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Instantaneous GSM Signal Strength Variation with Weather and Environmental Factors

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ABSTRACT: *Spatial and temporal changes that transmitted radio signals may go through are attributed to variations in the atmospheric conditions as well as other environmental factors. This work evaluates and establishes some atmospheric and environmental variables that have a dominating impact on temporal signal strength fluctuations that are experienced even on a fixed location. The average refractivity gradient dN/dh computed from hourly measurement taken at a fixed location for seven days was -61.3 N/km and so the average propagation conditions correspond to the normal mode, although super refraction was to be expected at about 10 am and 8 pm. On the overall, the variation in dN/dh does not actually explain the temporal variations in the received signal Pr, since the correlation between the variables is as low as 0.091. Among the environmental factors investigated for their effect on signal strength fluctuations, receiver location has a dominating impact.*

KEYWORDS: *Radio Signals, Weather, Refractivity, Environment*

I. INTRODUCTION

Recent studies have however shown that the transmitted radio signals may go through spatial and temporal changes due to variations in the atmospheric conditions as well as other environmental factors [9]. These conditions vary with changes in height, geographical location, and even with changes in time of the day as well as seasons of the year.

Virtually all weather phenomena take place in the troposphere which is the portion of the Earth's atmosphere that extends from the surface of the Earth to a height of about 6 km at the Poles and 18 km at the equator. The temperature in this region decreases rapidly with altitude, clouds form, and there may be much turbulence because of variations in temperature, density, and pressure.

These fluctuations in the atmospheric parameters like temperature, pressure and humidity in the troposphere are said to cause the refractive index of the air in this layer to vary from one point to another [14]. This study evaluates the correlation between instantaneous or temporal signal strength fluctuation and the associated refractivity gradient based on hourly data of the atmospheric parameters obtained from Nigerian Meteorological Centre, Bauchi station and the simultaneous hourly GSM Signal Strength measured at a fixed location.

II. RELATED STUDIES

Influence of atmospheric refraction on the propagation of electromagnetic waves has been studied by several researchers and it has been shown that the inhomogeneous spatial distribution of the refractive index result in multipath fading and interference, and these impair radio communication, navigation and radar systems [13]. It has also been shown that seasonal variation of refractivity gradient could cause microwave systems unavailability [22].

This variation of atmospheric refractivity in space and time as a result of some physical processes are often difficult to describe in a deterministic way and have to be considered as a random variable. Current research on the effect of refractivity is based on experimental measurements in some case [1, 3, 5, 7] and in other cases they are based on computational methods which are used to simulate the refractivity effects [20]. Such have been carried out for different propagation environments [6, 9, 14, 15, 21].

Statistical distributions of the refractive index modulus, its vertical gradient, and the diurnal and seasonal variations have been investigated and characterized for different regions and climates using measured local meteorological data [5, 8, 17, 19, 22]. The results of these works show that the local climate has an appreciable influence on the radio refractivity and hence on the transmitted radio signals. The result of [4] actually showed that the diurnal refractivity variation is basically a function of local meteorology, while seasonal variation follows the climatic condition.

In a related development, [16] evaluated the refractivity gradient for Bauchi based on a five year meteorogical data obtained between 1995 and 1999. A second order polynomial expression developed from the data of [17] was used to obtain the gradient. The foregoing show the possibility of higher path loss between January and March, and conditions conducive for ducting may exist between May and October. Also, the presence of the anomalous propagation discovered by [14], during their measurement campaign led to further studies and analysis to correlate weather conditions with the temporal variations in the received signal of a live VHF network. The abnormal conditions in the upper atmospheric layers were used to explain the observed variations in the received signal strength.

These related works only attempted to correlate the observed seasonal refractivity profiles with actual signal strength from a live network operating at VHF bands and not the instantaneous and temporal fluctuations. This work investigated the extent to which variation in refractivity and its gradient affect the temporary signal strength variations at fixed locations in Nigeria among others. Although other parameters like equivalent gradient and the potential refractive index have also been proposed for predicting or interpreting radio data, surface refractivity is more commonly used because of the relative ease in obtaining its related surface parameters namely; temperature, pressure and relative humidity from many widely separated stations [4].

III. MATERIALS AND METHODS

An experiment focusing on refractivity related effects was carried out by, first, taking the hourly measurement of signal strength at a fixed location (Plate I) on a live GSM network operating in the 900 MHz band and the fluctuations were observed. Secondly, data of tropospheric variables - temperature, pressure, and relative humidity were simultaneously obtained from Bauchi meteorological centre. The meteorological data available was only for the surface weather parameters, and were used to calculate vapor pressure, radio refractivity, and refractivity gradient, and Effective Earth Radius Factor.

