RF coverage analysis and validation of cellular mobile data using neural network

Z. Nadir, M. Bait-Suwailam, M. Shafiq

***Abstract*—**This paper provides an extension of pathloss analysis in Urban environments in Oman. The paper addresses the applicability of Okumura-Hata model in an area in Oman in GSM frequency band of 890-960 MHz. The root mean square error (RMSE) was calculated between measured Pathloss values and those predicated on the basis of Okumura-Hata model for that area. Artificial Neural Network (ANN) was also used to forecast the data for a much larger distance. ANN provides a wide and rich class of reliable and powerful statistical tools to mimic complex nonlinear functional relationships. The networks are then trained by learning through empirical data. These trained neural nets are finally used to make desired forecasts. These results are acceptable and can be used for OMAN.

***Keywords*—**Artificial Neural Network, GSM Frequency, Pathloss, Propagation models, Hata Model,

I. Introduction

IN the design of any cellular mobile system, the fundamental task is to predict the coverage of the proposed system. Propagation models are useful for predicting signal attenuation or path loss which may be used as a controlling factor for system performance or coverage so as to achieve perfect reception [1]. It has been found that the mechanisms behind electromagnetic wave propagation are diverse and characterized by certain phenomena such as reflection, refraction and diffraction of waves. These phenomena induces signal scattering, fading and shadowing along the signal path and their effects can best be described (in a large scale) by the path loss exponent which defines the rate of change of attenuation that the signals suffers as it propagates from the transmitter to the receiver [2]. The wireless communication relies on the broadcast of waves in the free space. This also provides mobility for users and satisfies the demand of the customers at any location covered by the wireless network. Growth in the mobile communications field has now become slow, and has been linked to technological advancements [3-4]. The need for high quality and high capacity networks, estimating coverage accurately has become extremely important. Therefore, for more accurate design coverage of modern cellular networks, signal strength measurements must be taken into consideration in order to provide an efficient and reliable coverage area.

This article addresses the evaluations between the statistical and the experimental analysis at GSM frequency of 900 MHz using Okumara model which is most widely used [5].

The cellular concept was a major breakthrough in solving the problem of spectral bottlenecks and user's capacity. It offered high capacity with a limited spectrum allocation without any major technological change. The cellular concept is a system level idea in which a single, high power transmitter is replaced with many low power transmitters. The area serviced by a transmitter is called a cell. Each small powered transmitter, also called a base station provides coverage to only a small portion of the service area. The power loss involved in transmission mode between the base station (BTS) and the mobile station (MS) is known as the pathloss and depends particularly on the antenna height, carrier frequency, distance and environmental parameters. At higher frequencies the range for a given Pathloss is reduced, so more cells are required to cover a given area. Base stations close to one another are assigned different groups of channels. Neighboring base stations are assigned different groups of channels so that the interference between base stations or interaction between the cells is minimized. As the demand for service increases, the number of base stations may be increased, thereby providing additional capacity with no increase in radio spectrum. The key idea of modern cellular systems is that it is possible to serve the unlimited number of subscribers, distributed over an unlimited area, using only a limited number of channels, by efficient channel reuse [4].

II. Theoretical Propagation Models

Propagation models are mathematical representation of results of experiments conducted on the wave propagation under different frequencies, antenna heights and locations over different periods and distances. Propagation models indicate that average received signal power decreases logarithmically

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with distance [6]. They are divided into two basic types; namely: Free space propagation and Plane earth propagation model.

A. Free Space Propagation Model

In free space, the wave is not reflected or absorbed. Ideal propagation implies equal radiation in all directions from the radiating source and propagation to an infinite distance with no degradation. Spreading the power over greater areas causes waves attenuation. Equation (1) illustrates how the power flux is calculated.

$$P_d = P_t \ / \ 4\pi d^2 \qquad (1)$$

Where P_t is known as transmitted power (W/m^2) and P_d is the power at a distance d from antenna. If the radiating element is generating a fixed power and this power is spread over an ever-expanding sphere, the energy will be spread more thinly as the sphere expands.

