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Radio Path Prediction Software for Command and Control Scenario Developers: Reference# C-168

Topics: C2 Analysis, C2 Modeling and Simulation, Network Centric Metrics

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Radio Path Prediction Software

for Command and Control Scenario Developers
Reference# C-168

Author: Michael Shattuck
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Topics: C2 Analysis, C2 Modeling and Simulation, Network Centric Metrics

ABSTRACT

In recent years, there has been great interest in incorporating the modeling of communication systems into combat simulations. However, development of supporting software tools for command and control (C2) scenario developers has not kept pace with the progress in combat simulation software. Scenario developers cannot easily experiment with alternate locations for base station repeaters/switches nor can they easily predict in advance where mobile platforms will experience communication failure. This information is crucial for scenario developers to plan and design scenarios to test proposed networked combat systems.

A proof of concept software radio path prediction application has been written in the Java programming language that allows a scenario developer to quickly answer these "what if?" questions. This software allows users to easily predict the significant propagation paths from a base station to a mobile station, as well as which paths will be compromised or ineffective. This presentation discusses the theory and concepts behind the application and the user interface presented to the user.

Link Planning for Wireless Networks

The main challenge of link planning for wireless networks is predicting the significant propagation paths from the base stations (hubs/repeaters) to the mobile radios as well as the losses among these paths. This is because once we know the relative power lost along the propagation paths we can determine whether sufficient power arrives at the receiver to establish a reliable communication link between the transmitter and receiver. The status of a link can be simply labeled as good or insufficient (bad). This is independent of modulation technique, encoding techniques, protocols, etc. It is valid for both analog and digital networks. In the terminology of the International Standards Organization's Open System Interconnect ISO/OSI 7-Layer Network model, we are concerned with the Physical layer. Data link and Network and Transport protocols Internet Protocol, and Transport Control Protocol (IP, TCP) are higher-level layers. Error detection, correction, and automatic retransmission are handled at the higher-level layers.

The goal is to transform link planning for wireless networks from a problem in the physics domain to a graph theory domain problem. Once we have discovered all the potential good links between radios, we can use classical graph theory techniques and algorithms to answer questions relating to network connectivity, optimal routing paths, etc. Some radio pairs will not be able to communicate directly. However, a path using neighboring radios as intermediate repeaters/routers may be possible. In some cases, parts of the network may be isolated from other parts. We would like to identify the distinct components as well as which radios belong to each component. Finally, there is the opportunity to configure the network to optimize some aspect of the network performance. For example, for minimum number of hops or for maximum potential bandwidth, we can utilize link margin values as a proxy for link bandwidth values.

Basic Radio Theory

To understand the requirements for software to assist with wireless network planning and analysis we must first understand some basic radio theory. A brief introduction will be provided to radio signal transmission, propagation, and reception. At the transmitter we need to consider the transmitter power, the power lost before it gets to the antenna, and the gain associated with the directivity of the antenna. As the radio waves travel through the air and encounter obstacles, power is lost by many mechanisms. Finally, at the receiver the directivity of the antenna and power lost in cables is considered before comparing the received signal level with a threshold value determined by aspects of the receiver design and by a safety margin. We will also discuss how under most circumstances the margin of received power above the receiver sensitivity is an adequate prediction of radio link performance.

Power (Decibel Relative Units)

The dB (Decibel), a basic unit of measure for power levels, is a logarithmic scale unit that measures the difference (or ratio) between two signal levels. It is used to describe the effect of system devices on relative signal strength. A change in power level is reflected in a change in the dB metric. (*ARRL UHF/Microwave Experimenter's Manual*, 1990).

Power is expressed in Watts or in Decibel relative units compared to milliWatts (dBm).

$$\mathbf{dBm = 10*log_{10}(Watts/0.001)}$$

Every time the power level in watts is doubled (or halved) , the power level increases/decreases by 3 dB. This corresponds to a 50% gain or reduction. 10 dB gain/loss corresponds to a ten-fold increase/decrease in signal level. A 20 dB gain/loss corresponds to a hundred-fold increase/decrease in signal level. In other words, a signal passing through a device (like a cable) that has 20 dB loss through it will be degraded to 1% of original strength by the time it gets to the other side.

0 dBm is defined as 1 mW (milliWatt) of power into a terminating load such as an antenna or power meter. Even smaller signals are expressed as negative numbers (e.g., -83 dBm) in decibels.

Antenna Gain at Transmitter and Receiver

The more gain an antenna has the more it is directive (energy sent in a preferred direction). The higher the directivity, the more accurately the antenna must be pointed. Antenna gain is normally given in isotropic decibels (dBi). It is the power gain in comparison to an isotropic antenna. An isotropic antenna spreads energy in every direction with the same power, radiating as if from a single point. This is a theoretical abstraction that does not exist in reality. Gain relative to a theoretical isotropic (point source) antenna is useful for calculating theoretical fade and System Operating Margins. However, many omni antennas have gain rated relative to a dipole antenna (dBd). A dipole antenna has 2.14 dB gain over a 0 dBi isotropic antenna. So, if an antenna gain is given in dBd, not dBi, add 2.14 to it to get the dBi rating. (*ARRL UHF/Microwave Experimenter's Manual*, 1990), (*ARRL Handbook for Radio Amateurs*, 2001), (Saunders, 1999).

Effective Isotropic Radiated Power (EIRP)

Effective Isotropic Radiated Power is defined as the effective power found in the main lobe of a transmitter antenna relative to an isotropic radiator that has 0 dB of gain. It is equal to the sum of the antenna gain (in dBi) plus the power (in dBm) into that antenna. (*ARRL UHF/Microwave Experimenter's Manual*, 1990), (Saunders, 1999).

Effective Isotropic Radiated Power (EIRP) can be easily computed (in dBm):

> **EIRP [dBm] = transmitted power[dBm] – cable loss[dB] + antenna gain[dBi].**

Signal loss due to the cable between the transmitter and the antenna is subtracted. For very short cable runs (i.e., hand held transceivers), cable losses may be negligible.

Here are typical loss values for common coaxial cables at 2.1 gigahertz (GHz):

RG 58: 1 dB per meter.
RG 213: 0.6 dB per meter
LMR-400: 0.22 dB per meter

Propagation Losses

Power carried by a radio wave is diminished as it travels through space, and as it encounters obstacles between the transmitter and receiver antennas. There are many mechanisms how power is lost. We will only consider some of them here.

Limitations

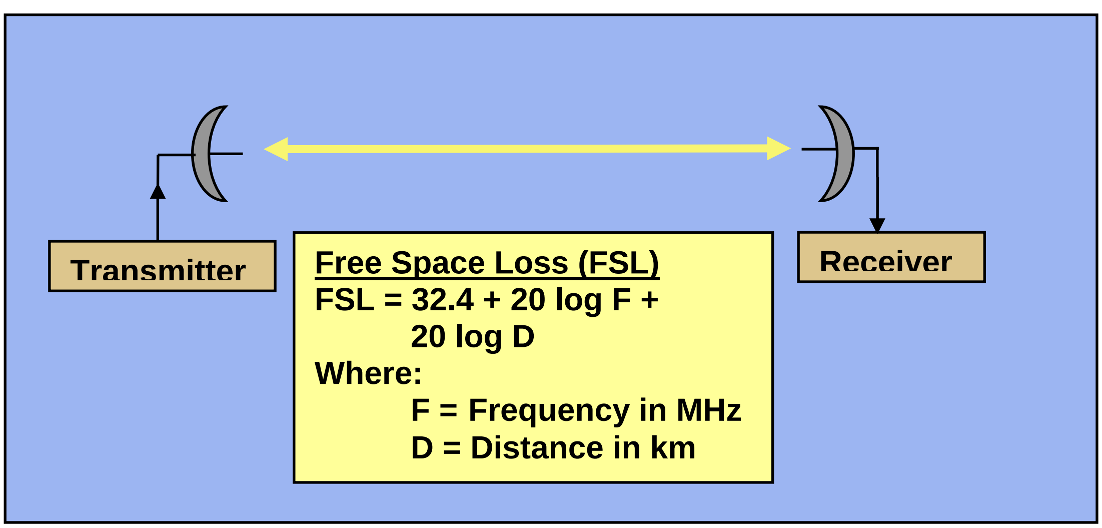
This paper limits the scope of discussion to radio systems and very high frequency (VHF), ultra high frequency (UHF), and near microwave frequencies for ground and air radios. At high frequency (HF) frequencies beyond line of sight propagation by refraction of radio waves off the ionosphere is the dominant propagation mechanism and source of loss. At higher microwave frequencies losses and reflections from moisture in the air is significant. Radio propagation at both of these ends of the radio spectrum and satellite communications are beyond the scope of this paper. Radio propagation modeling for satellite communications is complicated by the fact that radio waves must penetrate the ionosphere. Therefore, they will not be discussed further in this paper.

Free Space Loss (FSL)

The power loss of a wave traveling in free space (without obstacles) is governed by inverse square law; inversely proportional to the square of the distance. FSL = 32.4 + 20 log F + 20 log D (F = frequency in megahertz (MHz), D = Distance in kilometers). (Hall, 1996), (McLarnon).

Rule of Thumb: Double/halve the distance -> Add/subtract 6 dB.

Figure 1 Free Space Loss (FSL)



Diffraction
When an obstacle is located between the transmitter and the receiver some energy still passes through thanks to the diffraction phenomenon on the top edge of the obstacle. The higher the frequency the higher the loss will be. This is a significant factor in urban environments. (Hall, 1996), (McLarnon).

Polarization
Wave polarization is determined by the type and orientation of the transmitter antenna. A whip antenna has a vertical polarization. Antennas at the transmitter and receiver should have the same polarization for best performance. (*ARRL Handbook for Radio Amateurs*, 2001), (McLarnon).

Reflections and Delay Spread
Radio waves reflect from the obstacles they meet. At the receiver we can catch the direct wave (if LOS) and the reflected waves at the same time. This leads to power canceling at certain frequencies and a time difference between the received components. (Hall, 1996), (McLarnon).

Fresnel Zone

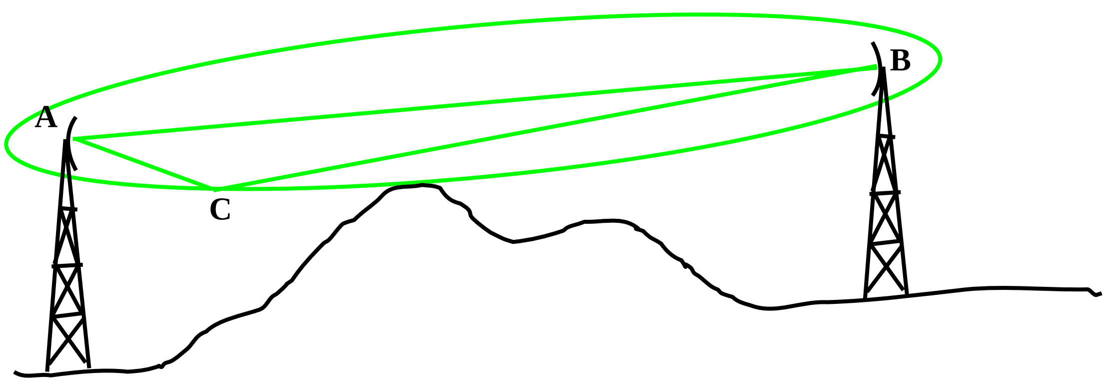


Figure 2 Fresnel Zone

Free space loss is an ideal. Obstacles must not protrude within the three dimensional ellipsoid Fresnel zone to avoid significant propagation losses due to diffraction and reflection. A radio path has first Fresnel zone clearance if no objects that are capable of causing significant diffraction penetrate the corresponding 3-dimensional ellipsoid. McLarnon, provides an easily understood explanation of the Fresnel Zone. (McLarnon). Figure 2 illustrates the concept of the first Fresnel Zone. The path ACB defines the surface of the ellipsoid; and exceeds the length of the direct path AB by some fixed amount. This amount is $(n\lambda)/2$, where n is a positive integer and λ is the wavelength of the radio wave. For the first Fresnel zone $n = 1$. Therefore, the path length differs by $\lambda/2$; (that is, a 180 phase reversal with respect to the direct path.).

