IMPACT OF SOME ATMOSPHERIC PARAMETERS ON GSM SIGNALS

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***Abstract*— Rxlevel of Global System for Mobile Communication (GSM) signals is affected by the dynamics of the troposphere through which it propagates. Adequate knowledge of the prevailing atmospheric propagation conditions in an environment is essential for optimal terrestrial network planning. To investigate the effect of variation in atmospheric parameters on GSM signals, measurements were carried out in a location at a fixed distance from a selected base transceiver station (BTS). Nineteen months (June 2014 – December 2015) atmospheric data of temperature, pressure, relative humidity and dew point were acquired from the NECOP weather station at the Bosso Campus of the Federal University of Technology, Minna, Nigeria. Concurrently, the RxLevel of MTN Network was measured at 300 m from a BTS using a spectrum analyzer (SPECTRAN HF 6065) connected to a laptop loaded with Aarisona data logging software. Results of this study show that surface atmospheric temperature has positive correlation values ranging from 0.57 to 0.88 with RxLevel of GSM signals while relative humidity has negative correlation values ranging from -0.57 to -0.89 with the signal level. Atmospheric pressure showed no consistent relationship with GSM RxLevel variation, while dew point showed strong positive correlation of 63% with GSM RxLevel variation.**

***Keywords*—Dew point; Relative humidity; Rxlevel; Temperature.**

I. INTRODUCTION

Mobile communication, like other wireless communication systems, depends on the propagation of radio waves within the troposphere, the region of the atmosphere extending from the Earth's surface up to an altitude of about 16 km at the equator or 8 km at the poles [1]. The Earth's weather system is confined to the troposphere and the fluctuations in weather parameters such as temperature, pressure, humidity, clouds and rain within the atmospheric layer cause the refractive index of the air in this layer to vary from one location to another and from time to time. The refractive index of air can be expressed by a parameter called refractivity. Surface refractivity is highly correlated with radio field strength values [2].

The electric field strength of signals radiated from a transmitter is subject to propagation loss due to reflection, refraction, diffraction, absorption and scattering. Hills, buildings and other human-made obstacles often diffract, absorb or reflect radio waves. The presence of foliage results in absorption of electromagnetic energy. Precipitations such as raindrops, and aerosols like harmattan dust, absorb and scatter electromagnetic energy, resulting in attenuation and reduction in signal strength [3; 4]. These factors limit the performance of mobile communication signals which, as radio waves, are very sensitive to the effects of the transmission path [2].

The velocity of propagation of a mobile signal, which is an electromagnetic wave, is a function of the permittivity and permeability of the medium, as shown in equation 1.

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_r\varepsilon_r}\sqrt{\mu_o\varepsilon_o}} \tag{1}$$

where μ_r is relative permeability of the medium and ε_r is relative permittivity of the medium. Using the value of μ_o ($4\pi \times 10^{-7}$ H/m) and ε_o (8.854×10^{-12} F/m) in equation 1 yields:

$$v = \frac{1}{\sqrt{\mu_r\varepsilon_r}}c \tag{2}$$

where c, the velocity of light in free space, is 2.998×10^8 m/s and v, the velocity of propagation of electromagnetic wave, which is a function of the relative permittivity and relative permeability of the medium of propagation. In mobile communication, the Earth's atmosphere is the medium of propagation.

The weather condition of these transmission paths also varies with season. Hence, mobile communication signals suffer greater losses during the rainy season due to increased foliage and greater ground conductivity [5]. Data collected on a radio transmission path over a long period of time give statistical generalizations that enable radio engineers to design services with reliability factor close to 100% and a near to zero vulnerability to interference [6].

II. LITERATURE REVIEW

Reference [7] investigated GSM signal strength variation with weather and environmental factor in Bauchi. The research revealed variation of signal strength in different locations but similar values were obtained at different times in the same location. Three of the seven days showed fairly positive/negative correlation of signal strength with humidity, with refractivity gradient and with temperature. However this study was carried out for a period of seven days which is not enough to predict weather variability.

Reference [8] studied the influence of air temperature, relative humidity and atmospheric moisture on UHF Radio Propagation in South Western Nigeria. It was observed that as air temperature increased, relative humidity decreased, a proportional decrease in UHF path loss and increase in the received signal strength (RSS) were also observed. Thus, air temperature and relative humidity have significant influence on UHF signal propagation within the tropospheric region of southwest Nigeria.

