

Cell Coverage Area Estimation From Receive Signal Level (RSL) Measurements

AbdImagid Basere, Ivica Kostanic

Abstract—Evaluation the coverage area in a wireless network is very important for cellular system designers in order to provide good service to users. It is hard to collect the Receive Signal Level (RSL) for an entire coverage area because of many obstacles, such as buildings, lakes, and vegetation, so that the estimation of the coverage area is essential for locations for which it is difficult to measure the RSL. Also, estimating the coverage area can help to reduce the consumption of time and money. Kriging is a well-known method of estimating unknown values at specific locations, and it has shown accurate results. This paper discusses the estimation of a coverage area in Melbourne, FL by using Kriging. The distance factor in Kriging has never been studied before. A drive test is used to collect RSL measurements, and they are gathered in different distance sizes, a procedure known as binning, to shape the coverage area. In this case, Kriging is used to estimate the coverage area in bin sizes that are 200x200, 100x100, 50x50, and 25x25 meters of resolution.

Index Terms— kriging; coverage estimation; coverage map; binning; spatial statistics

I. INTRODUCTION

THE cell coverage area is one of the most important factors in cellular communication system designs. It may be defined as the largest distance that a cell phone can be away from the base station while still maintaining an acceptable service [1]. The base station is usually located near the center of the required served area [2].

A. Cell Coverage Area

Any cellular system network is comprised of several cells. They are connected together to provide radio coverage over a larger geographical area. The cell coverage area allows a large number of users to communicate with each other and with fixed base stations in the cellular network. These base stations provide connections to transceivers regardless of their mobility, whether they are moving across cells or are stationary. The extent of cell and network coverage depends mainly on natural factors, such as propagation conditions, and human factors, such as the landscape (urban, suburban, rural), subscriber behavior, etc. [3].

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B. Importance of Understanding Cell Coverage Area

1) *Coverage Planning*: Coverage planning procedure may be divided into three phases. The first phase is called the preplanning phase. In this phase, the general properties of the future network are investigated. In the second phase, the site survey for the targeted coverage area and an investigation of possible base stations' locations are performed. Then, constant modification is made to move the network planning forward. In the final phase, driving test data collection is done repeatedly in order to examine the coverage area until good coverage is guaranteed. After that, the system is ready to be deployed in the target area to provide service [4].

2) *Concept of Handoff*: Handoff is an operation that allows a mobile user to move from one cell to another without interruption of service. The handoff procedure can be implemented based on many conditions such as interference levels and signal strength [5].

3) *Interference*: Interference occurs when neighboring cells operate on the same frequency at the same time. One of the main impairments that can limit performance of a cellular system in the multi-cell network is the inter-cell interference. Interference causes background noise and bad voice quality when a call is in progress. In this case, the coverage area determination is helpful to eliminate interference, leading to higher quality of service [6].

4) *User Location*: The mobile telecommunication network contains many base stations (BSs) which offer mobile telecommunication service to mobile users. Each BS represents a cell that is providing coverage to a particular area, and each cell is divided into sectors. Understanding the coverage of the sectors helps locate the users that are within systems service area [7].

C. Methods for Estimating Cell Coverage

A There are many methods of performing the estimation of coverage areas, and each of them has their own benefits and drawbacks, but none of them is 100% accurate [8]. Three performance estimation methods are described as follows.

1) *Geometry*: There are many methods of computational geometry. The Voronoi diagram is one of the most important data structures in computational geometry, and there are three reasons for its usefulness. First, Voronoi diagrams are seen in nature in many cases. Certainly, some natural processes may be used to describe specific classes of Voronoi diagrams. Human understanding is facilitated by visual perception. For example, if one grasps the underlying structure of anything, its complete status might be understood at an advanced level. Second, Voronoi diagrams

have amazing and exciting mathematical properties; for example, they are linked to many famous geometrical structures. As a result, some authors consider that “the Voronoi diagram is one of the most fundamental constructs defined by a discrete set of points” [9]. Lastly, Voronoi diagrams have been shown to be a strong tool in solving unconnected computational problems. In the last few years, Voronoi diagrams have caught the interest of computer scientists [9].