For first Fresnel zone clearance the distance h from the nearest point of the obstacle to the direct path must be at least:

$$\mathbf{h} = 2\sqrt{[(\lambda d_1 d_2)/(d_1 + d_2)]}$$
$$= 17.3\sqrt{[(d_1 d_2)/(f(d_1 + d_2))]} \qquad (\lambda \sim= 300/f)$$

where f is the frequency in MHz, d_1 and d_2 are in km and h is in meters.
Ground reflection at extended ranges produces a phase change approaching a complete phase reversal. In this region, the received power follows an inverse fourth-power law as a function of distance instead of the usual square law (i.e., 12 dB more attenuation when distance is doubled, instead of 6 dB). The distance at which path loss starts to increase at the fourth-power rate is reached when the ellipsoid corresponding to the first Fresnel zone just touches the ground.

A good estimate of this distance d can be calculated from the equation:

$\mathbf{d = 4(h_1 h_2)/\lambda}$; where h_1 and h_2 are the antenna heights above the ground reflection point and λ is the wavelength. The distance d, the antenna heights, and the wavelength λ are assumed to have the same unit of length. Generally we use distances in meters.

Receiver Sensitivity

Receiver sensitivity is the weakest RF signal level (usually measured in negative dBm) that a radio needs to receive in order to demodulate and decode a packet of data without errors. For analog systems, quality will be compromised if a minimum received power threshold is not achieved.

For digital radios, a receiver has a minimum received power threshold that the signal must have to achieve a certain bit rate. If the signal power is lower, the maximum achievable bit rate for a digital system will be decreased or at some point errors may not be corrected.

Example for a specific wireless network computer card operating at the follow bit rates measured in megabits per second (Mbps) the following relationship holds.

11 Mbps => -82 dBm
5.5 Mbps => -87 dBm
2 Mbps => -91 dBm
1 Mbps => -94 dBm

Signal to Noise (S/N) Ratio

The signal-to-noise ratio at the receiver makes a link reliable. It is the minimum power difference to achieve between the wanted received signal and the noise (thermal noise, industrial noise, interference noise, etc.). If the signal is more powerful than the noise, the signal-to-noise ratio will be positive. If the signal is buried in the noise, the ratio will be negative**.** Signal to Noise Ratio is defined as:

Signal/Noise Ratio [dB] =
10 * $\log_{10}$(Signal power[W]/ Noise power[W])

Signal and noise power are in units of watts [W]. For a data transmission system, the objective is usually specified by a minimum bit error rate (BER). Bit error rate is a function of the signal-to-noise ratio at the receiver demodulator. (Lee, J.S., 1998).

If the noise level is low, then the system will be limited more by the receiver sensitivity than by the signal to noise ratio. In this case, the minimum receiver sensitivity is the limiting factor for the system.

For example, suppose:

noise level = -100 dBm,
required S/N ratio = 16 dB
receiver sensitivity = -82 dBm
-82 > (-100 + 16) = -84.

Link Budget Calculation

The fundamental aim of a radio link is to deliver sufficient signal strength to the receiver to achieve some performance objective. We have seen that under most circumstances the receiver sensitivity and received power serve as the limiting factor, rather than signal to noise ratio. The margin of received power at the receiver demodulator above the receiver sensitivity value is called the Link Margin. The computation of the received signal power and the Link Margin is known as a Link Budget calculation.

Link Budget is the computation of the whole transmission chain. Generally, it is necessary to achieve a sufficient security margin to assure performance under conditions with poor signal to noise ratio. This safety margin, also known as Fade Margin, or System Operating Margin, is critical to dependable link performance. By doing a link budget calculation, an analyst can test various system designs and scenarios to see how much fade margin (or “safety cushion”) a link can theoretically have. (Bernhardt, 1989), (Lee, W.C.Y., 1987), (Rappaport, 1999), (Stuber, 1996).

EIRP (Effective Isotropic Radiated Power) [dBm] =
Transmitter Power[dBm] – cable loss[dB] + antenna gain[dBi]

Received Signal [dBm] =
EIRP[dBm] – Propagation Loss[dB] + antenna gain[dBi] –
cable loss [dB]

Link Margin (a.k.a. Fade Margin or SOM (System Operating Margin)) [dBm] =
Received Signal[dBm] – Receiver Sensitivity[dBm]

Generally, it is necessary to achieve a sufficient security margin to assure performance under a condition with poor signal to noise ratio. Most engineers agree that 20 dB or more is sufficient. Lower values may be adequate under good conditions (>10 dB).

Propagation Models for Non-LOS Prediction

As we have seen, even LOS paths are complicated by mechanisms, such as diffraction, reflection, phase changes, and polarization changes, which often cause them to differ from the "free space" assumption. When we have a path that is not LOS, it becomes even more difficult to predict how well a signal will propagate. Unfortunately, non-LOS situations are sometimes unavoidable, especially in urban areas.

Because of these limitations, more general techniques for prediction of non-LOS paths are necessary. These include empirical and semi-empirical models, abstract structure based models, and deterministic models. Many of these techniques are named for the developers. Some models are modifications or derivations of earlier work. Others are named for the sponsoring organization. In particular, several radio propagation models were sponsored by the Cooperation in Scientific and Technical Research organization in Europe (COST). Several propagation models were also developed by the Radio-telephone with Automatic Channel Evaluation (RACE) project. The Institut für Höchstfrequenztechnik und Elektronik (IHE) developed many of the deterministic models.

Empirical models (Okumura, Hata, COST-231-Hata, RACE Dual-Slope models)
The model parameters are estimated by means of regression methods applied to extensive measured data. Empirical models are typically easy to calculate, minimizing computational load. (Hata, 1980), (Hall, 1996), (Iskander, 2002), (Project 231), (Sarkur, 2003), (--, "Radio Propagation Models").

Abstract-structure-based models (Walfisch & Bertoni, Ikegami models)
The propagation loss is analytically derived assuming a simple abstract terrain structure that allows analytic treatment. They depend on a characterization of buildings and topographic parameters. Abstract structure based models have an intermediate level of computational complexity. (Bertoni, 1994), (Bertoni, 1995), (Iskander, 2002), (Lee, J.S., 1998), (Sarkur, 2003).

Semi-empirical models (COST-231-Walfisch-Ikegami models)
The parameters of the abstract-structured model are empirically corrected to fit measured data. They typically require only slightly more computational resources than an empirical model. (Project 231), (Hall, 1996), (Iskander, 2002), (Sarkur, 2003).

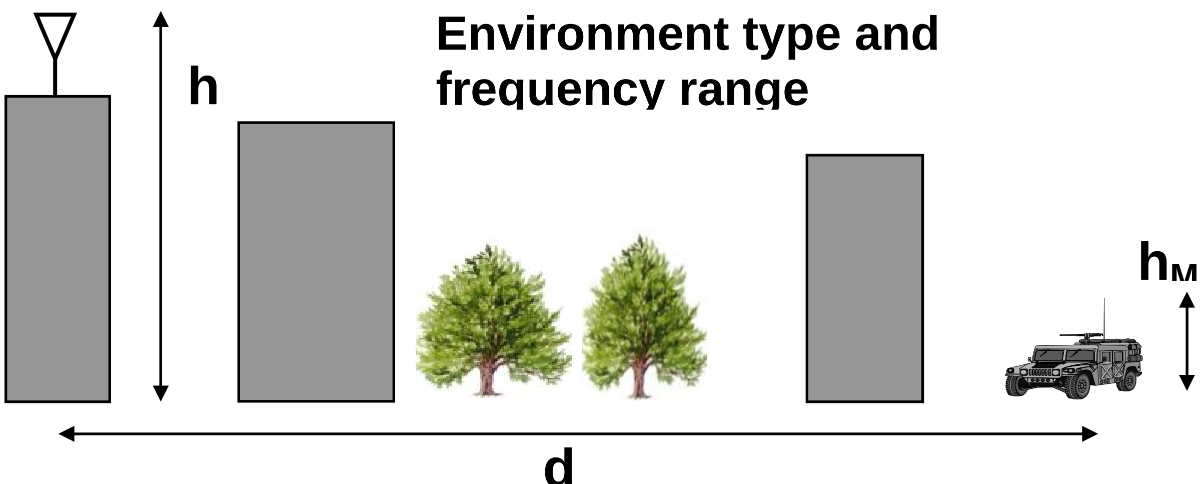
Deterministic models (IHE models)
The field is computed by using an approximation of a field integral or by ray-tracing techniques. Extensive geographic information about the terrain is exploited. They tend

to require significant computational resources. (Hall, 1996), (Iskander, 2002), (Sarkur, 2003).

Time and paper length restrictions prohibit extensive coverage of all the propagation prediction models introduced. However, it is important to realize that all the models have limitations and need to be applied for the right circumstances.

Inputs to non-LOS (NLOS) Propagation Prediction Methods.

We have seen previously that distance and frequency range are directly related to propagation losses. We have also seen that obstructions within the Fresnel zone lead to significant propagation losses due to diffraction and reflection effects. Consequently, the heights of the antennas compared to the expected height of intervening buildings and other obstacles are significant factors in path prediction methodologies. Figure 3 illustrates the most significant input factors. The principal input parameters supplied to the propagation models are center frequency; the characterization of the area type (urban, suburban, rural, etc.); the distance between the base station and the mobile station in kilometers, and the respective antenna heights.



h : height of the base station antenna (usually expressed in meters).
d : distance between base station and mobile station radios (usually in Km).
$\mathbf{h_m}$: height of mobile station antenna (usually expressed in meters).

Figure 3 Inputs to Path Loss Estimation Algorithms

Cell Classification (Terrestrial systems)

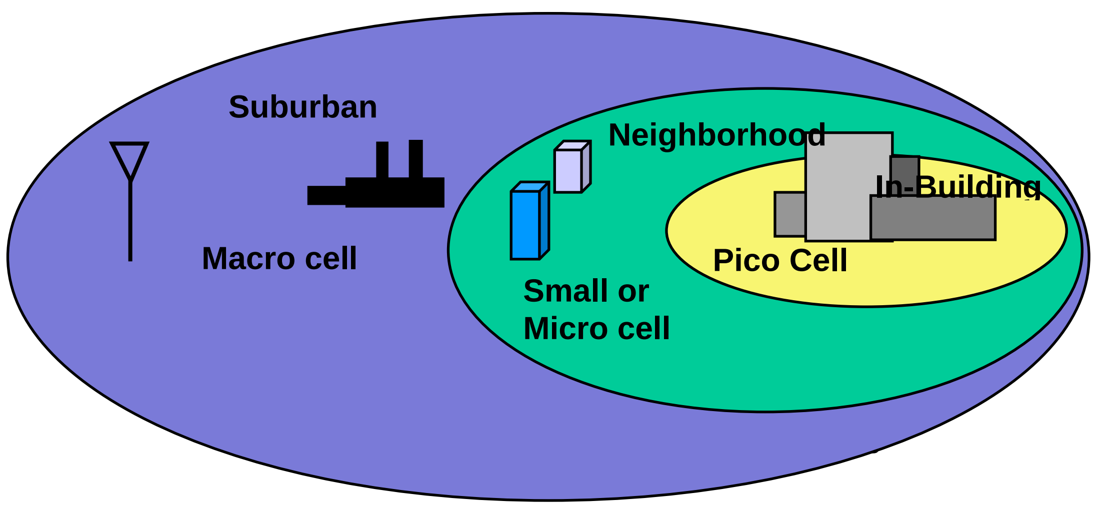
Propagation models can be classified by the size of the region of coverage or cell. For example, extent of coverage provided a cell corresponds to a suburb, a neighborhood, an inner city center, or an area indoors and indoors and in close proximity to single buildings. In Figure 4 we can graphically visualize the overlapping coverage areas provided by the different cell types.