Plate I: Digital Map of a Fixed Location in Bauchi, Nigeria, Downloaded from Google Maps website.

3.1 Refractive index in the troposphere

The refractive index of the troposphere is a function of pressure, temperature and water vapour content. The value of refractive index, n, approximately equals to one (varying between 1.000250 and 1.000400) at or near the Earth's surface and changes in this value is very small in time and in space. The concept of refractivity N was thus developed in practice for easy handling of figures and to make those changes more noticeable [10]:

$$N = (n-1)\times 10^{6} \qquad (1)$$

From Equation (1), it is easily deduced that a typical range of *N* will be between 250 and 400 N units. Radio refractivity *N* is given in equation (2) as:

$$N(P,T,e) = N_{dry} + N_{wet}$$

$$= \frac{77.6P}{T} + 3.732\times 10^{5}\frac{e}{T^{2}} \qquad (2)$$

where P is atmospheric pressure (hPa), e the water vapor pressure (hPa), and T is the absolute temperature (K). Equation (2) may be used for all radio frequencies up to 100 GHz with error less than 0.5% [10].

The water vapor pressure e is given by equation (3),

$$e = \frac{H_R e_s}{100} \qquad (3)$$

where H_R is the relative humidity, and e_s saturation vapor pressure (hPa) at a given temperature, *t* (^{0}C) is given by equation (4):

$$e_s = a\times \exp\left(\frac{bt}{(t+c)}\right) \qquad (4)$$

where a = 6.1121 hPa, b = 17.502 and c = 240.97 °C above liquid water and above ice a = 6.1115 hPa, b = 22.452 and c = 272.55 °C. In this work, the values above liquid water were used.

From equation (2), the refractivity *N* varies inversely with temperature *T* and is strongly dependent on water vapour pressure *e*. *N* also decrease exponentially in the troposphere with height [6, 10]

$$N = N_s \times \exp\left[\frac{-h}{H}\right] \qquad (5)$$

where *N* is the refractivity at the height *h* (km) above the level where the refractivity is N_s while *H* is the applicable scale height. [10] suggested that at average mid-latitude, N_s and *H* are 315 and 7.35 km respectively. Hence, *N* as a function of height *N(h)* is given in equation (6):

$$N = 315e^{-0.136h} \qquad (6)$$

However, the results of the work of [3] showed that the model using the scale height of 7.35 km and 7 km as recommended for global environment [10] and tropical environment [12] respectively gave reasonably accurate results for the refractivity at the altitude of 50m and 200m for seven out of the twelve months of the year. Although the scale height of 7 km gave a better result at 50 m altitude while 7.35 km scale height gave a better performance at 200 m.

3.2 The refractivity gradient

From equation (5) the refractivity gradient is given by equation (7);

$$\frac{dN}{dh} = \frac{-N_s}{H} \exp \frac{-h}{H} \tag{7}$$

For a standard atmosphere, the refractivity gradient is -39 N units/km. According to [12], when $h < 1$ km, refractivity gradient is well approximated by its value in a standard atmosphere. However, a study like the one by [17] which was within the first 100 m provides a good chart and was used in this work.

Generally, the value of *dN/dh* determines the ray path or the curvature of the radiowave. For $-40\ {}^{N}\!/_{km} \leq {}^{dN}\!/_{dh} \leq 0\ {}^{N}\!/_{km}$, the phenomenon known as sub-refraction in which the bending of the rays is less than normal occurs. This shortens the radio horizon and reduces the clearance over obstacles along the path and may lead to increased path loss, and possibly even an outage.

Normal mode of propagation is obtained when *dN/dh* lies between -75 and -40. If the gradient is between –75 to –156 *N*/km, super-refraction occur in which the ray path will increase, hence extending the radio horizon.

Below −157 *N*/km, the ray path deviates towards the Earth's surface, and a phenomenon known as ducting occurs [12]. Ducting is sometimes considered as beneficial if longer-range propagation is desirable. The downside is that the receiving antenna has to be within the height limits of the ducts, else, signal losses increases dramatically [6].

3.3 Effective earth radius factor (k)

The effective earth radius factor *k* can also be used to characterise refractive conditions as normal refraction, sub-refraction, super-refraction and ducting respectively. Thus, in equation (8), *k*, is expressed in terms of refractivity gradient [2,14]:

$$k = \left[1 + \left(\frac{dN}{dh}\right)/157\right]^{-1} \tag{8}$$

Near the earth's surface, $k = 4/3$ [12] and is referred to as normal refraction or standard atmosphere. Under this condition, radio signals travel on a straight line path along the earth's surface and go out to space unobstructed.

