Abstract—There are a lot of wireless communication systems being deployed in developing nations because of the low cost of infrastructure, ease of deployment and low maintenance. The ability to easily deploy wireless communication systems has increased the Internet data usage of the average person. However, the prices charged users of the wireless systems are exorbitant and the access speed is not comparable to that of a wired communication system. Thus, this work sets out to determine the optimal distance a user should be from the source of a wireless signal in order to maximize the communication in terms of information flow. The distance, received signal strength and signal-to-noise-ratio were obtained and the channel capacity calculated using the Hartley-Shannon equation. This paper presents results of experiments carried out with a mobile computer receiving wireless signals at varying distance from a wireless signal source.

Index Terms—channel capacity, IEEE 802.11, Hartley-Shannon, signal-to-noise ratio, Wi-Fi.

I. INTRODUCTION

The Shannon-Weaver model for communication has been adopted by many to explain and understand the communication between two participants. The model as shown in Figure 1 presents message generation i.e. Source, the transmitter, the media, noise affecting the media, the receiver and decoding of the message at the destination.

![Shannon-Weaver model of Communication](adapted from Osunade 2007)

Traditional computer networks were designed and implemented using guided media such as coaxial cable and twisted pair cable. The benefits of using computer networks especially the Internet created an enormous demand for computer networks and drove the need for faster deployment of network infrastructures. A look at the Shannon-Weaver model shows that unguided media such as microwave, radio signals could be used for communication. In order to meet demand, computer networks started using unguided media for communication.

The use of unguided media for computer networks led to the development of several technologies such as infra-red, bluetooth, microwave and radio signals. The most popular technology has been radio signals due to ease of deployment and requirement for minimal infrastructure.

The University of Ibadan computer network consists of a mixture of wired and wireless technologies. The wireless component of the network is meant to serve the need of the staff and students who are mobile and as a replacement for the wired component. Data communication experiences between devices and hosts have shown that information flow rate and quality of service delivered are not optimal. This has led to multiple deployment of wireless signal sources to reduce the effect of signal path loss, attenuation and obstacles in the environment.

Several research work have been done on problems associated with wireless signals by researchers such as Ndizi et al (2012); Iyer et al (2009); Kunanor (2005) and Planas (2006).
The aim of this experimental research work is to investigate the impact of distance on channel capacity for wireless radio signals conforming to the IEEE802.11n standard.

II. LITERATURE REVIEW

The Shannon–Hartley theorem tells the maximum rate at which information can be transmitted over a communication channel of a specified bandwidth in the presence of noise. The theorem establishes Shannon's channel capacity for such a communication link, a bound on the maximum amount of error-free digital data that can be transmitted with a specified bandwidth in the presence of the noise interference, assuming that the signal power is bounded, and that the Gaussian noise process is characterized by a known power or power spectral density. The Shannon–Hartley formula is given as,

\[ C = B \log_2 \left( 1 + \frac{S}{N} \right) \]  

or \[ C = B \log_2 (1 + \text{SNR}) \]  

Eq. (1)

Where \( C \) is channel capacity measured in bits/second, \( B \) is the bandwidth in Hertz, \( S \) is the signal level in watts across the bandwidth \( B \), and \( N \) is the noise power in watts in the bandwidth \( B \).

According to Benkic et al (2008) received power should be a function of distance. From this assumption they experimented with using the received signal strength indicator (RSSI) as a distance estimator. The findings indicate that RSSI is a poor distance estimator using wireless signals within a building. RSSI plays a significant role in deciding which link to use next so that packet delivery will be optimal in time/energy matter.

Faria (2005) used the log-distance path loss model to predict the received signal strength between two communicating participants using IEEE802.11b wireless equipment. The experiment was done inside and outside a building with distances varying from 1 to 50 meters in a straight line from the wireless source. The results suggest that signal strength in close range tends to be higher than predicted by the model. Also signal strength can be predicted using simple models when using off-the-shelf IEEE802.11 hardware. This is also supported by the work done by Ekpenyong et al (2013).

Ogunjemilua et al (2009) worked on the coverage of wireless signals, indoors and outside, based on the received signal strength in IEEE802.11n network. They worked on creating a mathematical model that can predict the network coverage of an IEEE802.11n device using the combined theory of antennae and inbuilt performance measurement values. The work done shows that the signal will travel further in a free air situation.