However, algorithms that use Voronoi diagrams to estimate coverage areas do not take into consideration the features of the propagation environment, and they oversimplify the coverage problem [10]. For this reason, among others, the use of Voronoi diagrams is not being followed in this work.

2) *Prediction*: One of the most elementary tasks in the cellular system design is propagation modeling and coverage prediction. Over many years a variety of approaches have been used to predict coverage areas using propagation models. These models are helpful in predicting path loss or signal attenuation, thus enabling acceptable reception [11]. Cellular designers usually use advanced planning tools for network coverage estimation. The coverage estimation is based on terrain data combined with a propagation model [12].

3) *Measurements*: Drive tests are normally used for collecting the Receive Signal Level (RSL). Because carrying out driving tests is time consuming and expensive, there is significant interest in improving the quality of coverage estimation that is obtained from a limited number of driving test measurements. The problem with drive test measurements is that data cannot be conducted in the whole region of the network because of many obstacles [12] such as buildings, lakes, and vegetation. In this case, the estimation of the coverage area is important and can rely on spatial prediction techniques such as Inverse Distance Weighting, Kriging, and Artificial Neural Networks.

II. LITERATURE REVIEW

A. Data Collection

Verification of cellular system coverage requires the RSL measurements that can be collected by spatial averaging of immediate signal power readings. The measurements are typically gathered in conformity with the well-known Lee sampling criteria [13]. Equation 1 describes the amplitude of the received signal envelope in the mobile propagation environment [13].

$$r(x) = m(x)r_0(x) \quad (1)$$

It is reasonable to denote the received signal by a stationary stochastic process, where $r_0(x)$ represents the fast fading variation of a mean signal strength value equal to 1. The mean value of the signal envelope is $m(x)$, and x is the location of the local mean [14].

There are two questions that need to be answered in order to get an estimate that is statistically valid for the local mean. First, how many ‘snapshots’ of the received signal level are required to be collected over a suitable distance, in order to

assure the statistical validity of the approximation, and second, what would be an appropriate spatial distance to average over. The space averaging over a distance should be performed in order to guarantee averaging Rayleigh fading effects. Estimation of the local mean can be characterized as an average of the power of the signal over a appropriate distance ($2L$) as shown in equation 2 [15]:

$$p(x) = \frac{1}{2L} \int_{x-L}^{x+L} r(y)^2 dy = \int_{x-L}^{x+L} m(y)^2 r_0(y)^2 dy \quad (2)$$

keeping $2L$ small enough so that $m(y) \approx m_x$ over $[x-L, x+L]$

The variance of the power estimate is given as [14].

$$\hat{p}(x) = \frac{m_x^2}{2L} \int_{x-L}^{x+L} r_0^2(y) dy \approx m_x^2 \times \langle r_0^2(x) \rangle = \frac{4m_x^2}{\pi} = p_{av} \quad (3)$$

$$\sigma_{\hat{p}}^2 = \frac{1}{2L} \int_0^{2L} \left(1 - \frac{x}{2L}\right) \left(m_x^4 R_{r_0^2}(x) - 16 \frac{m_x^4}{\pi^4}\right) dx \quad (4)$$

where $R_{r_0^2}(x)$ is the autocorrelation function of r_0^2 given by

$$R_{r_0^2}(x) = \frac{16}{\pi^2} \left[1 + J_0^2\left(\frac{2\pi x}{\lambda}\right)\right] \quad (5)$$

Equation (4) has been statistically evaluated [2] for different values of L , and the results for 1σ and 2σ spreads are shown in Table I [15].

TABLE I
SPREAD OF THE LOCAL MEAN ESTIMATE AS A FUNCTION OF THE AVERAGING DISTANCE

2L	$\sigma_{\hat{p}}$	1 σ Spread $\log\left(\frac{P_{av} + \sigma_p}{P_{av} - \sigma_p}\right)$	2 σ Spread $\log\left(\frac{P_{av} + 2\sigma_p}{P_{av} - 2\sigma_p}\right)$
5λ	$0.33p_{av}$	2.98dB	6.5dB
10λ	$0.24p_{av}$	2.14dB	4.5dB
20λ	$0.18p_{av}$	1.55dB	3.24dB
40λ	$0.12p_{av}$	1dB	2.1dB

For most practical situations, terrain variations (shadowing) over a 40λ distance can be assumed to be negligible, and, therefore, the assumption that the mean value of the signal is not changeable during the integration in equation (3) is valid [15].

