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Original Research

Investigating the Performance of Point to Multipoint Microwave Connectivity across Undulating Landscape during Rainfall

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Abstract

One of the most debated issues surrounding wireless connectivity is performance especially under different topographic and climatic scenarios. Performance has a direct relationship with throughput measured in terms of how well a given wireless connectivity provides consistent services over a given period compared to the wired alternative. Research has shown that wireless connectivity is constrained by significant physical components such as topography, weather conditions, propagation frequency, and distance. It is commonplace to see notable vendors of wireless network products make claims as to how their technologies are designed to remedy any signal degradation that may arise from the aforementioned physical elements. This paper is aimed at evaluating the performance of a point to multipoint connectivity using Ubiquiti's 5.8 *GHz* Point to Multipoint Base Stations deployed within a landscape marked by series of undulating highlands and lowlands. In this experiment, a base station node is established with connectivity to two other nodes of same specifications with one node as the destination radio whereas the other acts as the control which is located on a table land. The nodes were separated by triangular distances of 3 *km* and network connectivity was maintained over thirty days during periods of rainfall. Packets sent and received across each node was carefully recorded. The results from the analysis showed that packet losses to and from the control node was significantly lower than that of the other node under same weather conditions.

Keywords: Landscape, Microwave, Nodes, Performance, Signal

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1. Introduction

The technological breakthrough and development experienced in the field of wireless communication would not have been a success if references are not made to early scientists who did a lot of research in the field of wireless communications. Several inventions, theories and principles have been established in order to generate background foundation towards enormous advancement in the field of wireless communication [1].

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These technologies continued to develop for over a century as people began to unravel the intricacies of telecommunications [1, 2, 3]. The development from 1G to 4G and now into LTE and beyond to 5G is a milestone. The dramatic development was not just experienced at an instance, but was seen as an improvement over an existing technology, a breakthrough in the field, and a transition from one to another with marked elemental upgrades. The evolution of mobile communication cannot be well understood if proper description of mobile communications, is not reviewed in respect of the overall technology, speed, frequency and system in numeric generations such as 3G, 4G or 5G [1]. Each generation has unique technologies that define it, and explains the differences throughout the evolution of mobile communications and what we can expect from the future generations of these technologies.

Wireless networks have some constraints to a wider option in enterprise network design and implementation. Such constraints include: attenuation, latency, interference, distortion of signals, as well as the effect of weather conditions specifically rainfall on performance and signal propagation [4-18].

But with consistent advancement in technology, some mechanisms have been integrated into high-end radios to help mitigate some of these constraints. However, there are still some debatable issues as to the performance of wireless networks under extreme weather conditions and unusual landscapes [10, 11, 12].

The aim of this study is to investigate the performance of a 5 GHz point-to-point and point-to-multipoint radios across undulating landscape during rainfall. We intend to achieve this aim by understudying the geography of the study area, which according to previous studies [1-12], have remarkable topographic characteristics with emphasis on the distribution of weather conditions and signal propagation. We would attempt to determine the propagation and monitor the behaviour of radio signals within the 5 GHz frequency band from one point to another having regard to the undulating lowlands and highlands during rainfall. Appropriate comparison on performance of same radio specifications under normal weather conditions on lowlands would also be considered in this study.

2. Review of Related Works

Indisputably, movement of vegetation structures introduces an adverse environment for high frequency radio wave propagation [10].

Hashim *et al*., [19], examines a series of vegetation scattering measurement campaigns during various wind conditions. Their measurements were divided into controlled and outdoor environments. The controlled environment measurements were conducted in an anechoic chamber at 0.9, 2.0, 12.0 and 17.0 GHz., while the outdoor measurements were carried out at 1.8 GHz, as well as recording of a transmitted signal originating from an existing digital cellular system (DCS-1800) base station. Their results were presented in terms of first-order and second-order statistics. From their analysis, the received signal behaviour was highly wind dependent, especially when the environment is changing from calm to a windy condition. The signal fast-fading was found to be Rician distributed and an empirical model of the k-factor variation over wind speed were also presented in their study.

