Considerations for the Deployment of Communications for Commuter Railroad Positive Train Control Systems

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ABSTRACT

The design of communications infrastructure, required to support mandated Positive Train Control systems, has not been given prominent attention with regard to and support of large-scale public rail systems in high density areas and heavily used rail corridors. Required Federal deployment timeframes have necessitated fast track strategies for all PTC systems one of which is communications technology. Essential communications systems requirements for PTC deployment include RF spectrum and data radio systems. This paper reviews the detailed analysis of spectrum availability and selection issues and the requirements of radio systems to fulfill PTC deployment in an urban and regional environment. This includes the use of risk assessment methodologies, radio options analysis and the determination of spectrum requirements based on accepted design criteria for land/mobile UHF/VHF design.

INTRODUCTION

The challenges of deploying Positive Train Control are compounded by a very aggressive deployment schedule for the affected railroad operators. Communications technologies applied to PTC applications are limited and there are several areas of uncertainty in the capabilities of the technologies as they currently exist and the critical need for communications spectrum and bandwidth. There are limitations of available bandwidth, incomplete radio system requirements and limited approved radios offered by manufacturers. There are also issues of interoperability and of coordination of spectrum acquisition strategies that have added to the complexity of the Positive Train Control program.

SYSTRA Engineering and Consulting is a planning, engineering, design and construction management firm that specializes in transportation systems and associated facilities. SYSTRA Consulting in the United States is part of the SYSTRA Group, a global enterprise with 50 years of developing and improving transportation systems worldwide. The company has offices across the United States and provides train control and communications expertise in signal engineering and telecommunications services. The telecommunications organization has expertise in radio propagation and RF systems design, wireless data applications, fiber optical management and design, network engineering and maintenance planning as well as electromagnetic interference compatibility and testing.

The SYSTRA communications group has developed in-depth capabilities in the requirements and specifications development of PTC communications systems across a metropolitan region for multiple transit operations of a major transportation agency. The team has created a means by which to benchmark best practices in the development and planning of PTC communications systems and establish a strong but succinct network development program. These areas of work have included pre-project activities including stakeholder analysis, technology assessment and project planning. This has been followed with technical systems reviews, surveys of wayside, back-office and rolling stock communications systems, inventorying of current spectrum use and applications and further study of the current train operations and control.

The availability of critical spectrum resources is a major issue for PTC deployment. The Federal Railroad Administration has provided well intended but limited guidance on how commuter railroads are to attain adequate RF spectrum, particularly so for high density urban mass transit environments. The engineering of a robust data network design is challenged by limitations of spectrum in the 220 MHz spectrum, the recognized PTC spectrum for the freight or any other qualifying railroad.

The FCC has limited capabilities with regards to spectrum and has encouraged the use of stimulus funds for the commuter rail groups to acquire spectrum. Spectrum of all kinds is in very tight supply and present integration issues with the spectrum currently in place for the freight lines. Wireless network facilities are key to the successful deployment of PTC yet there remains scant guidance and attention to the issues of constructing an integrated wireless platform to support the possible array of PTC requirements. What is known is there are five critical systems that must interoperate for the successful deployment of PTC. They are: the network itself, the rail vehicle on-board systems or mobile communications packages (MCP), the wayside interfaces to switching equipment also referred to as wayside interface units (WIU's), the radio base station equipment or base communications packages (BCP) and the ground network services and IT facilities and systems support the PTC application such as safety servers and speed control systems. Lastly, network design responsibilities must establish the key deliverable of high quality of service (QoS) performance for all train movement information and the proper function of the PTC system components. This paper focuses on the critical telecommunications analysis and design that affects the performance of the PTC system and shall concentrate on the issues of finding suitable and sufficient spectrum, evaluating radio system options and also explains a method of determining total spectrum requirements for the regional transit operating area in order to fulfill the PTC deliverables.

PTC SYSTEM REQUIREMENTS

The Federal Railroad Administrations requires the deployment of a Positive Train Control System as specified by the FRR 49 CFR Part 236, Subpart I, § 236.1011. This requirement for positive train control became mandated by the Rail Safety Improvement Act of 2008 RSIA by President Bush on October 16th, 2008 as public law 110-432 and requires the deployment of PTC Systems by December 2015. The key objectives of PTC deployments include: protection against train-to-train collisions through enforcement of positive stop at interlocking home signals; protection against over speed derailments through enforcement of Maximum Authorized Speed (MAS), Permanent Speed Restrictions (PSR) and Temporary Speed restrictions (TSR); protection against unauthorized incursions into established work zone limits through track blocking functionality of the signaling systems; protection against a switch not properly aligned; warning or enforcement of operational restrictions because of highway-rail grade-crossing warning-system malfunctions and protection of wayside and bridge workers.

