Effect of Humidity on Tropospheric Received Signal Strength (RSS) in Ultra-High Frequency (UHF) Band

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Abstract. The variation of weather conditions can affect the performance and quality of a communication system and sensor network. Therefore, it is vital to explore the factors that influence the quality of the radio signal to adapt to weather conditions. This paper describes the tropospheric effect of the meteorological parameter (humidity) for Ultra High Frequency (UHF) band at KUSZA Observatory (KO), UniSZA, Terengganu. Received signal strength (RSS) and humidity were collected using spectrum analyser and weather station respectively for 24 hours in a rainy and a sunny day. Statistical analysis was used to determine the relationship between humidity and RSS. The results show that variation in humidity conditions give RSS with negative correlations in both conditions. The correlation of the RSS and humidity at both observation days ($r_r=\text{correlation of frequencies on rainy day}$, $r_s=\text{correlation of frequencies on sunny day}$) for frequency 382.5 MHz ($r_r=-0.423$, $r_s=-0.382$), while for frequency 945 MHz ($r_r=-0.512$, $r_s=-0.631$), frequency 1867.5 MHz ($r_r=-0.588$, $r_s=-0.669$) and frequency 2160 MHz ($r_r=-0.509$, $r_s=-0.805$). This study will benefit the active spectrum users such as mobile telecommunications, wireless signal, satellite transmission TV and radio astronomy expert in the management of radio frequency interference (RFI) for the observation and monitoring of the radio signal transmission.

Keywords: Weather, UHF, signal, radio wave, SmartPLS

1. Introduction
Radio waves very widely used in modern technology, especially in telecommunications. In communication, the propagation of electromagnetic waves influenced by the permeability and permittivity of a medium between transmitter and receiver[1]. Most radio transmission occurs in the troposphere, at the lower layers of the atmosphere near the Earth’s surface[2]. In this vein, the radio wave can propagate in many different physical mechanisms such as free-space propagation or line-of-sight propagation, reflection, transmission, diffraction, scattering and wave[3]–[5]. Ultra-High Frequency (UHF) is the part of the radio waves from the electromagnetic spectrum, which frequencies are from 300 MHz to 3000 MHz[6].
Changes in the environment can affect radio wave propagation which leads to loss of the signal and the influence of network quality metrics[4], [7]–[9]. The quality of the signal depends on the weather conditions. Humidity is one of the elements of the atmosphere; therefore, it plays an essential role in the propagation of radio signals. Malaysia has classified as an equatorial climate, a country that is hot and humid all year round. Humidity varies more throughout the day than it does annually. The relative humidity in Malaysia is high, ranging from 70 to 90%[10]–[12]. Humidity is the amount of water vapour, gases, water, air, and usually cannot be seen. Relative humidity (RH) defines, in per cent, how much water vapour (AH) in the air relative to the maximum amount of water vapor at the same temperature and pressure. Relative humidity of the air is 100% saturated[13].

The effect of weather factors on the strength of radio signals in communication have been explored in several previous studies. However, no definite decision has been reached so far. Some studies report that the humidity does not affect the signal strength, while others say the weather affects the signal strength is positive while others claimed that the negative relationship. Moreover, research methods, radios and multi-platform used and explored different weather variables between research, sometimes leading to conflicting results and conclusions. Hence, there definitively seems to be a need for further studies. In Malaysia, there have been few studies on the impact of environment on the radio signals have been done so far, but the humidity has not been reported yet[4], [8], [14]–[15]. Therefore, more data are required to confirm the effect of weather especially humidity on radio waves. To find out the role of humidity on this variation, we study how signal strength correlates with relative humidity. In this study, radio signal strength (RSS) and relative humidity (RH) has been observed at KUSZA Observatory (KO) to investigate their relationship.

