



Smart devices > Smart networks > Smart Planning

**The importance and value
of route-based coverage,
service quality and
throughput predictions for
PTC RF design**



The importance and value of route-based coverage, service quality and throughput predictions for PTC RF design

Kurt Drummond PE
Principal Engineer
RF Networks Inc (www.trfnc.com)

Steve Webster
Director, Product Management
EDX Wireless (www.EDX.com)

September, 2011

This white paper will demonstrate the power and utility of using route-based radio planning as well as advanced PTC network simulation studies to improve the design of PTC systems while using as few sites and radio channels as necessary.

Overview of PTC systems, purpose and radio technology

PTC (Positive Train Control) is a wireless communications-based technology that is being developed to provide a high-reliability data communications network for the delivery of movement authorities and other data to an on-board computer for the control of trains. The main purpose of PTC is to add a layer of safety to the operation of trains in order to avoid collisions, over-speed derailments and work-zone incursions caused by a failure of the train crew to obey signals and speed restrictions. It is therefore an overlay on the existing centralized traffic control (CTC) signaling system.

The need for a high-reliability wireless communication network arises from the fact that if the on-board computer of a train moving under PTC finds itself in an unknown state, due either to component failure or communication link failure, it must immediately restore itself to a known state. The fastest and most reliable way to accomplish this will be to execute an enforced stop.

PTC networks are composed of three main types of radios:

- Base Stations (BS) – these are located in strategic locations that offer wide area coverage of a rail network. They can be viewed as extensions of the PTC back office server (BOS) and they communicate wirelessly with the following two types of radios:
 - Wayside Radios (WR) – these are connected to wayside interface units (WIU) that are located trackside, usually adjacent to a switch or signal. These radios communicate with both BS and train radios.

- Train Radios – Every train that operates on a PTC-enabled rail subdivision must have a 220 MHz band PTC data radio that communicates with both BS and WR.
- Future radio additions are likely to be engineer-in-charge (EIC) radios and radios at grade crossings. Both would be configured in a manner similar to the radios used at WIU.

As can be seen from the diagram below, the base stations are the hub of the PTC network. BS interconnect the rail dispatch and BOS with the PTC radio systems and send instructions to PTC-equipped trains that operate in their area of control. BS also communicate with WR in order to pass commands and to obtain status. PTC BS need to have good RF coverage of the tracks to which they are required to provide service as well as have overlapping coverage with other PTC base stations in the network to support reliable device hand-off and for redundant coverage in the event of a Base Station site failure.

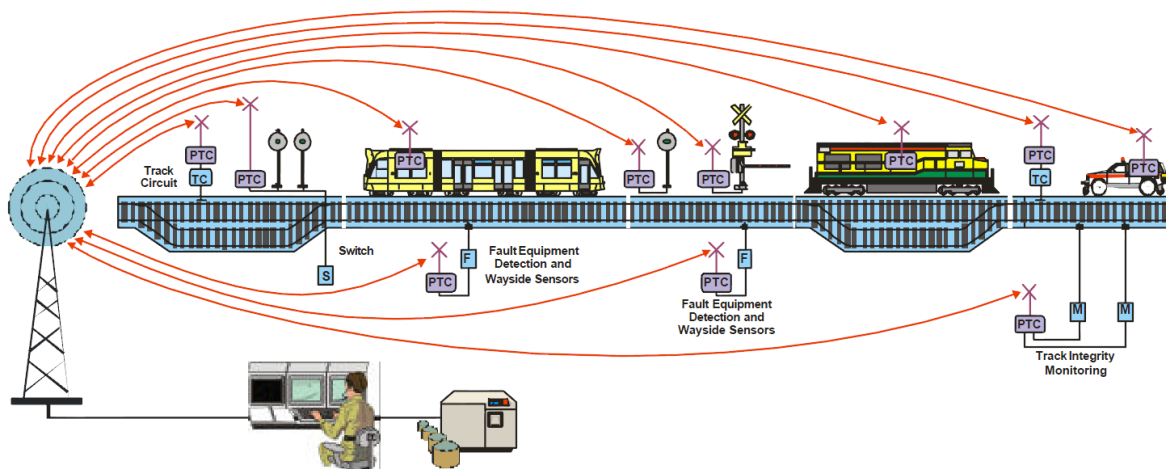


Illustration of PTC network components with Base Station represented on the left. From STI-CO's Wireless PTC Technology Outline White Paper (March 2009)

WR need to communicate their status with BS to let the nearby trains know whether they can safely continue through the crossing or switch that the WIU is controlling. Failure to receive an "all clear" message from a WIU will result in a forced slowing or even stopping of a train. For this reason, it is vitally important that WR are able to provide clear radio coverage of the track section(s) that they affect.

Train radios communicate with both BS and WR. Due to the fail-safe nature of PTC, not getting a safety-critical message in a timely fashion will result in the train automatically slowing down or stopping regardless of the train operator's commands. In order to avoid service disruptions it is imperative that the train radios be able to maintain a reliable radio link with the base stations and wayside radios that perform the required communications and control functions on the section of track on which the train is operating.



