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Full Length Research Paper

The Effect of Wind on Foliage GSM/LTE Propagation Channel

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ABSTRACT: In this research paper the effects of wind on a foliage GSM/LTE propagation channel at 900MHz/2500MHz was investigated. The paper focuses on the data collection process and its analysis. The process involved the use of GSM/LTE signal from a Mobile Telephone Network (MTN) base station transmitter, a very good smart phone on which a cell signal monitor application with data logger was installed, acting as the receiver. It also involved a similar mobile phone, with installed Anemometer software application, serving as wind speed meter. The received signal powers in the foliage channel were measured under different wind speeds at one minute interval in order to study the dynamic effect caused by the wind on the propagation channel. The recorded data was grouped under three different ranges of wind speed and finally analyzed using a statistical software program (developed by Mathwave Technology) called EasyFit5.5 professional. After successful analysis the mean (average) Reference Signal Received Power (RSRP) was found to decrease as wind speed increases, while the standard deviation increases with the increase in wind speed. These show that the probability of receiving the mean RSRP is less at higher wind speeds. The dynamic variations caused by the wind on the channel were characterized and found to be beta distributed. Further analysis shows that the variations also fit with normal (Gaussian) distribution which is one of the most commonly known probability distribution functions associated with radio wave propagation channels.

Keywords: Wind, Foliage, GSM/LTE, Propagation channel

INTRODUCTION

A GSM/LTE signal propagation channel is the free space between base station/eNB antenna and mobile phones or mobile terminals (MT). If this free space in between is embedded with trees or shrubs, the propagation channel is called foliage GSM/LTE propagation channel.

Nowadays mobile and wireless communications generally are a basic need in our societies, without which life will be miserable. Mobile phones are used everywhere not only in open spaces or indoors but also in forest (foliage) environments. In many cases these foliage environments are greatly disturbed by atmospheric wind which causes a great deal of branch movements. Movements of tree leaves are one of the major causes of variability in signal reception (Hairani and Chee, 2015; Meng, 2009). In these environments mobile phones service subscribers also require good coverage and high quality service. Despite these facts mobile systems were not deployed to satisfy specifically these requirements. Operator deployment requirements typically guarantee coverage, with certain quality requirements, of a minimum percentage of the geographical area and population (Lucio, 2006). Planning tools, used for fade mitigation of a network, usually provide only outdoor coverage predictions. Therefore an extra signal attenuation associated with foliage penetration is required in the planning of a mobile network.

The estimation of an extra attenuation associated with foliage penetration can be obtained via (i) physics based model which uses radiative transfer theory (incoherent approach) or wave theory (coherent approach), (ii) Method of Moment (MoM), (iii) Enhanced Millimeter

Propagation Model (EMPM) or (iv) using measurement campaigns. The coherent model is composed of two components: a forest stand generator that makes use of a stochastic fractal model, and an electromagnetic model that makes use of Foldy's approximation and single scattering (Feinian and Kamal, 2005). However this model is shown to overestimate the attenuation rate at millimeter frequencies. The full wave numerical technique, method of moment (MoM) can be used to calculate the scattering from a cluster of leaves or needles exactly. However this technique requires significant computational resources which prohibit its application in the wave propagation models. While the EMPM provides a computationally efficient technique that accounts for the multiple scattering in needle clusters (Feinian and Kamal, 2005). All the above mentioned mathematical models estimate extra attenuations associated with foliage penetration without taking the effects of strong wind into consideration.

There are few related works on wind effects over foliage channels. Meng et al. (2009) carried out a research work on the effects of tropical whether on foliage VHF and UHF radio waves propagation channels using palm tree plantation as the foliage environment. They found out that increase in wind speed affects the received signal strength negatively. Eric et al. (2004) used a fixed terrestrial broadband wireless system at 2.545 GHz, with a few temperate trees obstructing the line-of-sight. They concluded that the fading is well pronounced under strong wind speed condition.

In this paper, measurements campaign was conducted to study the dynamic effects imposed by wind on an LTE foliage channel, the frequency of which is in the Radar band (< 1.0 GHz). The collected data was grouped under three ranges of wind speeds and the additional attenuation caused by wind speeds under each group has been calculated and presented. Finally, characterization of the wind-imposed variations, using a statistical software programme has also been carried out and presented.

