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Analysis of the Effects of Linear Distance on Signal Strength, Signal Attenuation and Refractivity of Two Radio Stations in Yola, Nigeria

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ABSTRACT: *In this work, we have carried out the analysis of the effects of linear distance on signal strength, signal attenuation and refractivity of two radio stations Gotel FM transmitting at 91.1 MHz and Fombina FM transmitting at 101.5 MHz, both situated in Yola, Northeast Nigeria with the aim of determining the effects of some local meteorological parameters and linear distance on the propagation power from the stations. NP – 198 GPS and meter was used to measure linear distance, atmospheric pressure and relative humidity; MASTECH MS8217 digital thermometer was used to measure atmospheric temperature, while, 3 – axis RF meter (TM – 195) was used to measure the signal strength. Field measurements and theoretical values of signal strength and signal strength attenuation were carried out for a linear distance of 170 km for Gotel FM and 110 km for Fombina FM. Results show a strong negative correlation of – 0.887 and – 0.915 between the measured signal strength and linear distance for Gotel FM and Fombina FM respectively, and negative correlations of – 0.458 and – 0.522 for the respective numerical simulations. Consequently, the signals were progressively attenuated with distance for both the measured and simulated values. The refractivity of the signals from two stations varies with the linear distance, though, without a specified pattern.*

KEYWORDS: *Signal strength, signal attenuation, refractivity, linear distance, Gotel FM and Fombina FM*

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I. INTRODUCTION

Radio wave propagation is the behavior of radio waves as they travel, or propagated from one point to another. These radio waves, as they propagate through the atmosphere are either reflected, refracted, scattered or are absorbed by different atmospheric constituents. There is strong indication to show that changing atmospheric can lead to changes in radio wave propagation [1]. The effect of distance and some atmospheric conditions on Radio frequency signal strength and refractivity are important in very high frequency (VHF) propagation. In the atmosphere, radio waves travel slightly more slowly due to the interaction with air molecules, which leads to the radio wave been refracted, and subsequently affects its signal strength [2].

Signal attenuation or signal fading is an important figure of merit in communication. This is because; it is used to determine the strength of a radio frequency signal as a function of distance. Signal attenuation can be caused by transmission path length, obstructions in the signal path (such as harmattan dust clusters) and multipath effects, thereby leading to a drop in the signal power [3]. Temperature and fog are also significant factors that contribute to signal attenuation [4].

Refractivity is the ability of a material to change the direction and the speed of a wave because of the boundary interface. This could be as a result of the difference in densities between the media where the wave is propagated. A linear equation developed by [5] shows that refractivity is strongly affected by atmospheric pressure, atmospheric temperature and relative humidity. Better predictions of refractivity potentially help the designers of communication, navigation and radar systems to improve performance [6].

In this work, we studied the effect of distance on the signal strengths of two radio stations; namely Gotel FM and Fombina FM (both in Yola, Adamawa state Nigeria) along Mubi route, which leads to signal attenuation. We also studied the effects of some atmospheric conditions on the refractivity on these radio stations as the signals propagate to its skip distance. We equally determined the degree of correlation between the signal strength and the linear distance.

II. THEORY

The signal strength refers to the transmitter power output as received by reference point antenna at a distance from the transmitting antenna. It is measured by a signal strength meter calibrated in milli – Volt/meter. It can be calculated empirically using equation given by [7] as shown in equation (1)

$$S = \sqrt{\frac{\mu_o c P_{av}}{2\pi R^2}} \quad (1)$$

where μ_o is the permittivity ($4\pi \times 10^{-7}\ H/m$), c is the speed of light ($3\times 10^{8}\ m/s$), P_{av} is the power of transmission of the transmitting station, and R is the distance from the transmitter.

Signal attenuation which is defined as the fading in radio signal strength as a result of increase in distance of the receiver from the point of transmission, and other atmospheric or environmental conditions can be calculated mathematically, using signal attenuation equations (2) and (3)

$$Signal\ Attenuation = \frac{Signal\ Strength}{Distance} \quad (2)$$

in dB,

$$Signal\ Attenuation\ (dB/Km) = \frac{10\log(S_R)}{Distance} \quad (3)$$

where S_R is the signal strength measured at the point of reception. From equation (3), signal attenuation is expressed in dB/Km.