In the study carried out by Perras *et al*., [20], they compared the various temporal characteristics of radio channels for a broad range of frequencies, including 2.45, 5.25, 29.0 and 60.0 GHz, in various vegetation and weather conditions. A considerable number of data points, were in excess of 1.9 billion at 500 samples per second (equivalent to 45 days) was collected and analysed for three particular types of channels (foliated deciduous trees, non-foliated deciduous trees and coniferous trees). The radio channels were statistically analysed and the resulting probability density functions (PDFs) and cumulated density functions CDFs) were compared with existing models. Furthermore, wind speeds and rain precipitation were correlated with the power samples, this was done in order to consider RF propagation dependencies. Second order statistics was derived including level crossing rate (LCR) and average facie duration (AFD). The power profile was analysed for spectral components. The frequency characteristics of the RF propagation channel were also evaluated. They also presented the channel-specific RF propagation attributes.

Pellet *et al*., [21], used a fixed terrestrial broadband wireless system such as Multipoint Microwave Distribution System (MMDS) which is a cost-effective solution for cable coverage to the immediate surrounding rural area. The wireless system was operated with the existing cable headend and the same subscriber-end cable modem. The system works well with clear line-of-sight transmit/receive antennas. However, in near-line-of-sight transmission where a few foliated trees block the line-of-sight, signal distortion were experienced, especially under conditions of high wind. They argued, that the motion of the trees was responsible for the huge and rapid signal fading. Their measurements were taken on fixed wireless paths blocked with a few trees in the vicinity of the receive antenna. Fading characteristics of a 6 MHz channel centred at about 2.6 GHz were provided. The fades were mostly flat across the band but with some frequency selective fading. Fading rates under windy conditions ranged from 0.5 to 2.0 $fades/second$. The slope of the fades occasionally reached 50 $dB/second$.

Dal Bello *et al*., [22], carried out their studies on propagation in an urban forested park area, their aim was to investigate the statistical nature of the time fading for frequencies ranging from 0.9 GHz to 1.8 GHz, as well as to examine the range dependence and the base station height gain. They used a received signal of around 30 s intervals for a stationary mobile to design the distribution functions for the fading. According to them, the distribution could be approximated by a Rician distribution, whose K-factor was found to depend on transmitter height.

Cuiñas *et al*., [23], reported that the presence of vegetation in the radio channel could affect the coverage areas of cellular mobile phone systems. They argued that the various components of a tree have influence in the performance of the radio system. Although, the trunk is commonly in a fixed and stable location, the leaves could be in continuous movement as a result wind. Accordingly, the time variation which can be correlated with the wind speed and direction, could strongly modify the attenuation and scattering effects of the trees on the radio channel performance. Their study presents the results (both long-term and short-term) of a measurement campaign of scattering and attenuation effects of isolated trees, under the action of artificial wind of different controlled speeds and directions. They show that the median effect of the presence of a tree is the induction of higher attenuation in the shadow areas and a new distribution of the scattering pattern all around the specimen. But, the wind on the leaves forces their movement and an increment in the time variation around the median received power values.

Zennaro *et al*., [24], revisited the issue of link quality in

Wireless Sensor Networks (WSN). They studied the temporal and energy characteristics of a 24 *GHz* sensor network in an outdoor environment using different values of output power and sampling period. They analysed battery behaviour in motes placed at different distances and reported that farther motes have a shorter battery life. They suggested that when deployed in the real world, the sampling periods of sensor networks be adjusted according to distance to normalize battery lifetime and a more accurate energy-aware routing protocol be developed.

