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Influence of Atmospheric Temperature on the Signal Strength of Mobile Phone Communication

Joseph Amajama, Ahmed Tunde Ibrahim and Julius Ushie Akwagiobe
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Abstract: *The atmosphere serves as a medium for wireless (over-the-air) communication and is significantly influenced by weather conditions. Among various meteorological parameters, atmospheric temperature plays a critical role in radio signal propagation. This study investigates the impact of atmospheric temperature on mobile phone communication signal strength. A field campaign was conducted across five Nigerian cities: Calabar, Uyo, Port Harcourt, Yenagoa, and Warri. Signal strength data were collected from two leading mobile networks in Nigeria—MTN and 9Mobile. In the 3G band, MTN operates within the 2110.00–2120.00 MHz downlink spectrum, while 9Mobile uses 2130.00–2140.00 MHz. For 4G services, MTN transmits within the 2620–2690 MHz (2600 MHz band) and 791–821 MHz (800 MHz band), whereas 9Mobile transmits in the 1805–1880 MHz range (1800 MHz band). Signal strength was measured hourly using an Android-based transceiver device with dual SIM capability and the Cell Signal Monitor (v5.1.1) app. Data were collected from specific cell sites to ensure accuracy, and corresponding atmospheric temperature readings were sourced from the Nigeria Meteorological Agency (NIMET). The analysis showed a generally inverse relationship between atmospheric temperature and signal strength. However, inconsistencies observed may be attributed to factors such as local topography, antenna characteristics, seasonal variations, and the relative position of transmitters and receivers.*

Keywords: *Atmospheric temperature, mobile phone, mobile phone communication, signal strength and weather*

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1.0 Introduction

The atmosphere serves as the primary medium for wireless (or over-the-air) communication (Amajama *et al.*, 2023). All forms of wireless technologies—such as radio and television broadcasting, radar systems, satellite communication, cellular networks, the Global Positioning System (GPS), Wireless Fidelity (Wi-Fi), Bluetooth, and Radio Frequency Identification (RFID)—rely on the atmosphere for signal transmission (Iwuji *et al.*, 2023a). However, the performance of this atmospheric communication channel is significantly influenced by weather conditions (Alam *et al.*, 2016). Weather refers to the state of the atmosphere at a given time and location. The main parameters that characterize weather are atmospheric temperature, pressure, relative humidity, and wind (Emmanuel & Adebayo, 2013). Variations in these four key weather parameters alter the physical properties of the atmosphere, which in turn affect radio wave propagation (Joseph, 2016a; Joseph, 2016b;

Joseph, 2016c; Joseph & Oku, 2016; Valma *et al.*, 2010). The troposphere—the lowest layer of Earth's atmosphere—extends from the Earth's surface up to approximately 14.5 kilometers. This layer is where most weather phenomena occur ("Earth's Atmospheric Layer," 2013). Because it hosts nearly all atmospheric weather activity, the troposphere is of central importance to weather-related studies. This study, therefore, focuses on examining the impact of atmospheric temperature within the troposphere on mobile phone signal strength. Among the four principal weather parameters, atmospheric temperature plays a particularly significant role in determining the properties of the atmospheric communication channel. It refers to the temperature measured at various altitudes within the Earth's atmosphere. Changes in atmospheric temperature can alter the medium through which radio waves travel, potentially leading to signal reflection (scattering), absorption, and refraction losses (Iwuji *et al.*, 2023b). These phenomena are largely due to the fact that atmospheric density is temperature-dependent. As described by the Ideal Gas Law, at constant pressure, an increase in temperature results in a decrease in gas density. Furthermore, atmospheric temperature is influenced by the interaction of solar radiation with air masses, clouds, land, oceans, and other water surfaces (Iwuji *et al.*, 2023c). The Sun emits solar radiation across a range of wavelengths: approximately 7.8% in the ultraviolet and shorter wavelengths, 47.3% in visible light, and 44.9% in the infrared spectrum (Macdonald, 2017). These radiations can interact with and interfere in the propagation of radio waves in the atmosphere, thereby affecting signal quality and strength.

2.0 Literature Review

2.1 Mobile phone communications signal versus atmospheric temperature

Ofure *et al.* (2017) in Minna, Nigeria researched on: "Impact of some atmospheric parameters on GSM signal". 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 a weather station at the Bosso Campus of the Federal University of Technology, Minna, Nigeria. Concurrently, the received signal level 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 the study showed that surface atmospheric temperature has positive correlation values ranging from 0.57 to 0.88 with received signal level of GSM signals.

Osahenvemwen & Omatahunde (2018) studied the: "Impacts of weather and environmental conditions on mobile communication signals" in Benin City, Nigeria. A Glo mobile communication network operating in the 900MHz band was considered. The Glo fixed Base Transceiver Station (BTS) located at Glo-world in Benin City was considered. Frequency-signal tracker software, version 2.5.1 was installed and configured into a notebook Intel palm top and relevant parameters data were obtained from 200 meters from the Glo BTS from 28th of July to 31st of August 2016, with data obtained hourly. Morning, afternoon and evening, and dry weather, fog weather and raining conditions were based on the statistical central tendency parameters. The average refractivity gradient observed was -61.3N/Km. It was observed that in dry weather, signal strength variation was within 32dBm, in fog, variation was within 34dBm range, while the variation of rain was within 38dBm range indicating a higher variation. The duo observed that the more the mobile station move away from the BTS, the higher the signal loss and that temperature had 0.50 positive correlations with received signal strength respectively.

Dalip & Kumar (2014) in Haryana, India examined the: "Effect of environmental parameters on GSM and GPS". Weather data were taken from a weather report website named Weather2. For experimental analysis, outdoor tests were conducted for checking strength of signals. The data was collected in various scenarios. Readings were taken from different landmarks of same route. A 50Km distance route was selected for survey. This route cuts across rural and urban areas: it also contained open sky and under tree view. Due to humidity parameters, the surrounding areas of river are not considered for survey because in these areas humidity must be high. The average value of each reading was considered for consistent results. Data were collected during winter seasons. All weather conditions were considered like fog, clear sky, cloudy, partly cloudy and rain into this season. Data was analyzed using graphs to describe the signal strength information and deviation in Global Positioning System (GPS) latitude and longitude graphically. Results showed that air temperature and air condition affect signal strength values of GSM and accuracy of GPS.

2.2 UHF/VHF signals versus atmospheric temperature

Guidara *et al.* (2018) investigated the *impact of temperature and humidity variations on Received Signal Strength Indicator (RSSI)* in indoor wireless sensor networks (WSNs). Their experiments were conducted in a 9 × 9 m² laboratory room using Panstamp 2.0 NRG modules equipped with 868 MHz CC1101 radio chips and SparkFun HTU21D temperature and humidity sensors. The WSN comprised 9 beacon nodes, 3 anchors, and a base station. Beacons, installed at 1 m height along the side walls, transmitted every 5 minutes with 0 dBm power and included their positional coordinates. Anchors, placed on the ceiling at 3 m height, recorded RSSI, Link Quality Indicator (LQI), temperature (T), relative humidity (RH), and distance to the sender. All data were transmitted to a base station connected via USB to a PC and logged in CSV format. Measurements were collected over a week and analyzed using Python libraries. The results revealed spatial and temporal variations of temperature and humidity within narrow ranges. Notably, a strong negative correlation between temperature and RSSI was observed at distances ≥5 m, while the impact diminished at shorter ranges. This study has implications for RSSI-based applications such as indoor localization.

Felix *et al.* (2017) explored *the relationship between FM signal strength and environmental factors* for WE FM radio station (106.3 MHz) in Abuja, Nigeria. Using a CATV signal meter, hygrometer, and thermometer, they measured signal strength, temperature, and humidity during both cloudy and clear days. Their findings indicated that signal strength decreases with increasing atmospheric temperature, with correlation coefficients of -0.42369 and -0.51878. The effect was more pronounced during cloudy or rainy days, emphasizing the atmospheric impact on FM broadcast signals.

Roshidah *et al. 2016* studied *the effect of temperature on tropospheric radio signal strength* for the UHF band in Terengganu, Malaysia. Utilizing a spectrum analyzer for Radio Frequency Interference (RFI) and a weather station for temperature monitoring, they plotted attenuation graphs over time. Their findings showed varying correlations: a weak negative correlation at 945 MHz (r = -0.085) and positive correlations at 83 MHz (r = 0.249), 1800 MHz (r = 0.268), and 2160 MHz (r = 0.134). The study supports broader radio wave propagation research relevant to wireless communication, radio astronomy, and electromagnetic health studies.

Sabu *et al.* (2017) in Kerala, India, conducted *a study on the effect of temperature on cellular signal strength*. RSSI data were collected using three Android smartphones (Micromax, Mediatek chipsets) and the CrisisSignal app, while temperature was measured with an Arduino-based station using an AM2302 sensor. Data were logged in Excel and analyzed using correlation techniques. Though smartphones are not precision instruments for signal strength, the study highlighted the potential of crowdsourced cellular data for weather-related analysis. A weak positive correlation was noted, likely influenced by network traffic variations. The study underscores the potential of integrating mobile sensor data for large-scale environmental monitoring.

Ukhurebor & Umukoro (2018) examined *the influence of meteorological variables on UHF radio signal* in Benin City, Nigeria, using signals from EBS Television (743.25 MHz). Signal strength, temperature, pressure, and humidity were measured every 8 hours for a year using a CATV analyzer and a custom weather station. Results indicated a strong inverse relationship between signal strength and air temperature, with a correlation coefficient of -0.94, assuming other variables remained constant.

Amajama (2016) assessed *the impact of weather components on UHF radio signal* strength in Calabar, Nigeria. Using signal measurements from CRBC (519.25 MHz, 35 mdB) and weather parameters (temperature, pressure, humidity, wind), data were collected half-hourly. The study confirmed an inverse relationship between signal strength and temperature (r = -0.94), provided wind effects and other factors were constant.

Luomala & Hakala (2015) explored *temperature and humidity effects on radio signal strength in outdoor WSNs* in Kokkola, Finland. The network operated on the 2.4 GHz ISM band using Atmel ZigBit modules (ATZB-24-B0) integrated with Sensirion SHT75 sensors. Data were collected in both summer and winter and transmitted to a server via a Raspberry Pi. Weatherproof enclosures protected the nodes, leaving antennas and sensors exposed. Their results showed that temperature significantly and negatively affects signal strength, demonstrating the sensitivity of WSN performance to environmental conditions.

2.0 Methodology

The campaign to investigate the effect of atmospheric temperature on mobile phone communication signal strength was carried out in the following cities: Calabar, Uyo, Portharcourt, Yenagoa and Warri in Nigeria.

The signal strength of two (2) very popular mobile phone communication networks in Nigeria: MTN and 9Mobile were taking into account. MTN transmits in the downlink spectrum of 2110.00-2120.00MHz, while 9Mobile transmits in the downlink spectrum of 2130.00-2140.00MHz in the 2100MHz-3G band. In the 4G band, MTN transmits in the downlink spectrums of 2620-2690MHz in the 2600MHz band and 791-821MHz in the 800MHz band while 9Mobile transmits in the downlink spectrum of 1805-1880MHz in the 1800MHz band (Nigerian Communication Commission [NCC], 2020).

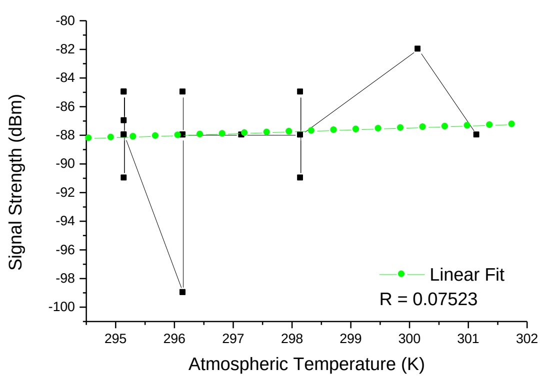
The signal strengths were measured using a mobile station in each station in each of the cities. The mobile station is an android (transceiver) device (having two SIM slots) with a Cell Signal Monitor (Version 5.1.1) application installed. The application has a signal strength data logger which was set at one (1) minute interval. The average signal strength level at the struck of the first fifteen (15) minutes every hour was registered. Measurements of signal strength in the various stations were restricted to specific cells for accuracy

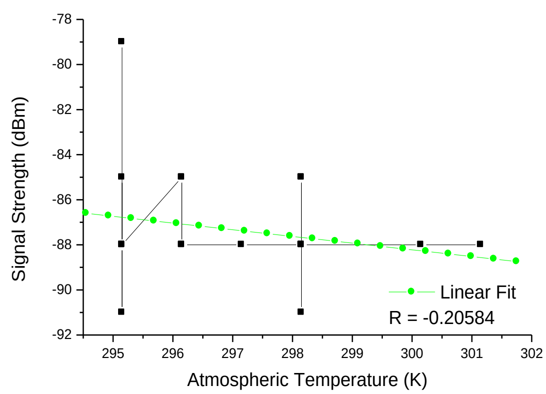
Atmospheric temperature data were excerpted online from the Nigeria Meteorological Agency (NIMET) hourly weather report for the various cities were the stations were situated. Signal strengths were measured hourly and simultaneously corresponding atmospheric temperature at the time of measurement of signal strength was registered.