B. Plane-Earth Propagation Model

The free space propagation model does not consider the effects of wave propagation over ground. When a radio wave propagates over ground, some of the power will be reflected due to the presence of ground and then received by the receiver. In order to better estimate the effect of the reflected power, the free space propagation model is modified and referred to as the 'Plane-Earth' propagation model. This model better represents the true characteristics of radio wave propagation over ground. The plane earth model computes the received signal to be the sum of a direct signal and that reflected from a flat, smooth earth. The relevant input parameters include the antenna heights, the length of the path, the operating frequency and the reflection coefficient parameter from the earth's interface. This coefficient will vary according to the terrain type (e.g. water, desert, wet ground etc). Pathloss Equation for the plane Earth Model is illustrated in equation (2)

$$L_{pe} = 40Log_{10}(d) - 20Log_{10}(h_1) - 20Log_{10}(h_2) \qquad (2)$$

Where d represents the path length in meters, and h_1 and h_2 are the antenna heights at the base station and the mobile, respectively. The plane earth model is not appropriate for mobile GSM systems as it does not consider the reflections from buildings, multiple propagation or diffraction effects. Furthermore, if the mobile height changes (as it will in practice), then the predicted Pathloss will also be changed.

III. Empirical Propagation Models

Empirical propagation models will be discussed in this section; amongst them are Okumura and Hata models.

A. Cellular Propagation Models

The two basic propagation models (free space loss and plane-earth loss) would require detailed knowledge of the location, dimension and constitutive parameters of every tree, building, and terrain feature in the area to be covered. This is far too complex to be practical and would yield an unnecessary amount of detail. One appropriate way of accounting for these complex effects is via an empirical model. There are various empirical prediction models among them are, Okumura – Hata model, Cost 231 – Hata model, Cost 231 Walfisch – Ikegami model, Sakagami- Kuboi model. These models depend on location, frequency range and clutter type such as urban, sub-urban and countryside.

B. Okumura's Measurements

Okumura carried out extensive drive test measurements with range of clutter type, frequency, transmitter height, and transmitter power. It states that, the signal strength decreases at much greater rate with distance than that predicted by free space loss [5, 7-8].

C. Hata's Propagation Model

Hata model was based on Okumura's field test results and predicted various equations for Pathloss with different types of clutter. It is well suited model for the Ultra High Frequency (UHF) band [9]. The limitations on Hata Model due to range of test results from carrier frequency 150 MHz to 1500 MHz, the distance from the base station ranges from 1 Km to 20 Km, the height of base station antenna (h_b) ranges from 30 m to 200 m and the height of mobile antenna (h_m) ranges from 1 m to 10 m. It was also observed that the signal strength is a function of distance and antenna height, as we can see in this work the highest antenna has less propagation path loss and as the distance increases the path loss also increases [10]. Hata created a number of representative Pathloss mathematical models for each of the urban, suburban and open country environments, as illustrated in following equations, respectively. Okumura takes urban areas as a reference and applies correction factors as following:

For urban areas:

$$L_{dB} = A + BLog_{10}R - E_{1,2,3} \qquad (3)$$

Where

$$A = 69.55 + 26.16\,Log_{10} f_c - 13.82\,Log_{10} h_b$$

$$B = 44.9 - 6.55\,Log_{10} h_b$$

$$E_1 = 3.2\left(Log_{10}\left(11.7554 h_m\right)\right)^2 - 4.97 \quad \text{for cities; } f_c \geq 300MHz,$$

$$E_2 = 8.29\left(Log_{10}\left(1.544 h_m\right)\right)^2 - 1.1 \quad \text{for cities; } f_c \leq 300MHz,$$

$$E_3 = \left(1.1 Log_{10} f_c - 0.7\right) h_m - \left(1.56\,Log_{10} f_c - 0.8\right)$$

for relatively smaller cities.

Definition of parameters:

h_m ;mobile station antenna height [m]
d_m ;distance between the mobile and the building [km]
h_0 ; typical height of a building above local terrain height [m]
h_b ;base station antenna height above local terrain height [m]
r; great circle distance between base station and mobile [m]
$R=r \times 10^{-3}$ great circle distance between BS and mobile [km]
$f_c=f \times 10^{-6}$ carrier frequency [MHz]
λ ; free space wavelength [m].
The practical Pathloss can be calculated using the equation:

$$L_p(dB) = P_t - P_r \quad (4)$$

Where P_t is the transmitted power which is equal to 47 dB and P_r is the received power.