The PTC requirements apply to freight lines, long distance passenger services and commuter railroads and where there are HAZMAT's. There are as many as eleven demonstration projects or systems in varying levels of operation or testing. Freight operators are using systems known as Electronic Train Management System (ETMS) while Amtrak has tested Incremental Train Control System (ITMS). Amtrak has also deployed the Advanced Civil Speed Enforcement System (ACSES) between Boston and Washington DC on the Northeast Corridor.

PTC SYSTEMS OVERVIEW

The wayside systems and components include all signal system interfaces and fixed communication systems that facilitate PTC related communications to trains operating on PTC mainline tracks. These wayside systems include: transponders that are placed between the running rails at designated locations; wayside encoders (WIU's) that read the real time status of vital interlocking devices such as signal status and switch position at signal; the Base Communications Package (BCP) that interfaces from the wayside to the Mobile Communications Package (MCP). The backhaul network connects the back office based servers that support the PTC systems featuring vital Safety and Temporary Speed Restriction (TSR) Servers and interfaces for user and data communications. The ground network's communication system shall provide data communications between these office based PTC systems and the BCPs. This may comprise of a fiber optical system, wireless or ground based copper circuits.

The Wayside Communications System consists of components that support data communications connectivity between the Mobile Communications Package (MCP) that reside onboard an equipped train with that of the wayside systems via the BCP. This connectivity to the control center-based Safety and TSR servers that also supports communications from the Wayside Interface Unit(s) of nearby interlockings. The wayside communications connects Wayside Communications Controllers (WCC) that will generally connect through routed hubs to the system Safety and TSR Server(s). In this manner, the wireless system routes communications packets between the BCP to the WCC's and centrally located servers. The information from the trains and the status of the local wayside switches as well as the location of other trains are tracked and monitored by the system's central safety servers and provide that status to any train approaching an interlocking home signal. PTC is designed to initiate braking instructions to the train's onboard computers to initiate braking and to provide information to the operators Aspect Display Unit (ADU).

The Wayside Communications System is comprised of the following major components, each performing one of the MCP's or BCPs primary functions: RF transceiver, RF transmission interface, wireline systems and communications interfaces. At present, the PTC radio systems are to operate nationwide from 220 to 222 MHz however; the national standards for the spectrum applications will support lower limits of the spectrum range to 217.0 MHz if needed. The key communications systems components and requirements are summarized as follow:

RF Transceiver- RF Transceivers (data radios) shall meet all applicable FCC or other appropriate government requirements, including type certification. The RF transceiver will meet over the air requirements such as data rate, method of modulation and environmental stability. The RF transceiver will support time division multiple access that will accommodate 12.5 to 25 KHz channels. The RF transceivers shall employ some Software Defined Radio Functionality and are to operate over a range of 217 to 222 MHz. The radios will operate over Ethernet ports and support TCP/IP.

RF transmission interface- RF Transmission interfaces include the components that connect the BCP to the antenna system. The radio interface also handles Layer 1 and Layer 2 transport of the data sent to and received from the radio transceiver. Further, it performs self health tests and reports buffers and queues traffic, and monitors the received RF signal quality and strength, appending this information onto the data received.

Wireline interfaces- Wireline interfaces connect the BCP to the ground network systems. It shall monitor traffic to and from the WCC and provides a control that is used by other system components to use an alternate (or back-up) ground network communication path to an alternate WCC. The wireline interface also connects the BCP to one or more WIU's.

Base Communications Packages- The RF transceiver transmits and receives radio frequency packets at specified frequencies for which the system is designed. Base Communications Packages (BCP) are placed strategically to provide radio coverage at interlocking sites throughout the railroad territory. The site of these facilities shall depend upon the terrain of the area, possible height of the towers, permitted power levels, adjacent frequencies and any pre-existing RF systems. Radio systems may include Time Division Multiplexed Access (TDMA) protocol to achieve throughput speeds sufficient to support up to 24 trains in a high capacity interlocking and up 100 trains per hour during peak periods at key locations.

Antenna System- The wayside antenna system is comprised of an antenna, the antenna support structure (tower, pole, or building), and coaxial cable. It provides over the air RF transmissions of the BCP to the MCP and interconnects to the ground network.

Ground Network Communications System- The ground network communications system connects the operations center(s) and servers to the wayside locations. These systems may ideally comprise of fiber optical systems that will employ multiple paths to Wayside Communications Controllers and other network equipment. Figure 1 presents the relationships between the MCP, the BCP, the WIU's and the ground network.

