Advanced Mission Planning Tool For Real-Time Kinematic (RTK) GPS Surveying

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BIOGRAPHY

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ABSTRACT

Conventional mission planning in GPS surveying involves locating a site with minimal obstructions and determining satellite availability at the location to be surveyed. Tools used in the planning process usually include topographic maps and satellite availability software. In recent years, with the advent of Real Time Kinematic (RTK) GPS surveying, it is possible to obtain centimetre level accuracy while in the field. One of the key factors in the RTK GPS technique is the data link between the reference station and rover. Without this link RTK GPS results are not attainable in the field. For this reason mission planning in RTK GPS surveying takes on another level of complexity: not only does the reference station have to visible to the satellites, but it must also be visible to the rover. However, available mission planning tools do not provide a means to predict the data link coverage of the reference station.

The purpose of this investigation is to determine the best wave propagation model or models to be used in a RTK GPS survey mission planning tool. This study will present current wave propagation models being used by communications planning software and then use these models to predict data link coverage. The performance of these models was evaluated through field testing of two RTK GPS systems. This investigation concludes that there are three wave propagation models that could be used to accurately predict data link coverage by using only digital terrain information. The implementation of these models relies on available documentation and potential source code. In researching this project it was evident the availability of documentation varies between models. Based on performance criteria and implementation considerations, two models are recommended to be implemented into a mission planning tool for RTK GPS surveying: Parabolic Equation and TIREM.

INTRODUCTION

This paper reports an investigation on the use of wave propagation models for use as a mission planning tool for Real Time Kinematic (RTK) GPS Surveying. RTK GPS positioning is a differential technique that typically uses a combination of carrier-phase and pseudorange measurements and reference station coordinates broadcast from reference station to rover station where the processing of the rover antenna is carried out in real time [Langley, 1998]. RTK GPS surveying can obtain sub-centimetre results as long as required number of satellites is in view of both reference and rover stations and there is a data link between the two.

In any RTK GPS application the two constraints for successful positioning, are visibility to required number of satellites and a data link between the reference station and rover. Mission planning software tools have been developed by most GPS manufacturers that allow for predicting satellite visibility at a given location and time. As the local terrain and obstacles may affect the visibility of the satellite, these tools also allow for predictions with obstacles. Walker and Sang [n.d.] implemented accurate digital terrain models (DTM) with satellite visibility software to achieve a more realistic prediction. The treatment of predicting the data link coverage between reference and rover by GPS manufacturers in the context of a mission planning tool is limited. Pacific Crest has published a document on data link applications [Pacific Crest Corporation, 2000] which includes the determination of the range of the data link. Walker and

Kubik [n.d.] showed that a wave propagation model along with a DTM could be used for predicting communications in open pit mining.

Wave propagation models for the prediction of radio wave coverage from a given transmitter location have been of great interest for well over 60 years. These models have continued to be developed and improved along with computing power and boom in personal communications in the past 30 years. Today there are communications planning software that allow for prediction of radio wave coverage in all environments, which take into account DTM, building databases, and land use/land cover (LULC) information. This software has been used in planning of many communications applications including Television, radio, digital audio broadcasting, and cellular networks. Unfortunately, there are two main drawbacks to this type of software, which are the required expertise to properly use the software and the cost, which is in the order of $30,000.

Wave propagation models implemented into a mission planning tool have the potential to provide an RTK GPS user with site information that can save field time and expense. Cost and complexity inhibit taking advantage of the data link coverage predictions, by RTK GPS users, in the current form of communications planning software. Ideally a mission planning tool that incorporates readily available data link system information such as transmitting power, antenna gains, and system losses along with DTMs and LULC information would allow for an RTK GPS user to predict data link coverage from a given location. This type of analysis would allow for a site to be evaluated based on the data link coverage or to evaluate the effect on coverage by modifying transmitting antenna heights or types. Furthermore, this type of mission planning tool would have to be inexpensive and relatively simple to use.

