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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*— For any cellular mobile radio system, determining a best base stations locations as well as a good frequency plan to well utilize the available spectrum for accommodating more users are extremely important and dependent on the environment characteristics such as the propagation path loss. Thus modeling the path loss is crucial to predict the cellular characteristics. Many models were developed by researchers based either on empirical or theoretical methods. Empirical models are simple and mainly designed for specific environment, so they are not very accurate when used in another different environment. In this work an empirical model using the Neural Network Approach ANN and based on real measurement was developed to predict the propagation path loss at the capital of Libya "Tripoli". This model is proposed to replace the Hata model which was used in the designing stage of Tripoli cellular network to improve the network performance when redesigning this network. The area of Tripoli is first divided into five area types namely Dense Urban, Urban, Dense Suburban, Suburban and Rural and the measurements were collected in these five types of areas at three different frequency bands; 900 MHz, 1800 MHz, and 2100 MH. The proposed model was tested and gives an acceptable accuracy results and gives 7.1 to 28.8 dB improvements in the accuracy over the Hata model results.**

***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 …etc.

The path loss is changeable and depending on many factors. One of the main important factor is the area type (Morphology). The area can be classified as one of five types; Dense urban, Urban, Dense suburban, Suburban and Rural. The classification is based on building density, building type, and the population density. Many works has been done to model this loss mathematically in either empirical or theoretical ways. These models are helping the engineers during the designing phase of the cellular networks.

In the empirical models such as Hata model, which is based on measurement, all environmental influences are implicitly taken into account regardless of whether they can be separately recognized. This is the main advantage of these models, but the accuracy of these models depends on the similarities between the environment to be analyzed and the environment where the measurements are carried out.

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, the RSS were measured as function of distance in 10 locations in Tripoli, two locations for each type of areas. For every location the measured values were averaged every distance equal to 40λ.[2-3].

The rest of this work is organized as follows. Section II gives a brief idea about three of the most famous propagation models, where section III contains relevant ANN background. Section IV illustrates the measurement methodology, and section V presents the ANN training procedure. The obtained results were discussed in section VI and finally section VII concludes the work.

II. PROPAGATION MODELS

Propagation model is a mathematical tool to simulate the propagation loss that can be used by engineers and scientists in designing and optimizing the wireless networks. The main goal in the design phase of the wireless network is to predict the amount of the signal strength as a function of the separation distance between the transmitter and the receiver, which is affecting the cell coverage radius in cellular networks. It is also used to avoid the expected interference with the neighboring sites. Here are some examples of the propagation models.

A. *Okumura Model*

The Okumura model for Urban Areas is a radio propagation model that was built using the data collected in the city of Tokyo, Japan. The model served as a base for Hata models. Okumura model was built into three modes which are urban, suburban and open areas. The model for urban areas was built first and used as the base for others. Formula for Okumura Model is expressed below:

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

Where

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$l(dB)$: Average path loss (median) [dB]
l_f: Free space path loss [dB]
$A_{mu}(f, d)$: 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 proposed a very simple signal propagation model originating from a series of measurements made in the USA at 900 MHz carrier frequency. According to the Lee model, the mean power measured at distance "d" from the transmit station is determined by [1-4-10]:

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

Where;
L_0 is the loss at 1km.
υ is the loss parameter.
$\propto_c$ is a correction factor.

The prediction were done for a carrier frequency of 900MHz, a base station (BS) antenna of height 30.5, and a receiving antenna or mobile station (MS) height of 3 m. The correction factor $\propto_c$ is included to account for any change in the standard parameters used in the model and can be expressed as

$\propto_c$=10 log10(F_0)
Where;
F_0 is the correction factor selected on the basis of a series of component factors according to the formula.

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

Where the subsequent factors F_i are described by expressions

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

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

The power υ =1 for the mobile station antenna height lower than 3m and υ =2 for the heights larger than 10m.

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

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

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

Where;
G_{MS} is the MS antenna gain.