In radio communication, refractivity is the ability of the ionospheric layers to refract or change the direction of a radio frequency signal due to the difference in the densities of these layers. As a result of this, the strength of the radio frequency signal is reduced. Radio refractivity is a function of the local meteorological parameters. Many equations have been developed to express the relationship between refractivity and other atmospheric parameters. A linear equation to calculate the radio frequency refractivity, N, with an accuracy of about $\pm 5\%$, has been developed [5] in equation (4)

$$N = K \times P^2 \times \sqrt{T} \times \sqrt[3]{H} \quad (4)$$

where K is a constant (= 0.01064097915), P is the atmospheric pressure in inHg, T is the temperature in ^{o}F, H is the relative humidity in %.

A well known equation used by [8,9] can also be used to calculate radio frequency refractivity, N, given as

$$N = 77.6\frac{P}{T} + 3.73 \times \frac{10^5}{T^2} e \quad (5)$$

where P is the atmospheric pressure in hPa (= 0.75 mmHg = 0.030 inHg), T is the absolute temperature in K, and *e* is the water vapour pressure in hPa given as

$$e = e_s H \quad (6)$$

in equation (6), H is the relative humidity in %, and e_s is the saturation vapour pressure given as

$$e_s = 6.11\exp\left[\frac{17.26(T - 273.16)}{T - 35.87}\right] \quad (7)$$

where T is the absolute temperature in K

A renowned Karl – Pearson correlation [ref] equation (8) was used to determine the degree of correlation between the signal strength and the linear distance.

$$r = \frac{N\Sigma XY - \Sigma X\Sigma Y}{\left\{\left(N\Sigma X^2 - (\Sigma X)^2\right)\left(N\Sigma Y^3 - (\Sigma Y)^2\right)\right\}^{\frac{1}{2}}} \quad (8)$$

where N is the number of value in each data set, X is the readings obtained for the linear distance, and Y is the corresponding values of the signal strength.

III. INFORMATION ABOUT THE TWO FM STATIONS

The two FM stations; Gotel FM and Fombina FM are all situated within, Yola, the Adamawa state capital in Nigeria. Yola is located at 9°13'N 12°27'E. The distance between the two radio stations is less than 5 Km. Gotel FM is part of Gotel Communications, and, operates up to 18 hours a day, while, Fombina FM belongs to the Federal government of Nigeria (or Federal Radio Cooperation of Nigeria), and, operates for 16 hours a day. The operational parameters of the two radio stations are shown in Table 1.

Table 1: Operational Parameters of the Two radio stations

Operational Parameters	Gotel FM	Fombina FM
Antenna Type	Unidirectional	Yagi uda
Distance Cover	250 Km	250 Km
Transmission Frequency	91.1 MHz	101.5 MHz
Transmitting Power	10 KW	8 KW
Mast Height	150 m	150 m
Year of Commissioning	2012	2003

Sources: (Gotel FM and Fombina FM, 2019)

IV. FIELD WORK AND DATA COLLECTION

Two FM stations listed above were considered and the covered distance was along Yola (9°13'N 12°27'E) and Mubi (10°16'N 13°16'E) road covering a linear distance of 196 km. The map of study area indicating the route traversed in data collection is shown in Fig. 1.

Data collection was done using 3-Axis RF meter, Model TM-195 (Fig. 2) measuring in mV/m, GPS land meter, Model NP-198 and MASTECH MS8217 Digital thermometer. The field measurements were carried out along Yola – Mubi route on the 7th September, 2019. Measurements were taken at linear distance of 10 km apart, from the respective reference points to where their respective signals were completely attenuated. The parameters that were directly measured include; the signal strength in mV/m, linear distance in km, atmospheric pressure in mmHg, atmospheric temperature in °C and relative humidity in %.

For Gotel FM, readings were taken at different 10 km intervals for up to 170 km. At a distance of 180 km, all the signals have been completely attenuated and there was no signal to measure. For Fombina FM, readings were taken for a distance of up to 110 km.