The principal goal of this paper is to determine the best wave propagation model or models for rural areas that incorporates readily obtainable radio system and terrain information, to be used in RTK GPS survey mission planning and control network planning. To accomplish this purpose we researched current wave propagation models being used in the current communications planning software, we developed a field testing method to validate the models chosen, present criteria to compare the prediction results and the field measurements and make a recommendation of the best model to be implemented in a mission planning tool for RTK GPS surveying.

PREDICTION MODELS

The prediction models used in this study are: Okumura-Hata, Longley-Rice, TIREM, CRC Predict and Parabolic Equation.

The **Okumura-Hata** (OH) model [Hata, 1980] is a set of empirical formulae based on measurements and analysis completed by Okumura [Okumura et al., 1968]. The model has been validated between 150 and 1500 MHz, with base station antenna heights of 30-200 meters, mobile station antenna heights between 1-10 meters, and separation distances from 1-20 kilometres. The basic formula is based upon urban areas, but has correction factor for both Suburban and Open areas. The OH model takes into account the heights of base and mobile antennas. According to Hata [1980] the following was taken into consideration during the formulation of the equations: (1) Propagation loss between isotropic antennas is treated; (2) quasi-smooth terrain, irregular is not treated; and, (3) the urban area propagation loss is presented as the standard formula. Equation 1 represents the urban prediction for path loss (L_{pu}):

$$L_p = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_b - a(h_m) + (44.9 - 6.55 \log_{10} h_b) \log_{10} R, \quad (1)$$

where L_{pu} in dB, f_c is the transmitting frequency in MHz, h_b is the base station height above the terrain in meters, h_m is the rover antenna height above the terrain in meters, and R is the distance between the transmitter and receiver in kilometres. Equation 2 is used to calculate the correction factor, $a(h_m)$, for a medium-small city:

$$a(h_m) = (1.1 \log_{10} f_c - 0.7)\, h_m - (1.56 \log_{10} f_c - 0.8). \quad (2)$$

The path loss for open areas (L_{po}) is determined using equation 1, 2 and a correction factor as follows:

$$L_{po} = L_{pu} - 4.78 (\log_{10} f_c)^2 + 18.33 \log_{10} f_c - 40.94. \quad (3)$$

At a given frequency and transmitter and receiver height combination, the path loss using the OH model becomes a function of the distance between the transmitter and receiver, R.

The **Longley-Rice** (LR) model was first presented in 1968 in an ESSA Technical Report [Parsons, 1992]. The model predicts the mean path loss relative to the free space loss and requires parameters such as frequency, heights of the transmitting and receiving antennas, distance between antennas, mean surface refractivity, Earth's conductivity and dielectric constant, polarization and description of the terrain [Yacoub, 1993]. The model is a computer-based algorithm that has been validated between 20 MHz and 20 GHz, antenna heights between 0.5 and 3000 metres, T-R separation from 1 to 2000 kilometres, and vertical or horizontal polarization.

When a digital terrain model is available the LR model will extract terrain profiles between the transmitter and receiver. These profiles are used to determine the distance respective radio horizon, the horizontal elevation angles, and effective antenna heights. A detailed description of these parameters can be found in IEEE [1988] and Parsons [1992].

Another parameter used by the LR model is the terrain irregularity parameter, Δh, which is an indicator of the terrain roughness or undulation. Assuming a normal distribution of the terrain over a given distance, the terrain irregularity parameter is estimated as the distance between the 10 and 90 percent ranges of the average. The method for calculation of the average path loss using the LR model depends on the separation distance between the transmitting and receiving antennas [Parsons, 1992]. Depending on the distance the model uses free space, plane Earth, and single or double knife-edge diffraction loss. Descriptions of knife-edge diffraction loss can be found in Parsons [1992], Yacoub [1993], and Rappaport [1996].

The **Terrain Integrated Rough Earth Model** (TIREM) was developed by the office of the United States Department of Commerce, National Telecommunications and Information Administration [IEEE, 1988]. TIREM predicts propagation loss between two points by taking into account the transmitting frequency, atmospheric and ground parameters (ground permittivity and conductivity), and the terrain profile between the transmitter and receiver. The model is valid between 40 MHz and 20 GHz. The range of valid antenna heights was not given.

