Neural Network Approach to Model the Propagation Path Loss for Great Tripoli Area at 900, 1800, and 2100 MHz Bands *

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Abstract— **Radio wave propagation models are extremely important in mobile network planning and design since it used to predict the Received Signal Strength (RSS). In this work an empirical model was develop to predicate the propagation path loss at the capital of Libya "Tripoli", based on quit good number of measurements conducted in different places in the target area using the Neural Network approach. This model is very helpful in designing a cellular network in this area and other places having the same environments.**

The work was done based on real measurements were the RSS conducted from 0 to 1 km distance range in the concerned area at three different frequency bands; 900 MHz, 1800 MHz, and 2100 MHz The measurements were collected in five types of areas; Dense Urban, Urban, Dense Suburban, Suburban and Rural.

The proposed model was tested and gives an acceptable accuracy results. The values of RSS obtained from this model were compared with other values obtained from applying the Hata model. It has been found that the results of this work are much closer to the real measurement data and gives 7.1 to 28.8 dB improvements in the accuracy over the Hata model results. The Means Square Error (MSE) was found between 3 to 6.7 for the proposed model.

Keywords— **Propagation Model, Propagation Loss, cell planning, Mobile Network, Neural Network, Path Loss.**

I. INTRODUCTION

Path loss is the unwanted reduction in power density of the signal which is transmitted [1]. This path loss may be arising by various effects such as; fading, scattering, reflection, refraction …etc.

Because of these phenomena, the received signal strength suffers not only from attenuation but also will fluctuate. Both attenuations and fluctuations describe the path loss or radio characteristics of an environment and depend mostly on environmental characteristics such as building density and population or area type. A propagation models are used to estimate the path loss of a given environment in either empirical or theoretical ways.

Empirical models such as Okumura, w. Lee, and Hata model, are a set of mathematical equations and algorithms obtained from many measurement results conducted in a certain areas. The main disadvantage of these models is the poor accuracy when used in a different environment than the one where the measurements were taken.

The theoretical models are based on the principle of physics and deals with the fundamental principles of radio wave propagation phenomena, and due to that they can be applied to different environments without affecting the accuracy. The algorithms used by theoretical models are usually very complex and lack the computationally efficiency.

An Artificial Neural Network (ANN) has been proposed in order to obtain prediction model for Almadar Aljadid Mobile Network in Tripoli area that is more accurate than the used Hata model whilst being more computationally efficient than theoretical model. For this purpose, 10 locations were selected in Great Tripoli area (two locations for each area type). And then for each location the RSS (Receiver Signal Strength) were measured as function of distance. The measured data were averaged every 40λ distance.

This paper is organized as follows. Section II is briefing the idea of three of the most famous propagation models, where section III contains relevant ANN background. Section IV illustrates the measurement methodology, and section V resents the ANN training procedure. The obtained results were discussed in section VI and finally section VII concludes the work.

II. PROPAGATION MODELS

The selection of proper base station locations and frequency plane are the first step in designing a cellular network. This can be achieved by using an accurate propagation model, which can be defined as a mathematical tool to estimate the propagation path loss. Propagation models help to understand the interference in the network, which leads to a well-structured network

In the following sub-sections, a brief description of some empirical models, namely (Okumora, Lee, and Hata) models, will be described.

A. Okumura Model

Okumura model is considers as a base for Hata models. It is modeling the radio propagation path for Urban Areas. It was developed empirically based on several measurement of RSS signal conducted in Tokyo, Japan. The model is suitable for three modes; namely, urban, suburban and rural areas. The urban areas model was developed first and it was the base for the other two. Formula for Okumura Model is expressed below:

$$l(dB) = l_f + A_{mu}(f,d) - G(_{eff}) + G(_{rx}) - G_{area} \quad (1)$$

Where

$l(dB)$: Average path loss (median) [dB]

l_f: Free space path loss [dB]

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$A_{mu}(f,d)$: Median attenuation relative to l_f[dB]
$G(h_{eff})$: Transmitting antenna height gain Factor [dB]
$G(h_{rx})$: Receiving antenna height gain Factor [dB]
G_{area}: Environment gain factor [dB].

