Using UNII-3 (Wi-Fi) Frequencies to Establish Long Distance Point-to-Point Links Capable of Providing Broadband Internet Access to Rural Areas: Experimental Validation

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Abstract
This paper demonstrates use of UNII-3 (Wi-Fi) frequencies, 5.725 - 5.825GHz in setting up long distance point-to-point links, capable of providing broadband internet in rural areas. Although this frequency band was intended for indoor wireless local area networks, its lack of licensing and inexpensive off-shelf networking devices has prompted many researchers and technology enthusiasts to extend its use to outdoor settings. This paper presents a long distance point-to-point test-bed model that uses high-gain directional antennas that may be replicated to provide broadband internet access in rural areas particularly in developing countries. Six long-distance point-to-point links have been set up. A link distance of 24.3kilometers, the longest so far, has been achieved. A peak throughput of 98.4Mbps has been observed on all of the links set up, irrespective of their link lengths. This test-bed model is easy and inexpensive to implement and it may be replicated to provide broadband internet access in the rural areas. This paper validates the use of these unlicensed frequencies and proves that as long as a clear line of sight between the nodes is achievable, high bandwidth link may be achieved capable of serving 1000+ simultaneous users each utilizing at least 100kbps.
Keywords: Point-to-point links, long distance Wi-Fi, broadband for rural areas, directional antennas

Acronyms
3G - third generation of mobile telecommunication technology standard
4G - fourth generation of mobile telecommunication technology standard
CSMA/CA – Carrier Sense Multiple Access/ Collision Avoidance
DSL- Digital Subscriber Line
IEEE – Institute of Electrical and Electronics Engineers
ISM – Industrial, Scientific and Medical
LAN – Local Area Network
LOS – Line of Sight
LTE – Long Term Evolution
MAC – Media Access Protocol
MIMO- Multiple Input Multiple Output
MIT - Massachusetts Institute of Technology
U-NII – Unlicensed National Information Infrastructure
VSAT- Very Small Aperture Terminal
Wi-Fi -Wireless Fidelity
WiMAX – Worldwide Interoperability for Microwave Access

1. Introduction
In the recent past, the information revolution has experienced accelerated growth particularly because of technological advancements in telecommunication industry. These technologies have brought forth what is commonly known as ‘global village’ because of the ease in which communication takes place between individuals and communities in distant localities. Broadband internet access has been one of the forces behind the advances in communication technologies currently being enjoyed. The term broadband generally refers to internet connectivity that is always on and that provides high capacity of data.

Rural areas have hardly experienced the advantages provided by broadband internet access. This is primarily because; they have economical challenges that make Internet service providers (ISPs) find it unprofitable to put up necessary infrastructure in such areas. Because of these challenges, other approaches have been put forward with an aim of providing broadband internet access to rural areas. Such approaches include mobile broadband access (3G, LTE, 4G), WiMAX, DSL, broadband over power lines, VSAT among others. As things stand, only wireless-based solutions have been observed to have the potential of making any tangible progress because of their generic low cost and ease of deployment.

The mobile broadband internet access provided by mobile telephone service providers hardly meets the demands for rural population in terms of throughput requirements per user. This is particularly because, the ISPs concentrate more on providing basic telephony services such as 2G technologies and forsake the only broadband solution that rural areas can afford leaving them under-served. This situation means that only the urban populaces fully enjoy the benefits associated with the information revolution.

In the view of the foregoing, the rural population needs a viable alternative to meet their broad access requirements. The IEEE-802.11 (Wi-Fi) family of wireless technologies has shown tremendous acceptance as well as growth since its inception. While it was designed for indoor use, for short-range access and primarily as a last-hop wireless access, its wide acceptance has motivated its use beyond its typical use. The range of indoor Wi-Fi spans up to a hundred meters from the access point. Because of its numerous advantages such as open standard and interoperability, it has enjoyed competitive mass production and thereby widespread acceptance. IEEE-802.11 (Wi-Fi) has been anticipated as being affordable and acceptable alternative to provide broadband access to rural areas(Subramanian et al., 2006). It is capable of providing a ubiquitous and cost effective broadband access alternative, which if properly planned, may be a viable solution to the rural broadband requirements.