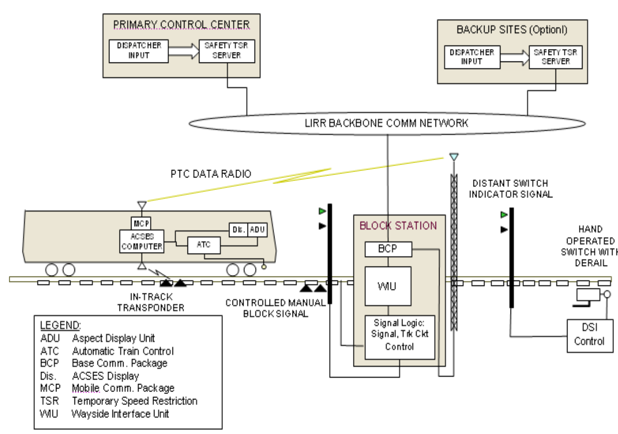

Fig. 1: PTC System Component Relationships

PTC DEPLOYMENT ISSUES AND CONSIDERATIONS

FRA has promulgated regulations by amendments to CFR Part 236 (the initial FRA Regulations). The PTC Implementation deadline set forth in the PTC Act presents challenges with regard to design, testing, furnishing and installing an FRA approved system. In this regard, the FRA required the submission of a Positive Train Control Implementation Plan by April 15, 2010. The mandated PTC system is to be completed by December 31, 2015. System design to completed deployment are to occur from mid-2010 to 2015 and shall include; procurement, construction and testing to be completed in about 4.5 years. This deployment schedule will mandate a fast paced program with little or no slack time for fulfilling key deliverables. The key deployment critical paths include the following deliverables; design, procurement, critical systems testing, installation of systems into rail cars, deployment of switch circuits and wayside systems, applications programming, deployment and testing and lastly communications systems.

The communications systems comprise of critical deliverables necessary for the successful deployment of the PTC for the nations railroads. The RF spectrum must be available in sufficient quantities to provide enough bandwidth to support a high level of communications services. The system must provide 1) congestion free and sufficiently available error free data channels and 2) radio communications technologies that permit the functionality of the PTC communications protocols which may include ETMS or in the case of SYSTRA's clients ACSES.

A number of the Class 1 freight railroads, through an alliance known as PTC 220 LLC, has purchased substantial holdings of spectrum in the required 220 to 222 MHz spectrum range. Nationwide, PTC 220 has accumulated the aggregation of 220 MHz spectrum of up to 275 KHz or about fourteen (14) 25 MHz channels in most areas, nationwide. The number of channels is more than sufficient to support low to moderate freight line traffic along the nations sprawling rail system and in most urban areas as well. In the high density urban areas however, the capacity requirements for other high volume transit operations mandate greater amounts of 220 MHz spectrum to meet these PTC needs and to provide throughput and reliability that is essential to the ultra large metropolitan transportation agencies of the nation's largest cities.

SYSTRA's largest clients support two of among the nation's highest used commuter railroads. In one region the aggregated peak period volumes of 200 trains per hour traveling is required over as few as six tracks during peak periods. The high demand is compounded by a mix of Northeast Corridor traffic and a moderate level of Class 1 and other freight traffic along with mainline and branch rail transit systems. The large transit system covers over 700 miles of trackage across ten counties in three States and a geographic service area of 5,400 square miles. There are over 100 known interlocking sites that will require one or more BCP radio devices. There is highest level of interlocking and BCP concentration is within a 25 mile radius (1,960 square miles) of the area central business district and rail hubs. Rail service approaches the central business district from the north, south, east and west.

From a communications design and operational perspective, the limiting factor to the deployment was identified as the availability of spectrum needed to support the enormous data traffic that the PTC will generate from the trains and wayside equipment to connect with centralized safety and speed reduction servers. The network must also support the reverse flow of TSR and other related information to the train and ion-board computer system that provide direct and indirect control to the operator and the trains speed control and braking systems.

Moreover, the PTC systems mandated by the FRA basically include either ETMS for the Class 1 freight lines and ACSES for some commuter and domestic passenger lines. The functionality requirements and features of the radio systems that support ETMS and ACSES are significantly different. The Class 1 carrier BNSF freight line with other partners Union Pacific, Norfolk Southern and CSX have invested heavily into the radio products of the firm MeteorComm Wireless Communications (MCC) and the ETMS system. The system uses GPS systems to identify the location of trains relative to wayside conditions including the presence of other trains, switch status and speed restrictions. The system also uses GPS technology due to the cost prohibition of the extensive field use of transponders in rural areas. As such, the MeteorComm radio has been designed largely for the functionality of the Class 1's. MCC has been developing an ITC (Interoperable Train Control) based radio predominantly but not limited to freight line use. MCC is the sole design firm for the ITC radio but its manufacture is to be contracted to one or more licensed vendors. The MCC radio has been largely developed for the Class 1's and information on the status of functionality and specifications are limited. As a result, an alternative to the ITC radio has been sought by some non-freight railroads. The SYSTRA team has investigated the available radio features and performance issues and has addressed an assessment and risk review program for evaluating the radio technologies. A PTC suitable radio for commuter rail use will constitute a critical deliverable and is one of the primary topics of this paper. The radio and its requirements that shall support system interoperability requires a demanding strategic assessment with secondary impacts that will warrant an alternative design approach to the use of radio communications technology and channel selection that profoundly impacts the control and connectivity of the PTC mobile to base communications systems.