Reference [9] investigated the effect of climatic change on mobile communication signal propagation by sampling the three ITU regions in Nigeria at different climatic seasons of rain (May-June) and harmattan (November -March). The result obtained revealed that climate affects signal propagation, depending on the climatic parameters (rain and harmattan), frequency of transmission and ITU regions of propagation (which is related to the volume of rain and harmattan intensity) in Nigeria.

Reference [4] explored the influence of atmospheric parameters on GSM outgoing calls quality in Mubi, Adamawa State, Nigeria. Reference [10] monitored in Ile-Ife, Osun State, the field strength of a 100.5 MHz radio transmitter located in Lagos, over a path length of 200 km. Measurements were carried out at approximately one-minute intervals for a 10-month period, using a yagi antenna, a field strength meter, a data logger and a personal computer. The hourly, daily and monthly mean values of field strength were computed from the measured data. The results revealed significantly high values of field strength during the dry months of November to March while lower values were obtained during the wet months of April to October. From the hourly mean values, high field strength values were observed in the night and early morning hours.

Reference [3] used computed densities of harmattan dust particle in air to determine the effects of harmattan on radio waves. From the study, it was observed that attenuation due to dust particles increases as harmattan intensity increases. Reference [11] also compared measured received signal level (RxLevel) at 1800 MHz with meteorological data in Zaria to determine the effect of harmattan dust on GSM signals. The study revealed considerable drop in RxLevel during the harmattan period.

III. Methodology

The study was carried out in Minna, Nigeria, located between latitudes $9^{o}34'$ and $9^{o}40'$ N, and longitudes $6^{o}29'$ and $6^{o}35'$ E. Nineteen months (June 2014 – December 2015) atmospheric data of temperature, pressure, relative humidity and dew point were acquired from the NECOP weather station at the Bosso Campus of the Federal University of Technology, Minna, Nigeria. Concurrently, the received signal level (RxLevel) of MTN Network (1835 - 1850 MHz) was measured at 300 m from a BTS in Tudun Fulani, Bosso, Minna, using a spectrum analyser (SPECTRAN HF 6065) connected to a laptop loaded with Aarisona data logging software. The NECOP station was about 13.97 km away from the MTN BTS and about 15.25 km away from the measurement site. Fig. 1 and Fig. 2 show the NECOP weather station and the GSM Rxlevel measurement setup used in this study.

(a) A view of the Weather Station (b) Downloading of Atmospheric Data to a Laptop

Fig. 1. The NECOP Weather Station

Fig. 2. Spectran HF 6065 and a Laptop for Data Logging

The atmospheric data and GSM Rxlevel were measured at 5 minutes and 500 ms intervals respectively, GSM Rxlevel data were averaged to 5 minutes intervals for each day of the 19 months. The terrain of the propagation environment is relatively flat and unpaved. There are farm lands, vegetation cover, few trees and bungalow buildings between the transmitting and the measurement sites. The physical profile of the fixed wireless link consisting of the MTN base station and the measurement site is shown in Fig. 3.

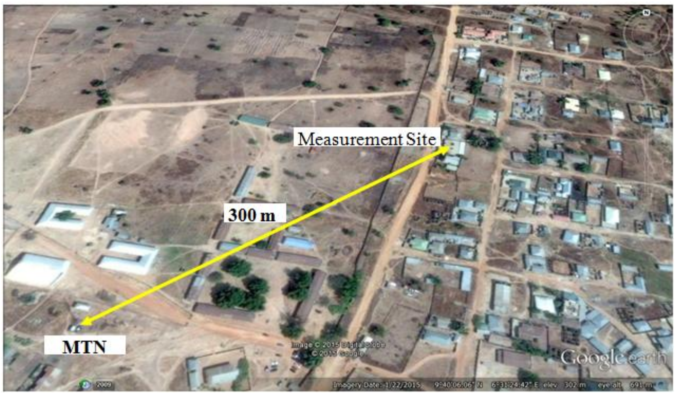

Fig. 3 Physical Profile of the Fixed Wireless Link (Google Earth)

The measured GSM RxLevels, at 500 ms, were averaged at 5 minutes for each day of the 19 months to correspond with the 5 minutes measurement interval of the atmospheric data. The mean monthly values of the atmospheric parameters and the GSM RxLevel were computed for each of the months. Using the values obtained for surface air temperature, pressure and relative humidity, surface refractivity N values were also computed using equations 3 to 5.

