to enter into a number of NDAs and service agreements in order to obtain access to critical design related information. It should be noted that once the NDAs were in place, the various vendors were very forthcoming with detailed information and were active participants in design focused working groups.*

As an example, for the SCRRA PTC Project, there are NDAs in place between design consultants and SCRRA, V/I and SCRRA, SCRRA and individual V/I vendors, SCRRA and the radio designer, V/I and the radio designer, and V/I and its own vendors. In addition to NDAs that provide an avenue for obtaining critical product information, it will be necessary to enter into separate service agreements with various vendors in order to actually be in a position to place orders for the hardware and software needed to access the RF network.

It is a possibility but not a certainty that after one or two PTC RF networks have been installed and placed into service, that much of the technical information will be more readily available to the marketplace. However, until that time, it is strongly recommended that information sources be identified and agreements be formalized early-on so that the real work of designing a network can begin.

Identify Area Boundaries

In most urban areas which are serviced by one or more commuter rail providers, the commuter rail service is laid out to serve a core area and typically extends out in various directions from the core by no more than fifty to one hundred miles. However, the freight rail carriers that also pass through the area typically extend for many more miles beyond the core area and may even extend cross-country. Freight and commuter traffic may share corridors in portions of the area and may have a host/tenant relationship on some trackage. It is also likely, that freight service may run into areas that are not located near a commuter line. Therefore, to provide an efficient design, an agreement needs to be reached between the commuter and freight carriers to define the limits of the combined radio network.

Case Study #5: *In the LA basin area, SCRRA commuter service spokes out from the central LA terminus on five main service corridors. The service routes operate over a combination of SCRRA owned tracks, BNSF owned tracks and UPRR owned tracks. Metrolink service also extends into the northern portion of San Diego County, where it is a tenant on NCTD owned tracks. However, initial PTC operation on Metrolink will only extend slightly beyond the Orange County border with San Diego County, as NCTD is not scheduled to implement PTC much in advance of the 2015 mandated deadline. Radio network coordination between SCRRA and NCTD will need to occur when NCTD is further into its own PTC implementation program. These Metrolink service routes and the affected BNSF and UPRR properties are shown on Figure 2.*

The basin-like configuration of the LA area presents a natural barrier to radio signal propagation that was instrumental in defining the limits of the shared network coverage area. The coverage area extends: to the west, to just west of the Metrolink Ventura Station; to the northwest, to just beyond the Metrolink Lancaster Station; to the north, on the Pasadena Sub to around MP115; to the northeast, to just beyond where the UPRR Mojave Sub and the BNSF Cajon Sub tracks diverge; to the east, on the UPRR Yuma Sub to around MP3.2; to the south, to CP Songs; and, to the southwest, on the Alameda Corridor to around MP15.5.[4]

Identify Initial Design Parameters

As noted above, currently the surest access to RF network design parameters is to execute NDAs with the various network developers and hardware manufacturers. A second source of information is through participation in various technical committees and symposiums.

Case Study #6: *The SCRRA PTC Team, through some networking, application of sound design principles, and a lot of hard work, were able to draw a box around the primary structure of the 220 MHz RF network, as it was understood in mid-2010 when they issued the RFP for the V/I contractor. The parameters given in the RFP, for proposal purposes, is included in Appendix A of this report. It should be noted, that these parameters were developed around the perceived needs and limitations of commuter rail operations in the LA basin area and may not be directly applicable for network development in any other metropolitan area. It should also be noted, that during the iterative design process, some of these initial design parameters were modified to accommodate the currently available spectrum and utilization of other over-the-air data transmission paths, such as WLAN and commercial cellular.*

[4] It should be noted, that even though PTC is not being installed on the Alameda Corridor, it will be necessary for trains operating on this corridor approaching PTC territory, around CP Redondo, to be within communication range so that they can "see" the first PTC governed signal at a sufficient range, and not need to stop short of the signal prior to entering the PTC Activated state.

One of the parameters examined during the design phase, was the limits of wayside coverage. Originally, the rule of thumb was that the radio at wayside signaling locations had to reach out 8 miles to any approaching train. It was recognized that in a congested urban area, an 8 mile umbrella would cover several complex CP's and the data processing demands on the PTC system could be overwhelming. After discussion and with consensus of the participating railroads, a rule of thumb was adopted that an on-board radio must see a minimum of three signals ahead of its current position. Since the message from the signal indicates the condition of the next downstream signal, all the on-board really needs to know is where the stop target would be if communications were lost. The on-board requirement is that the on-board system must continuously (every 12 seconds) "see" the signal ahead of itself. However, if the received indication is more permissive than "Approach," the system knows that the next signal beyond the one immediately in advance of its position is not a "Stop" target. Therefore, the system can tolerate a longer loss of communications duration for signals further away. These discussions allowed the participants to better define the real world parameters for PTC message management.

Plan for the Future, Identify Rail Traffic Loading

When considering the investment to be made in the infrastructure for PTC, the agency needs to make a realistic assessment of future growth under the RF coverage area for the useful life of the system. For a commuter operation, this includes anticipated new service lines, expanding the level of service on existing lines, and enhancements to the type of service provided, such as selective express train service. Freight operation is rebuilding after the slump of the last several years and the projected growth needs to be accounted for in the modeling projections. This may require that railroad users share growth projections that may otherwise have been tightly held business information.

With this information, the final projected level of rail traffic can be modeled using a rail simulation program to determine where the high levels of message traffic will most likely occur during peak traffic times. By examining the message traffic parameters against the traffic simulations, a quantitative projection can be made of the expected levels of RF message traffic at various points along the rail network. Based upon wayside-to-base station coverage projections, a projection can be made as to the level of message traffic into and out of any given substation. This can also reveal where message traffic may be excessive and where an additional base station may be required.

Case Study #7: *Based upon its service level projection out to Year 2020, SCRRA was able to formulate the distribution of growth along the entire rail network, and after factoring in the growth information provided by the freight railroads, came up with a reasonable projection for rail density in the entire LA basin area for the years 2015 and 2020. A graphic of the rail traffic load projections for 2015 and 2020 are depicted in Figure 3 and Figure 4.*

This projected traffic information was used by TTCI (working under contract to PTC-220, LLC) to simulate the entire base rail traffic. They then applied what was currently known of the message formatting to the simulation model to calculate the message density at various points along the network to identify the peak message loads for each proposed substation.

Identify Pre-Existing Assets

Unless the designer is dealing with a new start, it is assumed that there is at least one existing RF network in the subject area for voice communication. There may be multiple voice and data networks in place for one or more of the area railroads. The initial reaction is to try to leverage the existing network sites and equipment for the new PTC implementation. This may be both possible and economically feasible depending upon factors such as: site ownership (i.e., is the existing base station site being leased and are there any restrictions on expansion of site functionality); condition of existing site/equipment (i.e., is the existing site secure and readily accessible for repair and maintenance); capacity of existing site (i.e., can new PTC radio equipment be accommodated within the existing enclosures, is sufficient power available for the additional loads, and will existing towers accommodate additional PTC antennas); connectivity to the back office (i.e., is there sufficient capacity on the backhaul network to transmit message traffic between the base station and the back office equipment); and, coverage area (i.e., can the site reach out to a wide enough area to connect to both wayside sites and locomotives).

Case Study #8: *As mentioned above, both BNSF and UPRR have identified existing base station locations that can be modified to accommodate PTC radio traffic. SCRRA determined that a majority of its existing base stations were either on mountain-top sites which are not conducive for PTC coverage, were inadequate to accommodate the additional equipment required for the PTC radio network, or had insufficient backhaul connectivity. Therefore, most of the SCRRA furnished base stations will be new structures located on existing SCRRA right-of-way with upgraded backhaul connectivity.*

Develop Coverage Models

The area network design team needs to agree on the toolset that will be used to model the RF coverage in the shared area.