At the level of individual buildings, we define a picocell as a region within or in immediate proximity to a building. The range of communications within a picocell is limited to 10 – 100 meters. Base station antenna heights within picocells are usually considered lower than roof top level or within a building. In the commercial domain, this usually corresponds to wireless hotspots within buildings.

At a somewhat larger scale, micro-cells enclose a region with a radius between 0.1 kilometers and 1 kilometer. The base station antennas are usually located below or at the roof top level of surrounding buildings.

Small cells extend the radius of the enclosed region to between 1 and 3 kilometers. The antenna heights are considered at above the roof top level of surrounding buildings. Together micro-cells and small cells can be considered to provide coverage for a neighborhood.

Macro-cells are typically defined as having a maximum cell radius of between 3 and 35 kilometers. This often corresponds to a region containing a city and its surrounding suburb(s). For macro-cells, the base station antenna height is usually considered to be above the roof top level of surrounding buildings.



Propagation Models Classified by Cell Type and Suitability

Propagation models are usually suitable for only a limited range of cell types and radio frequencies. When selecting a suitable propagation methodology it is important to select one that is suitable for both the radio frequency and the range of coverage and terrain type anticipated.

In the Table 1 below, several methodologies are classified by cell coverage type.

Macro Cell	**Small or Micro Cell**	**Indoor or Pico Cell**
	COST-231-Hata model	One-slope model
Okumura's model	Walfisch-Bertoni's model	Linear model
Hata's model	COST-231-Walfisch-Ikegami	COST-231 multi-wall/floor model
COST-231-Hata model	RACE Dual-Slope model	
IHE deterministic models	IHE deterministic models	

Table 1 Radio Path Loss Prediction Models vs. Cell Classes

There are numerous choices of propagation models appropriate for each cell type. Every choice is a compromise. The old adage **"Cheap, Fast, Good, … Choose Two"** appears to apply here. The Free Space propagation model is easy to implement, runs quickly since it requires little computation resources, and is simply not good for applications in built-up urban and suburban areas because of diffraction and reflection losses. (Cheap, Fast, Not Good).

By contrast, deterministic, physics-based models can be very good, and may even be fast enough for most non-real time applications. However, they are not cheap. The complexity of the algorithms and data structures required to implement them correspond to longer software development time and execution runtime. In addition, the requirement to provide detailed terrain data may be cost or time prohibitive for fast turn around projects. (Expensive, Fast Enough, Good).

In general, empirical and semi-empirical models have the advantage of requiring less computational resources to run, are less complex to implement, and require less detail about the terrain than deterministic, physics based models, while offering higher fidelity than the Free Space model. (Fast, Fairly Cheap, Good Enough).

We will not go into a lot of detail about all the propagation methods shown. References are available that describe each of the models in detail for those who are interested. Instead, more details will be provided for three of the propagation models that were implemented in the proof-of-principle radio path prediction software.

Propagation Prediction Models Chosen for Proof of Concept Software

For the proof of concept radio path prediction software a choice was made to initially implement empirical and semi-empirical models that could be applied to macro and micro cells terrain. In general, empirical and semi-empirical models have the advantage of requiring less computational resources to run, are less complex to implement, and require less detail about the terrain than deterministic, physics based models, while offering higher fidelity than the Free Space model. (Fast, Cheap Enough, Good Enough)

The Free Space model was chosen as a benchmark for more complex methodologies, and it is still suitable for line of sight application in open terrain. Two empirical models Hata and COST-231-Hata (Project 231) were chosen for the initial implementation. Together they cover macro-cell areas for frequencies between 100 MHz – 2000 MHz. None of the methodologies discussed in this paper is appropriate for modeling propagation at high frequency HF radio or higher band microwave frequencies.

There are future plans to implement the semi-empirical COST-231-Walfisch-Ikegami model (Project 231); principally because it can be applied to both macro cell and micro cell applications. No model for indoor or picocell applications was considered at this time. However, the software architecture of the radio path prediction software makes adding new propagation models quite easy. Adding a new deterministic, physics based model, or a picocell propagation model should be relatively easy once the actual propagation code is written.

Hata Model

The Hata model provides an easily computable empirical methodology suitable for modeling radio frequency propagation over a macro cell-sized region with a range between 1 and 20 kilometers, where the terrain is built up on a quasi-smooth area. The methodology is limited to VHF, UHF, and low frequency microwave radio band frequencies (100 – 1500 MHz). The main advantage of the Hata algorithm (and most other empirical methods) is reduced computation cost and no need for detailed terrain representation (Hata, 1980), (Lee, J.S., 1998).

Path loss prediction formula:

$$\mathbf{L = 69.55 + 26.16\log(f\,[MHz]) - 13.82\log(H_B[m]) - H_M + [44.9 - 6.55\log(h_B[m])](\log(d[km])) - K_U \quad [dB]}$$

where for

Small or medium city:

$$\mathbf{H_M(h_M, f) = [1.1\log(f[MHz]) - 0.7]h_M[m] - [1.56\log(f[MHz]) - 0.8] \quad [dB]}$$

Large city:

$$\mathbf{H_M(h_M, f) = \begin{cases} 82.9[\log(1.54h_M[m])]^2 - 1.1 ; & f <= 200\ MHz\ [dB] \\ 3.2[\log(11.75h_M[m])]^2 - 4.97; & f >= 400\ MHz\ [dB] \end{cases}}$$

$\mathbf{K_U(f)}$ is the urbanization correction factor with respect to urban area:

Suburban area: $\mathbf{K_U(f) = 2[\log(f[MHz]/28]^2 + 5.4 \quad [dB]}$

Open area: $\mathbf{K_U(f) = 4.78[\log(f[MHz])]^2 - 18.33\log(f[MHz]) + 40.94 \quad [dB]}$

d is the distance in kilometers (1 – 20 km).

f is the frequency in MHz (100 – 1500 MHz).

$\mathbf{h_B}$ is the base station antenna height (30 – 200 m).

$\mathbf{h_M}$ is the base station antenna height (1 – 10 m).

$\mathbf{H_M}$ is the correction factor for the mobile antenna height.

COST-231-Hata Model

The COST-231-Hata model develop by the Project 231 Cooperation in the Field of Scientific and Technical Research (COST) program provides an adjustment of Hata's formulas for the frequency band 1500-2000 MHz. Like the Hata model, the COST-231 model provides an easily computable empirical methodology suitable for modeling radio frequency propagation over a macro cell-sized region with a range between 1 and 20 kilometers, where the terrain is built up on a quasi-smooth area. The methodology is limited to UHF and low frequency microwave radio band frequencies (1500 - 2000 MHz). It advantage is that it extends the frequency range of the pure empirical methodologies into the near microwave range commonly used for cell phones and data communications. (Project 231), (Lee, J.S., 1998)

Path loss prediction formula:

$$\mathbf{L = 43.6 + 33.9\log(f\,[MHz]) - 13.82\log(h_B[m]) - H_M + [44.9 - 6.55\log(h_B[m])](\log(d[km])) + C_m \quad [dB]}$$

With $\mathbf{d}$, $\mathbf{h_B}$, and $\mathbf{H_M}$ as previously defined and

f is the frequency in MHz (1500 – 2000 MHz)

Medium sized city and suburban area with moderate tree density:
$\mathbf{C_m = 0}$

Metropolitan area:
$\mathbf{C_m = 3}$

COST-Walfisch-Ikegami Model

The COST-231-Walfisch-Ikegami model is yet another adaptation of an existing model by the COST 231 Project. has not yet been implemented in the software. It uses a somewhat more sophisticated semi-empirical approach than the pure empirical methods seen in the Hata and COST-231-Hata models. The main advantage of the COST-Walfisch-Ikegami model is suitability for smaller cell coverage areas (0.02 – 5 kilometers). It does require slightly more topographic city information than the empirical approaches in order characterize typical building heights, widths, and spacing between buildings. However, a detailed representation of terrain and building is still not required.

The COST-Walfish-Ikegami model modifies the Walfisch-Bertoni's multi-screen abstract structure based model that represents rooftop diffraction and rooftop-to-street diffraction and reflection losses in a non-LOS (NLOS) environment, and uses a separate formula for total loss in a situation with LOS. It provides empirical modifications to the NLOS case based on parameters for urbanization, average building heights, average building separation, the difference between building height and base station antenna height, and the height of the mobile antennas. The actual formulas for computing NLOS multi-screen excess loss and LOS total loss are relatively simple. However, the number of empirical modification factors precludes including the entire model in this paper. For those interested, detailed explanation is available in the reference materials. (COST-231).

Network Link Planning Software Concepts

Modeling Concepts

A proof of concept software radio path prediction application has been created that allows a scenario developer to quickly answer the "what if?" questions we introduced earlier. This software allows users to easily predict the significant propagation paths from a base station to a mobile station, as well as which paths will be compromised or ineffective. Commercial software to perform this sort of analysis is currently used by commercial cell phone providers. However, these traditional software applications emphasize static base station/repeater locations and power settings. Representation of a digital network composed of multiple mobile radios, that is dynamically changing is not typical. However, that is what is precisely what is needed for representing digital radio networks for combat scenarios. The key concept underlying the software is to allow multiple heterogeneous views of data represented by a common representation of radios parameters and propagation methodology.

The Radios model contains all required radio parameters including radio identification (ID), role of the radio (Base, Mobile, Both, None), radio position, transmitter power, antenna height, center frequency, antenna gain, and receiver sensitivity may be set. (See appendix A2). The Propagation model allows selection of an appropriate propagation methodology and appropriate terrain characterization. (See appendix A1).

Multiple views of the predicted propagation loss and link budget calculations for each potential link are displayed in both multiple tabular views and graphical a graphical view. As the models change, the views are notified of the changes and recalculated and redrawn as necessary. The views that are currently supported display propagation losses, link budget margins, link status, and a graphical, map like, plan view of all the links that are good (See appendices A3, A4, A6). The link status view provides the transformation of the wireless network planning from a problem in the physics domain, into a graph theory problem that was alluded to earlier. (See appendix A5)

Propagation Model & Radios Model

The radio propagation model and the radios model represent the input variables to the radio path prediction software.

The user is offered a selection of propagation model methodologies. The current software provides options for the Free Space model, Hata's model and the COST-231-Hata model. Since all the currently implemented propagation models do not use an actual terrain representation, the user is only presented with options to characterize the urbanization and terrain type appropriate to the propagation model chosen. (See appendix A1).

The radios model contains parameters for every radio node to be simulated. The current model contains all the parameters necessary to perform propagation predictions, and link budget calculations. The radio parameters may be initialized using a file as input. The model representation is flexible in that new parameter fields may be added easily. For example, it would be a trivial change to the software to add a field for the radio type. (See appendix A2).

Proposed Future Enhancements to Radio Path Propagation Prediction Software

There are a number of enhancements to the Radio Path Prediction Software that have been proposed for incorporation in the future. Some of these changes simply expand the feature set of the current software. For example, printing of the output of tables as text-delimited files is a practical necessity that has not yet been implemented. Display of the graphical network display with a map image background will help the user visualize placement of the radios with respect to terrain features. Adding the COST-231-Walfisch-Ikegami model with expand the utility of the application beyond macro-cell regions to allow application of the software to micro-cell regions.

Some of the other proposed enhancements extend the scope of the application in a broader way so that all of the network planning questions posed in the introduction can be answered directly. For example, although the Link Margin Table and Link Status Table contain all the information necessary to answer the questions about network coverage and isolated subnets, it is not conveyed as concisely as is possible. If the network graph is not connected, then the network graph can be partitioned graphically into multiple sub-networks. Several suggestions have been put forward as means to alert a user when one or more radios will be isolated from the rest of the network. First, notify the user through a status bar alert. Second, color each isolated network subcomponent a unique color. Third, enumerate the IDs of all the radios in each isolated component.