$$N = N_{dry} + N_{wet} = 77.6\left(\frac{P}{T}\right) + 3.732 \times 10 \tag{3}$$

where T(K) = t (atmospheric temperature) + 273, and

$$e = \frac{He_s}{100} \tag{4}$$

where e is water vapour pressure, H is relative humidity, and e_s the saturated water vapour pressure given as [12]:

$$e_s = 6.11\exp\left(\frac{17.502t}{T}\right) \tag{5}$$

The correlation coefficient values of GSM RxLevel with the considered atmospheric parameters were computed to further explore their relationship. The atmospheric parameters having strong influence on GSM RxLevel were determined.

IV. RESULTS AND DISCUSSION

Plots of the atmospheric parameters such as temperature, relative humidity and pressure, surface refractivity and GSM signal level were made to explore the monthly variations of GSM signal levels in relation to atmospheric parameters and surface refractivity.

Fig. 4 shows the mean monthly variation of GSM RxLevel with surface atmospheric temperature in a 12-month period (June 2014 – May 2015) while Fig. 5 shows the mean monthly variation of GSM RxLevel with surface atmospheric temperature in a 7-month period (June 2015 – December 2015). It can be observed that in the 12-month period (Fig. 4), except for the months of December and January, the mean monthly GSM RxLevel increases with increase in mean monthly atmospheric temperature and also decreases with decrease in mean monthly atmospheric temperature. In the 7-month period (Fig. 5), GSM RxLevel is also observed to have a positive relationship with surface atmospheric temperature.

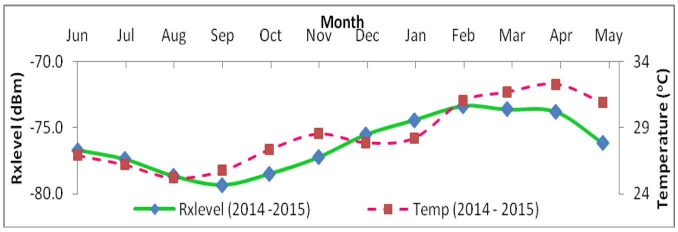

Fig. 4: Mean Monthly Variation of GSM RxLevel with Surface Atmospheric Temperature (June 2014 to May 2015)

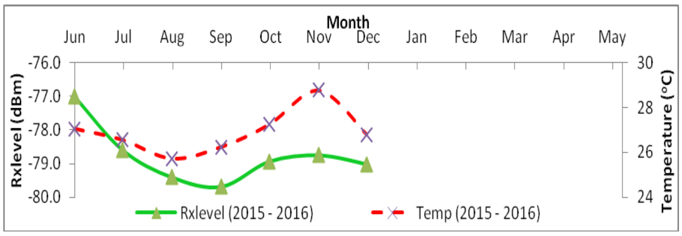

Fig. 5: Mean Monthly Variation of GSM RxLevel with Surface Atmospheric Temperature (June 2015 to December 2015)

Fig. 6 shows the mean monthly variation of GSM RxLevel with relative humidity in a 12-month period (June 2014 – May 2015), while Fig. 7 shows the mean monthly variation of GSM RxLevel with relative humidity in a 7-month period (June 2015 – December 2015). From Fig. 6, the month of January has the least relative humidity value, which may be due to peak harmattan effect [3]. It can be observed that the GSM RxLevel in the months of December 2014 and January 2015 do not correspond to the low relative humidity values recorded in the respective months. This can be attributed to the effect of harmattan dust haze in these months. Harmattan dust particles add up to the dielectric particles within the air space and these particles interact with the electric field of the electromagnetic wave propagating through the medium. And for relatively large wavelength of GSM, compared to dust particle size, attenuation by scatter is more.