Case Study #9: *SCRRA and PTC-220, LLC agreed that modeling of the proposed RF network would be performed using the Mentum Planet® propagation modeling tool set. The network designers entered base station and wayside location information into the tool set that produced a series of maps demonstrating the coverage under various conditions, including selective downing of sites to identify redundant coverage or lack of coverage.*

More information on the Mentum Planet® tool can be found on their website at: www.Mentum.com.

Spectrum Acquisition

The four major US Class 1 railroads have addressed their perceived PTC spectrum needs by creating PTC-220, LLC, a company whose primary responsibility is to acquire and manage spectrum in the 220 MHz range. PTC-220, LLC currently owns eighteen (18) frequency blocks of 25 KHz, each located between 220 MHz and 222 MHz. Nine (9) of these blocks in the 220-221 MHz range are commonly designated as "Base" frequencies and are generally suitable for large area coverage.

The remaining nine (9) blocks are in the 221-222 MHz range and are currently designated for "Mobile" use and have some restrictions on antenna height and transmission power levels. Given these restrictions, their use in an area-wide RF network is limited to specific PTC applications.

Whatever the source of the spectrum, it is the responsibility of the RF designer to become familiar with any local conditions or restrictions that may limit the utility of a given frequency. Reviewing Title 47 of the Code of Federal Regulations that addresses the FCC rules is strongly advised. Of particular interest is Part 90, Subpart T – Regulations Governing Licensing and Use of Frequencies in the 220-222 MHZ Band.

In addition, APTA has recently issued a white-paper entitled, "Positive Train Control (PTC) Radio Spectrum Planning for Passenger Commuter Rail Operators in the United States" that provides some useful information on the availability of spectrum in the 220 MHz range.

The type of restrictions that may be encountered will most likely be related to power limitations due to either incumbent licensed users on adjacent frequencies and limitations due to proximity to an adjacent band.

Case Study #10: *SCRRA determined early-on that it was in its best interest to identify and procure spectrum that would support its PTC program. Initial assessment of SCRRA needs based upon the large LA basin coverage area and traffic density indicated that between twenty (20) and forty (40) blocks of 25 KHz frequencies would be required. SCRRA conducted a search of the secondary spectrum market and identified a potential source for this level of spectrum. SCRRA subsequently entered into negotiations and arranged procurement of 40 frequency blocks. However, the final transfer of ownership has been delayed due to some third party involvements and the matter is currently being held in abeyance by the FCC. Lack of closure on the procurement of the frequencies has forced SCRRA to refine its initial RF network design to cover just its immediate coverage needs and delay implementation of a network based on its long term projected needs until the frequencies are in-hand.*

The SCRRA spectrum procurement process is detailed in FCC File No. 0004144435, located on the FCC website at: http://wireless.fcc.gov/.

Refine Design Parameters and Modeling

As noted above, a careful examination of available information will lead to a base set of design parameters. The parameters that are ideal for a high-density commuter rail operation may not be appropriate (or lead to the most economical design) for a relatively low speed and/or low density freight operator operating under the same coverage umbrella. There can either be some give-and-take between the area users on some of the design parameters, such as signal sensitivity, bit error rate, level of redundancy, etc., or there can be a larger assumption of design and implementation responsibility (and cost) by the party (or parties), requiring a higher level of availability and reliability than may be required by other RF network users.

Case Study #11: *The following summarizes the steps used to determine the spectrum required by SCRRA.*

RF Demand:
The first step in estimating spectrum requirements for the LA basin was to develop a simulation to estimate RF Demand. RF demand was derived from the simulation of message loads (offered payloads) generated by the SCRRA, BNSF, UP and Amtrak railroad infrastructures.

Base Station Design:
RF Base Stations serve as the interface point between the offered payloads of the railroad infrastructures (Back Office(s), waysides, trains) and the provided infrastructure capacities of the design. At each base station site, a determination was made of the bandwidth required to ensure that design capacities exceeded offered payloads, per the requirements of the contract technical specifications.

RF Coverage
RF coverage was designed for each base station site based on a cellular architecture to ensure communication link reliabilities to meet the message loads.

The initial area-wide design[5] was based upon the initial coverage criteria that called for a total of twelve (12) ROW located base stations and five (5) "Boomer" mountain top base stations. It was initially thought that the mountain-top substation sites would offer wider area redundant coverage. This design was based upon initial SCRRA criteria that there must be 100% redundant radio coverage of the entire rail network based upon Year 2020 projected rail utilization and on a freight criteria that included a minimum eight-mile wayside-to-locomotive direct coverage. This design was further

[5] This initial RF design configuration is captured in the 30% Design Submittal that was prepared by the V/I contractor in the 1st quarter of 2010. At this point-in-time, there was a limited amount of information available regarding the detailed characteristics of the PTC radios or the final message structures.

based upon the assumption that SCRRA's planned procurement of 40 frequencies[6] would be finalized in time to support this implementation.

After a number of iterations and recognizing the limitations on available frequencies, the limitations of mountain-top coverage, and other factors, the initial design for PTC deployment in the LA basin area was revised. The current design provides primary coverage for Metrolink, UPRR and BNSF messaging levels for an initial implementation that consists of a total of eighteen (18) base stations, utilizing a total of eight (8) of the PTC-220, LLC owned frequencies. Of these base stations, it was determined that twelve (12) would be provided by SCRRA, four (4) would be provided by BNSF, and two (2) would be provided by UPRR. The four BNSF sites and the two UPRR sites are exiting BNSF base station sites that will be modified to provide 220 MHz coverage. The SCRRA sites are a combination of new and existing base station installations to be located on existing SCRRA right-of-way. Most will be co-located or located adjacent to either an existing Control Point or passenger station radio site. The construction of these sites will be coordinated with a parallel SCRRA backhaul upgrade project.

An enhanced design was also prepared to provide redundancy based on immediate messaging needs. This design consists of twenty-seven (27) base station sites utilizing a total of eleven (11) frequencies. It consists of twenty-one (21) Metrolink base stations, four (4) BNSF base stations, and two (2) UPRR base stations.

The base stations are designed to handle the message loading received from a total of 411 Metrolink, BNSF and UPRR wayside sites that consist of approximately 639 WIUs. In addition to handling these wayside message loads, additional capacity needs to be factored into the design to accommodate conditions, such as topographic obstructions, where a wayside radio may not be able to directly reach an approaching locomotive. Under this condition, it will be necessary to route the message from the wayside back to the office (via a base station) and then re-transmit it from the office (again via a base station) to the receiving locomotive. This process is being referred to as, "wayside status relay service" (WSRS). WSRS is not a product offering of the ITC and will need to be developed by the individual user railroads for compatibility with the individual office systems.

For additional information on the projected frequency needs of SCRRA, refer to a memorandum prepared by SCRRA staff entitled, "LA Basin PTC 220 MHz Spectrum: Requirements for SCRRA, UP, BNSF – Host Railroads; AMTRAK as a Tenant Railroad" dated 12/10/2011, that is included in Appendix B.

[6] Refer to the section titled "Spectrum Acquisition" for more information concerning this spectrum procurement process.