B. Lee propagation model

W. Lee model was developed as a result of large number of measurements taken in USA around 900 MHz carrier frequencies. The model has a simple mathematical formulation and provides reasonably accurate predictions. The mean power at distance "d" from the transmitter can be found from [1-4-9]:

$$l_{(d)(dB)} = l_0 + 10\upsilon log_{10}(d) + \propto_c \quad (2)$$

Where;
$L_{(d)}$ is the loss at distance "d" km
υ is the loss parameter.
L_0 is the loss at 1km.
αc is a correction factor.

The above formula was developed based on several measurements done at 900 MHz frequency, 30.5 m base station antenna height, and 3 m receiver antenna or mobile station (MS) height.

The correction factor αc can be found from ;

α_c=10 log10(F_0)
Where;
F_0 is a correction factor and can be calculated from five factors using the following equation;

$$\mathrm{F_0} = \prod_{\mathrm{i}=0}^{5} \mathrm{F_i} \quad (3)$$

the factors "F_i's" are given by

$$F_1 = \left(\frac{\text{Actual BS antenna height[m]}}{30.5\text{[m]}}\right)^2 \quad (4)$$

$$F_2 = \left(\frac{\text{Actual MS antenna height[m]}}{3\text{[m]}}\right)^{\upsilon} \quad (5)$$

The power υ =1 for < 3 m mobile station antenna height and υ =2 for > 10 m.

$$F_3 = \left(\frac{\text{Actual power}}{10\text{ W}}\right) \quad (6)$$

$$F_4 = \left(\frac{\text{BS antenna gain}}{4}\right) \quad (7)$$

$$F_5 = G_{MS} \quad (8)$$

Where; G_{MS} is the antenna gain for the mobile station.

C. Hata Model

The most commonly models used to predict the radio signal attenuation in macro cell environment is Hata model, or also sometimes called Okumura–Hata model. It has been developed by using different field measurements conducted at the capital of Japan (Tokyo). The obtained results was published in two ways; mathematical equations, and graphical format. The model originally is valid for quasi-smooth terrain in an urban area. Correction factors are used for other terrain types [4-6-8-10-11].

The valid ranges of the Hata model parameters are given table 1 below

TABLE I. HATA MODEL PARAMETER RANGE

Parameter	Symbol	Range
Frequency (MHz)	f	150–1500
Frequency Extension (MHz)		1500–2000
MS to BTS Distance (km)	d	1–20
Transmitter antenna height(m)	H_b	3–200
Receiver antenna height (m)	H_m	1–10

For Urban area, the Hata model for path loss prediction can be written as

$$L = A + B \log_{10}(f) - 13.82 \log_{10}(H_b) - a(H_m) + [44.9 - 6.55 \log_{10}(H_b)] \log_{10}(d) \quad (9)$$

Where:-
f is the frequency (MHz).
H_m is the Mobile station antenna height (m).
H_b is the base station antenna height (m).
$a(H_m)$ is the correction factor for the mobile antenna
d is the separation distance in (km) between MS and BTS.

The mobile station antenna height correction factor is represented as follows below:

For a city has a small or medium size:

$$a(H_m) = [1.1 \log_{10}(f) - 0.7] H_m - [1.56 \log_{10}(f) - 0.8] \quad (10)$$

and for large city:

$$a(H_m) = \begin{cases} 8.29[\log_{10}(1.54H_m)]^2 - 1.1 & f \geq 200\text{MHz} \\ 3.2[\log10(11.75H_m)]^2 - 4.97 & f \geq 400\text{MHz} \end{cases} \quad (11)$$

The constants A and B are frequency dependent and can be obtained from [1-6-9]:

$$\mathrm{A} = \begin{cases} 69.55, & 150 < f < 1500\,MHz \\ 46.30, & 1500 < f < 2000\,MHZ \end{cases}$$

$$\mathrm{B} = \begin{cases} 26.16, & 150 < f < 1500\,MHz \\ 33.9, & 1500 < f < 2000\,MHZ \end{cases}$$

For area type has sub urban environments

$$L = L_{urban} - 2[\log_{10}(f/28)]^2 - 5.4 \quad (12)$$

For rural areas

$$L = L_{urban} - 4.78[\log_{10}(f/28)]^2 + 18.33 \log_{10}(f) - 40.94 \quad (13)$$

Hata model is not valid for planning a micro-cell, where the base station antenna located below the roof height.

III. ARTIFICIAL NEURAL NETWORKS

The theoretical models usually has some lack the computational efficiency main, where the empirical models does not provide high accuracy. This can be compromised by the implementing Neural Network model.