Finally, the Link Margin Table contains the information necessary to optimize the network configuration. It is possible to generate the network configuration (routing table) that achieves that optimizes link margin (as proxy for bit-rate) for the network as a whole. The minimum spanning tree can be calculated and displayed in tabular and graphical forms in the same fashion as the Link Margin Table and Graphic Display of Links respectively. Output Minimum Spanning Tree (i.e., Routing Table) can then also be saved in the same text delimited format as the link status margin table.

Summary

The radio link prediction software presented in this paper assists combat scenario developers and analysts with the task of planning and design of scenarios to test proposed networked combat systems. The software provides analysts with a tool to predict the significant propagation paths from base stations to mobile stations, as well as the losses among these paths. Using the software a scenario developer or analyst can easily experiment with alternate locations for base station repeaters/switches and to predict in advance where mobile platforms will experience communication failure. And since the software is independent of any particular simulation application, and does not require detailed representation of terrain data in promised to provide quick answers to these sort of “what if” questions.

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Notes:

Cable attenuation data based on values from the “Communications Coax Selection Guide”, from Times Microwave Systems (http://www.timesmicrowave.com/products/commercial/selectguide/atten/) and other sources.

The LMR series is manufactured by Times Microwave. RG series cables are manufactured by Belden and others.

Appendix: User Interface for Radio Path Prediction Software

1. Radio Propagation Editor

2. Radio Parameters Table

3. Propagation Path Loss View

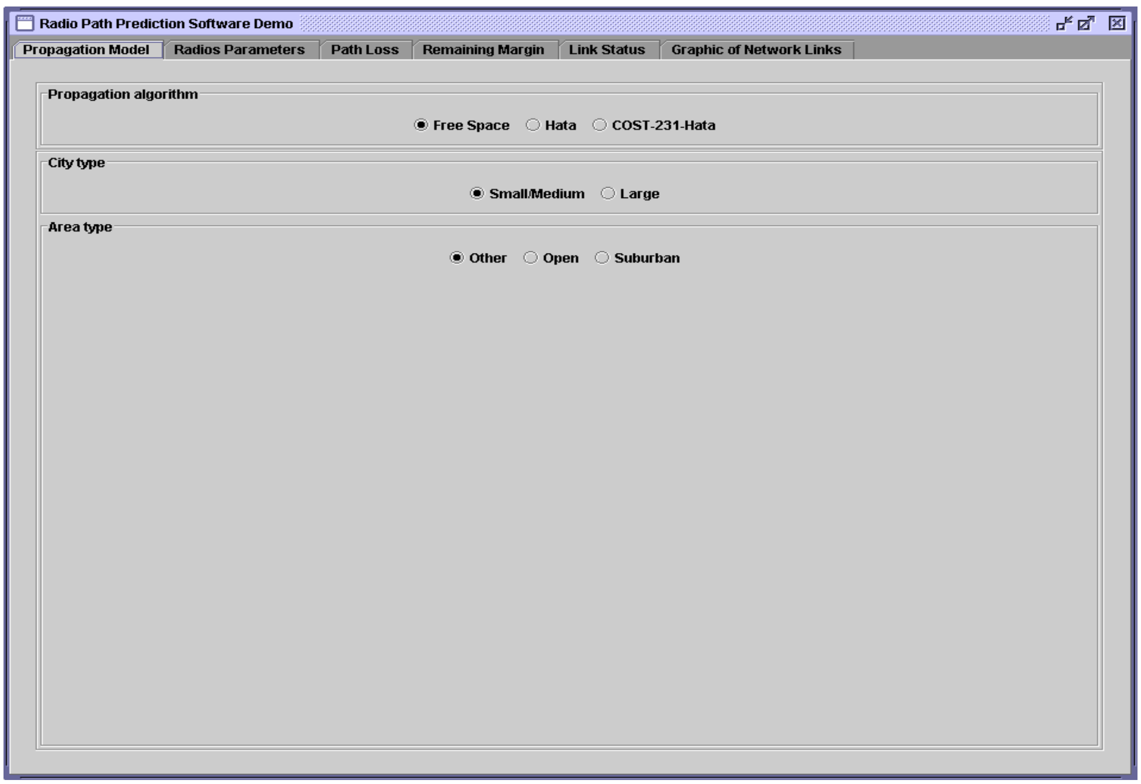
4. Link Margins View

5. Link Status View

6. Graphical Display of Network Links

Appendix 1: Propagation Editor

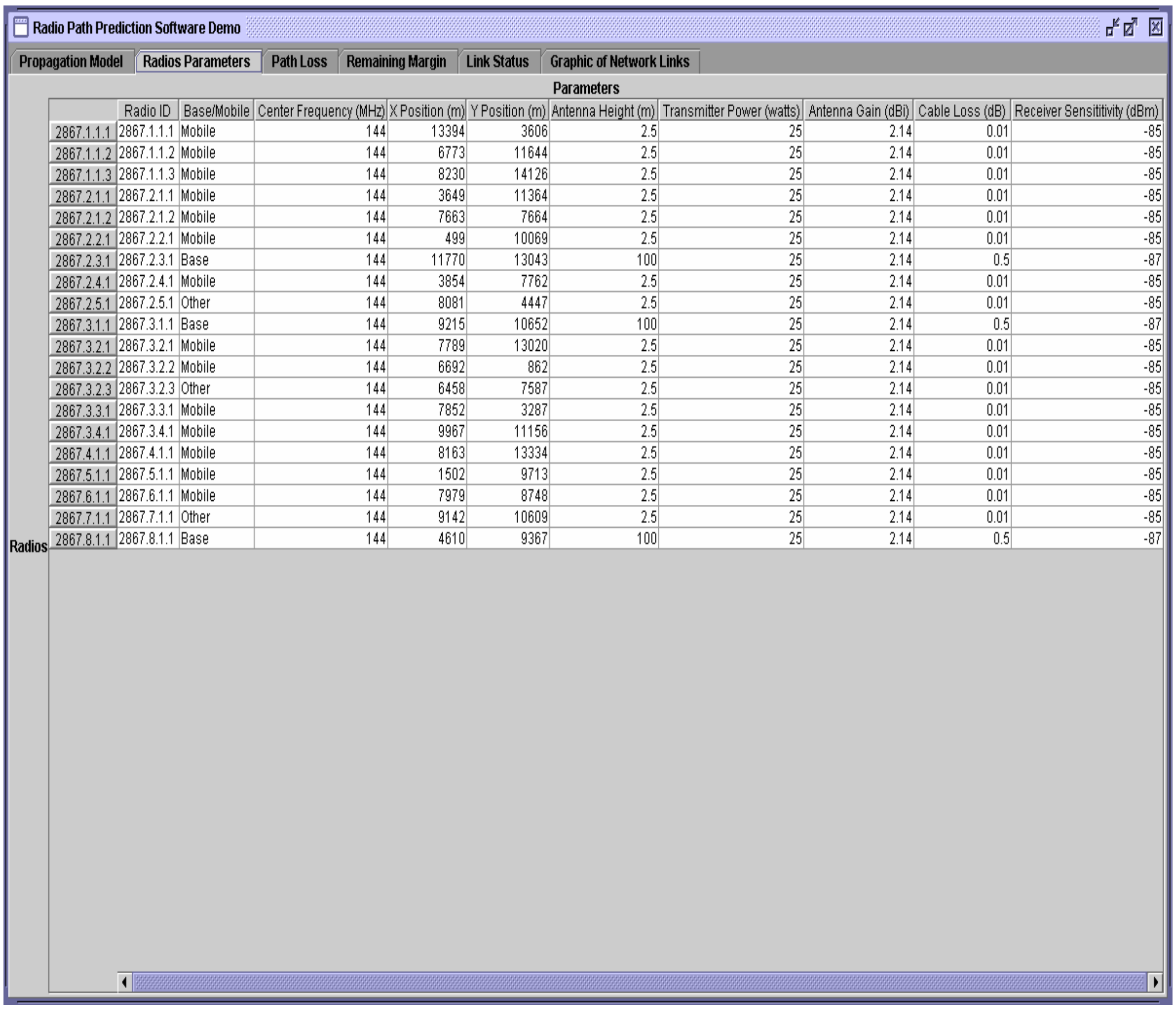
The user is given the option of selecting the propagation methodology to apply. The software implementation provides options for three propagation methodologies that can be applied. The Free Space methodology serves as a benchmark for the more complex methodologies. It also remains a practical approach for unrestricted, flat, open, terrain areas. The Hata methodology is the empirical methodology that is most appropriate for radio frequencies between 100-1500 MHz. The COST-231-Hata methodology adjusts the Hata formula for frequencies beyond 1500 MHz up to 2000 MHz. Other propagation algorithms are being considered for implementation. The COST-Walfisch-Ikegami methodology appears to be the next candidate since it allows representation of micro-cell regions in addition to macro-cell regions.



Appendix 2: Radio Parameters Table

In the Radio Parameters Table displays, radio parameters including radio ID, role of the radio (Base, Mobile, Both, None), radio position, transmitter power, antenna height, center frequency, antenna gain, and receiver sensitivity are displayed. The parameter values may be initialized by importing a delimited text file. They may also be changed by the user at any time. Changes to any of the parameters automatically cause recalculation of dependent propagation losses, link margin and status, and graphical link displays.

A proposed improvement to the software is to allow the imported file to include time tags for each record. This would allow the program to operate as a discrete event simulation, simulating changes to radio links as radios move about the terrain or change other associated parameters (power, for example).