Reach Consensus on Final Asset Distribution

The final decisions on asset distribution will most likely be based on a number of technical and business considerations. These can include such things as: number of available frequencies, number and location of existing sites, comfort factor of user railroads related to maintenance/repair response by another railroad, traffic/message density, and final cost allocation agreements.[7]

> ***Case Study #12:*** *As noted above, the LA basin RF network design makes use of four (4) existing BNSF base station sites and two (2) existing UPRR base station sites, as well as fourteen (14) SCRRA sites. The selection of the BNSF sites was simple, as they were already under construction by the time that final decisions needed to be made. The selection of the UPRR sites could have gone either way, as each UPRR site has a nearby SCRRA site that was originally designated for a substation and would provide comparable coverage for both Metrolink and UPRR trains.*

Identify Site Specific Constraints

Throughout the RF design process, the design team needs to keep in mind the practical elements associated with deployment of an RF Network. They need to identify any local physical or societal conditions that may constrain the installation of the radio equipment, especially from the most visible component, the antenna towers. These constraints can include:

- Availability of sufficient railroad property to install base stations and install wayside antennas: procurement of property and the potential pitfalls associated with obtaining environmental approvals for construction outside of railroad property that can result in significant delays to the schedule.
- Proximity to geologically, environmentally, or historically sensitive areas: trying to install equipment buildings and/or towers near sensitive habitats or wetlands can result in unforeseen delays.
- Socio-economic considerations (i.e. NIMBY): need to be sensitive to local community issues when planning installations, including factoring things such as visual impacts, i.e., adding screening and camouflaging into the final design plans.
- Proximity of local flight paths: submittal of a license application to FCC automatically triggers a clearance analysis with the FAA.[8]
- Access to backhaul connectivity to the railroad's Back Office: high-bandwidth interconnectivity between base stations and the back office is a critical component of efficient message traffic handling. Ready accessibility to a fiber optic network is a bonus, while access to microwave or leased lines is a viable alternative.

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[7] A companion document to this report is being prepared to describe the methodology for determining equitable cost apportionment to the various participants in a shared asset environment.
[8] For more information concerning FAA constraints on tower installations, refer to the FCC website at: http://transition.fcc.gov/mb/policy/dtv/lighting.html

Case Study #13: *Given the aggressive schedule adopted by SCRRA to implement PTC, it was decided early on that all PTC antenna towers would be constructed on existing SCRRA property to avoid potential delays associated with property procurement.*

The RF designers were also sensitive to local area conditions when laying out equipment to try to mitigate any neighbor concerns or potential protests. Additionally, several of the proposed antenna heights were adjusted during the design process to comply with FAA clearance requirements.

Verify Coverage by Field Tests

A critical stage in the deployment of the PTC RF network is to conduct exhaustive pre-design survey and post installation field verification of the coverage that was modeled in order to fine tune the network by adjusting antenna alignments and transmitter power.

A typical listing of surveys and tests related to RF design include, but are not limited to:

- Interference Testing – Measure and identify any licensed or unlicensed users
- Intermodulation Testing – Required to test when multiple radio systems are used at or on one location
- EMI – Electromagnetic Interference – Required to identify any interference with electrical circuits
- Site Specific Radio Tests for each Base Station and Wayside Radio Location:
    - LED Indicator Lights: Run self diagnostics on all hardware to determine if it is operating within manufacturer's parameters.
    - VSWR – Visual Standing Wave Ratio: Verification of physical/electrical connectivity between the radio and antenna
    - RSSI: Signal Strength levels
    - Tx / Rx Tests: Transmit and Receive coverage, including verification of redundant coverage
    - BER / PER - Bit error rate / packet error rate: Performance and message handling reliability
    - Key Performance Indicators (KPI): Load and throughput verification.
    - Optimization: Adjustment of antenna alignments and hardware settings made as necessary followed by re-testing and verification.
    - Verification: Measure and record the above performance parameters against design criteria.
- Integration Testing: Exercise the RF network against the other, parallel data transmission paths such as cellular, satellite, and WLAN to verify redundant features of the communications network design.

Case Study #14: *As this paper is being written in the 1st quarter of 2012, the SCRRA, BNSF and UPRR are finalizing the overall network design and are just beginning the field hardware installation. The actual base station radios are not expected to be* *available until the beginning of the third quarter of 2012, though a limited quantity of pre-production radios are just beginning to be made available from the designer/manufacturer. Therefore, no actual field testing of an RF network has been started. An update to this paper may be issued after testing has progressed if it is felt that the field testing uncovered any major flaws in the design process that would result in a major re-assessment of the design methodology.*


METROLINK
SYSTEM WIDE STATIONS MAP
REV: 10/01/2010
FILE NAME: PTC209-S2.DWG
DWG NO.: S-2
Legend
SCRRA / Metrolink Track
BNSF Track
UPRR Track
San Diego Northern Track
Alameda Corridor Track
Station
Control Point
Major Facility / Freight Yard
Future Station
VHF/ATCS Base Station
PTC Backhaul Site
VHF/ATCS Base Station & PTC Backhaul Site
Microwave Antenna & PTC backhaul Site
* RED for existing site; BLUE for future site.
Santa Barbara County
Ventura County
Los Angeles County
San Bernardino County
Riverside County
Orange County
San Diego County
SAN DIEGO COUNTY
Valley Sub.
Santa Paula Branch
Ventura Sub.
River Sub.
Pasadena Sub
San Gabriel Sub.
Los Angeles Sub. (UP)
(BNSF) San Bernardino Sub.
Olive
Orange Sub.
Perris Valley Line
Redlands Branch
San Diego Sub. (SDNR)
Lancaster
Palmdale
Vincent Grade / Acton
Via Princessa
Santa Clarita
Newhall
Sylmar / San Fernando
Sun Valley
Burbank
Burbank Airport
Glendale
Van Nuys
Northridge
Chatsworth
Simi Valley
Moorpark
Camarillo
Oxnard
Montalvo
LAUS
CMF
Cal State LA
El Monte
Baldwin Park
Covina
Pomona
Montclair
Claremont
Upland
Rancho Cucamonga
CA Speedway
Fontana
Rialto
San Bernardino
IELF
EMF
Montebello / Commerce
Commerce
Industry
Downtown Pomona
Ontario
Pedley
Riverside Downtown
Marlborough
Moreno Valley / March Field
Perris
South Perris
Norwalk / Santa Fe Springs
Buena Park
Fullerton
Anaheim / Canyon
W. Corona
Main Corona
La Sierra
Anaheim Stadium
Orange
Santa Ana
Tustin
Irvine
Laguna Niguel
San Juan Capistrano
San Clemente North Beach
San Clemente
Oceanside
N
S
W
E

FIGURE 1


Legend
SCRRA / Metrolink Track
BNSF Track
UPRR Track
San Diego Northern Track
Alameda Corridor Track
Station
Control Point
Major Facility / Freight Yard
Future Station
VHF/ATCS Base Station
PTC Backhaul Site
VHF/ATCS Base Station & PTC Backhaul Site
Microwave Antenna & PTC backhaul Site
* RED for existing site; BLUE for future site.
Santa Barbara County
Ventura County
Los Angeles County
San Bernardino County
Riverside County
Orange County
San Diego County
LA Boundary
Ventura Sub.
Valley Sub.
Santa Paula Branch
River Sub.
Pasadena Sub
San Gabriel Sub.
Los Angeles Sub. (UP)
San Bernardino Sub. (BNSF)
Olive
Orange Sub.
Perris Valley Line
San Diego Sub. (SDNR)
Redlands Branch
Lancaster
Palmdale
Vincent Grade / Acton
Via Princessa
Santa Clarita
Newhall
Sylmar / San Fernando
Sun Valley
Burbank
Burbank Airport
Glendale
Chatsworth
Northridge
Van Nuys
Simi Valley
Moorpark
Camarillo
Oxnard
Montalvo
LAUS
CMF
Cal State LA
El Monte
Baldwin Park
Covina
Pomona
Montclair
Claremont
Upland
Rancho Cucamonga
CA Speedway
Fontana
Rialto
San Bernardino
IELF
EMF
Montebello / Commerce
Commerce
Industry
Downtown Pomona
Ontario
Pedley
Riverside Downtown
Marlborough
Moreno Valley / March Field
Perris
South Perris
Norwalk / Santa Fe Springs
Buena Park
Fullerton
Anaheim / Canyon
W. Corona
Main Corona
La Sierra
Anaheim Stadium
Orange
Santa Ana
Tustin
Irvine
Laguna Niguel
San Juan Capistrano
San Clemente North Beach
San Clemente
Oceanside
SAN DIEGO COUNTY
METROLINK
SYSTEM WIDE STATIONS MAP
REV: 10/01/2010
FILE NAME: PTC209-S2.DWG
DWG NO.: S-2

