Wavelet Based Residual Method of Detecting GSM Signal Strength Fading

Danladi Ali, Onah Festus Iloabuchi

Abstract**—**In this paper, GSM signal strength was measured in order to detect the type of the signal fading phenomenon using one-dimensional multilevel wavelet residual method and neural network clustering to determine the average GSM signal strength received in the study area. The wavelet residual method predicted that the GSM signal experienced slow fading and attenuated with MSE of 3.875dB. The neural network clustering revealed that mostly -75dB, -85dB and -95dB were received. This means that the signal strength received in the study is a weak signal.

Keywords**—**One-dimensional multilevel wavelets, path loss, GSM signal strength, propagation and urban environment.

I. Introduction

INVESTIGATION of the global system for mobile communication (GSM) signal strength fading may help us in planning and designing of a radio communication system more especially unguided path like GSM signal which is prompted to the many types of interferences. Usually, better understanding of the GSM signal strength fading helps us to choose some important network parameters, for example, transmitter power, antenna height, antenna gain, and antenna general location [7]-[10], [12]. An ideal propagation means equal propagation in equal directions. Unfortunately, in real life situation, it is not feasible due to some factors between the base station (BS) and the mobile unit (MU) that attenuates the signal, such factors may be responsible for reflecting, refracting, absorbing, and scattering the GSM signal before reaching the MU [1]-[6]. Therefore, in order to receive efficient signal strength it becomes essential to conduct feasibility studies to have almost or an accurate bill of these factors before undertaking a design of the radio communication path.

This work, propose to use wavelet residual method to detect the type of fading in the study area in terms slow or fast fading phenomenon and also, to use neural clustering to determine the signal received in the study area.

II. Study Area and Method of Data Collection

The data is collected in a day time with MU in Dnepropetrovsk city, Ukraine at different locations. The city is typically an urban area which consists of; tall buildings, significant number of trees, river Dnepr that divides the city into two and usual human activities like vehicle movements during the time of the day. On the MU, there are 0 to 5bars signifying the signal strength received at the destination. The network bars on the MU range from 0 to 5 bars, the lowest bar is 0 and is the weakest signal while the signal strength increases as the number of the bars increase, which means the strongest signal is 5 bars. Usually, GSM signal strength is measured in -dBm; that is, the power measured (dB) multiple by the distance between the transmitter (BS) and receiver (MU). The useful range is from -110dBm to -50dBm in a frequency range of 900MHz to 1800MHz or 1900MHz depending on the environmental requirements. The smaller the number of the dB received by the MU the worse the reception or quality of service (QoS). Therefore, -50dBm is much better than -110dBm. In this work, 0 (no bar) is assigned to -105dBm, subsequently, 1bar = -95dBm, 2bars = -85dBm, 3bars = -75dBm, 4bars = -65dBm and 5bars = -55dBm. The MU from transmitter is located in different positions. Starting, from; 400m to 4000m.

III. Wavelet Decomposition and the Residual Prediction Algorithm

The wavelet transform is used to decompose the attenuated signal measured with one-dimensional multilevel wavelet. Full wavelet decomposition of the attenuated signal measured usually provides information about the time and the frequency of the signal at numerous scales. Thus, the signal can be seen in detail and approximated form both on the octave axis (j, J) respectively [11]-[13]. As shown in the Fig. 1, where the approximated signal is situated on the upper scale ranging from $1 \leq J \leq J_0$ while the detail signal on the lower scale ranging from $1 \leq j \leq J_0$. The wavelet coefficients $a_x(J,k)$, $d_x(j,k)$ are derived from the relationship in (1) below after full decomposition.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (1)$$

where a is the positive number which defines the scales and b is the real number that defines the shift in (1) sometimes called child wavelets derived from mother wavelet. Full wavelet decomposition (FWD) of (1) is given in (2)

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$$y = a_x(J,k)\,\psi_0(J,k) + \sum_{k=1}^{j} d_x(j,k)\,\psi_0(j,k) \quad (2)$$

y is decomposed using Haar at level 5. Haar is chosen for the decomposition because of the following reasons; physical appearance of the experimental data, the wavelet Haar have a coefficient of correlation approximately equal to that of experimental data and the wave's energy is almost the same.