According to Zhao *et al.*, [25], wireless sensor networks promise fine-grain monitoring in a wide variety of environments. Many of these environments (like indoor environments or habitats) can be harsh for wireless communication. From a networking perspective, the fundamental aspect of wireless communication is the packet delivery performance (the spatio-temporal characteristics of packet loss and its environmental dependence). These factors would severely have impact on the performance of data acquisition from these networks. Their study was centred on a systematic medium-scale (up to sixty nodes) measurement of packet delivery in three different environments (an indoor office building, a habitat with moderate foliage and an open parking lot). Their results would have interesting implications for the design and evaluation of routing and medium-access protocols for sensor networks.

Puccinelli and haenggi [26], reported that multipath fading severely contributes to the unreliability of wireless links, causing fairly huge deviations from link quality predictions based on path loss models. Accordingly, its impact on wireless sensor networks is considerable. Although, analytical models provide a probabilistic description, multipath fading is a deterministic phenomenon. Moreover, in the case of static nodes, fading is time-invariant. They illustrated its spatial nature with experimental evidence obtained using lower-end sensing node hardware. They also show the limitations of the supposed immunity of wideband radios to multipath fading in indoor deployments.

The works of Ukhurebor *et al.*, [27] and Ukhurebor and Umukoro [28] dealt extensively on the effects of some essential meteorological variables such as temperature, relative humidity and mean sea level pressure on the Ultra High Frequency (UHF) and Very High Frequency (VHF) radio signals. They stated that the radio signals from both the UHF and VHF television stations were directly proportional to the temperature, inversely proportional to the relative humidity and no defined pattern of proportionality with the mean sea level pressure. They argued that, the radio signals from the UHF television station were seen to be mostly affected by these weather variables. These effects according to them were more pronounced during the months with high relative humidity compared with the months with lower relative humidity.

According to [4]-[12], signal attenuation caused by rainfall, is a major challenge to microwave satellite communication especially at frequencies above 10 *GHz*. In several occasions, they cause signals unavailability. Rainfall attenuation predictions have become one of the vital considerations while setting up a satellite communication link [4] - [12]. In their respective studies, rainfall attenuation models, cumulative distribution curves and other analytical tools for successful prediction of rain attenuation were presented.

Basically, this study focussed on comprehensive evaluation of the performance and operation of 5 *GHz* microwave radios during propagation and transmission of signals across undulating land areas taking into consideration the effect of weather in such circumstances [29]. Apparently, the results obtained offered some additional and novel insight on the effects of topography on the propagation of signals under certain weather conditions even where high frequency radios are employed.

3. Materials and Methods

The hierarchical approach to network design and implementation was adopted in this study. The hierarchical approach stipulates that a network be structured in such a way as to categorize similar functions into a layer and separate each layer from other layers, while ensuring communication among the different layers [4] - [12]. Each layer focuses on specific functions. The advantages of the hierarchical approach are notable, which include:

i. Enables the network planner or designer to identify and make proper choice of the right equipment for the design and implementation of each layer.
ii. Ensures proper evaluation of features that makes up the layers.
iii. Suitability for network designs of varying sizes and requirements.

In a hierarchical network the entire network is segmented into discrete layers. Each layer, or tier, provides specific functions that define its role within the overall network. This helps to optimize and select the right network hardware, software and features to perform specific roles in the network. Three main layers are recognized: Access, Distribution, and Core layers respectively.

3.1. Hardware

i. Three units of Ubiquiti rocket M5 point to multi-point (PtmP) base stations. The specification of the radios is: $5-5.83$ *GHz* spectrum, hi-power 2×2 MIMO TDMA AirMAX, Power-supply: 24 *V*, 1 *A* POE.
ii. Router (Huawei 1200 series).
iii. Switch (S5700 8-port).
iv. Cat-6 shielded twisted pair cable (40 *m* crimped cables).
v. Three computer systems with same specifications: HP Probook 6450b, intel R core^{TM} i5 CPU @2.40 *GHZ*, running Microsoft Windows 10 professional operating system.
vi. Infinix S4 Smart phone with Android 9.0, GPS coordinate and elevation apps respectively.