FIGURE 2

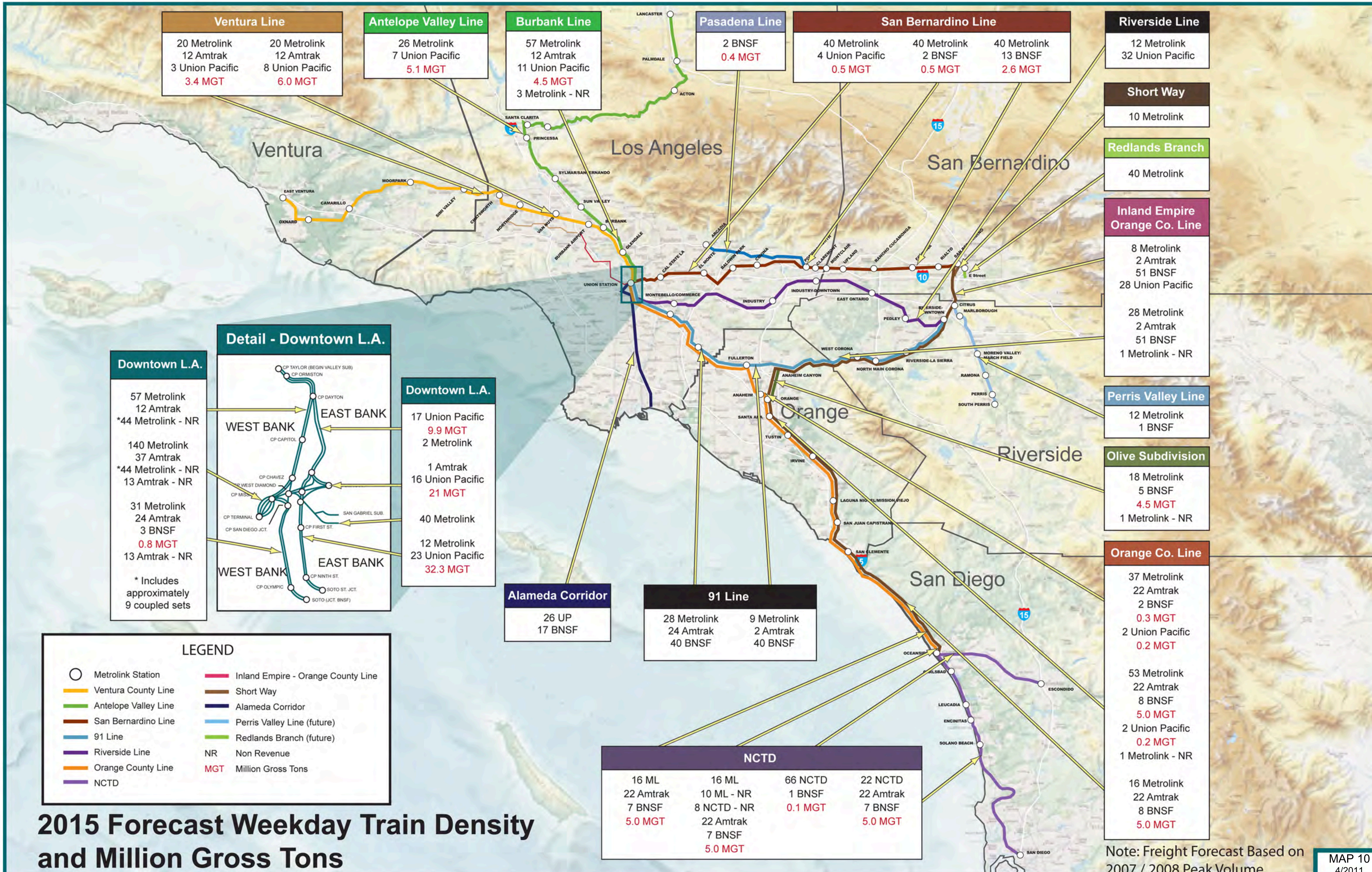
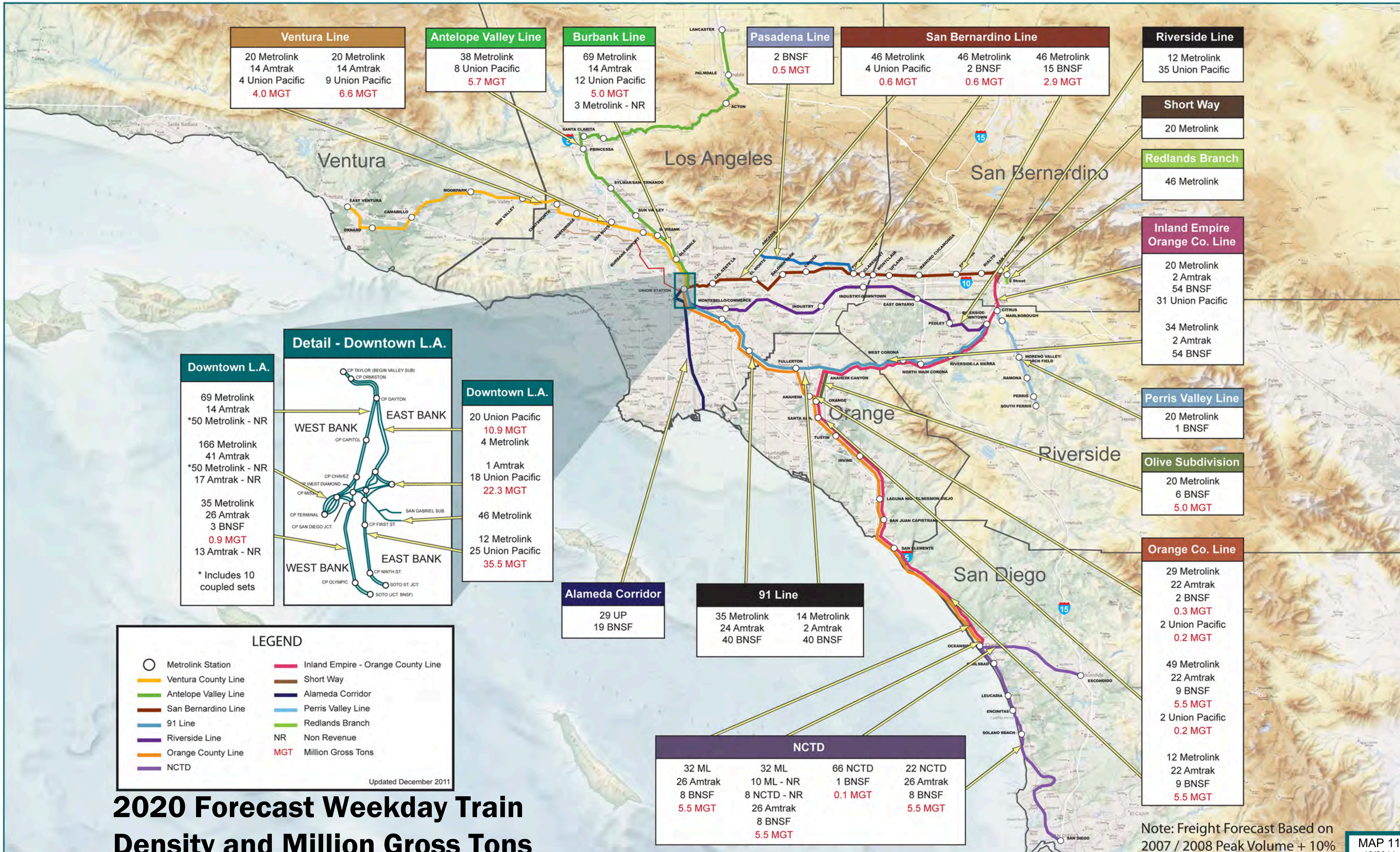