C. Hata Model

The Hata model, also known as the Okumura–Hata model, is one of the most commonly used models for macro cell environments to predict the radio signal attenuation. The model is considered as an empirical model, since it has been developed using field measurements data. The field measurements have been performed in Tokyo-Japan and the obtained results was published in a graphical format and put into equations. The model is valid for quasi-smooth terrain in an urban area. For other terrain types correction factors are [5-6-7-10-11].

The ranges of the used parameters for this model are shown in table 1

TABLE I. HATA MODEL PARAMETER RANGE

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

The Okumura–Hata model for path loss prediction in urban area 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_b is the base station antenna height (m).
H_m is the MS antenna height (m).
$a(H_m)$ is the mobile antenna correction factor
d is the distance between the BTS and MS (km).

The correction factor for the MS antenna height is represented as follows, for a small or medium sized city:

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

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 parameters A and B are dependent on the frequency as follows [1-4-5]:

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

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

For sub urban area

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

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 suitable for micro-cell planning where antenna is below roof height.

III. ARTIFICIAL NEURAL NETWORKS

The main problem of the empirical models is the unsatisfactory accuracy. On the other hand, the theoretical models lack the computational efficiency. A compromise can be made by the ANN 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 biological nervous systems.

As in nature, the network function is determined largely by the connection between elements. A neural network can be trained to perform a particular function by adjusting the values of the connections (weights) between elements. Figure 1 shows a simple neuron model with a single input vector 'p'

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

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

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

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.

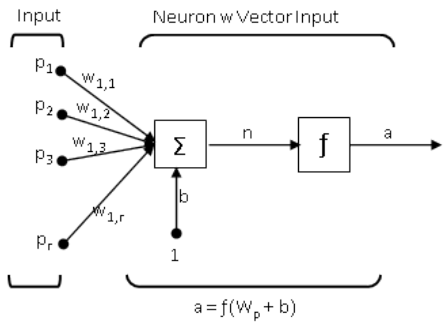


Figure 1. Neuron with single input vector

The training set should be representative of the problem the ANN is designed to solve. A properly trained ANN should be able to recognize whether a new input vector is similar to learned patterns and produce a similar result. Also, when new unknown input parameters are presented to the ANN, it is expected to give an output using interpolation and extrapolation if the input vectors exceed the parameter space used in the training process. 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 areas of Tripoli has been divided into small parts based on their morphology, which is depends on the population density, the height of buildings and how far they are separated from each others. Each part of Tripoli was classified as one of five area types; Dense Urban (DU) – Urban (U)- Dense Suburban (DSU) – Suburban (SU)- and Rural (R). In this work the classification of Tripoli parts was based on previous work done by Ericsson Company [12].

The measurement 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 a 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 road was taken starting from the base station (BS) to about 1km apart from the BS. The measurement rate was 15 samples for 40λ, where λ is the wavelength of the measured signal. Each 15 samples were averaged and subtracted from the transmitted power to get the path loss corresponding to the average distance of these15 samples. The values of these path loss and the corresponding distances were put in table.

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

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

Where p_n is an input vector denotes the distance between the transmitter and the receiver, while 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) which is frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled.

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

Where;

P_m: Measured path loss (dB)

P_r: calculated path loss from the modified model (dB)

