# An Optimal Signal Loss Propagation Model For LTE Networks

**Stephen Ojo, Arif Sari, Murat Akkaya**

**Abstract:** This article presents an optimal signal loss propagation model developed for Long Term Evolution (LTE) networks in Cyprus at an operating frequency of 3.1GHz. Experimental and Analytical studies of signal loss in LTE networks were carried out and propagation measurements were collected across rural, suburban and urban areas of Cyprus. Five signal loss propagation models were selected and compared with the measured signal loss. The Cost-231Walfisch-Ikegami model gave the best performance using the performance metric of root mean square error (RMSE). The model was then optimized for LTE networks in Cyprus using the second order polynomial least square regression algorithm and the results clearly shows that the developed model agrees well with the measured signal and is therefore suitable for use as an effective signal propagation model. The developed model accurately characterized radio coverage and network planning of LTE networks in Cyprus, thus enhancing the quality of mobile services. The developed model can be used to accurately determine signal loss across all the LTE networks thus improving the quality of service (QoS).

**Keywords:** Signal loss, Quality of service, Propagation, Experimental, Optimal, regression, least square

## 1. INTRODUCTION

Wireless networks have brought a great revolution to the telecommunication industry having provided a great opportunity for subscriber's mobility on plethora of networks thereby increasing the demands by customers for wireless communication services [1]-[4]. The wireless mobile networks uses high frequency radio waves to establish communication between a base transceiver station and a mobile receiver in a seamless way without any wired connection between them [5]-[6]. There are many growing issues when it comes to wireless communication and the sustainability of such a system in which some of them are channel capacity, noise, interference, losses in signals, frequency reuse and security of wireless system. The main objective of signal transmission in wireless channels is to have a seamless transmission without much attenuation in signal strength as it travels from the transmitter to the receiver and achieving this will be the central theme of this article. Probabilities of call blocking and dropping should be reduced to the minimum level if the transmission is to achieve the purpose to which it is intended. Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Received Signal Strength Indicator (RSSI) are the major performance metrics that can be used to ascertain the quality of signal strength in wireless channels. The prevalence of signal loss in LTE networks and the challenge of accurately characterizing it in Cyprus brought about this development of an optimized signal loss model so as to effectively characterize signal loss in LTE networks[7]-[11]. Many signal propagation models have been developed for LTE networks but most of them are environmental dependent. Most of the existing models on signal loss in LTE networks have not yielded an optimal results when deployed to LTE networks in Cyprus. This is the first experimental study that will be conducted on LTE network in this location with extensive propagation measurements at 3.1GHz. The existing signal propagation models will be compared with the measured signal loss and the best performing model will be selected. The model will be developed for LTE networks for this location so as to arrive at an optimal solution. Proper validation of the developed model will be done using key performance metric of root mean square error. The optimization will be done using the least square error.
The remaining aspects of this paper will be structured as follows: section 1 presents the introduction, section 2 discusses Signal loss in wireless channels, section 3 presents the propagation measurements and experimental setup, section 4 presents the methodology and algorithm used in best model selection, the results and discussion is given in section 5 and the conclusion is given in section 6.

## 2. SIGNAL LOSS IN WIRELESS CHANNELS

Signal loss in wireless channels has dominated the research space in recent years and this dominance has emphasized the key role of this subject in wireless communication. When signals travels from the transmitter, propagating through space, the strength of the particular signal gets weaker as the distance of propagation increases in the propagating medium [1][7]. This attenuation in signal strength as it travels from the transmitter to the receiver is referred to as signal loss [12]-[14]. Non-line of sight (NLOS) in which most signal propagates through in the present densely packed urban centers introduces multipath component in the path of the propagating signal thereby decreasing the signal strength and increasing the Bit Error Rate (BER). The signal loss is a function of the environment through which the signal is propagating and the strength of the signal gets attenuated or otherwise depending on the environment of propagation [15]-[18]. Wireless signals propagating in a line of sight environment will not suffer any attenuation but signals propagating in non-line of sight will suffer signal attenuation. The latter situation described is what is prevalent in the present day urban cities across the world which brings to relevance the subject of signal loss [19]. Signal travelling cannot propagate in space without suffering one form of loss or the other before reaching its destination and thus the signal received by the mobile receiver is attenuated signal distorted in amplitude and phase. In mobile communication, signals suffer from radio attenuation and multipath fading caused by surrounding objects.