Ventura Line
20 Metrolink
12 Amtrak
3 Union Pacific
3.4 MGT
20 Metrolink
12 Amtrak
8 Union Pacific
6.0 MGT
Antelope Valley Line
26 Metrolink
7 Union Pacific
5.1 MGT
Burbank Line
57 Metrolink
12 Amtrak
11 Union Pacific
4.5 MGT
3 Metrolink - NR
Pasadena Line
2 BNSF
0.4 MGT
San Bernardino Line
40 Metrolink
4 Union Pacific
0.5 MGT
40 Metrolink
2 BNSF
0.5 MGT
40 Metrolink
13 BNSF
2.6 MGT
Riverside Line
12 Metrolink
32 Union Pacific
Short Way
10 Metrolink
Redlands Branch
40 Metrolink
Inland Empire Orange Co. Line
8 Metrolink
2 Amtrak
51 BNSF
28 Union Pacific
28 Metrolink
2 Amtrak
51 BNSF
1 Metrolink - NR
Perris Valley Line
12 Metrolink
1 BNSF
Olive Subdivision
18 Metrolink
5 BNSF
4.5 MGT
1 Metrolink - NR
Orange Co. Line
37 Metrolink
22 Amtrak
2 BNSF
0.3 MGT
2 Union Pacific
0.2 MGT
53 Metrolink
22 Amtrak
8 BNSF
5.0 MGT
2 Union Pacific
0.2 MGT
1 Metrolink - NR
16 Metrolink
22 Amtrak
8 BNSF
5.0 MGT
Ventura
Los Angeles
San Bernardino
Orange
Riverside
San Diego
Detail - Downtown L.A.
WEST BANK
EAST BANK
WEST BANK
EAST BANK
Downtown L.A.
57 Metrolink
12 Amtrak
*44 Metrolink - NR
140 Metrolink
37 Amtrak
*44 Metrolink - NR
13 Amtrak - NR
31 Metrolink
24 Amtrak
3 BNSF
0.8 MGT
13 Amtrak - NR
* Includes approximately 9 coupled sets
Downtown L.A.
17 Union Pacific
9.9 MGT
2 Metrolink
1 Amtrak
16 Union Pacific
21 MGT
40 Metrolink
12 Metrolink
23 Union Pacific
32.3 MGT
Alameda Corridor
26 UP
17 BNSF
91 Line
28 Metrolink
24 Amtrak
40 BNSF
9 Metrolink
2 Amtrak
40 BNSF
NCTD
16 ML
22 Amtrak
7 BNSF
5.0 MGT
16 ML
10 ML - NR
8 NCTD - NR
22 Amtrak
7 BNSF
5.0 MGT
66 NCTD
1 BNSF
0.1 MGT
22 NCTD
22 Amtrak
7 BNSF
5.0 MGT
LEGEND
Metrolink Station
Ventura County Line
Antelope Valley Line
San Bernardino Line
91 Line
Riverside Line
Orange County Line
NCTD
Inland Empire - Orange County Line
Short Way
Alameda Corridor
Perris Valley Line (future)
Redlands Branch (future)
NR Non Revenue
MGT Million Gross Tons
2015 Forecast Weekday Train Density and Million Gross Tons
Note: Freight Forecast Based on 2007 / 2008 Peak Volume
MAP 10
4/2011

FIGURE 3



Ventura Line
20 Metrolink
14 Amtrak
4 Union Pacific
4.0 MGT
20 Metrolink
14 Amtrak
9 Union Pacific
6.6 MGT
Antelope Valley Line
38 Metrolink
8 Union Pacific
5.7 MGT
Burbank Line
69 Metrolink
14 Amtrak
12 Union Pacific
5.0 MGT
3 Metrolink - NR
Pasadena Line
2 BNSF
0.5 MGT
San Bernardino Line
46 Metrolink
4 Union Pacific
0.6 MGT
46 Metrolink
2 BNSF
0.6 MGT
46 Metrolink
15 BNSF
2.9 MGT
Riverside Line
12 Metrolink
35 Union Pacific
Short Way
20 Metrolink
Redlands Branch
46 Metrolink
Inland Empire Orange Co. Line
20 Metrolink
2 Amtrak
54 BNSF
31 Union Pacific
34 Metrolink
2 Amtrak
54 BNSF
Perris Valley Line
20 Metrolink
1 BNSF
Olive Subdivision
20 Metrolink
6 BNSF
5.0 MGT
Orange Co. Line
29 Metrolink
22 Amtrak
2 BNSF
0.3 MGT
2 Union Pacific
0.2 MGT
49 Metrolink
22 Amtrak
9 BNSF
5.5 MGT
2 Union Pacific
0.2 MGT
12 Metrolink
22 Amtrak
9 BNSF
5.5 MGT
Ventura
Los Angeles
San Bernardino
Orange
Riverside
San Diego
Detail - Downtown L.A.
WEST BANK
EAST BANK
WEST BANK
EAST BANK
Downtown L.A.
69 Metrolink
14 Amtrak
*50 Metrolink - NR
166 Metrolink
41 Amtrak
*50 Metrolink - NR
17 Amtrak - NR
35 Metrolink
26 Amtrak
3 BNSF
0.9 MGT
13 Amtrak - NR
* Includes 10 coupled sets
Downtown L.A.
20 Union Pacific
10.9 MGT
4 Metrolink
1 Amtrak
18 Union Pacific
22.3 MGT
46 Metrolink
12 Metrolink
25 Union Pacific
35.5 MGT
Alameda Corridor
29 UP
19 BNSF
91 Line
35 Metrolink
24 Amtrak
40 BNSF
14 Metrolink
2 Amtrak
40 BNSF
NCTD
32 ML
26 Amtrak
8 BNSF
5.5 MGT
32 ML
10 ML - NR
8 NCTD - NR
26 Amtrak
8 BNSF
5.5 MGT
66 NCTD
1 BNSF
0.1 MGT
22 NCTD
26 Amtrak
8 BNSF
5.5 MGT
LEGEND
Metrolink Station
Ventura County Line
Antelope Valley Line
San Bernardino Line
91 Line
Riverside Line
Orange County Line
NCTD
Inland Empire - Orange County Line
Short Way
Alameda Corridor
Perris Valley Line
Redlands Branch
NR Non Revenue
MGT Million Gross Tons
Updated December 2011
2020 Forecast Weekday Train Density and Million Gross Tons
Note: Freight Forecast Based on 2007 / 2008 Peak Volume + 10%
MAP 11
12/2011

FIGURE 4

Assumptions to be Used for Communications Design

Assumptions a - m below are to be used to define the parameters of the PTC 220 MHz network, assumptions n - u are used to define the 802.11x WLAN and v – x the GPS navigational tool to be used. The assumptions listed below should be used in addition to the technical specifications presented above, not in-lieu of the technical specifications presented above. It is possible that some or all portions of the applicable ITC specifications may be released post this RFP issuance and prior to the deadline set for RFP responses. In such a case, the SCRRA shall issue directions regarding the usage of some or all of the assumptions defined below.