1.1. Proposed Design

The design proposes use of the unlicensed UNII-3 frequencies to establish long distance point-to-point link. These links can be used to extend the internet ‘hotspot’ from urban localities to the distant rural areas. Most of the rural areas are often a few kilometers to a few tens of kilometers (5-30km) from the urban areas. This means that, a broadband internet access can be tapped from an urban area and distributed to the neighboring rural areas using few point-to-point links and then distributed to the entire area using Wi-Fi technologies as depicted in figure 1 below.

In the figure 1, the typical design scenario is represented by the following:

1. Internet Backbone provided by ISP in an urban area
2. ISP access point
3. A high directional antenna to establish point-to-point link in urban area
4. A high directional antenna to establish point-to-point link in a rural area

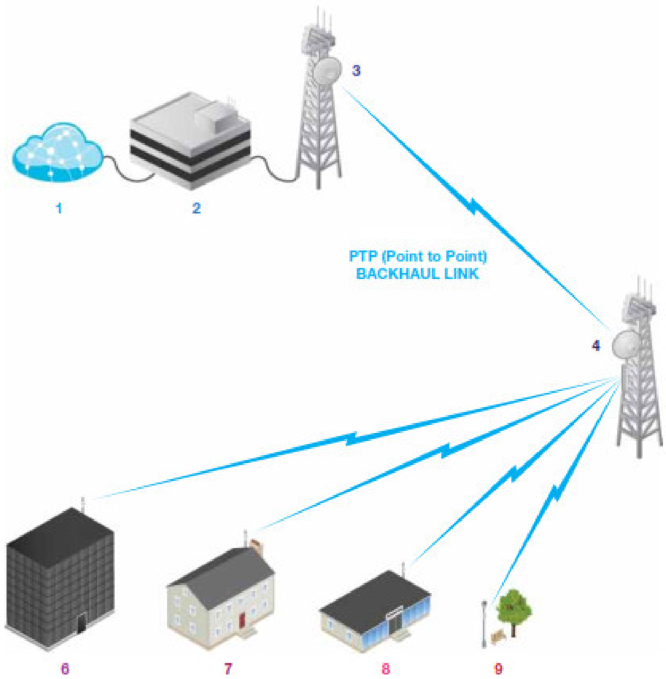

Figure 1: Typical point-to-point and point-to-multi point Broadband access

5. An antenna mast in a rural/remote area from which the internet is distributed as point to multi point broadband

access
6. A corporate building in a remote/rural area
7. A house in a remote/rural area
8. A business a remote/rural area
9. A small village mast with omni-directional antenna acting as a wireless hotspot

There is evidence of ongoing research on the feasibility of using Wi-Fi over long distance point to point links; the Ashwani, the Ak-shaya, Aravind Eye Care System (www.aravind.org) and Digital Gangetic Plains (DGP) projects all in India(Raman and Chebrolu, 2007)(Bhagwat, Raman and Sanghi, 2004). Long-distance Wi-Fi based links are being used in the these projects to realize long distance point-to-point network deployments ranging up to hundred kilometers. Most of these studies and implementations of Wi-Fi based long distance point-to-point links are based on the ISM band of 2.4GHz frequencies. The standard in use is the IEEE 802.11b/g whose data link layer been modified from the CSMA/CA based MAC protocol to the TDMA based protocols. The performance of theses 2.4GHz based long distance point-to-point links has extensively been extensively studied, results documented and characterized (Chebrolu, Raman and Sen, Sep, 2006)(Flickenger et al., 2008)(Patra et al., April, 2007). Since the latter has lower transmit speeds capped at 11Mbps, the maximum achievable throughput recorded by (Chebrolu, Raman and Sen, Sep, 2006) was 7.63Mbps at the maximum transmit speeds of 11Mbps.