In their research work, Whitehouse et al (2007) demonstrated how the received signal strength can be used to localize a multi-hop sensor network. This work was carried out in a half-football field sized area using 49 and 25 nodes. Three metrics, grass height, radio enclosure and elevation of nodes from the ground, were used to describe the received signal strength while analyzing the metrics for sensitivity to environmental factors. The analysis revealed that received signal strength is not straightforward even in ideal environments.

Discussed below are the parameters, devices and software used for the evaluation of wireless signals in this work:

- Received Signal Strength Indicator (RSSI): Received Signal Strength Indicator (RSSI), commonly referred to as signal strength, is the magnitude of the electric field at a reference point that is a significant distance from the transmitting antenna. In an IEEE 802.11 system, RSSI is the relative received signal strength in a wireless environment, in arbitrary units. RSSI is an indication of the power level being received by the antenna. Therefore, the higher the RSSI number (or less negative in some devices), the stronger will be the signal. It is measured in decibels (dB).

- Signal-to-Noise Ratio (SNR): The Signal-to-Noise Ratio is a measure used to compare the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power. It is measured in decibels (dB).
Bandwidth (B): Bandwidth describes the maximum data transfer rate of a network connection. It measures how much data can be sent over a specific connection in a given amount of time. It is measured in Mbps.

Packet Loss: Packet loss is the failure of one or more transmitted packets to arrive at their destination. This event can cause noticeable effects in all types of digital communications. It is measured in percentages (%) or no of packets.

Distance (d): This is how far a signal source is from the receiver. It will be measured in meters.

Channel Capacity (C): represents the highest rate in bits per channel use at which information can be sent with arbitrarily low probability of error (Cover et al, 1991).

MikroTik Router: a data communication device for directing the flow of data between many communicating devices. The particular device used is for wireless data communication. The router consists of an operating system called Router OS that provides various performance metrics about the on-going wireless communication. A variety of Wireless technologies are supported in Router OS, the most basic of them being the wireless access point and client.

WirelessMon: WirelessMon is a software diagnostic tool from PassMark Software (2011) that allows network engineers to do the following you:
- Verify that the 802.11 network configuration is correct.
- Test WiFi hardware and device drivers are functioning correctly.
- Check signal levels from your local WiFi network and nearby networks
- Help locate sources of interference to a network
- WirelessMon supports the MetaGeek Wi-Spy (2.4i, 2.4x and DBx) useful for finding interference from non 802.11A/B/G devices transmitting on the same frequencies.
- Scan for hot spots in a local area
- Create signal strength maps of an area
- GPS support for logging and mapping signal strength
- Correctly locate a wireless antenna
- Verify the security settings for local access points.
- Measure network speed & throughput and view available data rates
- Help check wi-fi network coverage and range

The following information about a wireless network can be displayed by WirelessMon using available features on the wireless adapter(s) being monitored:

- **Current connection information**: SSID; Connected access point MAC address; Signal strength; Tx Power; Authentication type; RTS Threshold; Fragmentation Threshold; Channel in use; Frequency being used; Number of Antennas; Beacon Period; ATIM Window; Dwell Time; Hop Pattern; Hop Set.

- **Statistics information**: More than 30 parameters are reported. Including a detailed break down of frames sent and received, error counts, transmission retry counters and related low level data.

- **IP information**: Information about the current TCP/IP connection is reported. Including the adapter MAC address; Adapter device driver name; the IP Address; Subnet Mask; if DHCP is enabled; the Gateway Address and the DHCP server IP address.

- **IP counter information**: Network throughput is monitored and displayed. This includes the maximum bandwidth available from the network adapter hardware, the current send and receive data rates in bytes per second and packets per second, plus error counters.
III. METHODOLOGY

This is an experimental work. The field work was done in the Faculty of Education, University of Ibadan, Nigeria.

The tools used for the experimental work included a laptop computer (with wireless adapter), a measuring tape, MikroTik router and WirelessMon software.

The network monitoring software, Wireless Mon was installed on the laptop computer to be used for the fieldwork. The wireless network was scanned and these three wi-fi signals; STEPBUI_ED_BTS1, STEPBUI_ED_BTS2 or STEPBUI_ED_BTS3, were detected. Using WirelessMon, a selected wi-fi signal was connected to so as to obtain its SNR value at a distance of 1 meter. The values for other parameters such as RSSI, Bandwidth, first time seen, last time seen, max RSSI were also captured for the specified signal. The MikroTik router was connected to for values of SNR at the distance of 1 meter.