An ANN can be seen as an adaptive system that changes its structure and response characteristics during a learning (training) process. Neural networks are composed of simple elements operating in parallel. The theory of neural network elements is based on the systems of the biological nervous.

The main function of the network is determining the links weights between its components. It can be trained to do a specific function by adjusting the values of the weights between its components. Figure 1 shows a simple neuron model with a single input vector ‘p’

$$p = [p_1\, p_2 \ldots \ldots p_r]^T \tag{14}$$

And accordingly produce an output value

$$n = w^T p \tag{15}$$

Where $(.)^T$ denotes the transpose and the neuron weights w, are defined as

$$w = [w_1 w_2 \ldots \ldots w_r\ b]^T \tag{16}$$

Also to provide the possibility to shift the activation function f, to the left or right, an additional scalar bias parameter, b, is added to the weights.

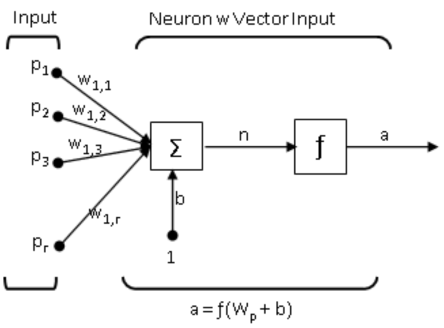


Figure 1. Neuron with single input vector

The training input/output sets should include all the possible cases of the concerned problem to be solved by the Neural Network (NN). The proper training for the NN should make it able to recognize parameter of any new input vector and look at whether it is equivalent to the one of the trained sets and to produce the corresponding output. Also, if an unknown input vector is entered, its output should be produced by using the interpolation and extrapolation process to the trained data.

In this work, propagation measurements taken in Tripoli at different type of areas are used to train the ANN radio wave path loss prediction model.

IV. . MEASUREMENTS METHODOLOGY

The measurements in this work were carried out according to a previous work done by Ericsson Company, in which the area of Tripoli was divided and classified into five area types namely Dense Urban, Urban, Dense Suburban, Suburban and Rural, [12]

These measurements where conducted using a transportable test transmitter which is capable to supply RF power up to 20dBm and operating frequency range of [100Hz - 4GHz].The used transmitter antenna was Omni direction antenna with 2dBi gain for frequency band of 900MHz and 4dBi for [1800MHz - 2100MHz].

The used receiver with sensitivity down to -120dBm was a test measurement receiver consists of a main unit that has space for plug in modules which are the receiver module and the global positioning system (GPS) module which during the measurements was placed on the roof of a car at a height of approximately 1.5 m above ground.

Fig.2 shows the measurement procedure. The RSS measurements were taken in ten locations, two for each area type, where each area type is divided in two roads (paths). The measurement for each path was started from the base station (BS) to about 1km. the measurement process was done as follows. For each 40 λ distance, 15 samples of the RSS were measured, averaged, subtracted from the transmitted power, and recorded as the corresponding path loss for that distance. The records for each path was tabulated and kept as the path loss measurement data for that path.

The above process was repeated for each road of the selected 10 roads at three different frequencies [900MHZ, 180MHZ and 2100MHz] and ten tables were obtained, two tables for each frequency and area type. One of these tables was used to train the model and the other for validation.

V. TRANING AND PREDICTION

In this work, the input-output training pairs are chosen from the measurement data and are defined as

$$\{p_1, t_1\}, \{p_2, t_2\} \ldots \ldots \ldots \{p_N, t_N\} \tag{17}$$

Where $\mathrm{p_n}$ is an input vector denotes the distance between the transmitter and the receiver, while $\mathrm{t_n}$ is the corresponding RSS output. The measurement data is divided into two subsets (training and evaluation), where about 80% of measured data are used in the training process and 20% are used for evaluation process.

In training phase, the ANN uses the input- output pairs to calculate the weights of the neurons and optimize the network. Later, only the input values of the evaluation sets are entered to the trained network and its output were compared with the outputs of the original evaluation sets.