a. Assume the 220 MHz Radio Equipment shall use a packet-digital, adaptive TDMA air interface, and further that CSMA shall be incorporated in the air interface such that each hybrid TDMA/CDMA radio is capable of 64 time-slots per TDMA epoch and further that the hybrid TDMA/CSMA protocol utilizes a cycle consisting of two CSMA cycles followed by a TDMA epoch. Ad-hoc, unscheduled communication between WIUs and trains or between EIC and trains can be provisioned using the available CSMA time slots.

b. Reference communications Exhibit 24 E for a frequency plan of the proposed PTC spectrum; assume a minimum of 14 frequencies shall be immediately available from the UPRR, BNSF and SCRRA for interoperable 220 MHz packet-digital TDMA radio communication in SCRRA territory. If this quantity turns out to be insufficient to meet the needs of all railroads, assume that SCRRA will procure whatever additional spectrum is required separately.

c. Assume each PTC 220 MHz Base Station shall be located such that direct access to the SCRRA back-haul infrastructure is available with the required bandwidth capability by 2012.

d. Assume that a worst-case scenario of 56 “simultaneous” TDMA data paths, of bandwidth equivalency 390 Hz or less (to/from 24 locomotives and cab cars, to/from 30 wayside devices, and two initializing trains), plus 8KB/s for business critical use is the maximum load of any single Base Station site.

e. Assume that the 220 MHz TDMA Base Stations utilize 50W or lower transmitter power and receivers, in the presence of no co-channel noise, (thermal noise only) with a minimum acceptable sensitivity threshold of -96 dBm for 10E-6 BER.

f. Assume that the cellular architecture is selected for the PTC 220 MHz network. For purposes of producing a preliminary network architecture design, assume further that a cellular hierarchy, sectorization and power control techniques are allowed by the ITC specifications.

g. Assume that the 220 MHz TDMA radios on trains and wayside devices use 40W or lower transmitters and receivers, in the presence of no co-channel noise, (thermal noise only) with a minimum acceptable sensitivity threshold of -96 dBm for 10E-6 BER.

h. Assume that the 220 MHz TDMA radios used by the EIC use 5 W transmitters and receivers, in the presence of no co-channel noise, (only thermal noise) with a minimum acceptable sensitivity threshold of -90 dBm for 10E-6 BER.

i. Assume that trains and wayside devices operating on SCRRA territory require a bandwidth equivalency no greater than 390 Hz to provide the data throughput required to meet all PTC 220 MHz Base to/from train and Base to/from wayside device data communications.

j. Assume worst case SCRRA traffic density of 120 locomotives and cab cars and wayside devices uniformly spaced in the busy hour of the busiest circular area of radius 10 miles, centered at CP Mission in the River subdivision only and a uniform traffic density of 25 locomotives and cab cars and wayside devices evenly spaced per circular area of radius 10 miles, everywhere else. Assume these traffic densities will double in ten years, which must be factored in the design.

k. Assume that GPS is used for TDMA timing and synchronization.

l. Assume that as trains approach wayside devices, that all trains are required to begin checking for beacon from said wayside device, at a distance of eight (8) miles from the most distant wayside device, and if said beacon is off for any reason such as power conservation, use a CSMA time slot in the hybrid TDMA/CSMA air interface to request that the respective device activate its beacon, in response to which the respective wayside device activates its beacon, and begins to send status data back to the train. Assume further that each locomotive is required to obtain and clear status from all wayside devices at a minimum of five (5) miles ahead of said train. Assume further that wayside devices are no closer than 0.8 miles apart, and that the train to wayside communication occurs without the aid of a base station, and further that the trains must, for each wayside device within the five (5) mile range, receive a status beacon a minimum of once every fifteen (15) seconds, otherwise a special request for status is required to be sent from the train to the missed wayside device.

m. Assume an EIC is located at five (5) mile intervals in each sub-division, and all trains communicate with them from a radius no greater than five (5) miles using the PTC 220 MHz network. EIC to train communication is a future enhancement and not part of this contract. The system shall be designed with sufficient bandwidth to accommodate this feature.

n. Assume a total of 15 802.11x database upload sites for stationary trains. Assume, that these 15 sites are located as follows: San Bernardino Yard (MP 56.3), IELF yard (MP 58.0), Colton EMF yard (MP 56.0), E. Street yard (future), Montalvo Layover (MP 403.4), Moorpark Layover (MP427.1), Riverside Layover (MP9.8), Lancaster Layover (MP 76.6), CMF aka Taylor Yard (MP 3.5), LA Union Station (MP 0.0), Keller Street Yard (MP140.2), Amtrak Eight Street Yard (MP0.0), South Perris Layover (Future, TBD), Laguna Niguel turn-around (MP 193.7) and the Anaheim Layover (MP 165.5). Assume that only one (1) five-frequency Base Station and antenna tower site will be required for each location except for LA Union Station and at CMF, where one (1) five-frequency Base Station and antenna tower and one (1) six-frequency Base Station and antenna tower, each with coverage that overlaps the other, and each with distinct frequencies in the frequency plan are deployed. Stationary trains from the SCRRA only, shall connect to the 15 local 802.11g WLAN at these sites to receive database initialization uploads. Reference drawings E24K03 and E24K04 of exhibit 24 F, the V/I shall assume that there will be adequate space inside an existing shelter located within the limits of each yard to install the required 802.11 base station and network interface equipment. For yards, terminals and layovers which do not have an appropriate shelter, or adequate space inside an existing shelter, assume that the SCRRA shall provide the required shelter, delivered to the respective site. The V/I shall price this item based on the assumption that 10 of the 15 yards will have the required shelter, and the funding for the five (5) new shelters shall be obtained from a contract allowance. Refer to section 16.7.1 for the functional requirements of the equipment used at 802.11 base station sites.

o. Tenant trains shall receive their initial database uploads from the terminals and yards of their respective railroad. They shall receive only updates to this uploaded database, while on SCRRA tracks, using the PTC 220 MHz network.

p. Each of the 15 databases upload sites approximates a circle of radius 0.8 miles, with flat terrain.

q. Trains shall have a maximum of 10 minutes at each site to receive the 802.11x WLAN database uploads.

r. A maximum of one (1) GByte of data shall be uploaded to each train, before they can depart any of these 15 sites.

s. A maximum of five (5) trains, requesting simultaneous database uploads can be present in any of the 15 database upload sites.

t. Each of the 15 database upload sites shall be sufficiently separated, so that each operates on a separate, independent WLAN.

u. Assume 802.11g is selected as the WLAN, and WPA2 is used to provide authentication and AES-based encryption. Based on the WLAN parameters described above, the V/I shall include a preliminary design of the proposed network of WLANs, including a draft frequency plan. The design shall also demonstrate the coverage redundancies defined in Section 16.5.7.3.

v. Assume that both the NDGPS and WAAS meet the coverage criterion, and that WAAS is deployed to support PTC. Assume two (2) differential GPS units are installed per locomotive and per cab car.

w. Assume the real-time WAAS and database processing adds no latency to the navigation process on the locomotives and cab cars.

x. In the event of a loss of the GPS timing signal, for whatever reason, assume that the PTC 220 MHz radio will be able to function for approximately 15 minutes or 17 miles, whichever occurs first, using its own clock, before timing/synchronization errors result in any data loss.

SCRRA POSITIVE TRAIN CONTROL PROGRAM

LA BASIN PTC 220 MHz SPECTRUM REQUIREMENTS FOR SCRRA, UP, BNSF - HOST RAILROADS AMTRAK AS A TENANT RAILROAD.

INTERNAL TECHNICAL MEMORANDUM
12/10/2011

Prepared by:
Kurt Drummond, PE.,
Paul Wadum,
Joe Zerzan.

Reviewed by:

D.J. Maxey, PE.