3.2. Software

i. Wireshark 3.0.5(Network packet analyzer)
ii. Enterprise Network Simulation Platform (eNSP)
iii. Microsoft Visio 2010
iv. IBM SPSS v.24
v. Ubiquiti Unifi controller software

3.3. Study Area

This study was conducted in Iyamho community, a small town in Etsako West Local Government of Edo State, Nigeria. Iyamho is host to the fast-growing model University, Edo University Iyamho. It has approximately 5,000 inhabitants who are mostly rural dwellers. However, since the establishment of the University, the community is rapidly transforming to a beautiful semi-urban centre following the influx of workers, visitors and students. Consequent upon the foregoing, the town is witnessing an upsurge of modern communication infrastructure amidst other notable capital infrastructure such as police barracks, community health clinics and private-owned businesses. In the area of communication, there is relatively a heavy presence of mobile network base stations which have given rise to increased growth in the use of the Internet. It is presumably estimated that 55 % of the population are active users of the internet. Geographically, Iyamho is located on latitude 7.07 ^{o}N and longitude 6.27 ^{o}E with an elevation of about 188 m above sea level [16, 17, 18]. Like other tropical areas of Southern Nigeria, Iyamho enjoys two seasons often categorized as rainy and dry seasons. It enjoys a Savannah vegetation. According to Ukhurebor *et al.*, [17], its topography is marked with undulating and table lands. Figure 1 shows the aerial view of the community.

Figure 1: Aerial View of Iyamho, EtsakoWest of Edo State, Nigeria (Source: Google Earth).

3.4. Design of Experiment

The experiment involved three locations which were marked as follows:

Primary Station (the Base Station) is located at the Faculty of Science, Edo University Iyamho. The primary station has an elevation of about 45 m above sea level. Its location provided by coordinate 7.15174 ^{o}N and 6.30098 ^{o}E. The experiment is modelled as shown in Figure 2. Remote Station 1 (the Control Station) is located at the Administrative building in the main campus of Edo University Iyamho. The control station has an elevation of about 188 m above sea level. The Remote Station 2 (the Test station) was deployed in an undulating landscape, located in Iyamho town). The elevation is 88 m above the sea level.

3.5. Method of Data Collection

Data collection was done using Wireshark 3.0.5 installed on all the participating computers. Connectivity between the base station and the two remote stations located 3 km away from the base station was continuously monitored. Packets from the two remote stations were captured simultaneously from April to September, 2019 over a period of 30 days during rainfall. The failure rates from the base station to the remote stations were recorded. The failure and success rates at which packets were received from both remote stations were recorded under the same weather conditions.

3.6. Network Modelling

The following tools were used for Network modelling and simulation: Huawei enterprise network simulation platform (eNSP); Huawei AP6510DN series wireless 5 GHz radios, Huawei S700 series switch, and a HP Probook. Figure 3 shows the topology of the model. A class C network with network address of 192.168.1.0 and subnet mask 255.255.255.0 was used. The base station is connected to highly efficient switch, while the other remote stations were connected directly to a HP Notebook of same specifications.

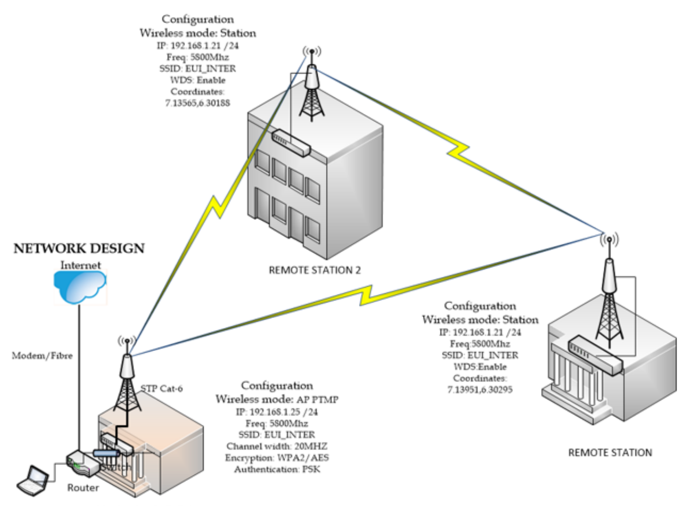

Figure 2: Diagrammatic Description of Experimental Design.