RF Engineering Design for PTC - A series of Suggested Steps

PTC provides many benefits for the public as well as for the railroads; most notably the significant safety benefits. However, these come at a price both in monetary terms and in operational inefficiency if the communication network is not adequately designed. This is because a failure in any PTC radio or PTC backhaul communication link has the potential to put the on-board train computer into an unknown state which will result in an enforced stop. This will have a significant detrimental effect on operational efficiency.

The first step to be taken by the RF design engineer should be to determine the maximum required bit error rate (BER) for the network design. For PTC operation in rural areas where there are large distances between wayside devices along with low traffic densities this BER may best be computed based on miles travelled per false enforcement event. However for dense metropolitan areas, this BER would best be computed based on the value required to support the maximum speeds and minimum headways defined by operations for each track segment or sub-division. This step will require coordination with the client railroad's operations group to determine what maximum speeds and minimum headways can be safely supported by existing and planned future signaling infrastructure, so that the PTC communication network can be designed to support these values plus a margin to allow for unknown factors that may affect radio coverage.

Therefore, railroad maximum speeds and/or minimum headways become the first design parameter for the RF engineer for determining the definition of an acceptable design BER. Once completed, the next step will be the computation of the minimum $C/(I+N)$ required to guarantee this BER requirement. $C/(I+N)$ is computed from E_b/N_0 , for which a continuous set of values are typically provided by the radio manufacturer as graphical plots versus BER for the modulation scheme used, and for the channel model selected. This paper will not delve into the details of this computation, however readers interested in this can find more information in the readily available technical literature on the subject.

Integral in the computation of minimum $C/(I+N)$ is the determination of the most appropriate channel model(s) for the various PTC communication links. This is required in order to *adequately and accurately* account for the worst-case fading to which the channel will be subjected. The correct channel model also suggests the required fade margin to be added. The additional fade margin assures a minimum link availability which is correlated to the target BER. For PTC, there are three RF communication channel types. These are train to/from WR, train to/from BS and BS to/from WR. The train to/from WR and the Train to/from BS communication is fixed-point to mobile-point link best modeled as a Rayleigh-faded channel. The BS to/from WR fixed link is best modeled as a Ricean channel because most existing railroad BS will likely have a primarily line-of-sight path to most of the WR which it supports. In all cases, a modern deterministic propagation model such as EDX's Anderson-2D can be employed to account for the static path loss in each link situation (line-of-sight or diffracted).

Subsequent steps require an offered-payload study as a prerequisite to determining how much RF spectrum will be required to support PTC for the client railroad. This spectrum must be checked for potential co-channel interferers (aka, a "fitness-for-use" study) and once available, the RF engineer will use the RF planning tool to begin the design process. Before committing too much energy and resources



to the simulations, the RF engineer must perform model tuning in order to optimize the tool for the PTC design. This is typically done by measuring the actual coverage of existing transmitters or temporary test transmitters using calibrated receivers containing GPS location logging. The results of these measurements are then imported into the planning tool and compared to the predicted coverage for these same transmitters. Adjustments to the propagation model or land use (clutter) parameters are made to align the predictions with the measurements.

Important design parameters for RF performance of PTC systems

The following data is required by the RF engineer in order to design a PTC wireless network:

- PTC coverage - This is typically defined as being confined to a narrow corridor along the track segments (often referred to as subdivisions). Track segment data, including latitude and longitude (with datum specification) of track points is critical to the planning process and should be obtained from the railroad. Track elevation (AMSL) data is also necessary in order for the planning tool to be able to use its digitized terrain and clutter data to determine the effects of cuts, fills, bridges and tunnels on the radio signals. Multiple tracks sharing the same ROW also need to be specified.
- Required service level and service margins - These include the following:
 - Minimum required signal levels along the track for the WR to BS fixed links (in dBm)
 - Minimum required C/(I+N) for acceptable fixed and mobile service
 - RF fade margins, either in dB (decibels) or in percentage of time and location for both the fixed and mobile radio links.
 - Required coverage distance along the track and overlap of WR.
 - Required radio capacity for the track segments in the PTC coverage area. This is typically dependent on the number of parallel tracks in the ROW's as well as the usage (rail traffic) of the rail segments. This is typically provided by the rail operator or a third-party consultant as an offered payload analysis, which can be used to compute a network RF demand. Future growth margins for radio capacity are also important to know to ensure that the PTC network can grow with the increased traffic without significant redesign.
 - The radio channels available for the PTC system.
 - The air-interface technology (i.e. TDMA/CSMA) used for the PTC system.
- Potential base station locations - The location and available heights of existing towers or structures to which the rail operator has access. These should be used preferentially for locating PTC base stations.
- Required WR locations - These will be placed at switches and signals in the rail subdivisions that require PTC control by means of the WIU. Knowledge of the typical or location-specific radio mast details for WR is helpful. Radio masts in rail rights of way are often exempt from local zoning restrictions, but it is helpful to know what is considered to be reasonable or expected for



radio mast heights.