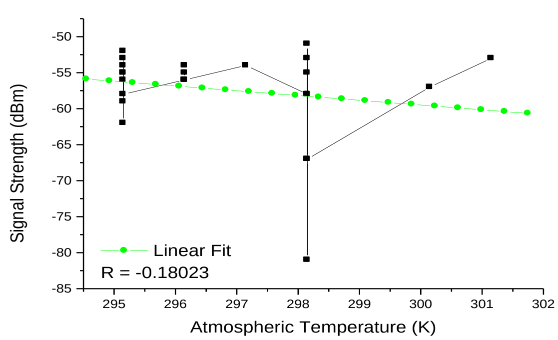
3.0 Results and Discussion

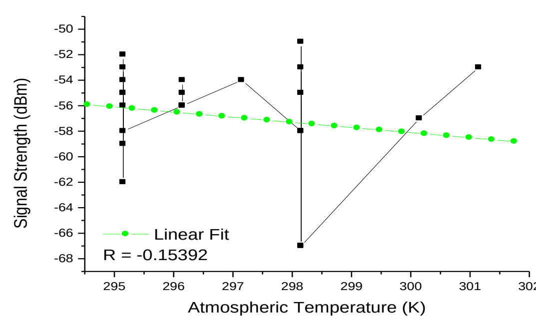
From the linear graphs (Figs 1 to 5) between received signal strength and atmospheric temperature, for the eighty eight (88) cells considered, out of all; sixty six (66) cells showed a negative co-relation between received signal strength and atmospheric temperature while twenty two (22) cells showed a positive linear relationship. The correlation between received signal strength and atmospheric temperature ranged between -0.74645 and 0.54425.

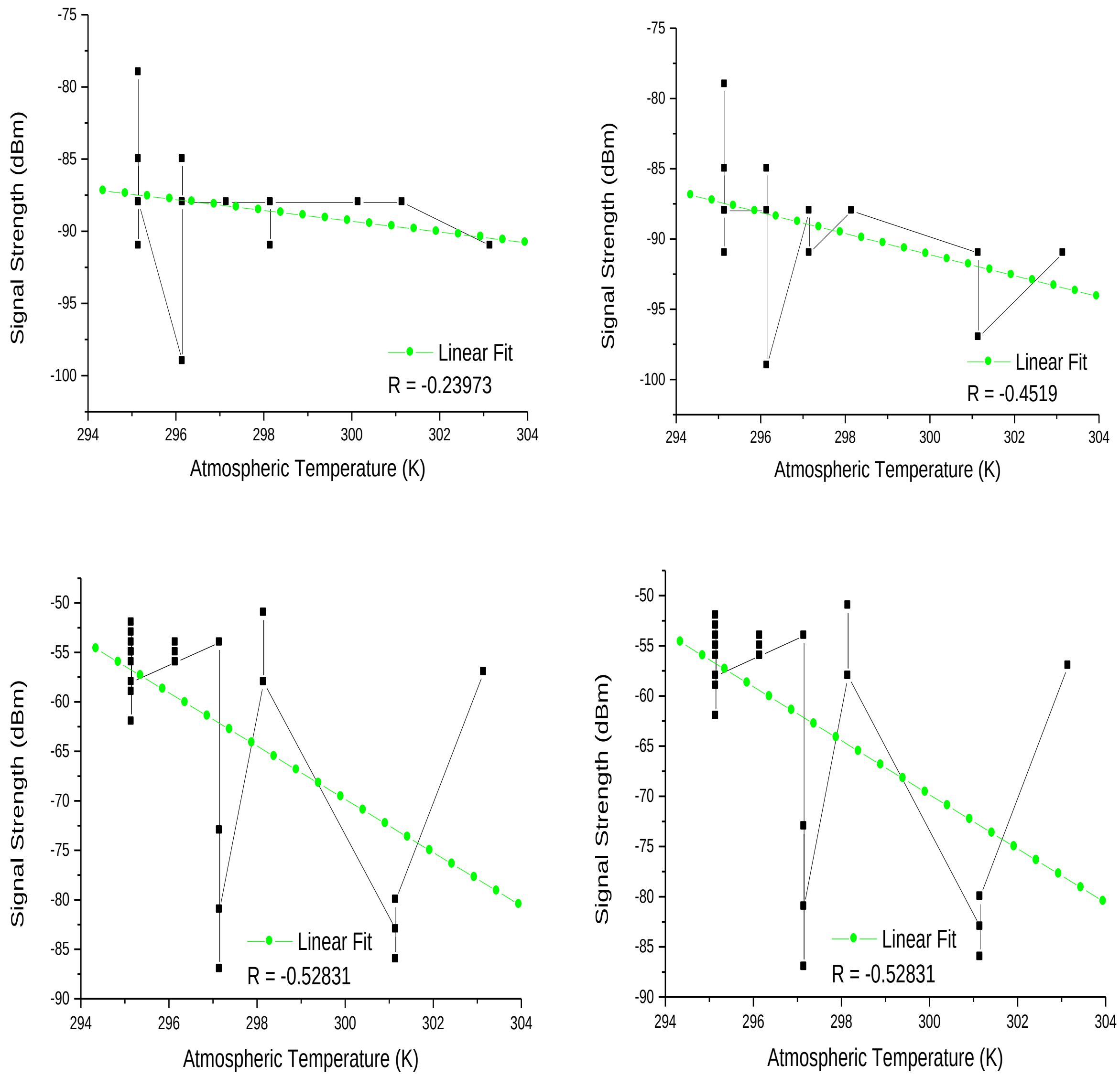
In the city of Calabar, measurements were taken from the following transmitting cell IDs: 14631, 14635, 1383, 1385, 29282, 29286, 23143, 23253, 25912, 25916, 23112, 2553, 14671, 14675, 25202, and 25209. At Uyo city, measurements were taken from the following transmitting cell IDs: 21013, 21017, 200313-1, 200225-2, 2034-1, 2034-3, 200222-13, 200085-83, 21041, 21045, 200085-82, 200222-13, 13743, 13747, 200584-13, and 200078-81. At Portharcourt city, measurements were taken from the following transmitting cell IDs: 20201, 20205, 230240-6, 230458-4, 19843, 19847, 230335-6, 230403-6, 48412, 48416, 22071, 22078, 20172, 20176, 902067-6, and 2303316. At Warri, measurements were taken from the following transmitting cell IDs: 42707, 42703, 510490-81, 510490-83, 4275, 45871, 902744-81, 510481-81, 42773, 42777, 510034-82, 510865-83, 42731, 42733, 510664-4, and 510512-83. Lastly, at Yenagoa, measurements were taken from the following transmitting cell IDs: 20431, 20437, 24696, 24036, 13217, 13219, 24634, 24647, 20431, 20437, 1215, 24696, 13712, 3717, 24786, and 24787.