“Macroscopic propagation models predict the mean received signal level over a small geographical area called a bin” [15]. The bin’s size is calculated as a function of accuracy and the database terrain resolution, computation time, roughness of the terrain, etc. and usually ranges from 50m to 500m. The local area mean (LAM) is the mean received signal of a bin. Performing averaging of several

local means can allow comparing measurement data with the predictions of the propagation model [15].

During driving through a particular bin, the measurement equipment implements the collection of the local means within the bin. The local means tend to comply with a normal distribution in the logarithmic domain with a standard deviation σ and mean value m . The local area mean for the specific bin is calculated as an average value of the local means collected in that specific bin.

$$L_{AM} = \frac{\sum_{k=1}^N L_{Mk}}{N} \quad (6)$$

where L_{AM} is the local area mean, L_{Mk} represents the k^{th} local mean and N is the total number of local means collected in the bin [15].

B. Spatial Binning

In order to enable users to understand how the data are changing between the temporal bins, spatial binning is essential. Spatial binning gathers data points that are near one another to prevent the situation in which data points share the same location in space. Both Longitude and Latitude contain numeric information. A simple grid is used in the binning procedure; the resolution is controllable by the users [16].

Insufficient drive test data can cause inaccurate estimation of coverage area. However, collection of too much data is costly and time consuming. Combining data by averaging can help with reducing the processing load and quantifying data to the resolution of a specific terrain, which is referred to as the bin of the area [15].

C. Interpolation Methods

Through interpolation, one-use measurement data samples can be collected and used to estimate measurement data at other points where measurement data are not available. The most popular spatial interpolation methods are Kriging, spline interpolation, interpolating polynomials, and Inverse Distance Weighting (IDW) [17]. Among the above methods, IDW and Ordinary Kriging (OK) are the most commonly used, and are typically the most frequently suggested interpolation techniques [18].

“Kriging is an interpolation technique based on the methods of geostatistics” [19]. Krige (1951) collected samples over mining fields and used them to develop optimal interpolation methods for use in the mining industry. Nowadays, the Kriging method is being used in soil mapping, groundwater modeling [20], [21], and in many other spatial problems [20].

III. PROPOSED APPLICATION

A. Kriging Method

The principle interpolation equation in the Kriging model is given by [19].

$$\hat{z}(x_0) = \sum_{i=1}^n \lambda_i z(x_i) \quad (7)$$

where $z(x_i)$ is the measured value at the i^{th} location, λ_i is an unknown weight for the measured value at the i^{th} location, and $\hat{z}(x_0)$ is the prediction location.

As seen, at the point where the algorithm performs the interpolation the value is obtained as a weighted average from the points in the immediate neighborhood. The most significant task associated with the implementation of (7) is the determination of the appropriate weights. The fitted variogram is used to determine the weights λ_i that are required for local interpolation. The estimation $\hat{z}(x_0)$ may be unbiased by choosing the weights λ_i . Predicting numerous locations may give some values which could be below the real values and some above, so the sum of weights λ_i must be equal to 1 in order to guarantee that the prediction of the unknown measurement is unbiased [20].

$$\sum_{i=1}^n \lambda_i = 1 \quad (8)$$

1) *Semivariogram*: “The variogram characterizes the spatial continuity or roughness of a data set. Usually, one dimensional statistics for two data sets might be equal” [19]. However, the spatial continuity could be dissimilar. The difference between the semivariogram and the variogram is just a factor of 2. The variogram is described as [20].

$$2\gamma(\mathbf{h}) = E[Z(\mathbf{x}) - Z(\mathbf{x} + \mathbf{h})]^2 \quad (9)$$

shows the variogram $2\gamma(\mathbf{h})$ of differences between sites which are functions of the distance \mathbf{h} between them, where $Z(\mathbf{x})$ and $Z(\mathbf{x} + \mathbf{h})$ are the values of the random variable Z of interest at locations (\mathbf{x}) and $(\mathbf{x} + \mathbf{h})$. The function of interest in practice is $\gamma(\mathbf{h})$, which is called a semi-variogram and is used in Kriging. The statistical expectation operator is $E[\]$. Kriging uses the empirical variogram $\gamma(\mathbf{h})$ as a theoretical variogram to get the first approximation of the variogram for spatial prediction [20], [22].