The root mean squared errors (RMSE) is used to assess the performance of the network. It shows how far the predicted value obtained from implementing the model apart from the measured values. Mathematically; .

$$RMSE = \sqrt[2]{\left(\frac{\sum(Pm - \mathrm{Pr})^2}{N-1}\right)} \tag{18}$$

Where;

P_m: the measured path loss in (dB)

P_r: the path loss in dB obtained from the new model

N: is the number of the measured data

VI. OBTAINED RESULTS

The work presented in this paper utilizes radio wave propagation measurements at three frequencies [900MHz, 1800MHz, and 2100MHz].

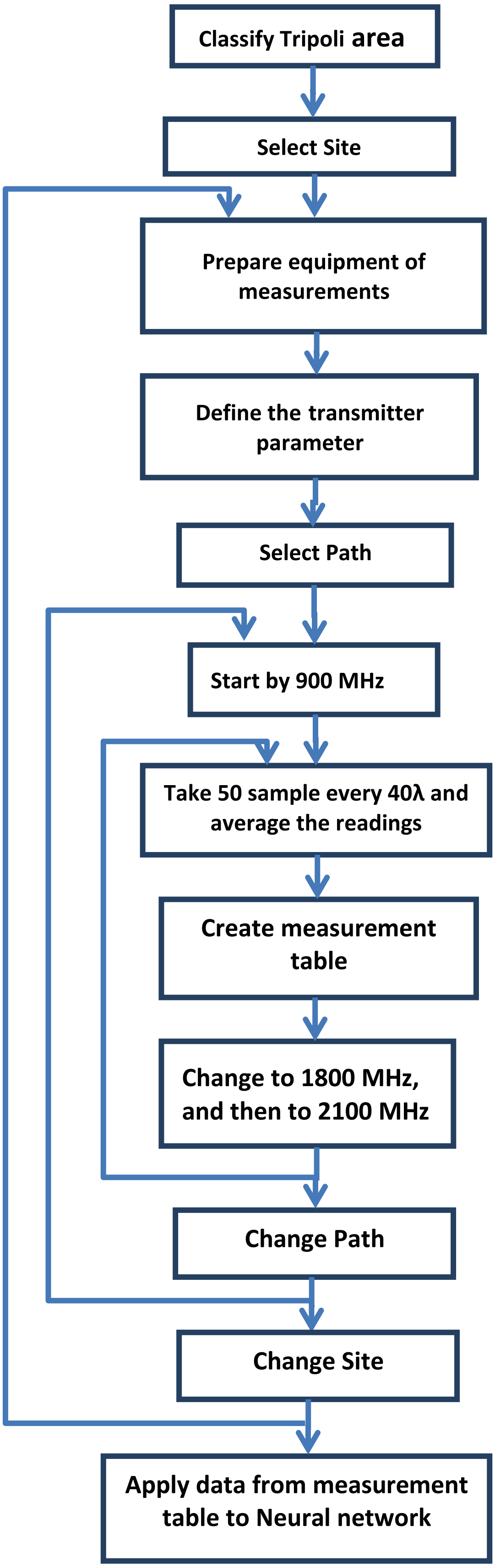


Figure 2. Measurement and analysis flow chart

The measurement data covers a distance of about 1km and consists 900 readings, which averaged to 150 readings for 900MHz and 100 readings for the other two frequencies, where each average power value has been calculated each 15 samples.

The ANN model was trained using 120 input-output pairs for 900MHZ and evaluated using the other 30 measured data. For the other frequencies, 80 input-output pairs were used for training and 20 for evaluation. The results were compared with the real values and plotted on graphs for each area type. Also it has been compared with other values obtained from Hata model. The graphs for DU, U, DSU, SU, and R are shown in figures 3,4,5,6, and 7 respectively, each figure consists of three sub figures, the top one for 900MHz and the bottom for 2100MHz. The results show that the overall ANN path loss predictions for all areas provide smoother and acceptable agreement with the real measurements. We can notice ANN results give 7.1 to 28.8 dB improvement in the accuracy over the Hata model results. The Means Square Error (MSE) was found between 3 to 6.7 for the proposed model.

It is also shows that at 900MHz the R area has the more accurate result, while at the other frequencies [180MHz and 2100MHz] the SU was more accurate.