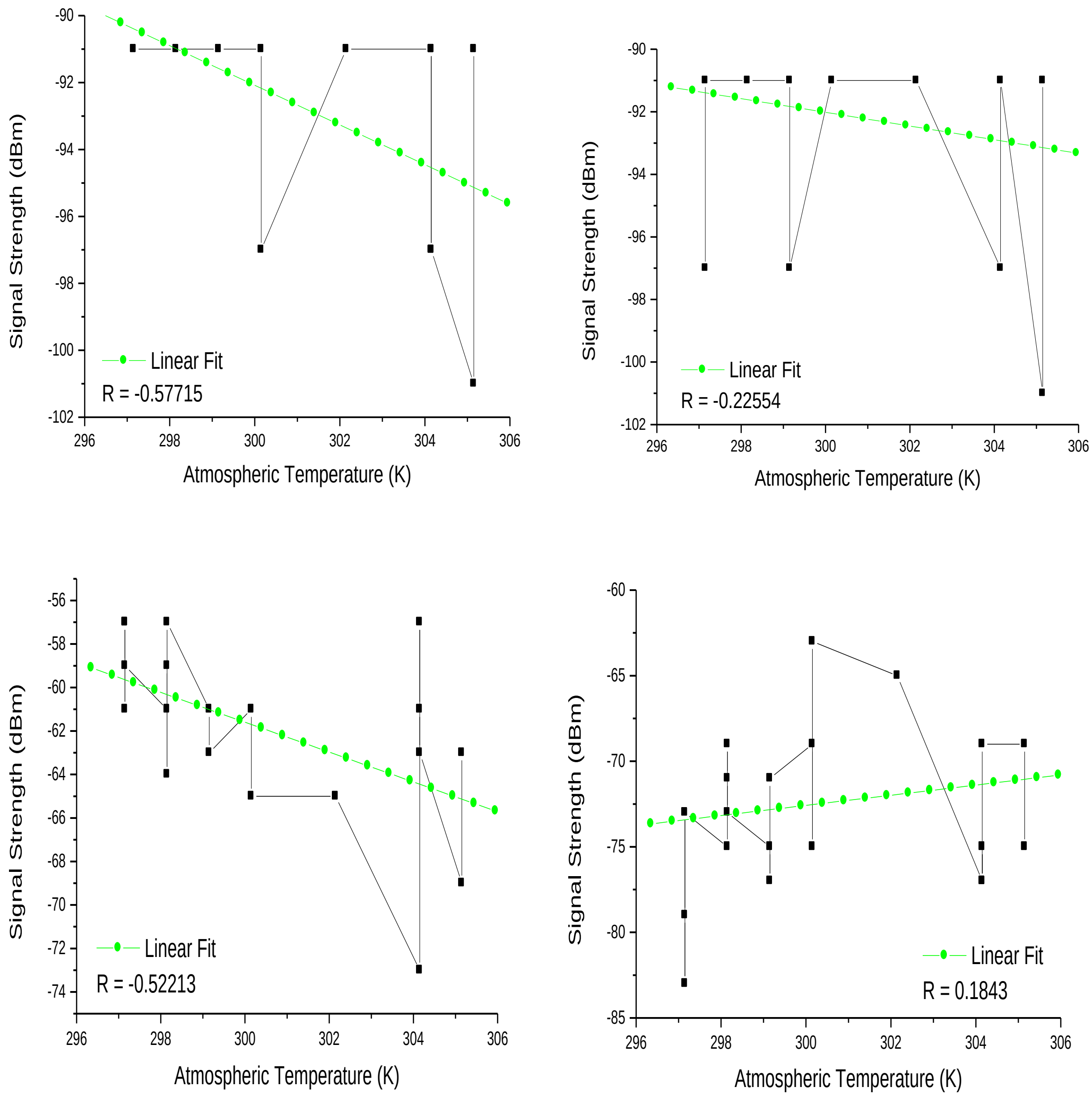


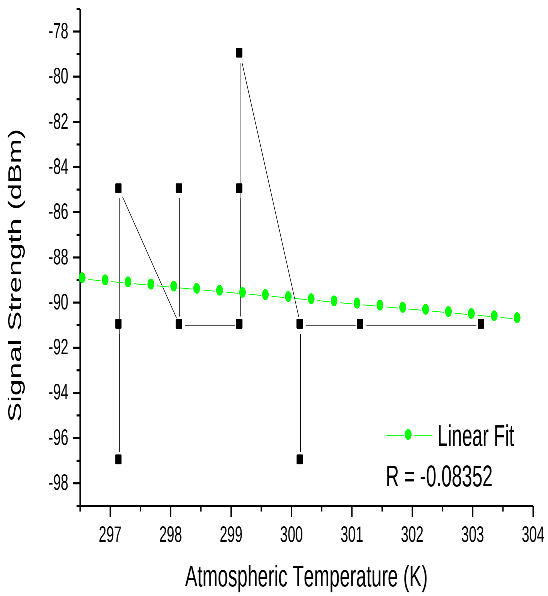


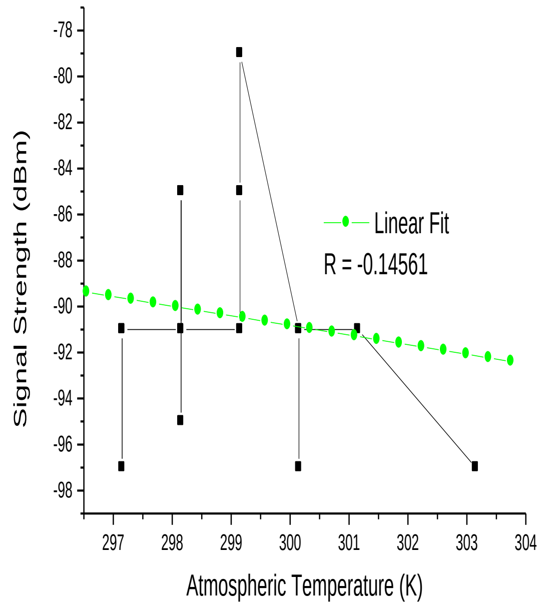


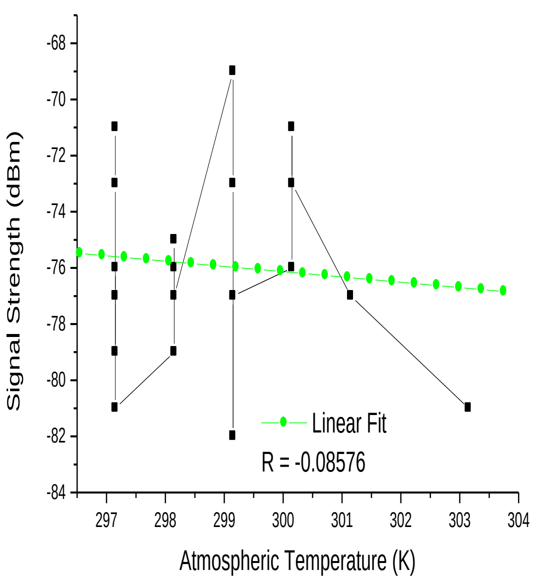


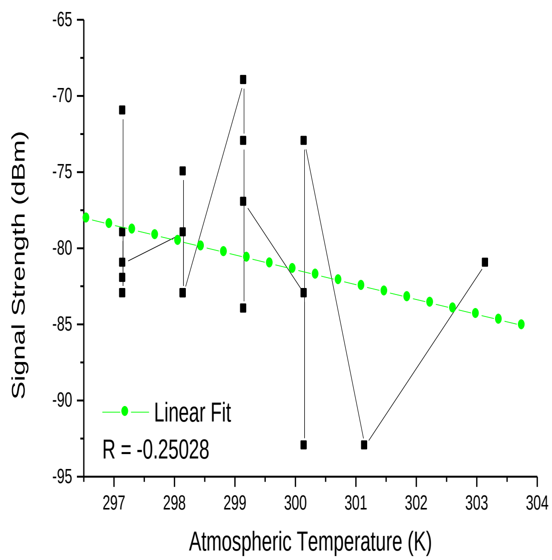

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.23973
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.4519
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.52831
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.52831


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.57715
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.22554
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.52213
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.1843