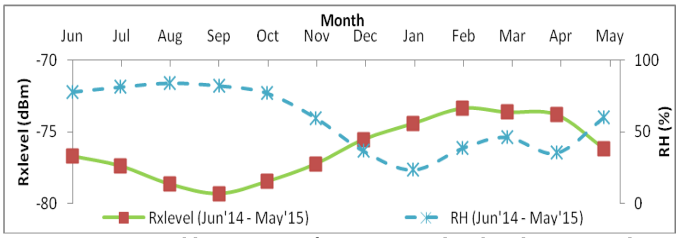

Fig. 6. Mean Monthly Variation of GSM RxLevel with Relative Humidity (June 2014 to May 2015)

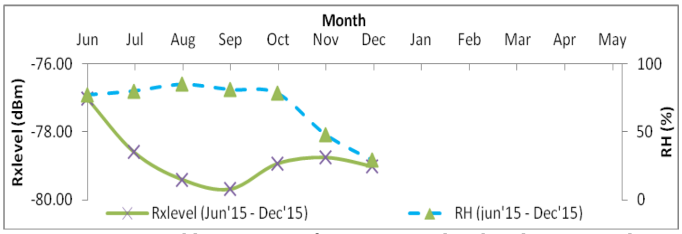

Fig. 7. Mean Monthly Variation of GSM RxLevel with Relative Humidity (June 2015 to December 2015)

Fig.s 8 and 9 show the mean monthly variations of GSM RxLevel with atmospheric pressure. It is evident that, at surface level and with the distance between the BTS and measurement site (300 m), there is no relationship between variations of GSM RxLevel and the variations of atmospheric pressure.

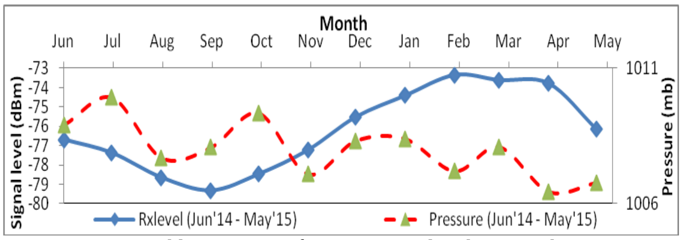

Fig. 8. Mean Monthly Variation of GSM RxLevel with Atmospheric Pressure (June 2014 to May 2015)

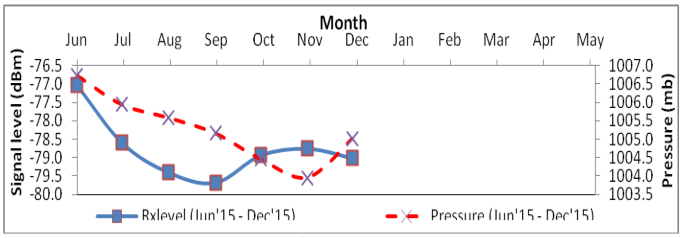

Fig. 9. Mean Monthly Variation of GSM RxLevel with Atmospheric Pressure (June 2015 to December 2015)

Fig.s 10 and 11 show the mean monthly variation of GSM RxLevel with atmospheric dew point, while Fig.s 12 and 13 show the mean monthly variation of GSM RxLevel with atmospheric refractivity.

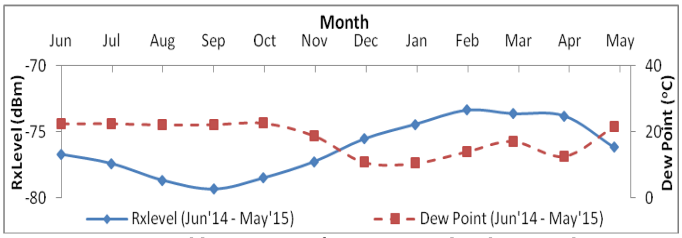

Fig. 10. Mean Monthly Variation of GSM RxLevel with Atmospheric Dew Point (June 2014 to May 2015)

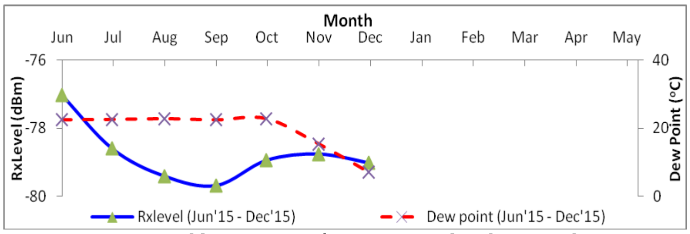

Fig. 11. Mean Monthly Variation of GSM RxLevel with Atmospheric Dew Point (June 2015 to December 2015)