- Information on Existing or planned radio systems or links for adjacent PTC systems - Coordination between PTC system operators or railroad operators is necessary to avoid interference and to ensure interoperability for trains that move between different PTC networks. Typically this information would include information on the fixed radio locations that are adjacent or near to the boundary of the planned PTC network including their latitude, longitude, antenna height, type and azimuth, RF power and most importantly their assigned radio channels (frequencies). Railroads operating PTC networks adjacent to each other will be required to coordinate with each other to develop a common frequency usage plan. Other PTC base station and network identification parameters that are relevant for interoperability are also required.
- Information on other radio systems - These include VHF or UHF voice dispatch systems, WiFi or commercial cellular for train initializations at yards and terminals, GPS or differential GPS such as NDGPS and WAAS systems for navigation en route. Information about these systems should include their coverage area, fixed station locations and other relevant parameters.
- The radio equipment that will be used in the PTC network - This includes the following radio types:
 - Base station radios (BS)
 - Wayside device radios (WR)
 - Train mobile radios
 - Employee-in-charge (EIC) radios (future enhancement)

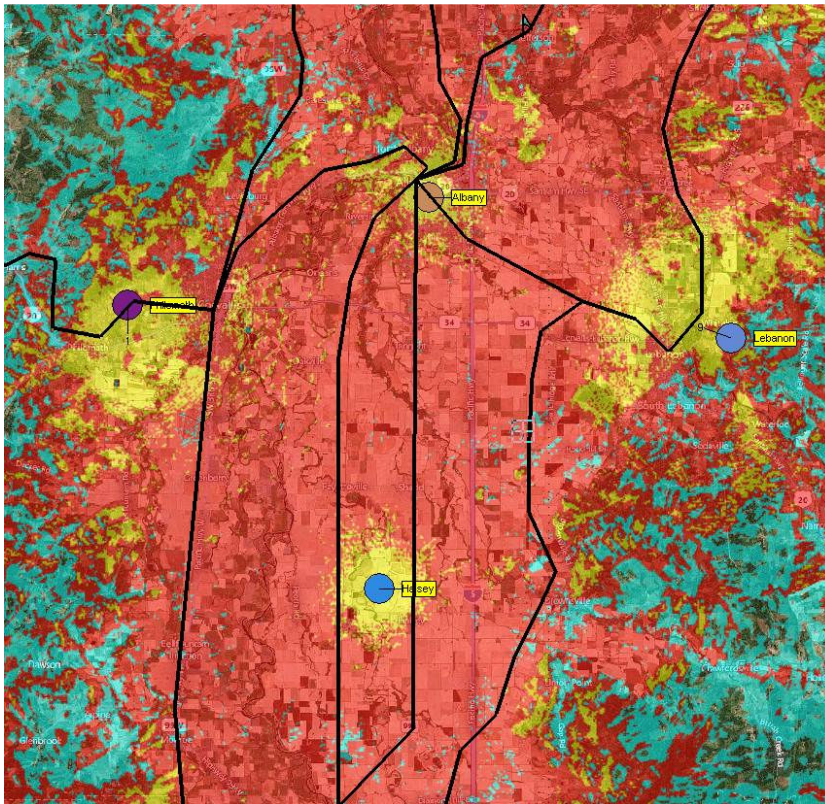
For each type of PTC radio, it is important to obtain the following information:

- The RF output power of the transmitter. Maximum, minimum and typical/usual operating RF power information is useful to the planner to ensure service margins.
- The sensitivity (minimum signal level for useful BER) and/or Noise Figure of the receiver. BER versus $C/(I+N)$ and data rate versus $C/(I+N)$ performance curves for the radios is necessary to characterize the digital performance of the PTC network.
- The typical antenna RF transmission lines/cables and their losses.
- The antennas used including their gains in dBd or dBi as well as their digitized antenna coverage patterns (in both the horizontal and vertical planes)

PTC system planning requires the use of detailed terrain and land use (clutter) data. For rural and many suburban areas 30m (one arc-second) resolution terrain and clutter data should be sufficient. Built-up urban areas will require finer-resolution clutter data. Dense urban areas also may require digitized building data to properly account for shadowing from buildings along the PTC system routes. VHF radio propagation is more obstacle-tolerant than UHF radio propagation, but obstacles in the radio path still can cause significant reductions in signal strength that need to be factored into the PTC RF design.

Design of PTC along rail networks requires a unique radio planning methodology

Most radio networks, including broadcasting, 2-way and cellular are designed to cover an area or region (such as a city, county or state). Historically this has been the way that most radio networks are designed. The problem with this approach in designing a PTC network is that it will lack resolution of coverage prediction along the rail lines themselves. A PTC network requires a different design method since the need is for focused coverage along defined routes rather than simply achieving uniform coverage over an area. For example, below is typical area coverage prediction plot that also shows a section of a rail network that is in Western Oregon. This type of plot can be produced from a wide variety of radio planning tools including EDX SignalPro®.