2 Literature Review

Several studies have explored the effect of humidity on radio waves propagation in various frequency [13], [16]–[19]. The most recent work in this area centres around the tropical weather such as Nigeria. [16]investigated the impact of air temperature, atmospheric pressure and the relative humidity on RSS from EBS Television, transmitting at 743.25 MHz UHFusing the Digital Community-Access/Cable Television (CATV) analyser respectively in South Nigeria. The results showed that the signal strength and these meteorological variables were having correlation values of -0.94, -0.92 and -0.96 for the air temperature, atmospheric pressure and the relative humidity. Similar work was also carried out by[18] studied the impact of the weather components: atmospheric temperature, pressure, humidity and wind on radio signals. The radio signal strength was measured from Cross River State Broadcasting Co-operation (CRBC), (4057'54.7"N, 8019'43.7"E) transmitted at 35mDB and 519.25 MHz (UHF) in a residence along Etta-abgor, Calabar (4057'31.7"N, 8020'49.7"E). Their results also indicated that radio signal strength is inversely proportional to atmospheric temperature, pressure and humidity with The correlation of the signal strength and atmospheric temperature, pressure and humidity were respectively r = -0.94, -0.99and -0.93.[20]in their work also proved a significant relationship with negative correlation between humidity and signal at frequency 2.4 GHz. A comparison of different result is given in [13]where the author claims that signal strength gives positive correlation with relative humidity and the ambient temperature (0.29 and 0.39). They concentrated on the study of the relationship between the signal strength of the WE FM, radio station, Abuja with weather factors (temperature and relative humidity) which operates at the frequency of 106.3 MHz.

3 Methodology/Materials

To determine the impact of the humidity on RSS, the methodology for this study was outlined in Figure1. The observation was carried out in KUSZA Observatory (KO) which is located in Merang, Terengganu (5° 32' 10" N and 102° 56' 55" E). This observatory was chosen because it is one of the astronomical observations in East Coast Malaysia with possible low profile Radio Frequency Interference (RFI). It also has tropical climate and located on a hill near the beach. RSS measurements obtained at each minute in KO for over 24 hours and at the same time, the RH was recorded to study the effect of weather on the radio signal.
Figure 1. The flow chart of the process followed in Methodology.

RSS measurements were made using spectrum analyser (KEYSIGHT N9915A 9GHz, USA) which covers frequency up to 9 GHz with a resolution bandwidth 180kHz to detect the radio signal. The weather station (Vantage Pro 2, USA) was used to record the humidity effect. Both RSS and RH were observed on 3rd February 2016 (rainy day) and 31st of May 2016 (sunny day) which is in the hot season for the East Coast of Peninsular Malaysia due to Northeast monsoon. The instrument setup was illustrated in Figure 2. It was adapted from [8], [15], [21] which discone antenna was used in this study.

Figure 2. The instruments setup for observation work.

Discone antenna was used as a solution to identify RFI near the site. According to [22], discone antenna suitable for UHF frequencies, such as applications that has used in telecommunications, wireless and internet. It is also suitable for assessing optimising RFI 0 - around 2800 MHz. Discone antenna was connected to Low Noise Amplifier (LNA) and spectrum analyser. The sensitivity of an observation in radioastronomy can be defined in terms of the smallest power level change $\Delta P$ in the power level $P$ at the radiometer input that can be detected and measured (Recommendation ITU-R RA.769-2 (2003))[23]. The sensitivity equation is:
\[ \frac{\Delta P}{P} = \frac{1}{\sqrt{\Delta f_0 t}} \]  

(1)

where:

- \( P \) and \( \Delta P \): power spectral density of the noise
- \( \Delta f_0 \): bandwidth
- \( t \): integration time. \( P \) and \( \Delta P \) in equation (1) can be expressed in temperature units through the Boltzmann’s constant, \( k \):

This raw data was sent to a server to be further processed and analysed. The collected raw data was downloaded from the server to be further processed and analysed. We used Microsoft excel and SPSS for processing, analysing and presenting data. Both RSS data and weather data (RH) were averaged over 24 hours. There were 1440 RSS samples in 24 hours for each frequency. RH data was measured once in a minute; thus there were 60 samples in an hour. Statistical analysis was performed to determine the correlation between RSS and humidity using Spearman correlation formula [24]:

\[ \rho = \text{Spearman rank correlation} \]

\[ \rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \]  

(2)

\( \rho \) = Spearman rank correlation
\( d_i \) = the difference between the ranks of corresponding values \( X_i \) and \( Y_i \)
\( n \) = number of value in each data set

In our case, since data do not follow a normal distribution at all, non-parametric tests must be used. We chose the Spearman’s rank correlation in order to determine whether there is any relation between pairs of data. We have used here the experience learnt from previous experimental work by [20].