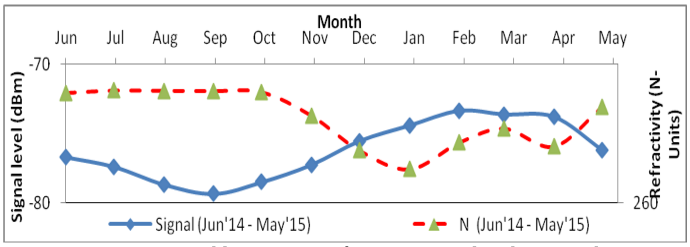

Fig. 12. Mean Monthly Variation of GSM RxLevel with Atmospheric Refractivity (June 2014 to May 2015)

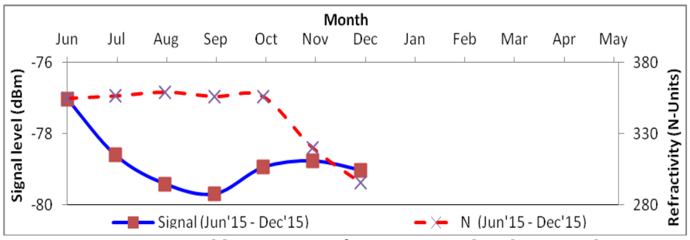

Fig. 13. Mean Monthly Variation of GSM RxLevel with Atmospheric Refractivity (June 2015 to December 2015)

From Fig.s 12 to 13, it is evident that variations of GSM RxLevel have negative relationship with surface radio refractivity. As earlier observed in Fig. 6, the month of January has the least relative humidity value and the low humidity value relates to the peak harmattan effect [3]. Harmattan dust haze also has scattering effect on GSM signals which results in reduction of GSM RxLevel. Apparently the observed negative correlation between GSM RxLevel and surface refractivity may be due to strong negative correlation between GSM RxLevel and relative humidity (as relative humidity has strong influence on surface refractivity).

To measure the degree of linear dependence between GSM RxLevel and the considered atmospheric parameters and atmospheric refractivity, Pearson correlation coefficient was computed for each of the months as shown in Table 1 using Pearson Product Moment Correlation Coefficient (PPMC) formula,

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \qquad (6)$$

where:

r = Pearson correlation coefficient
x = values in first set of data
y = values in second set of data
n = total number of values.

Table 1. Correlation Coefficient Values of GSM RxLevel with Atmospheric Parameters and Surface Refractivity

Month	Temp	Rel. Hum.	Pressure	Dew Point	Refractivity
June	0.75	-0.74	-0.09	0.73	-0.59
July	0.76	-0.75	-0.01	0.78	-0.63
August	0.86	-0.83	-0.42	0.91	-0.55
September	0.78	-0.77	-0.51	0.72	-0.67
October	0.57	-0.61	-0.14	0.08	-0.71
November	0.04	-0.01	0.44	0.41	-0.14
December	0.75	-0.68	-0.26	0.36	-0.55
January	0.75	-0.57	-0.39	0.79	-0.41
February	0.78	-0.67	-0.36	0.65	-0.40
March	0.76	-0.81	-0.59	-0.45	-0.79
April	0.42	-0.39	-0.15	-0.55	-0.40
May	0.72	-0.77	-0.82	-0.67	-0.85
June	0.84	-0.85	-0.40	0.69	-0.84
July	0.73	-0.72	0.00	0.77	-0.61
August	0.67	-0.65	-0.13	0.70	-0.40
September	0.77	-0.76	-0.27	0.84	-0.62
October	0.88	-0.89	-0.33	0.82	-0.87
November	0.03	-0.06	0.09	-0.31	-0.14
December	0.78	-0.83	-0.27	0.58	-0.79

Except for the month of October with a value of 0.57, strong positive correlations of 0.67 to 0.88 were observed for the variations of GSM RxLevel with atmospheric temperature. However, exceptionally poor correlations were observed for the months of April (0.42) and November (0.03 and 0.04). This may be attributed to the fact that the surface position of the Inter Tropical Discontinuity (ITD) is around Minna (latitude 9.62^o and longitude 6.55^o) in April and November which are transition months between the dry and rainy seasons. An average correlation of 84.2% was observed between the variations of GSM RxLevel and atmospheric temperature. Thus surface atmospheric temperature has significant effect on GSM RxLevel which is in agreement with [8]. As surface temperature decreases, the water retention of the propagating media such as the atmosphere, buildings, foliage and other environmental obstacles on the propagation path increases, thereby increasing conductivity and thus signal attenuation increases.