The issue of the availability of radio spectrum for the high demand PTC application in high density rail corridors has become one of the most challenging of the communications concerns in the pre-design phase of the program. With virtually no 220 to 222 MHz spectrum available for the passenger lines in the region SYSTRA for available frequencies in the adjacent spectrum areas known as the Advanced Mobile Telephone System (AMTS) and the Interactive Video and Data Services (IVDS) and now referred to by the FCC as the 218-219 MHz Auction Elections and Payments spectrum. The AMTS spectrum consists of A and B blocks within the 217 to 218 MHz range and the 219 to 220 MHz range, each block providing 1 MHz of spectrum. The IVDS spectrum consists of two blocks that are equally divided at 500 MHz between 218 and 219 MHz. The acquisition of spectrum rights for adjacent counties has been examined in order to prevent co-channel or adjacent channel interference to the critical PTC application in the clients operating territories. The complexities of the procurement of the spectrum are beyond the scope of this technical paper however the development of a methodology to quantify the required spectrum for the PTC application was developed along with a frequency assignment plan to validate the method of the quantification studies as part of the due diligence efforts.

The challenge of acquiring spectrum forced the development of risk assessment methods in conjunction with efforts to quantify the spectrum requirements based on the total number of BCP sites and locations in the region. Recognizing that the acquisition of spectrum may be limited to 500 KHz, it has been absolutely essential from the client's position to know that the acquired spectrum will meet the railroads full PTC needs. The selection of the radio technology for the PTC systems will also depend upon the availability of PTC ready radios on the market, type approved, prior operational experience and capacity to support the high bandwidth needs of the high volume commuter lines. This paper outlines the evaluation processes to address these questions.

ACQUISITION OF SPECTRUM

SYSTRA has familiarized itself with the PTC spectrum availability issues as early as June, 2009 when it researched the intended use of 220 to 222 MHz spectrum for potential clients. It became readily apparent that 220 to 222 MHz spectrum would not be available for the client railroads in sufficient quantity for a large-scale deployment. Through the use of spectrum brokers such as Spectrum Bridge Inc. to seek out the availability of the AMTS spectrum in the 217 to 219 MHz range was evaluated. While seemingly available for sale, the one reasonably available block was not capable of being deployed in the region due to interference from much of the spectrum in an adjacent county. (The 220 MHz spectrum propagates quite readily at moderate transmission of 50 to 100 watts ERP and the resulting spectrum extended heavily into the clients operating region). The alternative AMTS spectrum block of 500 KHz was not on the market according to its owner. As a result, as ideal as the AMTS spectrum appeared to be, there would be no immediate selection of that spectrum without extensive modification to the subleases that the one owner interested in a sale had in place. Accordingly, the next area of interest was the 218-219 MHz former IVDS spectrum. Discussions and negotiation with the spectrum owners are beyond the scope of this technical document however the spectrum offers desirable operating characteristics. With two 500 MHz blocks located between the AMTS A and B blocks, at least one block can suffice for the client needs and provide at least forty (40) 12.5 KHz channels for the PTC application. Since the original FCC 1992 spectrum auction (intended for enabling the use of set-top boxes to facilitate home shopping or voting) the use of the spectrum has been superseded by other technologies, and there remain few incumbent owners across the region and only two owners of Metropolitan Statistical Areas in the home PTC service area of SYSTRA's client.

The IVDS spectrum is governed by the FCC Part 95 of the FCC Code, Applicable to Personal Radio Services, Subpart F, Section 95.861. These regulations stipulate that the IVDS base station is limited to 20 watts ERP and for mobile units the power is limited to 4 watts ERP. While the reduced power limits would be a limiting factor in the use of the IVDS across large areas of coverage, the lower power is ideally suited for the congested urban area of the client and the relative close distances of BCP sites within the railroads territory. These power limitations will be a critical design benefit as will be discussed further in the sections that follow.

While the use of IVDS spectrum represents an excellent solution for the railroads, there are only two possible blocks that are available for a total spectrum bandwidth of 1.0 MHz for any one FCC MSA and limited to 500 KHz from either of the two present owners in the clients region. The spectrum characteristics of the IVDS spectrum are very similar to that of the AMTS and the PTC-220 spectrum. PTC based on-board 'software defined' radios can tune any of the channel ranges through codes provided to the trains onboard computers and transponders along the track bed. The transponders or alternately common control channels can direct the train's radio to tune to the IVDS spectrum through the use of a communications manager, to be described further in the paper.