IV. Fast and Slow Fading

Fast fading phenomenon follows the Rayleigh distribution and the probability distribution function (PDF) can be computed using (3).

$$\varphi_0(x,\sigma) = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}} \quad (3)$$

where in this case, β is the scale parameter of the experimental data measured, x is the GSM signal received. The mean and the variance of the GSM signal received can be evaluated using (4) and (5). Usually, $x \geq 0$ and $\sigma > 0$.

$$\mu(x) = 1.253\beta \quad (4)$$

$$\sigma^2(x) = 0.429\beta^2 \quad (5)$$

The cumulative distribution function of the Rayleigh distribution may be obtained using (6). However, $x \in [0,\infty)$.

$$CDF = 1 - e^{-\frac{x^2}{2\sigma^2}} \quad (6)$$

Fast fading phenomenon is characterized by reflection of local objects or movement of MU around these objects which can cause fast fluctuation of the signal amplitude, for example, signal reflected by the large water surface, glasses, or vehicle movements. Slow fading follows a Gaussian distribution as given by (7), where $\mu \in R$ and $\sigma^2 > 0$ are the mean (location) and the squared scale respectively.

$$\phi_0(x,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (7)$$

Slow fading phenomenon usually occurs due to the diffraction and large reflection from building, mountains, and PDF can be computed using (7) and the cumulative distribution function (CDF) may be obtained using (8), where μ is mean of the distribution.

$$CDF = \frac{1}{2}\left[1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right] \quad (8)$$

Table I shows some usual mathematical features of the Rayleigh and the Gaussian distributions.

TABLE I
STATISTICAL PARAMETERS FOR THE DISTRIBUTIONS

Parameters	Gaussian Distribution	Rayleigh Distribution	Unit
Mean (μ)	-2 –0	0.63 – 5.01	dB
Variance (σ^2)	0.2 – 5.0	0.25 – 16.0	dB
Skewness	0	0.631	-

V. Clustering of the Variation of Signal Strength Received

Clustering simply means grouping elements together based on their properties, appearance, contents and other features. The experimental data collected was trained using neural network clustering, the network learned about the data and produced clusters of the power measured. As shown in Fig. 1, the signal is grouped into six different groups, -75dBm appeared more frequent, followed by -85dBm, then -65dBm and -95dBm, -105dBm and -55dBm are the least signals received.

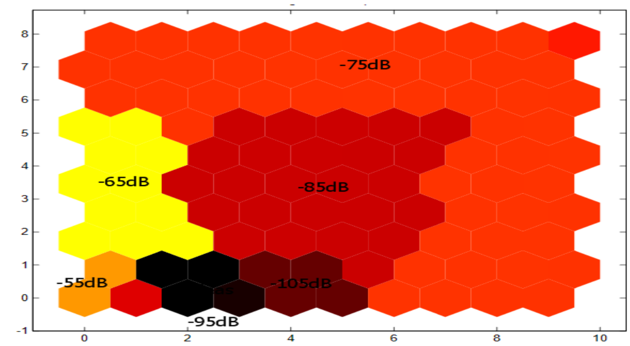

Fig. 1 Clusters of the signal strength received

VI. Results and Discussion

As shown in Fig. 2, the red color graph represents the attenuated signal received and the black color graph represents the de-noised signal. As it can be seen the signal received at the destination is highly attenuated.

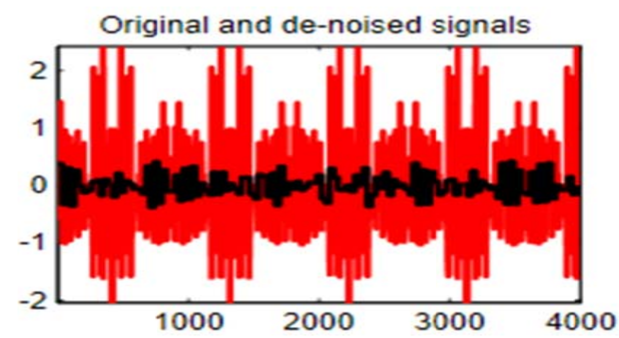

Fig. 2 Original and De-noised Signal

The residual part of the signal de-noised from the original signal is then used to detect the type of the fading in terms of slow or fast fading phenomenon. Fig. 3 shows the histogram of the residual part of the signal which is distributed at the center and is neither skewed left or right with zero mean. This means that the residual signal follows the Gaussian distribution. In conclusion, the signal experienced slow fading.