'A' and 'E_3' are as mentioned above for small and medium cities [11-13].

The generation of such predictions is based on the assumption that the power of a signal decreases monotonically with the increase of the distance traveled by the signal [14]. Thus, Hata model is not suitable for micro-cell planning where antenna is below roof height and its maximum carrier frequency is 1500MHz. It is not valid for 1800 MHz and 1900 MHz systems.

IV. Results and Discussions

Data Collection

An intensive drive test has been conducted along all pre-identified paths. GSM sample every 450 ms. This sampling rate is adequate to determine representative signal levels. The drive test process was conducted using TEst Mobile System, (TEMS) Investigation Data Collection V13.0 tool. TEMS Investigation is widely used for drive testing (Collecting handset data while moving) purpose and it supports all major technologies including GSM, Wi-MAX, UMTS and LTE. The measurement reports of radio signal strength and many other RF parameters are collected by a special purpose mobile handset connected to the PC in which the TEMS program is installed. Furthermore, the positioning information is collected via GPS antenna terminal which have direct communication with GPS satellite

Data Processing

The measured data for each path has been recorded in terms of log files. These log files have been exported to a post processing tool called ACTIX for further processing and extraction of the required data. ACTIX Analyzer is a tool used for drive test post-processing, supporting network optimization and network troubleshooting. It is capable of troubleshooting RF problems automatically for GSM, Wi-MAX, WCDMA and LTE technologies.

The data files collected from TEMS Investigation is post-processed from this tool. Also, it has been used to convert the recorded log files into graphical format for map viewing via Google Earth program (not shown). Moreover, it has been utilized to export coverage log files into Excel worksheets format for further manipulation. After that, the required data has been manipulated as the main aim of the conversion was to obtain the path loss and the link distance. However, the road of Al Khuwair can be considered as an urban area, in which Okumura-Hata model was used.

After determining the Pathloss of the practical measurements for each distance, the study was carried in order to make a comparison between the experimental and theoretical data and the result is as shown in Fig. 1.

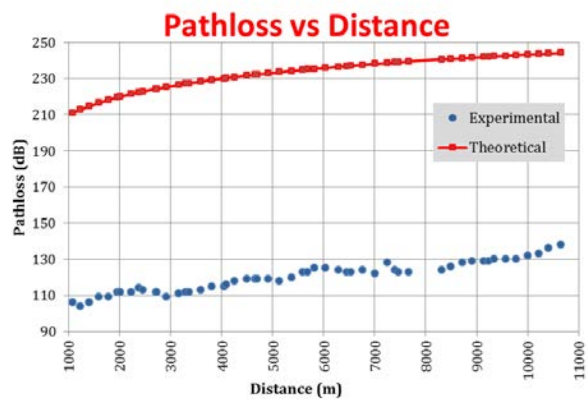

Fig. 1: Theoretical and Experimental Pathloss versus distance

From the above plot, the results clearly show that the measured Pathloss is less than the predicted Pathloss by a difference varying from 4 to 20 dB. However, there are several reasons that may have caused those significant differences. First of all, in Japan there are few areas virtually satisfying the conditions; and if any, they are narrow. Because of that reason Okumura selected the value for urban area as standard for open areas [8]. Moreover, the geographical situation of Japan is different from that in Oman due to geographical differences. As such, root mean square error (RMSE) was calculated between measured Pathloss value and those predicted by Hata model using the following (5) [15-16]:

$$RMSE = \sqrt{\left(\sum \frac{(P_m - P_r)}{(N-1)} \right)} \quad (5)$$

where;
P_m: Measured Pathloss (dB)
P_r: Predicted Pathloss (dB)
N: Number of Measured Data Points

The RMSE was found 113.459 dB but the acceptable range is up to 6 dB. Therefore, the RMSE is adjusted with the Hata equation for urban area and the modified Hatas' equation is as given below (6):

$$L_{p\_mod}(urban) = 69.55 + 26.16\,Log_{10}(f) - 13.82\,Log_{10}(h_b) + (44.9 - 6.55\,Log_{10}(h_b))\,Log_{10}(d) \pm MSE - (1.1\,Log_{10}(f) - 0.7)h_m - (1.56\,Log_{10}(f) - 0.8) \quad (6)$$

The modified result of Hata equation is shown in Fig. 2 and the RMSE in this case is less than 6dB, which is acceptable.