$$\hat{\gamma}(h) = \frac{1}{2n} \sum_{i=1}^n \{z(x_i) - z(x_i + h)\}^2 \quad (10)$$

where $Z(x)$ is the value at location x_i , $Z(x_i + h)$ is the value at location $x_i + h$, and n is the number of pairs of points of observations of the values of attribute Z separated by distance h ; the plot of $\hat{\gamma}(h)$ against h is known as the experimental variogram. The experimental variogram provides useful information for interpolation, optimizing sampling, and determining spatial patterns. It is clear that the number of semi-variogram samples is proportional to the available pairs of locations. When datasets are large, the number of pairs of locations will grow quickly. Therefore,

the binning of the distance is required in order to get the variogram parameters, which are the sill, the nugget, and the range [20]. Also, the case of the RSL interpolation, the binning of the data is necessary so that the effects of fast fading are reduced.

2) *Fitting Variogram Models*: The fitting model is obtained by plotting the empirical semivariance $\gamma(h)$ versus the lag distance (separation distance of the pairs) [23], and it provides specific parameters, namely the sill, the nugget, and the range as shown in Fig. 1.

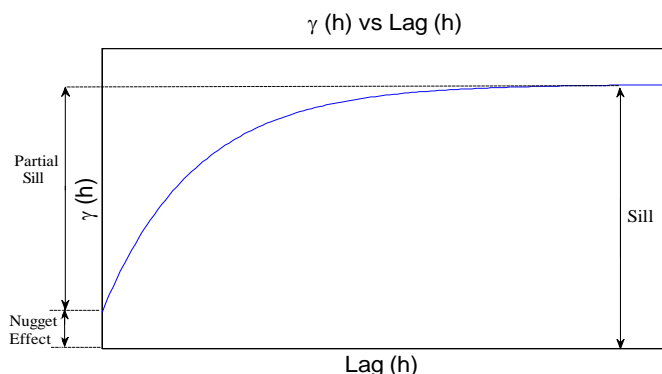


Fig. 1. Simple transitional variogram with range, nugget, and sill

A variogram model is a parametric curve fitted to a variogram estimator. There are four variogram fitting models that are used in the Kriging method to help interpolate data accurately, and the most commonly used variogram models are summarized as follows [20]:

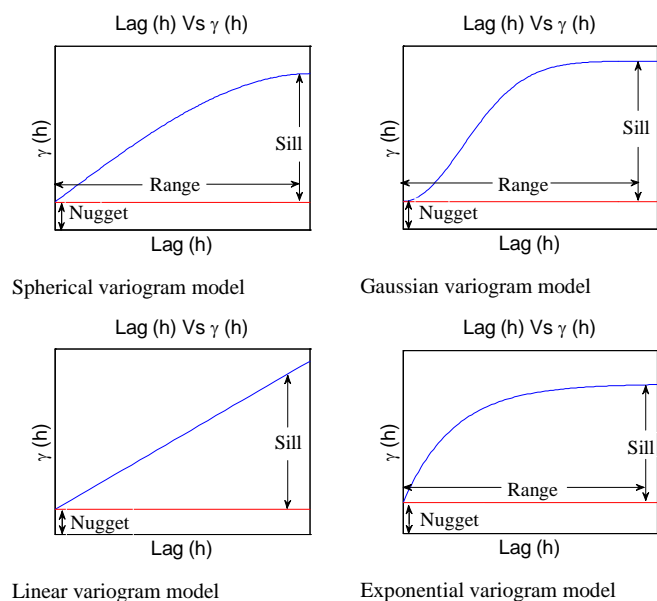


Fig. 2. Examples of most commonly used variogram models

The remainder of this paper is organized as follows: Section IV gives an overview of experimental verification, which is divided into measurement setup, data collection, and results of interpolation; in Section V, a brief summary and conclusions are provided.