For $0 < k < 4/3$, sub-refraction occurs, under this condition, radio waves propagate away from the earth's surface. When $4/3 < k < \infty$, super-refraction occurs and radio waves propagate towards the earth's surface thus extending the radio horizon and lastly, for $0 > k > -\infty$, result in ducting and the waves bend downwards with a curvature greater than that of the earth. These conditions are illustrated in Figure 1.

Figure 8: R

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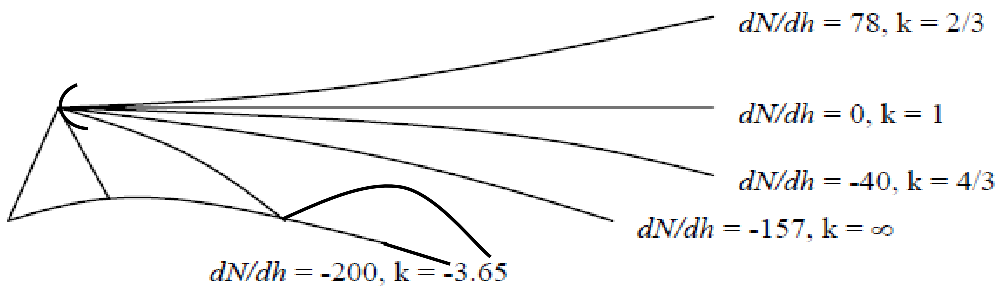


Figure 1:Ray Path for different values of dN/dh and k.

Correlation Coefficient: The correlation coefficient given in equation (9), is a measure of the extent to which two measurement say *X* and *Y* vary together. Correlation analysis examines each pair of measurement to determine whether the two tend to move together. The correlation coefficient can assume any value between -1 and +1. Positive correlation is obtained when large values of one variable tend to be associated with large values of the other. Negative correlation results when small values of one variable tend to be associated with large values of the other and a correlation near 0(zero) is obtained when values of both variables tend to be unrelated.

$$Correl(X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad (9)$$

IV. RESULTS AND DISCUSSION

The subsections under this heading describe the result of temporal signal strength variation with environmental factors, time of the day and weather.

4.1 Signal strength variation with environmental factors

Result of [18], shows that signal strength Pr, is strongly correlated with radial distance from the entire four base stations investigated irrespective of the frequency of operation. However, the same result suggests the need to further investigate the potential environmental factors —such as location, weather, time of day, etc that have a dominating impact on the received signal strength. Effects of these environmental factors on the measured signal strength have been investigated herein. As shown in Figure 2, each line indicates a different experiment that was performed at different times on the same route.

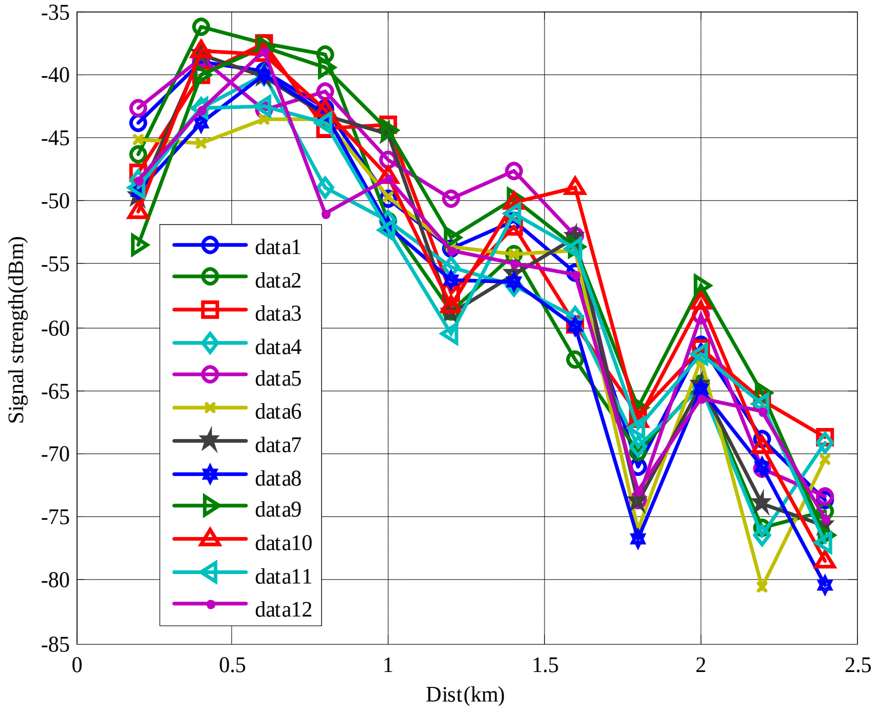
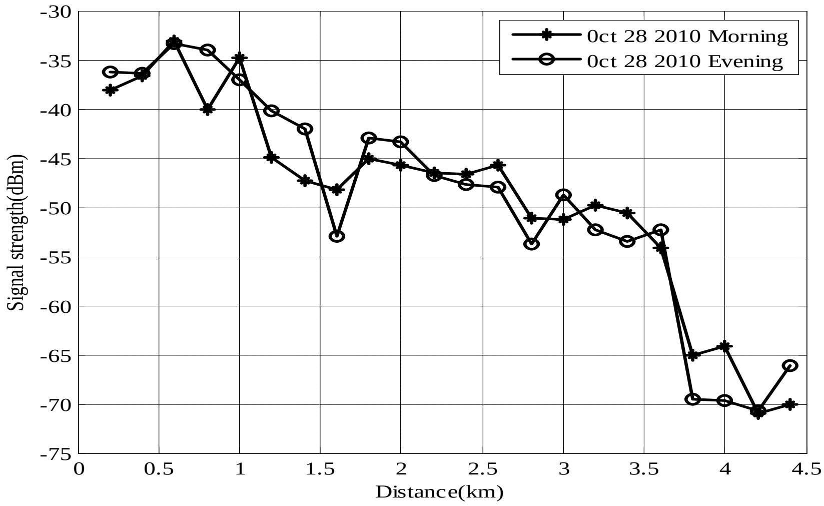