The provision of adequate, unimpaired and interoperable spectrum for the deployment of PTC in the LA basin is one of the most important and fundamental of the supporting activities required of the SCRRA and Class 1 freight railroads towards this effort. The role of this spectrum is analogous to the role of roadway network in a ground transportation system, or railway tracks in a railroad. This is because messages must travel, with no or very minimal interference or obstructions to and from operational command and control centers (such as SCRRA's MOC and proposed TCOSF sites in Pomona) to static and mobile sites located over a wide geographic regions. Static sites include base stations and railroad wayside sites such as signals and remote switch control sites (control points). Mobile sites include trains and maintenance equipment. The message transport will use a high-reliability, high capacity PTC backhaul network (analogous to the expressways or railroad main tracks) to get to the base station sites, from where the messages are carried over the designated PTC spectrum by wireless radios frequencies (analogous to the maze of local roads and streets or railroad industry spur tracks) to the mobile trains and static wayside signal and control point sites. A significant amount of PTC wireless message traffic also travels locally to and from trains to local wayside signals and signal control points. In order to better assure effective use of the available spectrum, the PTC 220 MHz communication network will use best available technologies. These technologies include the use of the most spectrum-efficient architecture (cellular) and the most spectrum efficient sharing algorithms known as Time Division Multiple Access – TDMA, and Carrier Sense Multiple Access - CSMA.

In determining the amount of spectrum required, the designers of this PTC radio network must allow sufficient capacity for future growth of radio traffic resulting from the following:

- Increase in the quantity of trains and wayside devices (from the SCRRA as well as the UP, BNSF and Amtrak),
- Addition of new PTC features and scope, such as those in PTC "Rung 2", "3" and "4…."
- Addition of grade crossing and EIC (Employee in Charge) devices to the PTC scope,
- Anticipated probable migration of some Centralized Traffic Control (CTC) data radio traffic in the 900 MHz band to the 220 MHz band. This CTC wireless data radio is used for remote control of switches, signals and monitoring train movements,
- Potential for increasing passenger train maximum speeds from the current 79/90 mph to 100/110 mph, while reducing headways,
- Increase demand remote monitoring or SCADA (supervisory control and data acquisition) for the large array of new PTC devices being installed at hundreds of remote sites as well as enhanced SCADA for existing signal, grade crossing and communication sites and devices.
- Expansion of SCRRA and other passenger rail services to new service territories,
- Other parameters that result in increase spectrum use, yet to be identified.

A brief explanation of each of the growth parameters identified above is presented in the following paragraph, starting with the anticipated increase in train and wayside devices.

It is expected, based on economic and population trends that the quantity and hence the density of commuter and freight traffic in the LA basin will continue to increase through the next decade and beyond. The design of the LA basin PTC network must therefore account for these growth trends. The PTC communication network will use a TDMA (Time Division Multiple Access) based air–interface in order to guarantee the highest message reliabilities, however each additional train or wayside added to this network requires additional TDMA *time slots*, which ultimately will translate into the need for additional spectrum. The addition of new PTC features and scope such as those planned for PTC "rung 2" and beyond, such as grade crossing and EIC devices will, for the same reasons, result in an increase in the quantity of TDMA *time slots* required and ultimately an increase in required spectrum. The

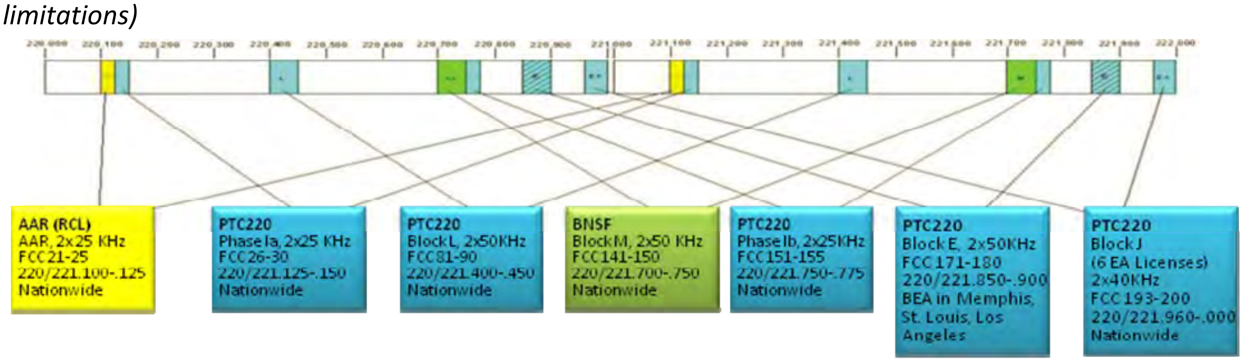
Interoperable Train Control Committee (ITC) composed of the Class 1 Freights- UPRR, BNSF, CSX and NS railroads and their associated spectrum arm, PTC- 220 LLC led the effort in developing interoperable standards for PTC. One of the basic premises of the ITC design for PTC assumes an overlay configuration of the existing signal system for the PTC architecture. The fact that PTC is an overlay on the existing CTC system effectively means that PTC can only be as robust, reliable and effective as the underlying CTC infrastructure will support. At the present time, this CTC infrastructure in the LA basin is supported using ATCS radio communication in the 900 MHz band for about 75% of all wayside signal control point sites, and is operating at its limits due to bandwidth limitations resulting from unavailable spectrum. (The Metrolink railroad is currently constrained to use of a single 25 KHz ATCS frequency pair for CTC operations in the entire LA basin, and although efforts are underway to migrate to other technology alternatives, this will take some time). It is likely that in future years train traffic train density and speeds will increase and headways or separation between trains will be reduced. For a fixed train population, as trains go faster while simultaneously reducing headways, the number of time slots required system-wide at any time instant will proportionally increase. This consumes more spectrum from the contingency set aside for speeds, headways and density resulting in a need to either add more contingency or more spectrum. As the geographic territory dispatched by the SCRRA grows, so will the need for additional spectrum. Finally, the need to remotely perform health monitoring and perform remote software updates via wireless spectrum to the hundreds of PTC sites, and with each site often featuring with multiple devices will require additional spectrum.

The above discussion illustrates the importance of procuring adequate spectrum now in order to support interoperable future growth. It is important to point out that a conservative approach in acquiring spectrum is for the long term (20 year time horizon) is warranted and prudent given the limited amount of spectrum available for PTC applications.

Figure 1a below show the only current interoperable frequency bands supported by the existing radio infrastructure.

Figure 1a*: Potentially available spectrum; SCRRA considering AMTS-A Block. The defined PTC Frequency Range is from 217.6125 MHz to 221.9875 MHz.*

Figure 1b*: Spectrum between 220 and 222 MHz acquired by PTC 220 LLC (Eighteen 25 KHz blocks, 9 of which are constrained by HAAT limitations)*

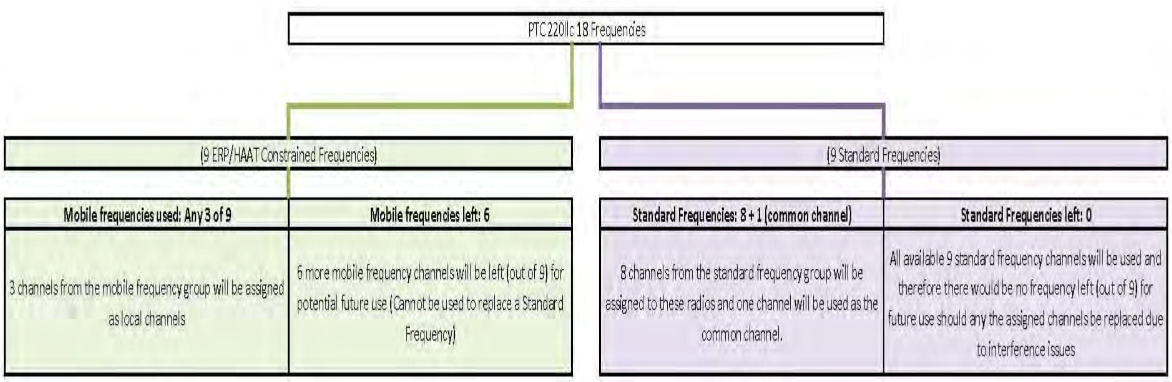


Further, an examination of the consequences of insufficient PTC spectrum shows that SCRRA railroad operational efficiency would be significantly impacted if there is insufficient or unreliable PTC spectrum. Each time there is a ***demand*** for a frequency, either from a train, a wayside device or the BOS (via a Base Station), an **unimpaired** frequency **must** be available **immediately**, otherwise the PTC communication link between the train and wayside signal or base station will be lost and the on-board train management computer will **enforce** a stop of one or more trains.