IV. EXPERIMENTAL VERIFICATION

The measurements are performed in a study area that is located in Melbourne, FL. The map of the area is presented in Fig. 3. Although, the study is performed at a specific

frequency; the methodology should be widely applicable across all UHF/VHF frequencies used for personal communication systems. The Melbourne area is a suburban area. For the study, the transmitter is located on the rooftop of a multi-story building, making for good wide area coverage. The majority of houses in the selected area are one to two floors, and their heights range from 4 to 9 meters. Also, there are open areas such as small artificial lakes, parks, and vegetation. The satellite view of the study area is shown in Fig. 3.

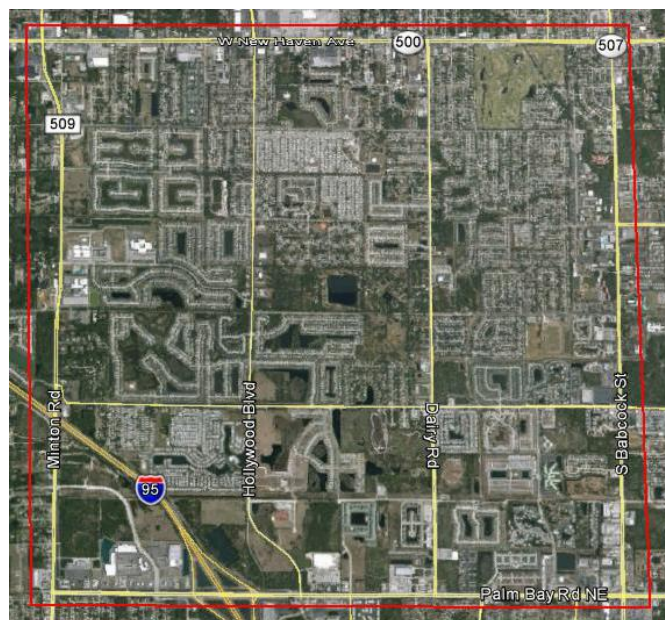


Fig. 3. Satellite view of the studied environment

A. Data Collection

An illustration of the data collection system is presented in Fig.4. The system consists of the following parts:

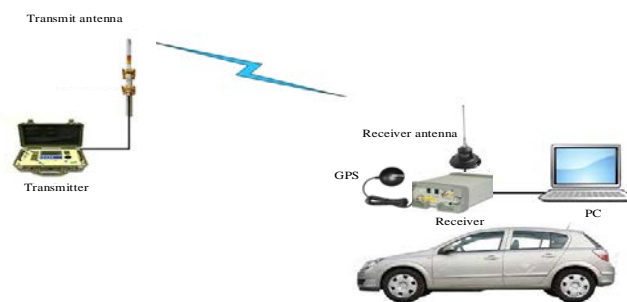


Fig. 4. Illustration of the measurement system

1) *Transmitter*: The transmitter is used to evaluate PCS band signal propagation, and the frequency range is 1.85 to 2.1 GHz, where the power is up to 43 dBm. This transmitter allows the transmission of the signal at the radio frequency of 1925MHz.

2) *Transmit Antenna*: The transmitter antenna is used in the transmission of signals to be measured. It is an omnidirectional antenna, and its frequency ranges between 1850 MHz and 1990 MHz. It also radiates in a horizontal plane with 6 dBi gain.

3) *Receiver*: An Agilent Technologies E6474A receiver is used to collect RSL measurements at different spatial points.

4) *Receiver Antenna:* The receiver antenna is used to collect RSL measurements. It is an omnidirectional antenna with a frequency range between 1850 and 1990 MHz.
Planning: Coverage planning.

5) *GPS Antenna:* The GlobalSat BU-353-S4 is a USB magnet mount GPS receiver whose characteristics are extreme sensitivity, low power consumption, and an ultra-compact chipset. The BU-353-S4 GPS is appropriate for automotive navigation, marine navigation, mobile phone navigation, personal positioning, and fleet management. It is compatible with Microsoft Windows. A SiRF Star IV GPS chipset is used in this GPS, which delivers high performance in urban canyons as well as in dense foliage. It uses a 48-channel antenna, which allows the receiver to give the highest degree of accuracy. It is connected with the PC to allow JDSU Wireless Solutions software to identify and store the position of measured data in terms of latitude, longitude, and altitude. The stored position helps the user to get the best interpolation of the coverage area.