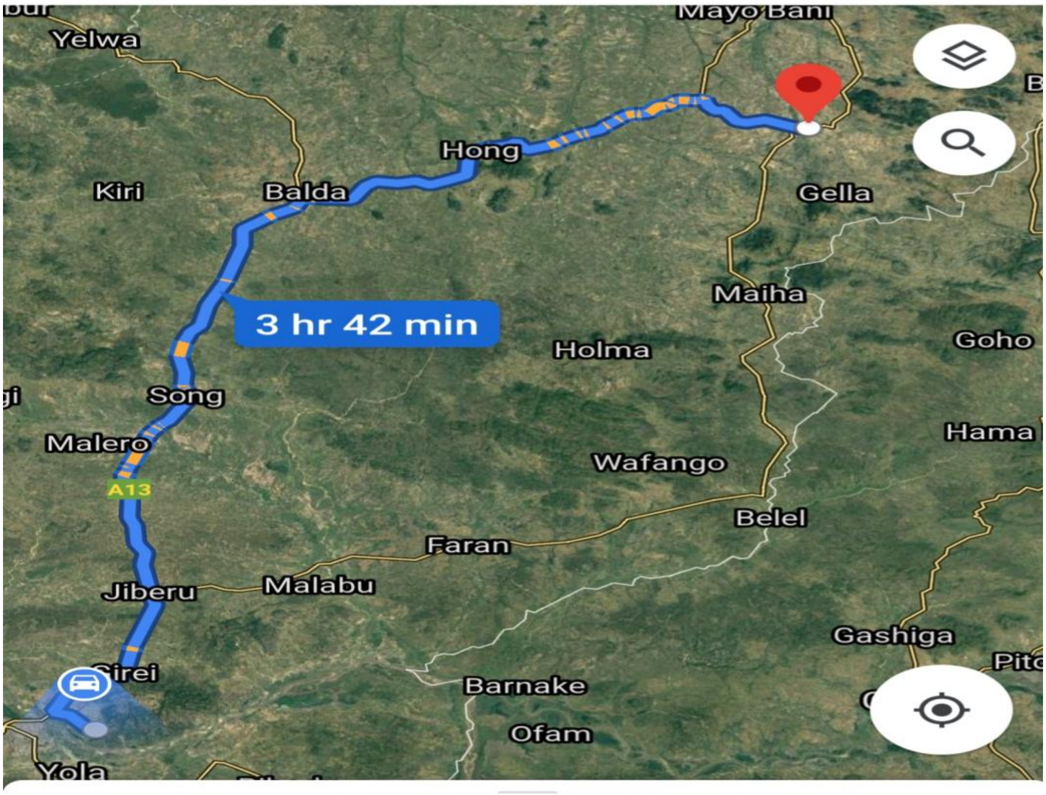

Fig. 1. Map of the Study Area (Google Map)

V. RESULTS AND DISCUSSIONS

V.I Results

Tables 2 and 3 show the results obtained from field measurements and the calculated value using equations (1) and (3) for both the signal strength (mV/m) and the signal attenuation (dB/km) for the two radio stations respectively. The calculated values are high because it is based on the assumption that propagation is only affected by distance from the station without the effects due to the atmospheric conditions.

Table 2: Measured and Calculated values of Signal Strength and Signal Attenuation for Gotel FM

Distance (Km)	Measured Signal Strength (mV/m)	Measured Signal Attenuation (dB/Km)	Calculated Signal Strength (mV/m)	Calculated Signal Attenuation (dB/Km)
1	9.80	9.91	774.60	28.89
10	9.58	- 0.19	77.46	8.89
20	9.57	- 3.20	38.73	2.87
30	9.56	- 4.96	25.82	- 0.65
40	9.54	- 6.22	19.37	- 3.15
50	9.51	- 7.21	15.49	- 5.09
60	9.49	- 8.01	12.91	- 6.68
70	9.40	- 8.73	11.07	- 8.01
80	9.01	- 9.47	9.68	- 9.17
90	8.70	- 10.15	8.61	- 10.18
100	8.68	- 10.62	7.74	- 11.31
110	8.12	- 11.32	7.04	- 11.94
120	7.56	- 12.01	6.46	- 12.68
130	6.80	- 12.92	5.95	- 13.37
140	4.10	- 15.33	5.53	- 14.03
150	3.98	- 15.77	5.16	- 14.63
160	3.71	- 16.35	4.84	- 15.19
170	3.12	- 17.35	4.56	- 15.72

From equation (8), the correlation between the measured signal strength and the linear distance for Gotel FM is – 0.887, while for calculated, the correlation is – 0.458.