The calculation of the average path loss is complete for radio line-of-sight (or radio horizon) paths and for beyond line-of-sight paths. For line-of-sight paths the computation depends on the minimum ratio, along the entire path of the ray, of terrain clearance height, h, and the width of the first Fresnel zone, r, at that point. Beyond the line-of-sight there are nine different propagation modes that are used [IEEE, 1988]. These include knife-edge diffraction, double knife edge diffraction, rough-earth diffraction, tropospheric scatter, or a combination of these.

The **CRC Predict model** was developed at the Communications Research Centre (CRC) in Ottawa. The model has been validated for transmitting frequencies between 30 and 3000 MHz, transmitting antenna heights between 30 to 200 metres, and receiving antenna heights between 1 to 10 metres [Chouinard et al., 1996]. The calculation of path loss is complete by calculating the loss due to diffraction [Whitteker, 1990] and tropospheric scatter [CRC, 1996] using terrain and land cover information. Diffraction loss is based on numerical integration and takes into account all terrain between transmitter and receiver. The integration is complete in both directions and the weighted average is taken for the solution [CRC, 1996]. The theory behind CRC Predict model can be found in Whitteker [1990] and [1994] and a description of the Predict algorithm can be found in CRC [1994].

The foundation of the **parabolic equation** for modeling waves lies in Maxwell's equations, a detailed description of which can be found in Feynman et al. [1964], and solutions to the partial differential equations formed by Maxwell's equations. The three dimensional (x, y, z) partial differential wave equation in free space can be written as follows [Feynman et al., 1964]:

$$\partial^2\mathbf{E}/\partial x^2 + \partial^2\mathbf{E}/\partial y^2 + \partial^2\mathbf{E}/\partial z^2 - c^{-2}\partial^2\mathbf{E}/\partial t^2 = 0, \qquad (4)$$

where **E** electric field, t is time, and c is the vacuum speed of light. The terminology "parabolic", comes from the classification of partial differential equations and an analogy to the quadratic equation in analytic geometry [Myint-U, 1980]. Given the following quadratic equation:

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0, \qquad (5)$$

is it hyperbolic, parabolic, or elliptical if $B^2 - 4AC$ is positive, zero, or negative respectively.

The parabolic equation was first introduced in the 1940s, but with the advent of the digital computers the use of the PE has increased [Levy, 2000]. The use of the PE has been proposed for many circumstances including, over seas and tropospheric propagation. Of primary interest for this project is the propagation of radio waves over irregular terrain. Descriptions of various implementations of the parabolic equation over irregular terrain can be found in Dockery [1988], Levy [1990], Kuttler and Dockery [1991], and Levy [2000].

COMMUNICATIONS PLANNING SOFTWARE

The communication planning used in this study are: CRC-COV and WinProp.

The Communications Research Centre (CRC), in Ottawa, is a government agency of Industry Canada, developed **CRC-COV** software. CRC-COV and the updated version, CRC-COV Lab, are used to design and predict coverage of broadcast systems. These are well-developed software that takes into account advanced system parameters such as antenna patterns and multiple transmitters, environmental factors, and various terrain databases [CRC, 2001]. The estimated cost of the CRC-COV Lab is $25,000 (CDN). The specific models from CRC-COV used for this project were: Okumura-Hata, Longley-Rice, TIREM, and CRC-Predict.

AWE Communications Corporation is a spin-off from the Institute of Radio Frequency Technology at the University of Stuttgart in Germany. The main focus of this company is the development of software tools for radio network planning and wave propagation [AWE, 2001]. **WinProp** software can be used for rural (macrocell), urban (microcell), and indoor (picocell) propagation. The software is modular in nature and specific components can be purchased for particular scenarios (i.e., indoor propagation). The cost of the software is approximately $33,000 (CDN) for all modules and $4,000 (CDN) for urban module required for this project. The specific models from WinProp used in this project were Okumura-Hata and Parabolic Equation. The implementation of the Okumura-Hata model is similar to that explained before. AWE communications has introduced a variable called h_{eff} (effective antenna height), which is the height difference between transmitter and receiver, to account Hata's assumption of flat terrain. This variable replaces h_b in Equation (1), otherwise the implementation is similar to Okumura-Hata method. Implementation details of the PE can be found in AWE Communications [n.b. b] and [n.b. c], unfortunately these documents are not available in English.