N: Number of measured data points

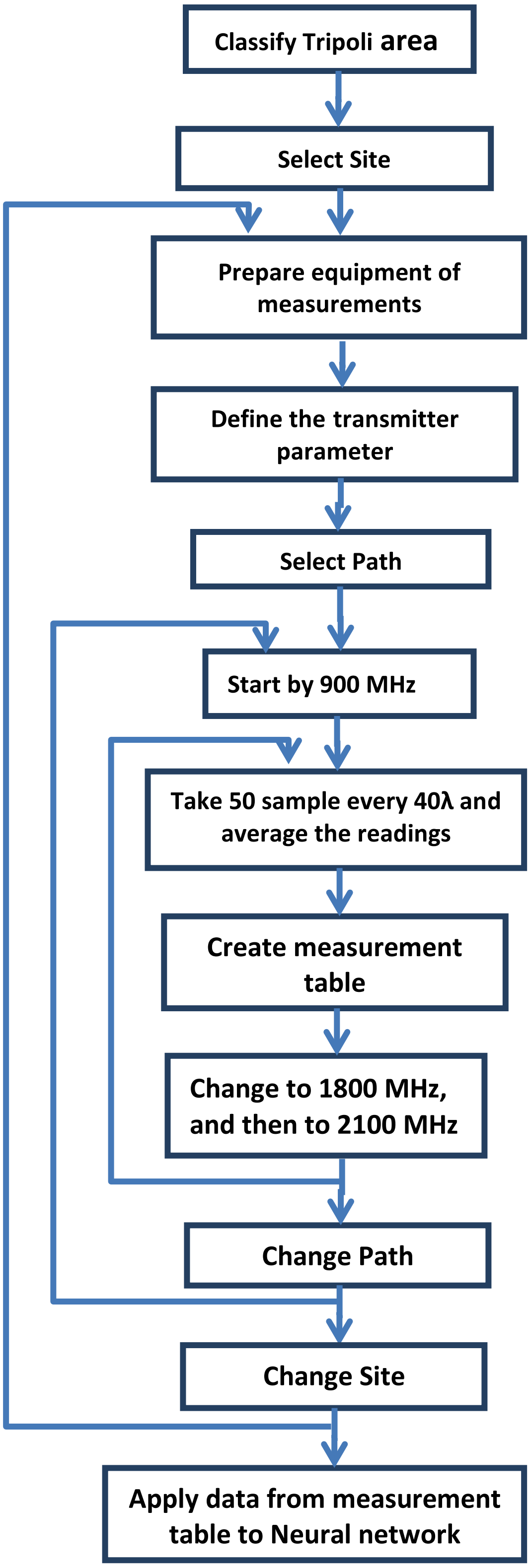


Figure 2. Measurement and analysis flow chart

VI. OBTAINED RESULTS

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

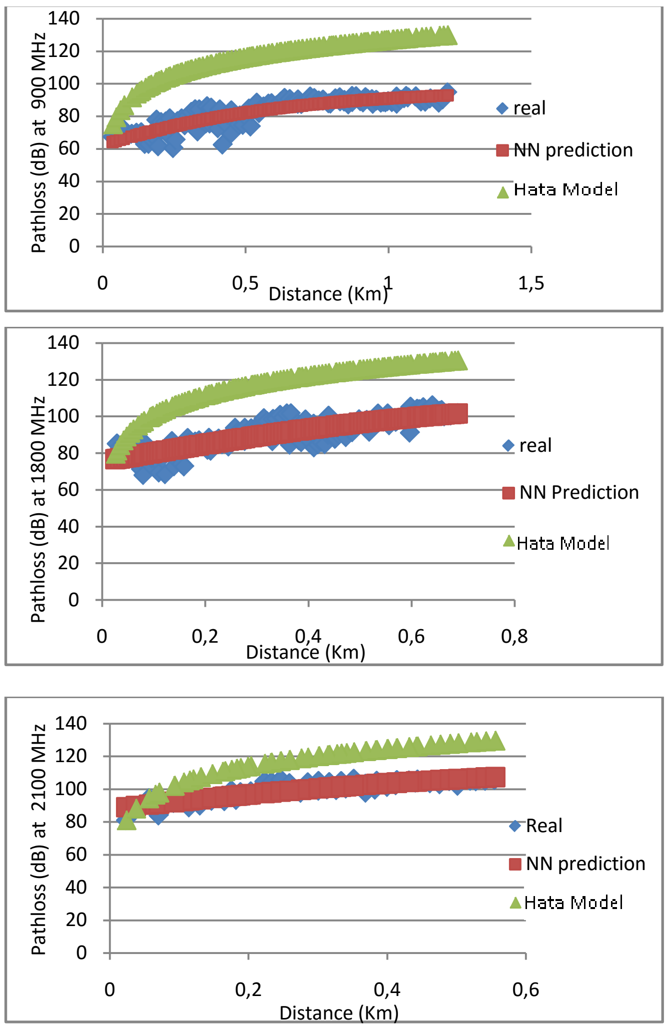


Figure 3. Results for Dense Urban area.