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.08352


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.14561


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.08576


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.25028

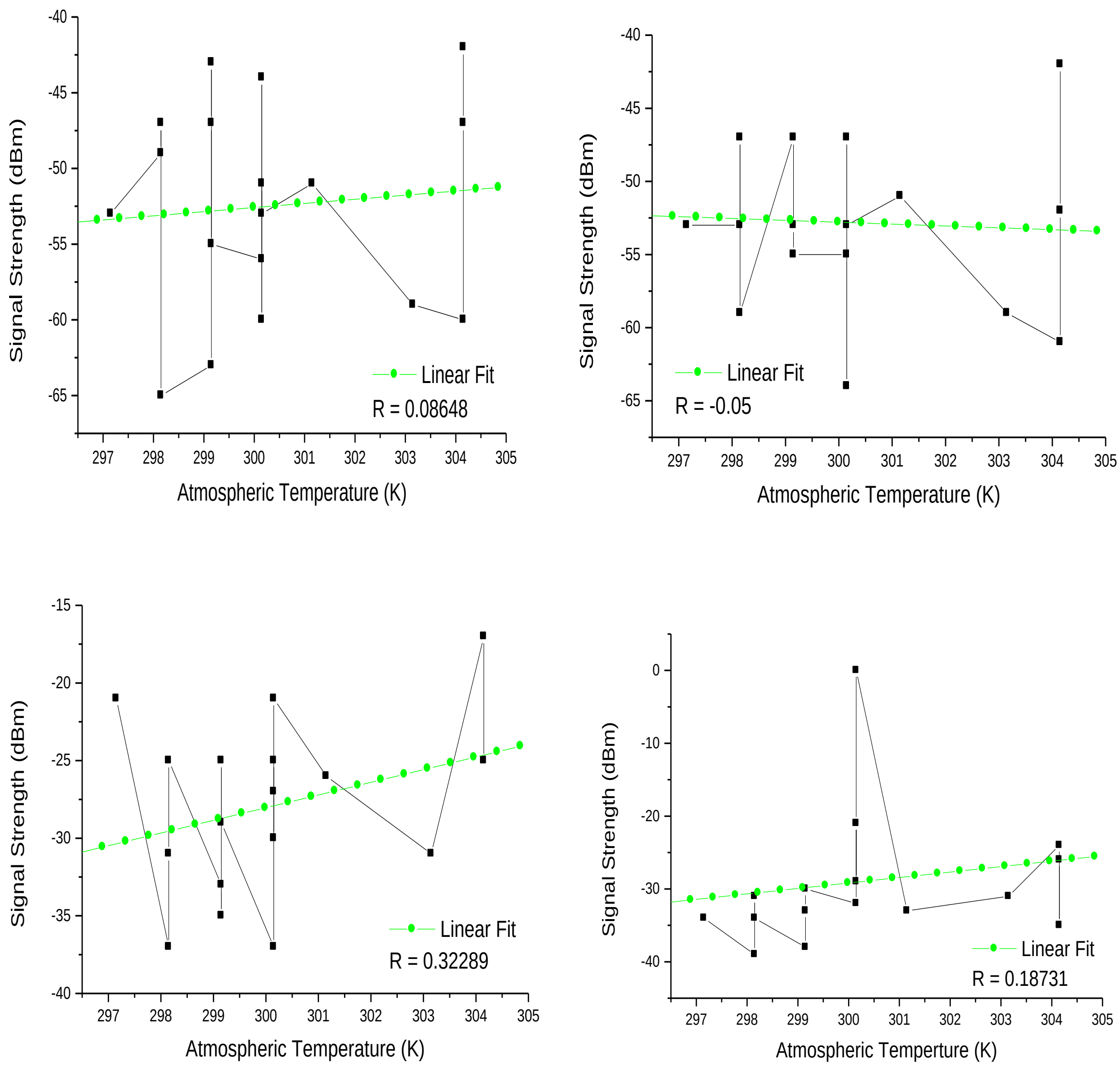
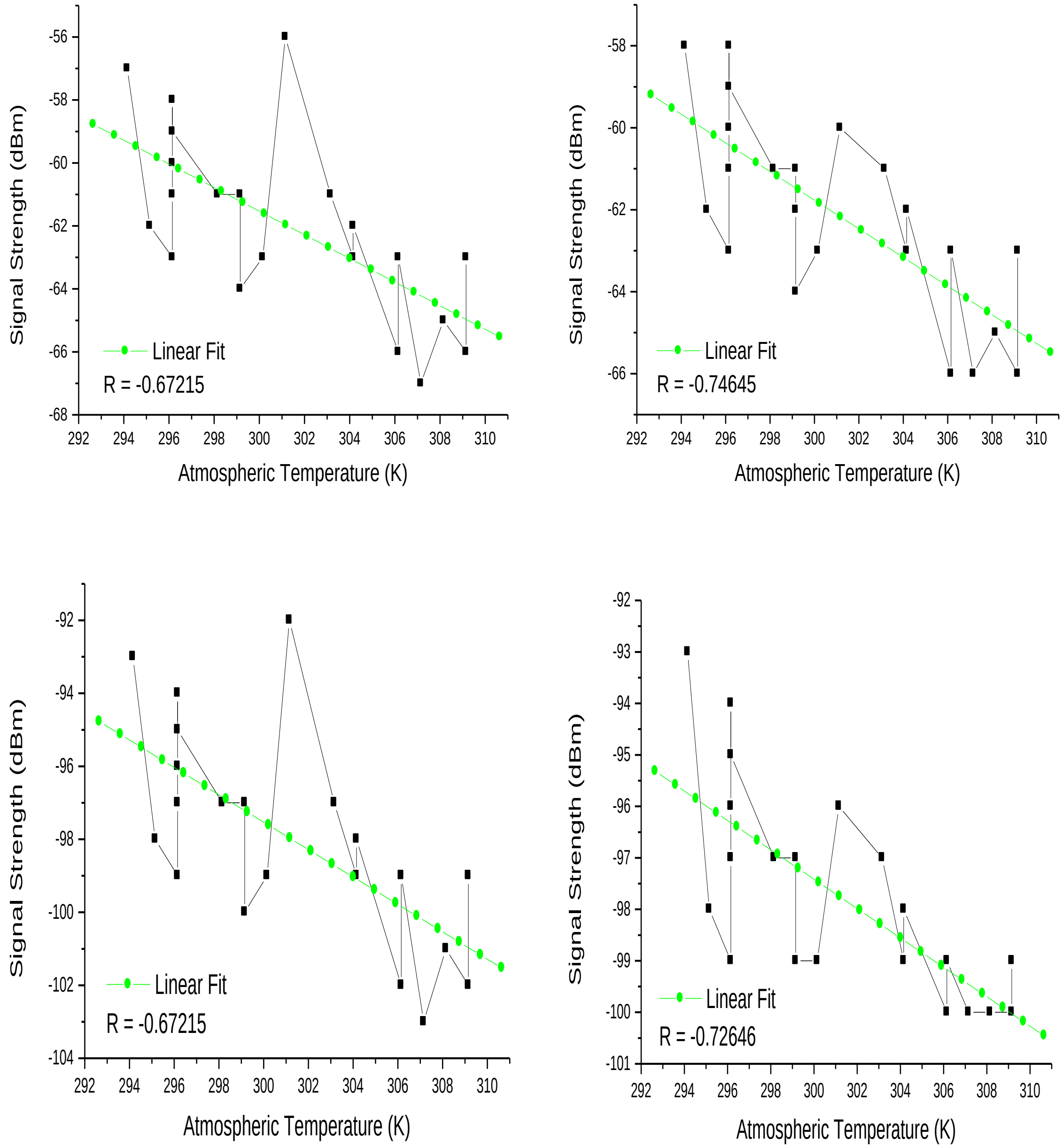
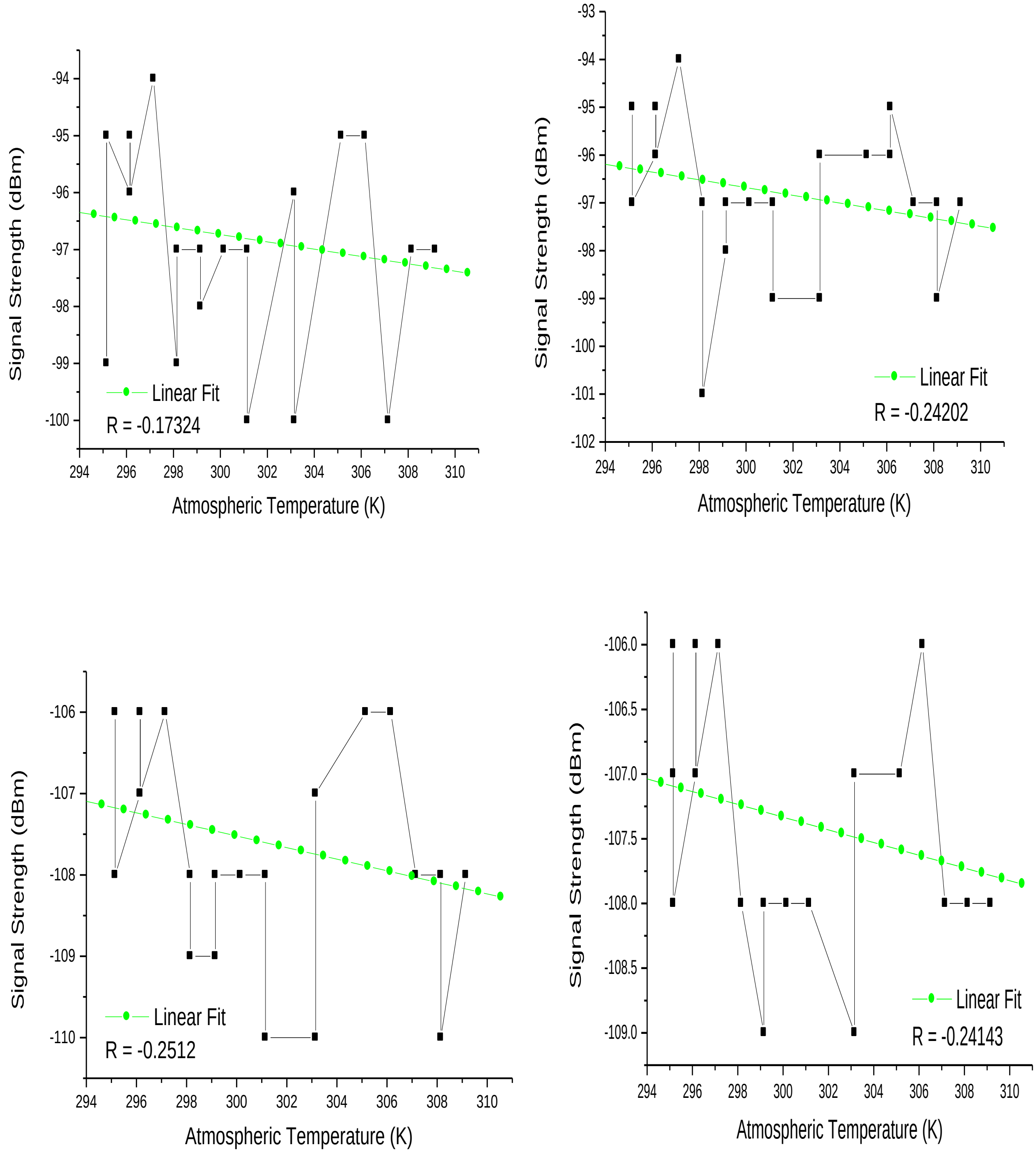
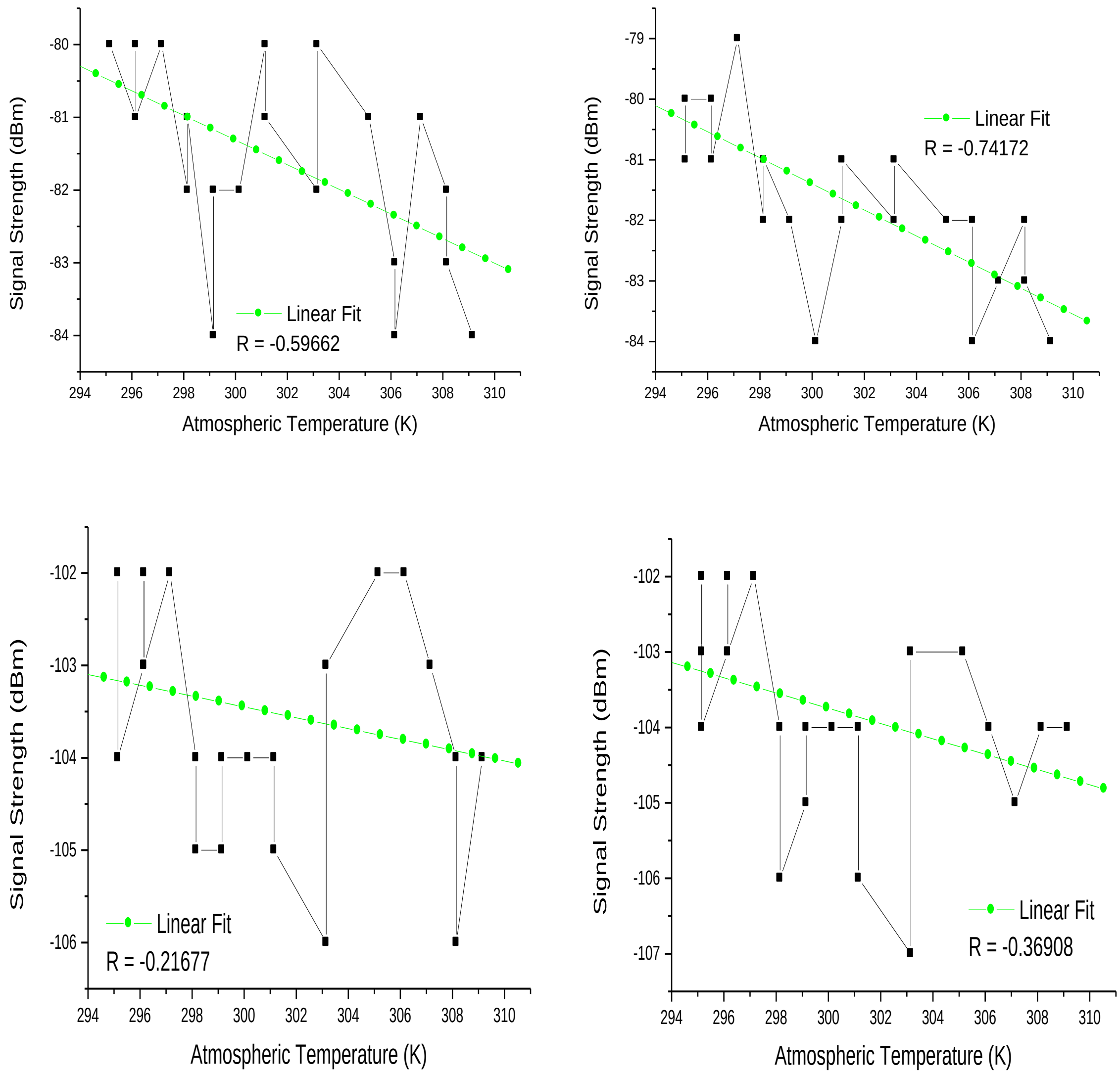
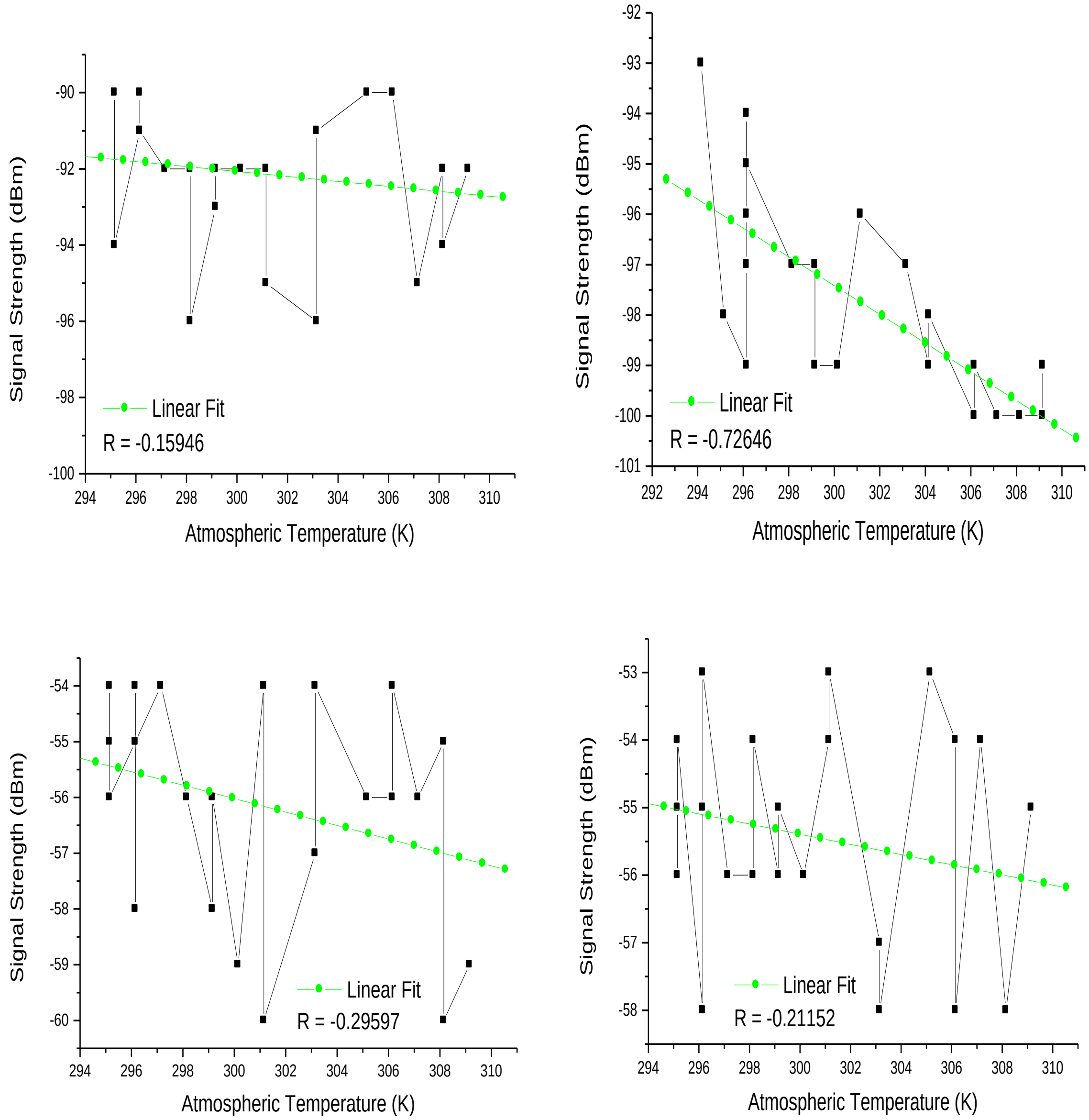


Fig.1 Signal strength VS Atmospheric Temperature in Some Cells in Calabar


Signal Strength (dBm)
Linear Fit
R = -0.67215
Atmospheric Temperature (K)
Signal Strength (dBm)
Linear Fit
R = -0.74645
Atmospheric Temperature (K)
Signal Strength (dBm)
Linear Fit
R = -0.67215
Atmospheric Temperature (K)
Signal Strength (dBm)
Linear Fit
R = -0.72646
Atmospheric Temperature (K)


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.17324
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.24202
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.2512
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.24143


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.59662
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.74172
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.21677
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.36908


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.15946
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.72646
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.29597
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.21152