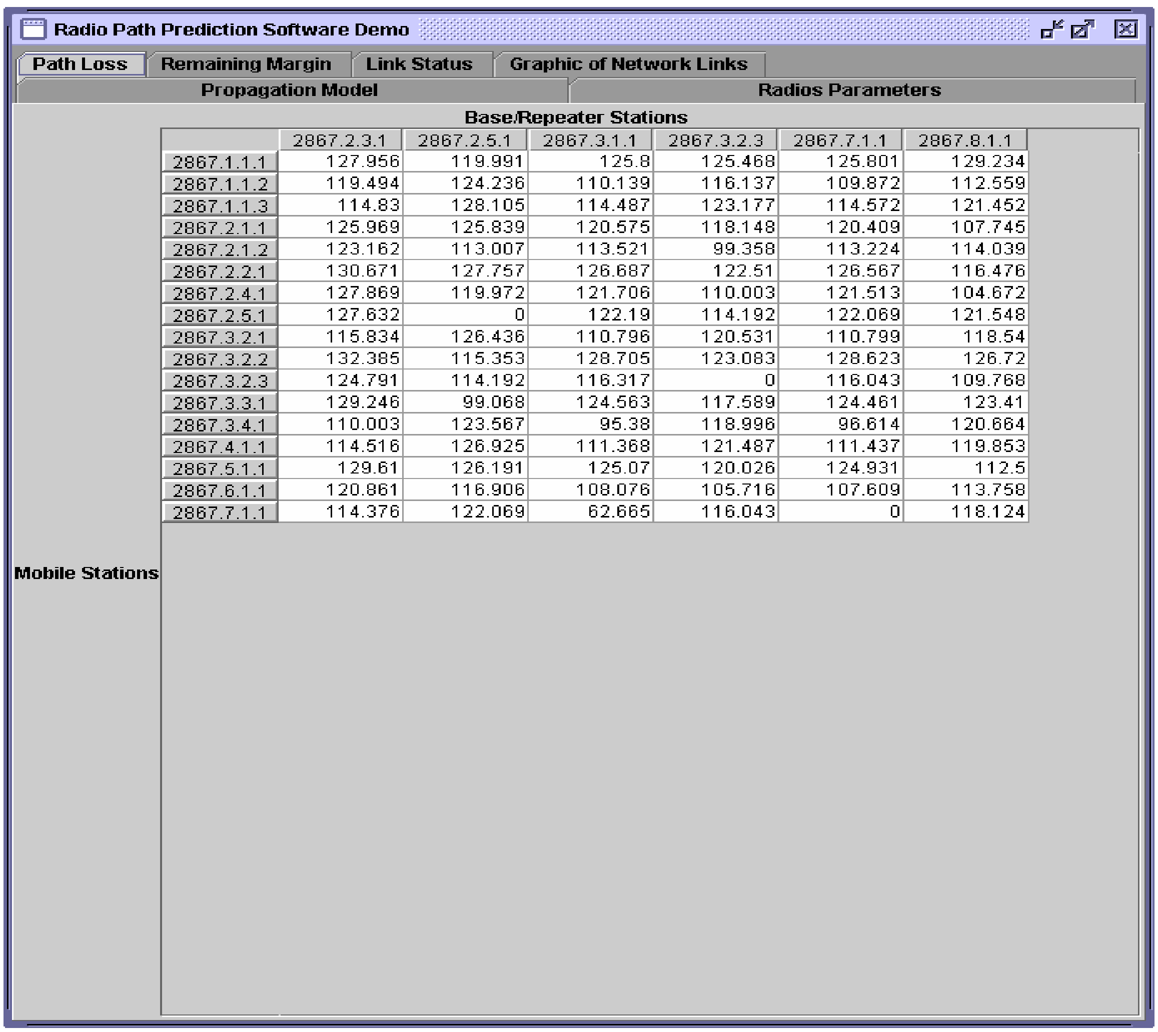


	Radio ID	Base/Mobile	Center Frequency (MHz)	X Position (m)	Y Position (m)	Antenna Height (m)	Transmitter Power (watts)	Antenna Gain (dBi)	Cable Loss (dB)	Receiver Sensititivity (dBm)
2867.1.1.1	2867.1.1.1	Mobile	144	13394	3606	2.5	25	2.14	0.01	-85
2867.1.1.2	2867.1.1.2	Mobile	144	6773	11644	2.5	25	2.14	0.01	-85
2867.1.1.3	2867.1.1.3	Mobile	144	8230	14126	2.5	25	2.14	0.01	-85
2867.2.1.1	2867.2.1.1	Mobile	144	3649	11364	2.5	25	2.14	0.01	-85
2867.2.1.2	2867.2.1.2	Mobile	144	7663	7664	2.5	25	2.14	0.01	-85
2867.2.2.1	2867.2.2.1	Mobile	144	499	10069	2.5	25	2.14	0.01	-85
2867.2.3.1	2867.2.3.1	Base	144	11770	13043	100	25	2.14	0.5	-87
2867.2.4.1	2867.2.4.1	Mobile	144	3854	7762	2.5	25	2.14	0.01	-85
2867.2.5.1	2867.2.5.1	Other	144	8081	4447	2.5	25	2.14	0.01	-85
2867.3.1.1	2867.3.1.1	Base	144	9215	10652	100	25	2.14	0.5	-87
2867.3.2.1	2867.3.2.1	Mobile	144	7789	13020	2.5	25	2.14	0.01	-85
2867.3.2.2	2867.3.2.2	Mobile	144	6692	862	2.5	25	2.14	0.01	-85
2867.3.2.3	2867.3.2.3	Other	144	6458	7587	2.5	25	2.14	0.01	-85
2867.3.3.1	2867.3.3.1	Mobile	144	7852	3287	2.5	25	2.14	0.01	-85
2867.3.4.1	2867.3.4.1	Mobile	144	9967	11156	2.5	25	2.14	0.01	-85
2867.4.1.1	2867.4.1.1	Mobile	144	8163	13334	2.5	25	2.14	0.01	-85
2867.5.1.1	2867.5.1.1	Mobile	144	1502	9713	2.5	25	2.14	0.01	-85
2867.6.1.1	2867.6.1.1	Mobile	144	7979	8748	2.5	25	2.14	0.01	-85
2867.7.1.1	2867.7.1.1	Other	144	9142	10609	2.5	25	2.14	0.01	-85
2867.8.1.1	2867.8.1.1	Base	144	4610	9367	100	25	2.14	0.5	-87

Appendix 3: Propagation Path Loss View

The Propagation Path Loss Table panel displays the predicted propagation path loss for each potential link using the current radio parameters and selected propagation methodology.

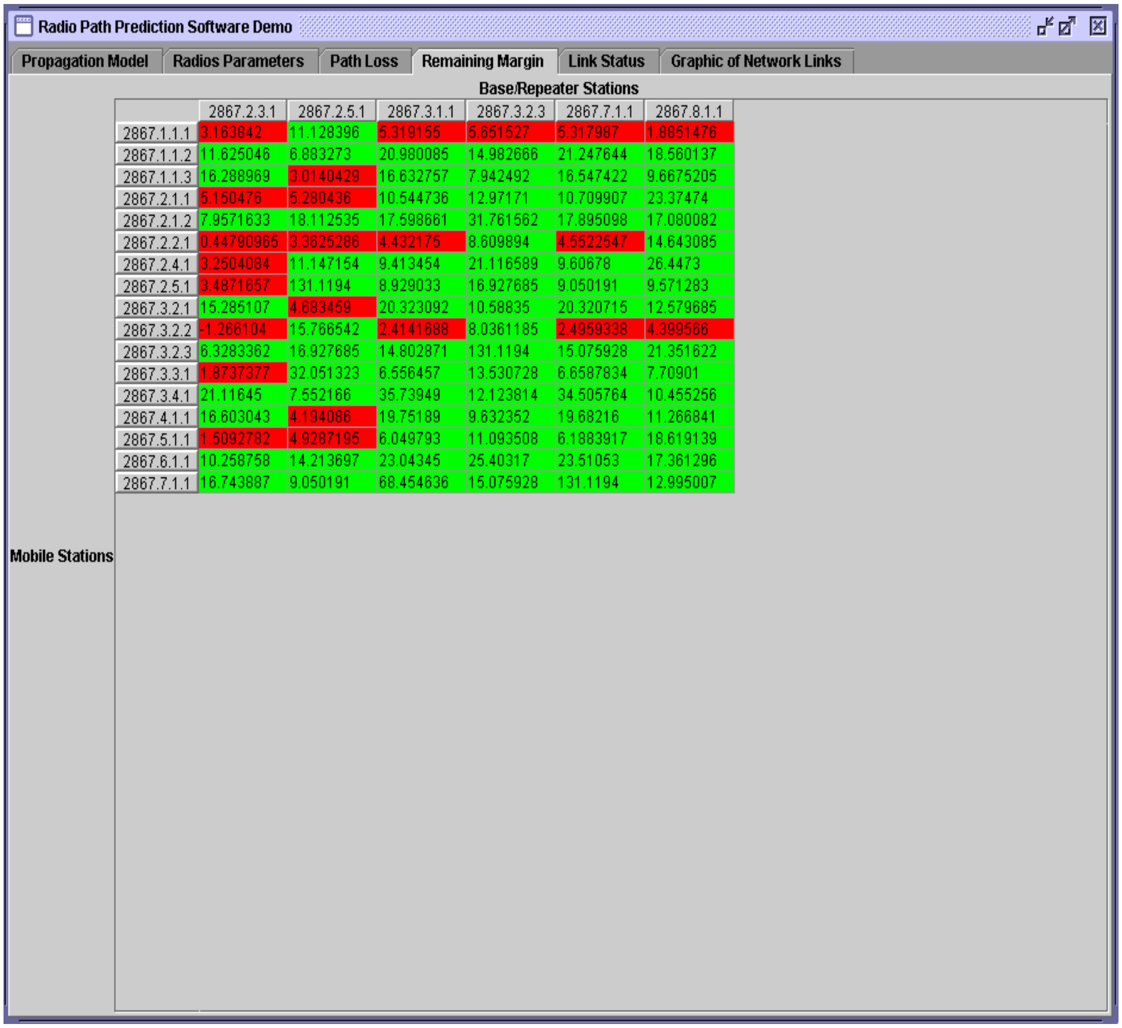
The identification of row and column entries as Mobile and Base station respectively, is somewhat misrepresentative. The identifiers Mobile and Base were chosen simply for consistency with literature for the propagation algorithms that are normally used for cell phone networks. An alternative choice for names might have been Spoke and Hub. If a user wanted to analyze all potential peer-to-peer links, each radio would be added as both a row and column entry in the radio parameters table. When a radio is added as both a row and a column (or Mobile and Base), the propagation loss is automatically set to 0.



	2867.2.3.1	2867.2.5.1	2867.3.1.1	2867.3.2.3	2867.7.1.1	2867.8.1.1
2867.1.1.1	127.956	119.991	125.8	125.468	125.801	129.234
2867.1.1.2	119.494	124.236	110.139	116.137	109.872	112.559
2867.1.1.3	114.83	128.105	114.487	123.177	114.572	121.452
2867.2.1.1	125.969	125.839	120.575	118.148	120.409	107.745
2867.2.1.2	123.162	113.007	113.521	99.358	113.224	114.039
2867.2.2.1	130.671	127.757	126.687	122.51	126.567	116.476
2867.2.4.1	127.869	119.972	121.706	110.003	121.513	104.672
2867.2.5.1	127.632	0	122.19	114.192	122.069	121.548
2867.3.2.1	115.834	126.436	110.796	120.531	110.799	118.54
2867.3.2.2	132.385	115.353	128.705	123.083	128.623	126.72
2867.3.2.3	124.791	114.192	116.317	0	116.043	109.768
2867.3.3.1	129.246	99.068	124.563	117.589	124.461	123.41
2867.3.4.1	110.003	123.567	95.38	118.996	96.614	120.664
2867.4.1.1	114.516	126.925	111.368	121.487	111.437	119.853
2867.5.1.1	129.61	126.191	125.07	120.026	124.931	112.5
2867.6.1.1	120.861	116.906	108.076	105.716	107.609	113.758
2867.7.1.1	114.376	122.069	62.665	116.043	0	118.124

Appendix 4: Link Margins View

In the Links Margin Table, the link margin of each potential link is displayed. If the margin exceeds a specified threshold value, the background of the cell representing the link is displayed in green. Otherwise, the cell background is red, indicating that the link does not have adequate margin to sustain communications. The information contained in the Links Margin View can be further processed to obtain optimize the network by utilizing remaining margin values as a proxy for potential bit-rate bandwidth.