The procedure was repeated for distances of 3m, 6m, 9m, 12m, 15m, 18m, 21m, and 24m respectively from the reference point. The wireless network had a specified bandwidth of 54Mbps.

IV. RESULTS AND DISCUSSIONS

The results and analysis of the data collected from the router and WirelessMon are presented and discussed below.

<table>
<thead>
<tr>
<th>Distance</th>
<th>SSID</th>
<th>RSSI</th>
<th>SNR=(RSSI/dist)</th>
<th>Channel Capacity</th>
<th>SNR</th>
<th>Channel Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m</td>
<td>UI_ED_BTS1</td>
<td>-67</td>
<td>-67</td>
<td>328.76</td>
<td>34</td>
<td>277.01</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-95</td>
<td>-95</td>
<td>355.62</td>
<td>34</td>
<td>277.01</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-82</td>
<td>-82</td>
<td>344.29</td>
<td>34</td>
<td>277.01</td>
</tr>
<tr>
<td>3m</td>
<td>UI_ED_BTS1</td>
<td>-75</td>
<td>5</td>
<td>253.85</td>
<td>27</td>
<td>259.63</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-78</td>
<td>6</td>
<td>256.79</td>
<td>27</td>
<td>259.63</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-90</td>
<td>13</td>
<td>205.62</td>
<td>14</td>
<td>210.99</td>
</tr>
<tr>
<td>6m</td>
<td>UI_ED_BTS1</td>
<td>-79</td>
<td>13</td>
<td>205.62</td>
<td>14</td>
<td>210.99</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-90</td>
<td>15</td>
<td>216.02</td>
<td>14</td>
<td>210.99</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-94</td>
<td>16</td>
<td>220.74</td>
<td>14</td>
<td>210.99</td>
</tr>
</tbody>
</table>

Table 1 shows that the channel capacity obtained at distances of 3m and 6m for both WirelessMon and MikroTik are very close in value. This suggests that the three transmitting devices have strong signals at that range.

<table>
<thead>
<tr>
<th>Distance</th>
<th>SSID</th>
<th>RSSI</th>
<th>SNR=(RSSI/dist)</th>
<th>Channel Capacity</th>
<th>SNR</th>
<th>Channel Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9m</td>
<td>UI_ED_BTS1</td>
<td>-79</td>
<td>9</td>
<td>179.40</td>
<td>33</td>
<td>274.75</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-93</td>
<td>8</td>
<td>171.19</td>
<td>20</td>
<td>237.21</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-93</td>
<td>8</td>
<td>171.19</td>
<td>20</td>
<td>237.21</td>
</tr>
<tr>
<td>12m</td>
<td>UI_ED_BTS1</td>
<td>-87</td>
<td>7</td>
<td>162.02</td>
<td>20</td>
<td>237.21</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-93</td>
<td>8</td>
<td>171.19</td>
<td>20</td>
<td>237.21</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-93</td>
<td>8</td>
<td>171.19</td>
<td>20</td>
<td>237.21</td>
</tr>
<tr>
<td>15m</td>
<td>UI_ED_BTS1</td>
<td>-79</td>
<td>5</td>
<td>139.60</td>
<td>21</td>
<td>240.83</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-94</td>
<td>6</td>
<td>151.61</td>
<td>21</td>
<td>240.83</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-94</td>
<td>6</td>
<td>151.61</td>
<td>21</td>
<td>240.83</td>
</tr>
</tbody>
</table>

Table 2: SNR and Channel Capacity at distances of 9m, 12m and 15m

There is a big difference between the channel capacity available according to the router and the mobile computer as listed in Table 2. The difference is based on the SNR values obtained by the MikroTik router and WirelessMon on the mobile computer. No values were obtained for two of the wireless signals at 9meters. Also at 15meters, no signals were received for one of the wireless transmitters. The non-reception can be attributed to obstacles in the environment.
Table 3: SNR and Channel Capacity at distances of 18m, 21m and 24m