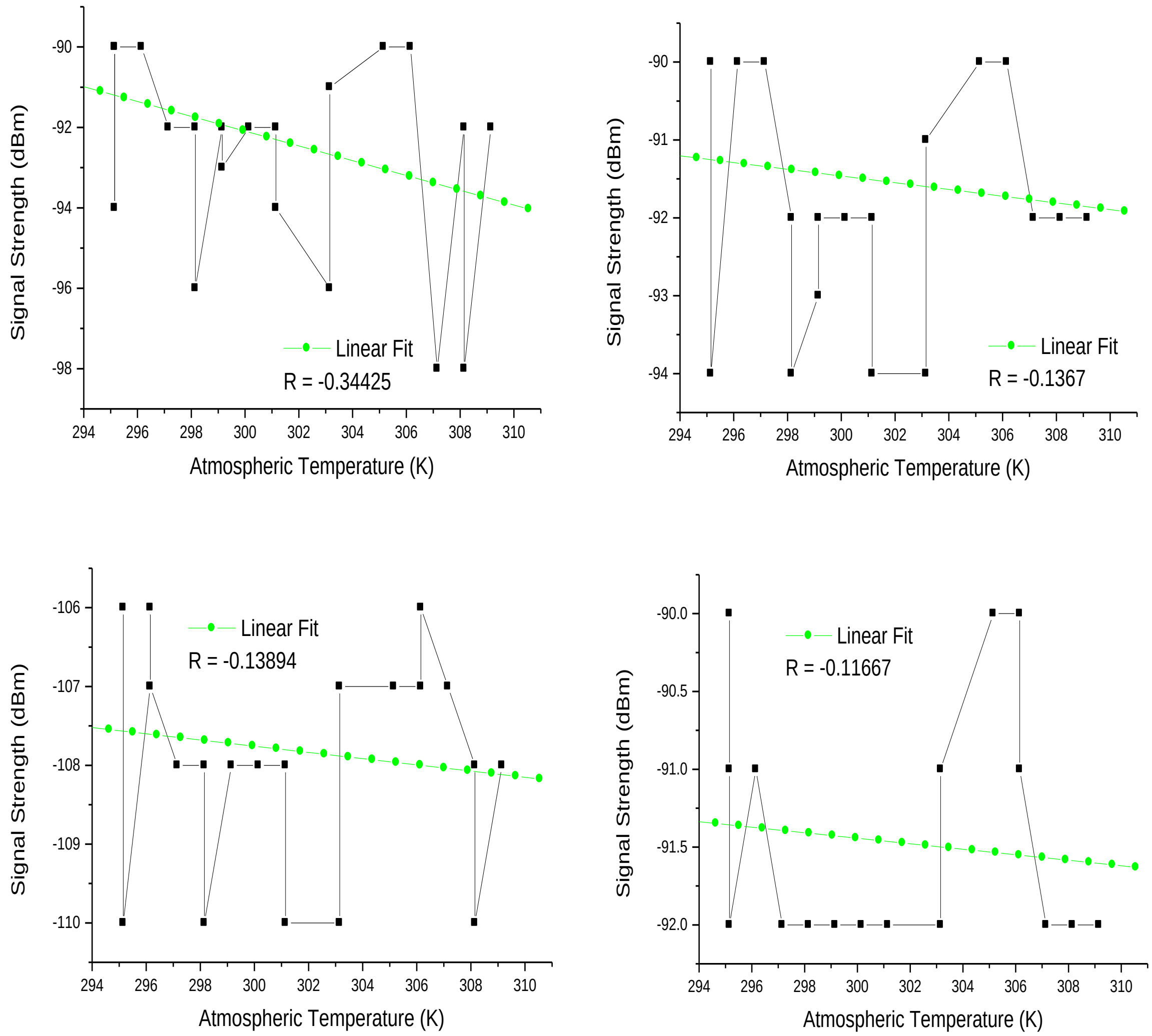
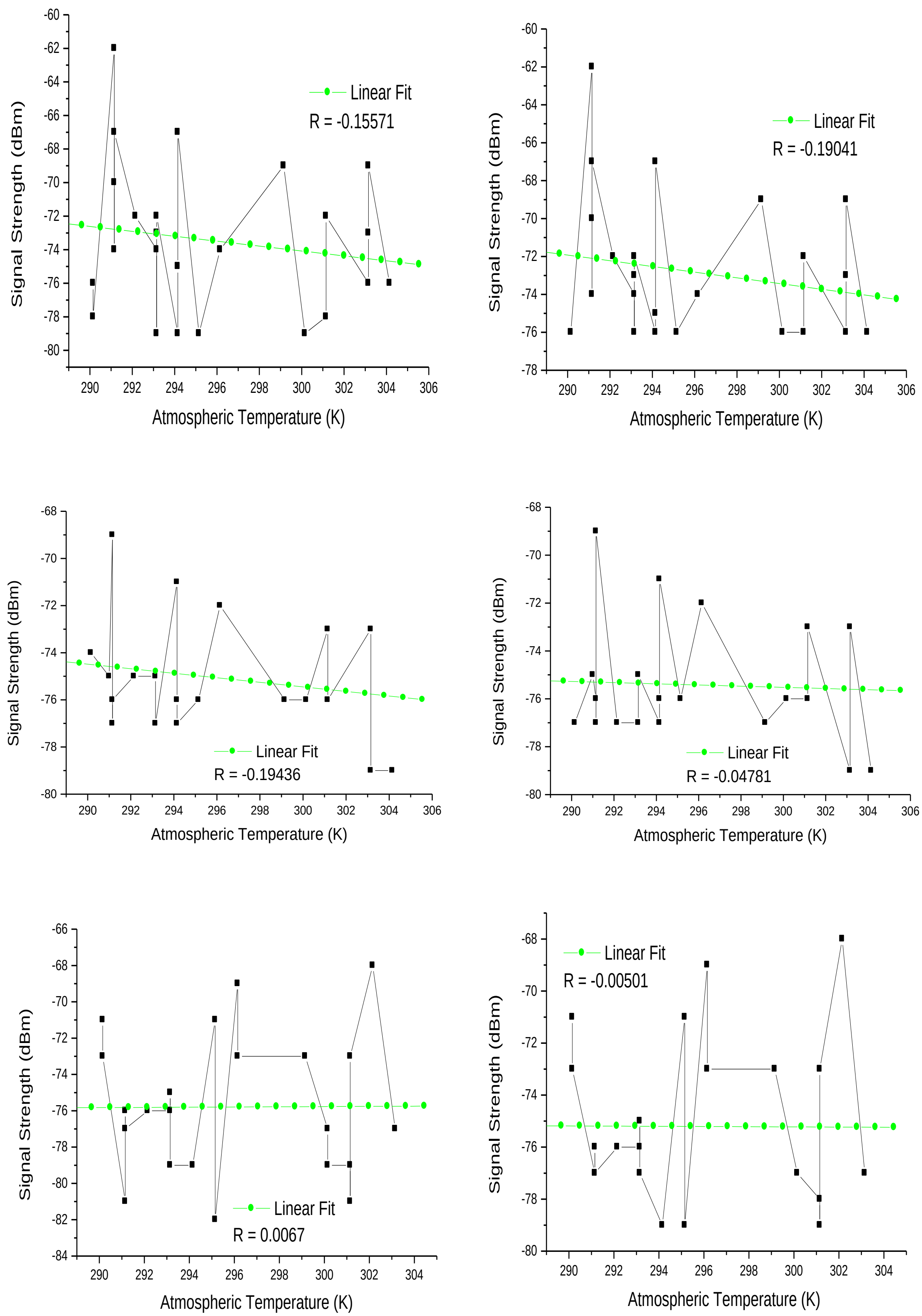
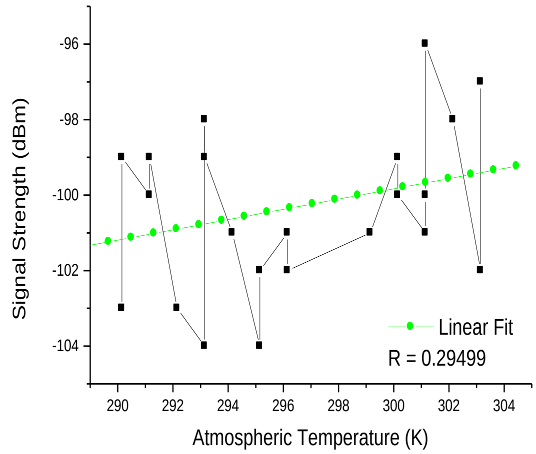
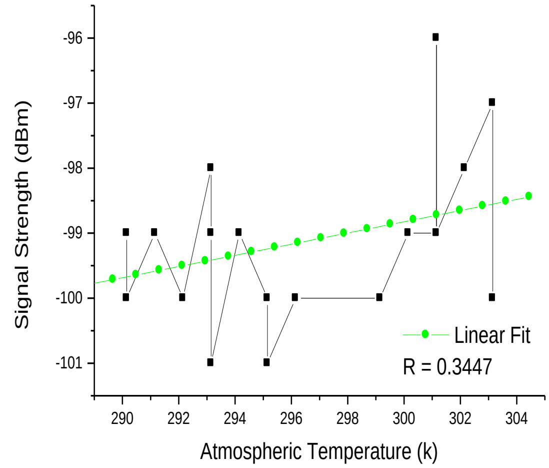
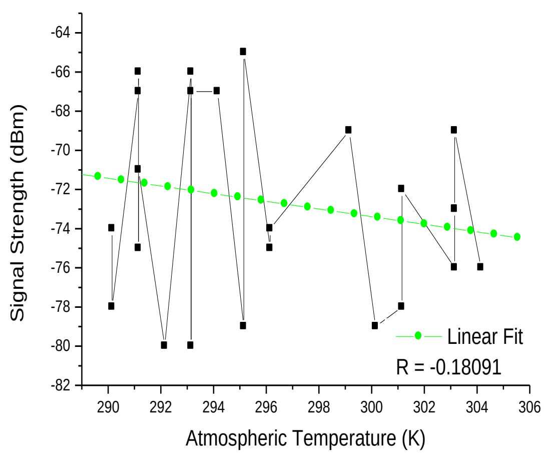


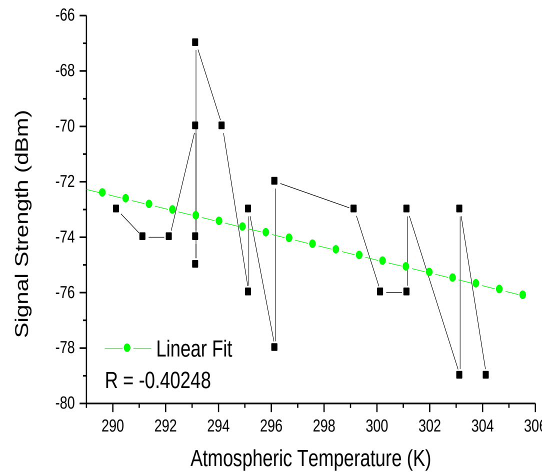
Fig.2 Signal strength VS Atmospheric Temperature in Some Cells in Uyo

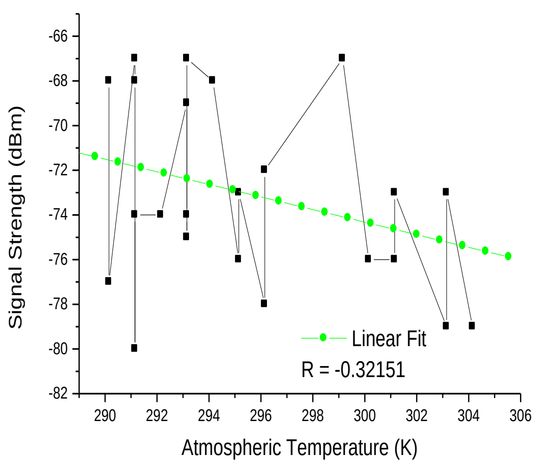

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.15571
R = -0.19041
R = -0.19436
R = -0.04781
R = 0.0067
R = -0.00501