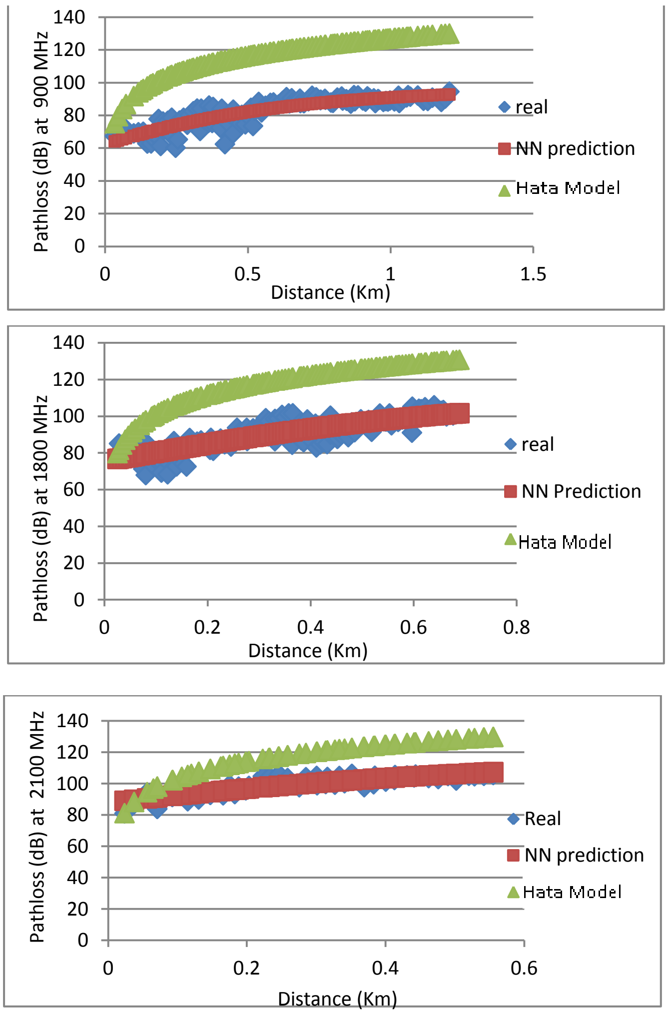


Figure 3. Results for Dense Urban area.

TABLE II. RMSE FOR DENSE URBAN AREA.

Frequency	RMSE
900MHz	4.3501
1800MHz	5.3138
2100MHz	3.3527

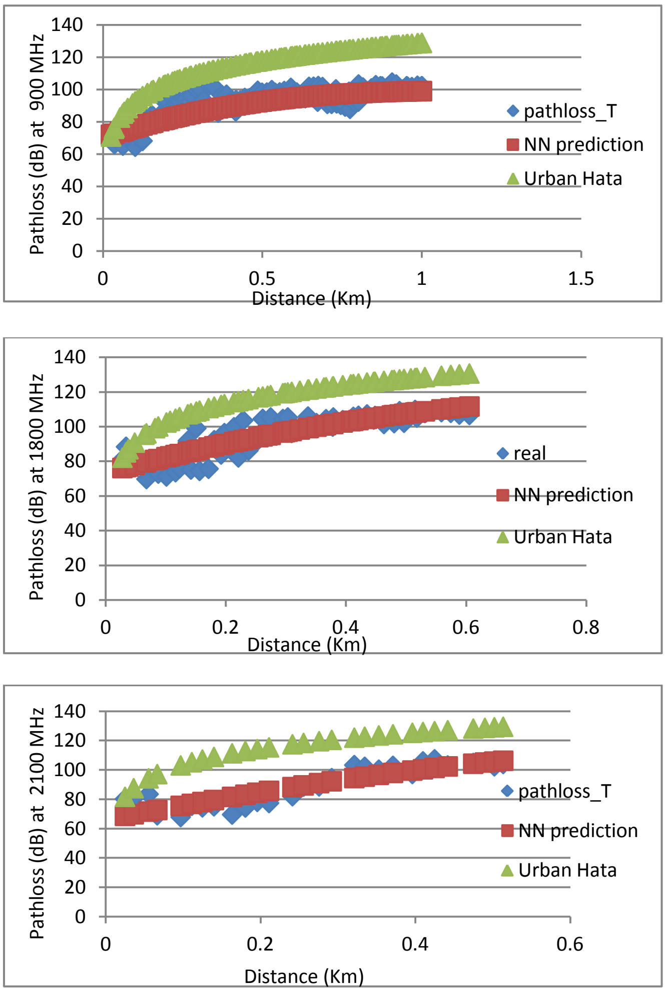
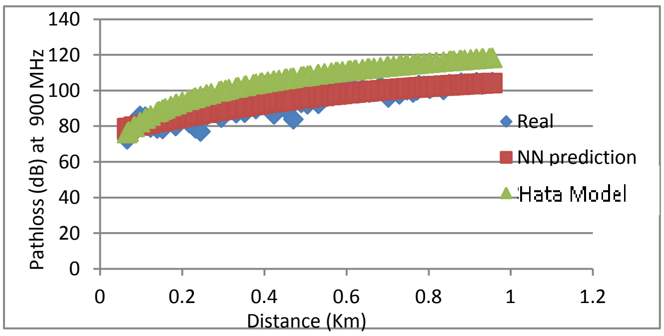
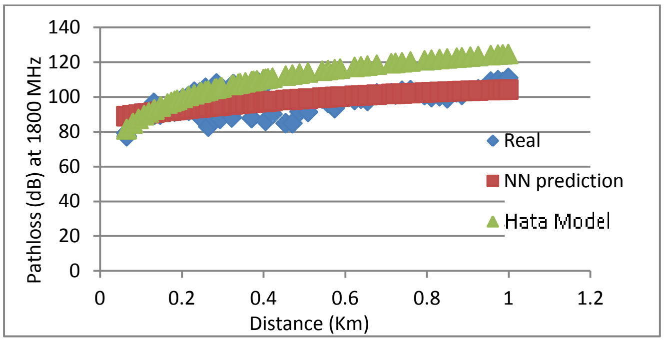