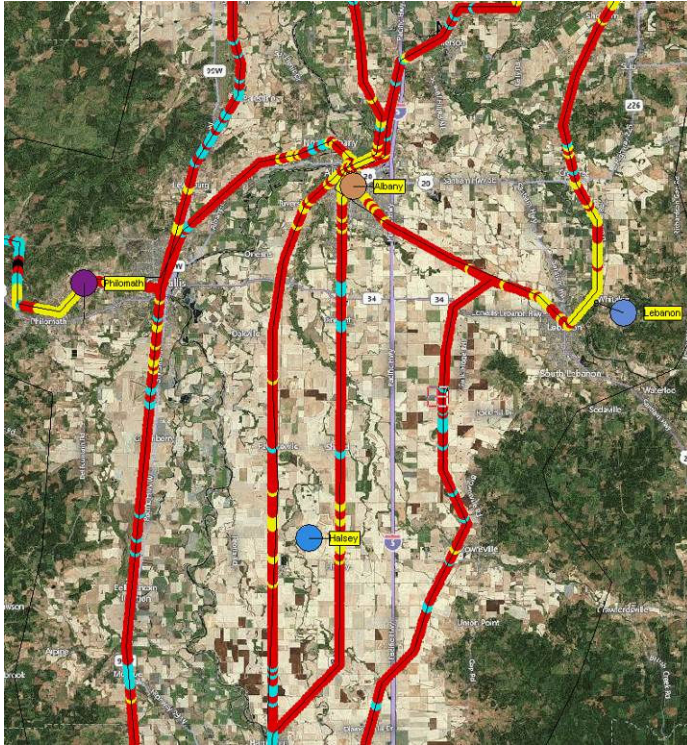


Predicted PTC base station area coverage with rail lines shown in black (EDX SignalPro)

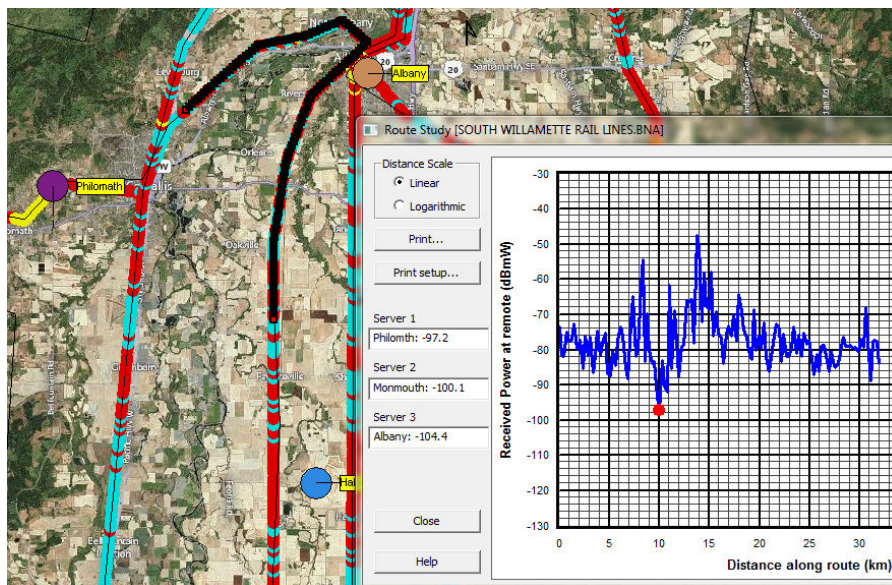
This type of plot gives a quick view of the general area coverage of the PTC radio devices, but when the user wishes to drill down into the detail of coverage along a rail segment, they're left with the fact that an area coverage prediction is made up of a single signal level prediction for each individual rectangular area (a "bin") that make up the larger grid study area. These bins include not only a segment of the track but also all the area around them. There is no practical way to get highly detailed line segment or point information from an area study.

Route-based radio network planning involves using a flexible and powerful radio network planning software tool, such as EDX SignalPro, which can perform detailed predictions on routes of interest.

These routes, which can be easily, drawn, specified or imported, can be broken up into as many study points spaced as close together as the user wishes to have. This allows the PTC network to be planned with track coverage prioritized over general area coverage.



A route-based radio coverage prediction of the same group of base stations (EDX SignalPro with Bing® map underlay)



A route-based radio coverage prediction with a graph of a user-selected portion of the route (EDX SignalPro)

Smart Planning for Smart Networks



EDX SignalPro allows the user to select any section of a route study for detailed investigation. One option is to display a route graph. This is a powerful tool that allows the engineer to quickly drill down into potential problem areas for further investigation.