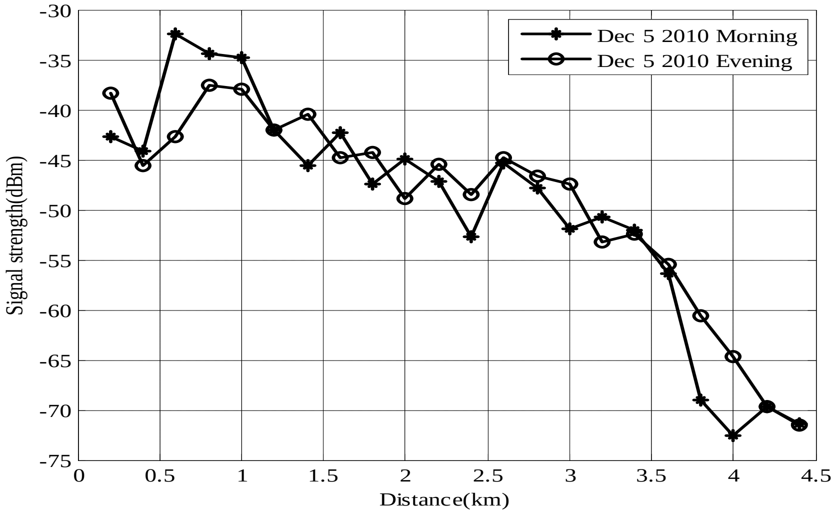
Figure 2: Signal Strength Measured at Different Times across Different Locations

4.2 Diurnal variation of signal strength

To evaluate the variation with time of the day, signal strength was measured over the same route at two different times: morning (8 to10 am) and evening (4 to 6 pm). Figure 3 (a) and (b) shows a sample of such measurement conducted on October 28, 2010 and Dec 5, 2010 respectively. The statistics of the differences observed between the morning and evening measurements are presented in Table I.



(a)



(b)

Figure 3: Signal Strength Variation along a Specified Path at Different Times of Same Day.

Table I: Statistics of Morning and Evening Samples

	Oct 28 2010		**Dec 5 2010**	
	Morning	**Evening**	**Morning**	**Evening**
Min	-71.00	-70.75	-72.55	-71.50
Max	-33.05	-33.40	-32.45	-37.60
Mean	-49.10	-48.98	-49.89	-49.24
Median	-47.03	-47.80	-47.35	-46.13
Mode	-71.00	-52.25	-72.55	-44.85
Std	10.54	11.62	11.63	9.76
Range	37.95	37.35	40.10	33.90

4.3 Signal strength variation with weather

To determine signal strength variation with weather, hourly signal strength was measured at a selected field point for seven days. Figure 4 shows measurement of Day 4 and Day 6 that present significant 0.65 correlation coefficient value, signal strength of other days is strongly uncorrelated. Using equations (2) to (4), refractivity *N*, was computed and since the Bauchi meteorological data was taken at a fixed height of 609.3 m, refractivity gradient *dN/dh*, was computed using the regression formula deduced by [16] from the work of [17]. A plot of the refractivity gradient, as is often used in literature to explain the weather effect on the radio signal is shown in Figure 5.