HARDWARE SYSTEMS, SOFTWARE APPLICATIONS AND MEASUREMENT DESCRIPTION

Hardware and software applications

The 2500 MHz foliage propagation measurements were conducted using Tecno Pouvoir LC6 phone which uses the Mediatek Helio A22 MT6761 microchip. The microchip is a lower mainstream Advanced Reduced instruction set computer (RISC) Machine System on Chip (ARM SoC) processor for smart phones (Klaus, 2019). It integrates four ARM cortex-A53 cores clocked at up to 2 GHz. It also integrates a power virtual reality (power VR) GE6300 GPU (graphics processing unit) clocked at up to 660 MHz. the integrated memory controller supports Low Power Double Data Rate (LPDDR) 4x-32000 (Max 6 GB). Furthermore a long term evolution (LTE) radio with category-7 (Cat-7) DL (300 Mbps) and Cat-13 UL (150 Mbps) and a WiFi modem is also integrated (Klaus, 2019). In addition to this a cell signal monitor software application with data logger was installed to facilitate automatic recording of the required data at the required time interval. The MTN base transceiver/eNB with Location Area Code/Type Allocation Code (LAC)/TAC) 9943 and a CID Number 320455-1 was used as the source of the electromagnetic waves for the measurements. The wind speed measurements were carried out (at 1.7 metre height) using a similar mobile phone equipped with Zephyrus Application as an Anemometer. Zephyrus is an Application which brings the functionalities of an Anemometer (wind speed meter) and of a wind spectrum analyzer to a smart phone using the phone microphone as its sensor (Gaia, 2020).

Measurement environment

The foliage environment in which signal strength measurements were conducted is a dense nim tree plantation (about 1900m^2 area) at Kwado quarters Katsina town in Katsina state – Nigeria, along Daura – Katsina road. The centre of the plantation is about 128 metres from NASFAT Katsina Branch, Katsina (Field Area Measure). The nim trees (the commonest trees in Katsina town) are about 8 to 10 metres high separated 1.5 metres apart averagely. The leaf size is averagely 0.0016 m^2. As the measurements were conducted in the dry season, water contents of the leaves were considered to be low. The separation distance between the base station antenna and the mobile terminal used for the measurement was found to be 590.609 metres, using an application called Field Area Measure (Figure 1).

Measurement procedure

GSM 2G and CDMA 3G are becoming obsolete gradually in Nigeria (The News, 2014). Therefore measurements were conducted on only 4G LTE, by activating the 4G LTE mode of the mobile phone (acting as the receiver). This receiver was placed on a wooden stand about 1.7 metres high at a foliage depth of about 50 metres. The data logger was set to record the Reference Signal Received Power (RSRP) at one minute interval. The smart phone acting as anemometer (wind speed meter) was tied to a wooden stand (having the same height with the first one) and placed in an open space facing the wind direction. The dynamic wind speed was recorded manually at one minute interval by pausing the measurements. The two sets of measurements were started simultaneously so that each RSRP was recorded at the same time with its corresponding wind speed. The

Figure 1: Foliage Environment used for RSRP Measurements.

recorded data was saved in the WPS office on the phone, the screen shots of which are presented as appendix.

RESULTS

Software Program used for analysis

The software application used for the analysis is called "EasyFit 5.5 professional" developed by MathWave Technology. It is a data analyzing program that is designed to quickly provide statistical data on any subject, offering probability results that Engineers and Scientists can take advantage of. The application uses both classical and modern analysis techniques, offering two main types of analysis: distribution fitting and descriptive statistics. The former one provide graphic representation of the input data, while the later displays pieces of information such as sample size, the maximum and minimum values, mean, median, to mention just a few (MathWave, 2020).

DISCUSSION

The obtained RSRP data (appendix) was grouped into three in accordance with their corresponding ranges of wind speeds. The minimum recoded wind speed is 0.00 m/s while the maximum is 8.90 m/s. This range was divided into three as follows: Group one (0.0 m/s – 2.9 m/s), Group two (3.0 m/s – 5.9 m/s), and Group three (6.0 m/s – 8.9 m/s). The grouped data is as shown in (Table 1). Each of the three grouped data was used as a

Table 1: Reference signal received power (RSRP) under different ranges of wind speeds.