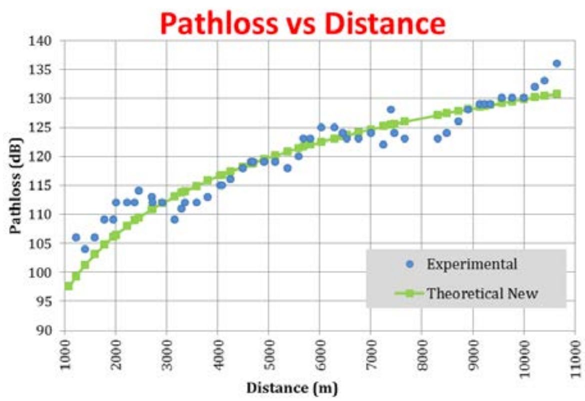

Fig. 2: Modified Hata's equation Pathloss on experimental data set B.

In order to verify that the modified Hata's equation is applicable for other areas in Oman, another data generated from TEMS tool for another cell in the road of Al Khuwair has been used. Based on that practical data, the propagation Pathloss and the distance have been re-verified for another cell [11].

Theoretical simulation and the obtained experimental data are compared and analyzed further using PCHIP to interpolate on the set of the experimental data which provides quite flexibility. A PCHIP, is any Piecewise Cubic Hermite Interpolating Polynomial that interpolates the given data, and has specified derivatives at the interpolation points. Just as two points determine a linear function, two points and two given slopes determine a cubic. The data points are known as "knots". We have the y-values at the knots, so in order to get a particular PCHIP, we have to somehow specify the values of the derivative, y', at the knots. PCHIP also provides a fairly smooth and efficient approximation without increasing the computational complexities required for higher-order polynomial approximation. A good correlation is observed for the entire range. The good agreement of the characteristics show that experimentally reproduced data is a good representation of that described by Hata propagation model.

Furthermore, the simulation and the obtained experimental data is compared and analyzed further using a cubic regression model on the set of the experimental data which gives acceptable results (Not presented in the current paper). After observation of experimental data, it can be predicted that the scatter plot of the experimental data on Pathloss versus distance reveals a third order polynomial trend. Therefore, the Cubic Regression Model was fitted [12-13] using method of least square error which estimates the parameters by minimizing sum of squares of the white noise. The estimated model is given as below:

$$P_m = 98.66 + \left(6.8e^{-3}\right)d + \left(7.0e^{-7}\right)d^2 + \left(4.0e^{-11}\right)d^3 \quad (7)$$

The coefficient of determination of this regression suggested that about 90% variation in Pathloss can be explained by distance using (7). The correlation between experimental, theoretical model and fitted by cubic regression were worked out by Pearson Correlation Coefficient which shows that the Pathloss estimated by (7) has highly significant correlation of 0.975 with the experimental data and a correlation of 0.974 with the theoretical model. The correlation between experimental data and theoretical model was 0.948 which is also highly significant at $p < 0.01$ value

Fig.3 shows the theoretical, experimental and PCHIP plots for Hata propagation model. As can be seen, results show good agreement between various studies.

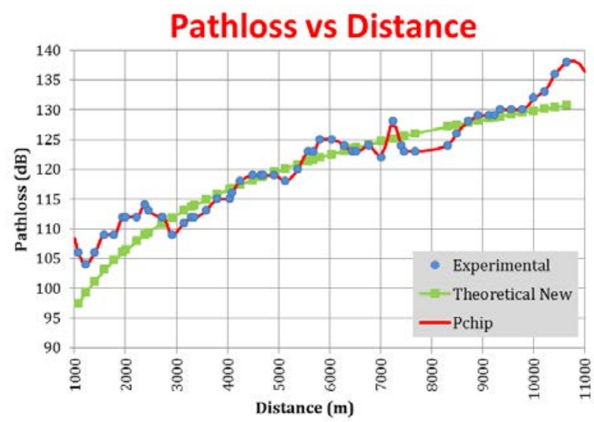

Fig. 3: Pathloss versus distance for Experimental, Theoretical, and PCHIP analysis.