Table 2: Measured and Calculated values of Signal Strength and Signal Attenuation for Fombina FM

Distance (Km)	Measured Signal Strength (mV/m)	Measured Signal Attenuation (dB/Km)	Calculated Signal Strength (mV/m)	Calculated Signal Attenuation (dB/Km)
1	8.29	9.18	692.80	28.40
10	8.08	- 0.93	69.28	8.41
20	8.03	- 3.96	34.64	2.39
30	8.02	- 5.74	23.09	- 1.14
40	8.00	- 6.99	17.32	- 3.64
50	7.98	- 7.96	13.86	- 5.58
60	7.26	- 9.17	11.55	- 7.14
70	6.64	- 10.22	9.90	- 8.51
80	6.02	- 11.25	8.66	- 9.67
90	5.48	- 12.15	7.70	- 10.66
100	5.00	- 13.01	6.93	- 11.59
110	3.25	- 15.23	6.30	- 12.42

From equation (8), the correlation between the measured signal strength and the linear distance for Fombina FM is – 0.915, while for calculated, the correlation is – 0.522.

The graph in Fig.1 shows the variation profiles of measured signal strength against distance for both Gotel FM and Fombina on the 7/09/2019, while Fig 2 shows the plot of calculated signal strength against distance for both Gotel FM and Fombina FM. Fig.3 is the variation profiles of measured signal attenuation against distance for both Gotel FM and Fombina on the same day, while Fig 4 shows the plot of calculated signal attenuation against distance for both Gotel FM and Fombina FM. In both cases, the 1 km distance is ignored, because it serves as a reference point.

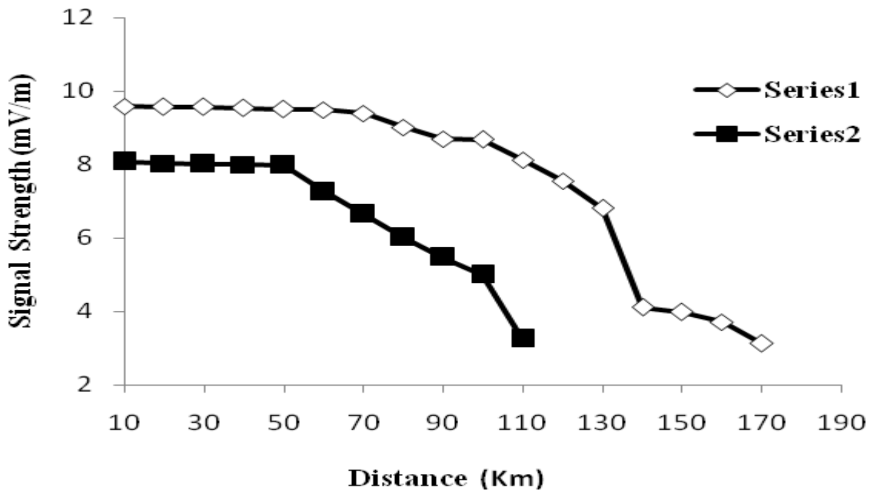

Fig. 1. Variation Profile of Measured Signal Strength against Distance for Gotel FM and Fombina FM (Series 1 for Gotel and 2 for Fombina)