TABLE II. RMSE FOR DENSE URBAN AREA.

Frequency	RMSE
900MHz	4.3501
1800MHz	5.3138
2100MHz	3.3527

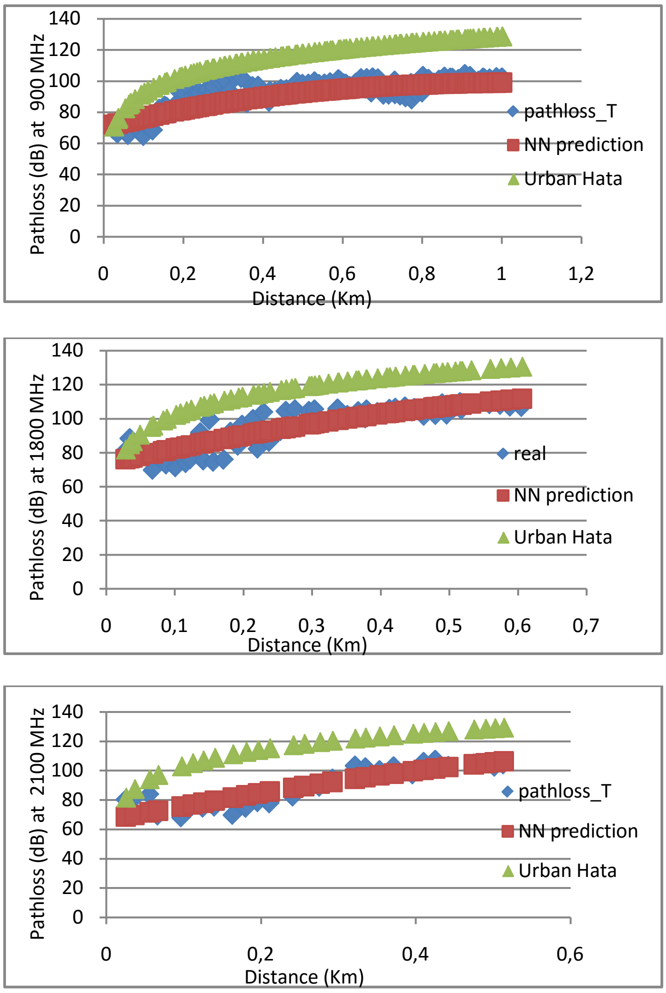
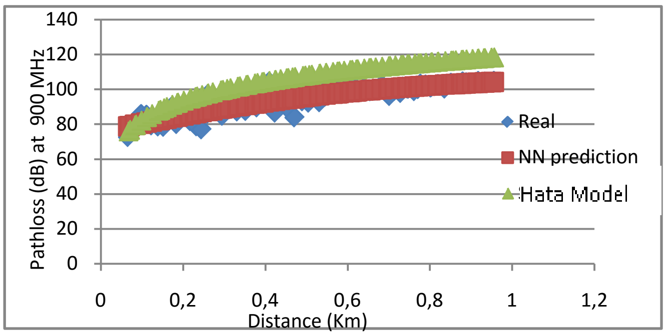


Figure 4. Results for Urban area.

TABLE III. RMSE FOR URBAN AREA.