Another advantage in using route studies to plan PTC radio networks is when assigning radio channels and predicting interference. Typical radio planning tools that were designed for cellular or 2-way radio networks have automatic frequency planning (AFP) algorithms that find the most optimal radio channels by considering the interference and subscriber traffic over the entire coverage area associated with each transmitter. But since PTC radio traffic lies only along tracks and rights of way assigning radio channels constrained by conditions found outside the track corridors makes no sense. The route based radio planning tools in EDX SignalPro® can allow the engineer to perform automated channel assignments based on route study data, which puts all of the emphasis of ensuring interference-free coverage to the PTC coverage area (rail lines). For example, a rail network that lies along a valley floor could have a frequency plan created that used a smaller pool of available channels and still avoid interference on the rail lines even though interference may exist on the hillsides away from the tracks.

The designer can also modify the route definition in order to emphasize the weighting of a particular segment. For example, if it is important to ensure good PTC service at certain crossings, sidings or stations/yards, then more closely spaced points can be added in these critical segments to increase their weighting (importance) when the AFP algorithm is deciding how to assign interference-free radio channels.

Effective and efficient Automated Frequency Planning algorithms are even more important for PTC than for cellular networks. PTC networks are designed to provide high availability data communications for fail-safe control of trains by on-board equipment. A missed signal due to poor coverage or interference on a cell network may be inconvenient to the user but for PTC it can result in having every train moving through a low-signal point apply its brakes until it can receive an “all clear” signal. In addition, cellular networks use UHF frequencies whose coverage is more limited by distance and obstacles than the VHF radio frequencies that PTC uses. This may seem to be an advantage for PTC, but there are a limited number of radio channels available for PTC and, especially in a congested area with significant rail traffic, each radio needs to ensure that its assigned channel isn’t interfered with by other users on the same channel as well as making sure that each PTC radio doesn’t cause interference to other PTC radios.

An example of this is when a train is crossing a mountain pass. Due to braking safety over descending grades, it is important to ensure that clear and reliable radio communications exist in these critical areas. Unfortunately, there is a potential for VHF PTC radios in the valleys below the pass to cause interference along the mountain grades. By using route-based radio predictions the user can specify the exact location and elevation of each point along a track in order to ensure that an accurate radio coverage and interference prediction is performed.

Being able to accurately and confidently model VHF radio propagation is essential to the success of PTC radio design. EDX SignalPro is used extensively, not only for UHF cellular system designs, but also for VHF land mobile radio networks, radio broadcasting systems as well as for microwave link system



design. This gives EDX a unique advantage in having radio propagation models that can accurately predict radio systems operating between 30 MHz and 100 GHz.

Advanced PTC network design tools

SignalPro with the Network Design Module or SignalRT® can also predict neighbor cells for all PTC base stations and/or wayside radios of interest. This shows the user which potential cells are available to hand over a PTC radio link as the train progresses through the rail network.

Other radio planning considerations for designing PTC networks

Another reason to use a sophisticated radio planning and design software tool, such as EDX SignalPro, is to ensure that digital radio links are properly modeled. With analog voice networks the user can often decipher garbled or partially intelligible transmissions. But with digital networks the performance in marginal radio conditions can end up in a total loss of data transfer. Digital radios have performance curves, such as BER (Bit Error Rate) versus $C/(I+N)$ (Carrier to Interference plus Noise ratio), which are similar to analog MOS (Mean Opinion Score) or SINAD (Signal to Interference, Noise plus Distortion) ratios that define the performance of legacy voice radio networks. EDX SignalPro uses receiver BER and data rate performance data along with adequate signal level margin parameters to predict both BER and data rate throughout the PTC service area. This gives the engineer the confidence to ensure that the PTC radio system that they're designing will perform in a robust fashion.

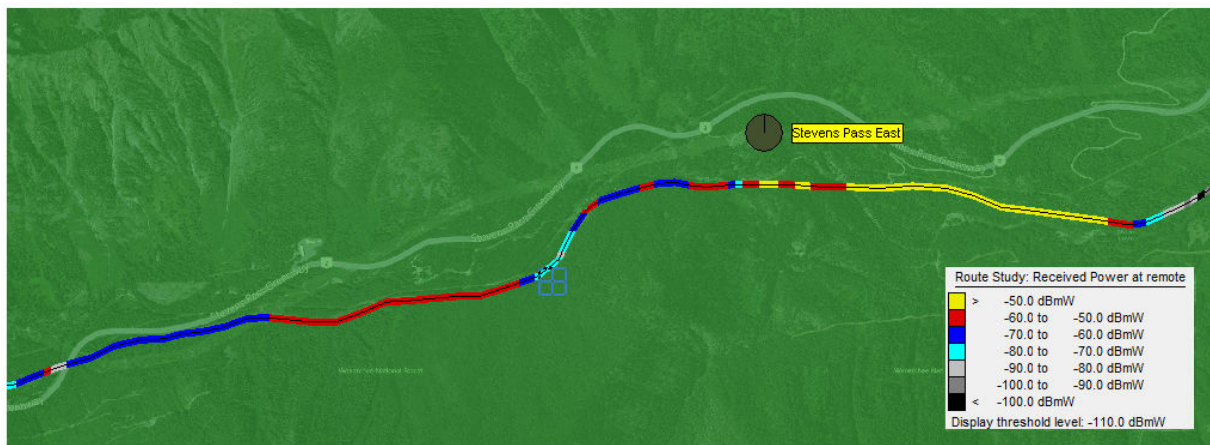
Here is a list of other useful PTC radio performance prediction studies that can be run in EDX SignalPro:

- Downlink (base to mobile) and uplink (mobile to base) predicted signal levels (in dBm, dBμV and dBμV/m)
- Most likely server (i.e. the base station that serves each point along a route)
- Downlink $C/(I+N)$ predicted or measured base station receiver interference levels.
- Uplink $C/(I+N)$ using estimated or measured base station receiver interference levels.
- Number of potential servers that are above a user-defined threshold (downlink or uplink). This is useful for ensuring that redundant radio links exist in critical areas.
- BER (bit error rate) on downlink or uplink
- Data rate on downlink or uplink

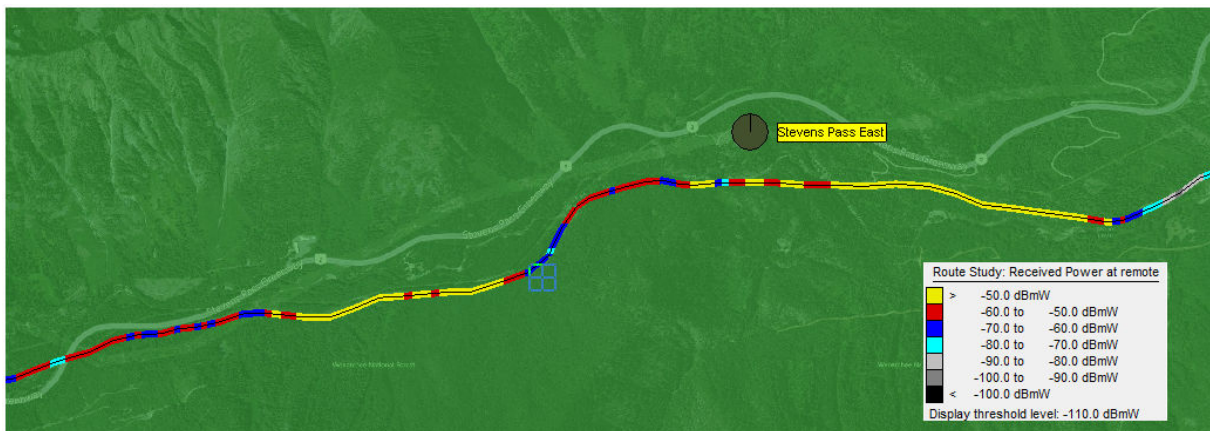
Most of the 30+ kinds of area or route based radio prediction studies that can be performed in EDX SignalPro for the downlink (BS or WR to train radio) can also be run for the uplink (train radio to BS or WR) as well. Uplink studies are important, especially when there is an RF power imbalance between fixed and mobile transmitters.

Features in EDX SignalPro® that improves predictions and speed up PTC planning workflow

One of the many advantages in using EDX SignalPro is its unique clutter carving feature that allows the use of lower resolution (and much less expensive) clutter (land use) data in less developed areas but still be able to take advantage of the fact that rail ROW's are clear of surrounding objects (such as buildings and trees). Clutter carving uses GIS road and/or rail data to carve canyons out of clutter databases. An example of this is shown in two studies run in SignalPro. The first study shown below is in a forested area in rural Washington State that has a BNSF rail line going through it. Using low-resolution 100m clutter data, it is obvious that the uniform forested clutter (the green colored area), if left uncorrected, would grossly under-predict the coverage of PTC radios on that rail line. The second screen capture shows the same area, but with the rail ROW "carved" out of the forested land use data.



A route-based radio coverage prediction using 100m clutter data shown in green for forested region (EDX SignalPro® with Bing® map underlay)



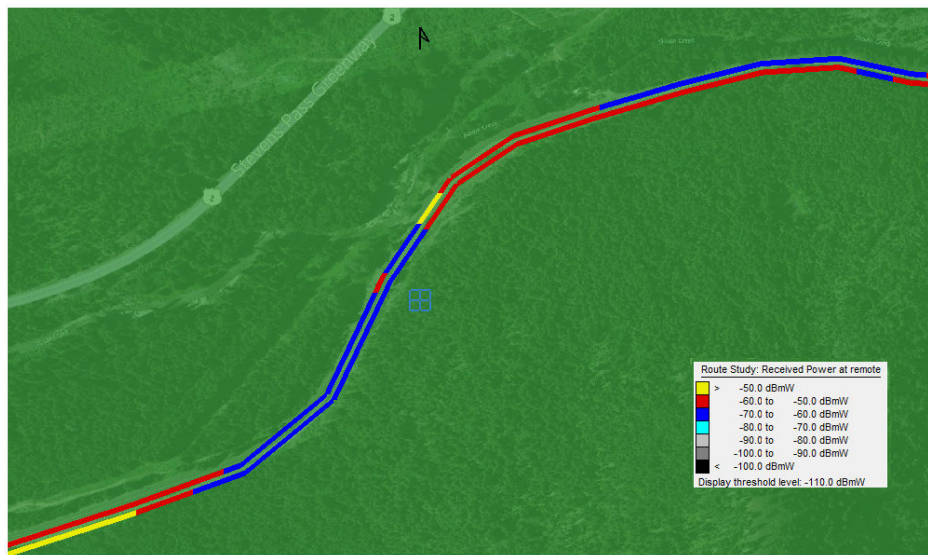
A route-based radio coverage prediction using 100m clutter data shown in green for forested region that has been carved to create a clutter-free canyon over the BNSF ROW (EDX SignalPro® with Bing® map underlay)