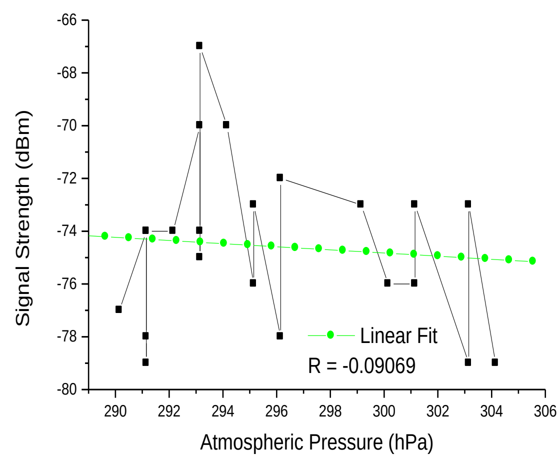

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.29499


Signal Strength (dBm)
Atmospheric Temperature (k)
Linear Fit
R = 0.3447


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.18091


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.40248


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.32151


Signal Strength (dBm)
Atmospheric Pressure (hPa)
Linear Fit
R = -0.09069

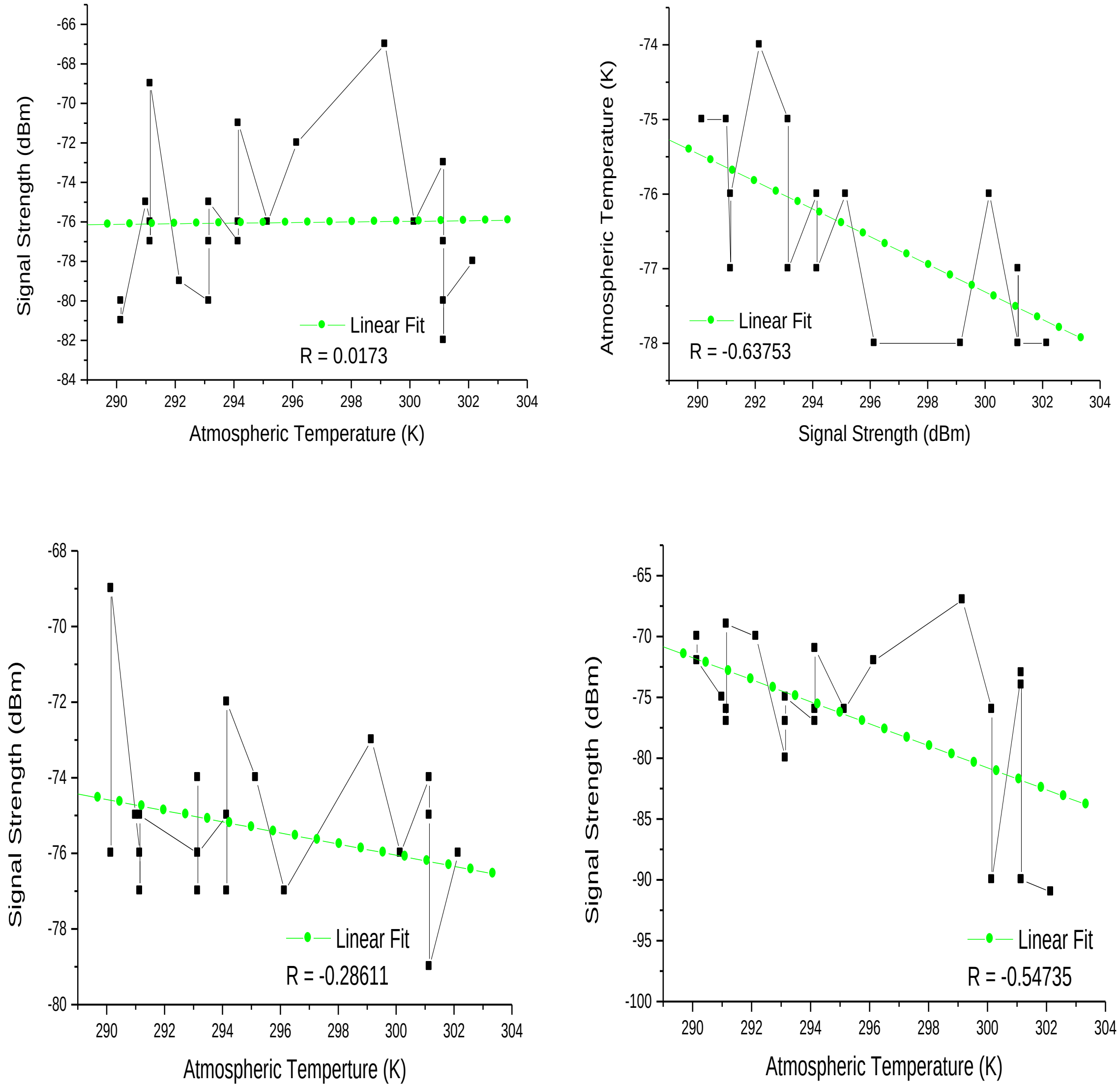
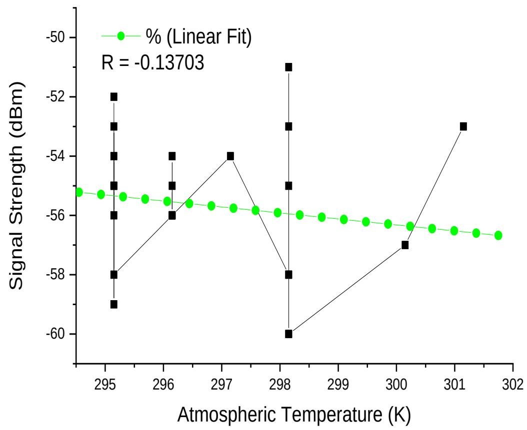
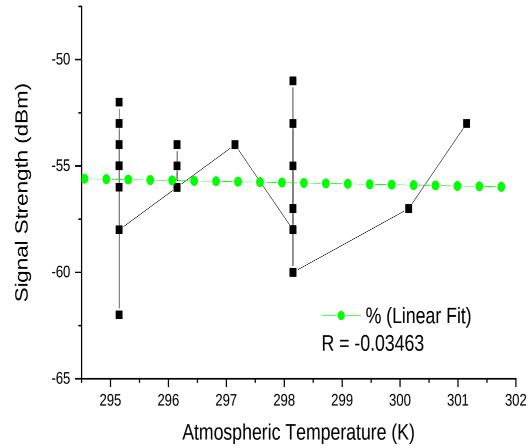
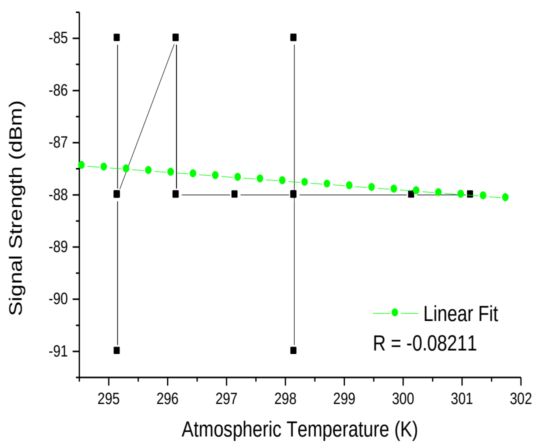
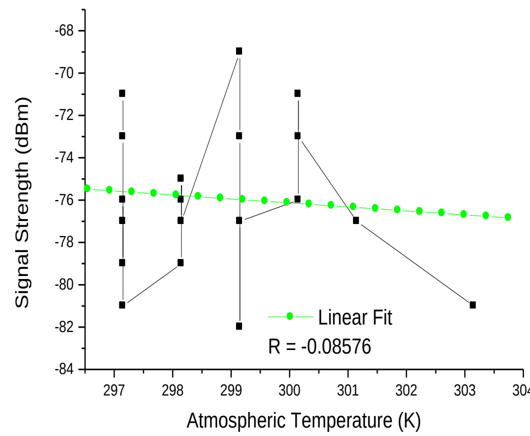


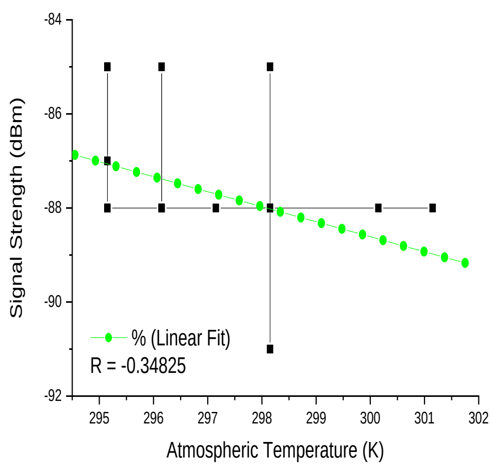
Fig.3 Signal strength VS Atmospheric Temperature in Some Cells in Port Harcourt

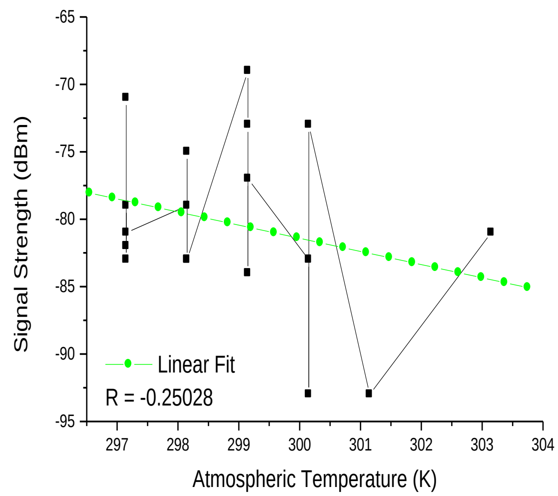

% (Linear Fit)
R = -0.13703
Signal Strength (dBm)
Atmospheric Temperature (K)

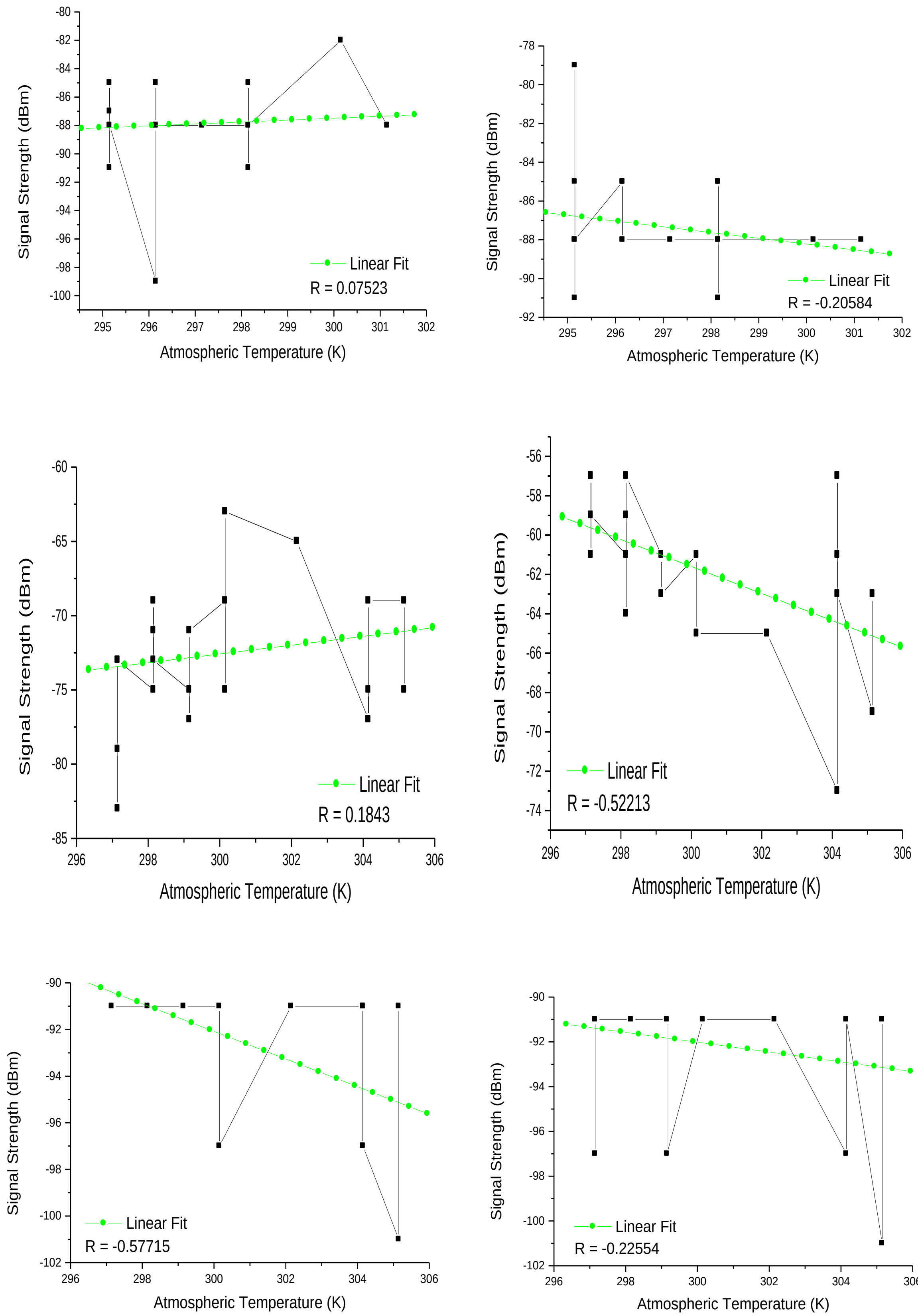

% (Linear Fit)
R = -0.03463
Signal Strength (dBm)
Atmospheric Temperature (K)


Linear Fit
R = -0.08211
Signal Strength (dBm)
Atmospheric Temperature (K)


Linear Fit
R = -0.08576
Signal Strength (dBm)
Atmospheric Temperature (K)


% (Linear Fit)
R = -0.34825
Signal Strength (dBm)
Atmospheric Temperature (K)


Linear Fit
R = -0.25028
Signal Strength (dBm)
Atmospheric Temperature (K)