<table>
<thead>
<tr>
<th>Distance</th>
<th>SSID</th>
<th>RSSI</th>
<th>SNR= (RSSI/dist)</th>
<th>Channel</th>
<th>SNR</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Capacity</td>
<td></td>
<td>Capacity</td>
</tr>
<tr>
<td>18m</td>
<td>UI_ED_BTS1</td>
<td>-81</td>
<td>5</td>
<td>139.60</td>
<td>17</td>
<td>225.20</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-99</td>
<td>6</td>
<td>151.61</td>
<td>17</td>
<td>225.20</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21m</td>
<td>UI_ED_BTS1</td>
<td>-71</td>
<td>3</td>
<td>108.01</td>
<td>18</td>
<td>229.41</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-91</td>
<td>4</td>
<td>125.40</td>
<td>18</td>
<td>229.41</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS3</td>
<td>-89</td>
<td>4</td>
<td>125.40</td>
<td>18</td>
<td>229.41</td>
</tr>
<tr>
<td>24m</td>
<td>UI_ED_BTS1</td>
<td>-81</td>
<td>4</td>
<td>125.40</td>
<td>19</td>
<td>233.41</td>
</tr>
<tr>
<td></td>
<td>UI_ED_BTS2</td>
<td>-94</td>
<td>4</td>
<td>125.40</td>
<td>19</td>
<td>233.41</td>
</tr>
</tbody>
</table>

There is a big difference between the signal-to-noise ratio (SNR) of the Mikrotik router and WirelessMon as shown in Table 3. Table 3 also shows that no signals were detected at 18 and 24 meters. This is due to obstacles in the environment.

A. Comparison of the Channel Capacity between WirelessMon and the MikroTik Router

The graph in Figure 2 shows WirelessMon giving a lower channel capacity as the distance is increased. The channel capacity is almost the same for both measurement methods between 3 and 6 meters.

Fig 2: Graph of channel capacity for UI_ED_BTS1 for all distances

Fig 3: Graph of channel capacity for UI_ED_BTS2 for all distances
The graph in Figure 3 shows the same pattern as that of Figure 2. Figure 3 however shows that the channel capacity becomes constant at 21 meters for both the router and WirelessMon.

![Graph of channel capacity for UI_ED_BTS3 for all distances](image1)

The data used in Figure 4 is not complete as wireless signals were not received at five out of the 9 distances used. The graph however shows that the two methodologies have channel capacity with similar behavior.

**B. Comparison of the SNR between WirelessMon and the MikroTik Router**

![Graph of SNR for UI_ED_BTS1 for all distances](image2)

**Fig 4: Graph of channel capacity for UI_ED_BTS3 for all distances**

**Fig 5: Graph of SNR for UI_ED_BTS1 for all distances**
The SNR of the two methodologies started from opposite values as shown in Figure 5, but converged at the 3m to 6m distance. The SNR values then differ at the 12m distance.

![Fig 6: Graph of SNR for UI_ED_BTS2 for all distances](image)

![Fig 7: Graph of SNR for UI_ED_BTS3 for all distances](image)

Though the data used in Figure 7 is incomplete, it shows that the SNR is similar at distances of 3m and 6m from the signal source.

V. CONCLUSION

From the results of the experiment, it can be deduced that there is a relationship between the channel capacity and distance. The nature of the relationship was revealed to be inversely proportional. The experiment showed that channel capacity is impacted by the distance of the receiver from the wireless signal source. This implies that users will get better access from an IEEE802.11n wireless signal source when they are within a 3m to 6m distance from it. There was variation between the results obtained using the SNR value from WirelessMon and those obtained...
from the MikroTik router. Further research can be carried out to determine how to resolve and eliminate the differences in the two technologies.

REFERENCES


AUTHOR BIOGRAPHY

Oluwaseyitanfunmi Osunade is a senior lecturer in the Department of Computer Science, University of Ibadan, Nigeria. He obtained his doctoral degree in 2007 with specialization on mobile agents. His research interests include data communications and computer networks. He is a member of the Nigeria Computer Society, IEEE, ACM, ISOC and Computer Professional Registration Council of Nigeria (CPN).

Toyin Oguntunde is an academic staff and researcher at the Department of Computer Science, University of Ibadan, Nigeria. He is a member of the Nigeria Computer Society. His research interests include computer networks and information collaboration sciences.

Omokehinde Deji-Akinpelu is a graduate student in the Department of Computer Science, University of Ibadan, Nigeria.. She is also a staff of Leads University, Ibadan, Nigeria.