The differences in predicted radio coverage show the improvement from a more accurate depiction of the ground cover in the vicinity of the BNSF ROW. The areas that showed poor or no coverage without

carved clutter now show better coverage. This helps to ensure that expensive PTC base stations are only added where they're required to provide coverage along the routes of interest.

Rail ROW routes are specified using polylines stored in data files. These can be created by tracing the mouse over a digitized map in SignalPro or by importing this type of GIS rail and/or road data into the program. When running route studies, the user has the option to specify interpolation distances between defined points in the original data files so that the predictions can be made on as many points along the route that the user wishes to have.

EDX SignalPro also has many user-friendly editing tools such as the ability to quickly replicate and shift a route file. For example, the BNSF line in the Stevens Pass area shown in the previous screen captures is a dual-track line in the same ROW. Using the polyline spreading tool in EDX SignalPro® the original digitized route file was replicated into two adjacent lines spaced 20' (6m) apart. Note how much difference can be seen in the coverage of rail track that is 20' apart versus a single rail track. This is another advantage of using route based planning, as it allows the engineer to drill down to this level of detail easily and effectively.



A portion of a dual-track route-based radio coverage prediction using 100m clutter data shown in green for forested region that has been carved to create a clutter-free canyon over the BNSF ROW (EDX SignalPro with Bing map underlay)

Predicting BER (Bit Error Rate) and Data Rate on routes of interest

In digital radio signalling the bit error rate (BER) changes as the Carrier to Interference plus Noise ($C/(I+N)$) level changes. The equipment manufacturer should provide the PTC designer with BER vs. $C/(I+N)$ tables that are easily imported into SignalPro. This data is then used in route or area study predictions to give the engineer a useful view of the PTC system network performance.



A route-based BER prediction (EDX SignalPro with Bing map underlay).



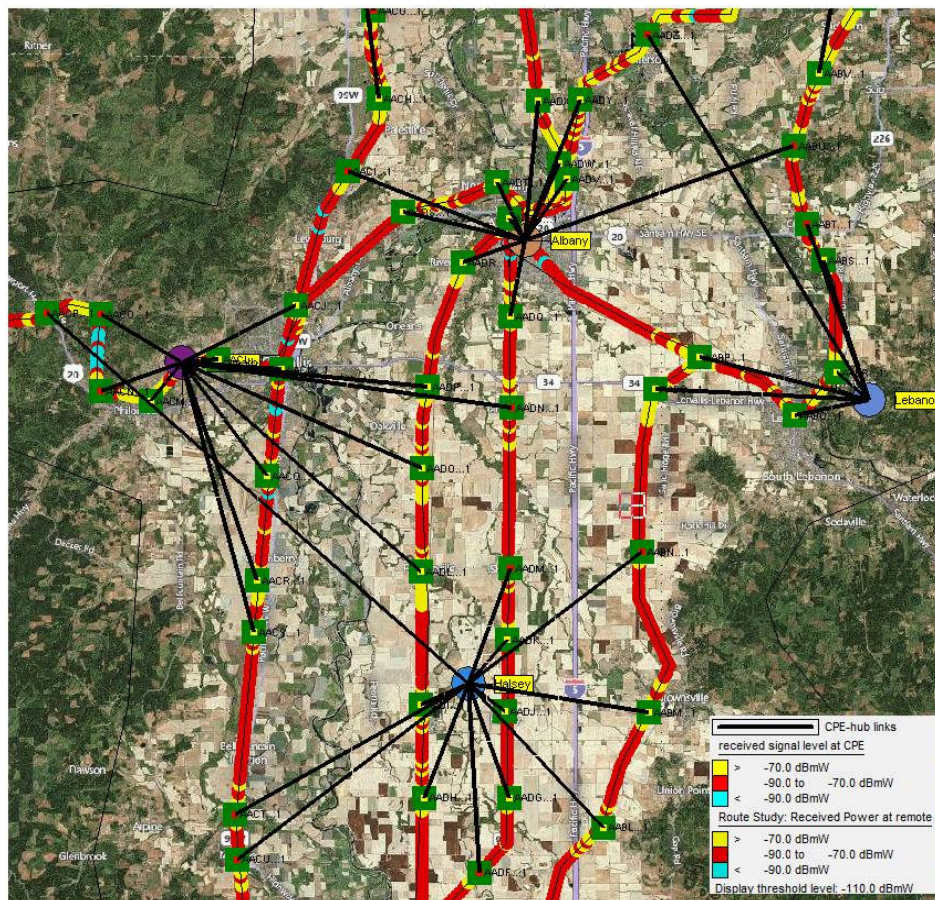
A route-based Data Rate prediction (EDX SignalPro with Bing map underlay)