There are risks in the prevalence of options associated with either of these spectrum acquisitions. Depending on demand and capacity requirements, there was a need to identify and assess potential risks associated with the spectrum acquisitions and the implications for the PTC program's technical deployment and schedules. As a result, an aggressive risk identification and management plan had been developed. The following section describes, in summary form, the strategy of that risk assessment plan and some of the metrics that were found to be useful in the analysis and eventual purchase strategies and decision making process.

SPECTRUM RISK ASSESSMENT

The spectrum and process risks identified by SYSTRA included the following component areas: the acquisition and deployment of the AMTS or the IVDS spectrum; the possible dual use of both spectrums; the network analysis and design process; the use of alternate spectrum and the use of the radio technology. The use of a dual spectrum design allows for some of the immediately available AMTS spectrum to be developed while the IVDS spectrum is procured. The AMTS spectrum can be used in service areas not presently available for the IVDS but a design that uses two spectrums with differing power levels can be problematic and needs to be carefully considered. There are risks associated with the availability of the remaining AMTS spectrum and the possible interference upon the PTC service area. In addition, there are risks in the analysis and design of the systems requirements due to uncertainties that the process must address. Finally, there are risks associated with the radio technology should spectrum alternatives preclude the use of PTC 220 spectrum and ITC based radio designs and other alternatives to the 'industry' radio. As a result, a risk matrix and rating scale process was developed that addresses both qualitative and quantitative measures of the potential risks that may be anticipated. Qualitative risk assessment tables were developed for each of the options that identify the feasibility, pros and cons, value resulting in a letter based risk score which is used to identify, at a gross level, the issues and risk rankings. Categories of assessing the qualitative risks include; performance, cost, contributions to possible schedule delays, support issues, business issues and stakeholder needs were all used to develop a risk grade ranging from A (low risk), B (moderate risk), C (high risk, moderate exposure) and D (high risk, high exposure). These rankings are not provided here.

Quantitative risk assessments were numerically based on the rating of 1.0 for highest risk and 0 for lowest risk for any number of case specific issues ranging from spectrum type, modifications required, potential for interference, cost, contract and lease issues, availability, FCC review processes, availability of alternate spectrums, design complexities and interdependencies and radio technology compatibilities with that of the spectrum itself. Risk factors included probability of occurrence, value, benefit, exposure and risk of occurrence. Further discussions on the metrics of risk are cited in Cooper et al in the reference Section 5 citations. Risk assessment scores were tallied and ranked and presented to the client in graphical format as shown in Figure 2 which serves to quantify a variety of specifically suited risk factors for each of the categories on the described 0 to 1.0 scale.

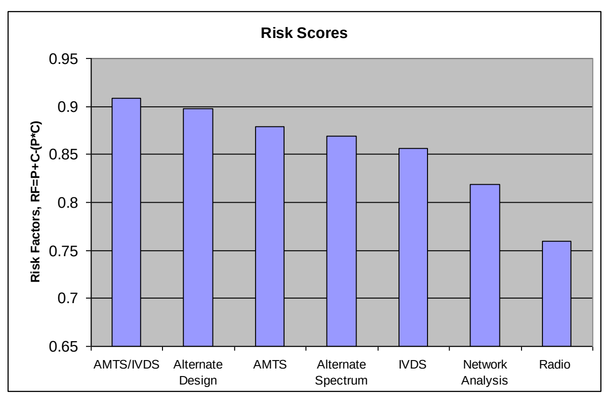

Fig. 2: PTC Communications Systems Risk Factors (1.0= highest risk and 0.0 = lowest risk).

In addition to the actual risk scores, the uncertainty of issues for all options were assessed and presented as were issues of technical systems dependencies. Finally, a risk management action plan was developed and served as the basis for proceeding with one particular spectrum and design strategy while providing for an actionable plan to proactively address risks and take the necessary precautionary actions if needed. The decision was jointly reached with the clients to move towards the IVDS spectrum which provides near full area coverage and to use a joint legal team to work with the FCC on any regulatory issues that arise through purchase and licensing.