B. Data Collection and Binning

A drive test was performed in the targeted geographic area, where RF measurements were detected and stored. The measurements that were collected to provide interpolation for gaps are shown in Fig. 5.

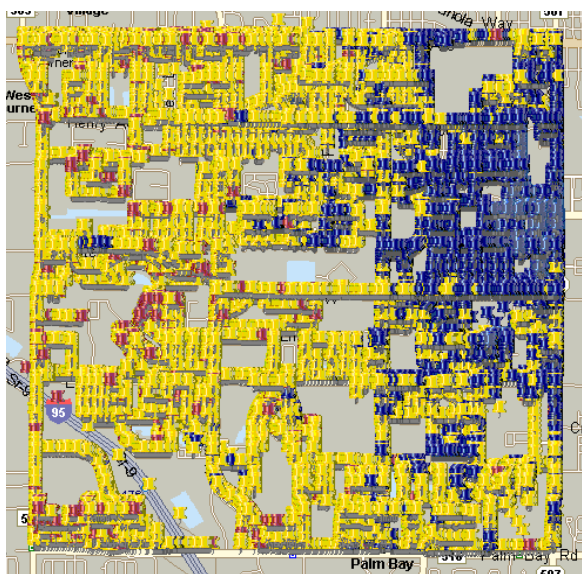


Fig. 5. Measured Data of the Study Area.

The measured data are used to generate a coverage area map for the area. Every spatial point can be described as a point of intersection of both the x-axis and the y-axis, where longitude is the x-axis and latitude is the y-axis. A Matlab code was used to do binning. Since the data set is large, the binning was done for the coverage area as shown in Fig. 6-9 with a different resolution. In this research, the binning is based on the distances, such as 200x200, 100x100, 50x50 and 25x25 meters binning.