The essence of using same computer specification across the three locations was to ensure that no extraneous factors were introduced into the network in respect of performance [29]. Presumably, the use of same computer specification with same configuration and applications installed which are operating within same physical conditions would help ensure uniformity in performance.

Following the modelling, a 64k ping flood was sent from the BASE to the remote stations (REMOTE 1 and REMOTE 2) for three consecutive hours. The same ping flood was sent from the two remote access points to the BASE over same period. Wireshark was used to capture the frequency of the packets sent and the packets received.

3.7. System Requirements and Physical Configuration

The physical configuration involves coupling the Ubiquiti Rocket M5 radios together with the sector antennae which were positioned at the three locations. For the base station, a Huawei

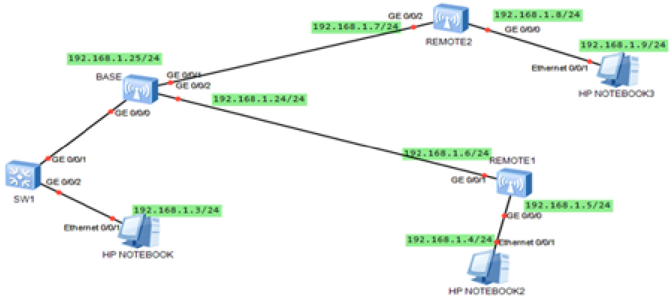

Figure 3: Topology of the Network.

S700 series switch was used to connect the HP notebook and the Access point. Figure 4-6 show the various configurations of the base station (BASE) and the remote stations (REMOTE 1 and REMOTE 2) respectively.

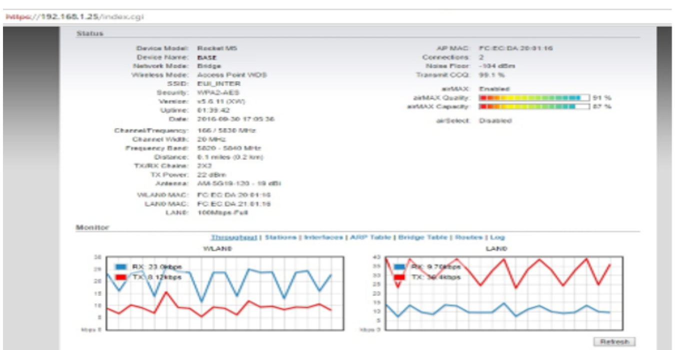

Figure 4: Configuration of the Base Station Radio.

3.8. *Data Capture with Wireshark*

As mentioned earlier, data capture on the physical network was done using wireshark installed on the three HP notebooks. Prior to capture on physical network, a simulation was done using eNSP and wireshark on one of the HP notebooks. The result of the simulation did not yield any departure as regards traffic sent to and packets received from the remote stations.

In the physical network, 64k frames were flooded to the remote stations from the base station for over a period of 30 days rainy period. It should be noted that the period was only during the rainy cloudy weather.

4. Results and Discussion

Table 1 to 6 show the statistics of the packets relayed and received by the base station from the remote stations. Note that the remote stations are tagged; REMOTE 1 and REMOTE 2. As previously stated, we used REMOTE 1 as a control station while REMOTE 2 was the test station.