Frequency	RMSE
900MHz	5.9442
1800MHz	6.2372
2100MHz	6.3185



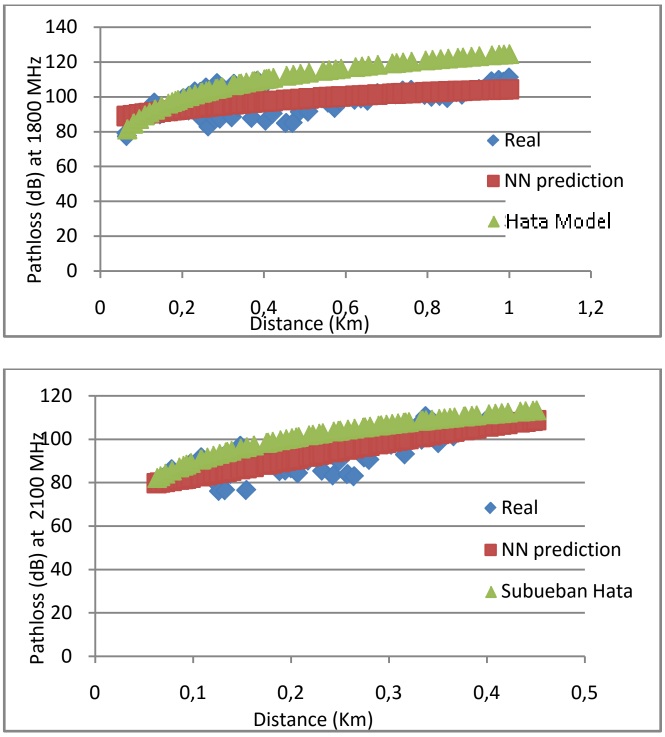
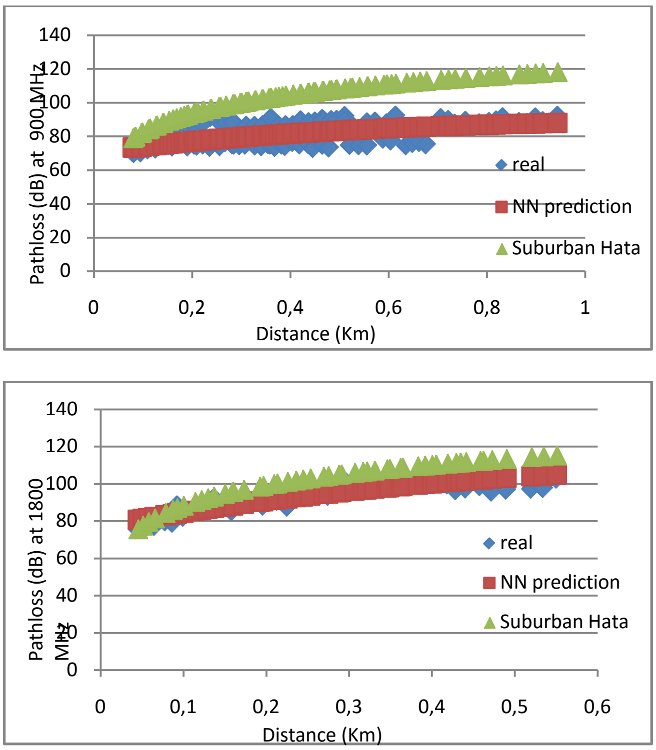


Figure 5. Results for Dense Sub Urban area.

TABLE IV. RMSE FOR DENSE SUB URBAN AREA.

Frequency	RMSE
900MHz	4.3186
1800MHz	6.7293
2100MHz	5.1854



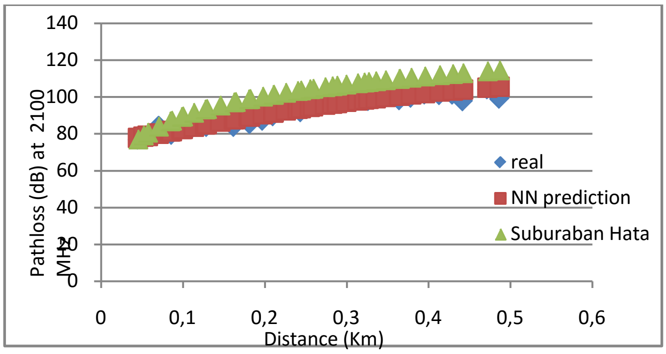


Figure 6. Results for Sub Urban area.