4 Results and Findings

These results were obtained using the methods described in this work. Figure 3 shows the average of RSS (dBm) versus frequency (MHz) for UHF band which identified at KO on 3rd of February 2016 and 31st May 2016. Based on the graph, it was found that there were four peaks of RSS at frequency 382.5 MHz, 945 MHz, 1867.5 MHz and 2160 MHz. All peaks are in UHF band and according to MCMC (2016) [25] mostly are come from digital trunked radio and cellular mobile services. Table 1 shows the frequencies of them and its sources. The UHF band covers radio astronomical sources including Deuterium (DI), Hydrogen (HI) and Hydroxyl (OH).
Figure 3. Frequency (UHF) identified at KO on 3rd February 2016 and 31st May 2016.

Table 1. Frequency identified and its sources.

| Frequency/ MHz | Sources                        |
|----------------|--------------------------------|
| 382.5          | Digital trunked radio          |
| 945            | Mobile phone- (Celcom)         |
| 1867.5         | Mobile phone (GSM 1800)- Digi  |
| 382.5          | Mobile phone(IMT 2000)- Digi   |

Figure 4 – Figure 5 show the graphical relationships between radio signal strength and relative humidity for four peaks respectively. Generally, signal strength decreased with increase relative humidity at all peaks. On the observation day, humidity ranging from 67% to 83% at constant pressure (569.3 Ba) with range of rain rate 0 -110.70mm/s. The decrease RSS is assumed to be due to humidity and rain effect.
Figure 4. Relationship between RSS (dBm) and relative humidity (%) at 3$^{rd}$ February 2016 (Rainy Day).
In order to confirm the relationship mathematically, we performed statistical analysis using Spearman Rank correlation. Table 2 shows the coefficient of correlation, $r$ between PL-Humidity on both conditions. As can be seen, all four frequencies show the high negative-correlation except frequency of Peak I is the lowest. Thus, the higher the humidity, the lower the signal strength. Therefore, the signal strength is inversely proportional to the relative humidity, at a constant pressure.

**Table 2. Summary of The Coefficient of Correlation, $r$ between PL-Humidity.**

| Observation Date | Coefficient of | M/ (Range) | SD | Coefficient of correlations |
|------------------|----------------|------------|----|-----------------------------|
| 3rd February 2016 (rainy day) | Peak Frequency/ |  |  |  |
| 31st May 2016 (sunny day) |  |  |  |  |
Moreover, the increase in relative humidity affects the RSS negatively. This phenomenon is caused by particles of atmospheric water content can cause diffraction, reflection and scattering of radio waves and therefore attenuation. This indicates that water in liquid or solid state on top of the nodes or antennas may cause unpredictable changes in signal strength. Therefore, humidity may have indirect effects on RSSI variation through condensation (RH ≈ 100%) and freezing of water or melting of ice/snow (T ≈ 0°C)[26]. Our findings confirm the previous results in the literature of the effects of humidity on radio signals. The result obtained agreed with previous work carried out by [16]–[18], [27].

5 Conclusion
Our findings confirm the previous results in the literature of the effects of humidity on UHF band in tropics. The findings indicate that there is a relationship between radio signals with the humidity. As we can see from the graph plotted, the signal strength decreased with increase in relative humidity. It can be concluded that almost all of the graph patterns showed similar trends. From statistical analysis, the correlation of the radio signal strength and humidity at 3rd February 2016 and 31st May 2016 for frequency 382.5 MHz ($r_\text{t}=-0.423$, $r_\text{s}=-0.382$), while for frequency 945 MHz ($r_\text{t}=-0.512$, $r_\text{s}=-0.631$), frequency 1867.5 MHz ($r_\text{t}=-0.558$, $r_\text{s}=-0.669$) and frequency 2160 MHz ($r_\text{t}=-0.509$, $r_\text{s}=-0.805$)

In conclusion, it was observed from the KO, that the humidity affected the signal strength with negative correlations. The findings will benefit radio wave propagation research field (space science, wireless communication, satellite, antenna, mobile communication, and also electromagnetic radiation (EMR) research for health. In our future studies, we intend to carry out more experiments and lab measurements to study the effects of temperature and humidity on radio link quality in a controlled environment.

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