RADIO TECHNOLOGY

The unique issue with the National deployment of a PTC program is the general lack of well known radios supporting high-speed land/mobile communications capabilities in the VHF 217 to 222 MHz spectrum range. The Class 1 freight railroads have tentatively selected the ITC standards based MeteorComm Corporation (MCC) radio technology. The ITC radio specifications have not accommodated the required ATCS communications protocol required by the ACSES application and as a result, the direction of the radio design leans toward the use of commercial off-the-shelf (COTS) radio technology, comparable to such radios in use for 160 and 800 MHz radio systems used by the railroads. Such radios would have the prerequisite of supporting the ATCS protocol and functionality of a slot based time division (TDM) type radio. A survey of the product literature revealed a very limited number of suitable 220 MHz radios available on the market. The SYSTRA team began a further evaluation of the radio technologies that may be suitable for the PTC system and represent an alternative to the ITC freight standards driven radio. The MCC radio, though it comes with a robust capability for train control, seemingly lends itself to the requirements of freight operations as opposed to commuter rail operations. While the following discussion is neutral to any particular manufacturer's product, it will emphasize the general technology direction and implications for the passenger rail industry and the goal being embraced by the SYSTRA client. To commence the review of radio products, a radio subcommittee was formed of members of a communications team working on the pre-design needs assessment associated with the PTC program. Included in scope of their activities was to identify functional requirements for the PTC radio for the ACSES platform and to assure sufficient data capacity to meet the demand needs of the client railroad operations. The team also studied power range issues, frequency range availability, available 'slot' channels for supporting train traffic and the suitability of a trend away from CSMA(contention based) radios towards Time Division Multiplexing (TDMA) radios with and without control channels is the radio platform of choice. Typical rail radio systems have relied upon controlled-access systems, with each mobile device assigned a timeslot across a contention based CSMA control channel. Regrettably, the investigation of nine radio manufacturers was limited to four possible choices to a competitive evaluation by the railroads, which has not formally commenced. The fundamental requirements of the radio needs today are that it support TDM communications, includes a range of output power of 5 to 25 watts, support a frequency range from 217.0 to 222 MHz with a channel bandwidth of 12.5 or 25 KHz, a minimum throughput of 9.6 kbps with a capacity of 30 time slots and support of an external communications manager.

The MeteorComm radios, anticipated for wide-scale Class 1 usage, will use Edge Messaging Protocols (EMP) and the newer ITP protocol as well as Class C and D messaging protocols. Alternative radios on the market place appear to provide the needed TDM slot configuration to an existing COTS radio that can also use a control channel for mobile to base slot assignment. At this point a fundamentally different approach to the radio functions were examined through the use of encapsulation of ACSES's ATCS packets into a UDP packet to communicate over the TDM radio. (ATCS is the long-standing ACSES communications protocol). The ACSES message structures are characterized by communications from the OBC to BCP that include Train Requests to Encoders (288 bits); a TSR list Train Request (760 bits) and from the BCP to OBC for Encoder Response message (464 bits) and TSR response (464 bits) with two TSR's per message. Multiple TSR responses can be received for up to three BCP sites with a maximum of TSR's per BCP. The suitable TDM radio must be able to support an interface with a proposed communications manager (CM) which will reside between the 220 MHz data radio and the ACSES based on-board computer. The CM can be engineered and procured separately but coordination and testing with the proposed radio will be a requirement. The CM will be capable of performing the encapsulation of the ATCS data from the OBC into an IP packet sent to the 220 MHz radio and will also remove the messages from the encapsulated packets received from the radio before sending the ATCS message over to the OBC. The CM will also host a channel parameter table to provide specific frequencies for the transponder based communications on the approach to home signals and the BCP. The communications manager will be advised of the change in frequencies from the track transponders which will use a combination of a unique railroad ‘Y’ number and a BCP number code. The CM will also manage time slot assignments and inspect messages from the OBC for geographic location data and obtain channel parameters from the channel parameter table and transmit that data to control the operational parameter of the radio. Other radio systems considered for the COTS radio solution include a soon to be announced 220 MHz IP based radio system. The actual procurement of radio technologies will be conducted by the client after the completion of the upcoming design phase.

Interoperability between different PTC systems will require, in some instances, different radio systems by certain Class 1 and domestic passenger rail lines. In the case of the Northeast Corridor from Washington D.C. to Boston, a group of NEC rail lines and SYSTRA consultants cooperatively developed common radio requirements for use along the corridor. These will potentially include: Amtrak, New Jersey Transit, Metro-North Railroad, the Long Island Rail Road and the South Eastern Pennsylvania Transportation Authority (SEPTA). These railroads chose to share a common radio standard based platform to use a COTS radio, with some modifications allowed, and the communications manager module. The on-board and base radios will be directed to tune to the appropriate frequency between 217.0 to 222 MHz based on the assignment and availability of that spectrum along the rail wayside. This is an enormous cooperative effort that will provide open interoperability among rail passenger service providers along the Northeast Corridor though challenges in the procurement, development and testing of the TDM radios and the associated communications manager must be addressed. As was the case of the RF spectrum, SYSTRA provided risk assessment tools to determine which of the radio options held the highest risk factors that shaped the decisions to use TDM based radios that eventually lead to a common technology platform among other railroads utilizing the Northeast Corridor.