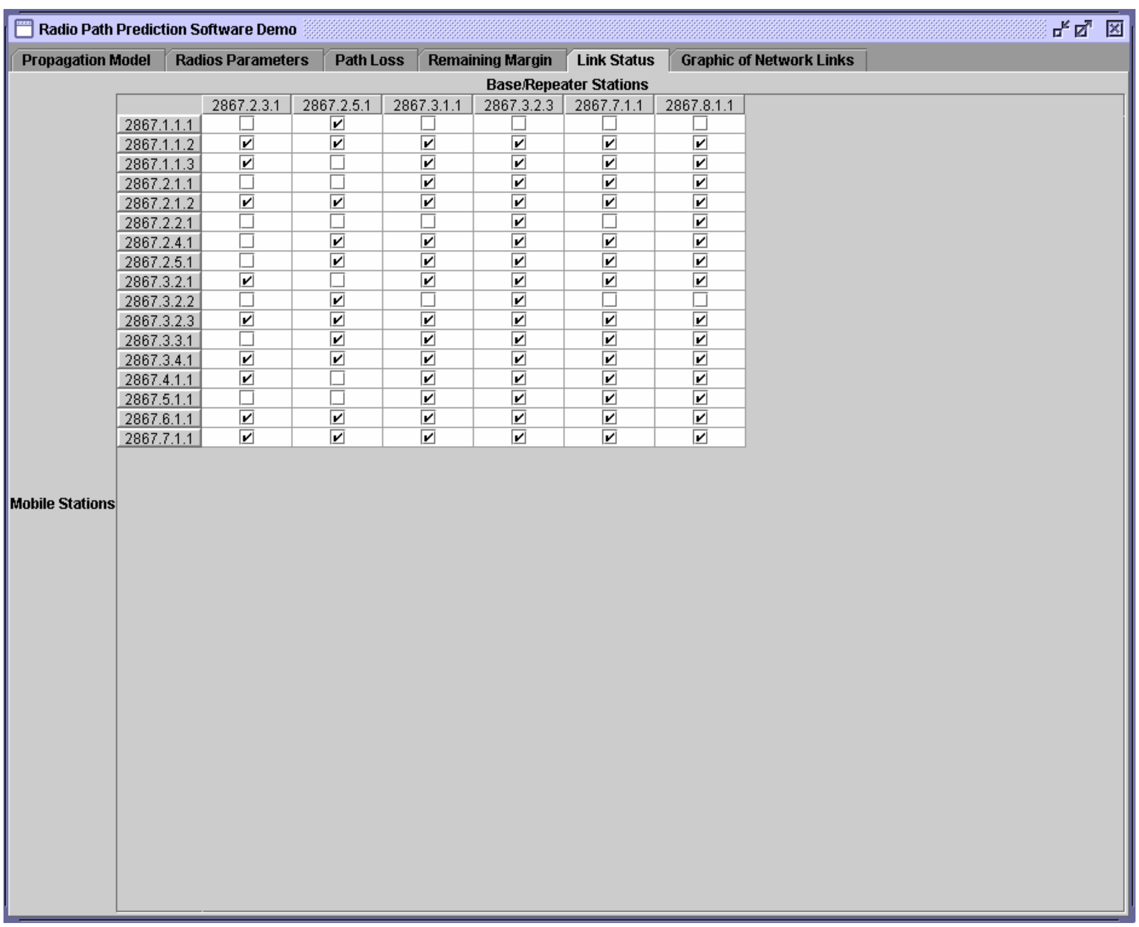


	2867.2.3.1	2867.2.5.1	2867.3.1.1	2867.3.2.3	2867.7.1.1	2867.8.1.1
2867.1.1.1	3.163842	11.128396	5.319155	5.651527	5.317987	1.8851476
2867.1.1.2	11.625046	6.883273	20.980085	14.982666	21.247644	18.560137
2867.1.1.3	16.288969	3.0140429	16.632757	7.942492	16.547422	9.6675205
2867.2.1.1	5.150476	5.280436	10.544736	12.97171	10.709907	23.37474
2867.2.1.2	7.9571633	18.112535	17.598661	31.761562	17.895098	17.080082
2867.2.2.1	0.44790965	3.3625286	4.432175	8.609894	4.5522547	14.643085
2867.2.4.1	3.2504084	11.147154	9.413454	21.116589	9.60678	26.4473
2867.2.5.1	3.4871657	131.1194	8.929033	16.927685	9.050191	9.571283
2867.3.2.1	15.285107	4.683459	20.323092	10.58835	20.320715	12.579685
2867.3.2.2	-1.266104	15.766542	2.4141688	8.0361185	2.4959338	4.399566
2867.3.2.3	6.3283362	16.927685	14.802871	131.1194	15.075928	21.351622
2867.3.3.1	1.8737377	32.051323	6.556457	13.530728	6.6587834	7.70901
2867.3.4.1	21.11645	7.552166	35.73949	12.123814	34.505764	10.455256
2867.4.1.1	16.603043	4.194086	19.75189	9.632352	19.68216	11.266841
2867.5.1.1	1.5092782	4.9287195	6.049793	11.093508	6.1883917	18.619139
2867.6.1.1	10.258758	14.213697	23.04345	25.40317	23.51053	17.361296
2867.7.1.1	16.743887	9.050191	68.454636	15.075928	131.1194	12.995007

Appendix 5: Link Status View

Most often, a user is only interested in which links will work. The actual link margin values are not of immediate interest as long as they are larger than the specified margin threshold value. This panel provides a simple table of Boolean yes/no checkmarks. A link that that is satisfactory gets a check, otherwise it gets no check. The link status view provides the transformation of a wireless network planning problem from the physics domain to the graph theory domain that was alluded to earlier.

The Link Status Table contains all the information necessary to check interconnectivity between radios on the network. Further, by applying graph theoretic algorithms (such as depth first graph traversal) we can identify all radios or subsets of radios that may be isolated from the rest of the network graph. This technique simply forms all subset of isolated sets of radios, utilizing only connectivity information previously calculated based on assumed propagation conditions.

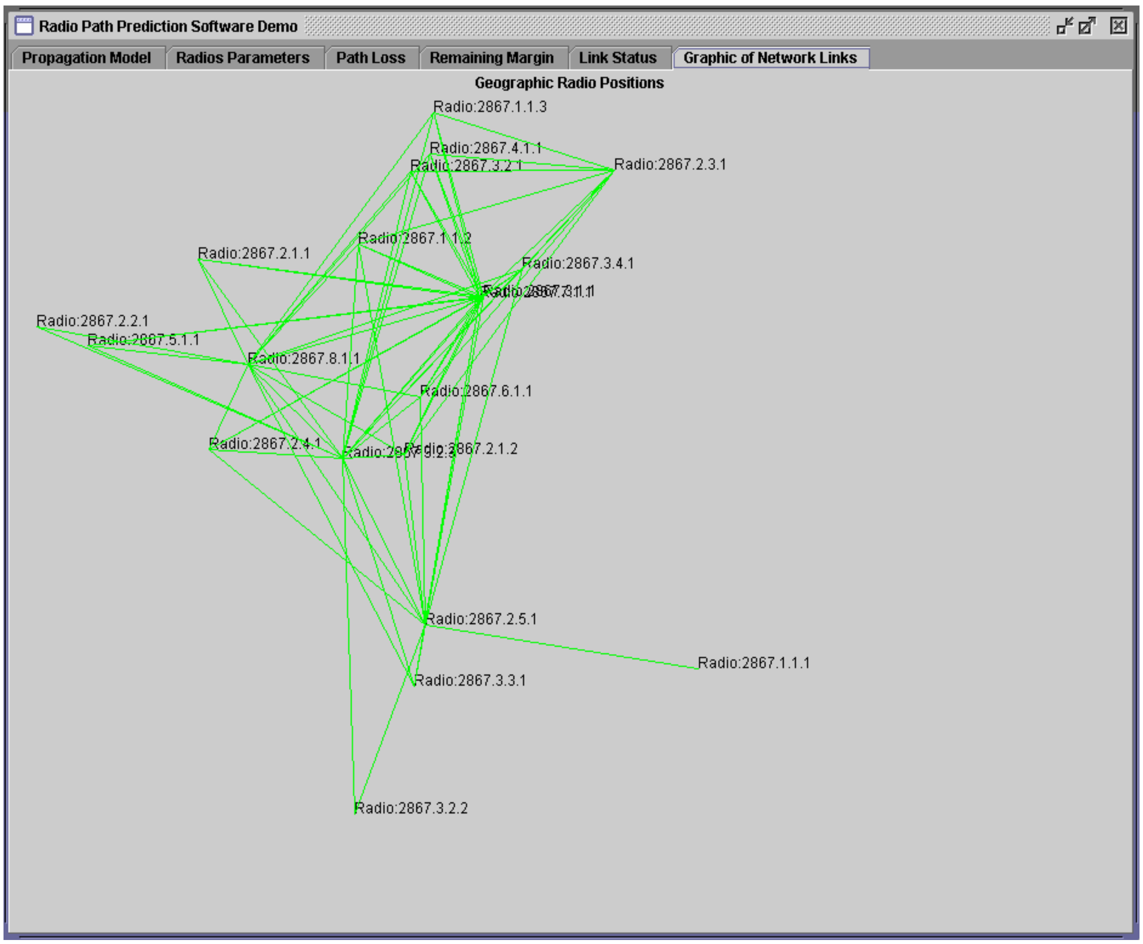


	2867.2.3.1	2867.2.5.1	2867.3.1.1	2867.3.2.3	2867.7.1.1	2867.8.1.1
2867.1.1.1		✓				
2867.1.1.2	✓	✓	✓	✓	✓	✓
2867.1.1.3	✓		✓	✓	✓	✓
2867.2.1.1			✓	✓	✓	✓
2867.2.1.2	✓	✓	✓	✓	✓	✓
2867.2.2.1				✓		✓
2867.2.4.1		✓	✓	✓	✓	✓
2867.2.5.1		✓	✓	✓	✓	✓
2867.3.2.1	✓		✓	✓	✓	✓
2867.3.2.2		✓		✓		
2867.3.2.3	✓	✓	✓	✓	✓	✓
2867.3.3.1		✓	✓	✓	✓	✓
2867.3.4.1	✓	✓	✓	✓	✓	✓
2867.4.1.1	✓		✓	✓	✓	✓
2867.5.1.1			✓	✓	✓	✓
2867.6.1.1	✓	✓	✓	✓	✓	✓
2867.7.1.1	✓	✓	✓	✓	✓	✓

Appendix 6: Graphical Display of Network Links View

The Graphic Display of Network Links presents all the geographic positions of the radios and predicted good link paths. In the implementation shown here, all the predicted good links for the entire network are displayed in green.

In an updated version of the software, radios or sub-networks that are isolated from the rest of the network will be displayed in distinct colors. A separate panel will tabulate each of the sets of radios contained in each of the isolated network components.



Radio Path Prediction Software

for Command and Control Scenario Developers

Reference# C-168,

Michael Shattuck

Command and Control Research and Technology Symposium

June 2006

Topics

- Link Planning for Wireless Networks.
- Basic Radio Theory.
- Link Budget Calculation.
- Radio Propagation Methodologies.
  - Basic: Free Space LOS.
  - Predictive Propagation Methodologies for non-LOS.
- Software Design Concepts.
- User Interface for Radio Path Prediction Application.

Link Planning for Wireless Networks

- Link Status: For any pair of radios does sufficient transmitter power arrive at the receiver to establish a communication link?

  This is independent of frequency, modulation technique, encoding techniques, protocols, etc. It is valid for both analog and digital networks. In the terminology of the International Standards Organization Open System Interconnect (ISO/OSI) 7-Layer Network model we are concerned with the Physical layer. Data-link, and Network and Transport protocols are higher level layers.

- Network Path: Is there a path between any pair of radios using one or more intermediate radios as repeaters/routers?
- Connectivity: Is there any subset of the network link graph that is isolated from the rest of the network?
- Optimization: What is the the network configuration that optimizes the network as a whole?

Main challenge:

To predict the significant propagation paths from the base stations (hubs/repeaters) to the mobile radios as well as the losses among those paths.

Radio Theory: Transmission

- **Power.**
  - The dB (Decibel) is the basic unit of measure for power levels; a logarithm scale unit, measures the difference (or ratio) between two signal levels. It is used to describe the effect of system devices on relative signal strength. A change in power level is reflected in a change in the dB metric.
  - Expressed in Decibel relative units compared to milliwatts (dBm).
- **Cable Loss.**
  - Signal loss due to the cable between transmitter and the antenna is subtracted.
- **Antenna Gain.**
  - Normally given in isotropic decibels (dBi), the power gain relative to a theoretical single point radiator.
  - Some antennas express their gain in (dBd). It's the gain compared to a dipole antenna. In this case, add 2.14 to obtain the corresponding gain in (dBi).
- **Effective Isotropic Radiated Power (EIRP).**
  - The effective power radiated in the main lobe of a transmitter antenna relative to an Isotropic radiator which has 0 dB gain.
  - EIRP [dBm] = transmitted power[dBm] – cable loss[dB] + antenna gain[dBi].