Figure 4. Results for Urban area.

TABLE III. RMSE FOR URBAN AREA.

Frequency	RMSE
900MHz	5.9442
1800MHz	6.2372
2100MHz	6.3185





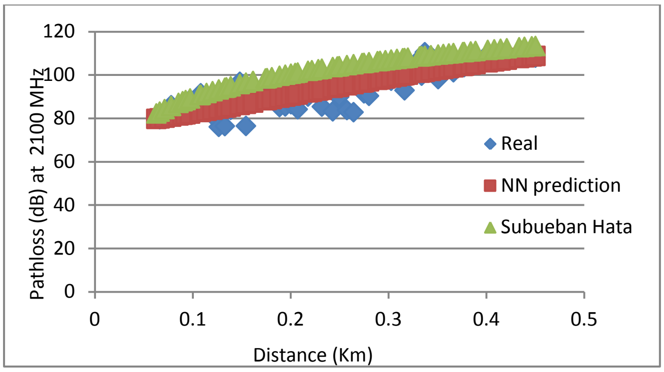
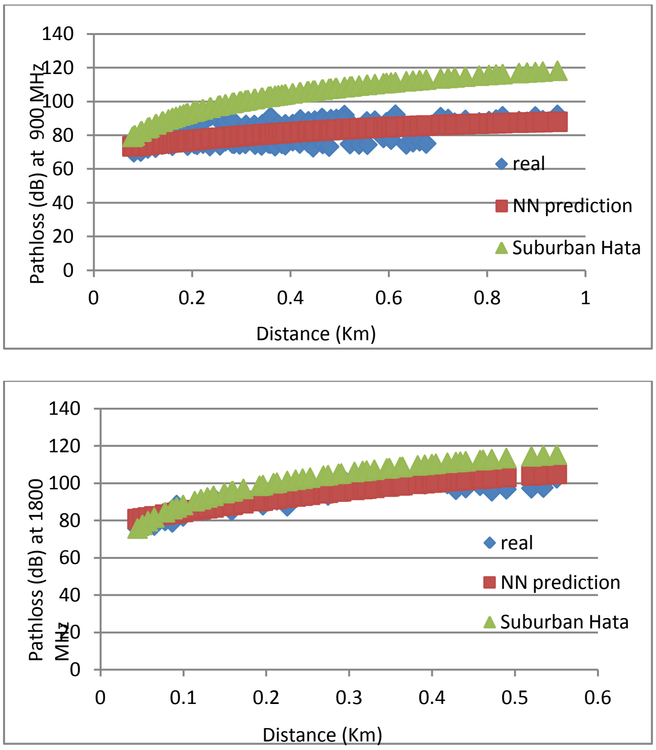


Figure 5. Results for Dense Sub Urban area.

TABLE IV. RMSE FOR DENSE SUB URBAN AREA.