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.07523
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.20584
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.1843
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.52213
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.57715
Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.22554

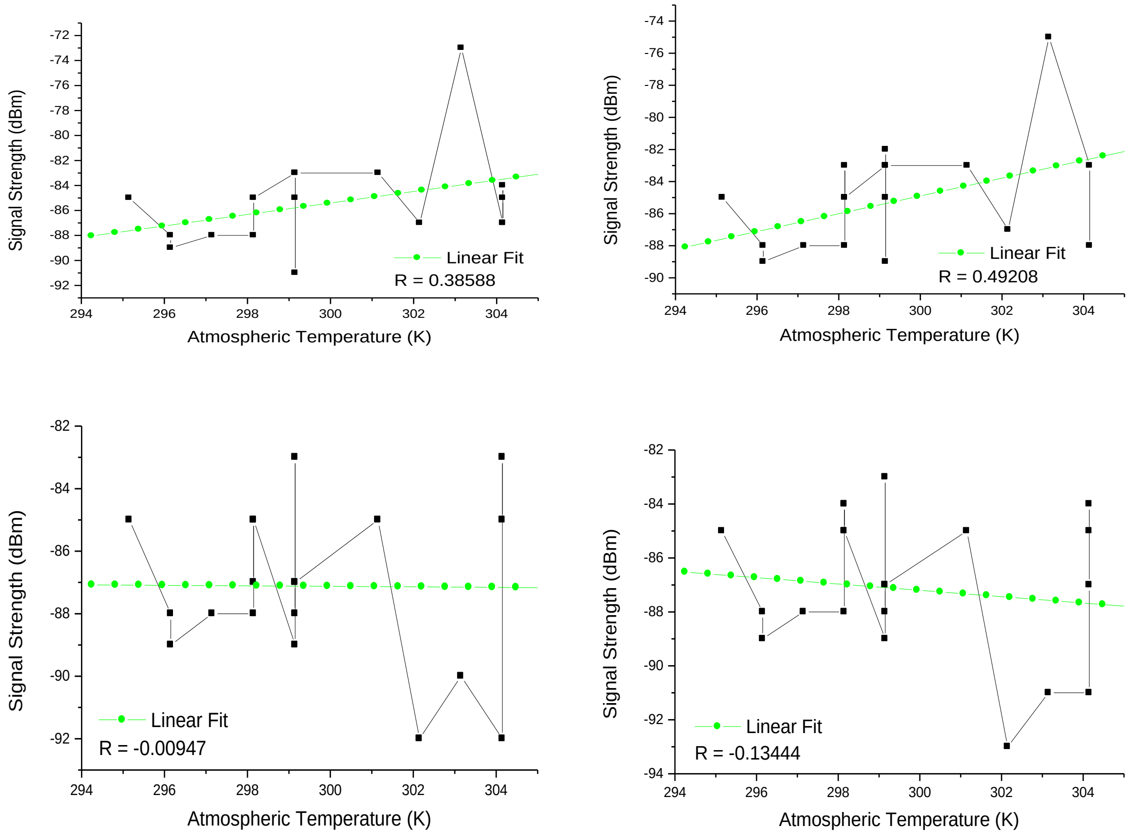
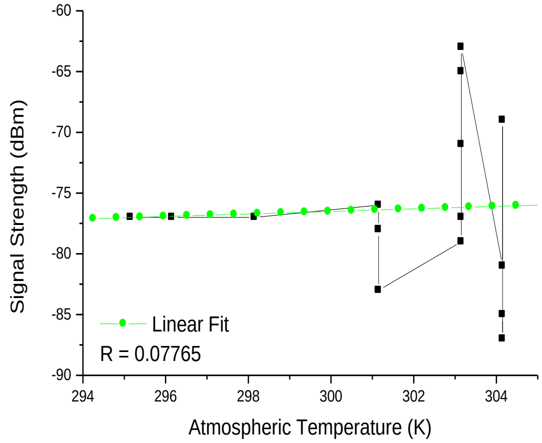
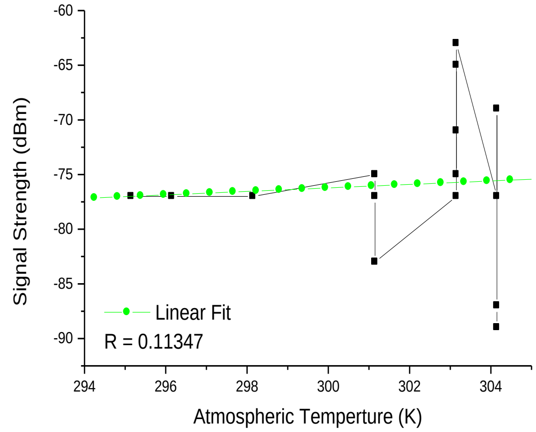
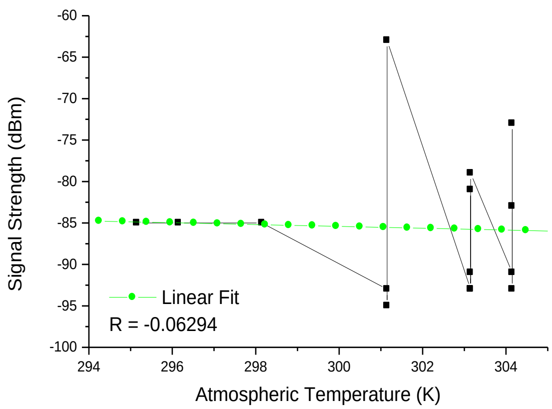
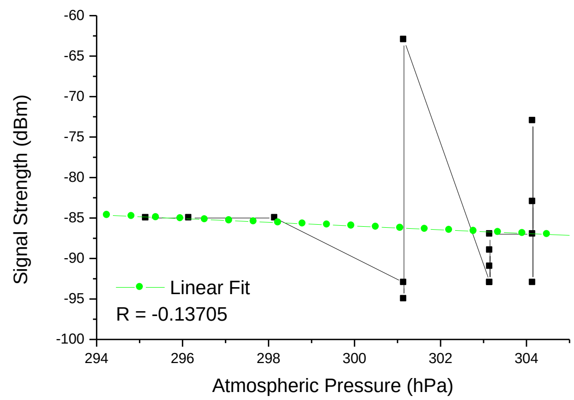


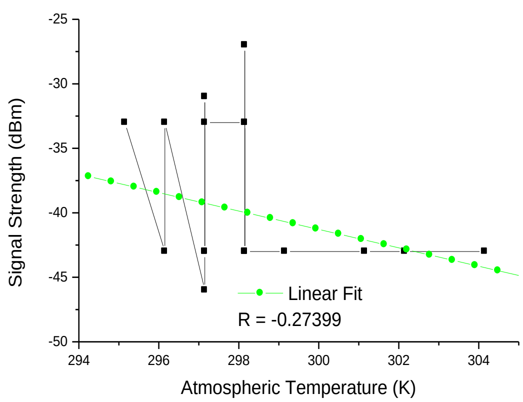
Fig.4: Signal strength VS Atmospheric Temperature in Some Cells in Warri