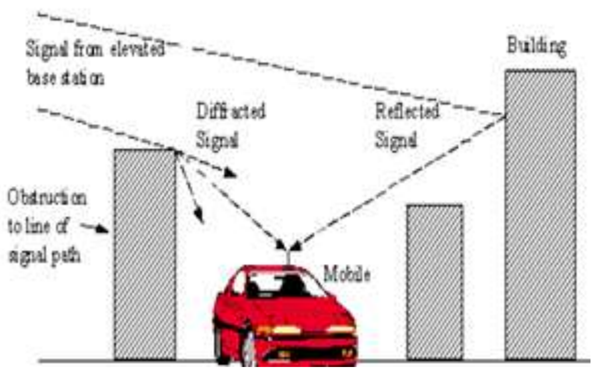


***Figure 1**. Signal loss in wireless channels.*

The persistent interaction between propagating signal, the propagating medium and the objects in the direction of propagation is responsible for the attenuation and signal loss as it travels from the transmitter to the receiver [20]. It must also be stated that signal loss also varies from one environment to the other. The attenuation suffered by a signal propagating in an urban area where there are many tall buildings will be definitely different from that suffered by another signal propagating in a rural area where there is clear line of sight and less obstructions in signal path. Multipath Propagation, Fading, co-channel interference are some of the major causes of signal loss in wireless networks [20].

**2.1 Signal Loss Models for LTE signal Propagation**Propagation models are used extensively in network planning especially for conducting feasibility studies and performing initial system development. Planning an efficient mobile cellular network that will characterize signal loss effectively requires an analytical model that will factor in all environmental details and conditions. Many analytical models have been developed for the characterization of signal loss and these models help the service and network providers to effectively plan so as to be able to predict signal loss accurately during propagation. Some of the models are enumerated in this article.

### 2.1.1 Stanford University Interim (SUI) Model

The Stanford University Interim model is a signal loss characterization model developed under the IEEE 802.16 wireless standard for fixed wireless access system [21][1]. The efficacy of this signal loss model is in its capacity to present signal characterization for wireless signals below 11GHz.

**The SUI mathematical formulations are given below**

$$\text{Signal loss} = B + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) + K_f + K_h + S_f \quad for\ d \succ d_0 \quad (1)$$

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \quad (2)$$

$$\gamma = a - bh_b + \frac{c}{h_b} \quad (3)$$

$$K_f = 6.0\log_{10}\left(\frac{f}{2000}\right) \quad (4)$$

$$K_h = -10.8\log_{10}\left(\frac{h_r}{2000}\right) \quad for\ terrain\ A\ and\ B \quad (5)$$

$$K_h = -20.0\log_{10}\left(\frac{h_r}{2000}\right) \quad for\ terrain\ C$$

Where, B is the free space signal loss model, $d$ is the distance from the base transmitting station to the mobile receiver in km, $d_0$ is the reference distance in this case 100m, $\gamma$ is the signal loss exponent, $a, b, c$ represents terrain parameters for urban, suburban and rural areas respectively, $h_b$ is the transmitting station height in meters, $K_f$ is the correction factor for the operating frequency, $K_h$ is the correction factor for the mobile antenna height, $f$ is the frequency in GHz , $h_r$ is the height of the mobile receiver in meters and $S_f$ is the log-normal distribution which represents shadowing effects like fading and other clutters.

### 2.1.2 ECC-33 Model

This signal loss propagation is an improved and updated version of the Okumura model which was developed in the year 1968 [22]. The ECC-33 model serves as an improvement and corrections of the errors in the original Okumura model.

$$S_L(dB) = A_{FS} + A_{BM} - G_B - G_R \quad (6)$$

$$A_{FS} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f) \quad (7)$$

$$A_{BM} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56(\log_{10}(f))^2 \quad (8)$$

$$G_B = \left(\log_{10}\left(\frac{h_b}{200}\right)\right)\left(13.958 + 5.8(\log_{10}(d))^2\right) \quad (9)$$

$$G_R = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585] \quad (10)$$

Where $A_{FS}$ the free space attenuation, $A_{BM}$ is the median signal loss, $G_B$ is the base station height gain factor, $G_R$ is the mobile station antenna gain factor, $f$ is the frequency in GHz, $d$ is the distance of separation between the transmitting station and the mobile station in km.