Radio Theory: Propagation Losses

- **Free Space Loss.**
  - Useful for propagation with LOS and no intervening obstructions.
  - Governed by an inverse square law; inversely proportional to the square of the distance.
  - Rule of thumb; Double/halve the distance -> Add/subtract 6 dB.
- **Diffraction.**
  - When an obstacle is located between the transmitter and the receiver, some energy still passes around the obstacle.
  - Radio waves may arrive out of phase because of diffraction.
  - The losses associated with diffraction are more significant at higher frequencies.
  - This is a significant factor in urban environments.
- **Polarization.**
  - Wave polarization is given by the type of antenna and its orientation.
  - Antennas at transmitter and receiver should have the same polarization for best performance.
- **Reflections.**
  - Radio waves reflect from the obstacles they meet.
  - At the receiver we catch at the same time the direct wave and the reflected waves. This leads to cancelled power at certain frequencies and also a time difference between the received components.

Radio Theory: Reception

- **Antenna Gain.**
  - Normally given in isotropic decibels (dBi), the power gain relative to an isotropic antenna.
- **Cable Loss between antenna and receiver.**
  - Signal loss due to the cable between transmitter and the antenna.
  - Some antennas have their gain expressed in (dBd). It's the gain compared to a dipole antenna. In this case, add 2.14 to obtain the corresponding gain in (dBi).
- **Receiver Sensitivity.**
  - Receiver sensitivity is the weakest RF signal level, (usually measured in negative dBm), that a radio needs to receive in order to demodulate and decode a packet of data without errors.
  - This is the minimum received power (dBm) threshold necessary to achieve a certain bit-rate.
- **Signal to Noise Ratio.**
  - The minimum power difference (dB) to achieve between the wanted received signal and noise.
  - If the noise level is low, the system will be limited more by the receiver sensitivity than by the signal to noise ratio. In this case the minimum receiver sensitivity is the limiting factor for the system.

Link Budget and Link Margin (Is this link good?)

Link budget is the computation of power losses for the whole transmission chain. By doing a link budget calculation, you can test various system designs and scenarios to see how much fade margin (or "safety cushion") your link may theoretically have.

EIRP (Effective Isotropic Radiated Power) [dBm] =

Transmitter Power[dBm] – cable loss[dB] + antenna gain[dBi]

Propagation Loss [dB] (calculated based on propagation model)

Received Signal [dBm] =

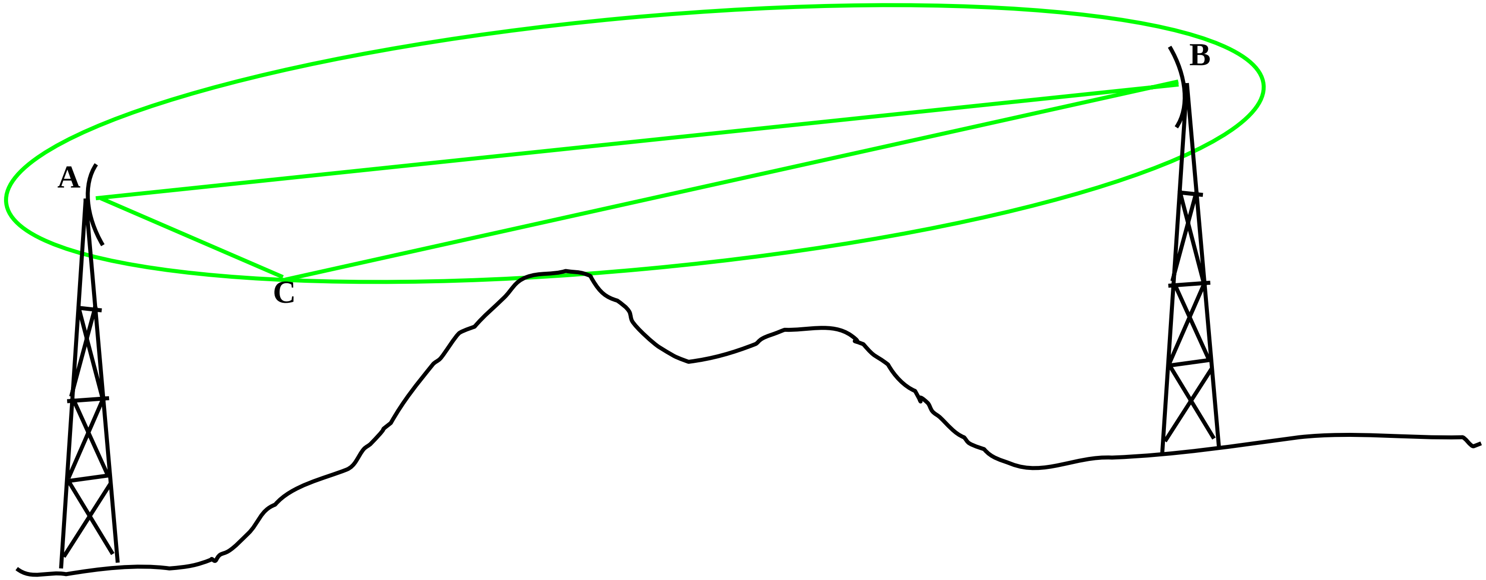
EIRP[dBm] – Propagation Loss[dB] + antenna gain[dBi] – cable loss [dB]

Link Margin [dBm] =

Received Signal[dBm] – Receiver Sensitivity[dBm]

Generally it is necessary to achieve a sufficient link budget security margin, also known as the System Operating Margin or Fade Margin, to assure performance under conditions with poor signal to noise ratio.

Fresnel Zone (why LOS is not enough)



Free space loss is an ideal. Obstacles must not protrude within the 3-D ellipsoid Fresnel zone to avoid significant propagation losses due to diffraction and reflection.

Propagation Models for Non-LOS Prediction

- **Empirical models (Okumura, Hata, COST-231-Hata, RACE Dual-Slope models).**
  - The model parameters are estimated by means of regression methods applied to extensive measured data. They are usually easy to calculate.
- **Abstract-structure-based models (Walfisch & Bertoni, Ikegami models).**
  - The propagation loss is analytically derived assuming a simple abstract terrain structure that allows analytic treatment. It is dependent on characterization of buildings and topographic parameters, and is intermediate in computational complexity.
- **Semi-empirical models (COST-231-Walfisch-Ikegami models).**
  - The parameters of the abstract-structured model are empirically corrected to fit measured data. This is only slightly more computationally complex than empirical models.
- **Deterministic models (IHE models).**
  - The field is computed by using an approximation of a field integral or by ray-tracing techniques. Extensive geographic information about the terrain is exploited. It is computationally complex.

Propagation Prediction Models Chosen for Proof of Concept Software

- **Free Space model.**
  - Benchmark for more complex methodologies.
  - Suitable for open terrain.
- **Empirical and Semi-Empirical models.**
  - Easier to implement.
  - Relatively low computational load.
  - Detailed representation of terrain not required.
- **Initially Implement Macrocell models.**
  - Hata’s model.
  - COST-231-Hata model.
- **Later Microcell model(s).**
  - COST-231-Walfisch-Ikegami model.
- **Indoor and Picocell models not considered at this time.**

Link Prediction Software Design Concepts
Models & Views

Propagation Model

- Allows selection of a propagation methodology.
- Encapsulates state of terrain parameters.
- Exposes propagation method functionality.
- Notifies views of state changes.

Radios Model

- Encapsulates state of radios parameters.
- Responds to state queries.
- Notifies views of state changes.