ESTIMATED PTC SPECTRUM REQUIREMENTS

- The estimated PTC spectrum requirements discussed below are based on the following assumptions and constraints.
- The design of the Communication Network by V/I Engineering and SCRRA Consultant staff provides full redundancy which will prevent a potential disruption to the network caused by a RF outage due to the failure ***of any one*** base station.
- Of the Eighteen (18) frequencies (channels) owned by PTC220 LLC, a total of 9 are standard, and the remaining 9 are ERP (Effective Radiated Power) and Height (HAAT- Height Above Average Terrain) constrained.
- Of the 9 ERP/HAAT constrained channels, only a maximum of three (3) can be simultaneously used in the 12-channel cellular architecture at lower power levels and antenna heights, without impacting the performance and/or cost of the communication network design. Refer to Figure 2, below for a proposed utilization plan of the existing 18-Channel PTC 220 LLC spectrum.

Figure 2; PTC 220 LLC Spectrum Utilization in the LA Basin.



SHORT TERM, 2012 THROUGH 2015

The deployment of PTC in the LA basin rail network and passenger and freight trains operating therein will most likely occur over a period of 24 to 36 months, starting in late 2012 or early 2013 and continuing until the end of 2015. By the end of calendar year 2013 it is estimated roughly 75% of the wayside signals and 50% trains will be equipped for PTC. By the end of 2015, essentially all of signals and 90% of trains will be equipped for PTC and all LA operating subdivisions designated for PTC will be operating under PTC. Intense training and testing exercises will be conducted and refinement of the PTC radio system and network will be underway. For this start up scenario, the SCRRA Consultant and V/I Design staff estimate that a total of Nineteen (19) 25 KHz frequencies (channels) will be required to support this deployment. A breakdown of these channels is as follows:

- Eleven (11) channels for the frequency-reuse plan of the Communication Network Cellular Architecture.
- One (1) Common Channel (this may eventually be replaced by a virtual channel that would not require a separate frequency, at a future date.)
- A 15% Design Contingency (2 channels) to allow for unplanned changes to the design requirements.
- A 15% Channel Impairment Contingency (2 channels) to overcome intractable interference from unknown 3rd parties that may yet occur on a corresponding quantity of channels.
- A WSRS (Wayside Status Relay Service) 3-channel ***allowance*** to allow for the deployment of radio or commercial cellular relay service to plug intractable radio coverage gaps in the network.

MID-TERM, 2016 to 2020

For the purpose of this report, mid-term is defined as 2016 -2020. By 2016, all freight and passenger trains required to be equipped with PTC. It is anticipated that some features of PTC “Rung 2” and “Rung 3” such as roadway worker EIC laptops with direct communications to trains will have been deployed in the LA basin. There will some growth in rail traffic and wayside signal devices and increase use of the wireless information capabilities of PTC. The SCRRA Consultant and V/I Design staff estimate that a total of Twenty Five (25) frequencies (channels) will be required to support the system during this time frame. A breakdown of these channels is as follows:

- Fifteen (15) channels for the frequency-reuse plan of the Communication Network Cellular Architecture.
- One (1) Common Channel (this may eventually be replaced by a virtual channel that would not require a separate frequency, at a future date.)
- A 15% Design Contingency (2.4 channels) to allow for unplanned changes to the design requirements or for initial SCADA (supervisory control and data acquisition) associated with remote monitoring and the need to remotely perform software updates to signal, radio and related train control devices.
- A 15% Channel Impairment Contingency (2.4 channels) to overcome intractable interference from unknown 3rd parties that may yet occur on a corresponding quantity of channels.
- A WSRS (Wayside Status Relay Service) 4-channel ***allowance*** to allow for the deployment of radio or commercial cellular relay service to plug intractable radio coverage gaps in the network.

LONG-TERM, 2021+

For the purpose of this report, long-term is defined as after 2020. The SCRRA anticipates that by or before this date, commercial supply and demand forces will result in the migration of some ATCS operations from the current 900 MHz band to the PTC 220 MHz band in order to mitigate the severe bandwidth constraints in the 900 MHz band. In anticipation of this, 6 channels (150 KHz) will be set aside to support ATCS redeployment. Refer to earlier discussions on page 1 for the explanation of the importance of the ATCS network. Although the SCRRA anticipates utilizing a separate Ethernet based network to support CTC by this time, ATCS will be used to provide diversity. The SCRRA Consultant and V/I Design staff estimate that a total of Thirty Five (35) frequencies (channels) will be required to support this long term deployment. A breakdown of these channels is as follows:

- Fifteen (15) channels for the frequency-reuse plan of the Communication Network Cellular Architecture.
- One (1) Common Channel (this may eventually be replaced by a virtual channel that would not require a separate frequency, at a future date.)
- A 20% Design Contingency (3.2 channels) to allow for unplanned changes to the design requirements or expanded use of the PTC frequencies for SCADA (supervisory control and data acquisition) associated with remote monitoring and performing remote software updates to signal, radio and related train control devices..
- A 15% Channel Impairment Contingency (2.4 channels) to overcome intractable interference from unknown 3rd parties that may yet occur on a corresponding quantity of channels.
- A WSRS (Wayside Status Relay Service) 5-channel ***allowance*** to allow for the deployment of radio or commercial cellular relay service to plug intractable radio coverage gaps in the network.
- A 30% expansion of PTC devices and scope (4.8 channels) (current expansion margins are designed to the year 2020.)
- A 6 channel CTC hardening network.

CONCLUSIONS

- A total of 19 frequencies are required to support PTC in the LA basin in its initial deployment for calendar years 2012 to 2015, and this requirement will grow to about 25 frequencies by 2020 and to 35 frequencies by the time the CTC underlay is fully hardened.
- Of the 18 PTC 220 LLC frequencies between 220.0 and 222.0 MHz, which are owned by the PTC LLC 220, only 12 can be used to support this deployment of PTC in the basin. This group of 12 is comprised of all 9 from the group identified in figure 2 as standard Base Station frequencies, plus any combination of 3 from the group identified in figure 2 as the ERP/HAAT-constrained 9. These 3 will also need to be constrained to lower power levels and antenna heights. Use of any more than 3 from this group, will result in performance and/or cost impacts to the communication network design. See figure 2, above for a utilization plan of the existing 18-Channel PTC 220 LLC spectrum.
- Conclusions are based on a fully redundant radio coverage environment. For lesser coverage environments, there will be a 25-30% reduction in the minimum spectrum requirements to implement PTC for each deployment date scenario.
- Assuming that SCRRA can successfully share PTC-220 LLC spectrum through a lease, the SCRRA will need to acquire in addition to the PTC-220 LLC spectrum an additional of seven (7) additional frequencies (175 KHz) of spectrum to meet the initial PTC deployment, and twenty three (23) additional frequencies (575 KHz) to meet the long term PTC requirements. These additional spectrums will be added to the 12 PTC-220 LLC frequencies in order to provide the required spectrum estimated on pages 3 and 4 of this report.