Wind Speed (m/s)	0.0 – 2.9	3.0 – 5.9	6.0 – 8.9
RSRP (dB)	-79, -85, -84, -79, -84, -80	-81, -87, -85, -80, -80, -85	-84, -85, -83, -85, -86, -85
	-80, -84, -80, -80, -86, -84	-80, -89, -85, -81, -87, -81	-84, -83, -84, -84, -86, -84
	-81, -84, -83, -81, -83, -83	-79, -88, -81, -87, -84,-82	-85, -85, -84, -86, -84, -85
	-81, -83, -83, -81, -83, -82	-84, -87, -82 -82, -83, -82	-86, -84, -83, -86, -82, -80
	-83, -81, -83, -82, -82, -81	-86, -83, -86, -83, -83, -86	-83, -88, -88, -87, -81, -88
	-82, -82, -81, -87, -81, -81	-83, -84, -83, -84, -81, -84	-88, -87, -81, -81, -89, -88
	-87	-81, -87, -84, -81, -80, -81	-81, -89, -80, -84
		-81, -82	

Table 2: Descriptive statistics for group one data (Wind Speed from 0.0 m/s to 2.9 m/s).

Statistic	Value	Percentile	Value
Sample Size	37	Min	-87
Range	8	5%	-87
Mean	-82.324	10%	-85.2
Variance	3.9474	25% (Q1)	-83.5
Std. Deviation	1.9868	50% (Median)	-82
Coef. of Variation	-0.02413	75% (Q3)	-81
Std. Error	0.32663	90%	-80
Skewness	-0.57836	95%	-79
Excess Kurtosis	0.14381	Max	-79

separate input to the software program and the following results were obtained:

Group One: After inputting, the group one RSRP data was analyzed by clicking “Analyze” on the software and selecting “Fit Distribution” and then “ok”. The result shows that the probability density function (pdf) denoted as $f(x)$ has a generalized extreme value distribution with the following parameters:

$$k = -0.49716, \quad \sigma = 2.1414, \quad \mu = -82.815$$

where k, σ and μ are shape, scale and location parameters respectively. Generalized extreme value (GEV) distribution is given by (Ripunjai and Trivedi, 2010).

$$f(x;\mu,\sigma,k) = \frac{1}{\sigma} t(x)^{k+1} e^{-t(x)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where

$$t(x) = [1 + k(x-\mu)/\sigma]^{1/k} \quad ; if\ k \neq 0 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$t(x) = e^{-(x-\mu)/\sigma} \quad ; if\ k = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The descriptive statistics (Table 2) was also obtained by clicking “Analyze” on the software. But in this case “Descriptive Statistics” was selected and then “ok”. The result of this operation gives the following pieces of information in (Table 2). The same procedure was used

Table 3: Descriptive statistics for group two RSRP data (Wind Speed from 3.0 to 5.9 m/s).

Statistic	Value	Percentile	Value
Sample Size	44	Min	-89
Range	10	5%	-87.75
Mean	-83.295	10%	-87
Variance	6.399	25% (Q1)	-85
Std. Deviation	2.5296	50% (Median)	-83
Coef. of Variation	-0.03037	75% (Q3)	-81
Std. Error	0.38136	90%	-80
Skewness	-0.41838	95%	-80
Excess Kurtosis	-0.76976	Max	-79

Table 4: Descriptive Statistics for group three RSRP data (Wind Speed 6.0 to 8.9 m/s).

Statistic	Value	Percentile	Value
Sample Size	40	Min	-90
Range	11	5%	-88.95
Mean	-84.65	10%	-88
Variance	6.4897	25% (Q1)	-86
Std. Deviation	2.5875	50% (Median)	-84.5
Coef. of Variation	-0.03009	75% (Q3)	-83
Std. Error	0.40279	90%	-81
Skewness	0.08576	95%	-80.05
Excess Kurtosis	-0.28993	Max	-79

for the remaining groups.