### 2.1.3 COST-231 Walfisch-Ikegami Model

The COST-231 Walfisch-Ikegami model was developed for signal propagation in wireless networks under line of sight and non-line of sight conditions [1], [23]-[26]

$$S_L(dB) = L_{CAF} + L_{BDH} + L_{MSD} \quad (11)$$

$L_{CAF}$ = Free space path loss

$L_{BDH}$ = Rooftop-to-street diffraction and scattering loss.

$L_{MSD}$ = Multiscreen diffraction loss

$$L_{CAF} = 32.4 + 20\log_{10} d(Km) + 20\log_{10} f(MHz) \quad (12)$$

$$L_{BDH} = -16.9 - 10\log_{10} w + 10\log_{10} f + 20\log_{10}(h_t - h_r) + T(dB) \quad (13)$$

$$T = \begin{cases} -9.646dB & 0 \le \psi \le 35^0 \\ 2.5 + 0.075(\psi - 35)dB & 35^0 \le \psi \le 55^0 \\ 4 - 0.114(\psi - 55)dB & 55^0 \le \psi \le 90^0 \end{cases} \quad (14)$$

Where T is the orientation loss and given as :

$$L_{MSD} = L_{BSH} + K_a + K_d \log_{10} d + K_f \log_{10} f - 9\log_{10} B \quad (15)$$

$$L_{BSH} = \begin{cases} -18 - 18(h_t - h_{roof}) & h_t \succ h_{roof} \\ 0 & h_t \prec h_{roof} \end{cases} \quad (16)$$

$$K_a = \begin{cases} 54 & h_t \succ h_{roof} \\ 54 - 0.8(h_t - h_{roof}) & d \ge 500m;\ h_t \le h_{roof} \\ 54 - 1.6d(h_t - h_{roof}) & d \prec 500m;\ h_t \le h_{roof} \end{cases} \quad (17)$$

$$K_d = \begin{cases} 18 & h_t \succ h_{roof} \\ 18 - 15\left(\dfrac{h_t - h_{roof}}{h_{roof} - h_r}\right) & h_t \prec h_{roof} \end{cases} \quad (18)$$

$$K_f = \begin{cases} 4 + 0.7\left(\dfrac{f}{925} - 1\right) & \text{for medium sized and suburban} \\ 4 + 1.5\left(\dfrac{f}{925} - 1\right) & \text{for metropolitan areas} \end{cases} \quad (19)$$

Where:

$h_{roof}$ = Maximum height of the buildings in meters

$B$ = Distance between buildings

$w$ = The road width in meters.

$\psi$ = Orientation angle measured in degrees.

### 2.2 Propagation Measurements and Experimental Setup

Signal measurements was carried out at 3.1GHz across 40 base stations in Cyprus via drive test using Test Mobile System (TEMs 16.3.6). TEMs 16.3.6 is a software developed by Ericsson Company to read the information on the network from the transmitting station to the receiving station [27]. During the drive test, the RSRP was measured and propagation measurements were taken at 3.1GHz using the Test Mobile System (TEMs 16.3.6) LTE software [28]-[30]. Measurements were taken across 40 base stations in environments classified as rural, suburban and urban representing the entire country. A propagation distance of 100m-2.0km was used in measurement in each base station. The RSRP of the mobile station is viewed from the screen of the computer and readings were taken at intervals of 100m. 3600 Propagation measurements were collected from the entire base stations from July 2019-December 2019. The TEMs 16.3.6 LTE software installed on the computer, a 4G mobile phone and a GPS all housed in the vehicle of the drive test gave the measured RSRP. Readings were collected on the screen of the computer. The base station heights used are 25m, 35m and 45m for urban, suburban and rural areas respectively. A mobile antenna height of 1.5m was used for the experimental study.

***Figure 2.*** *Propagation measurements at 3.1GHz in Cyprus*

***TABLE 1:*** *Base Station (enodeBs) downlink parameters*

| Parameters | Values |
|---|---|
| Transmitter Power | 46dBm |
| Antenna combined again | 4dB |
| Transmitting Station Antenna Gain | 16dBi |
| Total EIRP | 53.5dBm |
| Handoff Threshold | 2.5dB |
| HARQ Gain | 3dB |
| Margin of Interference | 2dB |

| | |
|---|---|
| Penetration, feeder and other losses | 20dB |
| Lognormal fading Margin | 6dB |
| Duplexing Gain | 2dB |
| LTE pilot power boosting | 3dB |

### 2.3 Methodology and Algorithm of Determining the Best Propagation Model

RSRP was measured across the 40 base stations. Signal loss of the LTE wireless network was then computed in rural, suburban and urban areas at an operating frequency of 3.1GHz. The measured Signal loss was then compared with the signal loss predicted from the existing signal loss models and the model that gave the least RMSE was identified and optimized for LTE signal propagation in Cyprus.