Figure 7 shows the comparative analysis of the packet losses to both Remote 1 and Remote 2. On the other hand, Figure 8 shows the relationship between the duration of rainfall and packet losses. The charts are created using data from Table 5.

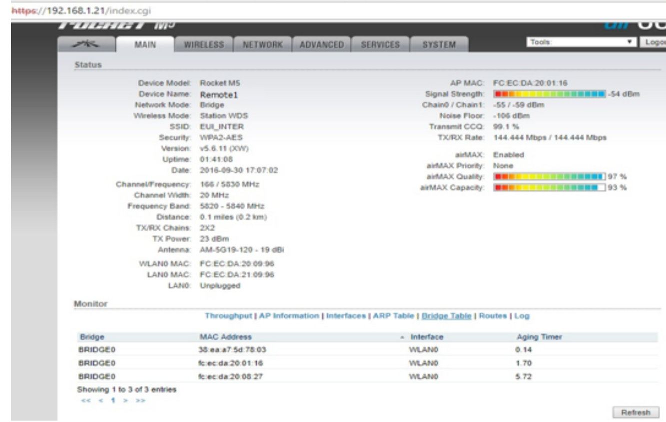

Figure 5: Configuration of the Control Radio (Remote 1).

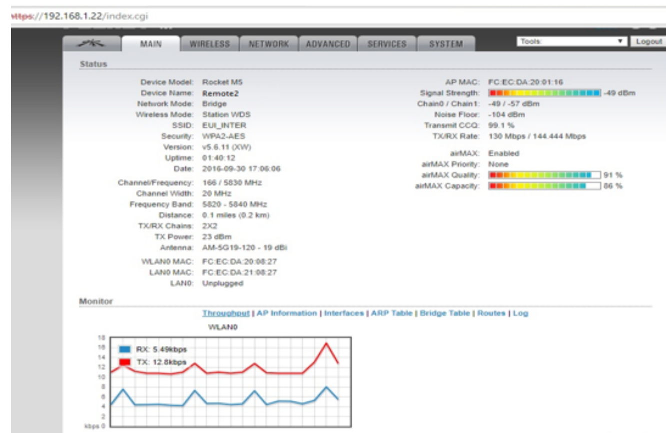

Figure 6: Configuration of the Test Radio (Remote 2).

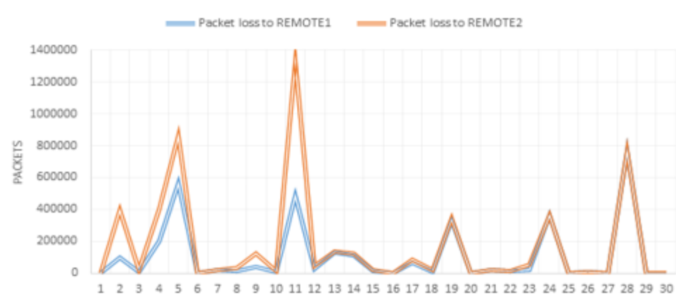

Figure 7: Comparative Analysis of Packet Losses from Base Station to Remote Stations.

Figure 9 shows a stacked area chart. The area chart summarized the relationship between the lost frames at both Remote 1 and Remote 2 respectively.

In this experiment, three radios were used. The base station was used as the reference point to coordinate the point to multipoint connections. Two remote stations were employed with one as the control radio and the second as the test radio. From the charts in Figures 7-9, it is evident that regardless of the duration of rainfall or cloudy weather conditions, data losses across the radio located on undulating paths are higher than that located on plane paths. It may be submitted that notwithstanding

Table 1: Traffic States on Base Station .