The communications manager will require separate development, construction and integration expertise and may take the form of a card that is integrated into a rack or as a standalone device. It must be environmentally durable as they will be used on-board and at all wayside BCP sites. The critical function of the communications manager is frequency and maximum output selection for the BCP radio and by the MCP which will operate across territory. The communications managers will likely encounter BCP power outputs that vary from radios using 220-222 MHz then spectrum in the 217 to 219 MHz range alternatively. A TDM radio must support 30 slots within a three second ‘epoch’ with 15 slots reserved for mobile to base communications with three open slots for timeslot requests for entering mobiles. The remaining 15 slots are reserved for transmissions from base to mobile communications. A 16th slot is used by the base communications manager to provide information to the mobiles on existing timeslot assignments. For the high capacity requirements of an urban area, with large and complex interlockings as many 24 trains may be held under certain circumstances and multiple TDM radios may be required. Further capacity analysis based on the ATCS message structure has been performed on an incremental arrival of trains to the ‘busiest’ of the interlockings resulting in a peak traffic demand of 10 kbps and the design goal is within reasonable range of the peak capacity of some of the TDM data radios that will be further evaluated. The deployment of the CM will be critical to the success of the PTC communications platform.

SPECTRUM REQUIREMENTS

Aside from the availability of spectrum for the PTC program across a wide geographic footprint, the minimum required number of channels and thus the required quantity of spectrum must be determined. This has represented the final pre-design phase of the project and is generally referred to as the spectrum quantification issue. Knowing the actual number of planned BCP sites that the PTC design requires, a sufficient distance between base sites using the same frequency must be determined. This is known as the co-channel interference distance and it is a critical determinant in providing guidelines on the design of the RF network, its bit error rate and signal to noise (or carrier to interference) performance when built and the primary factor in assessing if there is sufficient RF spectrum to build a performance based PTC system. The process is fundamental to planning the PTC network and may be used by others looking to make a careful assessment of their own proposed regional PTC spectrum requirements. The key steps are summarized as follow:

1) Determining the expected propagation behavior of the spectrum in free space and calculated fade margins

2) Determination of distances to provide a sufficiently high free carrier-to-interference (C/I) ratio of 17 or more
3) Propagation studies of a representative sampling of interlocking/BCP sites
4) Develop scale-drawings of the service areas and attempting a best fit of the frequencies and,
5) Perform a trial frequency assignment

Essential to the design process was the development of a baseline model for the minimum separation of the propagation characteristics of the 220 MHz spectrum across the service area footprint and specifically a sampling of eight characteristic interlocking sites. Propagation simulations of these sites were conducted using typical operating input parameters for the expected BCP sites. These included output power, antenna heights, type and gain, terrain factors and propagation models. In this case, Longley-Rice v. 1.22 was used (at 50%, 50%, 50% confidence levels in accordance with the model) using the RadioSoft Inc. RadioCompass (v. 1.2.0.315) product. Field validation of the results are to be done in the formal design phase however a correlation comparison was performed with an earlier 'verified' model using RadioSoft's ComStudy for a number of the area interlocking sites. The preliminary design issue is the determination of the minimum separation between co-channel sites. Several power levels were examined but it became apparent that limiting RF coverage was key to attaining the coverage with 40 channels within a large but dense region of BCP sites and service areas. A critical preliminary design criterion was to ensure that the -105 dBm receive levels of one site not extend beyond the line of demarcation of the -85 dBm receive level of other co-channel site. Figure 3 depicts the design criteria. C/I ratio guidelines for Land/Mobile radio applications identify a target minimum C/I ratio of 15 to 17 dB for TDMA based radios, using QPSK modulation based on NTIA criteria and as referenced in Section 5. For this PTC application, a C/I ratio design criteria of 20 dB was used. The receive level distances based on the propagation simulations were analyzed and averaged across the eight proposed BCP sites. The standard deviations of the trial sites were also computed and found to be consistent across the receive levels of interest. The measured receive levels included the following increments; -85 dBm, -95 dBm, -105 dBm, -115 dBm and -125 dBm. (The last level is not expected to be significant but its inclusion was helpful in examining propagation output charts).

The analysis resulted in the development of a Receive level vs. Distance from the BCP base station as provided in Figure 4. The generated curve shows reliable service and coverage out to five miles and usable receive levels out to as far as eight miles. Coverage in the areas between co-channel sites with greater separation will be provided by alternate frequencies. Validation testing of these predicted receive levels must be completed during the design phase.