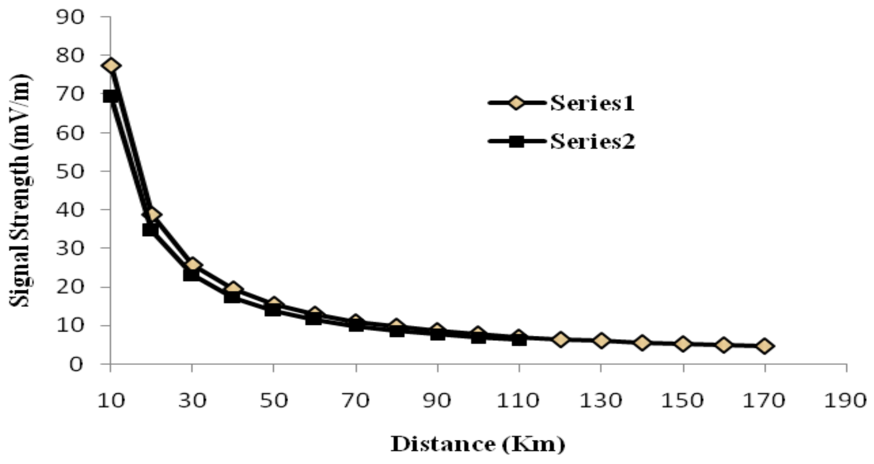

Fig. 2. Graph of Calculated Signal Strength against Distance for Gotel FM and Fombina FM. (Series 1 for Gotel and 2 for Fombina)

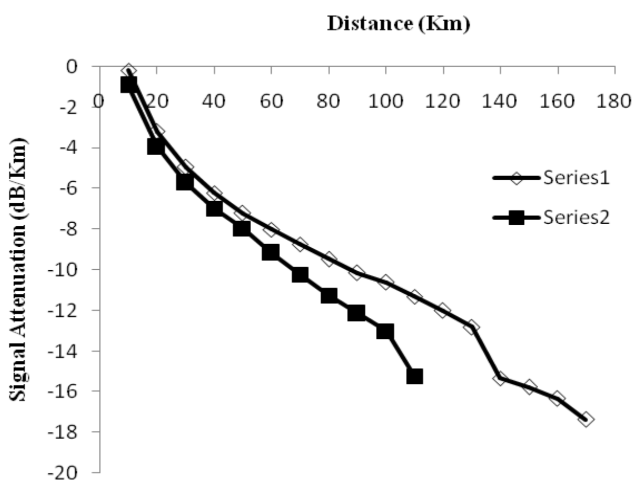

Fig. 3. Variation Profile of Measured Signal Attenuation against Distance for Gotel FM and Fombina FM (Series 1 for Gotel and 2 for Fombina)

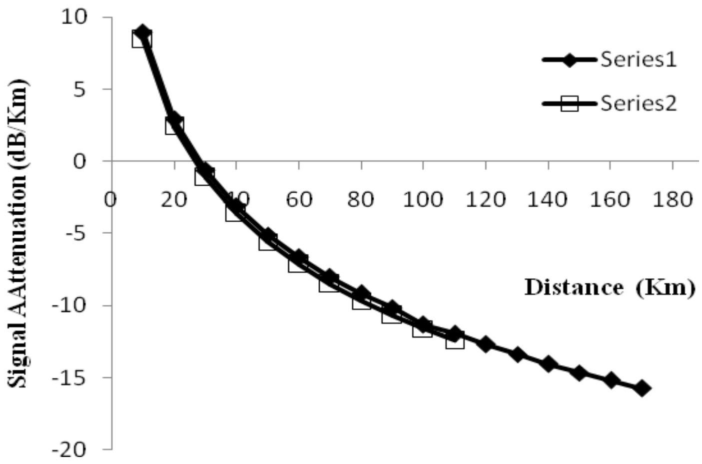

Fig. 4. Graph of Calculated Signal Attenuation against Distance for Gotel FM and Fombina FM.(Series 1 for Gotel and 2 for Fombina)

The graph in Fig. 5 is the variation of refractivity against linear distance for Gotel FM; the curve for Fombina FM also follows the same pattern but terminates at a distance of 110 km as the signal does not extend beyond that distance.