Signal loss = Isotropic radiated power – Received power (RSRP) (20)

Where:

Isotropic radiated power = $P_T + G_T + G_M - L_F - L_A - L_C$ (21)

$P_T$ = transmitted power (dB),

$G_T$ = antenna gain of transmitter (dB),

$G_M$ = antenna gain of mobile receiver (dB),

$L_F$ = feeder cable loss (dB),

$L_A$ = antenna body loss (dB),

$L_C$ = antenna filter loss (dB).

The effective Isotropic Radiated Power (EIRP) is 53.5dBm and the signal loss becomes

Signal loss = 53.5 – Received power (22)

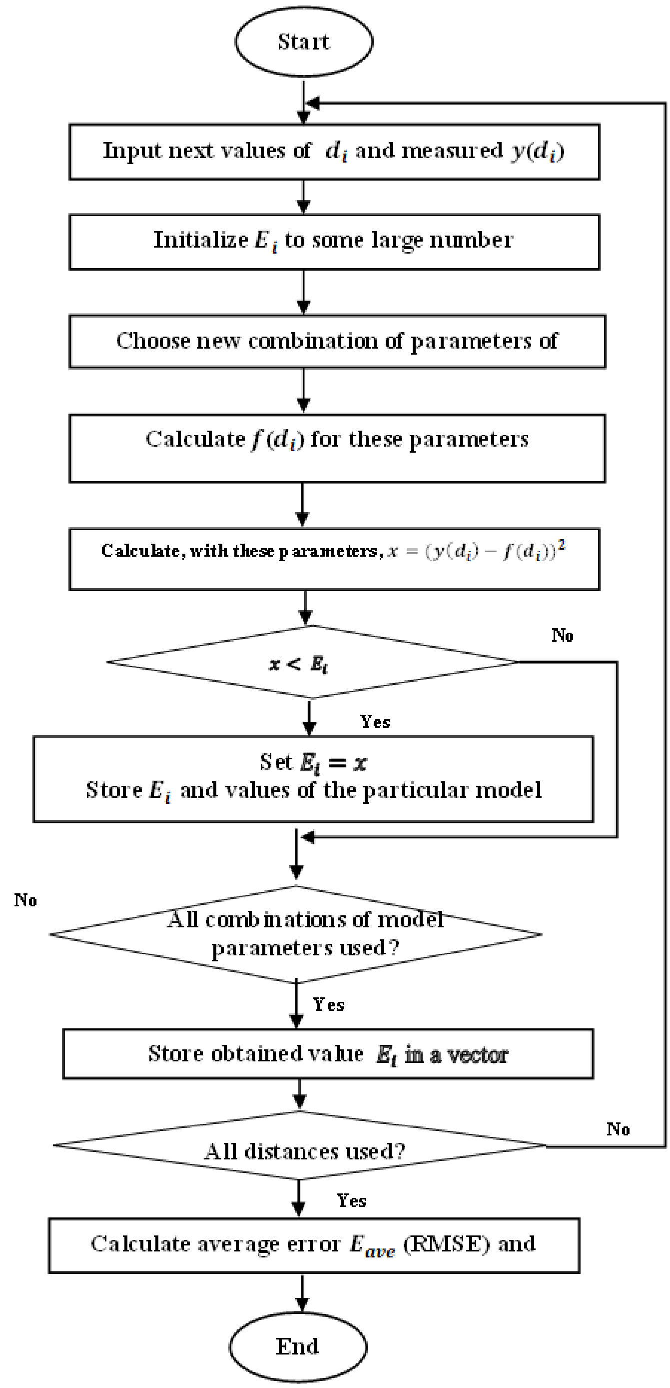


***Figure 3:*** *Algorithm for determining the model with the least error (RMSE)*

## 3. RESULTS AND DISCUSSION

Measured Signal loss was computed across the 40 LTE base stations and compared against the predictions made by the theoretical signal loss models. The measured signal loss was compared against the predictions. The plots are shown in Figures 4, 5 and 6.