Group Two: Group two RSRP data input was found to be beta distributed and the probability density function $f(x)$ has the following parameters:

$\alpha = 2.061, \quad \beta = 1.442, \quad a = -89.655, \quad b = -78.892$

a and b are lower and upper limits respectively. Beta Distribution is given by (ScienceDirect, 2016).

$$f(x;\alpha,\beta) = \frac{1}{B(\alpha,\beta)} x^{\alpha-1}(1-x)^{\beta-1} \ldots\ldots\ldots\ldots (4)$$

The shape parameters α and β are positive real quantities and the variable x satisfies $0 \leq x \leq 1$. The quantity $B(\alpha,\beta)$ is the Beta function defined in terms of the more common Gamma function as:

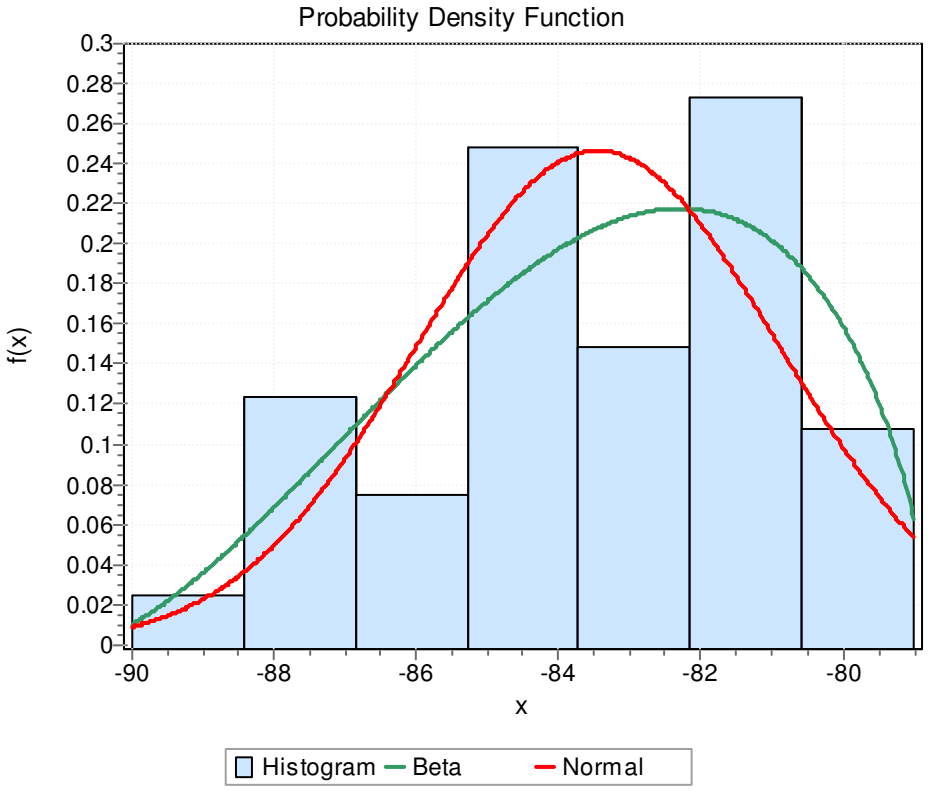
$$B(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The descriptive statistics is as shown in (Table 3).

Group Three: Inputting the Group three RSRP data into the software program gave an output which shows that

Table 5: Comparison of mean and standard deviations under different ranges of wind speeds.

Wind Speed range (m/s)	0.0 – 2.9	3.0 – 5.9	6.0 – 8.9
Mean RSRP (dB)	- 82.324	- 83.295	- 84.295
Std Deviation (dB)	1.9868	2.5296	2.5875



the distribution is Gamma (3P) and the probability density function $f(x)$ has the following parameters;

$$\alpha = 132.63, \quad \beta = 0.21912, \quad \gamma = -113.72$$

Probability density function of the Generalized Gamma or 3-parameter Gamma or Gamma (3P) distribution is given by (Kiche et al., 2019).