Day	Period of Rainfall (Minutes)	Packets Sent from Base to REMOTE 1	Packets Received from REMOTE 1
1	15	7005	5600
2	55	3575000	3479154
3	23	112876	102876
4	18	926547	725467
5	75	2367234	1803467
6	10	2136	1159
7	33	82345	61234
8	46	234654	223456
9	32	436788	394659
10	16	64763	59874
11	42	2348765	1863534
12	26	104566	80001
13	31	934525	802211
14	22	932442	823426
15	39	120001	103736
16	4	2034	1108
17	18	789686	723456
18	34	100870	90711
19	53	2346000	2012664
20	8	1264	1023
21	24	109827	90736
22	24	101453	90534
23	21	204332	183454
24	32	2364758	2002374
25	13	23487	21763
26	23	102876	98234
27	10	1726	1407
28	22	841234	80023
29	13	2305	1600
30	11	1656	1432

Table 2: Traffic on Base Station Computer.

Day	Period of Rainfall (Minutes)	Packets Sent from Base to REMOTE 2	Packets Received from REMOTE 2
1	15	7005	4600
2	55	3575000	3179152
3	23	112876	92176
4	18	926547	525167
5	75	2367234	1503467
6	10	2136	1102
7	33	82345	60024
8	46	234654	200856
9	32	436788	312259
10	16	64763	50174
11	42	2348765	1023434
12	26	104566	60020
13	31	934525	801241
14	22	932442	811606
15	39	120001	100123
16	4	2034	1003
17	18	789686	702356
18	34	100870	80034
19	53	2346000	2002344
20	8	1264	0865
21	24	109827	90502
22	24	101453	89534
23	21	204332	153454
24	32	2364758	2001234
25	13	23487	21456
26	23	102876	98234
27	10	1726	959
28	22	841234	80023
29	13	2305	1200
30	11	1656	1325

Table 3: Traffic from REMOTE 1 to Base Station.

Day	Rainfall Time (minutes)	Packets Received by BASE	Packets Sent to BASE Station
1	15	5523	5600
2	55	3455000	3479154
3	23	100876	102876
4	18	700547	725467
5	75	1727234	1803467
6	10	1140	1159
7	33	61200	61234
8	46	200654	223456
9	32	380788	394659
10	16	57763	59874
11	42	1858765	1863534
12	26	78956	80001
13	31	800525	802211
14	22	800442	823426
15	39	100001	103736
16	4	1100	1108
17	18	700686	723456
18	34	89487	90711
19	53	1986000	2012664
20	8	980	1023
21	24	889827	90736
22	24	90045	90534
23	21	180332	183454
24	32	1934758	2002374
25	13	19487	21763
26	23	92876	98234
27	10	1200	1407
28	22	789234	80023
29	13	1400	1600
30	11	1043	1432

Table 4: Traffic from REMOTE2 to BASE Station.

Days	Rainfall Time (minutes)	Packets Received by BASE Station	Packets Sent to BASE Station
1	15	4002	4600
2	55	3375000	3179152
3	23	75876	92176
4	18	486547	525167
5	75	1367234	1503467
6	10	950	1102
7	33	59345	60024
8	46	194654	200856
9	32	296788	312259
10	16	44763	50174
11	42	164876	1023434
12	26	50456	60020
13	31	724525	801241
14	22	782442	811606
15	39	90080	100123
16	4	950	1003
17	18	659686	702356
18	34	73387	80034
19	53	1896000	2002344
20	8	820	0865
21	24	88582	90502
22	24	80245	89534
23	21	162332	153454
24	32	1834758	2001234
25	13	18487	21456
26	23	92876	98234
27	10	800	959
28	22	72123	80023
29	13	1105	1200
30	11	1100	1325

Table 5: Statistics on Packets Losses to Remote Stations.

