Determination Of The Influence Of Wind On Received Cellular Signal In A Heavy Vegetation Environment

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Abstract: *In this paper the influence of wind in a heavy vegetation environment was empirically evaluated. This was achieved by conducting several field measurements at a spot and at a particular time period for mild breeze, light breeze and strong wind conditions. The experimentation period was for two years. Data collected was plotted and analyzed. Results show that strong wind causes fluctuations in the received cellular network signal which could lead to poor network receptions.*
Keywords: *cellular signal, signal fluctuation, signal fading, wind effect.*

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1. Introduction

For multipath reception, studies have shown that it is as a result of four major issues caused by physical factors in a radio communication channel, and which most times affect mobile signal strength as it travels from the base station to the mobile receiving unit and vice versa resulting in the observed interruptions and failures (Meng and Lee, 2009). These factors include: reflection, diffraction, obstruction and scattering of the propagated signal, as result of such obstructions like buildings, trees and other obstacles on the path of the propagated signal. There are other weather factors like rainfall and wind. Wind is air in motion. And air as fluid has weight and when it gets moving as wind it exerts pressure on anything that gets on its way. In foliage environment the pressure comes in form of movements of the branches and leaves of the foliage which has a scattering effect on the signal. The higher the speed of wind, the greater the pressure exerted.

The effect of wind is more pronounced in a heavy foliage environment. Foliage medium in the path of radio signal has significant effect on the quality of received radio signal. This is because such environment contain discrete signal scatters such as randomly distributed leaves, tree branches and trunks, twigs that attenuates significantly radio signals due to their Scattering, absorption and diffraction effects on radiated propagating waves (Meng etal, 2009,).

A: Free space reception   C: Received diffracted signal   E: Blocked signal
B: Received reflected signal   D: Received scattered signal

2. Theory

Weather-induced Temporal Variations on Received Radio Signal
The temporal variations in weather (rain and wind) induced signal changes on radio a signal is usually characterized through the statically modeling of the signal envelope (amplitude) using the well known radio propagation distributions channels: Gaussian, Rician, Rayleigh, and Nakagami distributions (Meng etal, 2009). Their mathematical expressions are given in the following equations:
For Gussian Distribution:

$$F(x) = a \exp\left(-\frac{(x-b)^2}{2c^2}\right)$$

Where a is the height of the curve's peak, *b* is the position of the center of the peak and *c* is the standard deviation
For Rician distribution:

$$I0\left(\frac{xs}{\sigma^2}\right)\frac{x}{\sigma^2}\ e^{-\left(\frac{x^2+s^2}{2\sigma^2}\right)}$$

Where s is the amplitude of the steady component, σ is the variance of the random component. Then, the noncentrality parameter $s \geq 0$ and scale parameter $\sigma > 0$, for $x > 0$ is considered. *I*0 is the zero-order modified Bessel function of the first kind. If *x* has a Rician distribution with parameters *s* and *σ*, then (*x*/*σ*)2 has a noncentral chi-square distribution with two degrees of freedom and noncentrality parameter (s/σ)2. The Rician distribution function can be described in terms of a fading parameter K commonly known as Rician K factor. This Rician K factor depends on the type of multipath channel and varies from + - ∞ decibels for a static propagation channel with temporal variations (which approaches a Gussian distribution) to - ∞ decibels for a dynamic propagation channel with strong temporal variations (which approaches a Rayleigh distribution). Note that Wind induced temporal variations on a foliage-obstructed cellular base-to-mobile channel has been found to be Rician distributed.

For Rayleigh distribution:

$$y = f\left(\frac{x}{b}\right) = \frac{x}{b^2} e^{\left(\frac{-x^2}{2b^2}\right)}$$

Rayleigh distribution when considered is a special case of the Weibull distribution. It is in such a way that if A and B are the parameters of the Weibull distribution, then the Rayleigh distribution with parameter b is equivalent to the Weibull distribution with parameters A = $\sqrt{2b}$ and B = 2. It then goes that if the component velocities of a particle in the *x* and *y* directions are two independent

normal random variables with zero means and equal variances, then the distance the particle travels per unit time is distributed Rayleigh.

