Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Throughput in Wireless LAN: Implications of Some Meteorological Variables in Undulating Landscape

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ARTICLE INFORMATION

Article history:
Received 21 Nov, 2020
Revised 14 Dec, 2020
Accepted 15 Dec, 2020
Available online 30 Dec, 2020

Keywords:
WLAN
Landscape
Signal propagation
Network performance
Quality of service

ABSTRACT

Generally, meteorological variables such as relative humidity, temperature and mean sea level pressure vary from place to place and it has been shown that these natural conditions may exert significant impact on wireless communication. In traditional settings, these variables are not critically analyzed when deploying wireless networks. This paper presents an account on the study of the throughput of wireless local area networks (WLANs) using an extensive campus network located in an undulating topography in a tropical climate in Iyamho, Edo North, South-South of Nigeria. The undulating topography, temperature, relative humidity and mean sea level pressure were evaluated in order to establish their interactions with WLANs. The result shows that the Wi-Fi signals were more affected by distance than by temperature, relative humidity and mean sea level pressure respectively in the absence of other obstacles that might have introduced some interference along the path of the radio signals. Nevertheless, this study confirmed that the throughput is affected by temperature and relative humidity respectively and that along undulating lowlands optimal performances were recorded under lower temperatures, lower relative humidity and higher mean sea level pressure.

1. INTRODUCTION

In 1997 the Institute of Electrical and Electronics Engineers (IEEE) released their first model standard for wireless local area networks (WLAN) codenamed IEEE 802.11. The premier model operated at the 2.4 GHz with data transmission rates between 1 and 2 Mbps. It was designed to use either the frequency hopping spread spectrum (FHSS) or the direct sequence spread spectrum (DSSS). Two years later, the IEEE 802.11b, which operates at the same frequency but with an improved data transfer rate of 11 Mbps, was released. IEEE 802.11a was developed thereafter to extend the data rates and frequency to 54 Mbps and 5 GHz respectively (Abd-Elrahman, 2018). Consequent upon the change in frequency, interoperability of the 802.11a standard with older equipment was forfeited. In response to backward compatibility issue, the IEEE 802.11g was developed, which also had a theoretical data transmission rate of 54 Mbps at 2.4 GHz. In September 2003, a new working group began the development of the IEEE 802.11n specification aimed at attaining a transfer rate of 100 Mbps. The working procedures were practically the same for all the previous specifications, however, there were modifications in the modulation, physical layer field specifications, duration of slot and interframe space times. Development of the 802.11 standard continues to evolve as gaps in previous specifications are identified as well as to cater for new socioeconomic or operational demand or requirement.

Till date, several studies have been conducted in respect of the IEEE 802.11 standard (Carlos *et al.,* 2010; Shafiq *et al.,* 2013; Gajanan and Deshmukh, 2013; Momodu and Akpamu, 2014; Dahunsi and Kolawole, 2015; Kadioglu *et al.,* 2015; Ukhurebor *et al.,* 2015; Lawal *et al.,* 2016; Alabar *et al.,* 2017; Ukhurebor *et al.,* 2017; Abd-Elrahman, 2018; Dawit and Adem, 2018; Olayinka *et al.,* 2019). Majority of the studies are aimed at studying various aspects of the specification such as throughput/efficiency, coverage aspects, limitations, hidden terminal problem, etc. A common finding among several studies is their restriction to a single cell.

Wireless signals are propagated over channels that extend to a certain distance. Depending on technology for signal propagation, the signal could widely propagate or be limited to a certain coverage area. Understanding the propagation characteristics for a proposed wireless-LAN or an existing WLAN is important in either deploying new network or improving the existing infrastructure. The ability to determine the extent of coverage and stability of a wireless network prior to actual installation of wireless devices will help ensure that connectivity across the intended user areas is sustainable. Thus, the strength, range and coverage area of a radio is strongly affected by its positioning in reference to its environment (Iskander and Yun, 2002). Signal strength may be affected by physical phenomena. These phenomena include reflection, refraction, diffraction, scattering and absorption (Durgin et al, 1998; Hucaby, 2007). Distortion could be constructive or destructive (i.e., it may lead to a remarkable improvement in signal quality or loss of signal). Also, signal strength can be affected in a WLAN by various forms of obstruction such as walls, furniture, etc. The loss of signal in this case will depend on the material used in the construction of the various items on the path of signals.