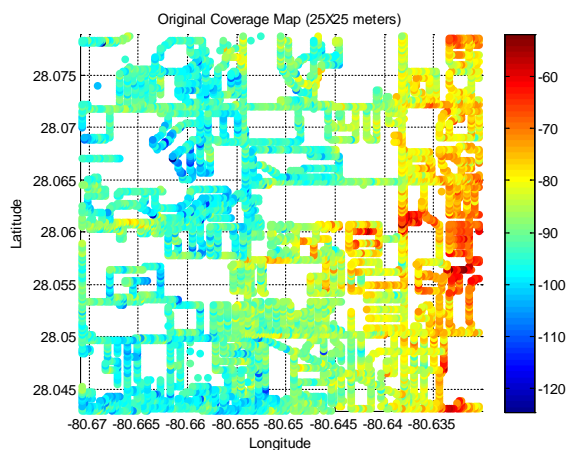


Fig. 6. Original coverage area of 25x25 meters resolution

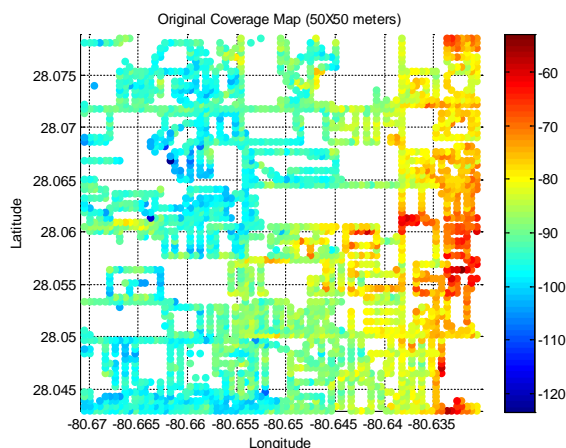


Fig. 7. Original coverage area of 50x50 meters resolution

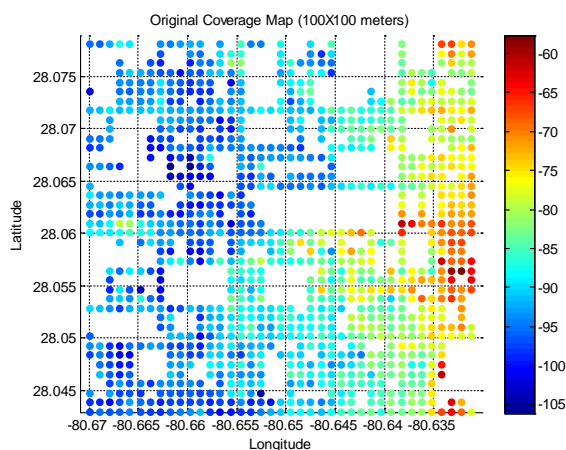


Fig. 8. Original coverage area of 100x100 meters resolution

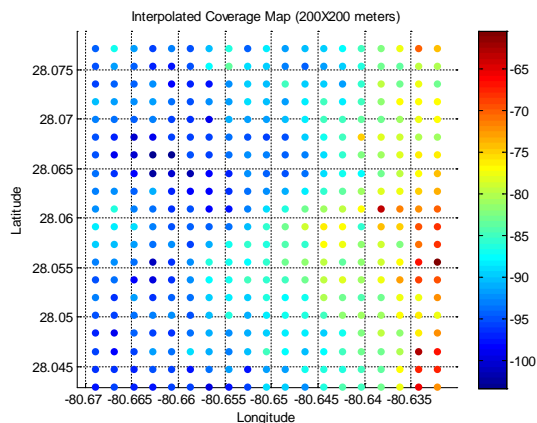


Fig. 9. Interpolated coverage area of 200x200 meters resolution

Calculating the semivariogram fitting model is done by plotting the empirical semivariogram versus the distance as shown in Fig. 10. The empirical semivariogram cloud shows that the number of pairs of locations will rise quickly when the dataset becomes large.

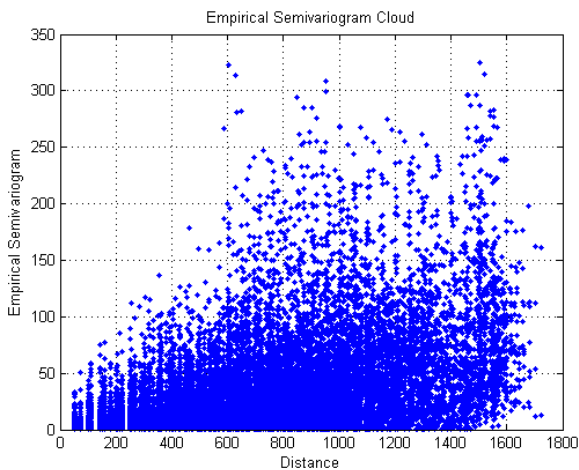


Fig. 10. Empirical semivariogram cloud

When the dataset is large, the calculation of the semivariogram fitting model becomes difficult. As a result, the points of the variogram cloud may be gathered into classes of distances ("bins") in order to find the variogram fitting model for the targeted area. The linear fitting variogram model is being the result of the measurements obtained from the collected data as shown in Fig. 11.

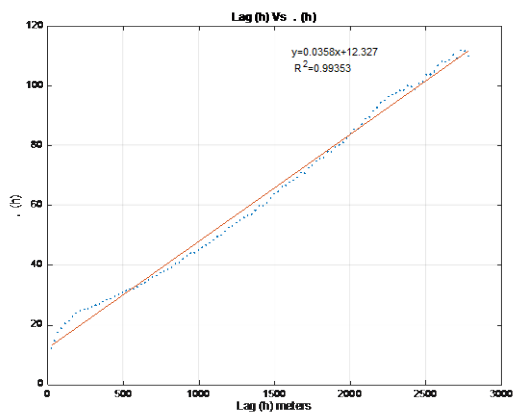


Fig. 11. Linear variogram model of study area

C. Results of Interpolation

The interpolation view of the coverage area for 200x200, 100x100, 50x50, and 25x25 meters resolution are shown in Fig. 12-15. The interpolation of the coverage area of 25x25 meters resolution gave more details about RSL, and it is smooth as shown in Fig. 12.