Nakagami distributions, Rician distributions, and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths, especially in communication theory. Subjecting the density of the scatter into consideration, the signal will display different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters, while Rician distributions model fading with a stronger line-of-sight. On the other hand, Nakagami distributions can be reduced to Rayleigh distributions, but give more control over the extent of the fading.

Nakagami distribution:

$$2\left(\frac{\mu}{\omega}\right)^{\mu} \frac{1}{\Gamma(\mu)} x^{(2\mu-1)} e^{\frac{-\mu}{\omega}x^2}$$

Γ is the gamma function. Nakagami is a general fade function that tries to model a combination of distributions. With shape parameter μ and scale parameter $\omega > 0$, for $x > 0$. If x has a Nakagami distribution with parameters μ and ω, then $x2$ has a gamma distribution with shape parameter μ and scale parameter ω/μ. The result of all the variations is that several versions of the transmitted signal arrives a receiving spot and the combination of this arriving signal will form the received signal level at the spot. If the combination is more constructive a good signal is therefore received and hence a good network, but if the reception is more destructive we have a degraded reception which may result in occasional or total absence of network.

3. Experimental Setup

Development of the Research Test bed

The major practical work for this research is measurement of signal field strength at a point of good signal reception in the field of study. Therefore to achieve a good result the following preparations were first made:

Choice of Study Field/ test spot

The study field for this research was chosen at a Hilly place located close to a very thick forest at Nsude (near Enugu) in Eastern Nigeria assumed to be a heavy vegetation environment. The experiments were conducted at a spot in the environment where the average received signal strength after several measurements was noted to be -78dBm (Alor etal 2014). It should be noted also that at around hilly locations a slight change in weather condition has a major influence on wind speed.

Test equipment

Wind vane: Used to determine the wind speed before and after every experimental period for the classification of the data obtained according to the wind speeds.

Field Signal Strength Measurement Meter

Two types of signal field strength measurement meters were used:

(i) Mongoose signal field strength meter (MSFSM) and
(ii) Base station analyzer (BSA).

The Mongoose field strength meter because of its very handy size was used to carry out the measurements. Then the more sophisticated Base station analyzer (BSA) monitored the bearing and distance of the experimental spot from the base transceiver of the network operator understudy.

Experimental Periods

The Enugu State Government House climate change unit handbook on the climate of Enugu State indicates that the annual wind speed for Enugu and its environs vary between 2.0 m/s and 6.2 m/s with the speeds higher between July and August the period of August break. Conversely, at the peak of the rainy season in June and July, wind speeds are lowest measuring between 2.0 and 4.1 m/s. From December wind speed begin to rise steadily till March just before the rains begin and later rise during the August break. From the Enugu State University of Science and Technology (ESUT) meteorological department, six major wind conditions exist in Enugu and its environs; these are calm, light, gentle, moderate, fresh and, strong breeze.

For the purpose of this study experiments were conducted only during low, mild and strong breeze conditions. From the ESUT meteorological records on wind conditions in Enugu State, wind speed for calm breeze condition is between 1.8m/s to 2.5m/s, moderate breeze 3.8m/s to 4.5m/s and strong wind condition between 4.8m/s to 5.5m/s.

For a better study on the influence of wind, experiments were conducted between January and March during the dry season period. This was to avoid the influence of moisture which could affect the readings.

Implementation Schemes

Wind is one of the weather conditions that affect signal reception in a GSM network. This is because Electromagnetic waves can be scattered and its direction can also be changed by wind movements (Pelet, 2004). The stronger the wind movements, the more its influence on signal waves in space. For this work only the influence of three wind conditions: calm, light and strong breeze were studied.

The duration of each experiment was 30 minutes. And several of such experiments were conducted for many days. For each experiment, the speed of the wind will first be measured and noted. Then with the Mongoose signal strength measurement meter, the received signal strength was measured for every second for 60 seconds (one minute). This will be done for 30 minutes. Then wind speed will again be measured at the end of 30 minutes experiment and noted. The average of the received signal for each minute will be recorded. Then depending on the measured speed of the wind the data obtained will be classified and recorded as either calm, light or strong wind measured data.

4. Measurement and Data Collection

Measurement of the influence of wind on received GSM Signal From the literature review, strong wind tends bend and also scatter radio signal beam which will in effect create more multiple signal that will either lower or increase the strength of received network signal at a point. The aim of this experiment is to show how in reality wind affects the received signal strength in a mobile network. It is not to determine the actual impact of wind on radio signal receptions.