From the Table, correlation between variations of GSM RxLevel and atmospheric relative humidity is exceptionally poor for the months of April (-0.39) and November (-0.01 and -0.06). However, 15 months out of the studied 19 months showed strong negative correlations of -0.61 to -0.89. An average correlation of 84.2% is observed between the variations of GSM RxLevel and atmospheric relative humidity. Thus relative humidity does have significant effect on GSM signals and this is in agreement with [8] and [13]. Again, the exceptionally low correlations observed between GSM RxLevel and atmospheric relative humidity in April and November can be attributed to the influence of surface position of the ITD, which is around Minna during these transition months between the rainy and dry seasons. Increase in atmospheric relative humidity increases the moisture content of propagation obstacles. Humidity of foliage medium can influence the shadowing effect of trees on radio signals. Increase in the moisture content of the terrain increases the dielectric constant of the ground on which the magnitude and phase of ground-reflected wave partly depend. Moisture also increases the lossy nature of the ground through absorption.

Except for the month of May which shows strong negative correlation of -0.82, poor correlations of -0.42 to 0.44 are generally observed between variations of GSM RxLevel with atmospheric pressure. Also, except for November with positive values (0.44 and 0.09) and July (0.00), correlation is generally negative. Average correlation of 16% is observed between the variations of GSM RxLevel and atmospheric pressure. Thus atmospheric pressure does not have significant effect on GSM RxLevel.

From Table 1, it is observed that October to December and March show lowest correlations (0.08 to -0.45) between the variations of GSM RxLevel and atmospheric dew point. Negative correlation values are observed in March (-0.45), April (-0.55), May (-0.67) and November (-0.31), while 2 months (April and December) show fair correlations (-0.55 and 0.58). However, 12 months show strong correlations (-0.67; 0.65 to 0.91). Low correlation values around March to April and October to November may be attributed to surface position of ITD in Minna. Other months show considerably high correlation (>0.6), especially in rainy season when it can be as high as 0.91(August). An average correlation of 73.7% is observed between the variations of GSM RxLevel and atmospheric dew point. Thus atmospheric dew point has significant effect on GSM RxLevel variation.

Out of 19 months, 6 months show poor correlations of -0.40 to 0.14 and 3 months show fair correlations of -0.55 to -0.59. However, 10 months have strong negative correlations (-0.62 to -0.87). The observed average correlation of 52.6% between the variations of GSM RxLevel and atmospheric refractivity is lower than the average correlation of 84.2% that the variations of GSM RxLevel has with atmospheric temperature and atmospheric relative humidity respectively. Also, the average correlation of 52.6% is lower than the average correlation of 73.7% between the variations of GSM RxLevel and atmospheric dew point, but higher than the average correlation of 16% between the variations of GSM RxLevel and atmospheric pressure. It is evident that, at surface level and with the distance between the BTS and measurement site (300 m), atmospheric refractivity does not have as much effect as atmospheric temperature and atmospheric relative humidity on GSM RxLevel.

Harmattan dust haze has scattering effect on GSM signals and this results in reduction of GSM RxLevel. The variations of GSM RxLevel in the month of January does not correspond to the low atmospheric relative humidity and atmospheric refractivity values for the month. Thus, in the month of January, GSM RxLevel variations seem to be more affected by the harmattan weather than the atmospheric parameters. The relatively large wavelength of GSM, as compared to dust particle size, makes it prone to attenuation by scattering by harmattan dust particles, which add up to the dielectric particles within the air space of the propagating electromagnetic wave. This is in agreement with the findings of [3].

V. CONCLUSION

Results from this research show that in the study area, the variations of atmospheric temperature and relative humidity have significant effects on GSM signals; the effects of buildings, foliage and other environmental obstacles are also significant. Strong positive correlations of 0.67 to 0.88 were observed for the variations of GSM RxLevel with atmospheric temperature, while strong negative correlations of -0.61 to -0.89 were observed for GSM RxLevel and relative humidity. These observations are in agreement with the findings of [8] and [13].

Exceptionally poor correlations were observed between variations of GSM RxLevel and surface atmospheric temperature for the months of April (0.42), November (0.03 – 0.04), as well as between variations of GSM RxLevel and relative humidity for the months of April (-0.39) and November (-0.01 and -0.06). The exceptionally low correlations observed in April and November for both atmospheric temperature and relative humidity may be attributed to the fact that the surface position of the ITD is around Minna (latitude 9.62^o and longitude 6.55^o) in April and November which are transition months between the dry and rainy seasons in the study area.