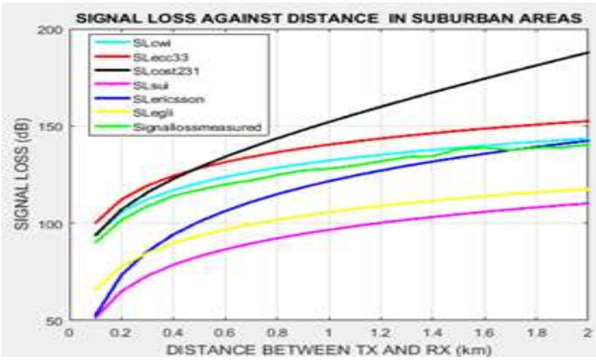


***Figure 4.*** *Signal loss of theoretical models compared to measured data in urban areas*

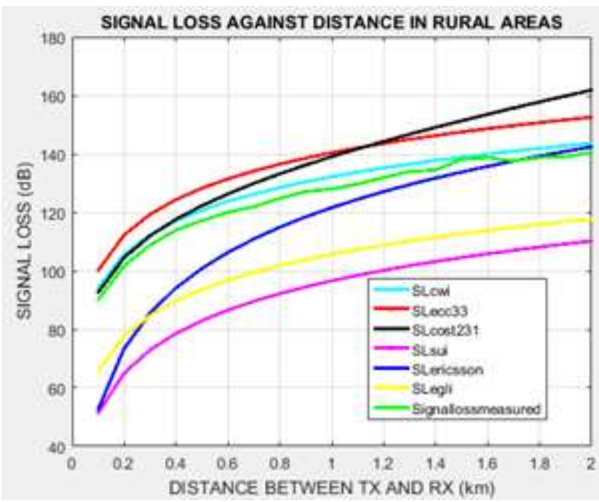


***Figure 5****. Signal loss of theoretical models compared to measured data in suburban areas*

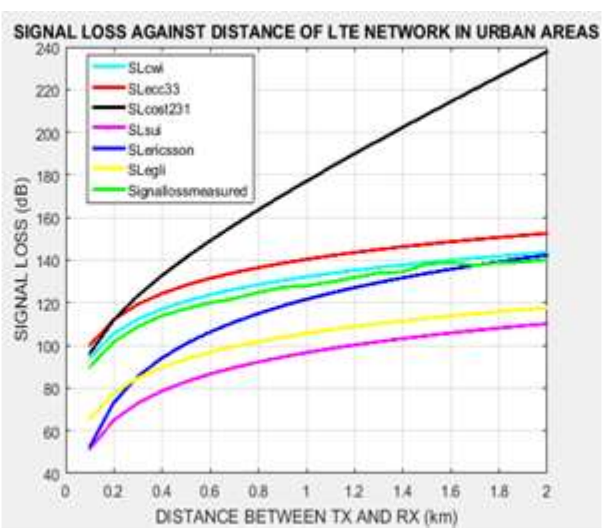


***Figure 6.*** *Signal loss of theoretical models compared to measured data in rural areas*

The measured signal loss was compared with the predictions made by Egli model (depicted as SLegli on the plots), Cost-231 Hata Model (depicted as SLCost231), SUI model (depicted as SLsui), Ericsson model (depicted as SLericsson), Cost-231 Walfisch Ikegami model (SLcwi) and ECC-33 model (depicted as SLecc33). The results from the plots in figures 3, 4 and 5 show that the Cost-231 Walfisch-Ikegami model aligned well with the measured data and performs best for LTE networks in Cyprus. The Cost-231 Walfisch Ikegami model matches with the measured signal loss. The plots of the SLcwi and measured signal loss aligned accurately as shown.

The performance of the models was then validated with root mean square error (RMSE). RMSE is used to determine the consistency or otherwise the variability of the theoretical models to the signal loss measured.

$$RMSE = \sqrt{\sum_{i=1}^{N}\left(\frac{(SL_F - SL_M)^2}{N}\right)} ,$$

(23)

Where: $SL_F$ is the signal loss obtained from field measurements in decibels; $SL_M$ is the signal loss estimated from the analytical model and N is the number of sampled points.