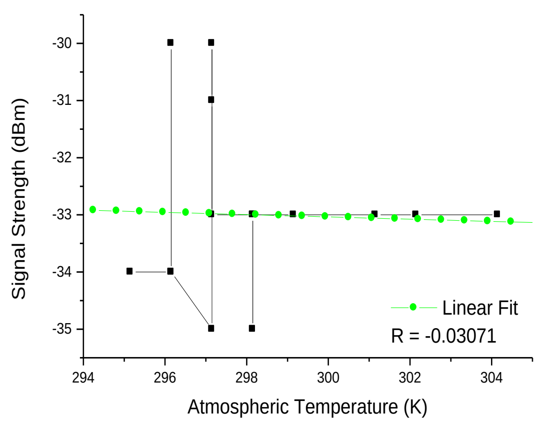

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.07765

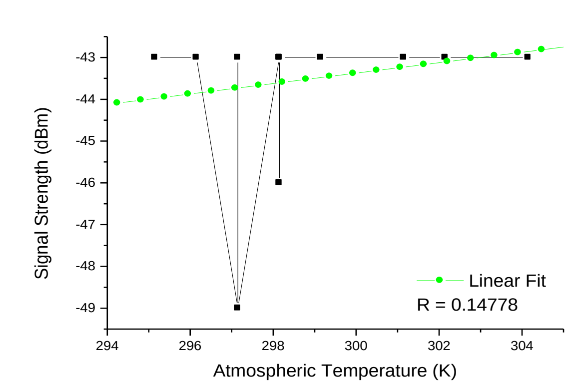

Signal Strength (dBm)
Atmospheric Temperture (K)
Linear Fit
R = 0.11347

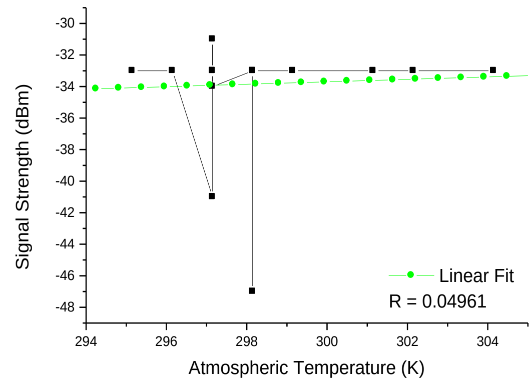

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.06294

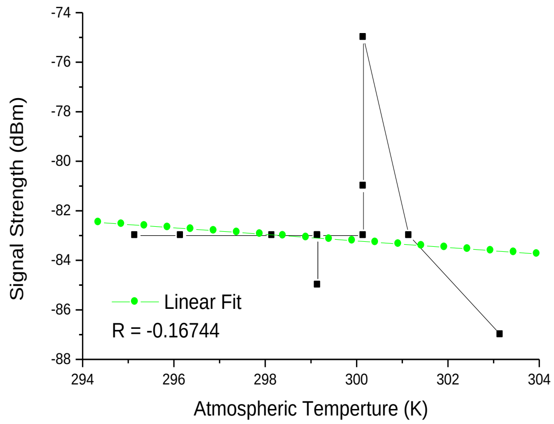

Signal Strength (dBm)
Atmospheric Pressure (hPa)
Linear Fit
R = -0.13705

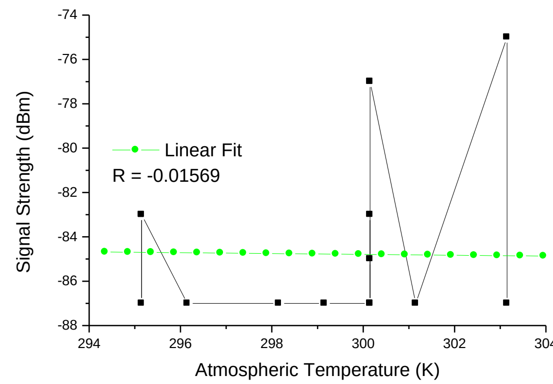

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.27399

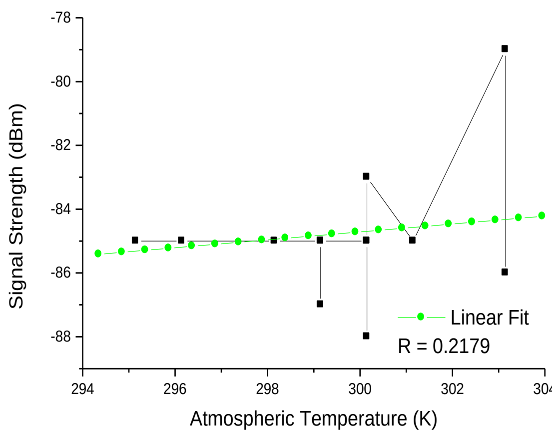

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.03071

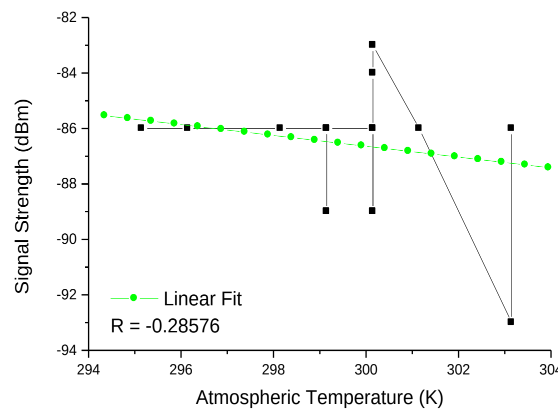

Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.14778


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.04961


Signal Strength (dBm)
Atmospheric Temperture (K)
Linear Fit
R = -0.16744


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.01569


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = 0.2179


Signal Strength (dBm)
Atmospheric Temperature (K)
Linear Fit
R = -0.28576

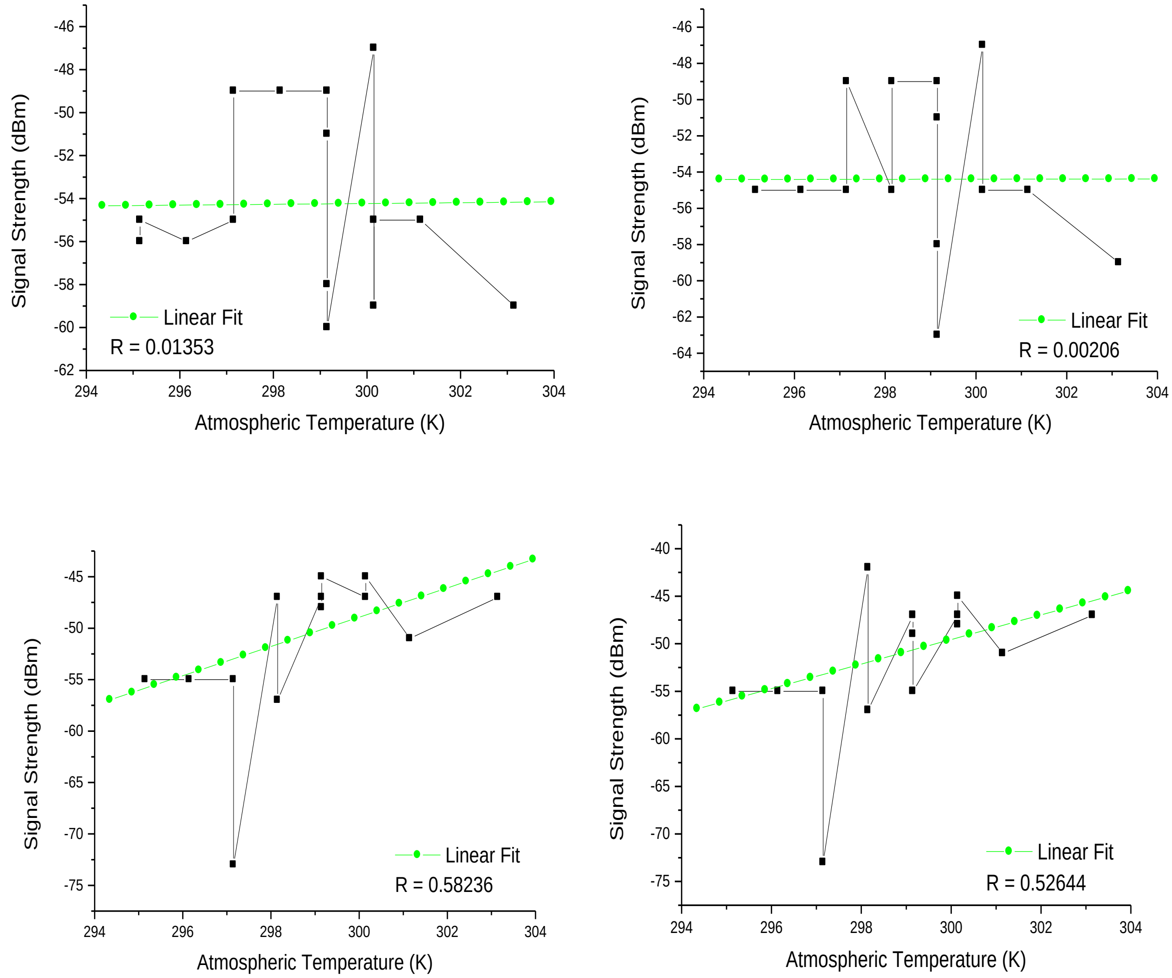


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Fig.5 Signal strength VS Atmospheric Temperature in Some Cells in Yenagoa

Table 1 shows the summary of results, that is, the average R-value in each location, the average standard deviation of R-value in each location, the overall average R-value and the overall average standard deviation of R-values.

Table 1: Summary of results

Location	Average R-value	Average standard deviation of R-values	Overall average R-value	Overall average standard deviation of R-values
Calabar	-0.187031	0.241096	-0.177145	0.225503
Uyo	-0.389073	0.236483		
Portharcourt	-0.149762	0.255211		
Warri	-0.153706	0.248468		
Yenagoa	-0.006155	0.146259		

Overall, there was a slight positive linear relationship between signal strength and atmospheric humidity since the overall average R-value is -0.177145 and the overall average standard deviation of R-values is 0.225503.

The discrepancies in the results above were basically due to topological differences between the locations of the base and mobile stations where measurements were taken, since the communication between the base station transmitter and the mobile station receiver is mainly point-to-point or line-of-sight. This is in agreement with the work of Dalip & Kumar (2014). They said at higher height levels, GSM receivers provide better signal strength because at higher heights fewer obstacles interfere. In locations or stations of lowland with the base station on a higher plane or highland; radio refractivity and signals strength showed a positive correlation. In other words, increase in radio refractivity enhanced signal strength to some extent. However in locations situated on higher plane or highland with the base stations on a lowland or lower plane; radio refractivity was to some degree detrimental to the signal strength.

By and large, wind speed and direction not considered in this research could also have influenced discrepancies in result as well, since water vapour (the major substance) in the atmosphere that contributes to the variation in the density of the vertical layers of the atmospheric channel can be transported and concentrated or de-concentrated in any region of the atmosphere at a specific place and time and could influence radio refraction and invariably signal strength. More so, radio waves double as particles, hence the direction of this particles could still be influenced by the wind, since the received signal strength by an antenna is proportional to the amount of the particles that fall on it. To buttress the before-mentioned claim, Chima, *et al.* (2018) observed in their research that wind may not have a direct effect on propagating signal but it has an effect on the refracting (bending) capability of the wave, thus a slight variation in the wind can cause a considerable effect on the received signal strength. Meng, *et al.* (2009) experimentally showed that wind and rain can impose an additional attenuation on signal propagating within an environment. This additional attenuation increases as the strength of the wind and rain and frequency increase. More so, they observed that there is a large power of variation and deep fades in received signal as the strength of the wind and the intensity of the rain increases. Zafar, *et al.* (2019) said that strong wind speed and rain could contribute to the attenuation of radio signals. In their analysis, results showed that between the wet and dry season, the former season showed a significant stronger negative correlation between received signal strength and wind speed. Zafar, *et al.* (2019) in a further analysis suggested that a fresh breeze had brought high rain water due to high rain rate and caused the absorption and scattering of radio signals which increased the attenuation of received signal strength. However, they forwarded that wind speed without rain and a decrease in humidity during the dry season was found to increase the received signal strength. More so, they said, refraction of radio waves was found not to have a negative impact on signal strength in the dry season, but increased received signal strength. Joseph & Oku (2016) hypothesised that at uniform atmospheric temperature, relative humidity and atmospheric pressure, wind has a marked effect on radio signal strength. They said, the signal received is better if the wind propagates in a similar path as the radio waves, but is worse in the contrary direction.

Also at UHF, radio propagation tends to be more of line of sight, however not all the time (Rappaport, 1996: Wayne, 2001). Hence, position away from the transmitter and antenna height may have been responsible for variations in result. This is owed to the fact that in a terrestrial environment, signals undergo multiple reflections and as such reach the receiver through a number of different paths. The received signal may superpose constructively or destructively depending on the relative phases of the signal. If the receiver is moved, the situation changes and the overall received signal are found to vary with position. Receivers of mobile communication devices are subject to this kind of effect termed Rayleigh fading. Also the height of antenna has an effect on received signal strength. Increase in the height of an antenna betters the received signal strength, however dependent upon the plane between the receiver and transmitter. In general, the positioning of an antenna system higher in the sky enhances communication capabilities and reduces the chances of RF exposure and electromagnetic interference. This corroborates finding from Anyasi & Uzairue (2014). The duo submitted that the location of a mobile station has an effect on received signal strength in addition to antenna factors or properties.

More so, the directivity or radiation pattern of the antenna could also have influenced variation in the results above. This is due to the fact that not all the antennas are omni-directional, some are directional [e.g. uni-directional, bi-directional etc.], depending on the intention of the transmission (Rappaport, 1996: Wayne, 2001). Thus, the position of the mobile station may affect the strength of signal received.

Seasonal changes in weather could also have been responsible for the uncertainties in the results obtained, since the research was conducted throughout the year 2019. In some locations (Calabar and Bayelsa) the research was conducted predominantly in the wet season while in some other locations (Uyo, Portharcourt and Warri) it was during the dry and wet seasons.

Effect of Atmospheric temperature on Received Signal strength

In general, the average correlation result showed that there was a negative linear relationship between signal strength and atmospheric temperature. This may be owed to the fact that during the day where there is a gradual rise in temperature from sunrise through noon, the atmosphere is inundated with particles of solar waves and these solar particles could interfere with the radio particles propagating through the atmospheric channel.

The above proposition is in line with the findings Luomala & Hakala (2015). They said changes in weather condition affects received signal strength and variation in signal strength could best be explained by variation in atmospheric temperature. They concluded that in general, temperature seem to have a negative influence on signal strength, while humidity may have some effect on it, particularly below 0^oC. In the same vein, Michael (2013) said that with increase in ground temperature, there is a relative increase in path loss of the radio wave propagation and the inconsistencies in the path loss values are due to effect of other climatic and environmental factors that can cause distortion of the radio wave. Sabu, *et al.* (2017) in a near similar tone, said that the graphical relationship between received signal strength for cellular communication and atmospheric temperature showed a weak direct correlation when average readings were taken hourly in a day, contrary to the inverse linear relationship expected. However, a strong inverse relationship between received signal strength and atmospheric temperature was obtained when hourly measurements were taken for different days which were similar and consecutive. Felix *et al.* (2017) shear the same conclusion. They said correlations between signal strength and atmospheric temperature for the two days their research was carried out were -0.42369 and -0.51878 respectively, that is, atmospheric temperature is inversely proportional to signal strength. Valerie (2020) on the same page said that atmospheric temperature is inversely proportional to strength of VHF radio waves.

However on a contrary submission, Segun, *et al.* (2013) said that as the air temperature increases, relative humidity decreases, hence a proportional decrease in UHF path loss, while the received signal strength shows a proportional increase. Thus, they added, atmospheric temperature (control factor) and relative humidity have significant influence on UHF signal propagation. They concluded that a sharp increase in received signal strength was observed when atmospheric temperature rises while increase in relative humidity resulted in increase in signal path loss. Ofure, *et al.* (2017) opined that surface atmospheric temperature and GSM received signal strength have a positive correlation values ranging from 0.57 to 0.88. And, Osahenvemwen & Omatahunde (2018) said that atmospheric temperature had 0.50 positive correlation with GSM signal strength.

None the less, in an inconclusive light, Chima, *et al.* (2018) said that atmospheric temperature has a significant effect on radio signal propagation in the troposphere and the condition of the tropospheric channel at a particular time determines the nature of the effect of temperature on UHF radio signal propagation that is, temperature inversion or usual state of the troposphere. And, Dalip & Kumar (2014) said that atmospheric temperature affect signal strength values of GSM.

4.0 Conclusion

Overall, atmospheric temperature exhibited a generally inverse relationship with mobile phone communication signal strength. However, variations were observed across different locations and cell sites, likely due to factors such as differences in topography, antenna characteristics, seasonal changes, and the relative positioning and distance between transmitters and receivers. These findings are of significant relevance to radio scientists and communication engineers, as they provide valuable insights for the design, optimization, and deployment of more effective and reliable wireless communication systems that operate through the atmospheric channel.

Author Contributions
Joseph Amajama conceptualized the study, designed the experimental methodology, and supervised the overall project. He led data collection and performed analysis related to atmospheric temperature variations. Ahmed Tunde Ibrahim conducted the literature review, developed data analysis models, and carried out statistical analyses. He also contributed to interpreting the results and drafting the manuscript. Julius Ushie Akwagiobe assisted with the experimental setup and data acquisition, contributed to the discussion of findings, and reviewed the manuscript for technical accuracy and clarity. All authors have read and approved the final manuscript.

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