Except for the month of May which shows strong negative correlation of -0.82, poor correlations of -0.42 to 0.44 are generally observed between variations of GSM RxLevel and atmospheric pressure. This shows that atmospheric pressure has no significant effect on GSM RxLevel. Computed correlation coefficient values show that 5 months have poor correlations (-0.45 to 0.36) between the variations of GSM RxLevel and atmospheric dew point, while 2 months (April and December) show fair correlations (-0.55 and 0.58). However, 12 months show strong correlations (-0.67; 0.65 to 0.91) of 63%, which is above average. Thus atmospheric dew point has substantial effect on GSM RxLevel variations. Variation of GSM RxLevel and surface refractivity has negative correlation.

Out of 19 months, 10 months have strong negative correlations (-0.62 to -0.87), which is an average of 53% correlation between GSM RxLevel and atmospheric refractivity. The observed negative correlation between GSM RxLevel and surface refractivity may be due to strong negative correlation between GSM RxLevel and relative humidity (as relative humidity has strong influence on surface refractivity). The non significant effect of surface refractivity on GSM RxLevel may be attributed to the relatively short distance between BTS and the receiver.

The relatively large wavelength of GSM, as compared to dust particle size, are prone to attenuation by scattering from harmattan dust particles which also add up to the dielectric particles within the air space particles, causing further attenuation of the propagating electromagnetic wave. Due to increase in foliage and ground conductivity, GSM signals suffer greater loss in the wet season than in the dry season.

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References

[1] B. M. Reddy, “Physics of the Troposphere,” in Handbook on Radio Propagation for Tropical and Subtropical Countries, URSI Committee on Developing Countries, UNESCO subvention, New Delhi,.pp. 59-77, 1987.

[2] B. R. Bean & E. J. Dutton, “Radio Meteorology,” 1st Edition, Dover Publications Inc., New York, 1968.

[3] D. D. Dajab, “Perspectives on the effects of harmattan on radio frequency waves,” Journal of Applied Sciences Research, vol. 2(11), pp. 1014-1018, 2006.

[4] D. A. Shalangwa, “Effect of precipitation on call quality (signal quality) of Global System for Mobile communication (GSM) network services in Gombi, Adamawa State, Nigeria,” Journal of Mobile Communication, vol. *3*(3), 54-55, 2009.

[5] O. O. Oyeshola, “Seasonal variation of mobile radio propagation characteristics in Kaduna metropolis and environs: A case study of MTN and Airtel,” MSc Thesis. Electrical Engineering Department, Ahmadu Bello University Zaria, 2011.

[6] M. P. Hall, “Effects of the Troposphere on Radio Communications” 1st Edition, Peter Peregrinus, United Kingdom, 1979.

[7] A. U. Usman, O. U. Okereke & E. E. Omizegba, “Instantaneous GSM signal strength variation with weather and environmental factors,” American Journal of Engineering Research (AJSER), *vol*. 4(3), 104-115, 2015.

[8] A. S. Adewumi, M. O. Alade and H. K. Adewumi, “Influence of air temperature, relative humidity and atmospheric moisture on UHF radio propagation in south western Nigeria,” International Journal of Science and Research (IJSR), vol. 4(8), 588-592, 2015.

[9] O. Sheowu and L. A. Akinyemi, “Effect of climatic change on GSM signal,” Research Journal of Computer Systems Engineering – RJCSE, vol. 4(3), 471-478, 2013.

[10] O. A. Aboaba, “Tropospheric VHF Radiowave Propagation Measurements in a Tropical Location in Nigeria,” 1st Edition, U.N.E.S.C.O. and International Atomic Energy Agency, The Abdus Salam International Centre for Theoritical Physics, Triestie, 2006.

[11] A. Folaponmile and M. S. Sani, “Empirical model for the prediction of mobile radio cellular signal attenuation in harmattan weather,” Information Technology Research Journal, vol. 1(1), 13-20, 2011.

[12] ITU-R, “The refractive index: It’s formula and refractivity data,” Recommendation ITU-R, 453-459, 2012.

[13] A. I. Idim and F. I. Anyasi, “Determination of building penetration loss of GSM signals, using selected buildings in Orhuwhorun, Delta State Nigeria as case study,” IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), vol. 9(5), 1-5, 2014.