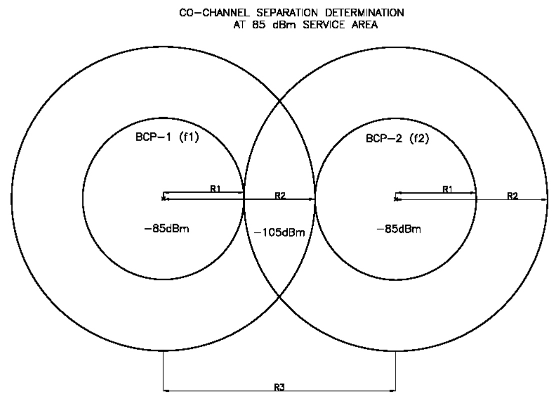

Fig. 3: Design criteria for Co-Channel Sites

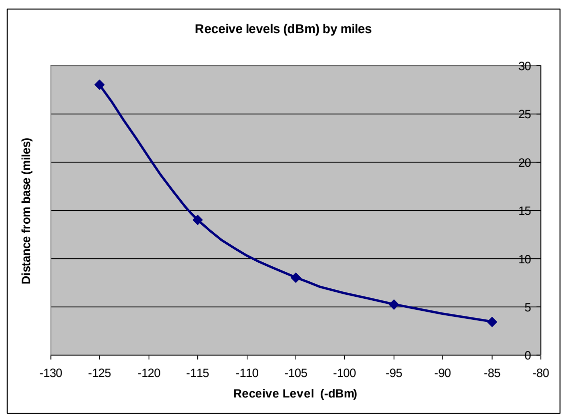

Fig. 4: Propagation output levels for 218 MHz Receive levels by Distance for BCP base test sites

The propagation findings, along with the C/I ratio criteria of 20 dB, resulted in a minimum co-channel distance of 20 miles based on the model presented in Figure 3. This takes into account the standard deviations associated with the propagation studies, extending the receive levels at -85 dBm and -105 dBm by two standard deviations, thus accounting for variability and extending the coverage prediction to account for 95% of the possible actual results in the field. As a result, the minimum co-channel distances are as follow based on Figure 3 relationships:

R3 (min.) = R1 + R2 = 6.8 + 12.2 ~20 miles

Finally a set of best fit trials were conducted using the 20 mile minimum and confirmed that the 40 channels can be reused throughout the region without significant interference as will be also be evaluated through field testing. The actual reuse of frequencies averaged 3.45 times i.e. each frequency was reused from 3 to 4 times. A limited view portion of the best fit diagram is shown in Figure 5.

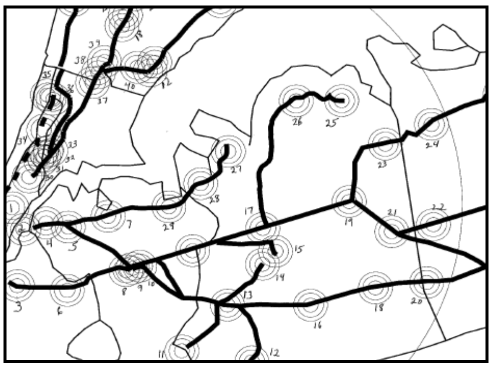

Fig. 5: Portion of Reuse Best Fit Trial

Finally a trial frequency assignment was performed for all 40 channels across the area based on the 20 mile separation of the base station antennas. The prohibition of the -105 dBm receive level to intersecting with the co-channel sites -85 dBm levels is depicted in Figure 6.

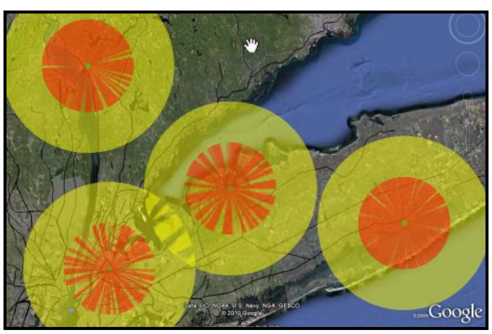

Fig. 6: Single Frequency Assignments

CONCLUSIONS

The goal of this paper was to provide deeper insight into the issues of deploying communications technologies to support a large, regional area, deployment of Positive Train Control. The issues associated with the availability and procurement of RF spectrum are critical to the success of deployment of PTC in the urban areas where spectrum is at a premium. Commuter railroads should look to the AMTS and IVDS spectrum if sufficient 220-220 MHz spectrum is not available. A consideration for the adoption of radio technology is also a critical decision and design issue. The use of COTS radios, even with modifications, \ has its advantages for product availability and support but modifications required for support of the actual PTC application and its communications protocols must be considered. The use of an adjunct device as a communications manager (CM) offers distinct advantages in multiple railroad use of shared facilities and where the PTC applications and protocols are not native to the radio itself. With short time frames for testing and deployment of radios, the CM can be considered vital to the communications platform but has its challenges for design, testing and deployment. Lastly, spectrum requirements are critical in very large urban environments such as New York, Boston, Los Angeles, Chicago and other metropolitan areas. The spectrum quantification technique explained in this paper represents a valid methodology for determining minimum distances between co-channel frequencies sufficient to provide guidance through the spectrum procurement and due diligence phase. Further analysis of adjacent channel and mobile interference will be required in the design phase of the PTC project.

Persons interested in learning more about the RF design process would benefit by reading Reference 1 of Section 5. The author wishes to thank his colleagues, the SYSTRA management team, John Catarino, SYSTRA Communications Designer and Mr. Joey Gottlieb for their support.

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