ADVANCED RTK MISSION PLANNING TOOL

A mission planning tool for RTK GPS surveying should provide a prediction of data link availability based on radio system and site characteristics, which may include terrain and land cover. The planning tool should include a measure of accuracy, for example, 95% probability that the signal will be available, and be easy to use. Figure 1 is perspective view of a three-dimensional digital terrain model, increasing in height from green to brown, with a radio transmitter. Using this terrain model a user may surmise based on the location of the transmitter that there could be areas where data link coverage is not available, but there is no guarantee of coverage.

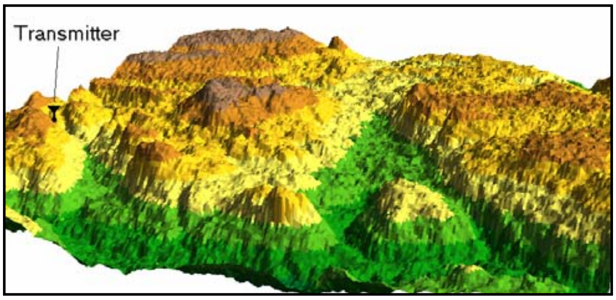

Figure 1 - 3D Perspective of Digital Terrain Model.

Using these terrain model and readily attainable radio system characteristics the user can then use a radio wave prediction model to determine the data link coverage. Figure 2 is a prediction of the data link signal strength draped over the terrain model, the signal strength decreases from green to yellow to red.

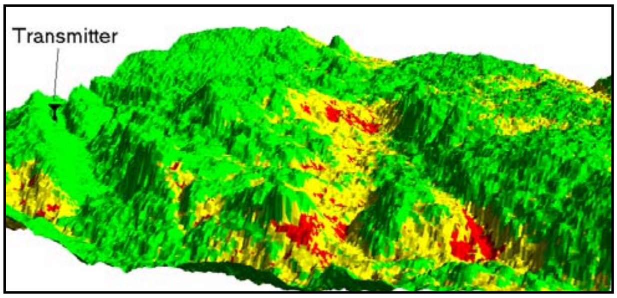

Figure 2 - 3D Perspective of data link prediction draped over terrain model.

This type of prediction would provide the RTK GPS system user with important site characteristics in the office. The RTK GPS mission planning tool would allow the user to plan sitting of RTK GPS data link transmitting antenna to ensure maximum coverage of the required area and minimize wasted field time due to data link outages.

FIELD TESTS

Field testing was limited to the use of Trimble Survey equipment available at UNB and CFB Gagetown CE Section, specifically the Trimble 4700 and the Trimble 4800. Using the output on the data logger LCD readout and the modes of the Trimble RTK surveying (Fixed, Float, and Autonomous) a measurements scheme was devised. When there is a data link between reference station and rover an icon appears on the LCD readout of the data logger. This icon may flicker, on and off, during the survey. If radio communications are lost between the reference and rover stations a warning appears stating "data link down". The modes for RTK surveying of the Trimble systems are as follows:

1. **RTK Fixed**- This mode, as indicated on the data logger, means that there is initialization between the reference station and rover. Centimetre level positioning is possible.
2. **RTK Float**- This mode, as indicated on the data logger, means that initialization has not been gained or it is lost between the reference station and rover. A float solution may occur if the number of visible satellites falls below four. Submetre level positioning is possible.
3. **Auto**- This mode, as indicated on the data logger, means that the data link has been lost between the reference station and rover. The rover GPS receiver will be making measurements as a stand alone receiver. Positioning consistent with SPS is possible.

Based on the RTK modes, the data link icon that appears on the data logger, and the warning message, the following measurement scheme for the data link at each RTK observation is proposed:

1. **GREEN**- If from the last measured point the radio link icon did not go on and off and the position is determined with fixed or float solution. Green would assume that

there is no interference with radio link between the reference and rover.