Days	Rainfall Time (minutes)	Packet Loss to REMOTE 1	Packet Loss to REMOTE 2
1	15	1405	2405
2	55	95846	395848
3	23	10000	20700
4	18	201080	401380
5	75	563767	863767
6	10	977	1034
7	33	21111	22321
8	46	11189	33798
9	32	42129	124529
10	16	4889	14589
11	42	485231	1325331
12	26	24565	44546
13	31	132314	133284
14	22	109016	120836
15	39	16265	19878
16	4	926	1031
17	18	66230	87330
18	34	10159	20836
19	53	333336	343656
20	8	241	399
21	24	19091	19325
22	24	10919	11919
23	21	20878	50878
24	32	362384	363524
25	13	1724	2031
26	23	4642	4642
27	10	319	767
28	22	761211	761211
29	13	705	1105
30	11	224	331

Table 6: Statistics on Packet Delivery to Remote Stations.

Days	Rainfall Time (Minutes)	Packet Sent	Packet Received by Remote 1	Packet Received by Remote 2
1	15	7005	5600	4600
2	55	3575000	3479154	3179152
3	23	112876	102876	92176
4	18	926547	725467	525167
5	75	2367234	1803467	1503467
6	10	2136	1159	1102
7	33	82345	61234	60024
8	46	234654	223456	200856
9	32	436788	394659	312259
10	16	64763	59874	50174
11	42	2348765	1863534	1023434
12	26	104566	80001	60020
13	31	934525	802211	801241
14	22	932442	823426	811606
15	39	120001	103736	100123
16	4	2034	1108	1003
17	18	789686	723456	702356
18	34	100870	90711	80034
19	53	2346000	2012664	2002344
20	8	1264	1023	0865
21	24	109827	90736	90502
22	24	101453	90534	89534
23	21	204332	183454	153454
24	32	2364758	2002374	2001234
25	13	23487	21763	21456
26	23	102876	98234	88234
27	10	1726	1407	959
28	22	841234	80023	80023
29	13	2305	1600	1200
30	11	1656	1432	1325

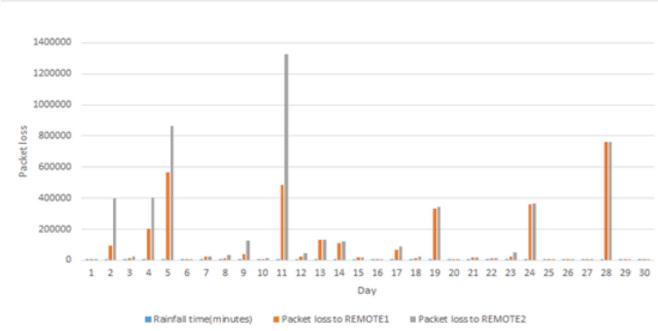

Figure 8: Relationship between Duration of Rainfall and Packet Losses to Remote Stations.

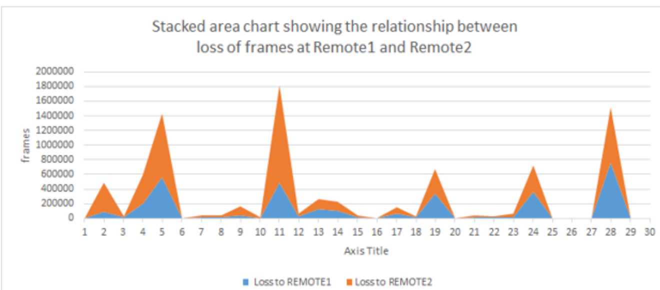

Figure 9: Stacked Area Chart Showing the relationship between Lost Frames from the two Remote Stations.

the line of sight existing between two geographically located radios, the impact of rainfall is very likely to intensify when radios are placed on terrains with highly undulating surfaces.

5. Conclusion

Following the data capture and subsequent statistical analysis, we have made the following conclusions:

i. Signal strength and propagation of 5 GHz radios placed on undulating terrains are severely affected by deteriorating or adverse weather conditions.
ii. Though the cause of the manifest deviation obtained are not very clear, it appears that signal losses are attributed to interference caused by rainfall owing to high relative humidity, amplified by possible bias introduced by the undulating terrains.
iii. Future studies are to take into consideration more meteorological variables, over a long period of time in order to have more beneficial and comprehensive results.

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