Quality of service plays a major role in the performance of wireless networks and the degree to which a wireless network could be rated provides network engineers with the assurance of their service to their clients (Ukhurebor *et al.,* 2015; Lawal *et al.,* 2016; Ukhurebor *et al.,* 2017; Olayinka *et al.,* 2019). Consequent upon the fact that atmospheric/meteorological conditions vary from place to place, it therefore follows that there is a possibility that such conditions may exert influence on communication signals especially wireless signals (Ukhurebor and Umukoro, 2018; Ukhurebor *et al.,* 2019; Ukhurebor and Azi, 2019).

This study thus seeks to investigate the relationship between those factors listed above as well as the quality of the signal transmitted that are received over specific distances.

2. MATERIALS AND METHODS

The direct experimental approach was employed because it does avail the observation and collection of firsthand data that reflects reality especially with the prevailing anomalous weather conditions caused by climate change. Specific pieces of hardware including measuring instruments, and relevant software were employed in the design and implementation of the various experiments. The procedures followed are detailed in this section.

2.1. Hardware and Software

The pieces of hardware employed were:

i. Three (3) units of Ubiquiti Bullet AC BulletAC-IP67 radios (2.4/5 GHz spectrum rated at 300 Mbps, hi-power 2*2 multi-input multi-output (MIMO) time division multiple access (TDMA) AirMAX technology, Power-supply: 24 V, 1 A POE).
ii. Omni-directional antennae
iii. Cat-6 shielded twisted pair cable (40 m crimped cables)
iv. Three computer systems with same specifications: HP Elitebook 820, intel core i7 CPU @ 2.50 GHZ, running Microsoft Windows 10 professional operating system.
v. Tecno Droidpad 10D tablet installed with Android 7.0

The following software were used:

i. Wireshark (Network packet analyzer)
ii. Enterprise network simulation platform (eNSP)
iii. Microsoft Visio 2010.
iv. IBM SPSS v.24
v. Ubiquiti Unifi controller software
vi. Acrylic Wi-Fi heatmaps

2.2. Geolocation and Meteorological Instruments

The meteorological instruments employed were:

i. Clime Barometer
ii. AcuRite Wireless Indoor/Outdoor Thermometer with Humidity Sensor
iii. Mobile GPS coordinate, and Elevation apps

2.3. Location of Study

This study was conducted in the campus of the fast-growing model university, Edo University Iyamho located in the small community Iyamho in Etsako West of Edo State, South-South, Nigeria. The community has approximately 3500 inhabitants who are mostly rural dwellers. Figure 1 shows the aerial view of the small semi-urban community. In the area of communication, there is a growing trend in the deployment of mobile network base stations for voice communication and Internet access. With respect of stable power supply to drive vital socioeconomic activities, Iyamho, unlike most communities in Southern Nigeria, enjoys a very stable electric power supply at an average of about 22 hours per day. Geographically, Iyamho is located on Latitude 7.07°N and Longitude 6.27°E and with an average elevation of 188 m above sea level (Ukhurebor et al., 2018). Like other tropical areas of Southern Nigeria, Iyamho enjoys two seasons categorized as rainy and dry seasons. The rainy seasons start from March and terminate around December. The community also enjoys a Savannah vegetation. Its topography is marked with both undulating and table lands.

Figure 1: Aerial view of Edo University Iyamho and surrounding community [Source: Google Earth]

2.4. Design of Experiment

The following methods were employed in this study:

i. Physical site survey
ii. Network modeling and instrumentation
iii. Point to point measurements of relative humidity, temperatures, atmospheric pressure, distance and quality of service
iv. Data analysis