Path Loss View

- Renders Path Loss
- Requests updates from models

Link Margin View

- Renders Link Margin
- Requests updates from models

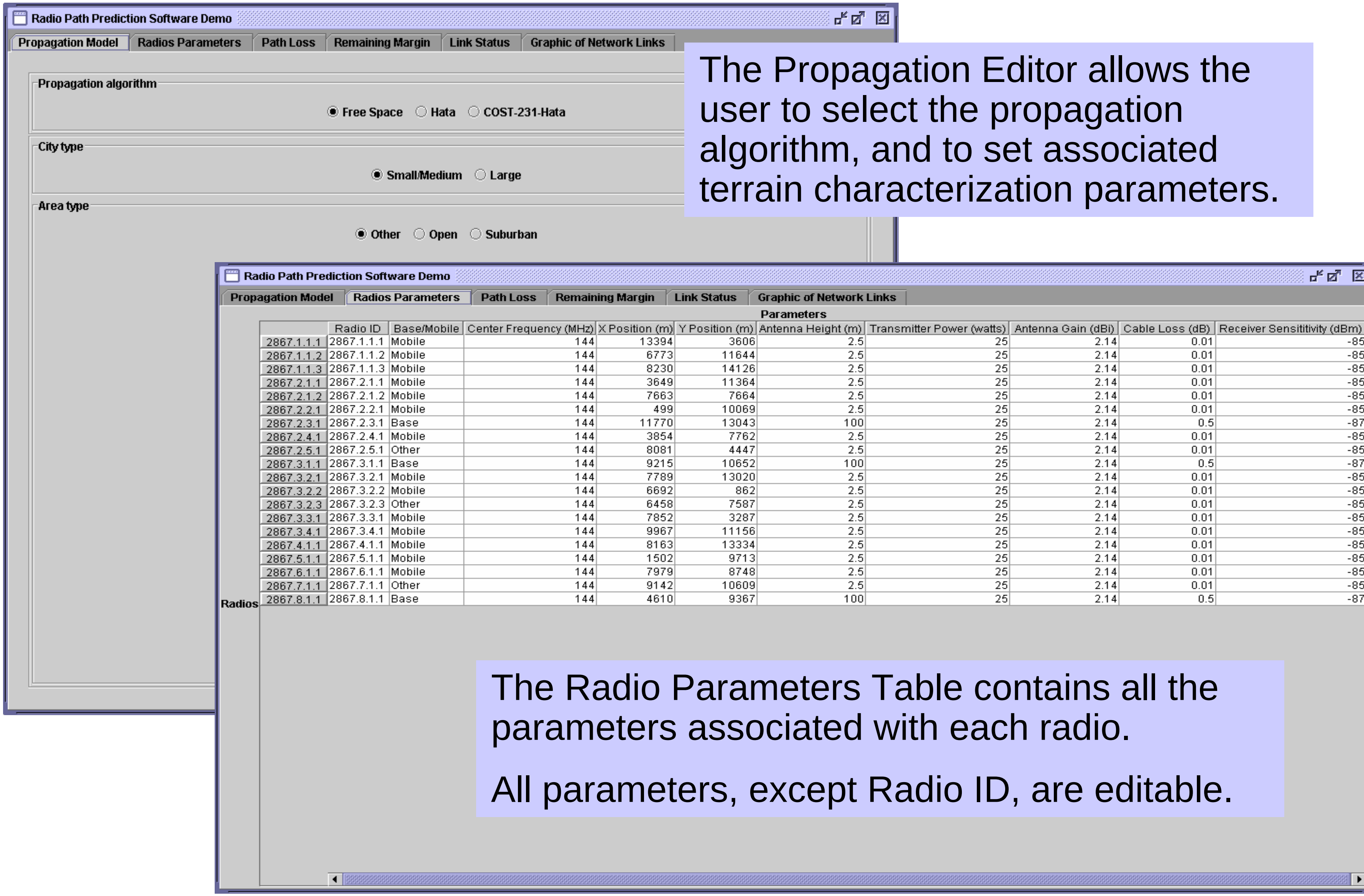
Link Status View

- Renders Link Status
- Requests updates from models

Graphical Link View

- Renders Geographic Display of Good Links
- Requests updates from models

GUIs for Propagation and Radios Models



	Radio ID	Base/Mobile	Center Frequency (MHz)	X Position (m)	Y Position (m)	Antenna Height (m)	Transmitter Power (watts)	Antenna Gain (dBi)	Cable Loss (dB)	Receiver Sensititivity (dBm)
2867.1.1.1	2867.1.1.1	Mobile	144	13394	3606	2.5	25	2.14	0.01	-85
2867.1.1.2	2867.1.1.2	Mobile	144	6773	11644	2.5	25	2.14	0.01	-85
2867.1.1.3	2867.1.1.3	Mobile	144	8230	14126	2.5	25	2.14	0.01	-85
2867.2.1.1	2867.2.1.1	Mobile	144	3649	11364	2.5	25	2.14	0.01	-85
2867.2.1.2	2867.2.1.2	Mobile	144	7663	7664	2.5	25	2.14	0.01	-85
2867.2.2.1	2867.2.2.1	Mobile	144	499	10069	2.5	25	2.14	0.01	-85
2867.2.3.1	2867.2.3.1	Base	144	11770	13043	100	25	2.14	0.5	-87
2867.2.4.1	2867.2.4.1	Mobile	144	3854	7762	2.5	25	2.14	0.01	-85
2867.2.5.1	2867.2.5.1	Other	144	8081	4447	2.5	25	2.14	0.01	-85
2867.3.1.1	2867.3.1.1	Base	144	9215	10652	100	25	2.14	0.5	-87
2867.3.2.1	2867.3.2.1	Mobile	144	7789	13020	2.5	25	2.14	0.01	-85
2867.3.2.2	2867.3.2.2	Mobile	144	6692	862	2.5	25	2.14	0.01	-85
2867.3.2.3	2867.3.2.3	Other	144	6458	7587	2.5	25	2.14	0.01	-85
2867.3.3.1	2867.3.3.1	Mobile	144	7852	3287	2.5	25	2.14	0.01	-85
2867.3.4.1	2867.3.4.1	Mobile	144	9967	11156	2.5	25	2.14	0.01	-85
2867.4.1.1	2867.4.1.1	Mobile	144	8163	13334	2.5	25	2.14	0.01	-85
2867.5.1.1	2867.5.1.1	Mobile	144	1502	9713	2.5	25	2.14	0.01	-85
2867.6.1.1	2867.6.1.1	Mobile	144	7979	8748	2.5	25	2.14	0.01	-85
2867.7.1.1	2867.7.1.1	Other	144	9142	10609	2.5	25	2.14	0.01	-85
2867.8.1.1	2867.8.1.1	Base	144	4610	9367	100	25	2.14	0.5	-87

The Propagation Editor allows the user to select the propagation algorithm, and to set associated terrain characterization parameters.

The Radio Parameters Table contains all the parameters associated with each radio.

All parameters, except Radio ID, are editable.

Propagation Path Loss View

Radio Path Prediction Software Demo

Propagation Model | Radios Parameters | Path Loss | Remaining Margin | Link Status | Graphic of Network Links

Base/Repeater Stations

Mobile Stations

	2867.2.3.1	2867.2.5.1	2867.3.1.1	2867.3.2.3	2867.7.1.1	2867.8.1.1
2867.1.1.1	127.956	119.991	125.8	125.468	125.801	129.234
2867.1.1.2	119.494	124.236	110.139	116.137	109.872	112.559
2867.1.1.3	114.83	128.105	114.487	123.177	114.572	121.452
2867.2.1.1	125.969	125.839	120.575	118.148	120.409	107.745
2867.2.1.2	123.162	113.007	113.521	99.358	113.224	114.039
2867.2.2.1	130.671	127.757	126.687	122.51	126.567	116.476
2867.2.4.1	127.869	119.972	121.706	110.003	121.513	104.672
2867.2.5.1	127.632	0	122.19	114.192	122.069	121.548
2867.3.2.1	115.834	126.436	110.796	120.531	110.799	118.54
2867.3.2.2	132.385	115.353	128.705	123.083	128.623	126.72
2867.3.2.3	124.791	114.192	116.317	0	116.043	109.768
2867.3.3.1	129.246	99.068	124.563	117.589	124.461	123.41
2867.3.4.1	110.003	123.567	95.38	118.996	96.614	120.664
2867.4.1.1	114.516	126.925	111.368	121.487	111.437	119.853
2867.5.1.1	129.61	126.191	125.07	120.026	124.931	112.5
2867.6.1.1	120.861	116.906	108.076	105.716	107.609	113.758
2867.7.1.1	114.376	122.069	62.665	116.043	0	118.124

The Path Loss View contains the calculated path loss (in dB) between the radios in the corresponding row and column.

Link Margins View

Radio Path Prediction Software Demo

Propagation Model | Radios Parameters | Path Loss | Remaining Margin | Link Status | Graphic of Network Links

Base/Repeater Stations

Mobile Stations

	2867.2.3.1	2867.2.5.1	2867.3.1.1	2867.3.2.3	2867.7.1.1	2867.8.1.1
2867.1.1.1	3.163842	11.128396	5.319155	5.651527	5.317987	1.8851476
2867.1.1.2	11.625046	6.883273	20.980085	14.982666	21.247644	18.560137
2867.1.1.3	16.288969	3.0140429	16.632757	7.942492	16.547422	9.6675205
2867.2.1.1	5.150476	5.280436	10.544736	12.97171	10.709907	23.37474
2867.2.1.2	7.9571633	18.112535	17.598661	31.761562	17.895098	17.080082
2867.2.2.1	0.44790965	3.3625286	4.432175	8.609894	4.5522547	14.643085
2867.2.4.1	3.2504084	11.147154	9.413454	21.116589	9.60678	26.4473
2867.2.5.1	3.4871657	131.1194	8.929033	16.927685	9.050191	9.571283
2867.3.2.1	15.285107	4.683459	20.323092	10.58835	20.320715	12.579685
2867.3.2.2	-1.266104	15.766542	2.4141688	8.0361185	2.4959338	4.399566
2867.3.2.3	6.3283362	16.927685	14.802871	131.1194	15.075928	21.351622
2867.3.3.1	1.8737377	32.051323	6.556457	13.530728	6.6587834	7.70901
2867.3.4.1	21.11645	7.552166	35.73949	12.123814	34.505764	10.455256
2867.4.1.1	16.603043	4.194086	19.75189	9.632352	19.68216	11.266841
2867.5.1.1	1.5092782	4.9287195	6.049793	11.093508	6.1883917	18.619139
2867.6.1.1	10.258758	14.213697	23.04345	25.40317	23.51053	17.361296
2867.7.1.1	16.743887	9.050191	68.454636	15.075928	131.1194	12.995007

The Remaining Margin View contains the results of the Link Budget calculations. Cells with values above the specified threshold are green. Cells with red background indicate insufficient margin for reliable performance.

Link Status View

Radio Path Prediction Software Demo

Propagation Model | Radios Parameters | Path Loss | Remaining Margin | Link Status | Graphic of Network Links

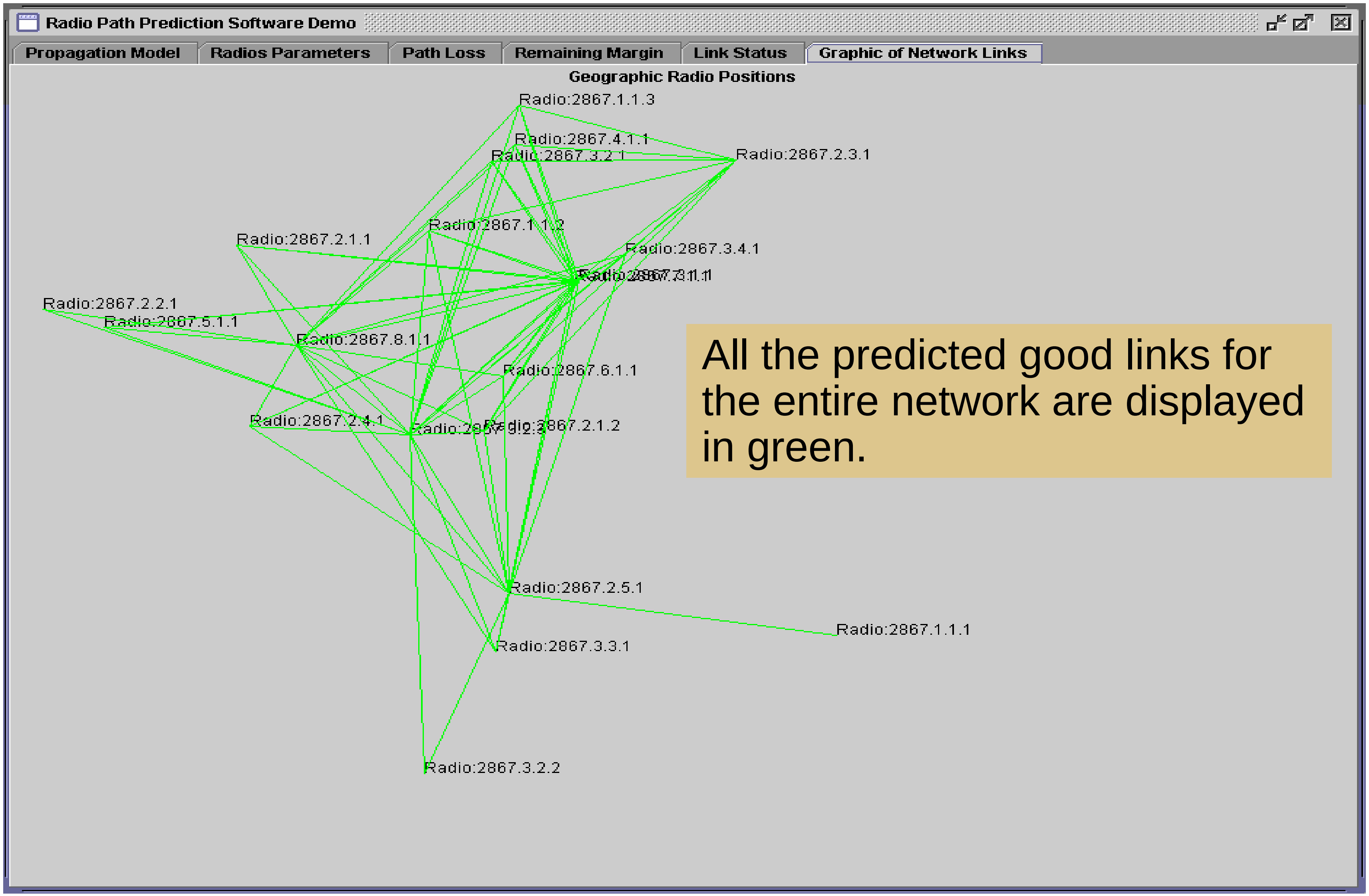
Base/Repeater Stations

Mobile Stations

	2867.2.3.1	2867.2.5.1	2867.3.1.1	2867.3.2.3	2867.7.1.1	2867.8.1.1
2867.1.1.1		✓				
2867.1.1.2	✓	✓	✓	✓	✓	✓
2867.1.1.3	✓		✓	✓	✓	✓
2867.2.1.1			✓	✓	✓	✓
2867.2.1.2	✓	✓	✓	✓	✓	✓
2867.2.2.1				✓		✓
2867.2.4.1		✓	✓	✓	✓	✓
2867.2.5.1		✓	✓	✓	✓	✓
2867.3.2.1	✓		✓	✓	✓	✓
2867.3.2.2		✓		✓		
2867.3.2.3	✓	✓	✓	✓	✓	✓
2867.3.3.1		✓	✓	✓	✓	✓
2867.3.4.1	✓	✓	✓	✓	✓	✓
2867.4.1.1	✓		✓	✓	✓	✓
2867.5.1.1			✓	✓	✓	✓
2867.6.1.1	✓	✓	✓	✓	✓	✓
2867.7.1.1	✓	✓	✓	✓	✓	✓

The Link Status View contains all the information necessary to check interconnectivity between radios on the network. Further, by applying graph theoretic algorithms (such as depth first graph traversal) to the link status information we can identify all radios or subsets of radios that may be isolated from the rest of the network.

Graphical Display of Network Links View



All the predicted good links for the entire network are displayed in green.