2. **YELLOW**- If from the last measured point the radio link icon went on and off or the warning appears, but the position is determined with fixed or float solution. Yellow would be a warning that there may be potential for interference with radio link, but positioning is still available.

3. **RED**- If from the last measured point the radio link icon went on and off or the warning appears, and the position is determined in autonomous mode. When Red is used there is no link between the reference and rover and RTK GPS positioning is not available.

Using the measurement scheme outlined above, the following steps were used for testing of the data link:

1. Set up the GPS Base Station and the radio transmitter on the control points.
2. Set up the rover receivers on the test vehicle.
3. Set both receivers in RTK mode and initialize with reference station.
4. Drive pre-determined test routes taking positioning observations depending on terrain and availability of the radio link. For example, distances between observations may be decreased if the signal is variable or it is evident by the terrain, that the signal may be affected.
5. RTK observations are classified by color.

This testing procedure should be complete on the same test routes at different times to provide redundancy in the measurements.

Three comparison performance criteria to indicate how the model predictions performed compared to the field measurements were used: visual comparison, route profile analysis, and coverage probability comparison.

The visual comparison consisted on analysis of plan view plots of two layers of data, prediction and field results. Depending on the sensitivity of the receiver, the predictions are classified using the colours of green, yellow, and red. This type of representation allows an intuitive analysis of how the predictions are affected by the terrain. For example, does the prediction make sense when compared with local terrain?

The route profile analysis looks at the predicted results against the field measurements along the drive test route. The predicted field strength is typically given in dBm, but the field measurements are colour coded. For these reasons constant values (in dBm) are assigned to each colour, for this project the constant values will be associated to the sensitivity of the receiver and legend of prediction results. This type of analysis highlights the trends in both the predictions and field measurements and allow for a correlation between the model and field test to be determined.

The Coverage Probability Comparison requires three elements for each field measurement: predicted average received power, the associated standard deviation, and sensitivity (specified signal level) of the receiver. A coverage probability must be chosen; typically this is in the order of 95-99%. From these a statistical comparison can be made between the field measurement and the corresponding prediction. For example, if the field measurement is green and the probability of the corresponding predicted value is greater than the sensitivity, then there would be a positive correlation.

The total length of the route used in the field tests was approximately 28 km and was broken down into three legs. The first leg is approximately 8 km long with terrain decreasing down to 20 m along the route. The second leg is circumferential to the reference station and is approximately 10 km long. The terrain for this leg varies between 30 to 170 m along the route. The third leg returns back to the reference station, with length of 10 km and terrain varying between 90 and 155 m. There is a large hill near the centre of the route approximately 2.5 km from the reference station with the peak reaching 220 m above mean sea level. Directly behind the hill, with respect to the reference station, is a valley. Figure 3 shows the 2 km marks along the drive test route and a terrain profile along the route. Also included in the terrain profile is the maximum height along a radial profile (stars) from transmitter to 1 to 24 km marks along the route at 1 km spacing. From this we see that the height of the terrain at specific locations between the transmitter and route varies between 25 to 125 m greater than that of the route height. The testing of the radio link using this route was complete during two sessions (in different days) labelled “Survey 1” and “Survey 2”, respectively, employing Trimble 4700 and 4800 systems (called “4700” and “4800” hereinafter).

RESULTS AND ANALYSIS

Field measurements results indicate that compared to survey 1, survey 2 had more yellow and red values. This trend is evident in both the 4700 and 4800 field measurements. Table 1 lists the percentage of the route that was green, yellow and red for each receiver and survey. There is 17% increase in yellow measurements for the 4800 with a corresponding 17% decrease in green. The 4700 had a 19% and 2% increase in yellow and red respectively, with a corresponding decrease of 21% in the green measurements. Based on the DTM the lost of the data link at the junction of legs 2 and 3, may be attributed to the large hill described earlier.

The test results from Survey 2 were different than what was expected. The signal was expected to be stronger due to the date of the survey and the fact that tree cover would be less, therefore reducing attenuation. Never the less, the results were consistent between the two receivers and surveys.