Artificial Neural Network

The dB-loss is a function of several variables. Some of these variables are distance between receiver and transmitter, the properties of the air, temperature, humidity, obstacle locations and their geometry, etc. The analytical relationship to compute the dB-loss needs measurement of these variables. The measurements of these variables are expensive and pose engineering challenges. The properties of these variables are also not uniform between the transmitter and receiver. To avoid these difficulties, constant parameters are used to represent these variables in the analytical expression of the dB-loss. This is a very rough approximation, which gives rise to fade prediction of the dB-loss. Neural networks and other numerical techniques are suggested for the prediction of the dB-loss. The proposed techniques are based on the minimization of the mean square error between the measured dB-loss and the predicted [16]. The mean square error minimization numerical techniques treat the abrupt variations in the measured data as noisy data. The consideration of the abrupt changes in dB-loss of measured data as noise is misleading. The abrupt change in dB-loss is a function of the abrupt change in the geometry of the obstacle and the location of the receiver. We are not considering the other variables as cause of this abrupt change based on the fact that the properties of the propagation medium (e.g. Temperature, Humidity, wind properties, etc.) and radial distance do not change abruptly. It is important to note that the geometry of the streets, buildings and roads remain unchanged for a long time. Interpolation based identified soft prediction model give exact solution at the given data points and approximate solution at other points [17]. The bound of the norm1 of the error is a function of the smoothness of the given data point and the validation data point [18]. Depending on the type of data smoothness and noise, different basis functions can be chosen for the soft prediction model [19]. Though there exists no deterministic method to choose these functions, engineering judgment of the data can help to choose the suitable basis functions [20]. Interpolation methodology can be used to train the radial basis neural networks [21]. It has been proved that radial basis neural networks are capable of universal approximation [22]. We used interpolation based radial basis neural networks to identify the soft prediction model of the dB-loss function. Short description of the radial basis neural network is given below. Detail can be found in [23]. Let us consider $x \in R^n$ be an n-dimensional real input data and $\hat{y} \in R$ be a single predicted output and $f(x)$ is the measured output data. Then the relationship of the input data with the output is given by (8):

$$\hat{y} \cong f(x) = \sum_{i}^{n} w_i \varphi\left(\frac{\|x - x_i\|}{2\sigma}\right) = \varphi W \tag{8}$$

There, the parameter vector W is given by:

$$W = \varphi^{-1} f(x) \tag{9}$$

where;

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ w_n \end{bmatrix} \; ; \; f(x) = \begin{bmatrix} f(x_1) \\ f(x_2) \\ . \\ . \\ f(x_n) \end{bmatrix} \quad and \quad \varphi = \begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \phi_{1n} \\ \phi_{21} & \phi_{22} & \cdots & \phi_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \phi_{n1} & \phi_{n2} & \cdots & \phi_{nn} \end{bmatrix}$$

$\varphi\left(\frac{\|x - x_i\|}{2\sigma}\right) = e^{-\left(\frac{\|x - x_i\|}{2\sigma}\right)^2}$, σ is the spread of the data which may be considered as standard deviation of the given input data, but it is not necessary [4]. A necessary and sufficient condition for the solution of interpolation problem which is given in (9) is the invert ability of φ. It has been shown that φ is invertible radial basis functions if the data 'x' consists of distinct point [24].

We used this algorithm to identify the soft prediction model of the dB-loss as a function of distance between the transmitter and receiver. We consider all the data points which show abrupt changes as data points and the smooth region is selected for the validation purpose. Fig. (4) show that the dB-loss computed by the soft prediction model exactly matches at the given data points. The relative mean square error of the experimental dB-loss and the predicted dB-loss is 0.01 at the validation data points. This error is well in the standard limits of the RMSE of dB-loss [16]. This simulation result as shown in Fig.4 shows that radial basis neural network based identified soft prediction model can be used for the prediction of dB-loss. 23% of the given data is used for the validation and rest of it for the training of neural network. The following table-1 is self-explanatory for data validation.