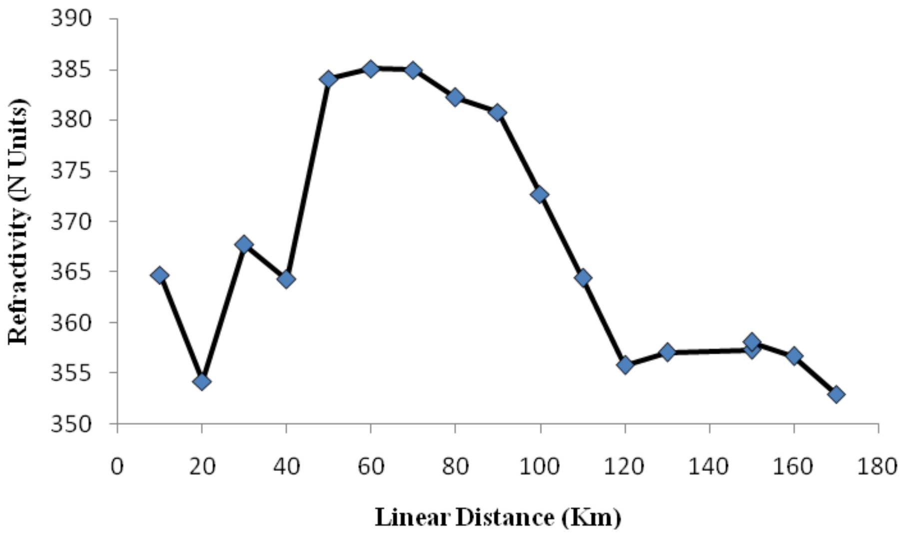

Fig. 5. Variation Profile of Refractivity against Linear Distance

VI. DISCUSSIONS

From tables 1 and 2, it is very clear that the distance covered by the signals from the radio station is a function of the transmitting power; the higher the transmitting power, the longer the distance. Radio Gotel with a 10 KW transmitting power has a distance coverage of up to 170 km, while radio Fombina FM with 8 KW has about 110 km coverage. From [10], the Orient FM in Imo state Nigeria with transmitting power of 4.2 KW has only 45 km distance coverage which is a confirmation of our result. Also, from Tables 1 and 2, the values of the measured and the calculated signal strengths for the two radio stations decrease with increase in linear distance, satisfying the empirical relationship between signal strength and linear distance, and in agreement with the result obtained by [10]. These results are further supported in Fig. 1 and 2. At linear distances of more than 70 km from the radio stations, the values of the signal strength and signal attenuation obtained from numerical simulations tend to agree with the measure values. This shows that equation (3) could be used to estimate the values of the signal strength and signal attenuation of a radio station for linear distances more than 70 km.

There is also a strong negative correlation between the measured signal strength and the linear distance of – 0.915 for Fombina FM and – 0.887 for Gotel FM respectively. Also a negative correlation of – 0. 522 and –

0.458 between the calculated signal strengths and linear distance for Fombina FM and Gotel FM respectively was established. The difference in the negative correlation values could be attributed to the absence of the effects of some atmospheric conditions, such as pressure, temperature and topography in the simulation process.

In Fig. 3, the signals of the two stations are attenuated progressively with linear distance, though the attenuation of the signals are not well observed at distances less than 10 km. In Fig. 4, the signals are equally attenuated progressively with linear distance, however, the attenuation is not very significant up to a distance of 30 km. Furthermore, the variation profiles of the signal attenuation and the linear distance for the two stations are very similar, unlike in Fig. 3 where field measurements were conducted. The variation in the two profiles is also an indication of absence of the effects of atmospheric conditions in the simulation process.

From Fig. 5, the refractivity of the signals from the two stations varies with the linear distance; it is highest at linear distances of between 60 and 70 km, and steeply decreases up to a distance of 120 km and a slight increase before decreasing from about 160 km to 170 km from the station.

VII. CONCLUSION

This work has studied the effects of linear distance and atmospheric conditions on signal strength, signal attenuation and refractivity of two radio stations. The results show a strong inverse relationship between the signal strength and the linear distance, and the dependence of the distance coverage on the transmitting power of the radio station. The difference in the correlation values between the measured and numerical simulation is an indication of the absence of the effects of atmospheric conditions in the simulation process. The signals are progressively attenuated with distance for both the measured and the calculated values. The refractivity of the signals from two stations varies with the linear distance, though, without a specified pattern.

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