Table 1 – Percentage green, yellow and red measurements along the test route.

Survey	4700			4800		
	Green	Yellow	Red	Green	Yellow	Red
1	76	14	10	53	30	17
2	55	33	12	36	47	17
Diff.	-21	19	2	-17	17	0

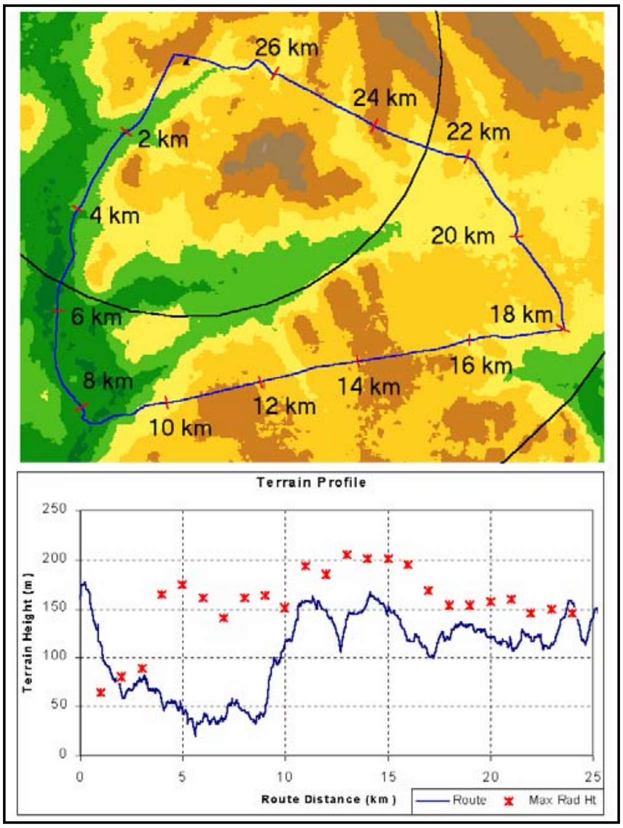

Figure 3 - DTM of testing area and terrain profile along the test route. The profile includes maximum heights along radial profile from transmitter to 1 to 24 km marks.

The DTM used for each model was a Digital Terrain Elevation Data (DTED) level 2 generated for the Department of National Defence using Synthetic Aperture Radar (SAR) interferometry (InSAR) using European Remotes Sensing (ERS) 1 and 2 sensors. The data used in the InSAR processing was collected on the 27th and 28th of April 1996. DTED level 2 has a grid spacing of 1 arc second (approximately 30 metres). The DTED specification calls for an absolute horizontal accuracy of less than 50 m and an absolute vertical accuracy of less than 30 m, both a 90% confidence level [DMA, 1996]. The final report [Atlantis, 2000] for the DTED generation stated that the terrain model meet both of these requirements.

The input parameters for each software package were standardized and kept to readily available radio system parameters and digital terrain data. All radio system parameters were extracted from the RTK GPS radio base station manual [Trimble Navigation Limited, 1998a]. Table 2 lists the input and output parameters used for all propagation models.

Table 2 – Input and output parameters

Input Parameters	**Input Values**
Transmitter	
Power (ERP):	40.82 Watts
Antenna Type:	Isotropic
Antenna Gain:	5 dBi
Antenna Height:	1.6 m
Polarization	Vertical
Receiver	
Antenna Gain:	
4700	5 dBi
4800	0 dBi
Antenna Height:	1.8 m
Model	
Sample Resolution:	30 m

Using the parameters and terrain model described above each model was used to generate predictions of the average received power (dBm) throughout the test area. These were 4700 and 4800 predictions for the models under study. The only difference between the two sets of predictions is that the 4700 predictions take into account the 5 dBi receiver antenna gain. The most evident difference between the predictions is the pattern shown by the Longley-Rice and Okumura-Hata (produced by CRC) models. Both models show concentric predictions indicating that the major influence on the prediction by these models is the separation distance between the transmitter and receiver and not the terrain variations. The Parabolic Equation, TIREM, CRC Predict and Okumura-Hata (produced by WinProp) all show varying degrees of correlation with topography.