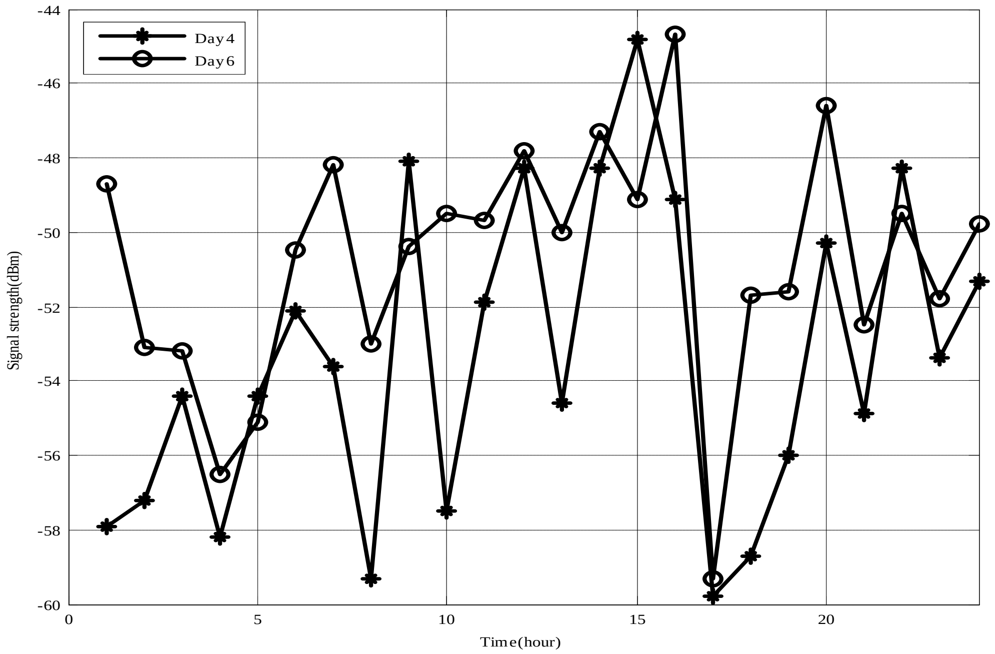


Figure 19: Signal Strength Measures in Day4 and Day6 with Strongest Correlation

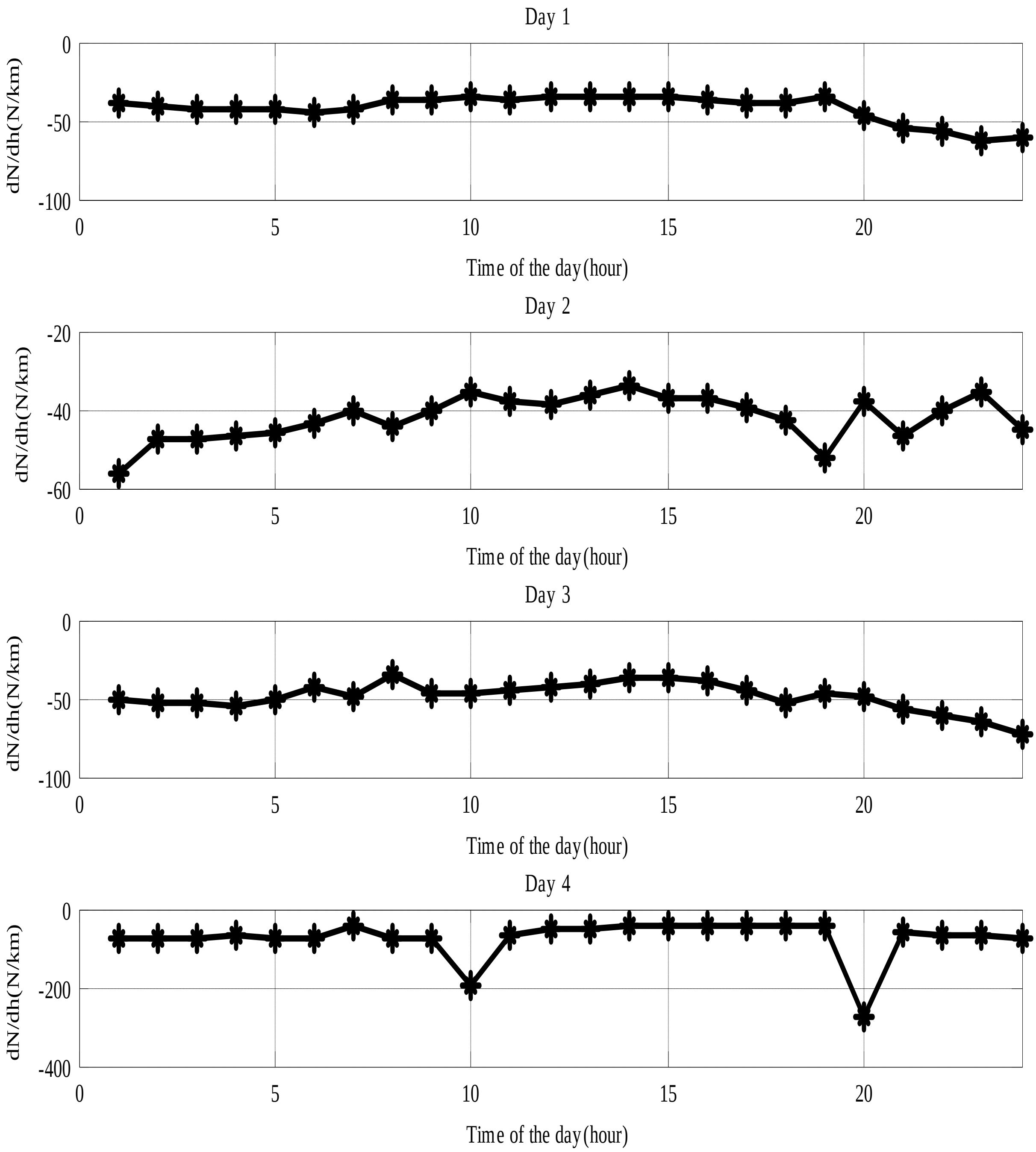


Figure 5 (a): Diurnal Variation of Refractivity Gradient for Days 1 to 4

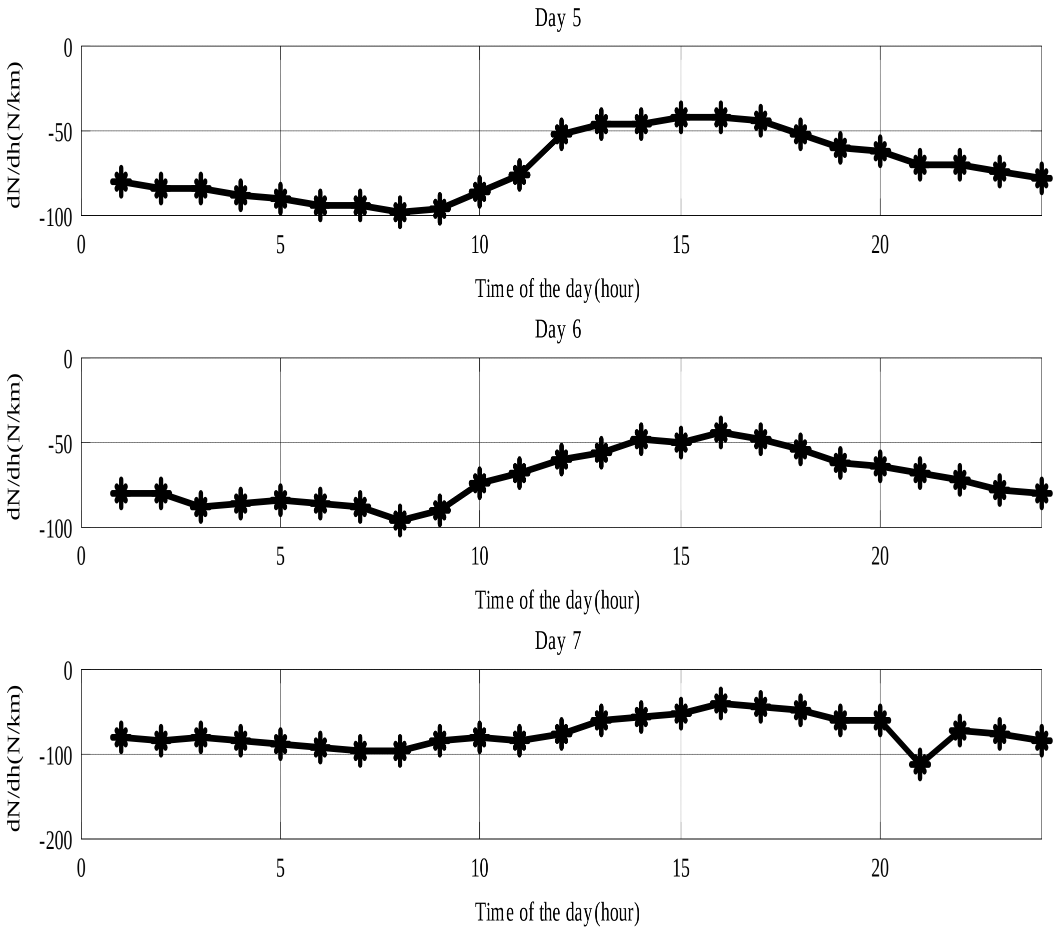


Figure 5b): Diurnal Variation of Refractivity Gradient for Days 5 to 7

Figure 6 shows refractivity gradient *dN/dh*, plots for the three days with strongest correlation and the overall average *dN/dh* values is plotted on Figure 7. Plotting the normalized *dN/dh* values against normalized signal strength measures on Figure 8 present a basis for comparing the simultaneous variation of the two quantities.