For this experiment the impact of call traffic on received cellular traffic was taken into account. Therefore the experimental period of 1000 hrs to 1030hrs was chosen and that was the time all experiments for these study were performed. Wind vane was mounted at the study location for the measurement of wind speed before and after each experiment. Several measurements following the implementation scheme were conducted from January to march 2011 and 2012. At the end of each experiment the data collected was recorded according to the wind speed measured. Any data collected outside the three wind speed under observation was discarded. For each year five readings taken at different days was made for each wind speed under observation and the average of the two years was then recorded as data obtained for the measurements as noted in table 1. The average of each class of wind was then recorded in table 2 to be used for MAT LAB plots. Table 3 is the rate of signal failure for each wind condition.

Table 1: Result of measurements conducted on the effect of wind

Time in min	Calm Breeze						Light Breeze						Strong wind					
	Received Signal in dBm						Received Signal in dBm						Received Signal in dBm					
	1st	2nd	3rd	4th	5th	Avg	1st	2nd	3rd	4th	5th	Avg	1st	2nd	3rd	4th	5th	Avg
1	-71	-76	-79	-80	-82	-78	-96	-100	-98	-95	-99	-80	-79	-75	-78	-77	-80	-78
2	-73	-75	-71	-77	-78	-75	-84	-86	-87	-82	-83	-78	-89	-88	-86	-90	-87	-88
3	-72	-73	-78	-75	-72	-74	-90	-91	-87	-88	-90	-89	-90	-90	-96	-92	-89	-91
4	-75	-77	-80	-78	-79	-78	-89	-91	-94	-90	-89	-91	-90	-93	-96	-93	-92	-93
5	-76	-79	-83	-75	-77	-78	-90	-87	-89	-86	-89	-92	-93	-97	-97	-96	-90	-95
6	-77	-81	-84	-87	-84	-83	-87	-88	-90	-91	-89	-89	-94	-93	-92	-95	-88	-92
7	-87	-85	-89	-81	-89	-86	-83	-84	-79	-84	-81	-69	-89	-90	-94	-92	-87	-90
8	-92	-87	-85	-94	-93	-90	-73	-74	-69	-74	-71	-72	-83	-86	-84	-88	-87	-86
9	-93	-83	-85	-89	-97	-89	-87	-89	-90	-85	-86	-87	-97	-98	-100	-99	-96	-98
10	-88	-89	-92	-87	-84	-88	-85	-84	-87	-86	-83	-85	-82	-84	-80	-83	-79	-82
11	-80	-78	-79	-82	-83	-80	-80	-77	-74	-76	-79	-77	-84	-83	-82	-80	-78	-81
12	-78	-81	-77	-79	-84	-80	-86	-90	-87	-88	-85	-87	-100	-102	-99	-101	-104	-101
13	-83	-83	-85	-84	-89	-85	-87	-91	-88	-89	-90	-89	-77	-74	-75	-76	-78	-76

14	-90	-85	-88	-86	-85	-87	-90	-91	-92	-96	-88	-91	-72	-70	-69	-68	-67	-69
15	-89	-92	-93	-95	-93	-92	-95	-100	-98	-98	-95	-97	-98	-102	-96	-100	-97	-99
16	-94	-97	-94	-95	-96	-95	-95	-95	-98	-91	-96	-95	-91	-92	-96	-97	-95	-94
17	-89	-86	-90	-88	-87	-88	-79	-77	-78	-80	-82	-79	-85	-90	-84	-87	-88	-87
18	-76	-75	-83	-79	-75	-78	-82	-79	-81	-83	-84	-82	-75	-77	-74	-82	-76	-77
19	-75	-78	-80	-76	-75	-77	-64	-68	-63	-67	-66	-63	-92	-88	-85	-89	-92	-89
20	-85	-86	-84	-87	-89	-86	-70	-73	-71	-72	-69	-71	-88	-89	-97	-91	-87	-90
21	-91	-92	-89	-90	-89	-90	-87	-86	-90	-89	-87	-88	-79	-81	-80	-78	-82	-80
22	-83	-81	-79	-81	-77	-80	-95	-95	-91	-95	-96	-94	-97	-100	-99	-98	-102	-99
23	-79	-82	-80	-77	-76	-79	-78	-79	-80	-83	-85	-78	-96	-97	-92	-94	-98	-95
24	-96	-100	-98	-95	-99	-98	-89	-92	-94	-93	-95	-92	-98	-91	-95	-99	-97	-96
25	-84	-86	-87	-82	-83	-84	-89	-87	-85	-86	-88	-87	-90	-89	-85	-87	-86	-87
26	-89	-90	-88	-87	-85	-88	-82	-88	-81	-86	-83	-84	-84	-85	-87	-84	-87	-85
27	-89	-87	-88	-90	-95	-90	-79	-78	-80	-83	-82	-80	-87	-83	-86	-85	-84	-85
28	-90	-87	-89	-86	-89	-88	-90	-88	-87	-89	-86	-88	-97	-100	-102	-101	-99	-100
29	-87	-88	-90	-91	-89	-89	-101	-98	-102	-99	-97	-99	-102	-96	-98	-97	-100	-99
30	-83	-84	-79	-84	-81	-82	-90	-88	-91	-87	-86	-88	-102	-100	-98	-99	-104	-101