TABLE V. RMSE FOR SUB URBAN AREA.

Frequency	RMSE
900MHz	5.9503
1800MHz	3.9262
2100MHz	3.0608

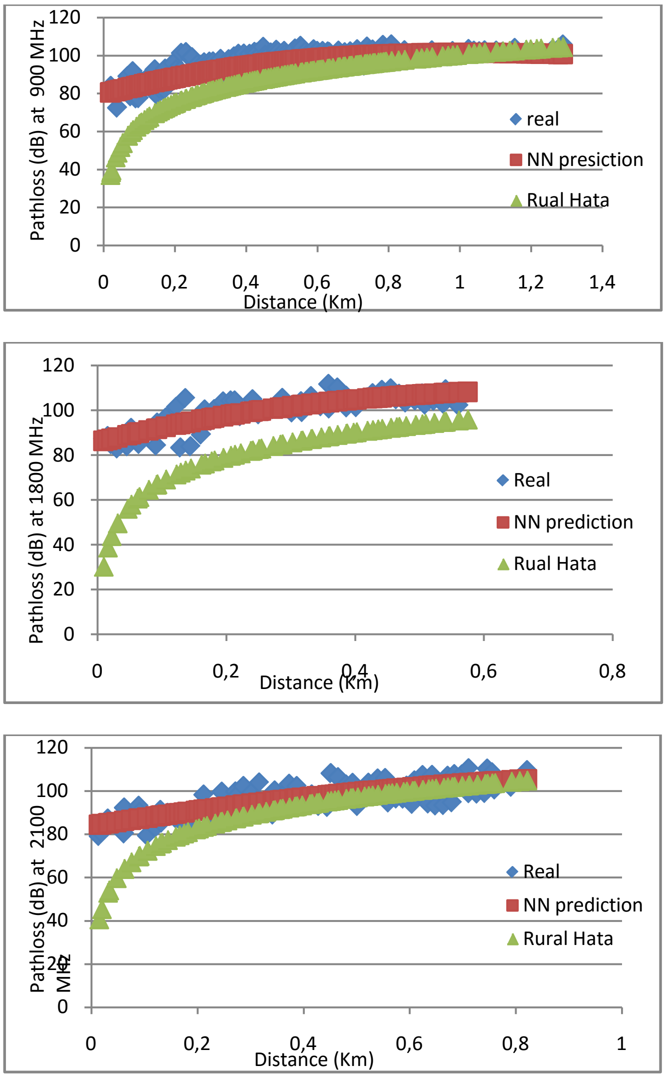


Figure 7. Results for Rural area.

TABLE VI. RMSE FOR RURAL AREA.

Frequency	RMSE
900MHz	4.0763
1800MHz	4.4024
2100MHz	4.8755

VII. CONCLUSION

One of the most important issue in planning and designing the cellular networks is modeling the radio wave propagation, which is used in predicting the Received Signal Strength (RSS). In this work the Neural Network (NN) technique has been used to develop this model in the Great Tripoli area at the celullar network frequency bands; 900, 1800, and 2100 MHz. The model was done based on quit good number of measurements conducted in different places in the target area. These places were selected according to their area type (morphology). Five area types were considered; Dense Urban, Urban, Dense Suburban, Suburban, and Rural. For each type, different measurements were conducted, and separate NN was built, trained and tested. The Root Mean Square Error (RMSAE) between the measured values and the NN model output values were varying between 3.7 to 6.7. The developed model also compared with other well known model; Hata Model. The results from the two models showing that the NN model closer to the measured vales by 7.1 to 28.8 dB's.

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