The comparison criteria described previously was used to determine which model or models had the best performance compared to the field measurements. Each model was tested using the three criteria. Figures 4 and 5 contain the field measurements overlay the predictions based on the parabolic equation model. The figures also include the corresponding plot of the route field measurements and predicted received power (dBm) against distance along the route (km). The fixed values of -64 dBm, -90 dBm, and -116 dBm were chosen for the field measurements of green, yellow and red, respectively, to match the maximum values of yellow and red in the prediction results colour legend.

For the coverage probability comparison the predicted average received power was extracted for each field measurement and receiver. The sensitivity of the 4700 and 4800 receivers is -116 dBm (12 dB SINAD). The standard deviation of 12 dB was used. A coverage probability of 95% was chosen for this comparison. Table 3 lists the proposed statistical test for each field measurement and respective prediction. For example, if a field measurement is green and if the probability of the prediction greater than the sensitivity is larger than coverage probability then the test passes and fails otherwise. For each prediction and field measurement combination the test will either pass or fail. Further analysis will only present the percentage of correct predictions (passes) or acceptance of the test.

Based on the field measurement technique and proposed tests in Table 3, an ideal prediction model should have a high percentage of correct predictions for both the green and red measurements. For this project a yellow measurement is an indication of a weaker signal, but RTK positioning is still possible (Fixed or Float). Using this measurement technique and Table 3, an ideal model should have a relatively high number of correct predictions, but not as great as the green.

Table 3: Statistical test for each field measurement and corresponding prediction

Field Measurement	**Test**
Green	pr (Prediction > Sensitivity) > Coverage Probability
Yellow	pr (Prediction > Sensitivity) > Coverage Probability
Red	pr (Prediction > Sensitivity) < Coverage Probability

Figures 4 and 5 show field test results from both 4700 and 4800, for surveys 1 and 2 and the Parabolic Equation predictions. The plots of the predicted received power and test results along the route show a high degree of correlation for each survey. The variations in the measurements between 5 to 10 km and 14 to 19 km marks correspond with those of the lower predicted values. For both surveys and receivers, the green measurements correspond to higher predicted values and the red measurements correspond to the lower predicted values.

Table 4 lists the percentage of acceptance for the Parabolic Equation predictions. The green measurements show the highest percent of correct predictions followed by yellow. The percentage of correct red predictions is quite low for both 4700 and 4800 receivers in each Survey. The green predictions are the most consistent for both receivers and surveys, whereas the red and yellow show a variation between 3 and 13 percent. The high percentage of green and low percentage of red may indicate an overly optimistic prediction.

Table 4 - Percentage of correct predictions for Parabolic Equation

	4700			**4800**		
	Green	Yellow	Red	Green	Yellow	Red
Survey 1	93.2	81.0	19.1	92.1	83.8	36.5
Survey 2	96.6	93.9	32.1	93.0	87.2	44.4
Average	94.9	87.5	25.6	92.5	85.5	40.4

Similar analysis was performed to all other models. Based on this analysis became evident that some of the models do not perform very well in the given circumstances. The visual comparison, route analysis, and percentage of true hypotheses show that the Predict, TIREM, and Parabolic Equation perform the best overall in these given circumstances. The plots showing the predicted received power along the test route of the Predict, TIREM, and Parabolic Equation have very similar trends in the peaks, valleys, and slopes. Figure 6 shows all three of these models plotted together. Other than the minor difference between 5 and 10 km marks, all models follow the same trends.

Overall the TIREM and Parabolic Equation models are closer in scale along the entire route. The Predict results are lower than both the Parabolic Equation and TIREM, with differences up to 20 dBm between the 5 and 25 km marks. This difference accounts for the greater number of correct red predictions determined by the Predict model, when compared to the Parabolic Equation and TIREM. The Parabolic Equation and TIREM may be classified as “optimistic”, whereas Predict may be classified as “pessimistic”.