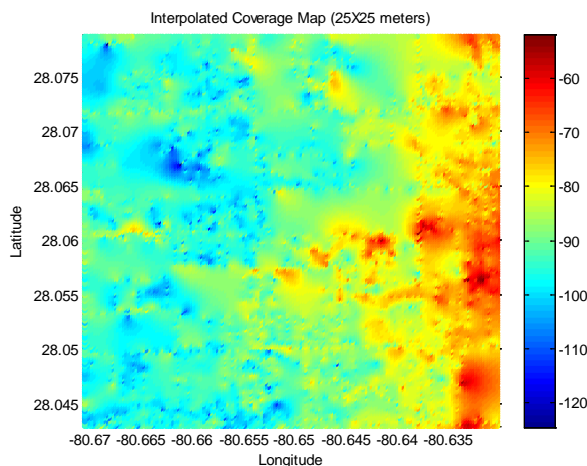


Fig. 12. Interpolated coverage area of 25x25 meters resolution

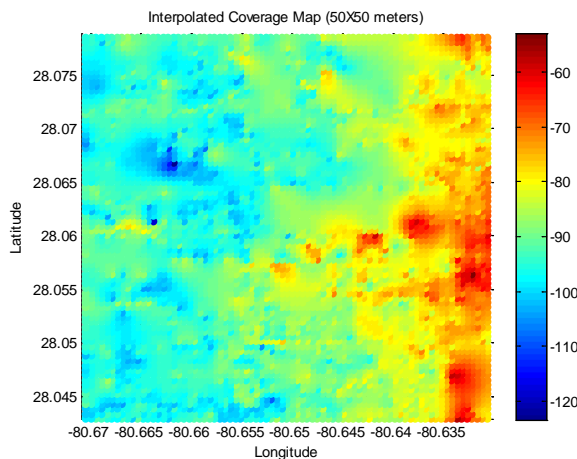


Fig. 13. Interpolated coverage area of 50x50 meters resolution

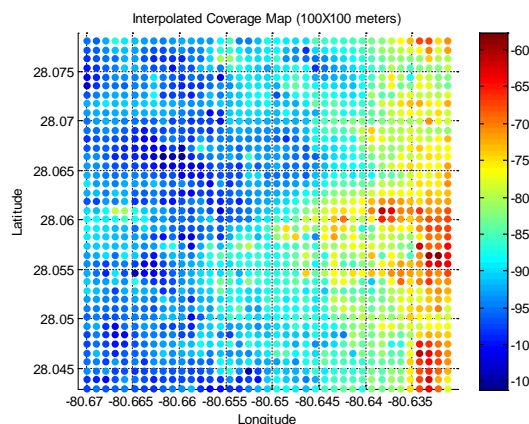


Fig. 14. Interpolated coverage area of 100x100 meters resolution

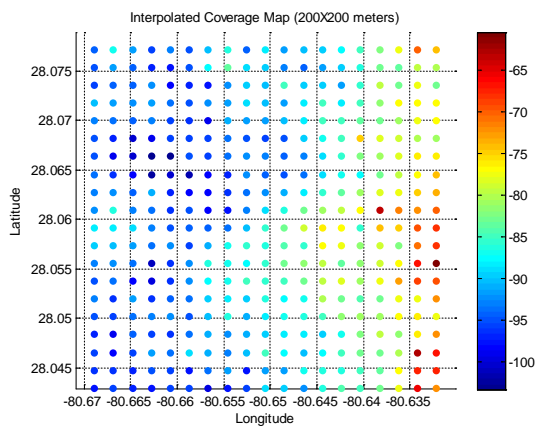


Fig. 15. Interpolated coverage area of 200x200 meters resolution

V. SUMMARY AND CONCLUSIONS

Measurements of the RSL in the 1925MHz band in a suburban area were collected. The interpolation of a specific coverage area was done successfully. Measurements show that the semivariogram model is linear. The use of Kriging proves to be very effective. It shows a good result when the coverage area was divided into different bin sizes that are 200x200, 100x100, 50x50, and 25x25 meters of resolution. Likewise, the importance of the exact measurements of the RSL for the binning procedure is shown. The approach looks very promising and it is believed to be worth pursuing at a larger scale.

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