Table-1: Data Validation

Exp. Data for Validation	Predicted Data for Validation	Square of error	% relative error
112	112.0	0.00	0.00
111	110.8	0.05	0.05
113	115.3	5.21	4.61
119	118.9	0.01	0.01
123	121.4	2.59	2.11
123	123.5	0.21	0.17
123	122.8	0.04	0.03
129	128.2	0.61	0.47
130	129.4	0.33	0.25
132	130.4	2.42	1.83
136	134.7	1.59	1.17
	Error	1.19	0.97

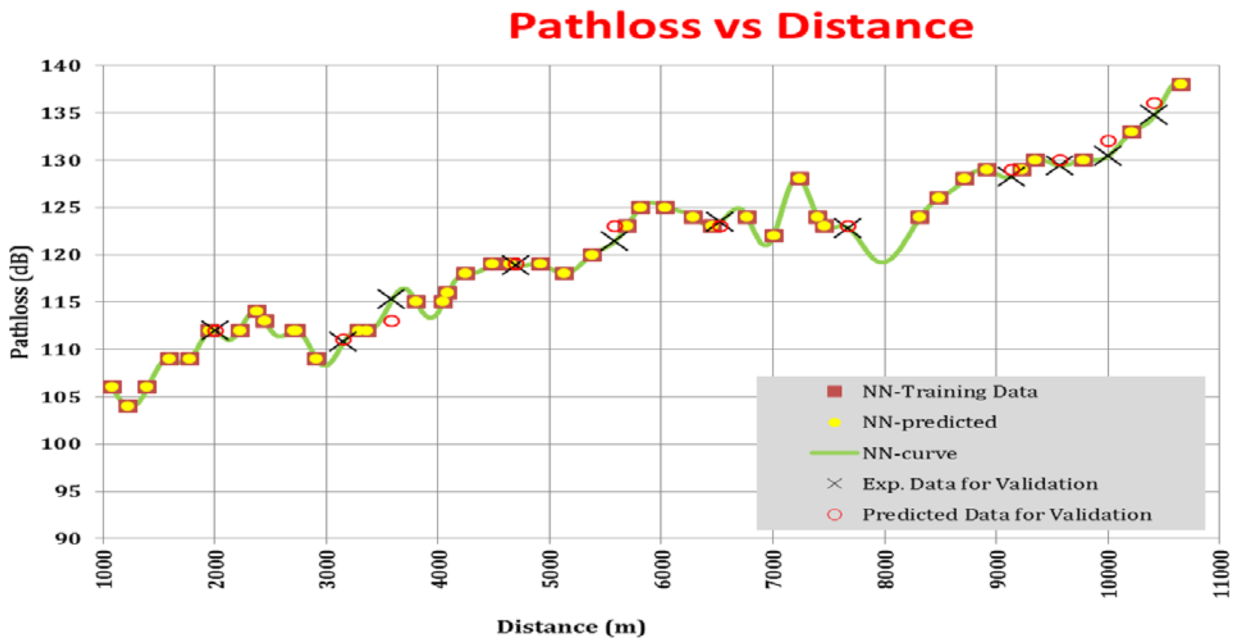

Fig. 4: Pathloss versus distance for Experimental, Theoretical, and Neural Network analysis

Overall, by calculating the RMSE for the second cell and for most of the data sets it was found to be 3.2058 dB, which is an acceptable figure. However, few data points were a bit far from the interpolated values which are attributed to the nature of the cell with high rise buildings. Although there are many predictions methods that are based on deterministic processes through the availability of improved databases, the Okumura-Hata model is still mostly used [25-27]. That is because of the ITU-R recommendation for its simplicity and its proven reliability.

We also know that the obstacles in the path significantly influence the radio signal propagation [28]. Above all, wireless communication system avoids obstacles such as crossing objects owned by others. There are also many problems in a realization of wireless communication system in some applications [29]. However, the current study of neural network and other methods might explain these that have influence in our data acquisition in business district area with high rise buildings and curved roads.

V. CONCLUSION

This work focused on predicting the root mean signal strength in different areas. As most propagation models aim to predict the median Pathloss, existing prediction models differ in their applicability over different terrain and environmental conditions. The effects of terrain situation predicted at 900 MHz were analyzed. Experimental results of radio signals propagation for an urban area in Oman were compared with those predicted based on Okumura-Hata model. The contribution is the prediction by neural network and validation of experimental data. If environmental information is included in the model, better prediction results might be achieved. Neural network gave us also the missing experimental points showing a good agreement within acceptable limits.

ACKNOWLEDGMENT

The authors would like to thank SQU for the support to carry out this study.

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