Both of these plots were generated using generic BER vs. C/I tables. The current release of the TDMA/CSMA PTC air-interface standard doesn't define this relationship yet but EDX SignalPro will include this as a standard digital system type when the standard is updated for this.

Modeling Base Station to Wayside Device to point to multipoint radio links

Another differentiating factor of PTC radio networks is that they contain not only fixed to mobile radio links, but they also have fixed point to point radio links between the Wayside Devices and their associated Base Station. SignalPro allows the user to accurately model these radio links quickly and effectively as a multipoint network. Wayside Devices can be modeled not only as base stations but as collocated CPE's (Customer Premise Equipment) that link with Base Stations that are multipoint hub sites in addition to mobile radio coverage stations.

Shown below is a screen capture of a SignalPro PTC system in the Willamette Valley. The route study plot is of the Wayside Devices' coverage on the rail lines and the links in the multipoint study between the Base Stations and the Waypoint Devices that communicate with them are also shown on the same map (along with a Bing underlay map). Note that this multipoint study chooses the best base station to connect to the wayside device, not the closest one. This helps the engineer to better understand actual coverage and service.





Summary

Planning PTC systems using a traditional cellular network design approach will result in a less than optimal PTC network at a greater cost than planning a PTC network using a route study based approach. This is because of the inherently different philosophy of the needs of a PTC network – that is, one based on service along defined routes rather than generic coverage over a defined area.

EDX has worked closely with the rail and transportation communities to define a PTC planning suite found in SignalRT, which is based on the extensive capabilities of the SignalPro suite of RF tools. SignalRT and the SignalRT module for SignalPro incorporate several innovations in RF planning which simplify and improve the design and planning of RF networks for PTC systems resulting in more efficient use of spectrum, improved safety and lower cost. The breadth and flexibility of RF design tools is unique to EDX and makes our tools a perfect application for PTC network design and planning.

Below is a summary list of the advantages of using EDX SignalPro with the Network Design Module or SignalRT for planning a PTC network:

- Powerful and flexible route studies focus the design engineering on the RF coverage and quality of the rail network.
- Route studies can include BER and data rate throughput predictions
- Route studies can be displayed on a GIS map and graphically.
- All route study results can be exported to Excel or to MapInfo.
- Automatic frequency planning using route-based methods efficiently assigns channels while ensuring that the rail tracks of interest meet the interference protection requirements.
- Fixed point to multipoint links between wayside radios and base stations can be quickly and efficiently planned and analyzed using multipoint studies.
- Clutter carving can be used to improve the quality and accuracy of studies in areas where low-resolution clutter (land use) data is used, which saves money while preserving accuracy.



Summary of EDX Software PTC features

Below is a features matrix showing the various versions of EDX software and their PTC network planning capabilities:

EDX Software → and features ↓	SIGNAL	SignalPro	SignalPro with the Network Design Module	SignalRT
Route Studies	X	X	X	X
Link Studies	X	X	X	X
Multipoint Studies		X	X	
Clutter Carving		X	X	X
PTC data rate studies			X	X
Route-based Auto. Frequency Planning			X	X
Area-based Auto. Frequency Planning			X	

About the Authors

Kurt Drummond is a Principal Engineer at RF Networks Inc., a small California based Consulting firm, specializing in the design of packet-digital radio and communication networks. Kurt is a Professional Engineer, licensed in the state of California, and earned a MSc. degree in Electrical Engineering, specializing in Communication Systems from the University of Southern California.

Kurt Drummond PE has been responsible for the design and integration of some of the most complex radio systems nationwide. Prior Clients include: PANYNJ, MHD, LVMPD, Wynn LV, PCJPB, SCRRA, LACMTA, NCTD and ACTA, creating Public Safety systems & networks across the USA

Steve Webster joined EDX in 2009 as the Director of Product Management. In this role, Mr. Webster works with EDX's customers to develop specifications for future releases of EDX's products. Mr. Webster has worked for 20 years in RF Engineering and Management roles in a variety of Wireless Industry organizations, including wireless carriers, consulting firms, site development firms, equipment vendors, and infrastructure (tower and DAS) providers in the US, Europe and Asia. Prior to working in the wireless industry, Steve worked in the 1980's for a university R&D lab developing complex radio network simulations for defense customers as well as for a large defense contractor to develop advanced communications electronic warfare systems.

Mr. Webster holds a BSEE from Clarkson University and an MSEE from Johns Hopkins University.