As expected, there is not a perfect model that predicts the coverage and no coverage exactly and is evident from the results of presented in the previous sections. From a RTK GPS user point of view the most important factor related to the data link is where there is no coverage or the potential for problems with the coverage. Therefore, based on the highest percentage of correct predictions for the red measurements, the Predict model performs the best followed by the TIREM then the Parabolic Equation.

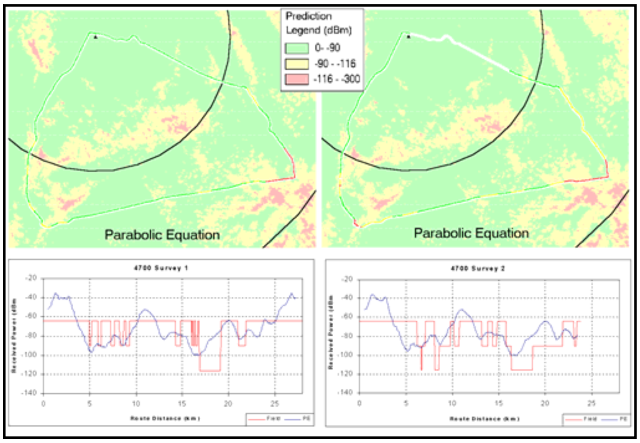

Figure 4 - 4700 survey 1 and 2 results and Parabolic Equation prediction results.

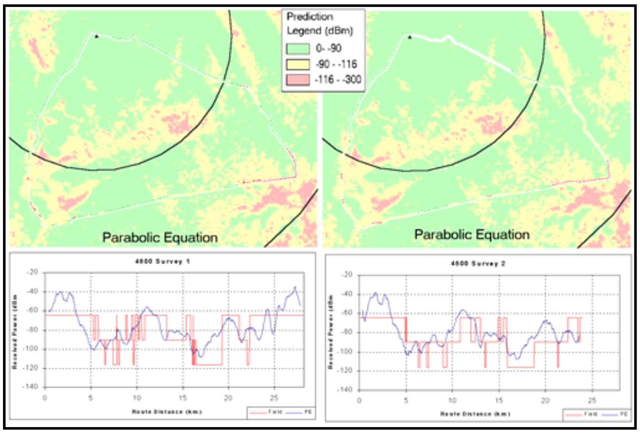

Figure 5 - 4800 survey 1 and 2 results and Parabolic Equation prediction results.

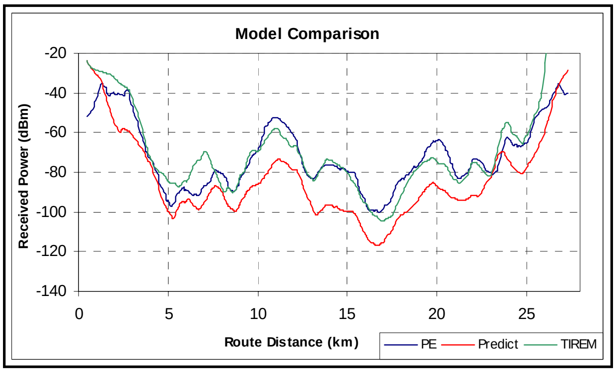

Figure 6 - Predicted received power of Parabolic Equation, Predict, and TIREM models along test.

CONCLUDING REMARKS

Based on the criteria the Parabolic Equation, TIREM, and Predict perform the best in the given conditions. Without considering the effects on the predictions due to land cover, the best model from the RTK GPS user point-of-view is the Predict.

Implementation of any of the three models into a mission planning tool will require documentation and references explaining the details. Based on the research for this project it is apparent that the Parabolic Equation has the most documentation outlining various implementation methods and in particular the newly published text by Levy [Levy, 2000]. Even though the Predict model performed the best in the project, based on conversations with CRC personnel an independent implementation of the Predict model may be difficult given the readily available documentation. Although not investigated for this project, IEEE [1988] suggests that TIREM computer program is available with all documentation. From an implementation point-of-view the Parabolic Equation and TIREM models are recommended. Further research into the effect of land cover should also be investigated to "fine tune" any implementation.

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