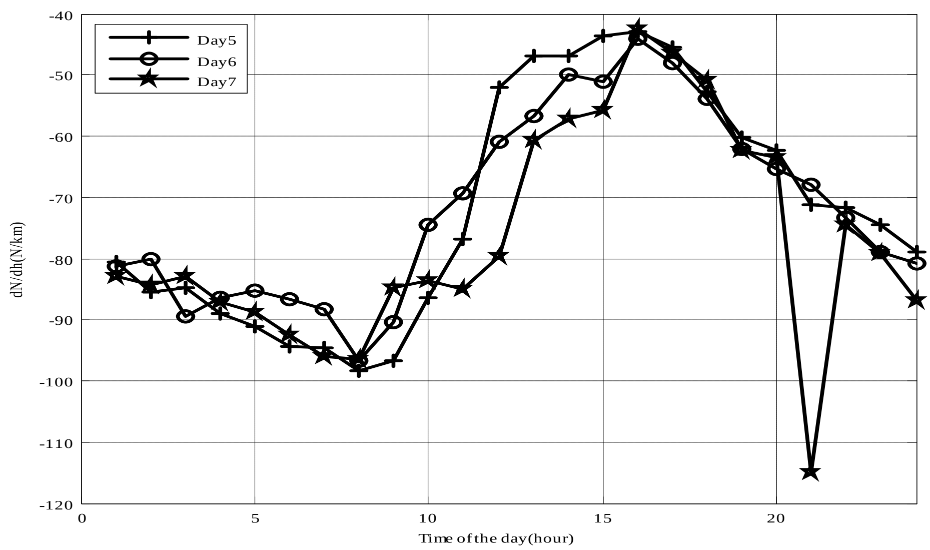


Figure 6: dN/dh Values of Day5, Day6 and Day7 with Strongest Correlation

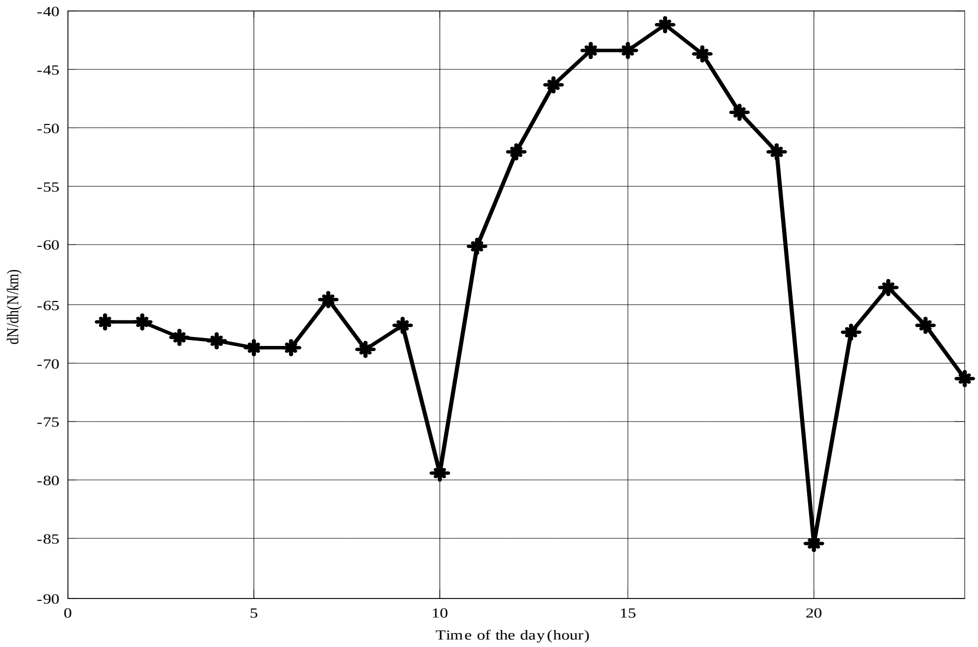


Figure 7: Average dN/dh Values for the Entire Measurement

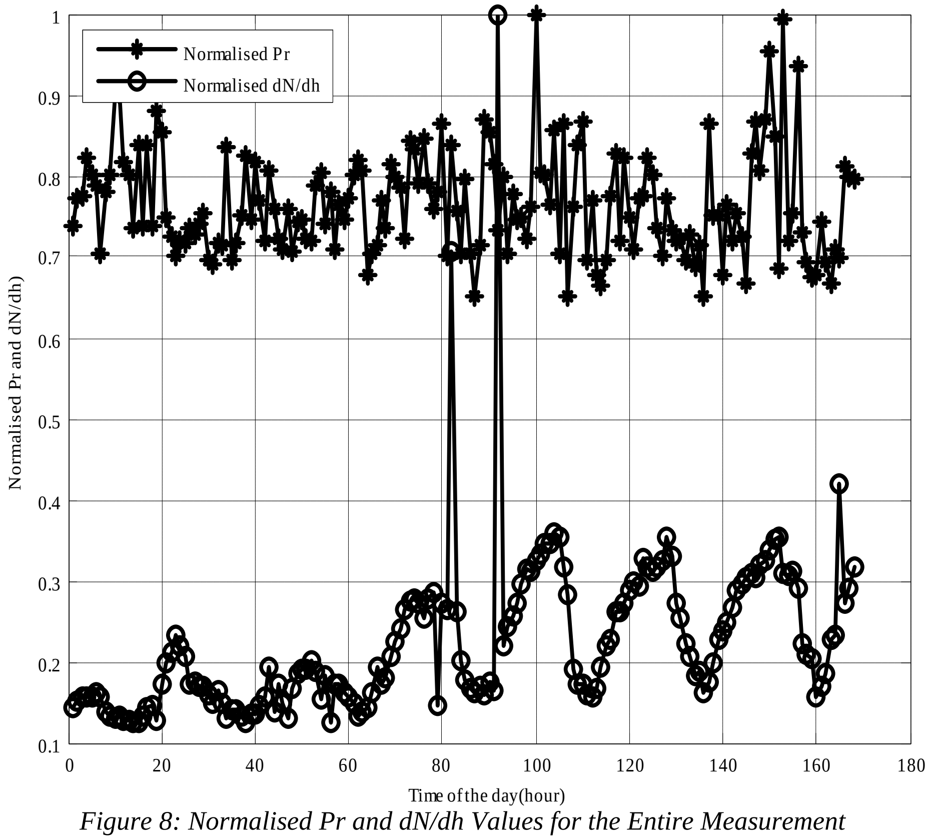


Figure 8: Normalised Pr and dN/dh Values for the Entire Measurement

Table II: Daily Correlation between *Pr* and the weather parameters

	Parameter			
Day	**T(K)**	**R. H(%)**	**P(hPa)**	***dN/dh***
1	-0.33	0.53	-0.25	-0.54
2	-0.46	0.46	0.26	-0.29
3	-0.03	0.15	-0.10	-0.15
4	0.32	-0.20	0.04	0.01
5	0.29	-0.30	-0.34	0.26
6	0.26	-0.27	-0.05	0.26
7	0.50	-0.50	-0.45	0.41

V. CONCLUSION

During the measurement campaign, potential environmental factors that may have a dominating impact on the received signal strength were investigated and it was observed that signal strength is strongly correlated with locations among other factors across the different times of measurement. The result presented in Figure 2 shows that the quality of signal varies significantly among different locations, but remains similar across the different times for the same location. Statistics of comparing morning and evening samples presented in Table I and the plot in Figure 3 suggests no distinct pattern for signal strength fluctuation with time of the day. Although the seven day hourly measurements at a fixed location indicates the range of signal strength fluctuation to be 24 dBm, only measurement of Day 4 and Day 6 are significantly correlated with 0.65 correlation coefficient value across the hours of the day as presented in Figure 4.