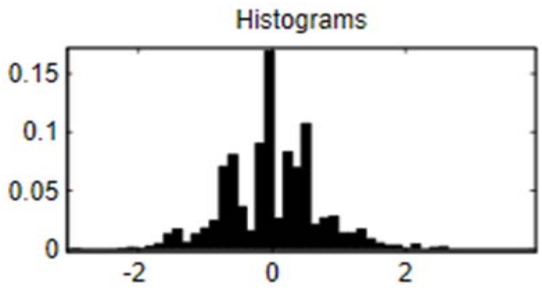

Fig. 3 Histogram of the Residual Signal

To further ascertain that the signal received is de-noised, autocorrelation function (ACF) parameter is used to confirm our de-noising effect. One obvious observation with ACF is that as the level of signal attenuation increases the ACF coefficient decay to zero [14]. As shown in Fig. 4, the ACF increased to close to 1, meaning the attenuated part of the signal is de-noised.

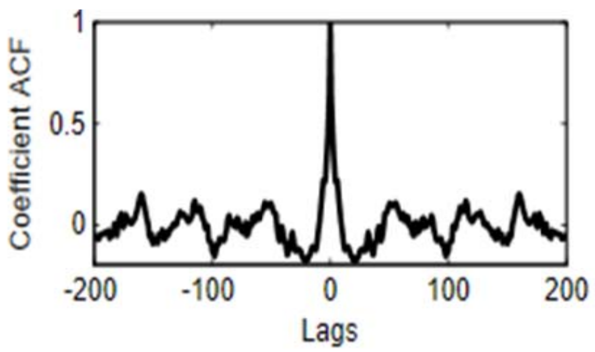

Fig. 4 ACF coefficient

The amount of the attenuation (error) of the signal is determined using (9).

$$MSE(x_0, x_d) = \frac{1}{n}\|x_0 - x_d\|^2 = \frac{1}{n}\sum (x_0 - x_d)^2 \quad (9)$$

where x_0 is the first norm of the signal, that is the length of the signal received, x_d is the second norm of the signal, that is the length of the de-noised signal. Whilst, the MSE computes the correlation or the difference between the attenuated signal and the de-noised signal which is computed as 3.875dB. Table II gives the statistics of the signal after de-noising.

TABLE II
STATISTICS OF THE SIGNAL AFTER DE-NOISING

Parameters	Gaussian Distribution	Rayleigh Distribution	Unit
Mean (μ)	0	93.975	dB
Variance (σ^2)	0.504	374.93	dB
Skewness	0	0	-

By comparing the statistical parameters in Tables I and II, the statistical parameters in Table II corresponds to that of the Gaussian distribution in Table I and this confirmed the prediction that, the signal follows a slow fading phenomenon.

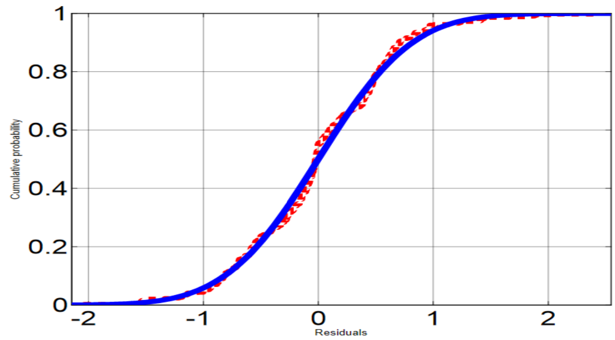

Fig. 5 Cumulative distributions of the residual and the normal distribution

As shown in Fig. 5, the red color graph represents the cumulative probability curve of the residual coefficients de-noised from the received signal and the blue color represents the Gaussian distribution cumulative probability curve, both follow the same pattern. This is evidence that the residual signal follows a Gaussian distribution known as slow fading.

VII. CONCLUSION

Signal fading is an important parameter that one needs to know before undertaking design or improving the existing radio frequency communication path. In this work, a wavelet residual method is used to predict the type of signal fading in the study area. The wavelet residual method predicted that the GSM signal strength fades slowly attenuated with MSE of 3.875dB and followed Gaussian distribution and neural network clustering predicted that the signal strength received in the study area is mostly a weak signal in order of -75dBm, -85dBm, -95dBm. This work demonstrated that the wavelet residual method is a good tool for GSM signal strength fading prediction.

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