Table 2: Average of the measurements obtained according to the 3 wind Conditions

	Received signal in dBm	Received signal in dBm	Received signal in dBm
Time (minutes)	Calm Breeze	Light Breeze	Strong wind
1	-78	-80	-78
2	-75	-78	-88
3	-74	-89	-91
4	-78	-91	-93
5	-78	-92	-95
6	-83	-89	-92
7	-86	-69	-90
8	-90	-72	-86
9	-89	-87	-98
10	-88	-85	-82
11	-80	-77	-81
12	-80	-87	-101
13	-85	-89	-76
14	-87	-91	-69
15	-92	-97	-99
16	-95	-95	-94
17	-88	-79	-87
18	-78	-82	-77
19	-77	-63	-89
20	-86	-71	-90
21	-90	-88	-80
22	-80	-94	-99
23	-79	-78	-95
24	-98	-92	-96

25	-84	-87	-87
26	-88	-84	-85
27	-90	-80	-85
28	-88	-88	-100
29	-89	-99	-99
30	-82	-88	-101

Table 3: Rate of signal fluctuations under different wind conditions

WEATHER CONDITION	RECEIVED SIGNAL (dBm)	NO. OF TIMES	TYPE OF NETWORK COVERAGE
Calm Breeze	-101 or less	0	No network reception
	-100 to -91	3	Weak network reception
	-90 to -81	16	Moderate network reception
	-80 or above	11	Good network reception
Light Breeze	-101 or less	0	No network reception
	-100 to -91	8	Weak network reception
	-90 to -81	12	Moderate network reception
	-80 or above	10	Good network reception
Strong Breeze	-101 or less	2	No network reception
	-100 to -91	12	Weak network reception
	-90 to -81	11	Moderate network reception
	-80 or above	5	Good network reception

The influence of wind on received cellular signal

From table 2, MAT LAB plot of the influence of wind on received cellular signal as given in fig 1 below. Also from table 3 the rate of signal fluctuations during the three rain conditions is shown in fig 2. Signal receptions between -91 and -100 dBm is weak and may cause intermittent network reception, Signal receptions above -81dBm is good and will sustain good cellular network (call and data network transmission and reception). While signal receptions below -101dBm is not good and may not support network receptions (MTN Handbook).