Refractivity gradient plots shown in Figure 5 presents no clear regular daily pattern in the first four days of the measurement, however, it was observed that the gradient shows a fall in the early morning hours to the minimal value at about 8 am and a rise to the peak value at about 4 pm and then starts to fall again in the evenings during the last three days of the measurement as shown in Figure 6. From Figure 7, it was observed that refractivity gradient values on the average, shows a decline in the early morning hours to the minimum value of -79.4 N/km at about 10 am and then begins to rise to a peak value of -41.2 N/km at about 4 pm. For the seven days hourly measurement, average refractivity gradient was -61.3 N/km and so the average propagation conditions correspond to the normal mode, although super refraction was to be expected at about 10 am and 8 pm. Figure 8 however shows that the variation in *dN/dh* does not actually explain the temporal variations in the received signal *Pr,* since the correlation between the variables is as low as 0.091.

From Table II, *Pr* shows a fair positive correlation with relative humidity, having a value of 0.53 and 0.46 on days 1 and 2 respectively. Negative correlation coefficient of -0.54 and -0.46 were obtained when *Pr* was compared with *dN/dh* and temperature respectively in the first two days. Days 3 to 6 show relatively low correlation between *Pr* and every weather parameter. On Day 7, fair positive correlations of 0.50 and 0.41 with temperature and *dN/dh* respectively were observed as well as negative correlations of-0.50 and -0.45 with relative humidity and pressure respectively. These results however suggest location as having a dominating impact on the received signal strength among other environmental factors such as weather and time of the day. This conforms to results of [11] where the effect of environmental factors on link quality for on-board communications were studied.

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