***Table 2.*** *The RMSE values for the different signal loss models*

| Signal loss Model | Rural | Suburban | Urban |
|---|---|---|---|
| ECC-33 | 6.58 | 6.44 | 6.02 |
| Cost-231Walfisch-Ikegami | 4.89 | 4.96 | 5.92 |
| Ericsson | 7.96 | 6.96 | 4.78 |
| Egli | 15.32 | 15.65 | 13.23 |
| SUI | 22.62 | 16.94 | 14.65 |
| COST-231 Hata | 25.8 | 20.4 | 18.6 |

The RMSE values given in Table 2 shows that the Cost-231 Walfisch-Ikegami model performs best for LTE networks in Cyprus as it gives the least RMSE in all the locations (4.89dB, 4.96dB and5.92dB) It gave RMSE within the acceptable range of 6dB [28].The Cost-231 Walfisch-Ikegami model was developed and optimized to give a lower error in comparison with the measured signal loss. Other models over predicted signal loss above 6dB and therefore inaccurate.

### 3.1 Optimization of the Cost-231 Walfisch Ikegami model

The optimization was done by subtracting the values of the RMSE from the signal loss equations of the COST-231 Walfisch Ikegami Model.

$$S_L optimized = L_{CAF} + L_{BDH} + L_{MSD} - RMSE \qquad 24$$

Where:

$L_{CAF}$ = Free space path loss

$L_{BDH}$ = Rooftop-to-street diffraction and scattering loss.

$L_{MSD}$ = Multiscreen diffraction loss

$RMSE$ = root mean square error

The equations (12)-(19) remains unchanged for the optimized model as stated in Section 2.

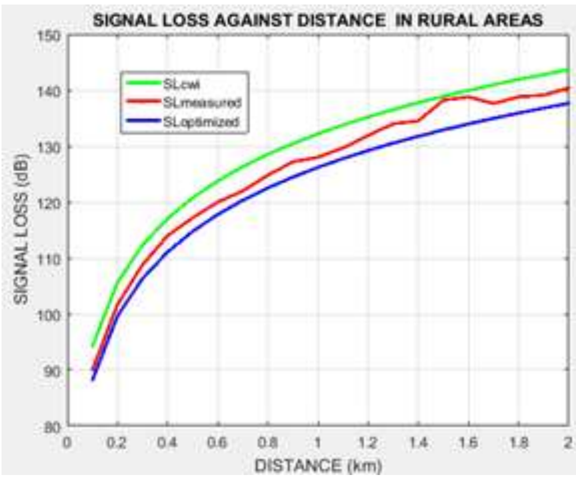


***Figure 7**. Signal loss against distance of optimized model in rural areas*

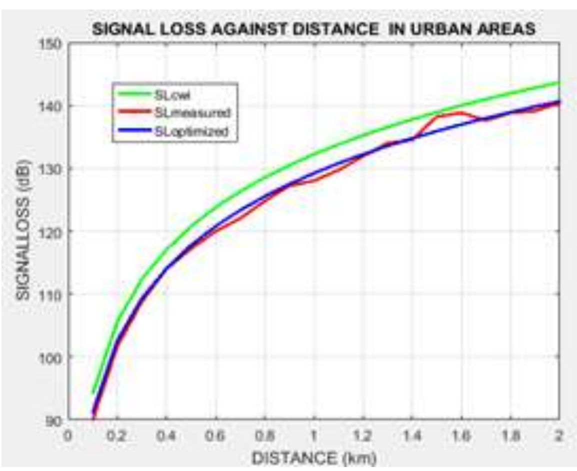


***Figure 9**: Signal loss against distance of optimized model in urban areas*

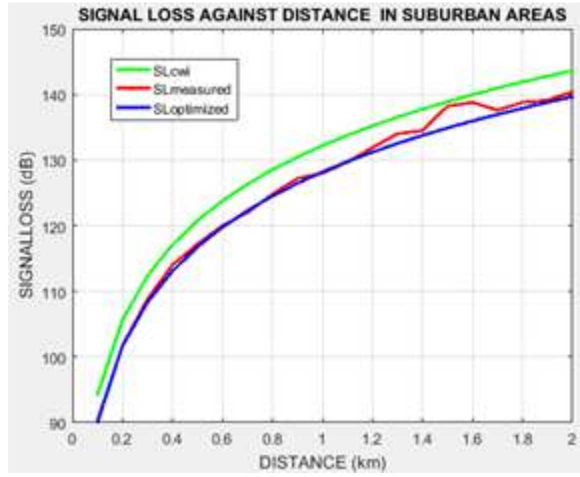


***Figure 8:** Signal loss against distance of optimized model in urban areas*

The RMSE values of 5.92dB, 4.96dB and 4.89dB were subtracted from the theoretical model of the Cost-231 Walfisch Ikegami model in urban, suburban and rural areas respectively. The optimized model was then compared with the measured signal loss and the results shown in Figures 7, 8 and 9. The optimized model produces an accurate result as it aligned accurately with the measured signal loss. The optimized model gives a lower deviation of error than the original Cost-231 Walfisch-Ikegami model before optimization. The optimized model can therefore be used for signal propagation of LTE networks in Cyprus. The RMSE values of the optimized model was reduced to 3.48dB, 4.04dB and 5.12dB respectively in rural, suburban and urban areas respectively. The optimized model produces an accurate solution because of the lower error.