To the best of the authors' knowledge, no consistent and systematic study has been done in regard to the use of IEEE802.11a/n standards at 5.8GHz frequency band in establishing long distance point-to-point links when used to provide broadband internet access in rural areas. In this regard therefore, the contributions of this paper are two-fold:

- To investigate the feasibility of using the unlicensed 5.8GHz (UNII-3) frequencies to establish long distance point-to-point links capable of providing broadband internet access to rural areas
- To evaluate the performance of such links and show their performance characteristics under different parameter configurations, such that a predictive model is developed that may be used to enable the planning of such links in future with some degree of certainty and accuracy.

2. Related work

The earliest of works that attempted the use of Wi-Fi beyond its typical range was called Roofnet Project and was carried out by a group of MIT students to form an unplanned wireless mesh network nodes that served a large area with broadband access(Aguayo et al., 2005). The mesh network comprised of individual outdoor point-to-multipoint links that extended the Wi-Fi range to a few kilometers using omni-directional antennas (Aguayo et al., 2005). Their objectives were limited to the use of omni-directional antennas and multiple hops mechanism to extend the range of the Wi-Fi links. They failed to utilize the capacity of single-hop point-to-point links that have the potential of reducing the routing challenges that accompanies multi-hop settings. This is gap is what this paper attempts to explore.

(Sheth et al., 2007) conducted further experiments on the performance of Wi-Fi based long distance links, using IEEE802.11b/g standards and their observations were rather disappointing. Their links exhibited very high and variable packet losses, resulting in very poor usability of the high throughput along the links. Further tests indicated that when higher transmit power (23dB+) and higher sensitivity Wi-Fi radios were used, longer links in the range of a hundred kilometers could be achieved. These two apparently contradictory results were revealed that the cause of high packet losses was the insufficiency the existing carrier-sensing IEEE802.11 MAC protocol in long distance links(Raman and Chebrolu, 2005)(Chebrolu, Raman and Sen, Sep, 2006)(Raman and Chebrolu, 2007).

Some further work in this field was advanced by TIER group in University of California Berkeley (Patra et al., April, 2007). They used high-gain directional antennas to boost the link length. This allowed them to achieve link distance spanning up to a few tens of kilometers. (Flickenger et al., 2008) achieved 6Mbps over a382km link. Their findings were based on a TDMA enhanced MAC protocol modifications on IEEE802.11b/g standard that are necessary for a long distance links, as described by (Raman and Chebrolu, 2005) and (Patra et al., April, 2007). Since IEEE 802.11b/g standards have highest data rates capped at 54Mbps, that explains why their highest observable throughput was relatively low. However, IEEE802.11n standard has since dominated the Wi-Fi markets and tests on its capacity in deployments of long distance outdoor Wi-Fi links is worth investigating and likely to give better speeds particularly because of their superior features such as MIMO technology. This justifies the attempts in using of the 5 GHz frequencies to establish long-range point-to-point links to provide broadband access to rural areas.

Since the introduction of TDMA based MAC protocol for long distance Wi-Fi links, increased interest was observed among many technology enthusiasts and manufacturers. (Raman and Chebrolu, 2007) describes two projects in India in which IEEE 802.11 b/g (Wi-Fi) was used as a cost-effective technology to provide wireless access to rural areas i.e. Digital Gangetic Plains (DGP), and Ashwini. The DGP project was initiated in

2002 at the Indian Institute of Technology, Kanpur (IITK), Uttar Pradesh, to explore the technical feasibility of establishing long-distance 802.11g – based link. The Ashwani Project is a network deployment effort by the Byrraju Foundation, to provide broadband access and services to a collection of villages in the West Godavari district of Andhra Pradesh, India. The authors claim to have achieved 364 Kbps throughput capable of supporting an interactive video-based applications such as distance-education and telemedicine, on the network.