2.4.1. Physical site survey

In this study the physical survey identified and defined the radio frequency (RF) coverage areas, tested for RF interference and determined the appropriate placement of wireless stations. No substitute was made for measuring real-world interference, blockage and 'Received Signal Strength Indicator' (RSSI) at the sites because in accordance with best practices only on-site measurements and surveys can give the true picture. The site survey was conducted at three levels using the Acrylic Heatmaps survey tool. Three stages of survey were done:

i. Active survey: the first phase was done with temporary access points prior to the deployment of the experimental radios. Factors checked include: latency, bandwidth across the mapped areas, and packet losses. The second phase was done with the designated radios.
ii. Passive survey. The following elements were accessed through passive survey: cell density, data rates, RSSI, SNR, Retries rate, channel overlap, detail grid, and channel coverage of the three radios (access points).
iii. RF spectrum survey

2.4.2. Localization

The experiment involved three locations and the model for experiment is shown in Figure 2. The locations were marked as follows:

i. Primary station (the base station) located at the Faculty of Science of Edo University Iyamho, with an elevation of 45 m above sea level.
ii. Remote station 1(REMOTE1) is the control station and is located at the Faculty of Law. The control station has an elevation of 188 m above sea level.
iii. The Remote station 2 (REMOTE2)- the observation radio, deployed in an undulating landscape within the Faculty of Engineering of Edo University Iyamho, with an elevation of 88m above the sea level.

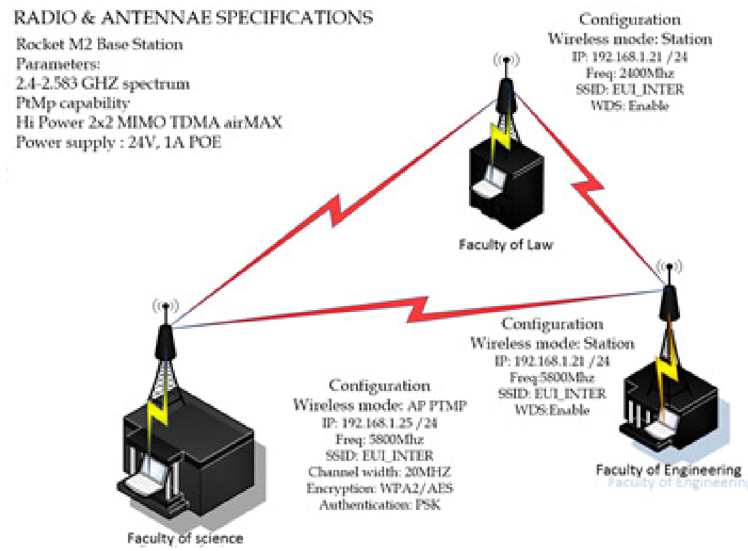

Figure 2: Design of the experiment

2.5. Method of Data Collection

Data collection was done using Wireshark to monitor the connectivity between the base station and the two remote stations located at approximately 300 m away from the base station. The base station was directly connected to a HP Elitebook, from where packets were sent to the two remote stations over a period of 45 work days divided into 9 weeks of 5 days each. Only work days (Monday-Friday) were considered. Discrete instances of nine (9) hours in each day from 9am to 6pm during the rainy months of July and August, were taken as daily operational period for which the said meteorological variables and packet transmission success/failure rates were taken. The failure and success rates at the base station and the two remote stations were recorded under the prevailing temperatures, relative humidity and atmospheric pressure using the weather equipment hung against the wall of each faculty building. The recorded atmospheric/surface pressure readings were reduced to the mean sea level pressure (MSLP) so as to make the readings comparable by cancelling out altitude-dependent differences. The reduction to the mean sea level was based on information on the atmospheric/surface pressure (P), altitude (h) and temperature (T) data obtained. Equation (1) was used for the reduction to the mean sea level (Ji *et al.*, 2018):

$$P_{(mslp)} = P \times \left[1 - \frac{0.0065 \times h}{T + 0.0065 \times h \times 273.15}\right]^{-5.257} = 0.03414 \times \frac{Ph}{(273.15 + T)} \quad (1)$$

2.6. Network Design

Prior to the actual deployment of radios for the live experiment, a modelling and simulation using the following tools was conducted:

i. Huawei enterprise network simulation platform (eNSP)
ii. Huawei AP6510DN series wireless 2.4GHZ radios,
iii. Personal computer

Figure 3 shows the model of the class C network used. The network address was 192.168.1.0/24. Each of the three stations was directly connected to HP Elitebook of same specification. The essence of using same computer specification across the three locations was to ensure that no extraneous element that had the tendency of impeding on performance was introduced into the network. Following the modelling, a ping of size 64k was sent from the base station (BASE) to the remote stations (REMOTE1 and REMOTE2) respectively over same period. Wireshark was used to capture the packets sent and the packets received on the systems.