### 3.2 Development of the Best Curve for Measured Signal Loss

The least square regression method will be used to fit a curve to the measured signal loss. We adopt a second order polynomial of the form in equation (25) to fit a curve to the measured signal loss data

$$y = a + bx + cx^2 \quad (25)$$

Polynomial equations of the $i^{th}$ order will be applied as shown in equation (26)

$$f(y) = a_{i y^i} + a_{i-1} y^{i-1} + a_{i-2} y^{i-2} \ldots + a_0 \quad (27)$$

The polynomial equation of the best fit are given in equation (28)-(30)

$$a_0 k + a_1 \sum y_i + \cdots a_1 \sum {y_i}^j = \sum y_i \, f(y)_i \quad (28)$$

$$a_0 \sum y_i + a_1 \sum {y_i}^2 + \cdots a_j \sum {y_i}^{j+1} = \sum {y_i}^2 \, f(y)_i \quad (29)$$

$$a_0 \sum {y_i}^j + a_j \sum {y_i}^{j+1} + \cdots a_1 \sum {y_i}^{2j} = \sum {y_i}^j \, f(y)_i \quad (30)$$

Where, $K$ is the number of sampled data points, $i$ is the position of each data points and $j$ is the order of polynomial.

The equations (28)-(30) can be written in matrix form and this generates the equation (31)

$$\begin{bmatrix} k & \sum y_i \cdots & \sum y_i{}^j \\ \sum y_i & \sum y_i{}^2 \cdots & \sum y_i{}^{j+1} \\ \sum y_i{}^j & \sum y_i{}^{j+1} \cdots & \sum y_i{}^{2j} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_j \end{bmatrix} = \begin{bmatrix} \sum y_i f(y)_i \\ \sum y_i{}^2 f(y)_i \\ \sum y_i{}^2 f(y)_i \end{bmatrix} \quad (31)$$

Equation (31) can be written in terms of the measured signal loss (SLmeasured) and the distance $d$ from the transmitter to the receiver. Equation (32) becomes

$$\begin{bmatrix} k & \sum d_i \cdots & \sum d_i{}^j \\ \sum d_i & \sum d_i{}^2 \cdots & \sum d_i{}^{j+1} \\ \sum d_i{}^j & \sum d_i{}^{j+1} \cdots & \sum d_i{}^{2j} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_j \end{bmatrix} = \begin{bmatrix} \sum d_i SLmeasured_i \\ \sum d_i{}^2 SLmeasured_i \\ \sum d_i{}^2 SLmeasured_i \end{bmatrix} \quad (32)$$

We generate a resultant second order polynomial which is principally in terms of the fitted curve and the distance $d$ from the transmitter to the receiver as it is given as

$$SL_{fitted} = a + bd + cd^2 \quad (33)$$

Where $a_0 = a, \ \ a_1 = b, \ \ a_2 = c$

The least square regression data for the measured signal loss in the urban, suburban and rural areas was used to generate the coefficients of the matrix. For the urban area, we have

$$\begin{bmatrix} 20 & 12.2 & 8.6 \\ 12.2 & 8.6 & 6.4 \\ 8.6 & 6.4 & 5.3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} 2700.9 \\ 1600.8 \\ 1000.7 \end{bmatrix} \quad (34)$$

The solution gives $a_0$ =114.7, $a_1$=211.1, $c$ =252.4, substituting these values in Equation (32) gives

$$SL_{fitted} = 114.7 + 2111.1d + 252.4d^2 \quad (35)$$

Similarly, for the Suburban area, the polynomial equation gives

$$SL_{fitted} = 90.4 + 80.4d + 120.6d^2 \quad (36)$$

For the Rural areas, the polynomial equation gives.

$$SL_{fitted} = 108.3 + 100d + 112.5d^2 \quad (37)$$

The plots of the fitted curve for the rural, suburban and rural are drawn with MATLAB (R2016b) and compared with the measured signal loss as shown in Figures 10, 11 and 12. The least square curve fitting fits the measured signal loss as shown in the plots. The fitted curve agrees well with the measured signal loss in Cyprus with smaller error bound.