Frequency	RMSE
900MHz	4.3186
1800MHz	6.7293
2100MHz	5.1854



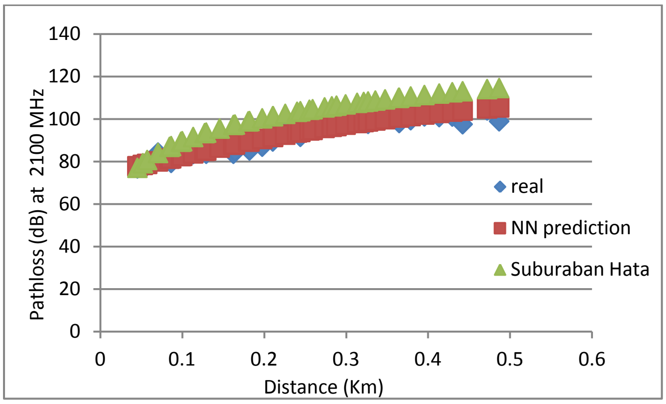


Figure 6. Results for Sub Urban area.

TABLE V. RMSE FOR SUB URBAN AREA.

Frequency	RMSE
900MHz	5.9503
1800MHz	3.9262
2100MHz	3.0608

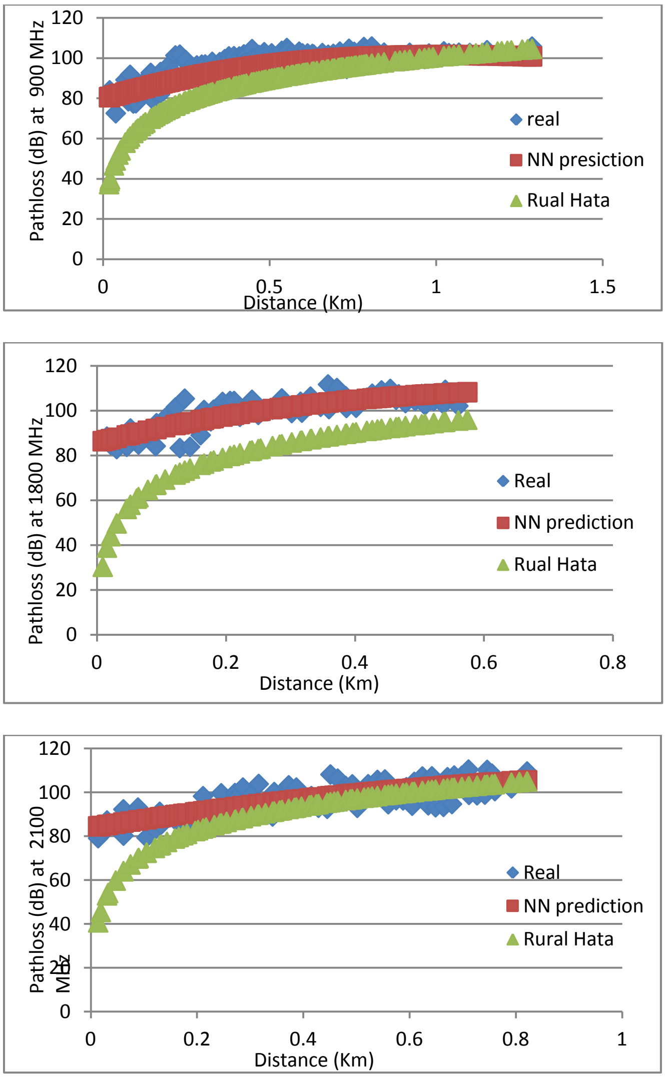


Figure 7. Results for Rural area.

TABLE VI. RMSE FOR RURAL AREA.

Frequency	RMSE
900MHz	4.0763
1800MHz	4.4024
2100MHz	4.8755

VII. CONCLUSION

In this work ANN path loss prediction has been modeled for Tripoli area at five different area types. The work was done based on real measurements of RSS, which used to train and evaluate the model. The results of the ANN in prediction the path loss is then compared with the real values. The RMSE for ANN varying from 3.0 to 6.7 depending on operating frequency and area type. This results was better than that obtained by using Hata model, this is because Tripoli area is totally different from Tokyo-Japan. The ANN model also shows 7.1dB to 28.8dB improvement in the accuracy of predicting the path loss.

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