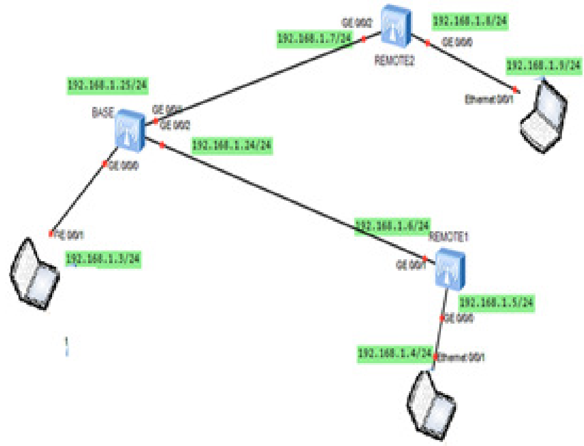

Figure 3: Network topology

2.7. Computing Throughput in the WLAN

Throughput is measure of number of packets successfully delivered in a network. It is measured in terms of packets/second (Ngala, 2012). According to Ochang and Irving (2016), throughput is a useful parameter in determination of the efficiency and/or performance of a network having regard to the fact that throughput directly affects network performance. Computation of throughput was done using Equation (2):

$$TP = \frac{\sum_i Packet\ Deliverd}{\sum_i Packet\ Arrival - Packet\ Start\ time} \quad (2)$$

3. RESULTS AND DISCUSSION

3.1. Temperature and Throughput

Figures 4-6 show the clustered and line charts of the relationship between temperature and throughputs at stations 1 and 2. From the charts in Figure 5 and 6, with an exponential smoothing factor introduced into both variables, it is evident that there was an upward adjustment in the throughput of the signals as the temperature decreased. This finding contrasts with earlier findings by Ukhurebor et al. (2019) wherein they had recorded a direct relationship between signal strength and temperature in VHF and UHF signals under similar conditions. However, it is instructive to note that the radios in this study operate within a higher frequency spectrum (2.4 GHz) as against the VHF and UHF transmitters that operate at 189.25 and 743.25 MHz respectively.

3.2. Relative Humidity and Throughput

In Figure 7-8, exponential smoothing was applied to the trend graphs to realize linearity in the trend as to how relative humidity fares with the throughput. There appears to be a slight improvement though not so consistent over time in the control station when the relative humidity adjusts slightly downwards. However, in the test station, there is a noticeable somewhat inverse relationship between the throughput and relative humidity. This is not in agreement with some research findings which suppose that signal strength has a direct relationship with relative humidity (Felix et al, 2017).

P.U. Chinedu et al. / Nigerian Research Journal of Engineering and Environmental Sciences
5(2) 2020 pp. 633-643