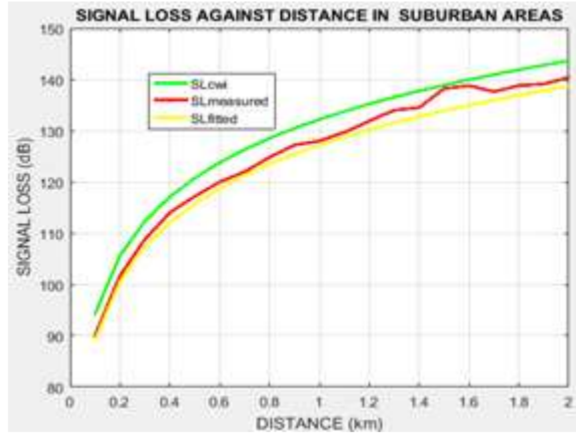


***Figure 10.*** *Fitted curve for measured data in rural areas*

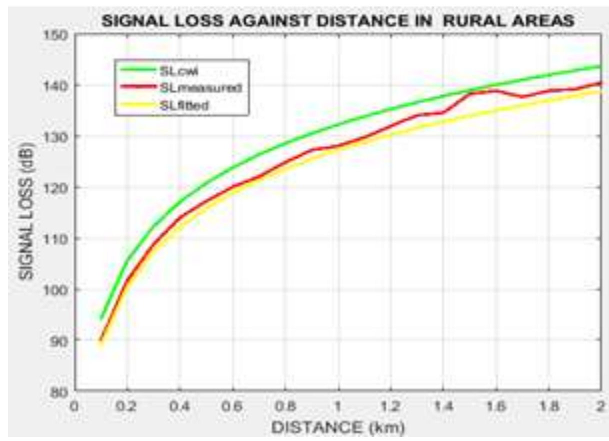


***Figure 11.*** *Fitted curve for measured data in suburban areas*

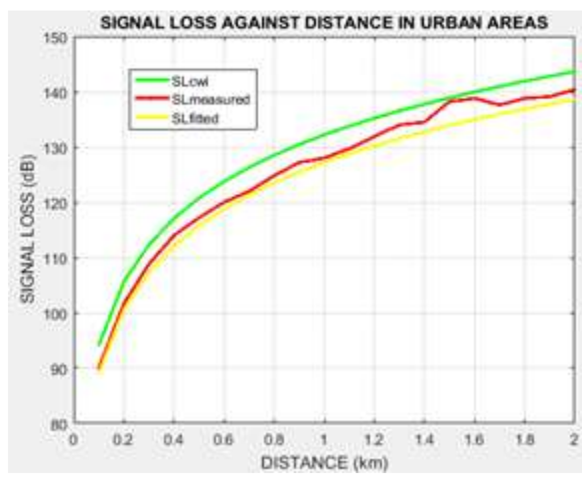


***Figure 12.*** *Fitted curve for measured data in urban areas*

## 4. CONCLUSION

This article has presented the first experimental study that will be carried out on signal loss across LTE networks in Cyprus. Signal loss was measured across 40 base transceiver stations at 3.1GHz in the rural, suburban and urban areas. The measured signal losses were compared with the predictions made by the existing signal propagation models and the results was validated using the root mean square error (RMSE).The results revealed that the COST-231 Walfisch-Ikegami model performs best in Cyprus with RMSE values of 4.89dB, 4.96dB, and 5.92dB in rural, suburban and urban areas respectively. The other propagation models predicted signal loss outside the given range of 6dB.The COST-231 Walfisch-Ikegami model was then developed and it produced a better performance in all the areas. The developed model produced a lower RMSE values of 3.48dB, 4.04dB, and 5.12dB in rural, suburban and urban areas respectively upon validation and therefore optimal for signal loss characterization in Cyprus. A fitted curve was then developed for the measured data using the least square regression second order polynomial method. From the results presented, it is evident that the developed Cost-231 Walfisch Ikegami model is the most suitable model for signal loss propagation, characterization and predictions for LTE networks in Cyprus. It is also very useful for data analysis in continuous time thereby producing accurate signal loss characterization for any measured distance.

## ACKNOWLEDGEMENTS

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