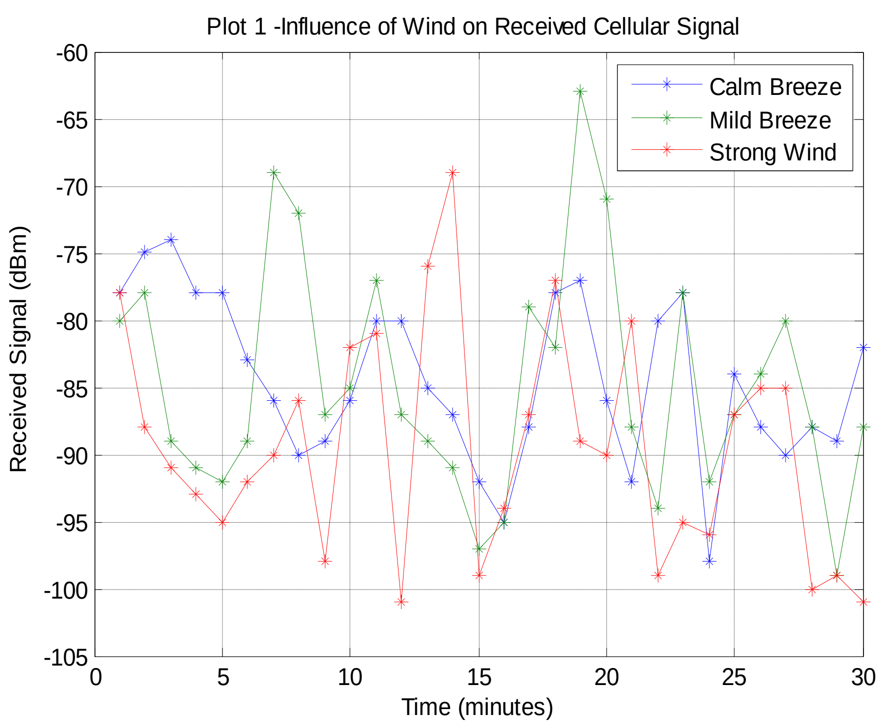

Fig 1: Plot of the influence Wind on Received Cellular Signal in Heavy Vegetation Environment

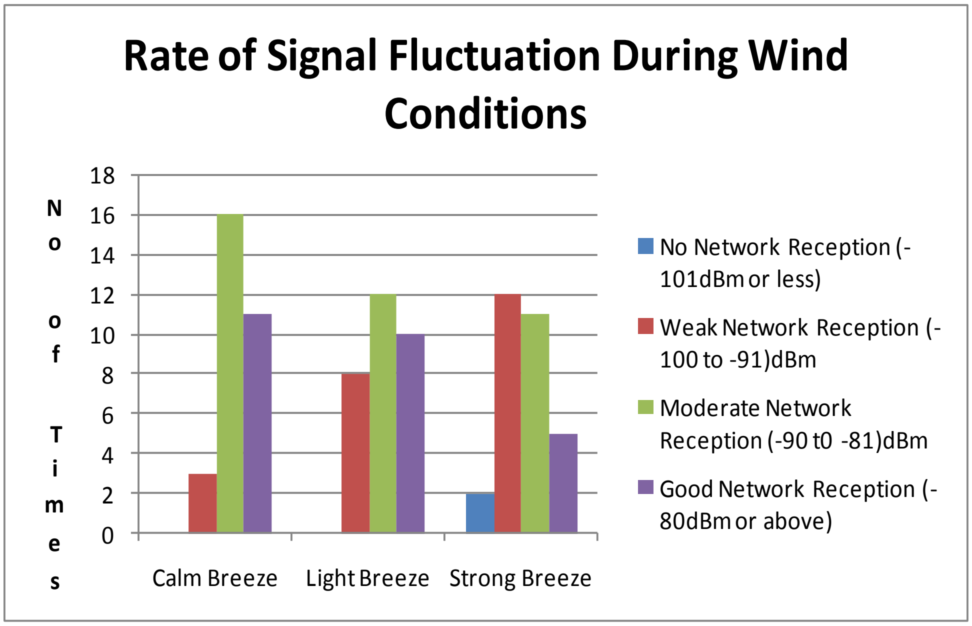

Fig.2: Rate of Signal Fluctuations during Calm, Mild and Strong Breeze Wind conditions

5. Analysis

The influence of wind in a foliage environment has been empirically determined. From figs 1 and 2, it can be seen that wind can impose an additional attenuation on received Cellular signal within a foliage environment which causes fluctuations on received signal. The additional attenuation increases as the speed of the wind increases as can be seen in the plot of calm breeze, mild breeze and strong wind conditions (more during strong wind and very much less during calm breeze). Hence, the higher or stronger the wind speed the weaker the received signal strength which means that call reception at such locations may likely be unsteady during mild and strong wind conditions and which if prolonged may lead to call drops.

6. Conclusion

This work involved a comprehensive empirical study of the effect of different categories of wind conditions on cellular network signal reception. From the analysis of results obtained, it can be deduced that wind imposes an additional attenuation on received cellular signal within foliage environment effectively, causing fluctuations on received signal especially during strong wind conditions. If condition continues or prolonged, call drops sets in.

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