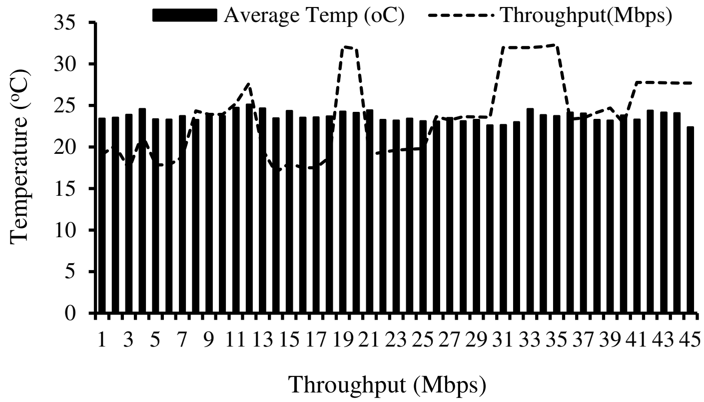

Figure 4: Combo plot of temperature against throughput at station 1

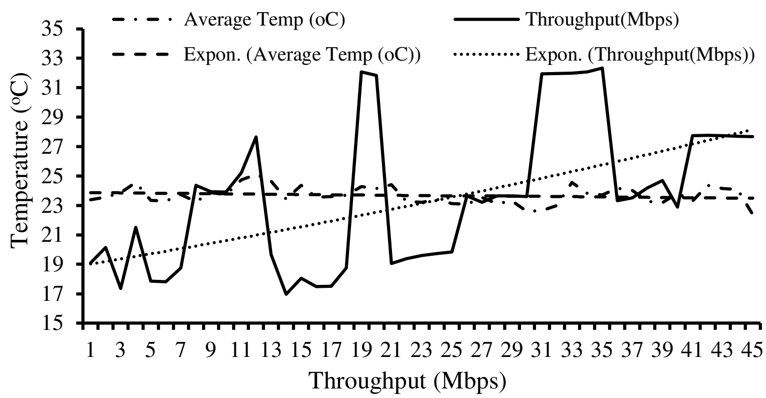

Figure 5: Line chart of temperature against throughput with exponential smoothing at station 1

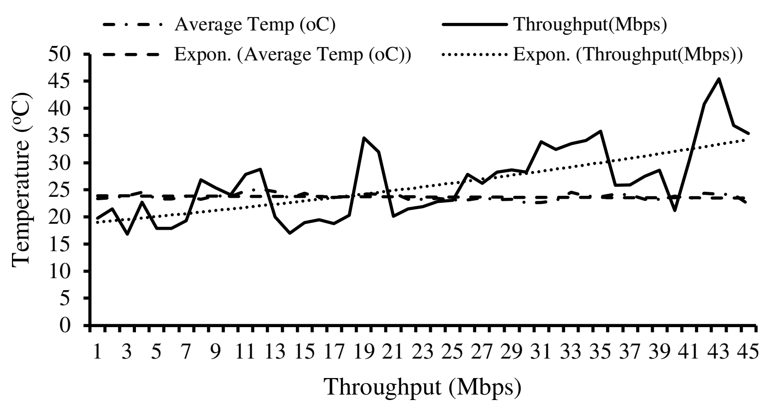

Figure 6: Line chart of temperature against throughput with exponential smoothing at station 2

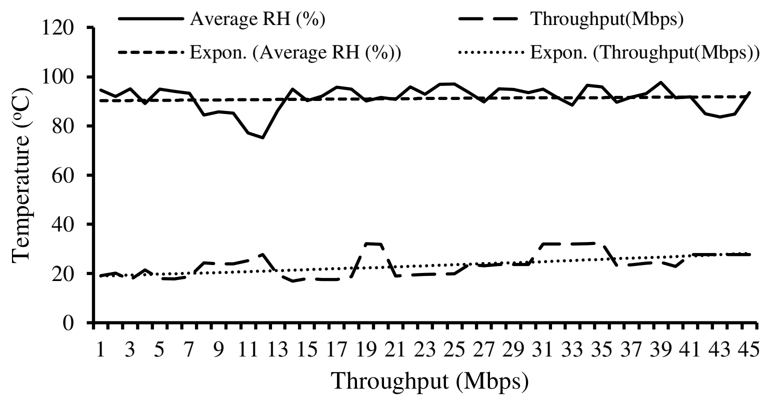

Figure 7: Trend chart of relative humidity against throughput with exponential smoothing at station 1

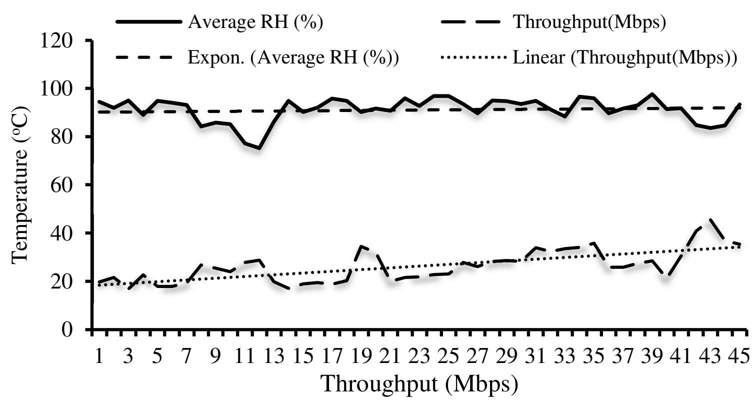

Figure 8: Trend chart of relative humidity against throughput with exponential smoothing at station 2