$$f(x;\alpha,\beta,\gamma) = \frac{\gamma\alpha^{-\beta}}{\Gamma\left(\frac{\beta}{\gamma}\right)} \exp\left[-(x/\alpha)^{\gamma}\right] \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where α (scale parameter), β and γ (shape parameters) are real positive numbers for a non-negative x and Γ(·) is Gamma function. The descriptive statistics is as presented in (Table 4). From Tables 2, 3 and 4, it can be seen that as wind speeds increase, the average (mean) RSRP decreases while the standard deviation increases. This is tabulated as shown in (Table 5). From Table 5, the average additional attenuation imposed by group two (3.0 – 5.9) m/s is ΔA_1 calculated thus:

$$\Delta A_1 = -82.324 - (-83.295) = -82.324 + 83.295 = 0.971\ \text{dB}$$

While that imposed by the third group (6.0 – 8.9) m/s is ΔA_2 given by:

$$\Delta A_2 = -82.324 - (-84.295) = -82.324 + 84.295 = 1.971\ \text{dB}$$

These calculated values of the additional attenuation (ΔA_1 and ΔA_2) show that an increase in wind speed increases the level of additional attenuations in the foliage propagation channel. The increase in standard deviation from group one to group two is Δstd_1 given by:

$$\Delta Std_1 = 2.5296 - 1.9868 = 0.5428\ dB$$

Table 6: Descriptive statistic of the entire RSRP data (Wind Speed from 0.0 m/s to 8.9 m/s).

Statistic	Value	Percentile	Value
Sample Size	121	Min	-90
Range	11	5%	-88
Mean	-83.446	10%	-87
Variance	6.4658	25% (Q1)	-85
Std. Deviation	2.5428	50% (Median)	-83
Coef. of Variation	-0.03047	75% (Q3)	-81
Std. Error	0.23116	90%	-80
Skewness	-0.36511	95%	-80
Excess Kurtosis	-0.58802	Max	-79

While that between group one and group three is Δstd_2 given by:

$$\Delta Std_2 = 2.5875 - 1.9868 = 0.6007\ dB$$

These calculated results of the increase in standard deviations (ΔStd_1 and ΔStd_2) show that when wind speed increases, standard deviation also increases, indicating that the probability of receiving the mean RSRP is less at higher wind speeds.

All the Data: To characterize the whole phenomenon, all the collected RSRP data (groups 1, 2, and 3) was used as a single input to the software program. When analyzed the distribution fitting which produces graphical representation of the input variables shows that the variations are Beta distributed (green curve) as shown in (Figure 1). The parameters of the probability density function of the Beta distribution (equation 4 and 5) are:

$$\alpha = 2.6165, \quad \beta = 1.6727, \quad a = -90.789, \quad b = -78.748$$

where α and β are shape parameters, and aand b are lower and upper boundaries respectively.

Further analysis shows that the dynamic effect caused by the wind on the foliage channel also compares to some extent with Normal (Gaussian) distribution (red curve). Probability density function of Gaussian distribution is given by (Jerome et al., 2017):

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} Exp\left[\frac{-(x-\mu)^2}{2\sigma^2}\right]; -\infty < x < \infty \quad \ldots\ldots\ldots\ldots (7)$$

where μ and σ represent the mean and standard deviation respectively.

The descriptive statistics of the function is as presented in (Table 6). Table 6 shows that the mean RSRP for the whole data is less than those of groups one and two obtained at lower wind speeds, but higher than that of group three which was recorded at higher wind speed. While, as expected, the standard deviation of the whole data is less than that of group three due to higher variability caused by higher wind speed in that group but greater than the standard deviations of the two groups obtained at relatively lower wind speeds.

Conclusion

This paper shows how two smart phones were used for data collection process to investigate the effect of wind on foliage GSM/LTE propagation channel. This was achieved by converting one phone into a receiver with cell signal monitor/data logger and the other one converted into wind speed meter using Anemometer software application. From the data analysis, the paper shows that as wind speed increases, the average (mean) Reference Signal Received Power (RSRP) decreases. In other words the additional attenuation imposed on the foliage channel by a strong wind increases as the wind speed increases. For the 8.9 m/s difference in wind speed (measured at 1.7 metre height) the average additional attenuation imposed on the propagation channel was found to be 1.971 dB. Therefore for effective fade mitigation scheme in foliage environments, prone to strong winds, additional transmitted power is required to

provide good quality services to subscribers. The paper also shows vividly that as wind speed increased from group one (0.0 – 2.9) m/s to group three (6.0 – 8.9) m/s, the standard deviation also increased by 0.6007 dB, indicating that the probability of receiving the mean RSRP is less at higher wind speeds. After characterization the dynamic variations caused by the wind were found to be Beta distributed. Further analysis shows that these variations also fit with Gaussian distribution which is one of the most commonly known probability distribution functions associated with radio wave propagation channels.

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