3.3. Mean Sea Level Pressure and Throughput

Unlike temperature and relative humidity whose impact were somewhat distinct, the mean sea level pressure neither exerted marked negative nor positive impact on the throughput. However, it may be submitted that this observation might be due to the lack of dispersion in the values of the mean sea level pressures computed (Ukhurebor and Nwankwo, 2020). There is a likelihood that where such variations exist, some distinctive responses in the throughput of the wireless signals might have been noticed particularly where the effect of altitude was not cancelled during the computation of the mean sea level pressure. As atmospheric pressure varies inversely with increasing altitude, it is believed that the control radio on a higher elevation would have had remarkably lower pressures and subsequently some impact. Notwithstanding the foregoing rationale, the series of undulating land lying between the base station (on a higher elevation) and the test radio (on a lower elevation) could have also contributed towards neutralizing the effect of pressures arising from the altitude, on the radio signal (Nwankwo and Ukhurebor, 2019; Ukhurebor and Nwankwo, 2020).

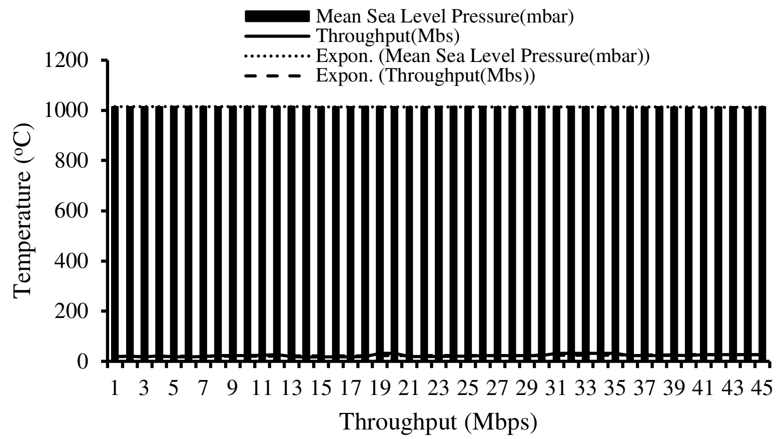

Figure 9: Chart of mean sea level pressure against throughput with exponential smoothing, at station 1

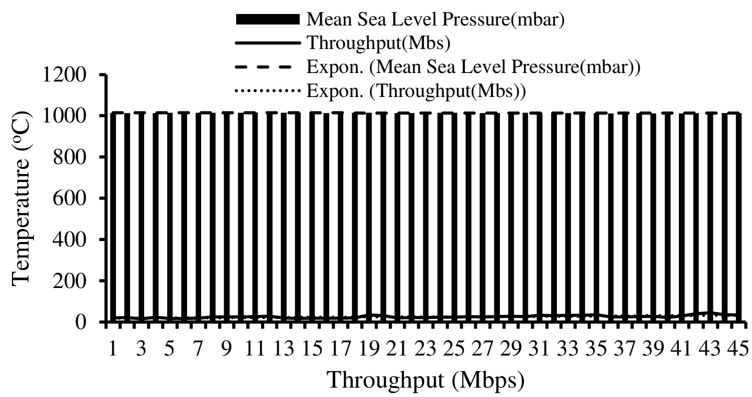

Figure 10: Chart of mean sea level pressure against throughput with exponential smoothing, at station 2

4. CONCLUSION

The objective of this study was to investigate the impact of the meteorological variables such as temperature, relative humidity and mean sea level pressure on the throughput of wireless radio deployed in wireless local area networks within undulating land environment. This study affirmed that the throughput of wireless networks is affected by temperature and relative humidity respectively. Conclusively, wireless networks in undulating lowlands tend to perform optimally under lower temperatures, lower relative humidity and higher mean sea level pressure. These findings are considered important in the design and management of campus networks in tropical environments.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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