3. Methodology

3.1. Design Considerations

When setting up the Wi-Fi based long-distance links, several factors are addressed. These considerations include site selection, terrain and elevation profile, tower heights, choice of antenna, link budget, Fresnel zone clearance, antenna polarization, earth grounding and effects of earth's curvature among others. Each of these considerations is factored for a successful link establishment. The following six links were established as shown in the figure 2 below

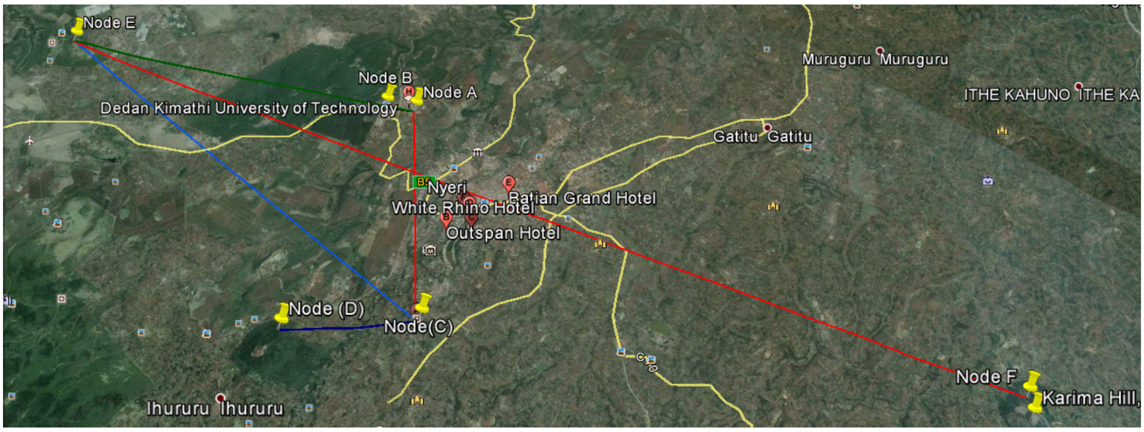

Figure 2: Satellite view of six nodes used as test beds

3.2. Basic requirements

The basic Wi-Fi based long-distance link required two Wi-Fi radios affixed at the focal point of the parabolic dish antenna. Each pair was located at each of the two nodes, one connected to the wired backhaul broadband access and serving as the access point while the other on the remote site. Two teams each with laptops was stationed at the two nodes and an additional wireless router were used to extend wireless LAN to unlimited number of computers, at the remote site. A pair of binoculars was used to obtain a general view of either nodes and ensure that a line-of-site (LOS) is achieved.

A cellular phone for each team was necessary communication purposes, particularly sharing of the setup link parameters and the link performance testing. Google Earth, topographical software, was employed to determine the best locations that were clear of topographical barriers, obstacles or rugged terrain for the LOS establishment. Figure 3 shows the elevation and terrain profile of a 24.3km link, the longest achieved distance so far. It is evident that a very clear line of site is established as well as the 60% fresnel zone clearance requirement.

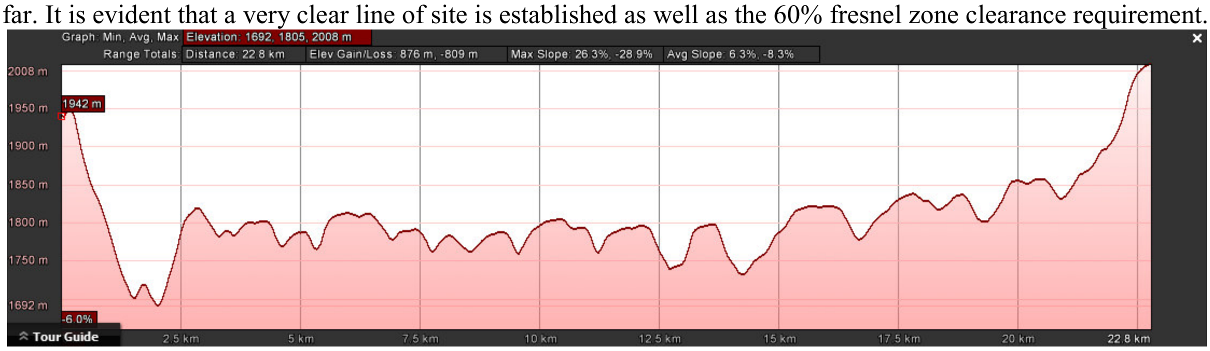

Figure 3: Terrain profile of nodes E & F, a 24.3KM link, between Aberdare country club and Kiangwaci, Othaya, Nyeri, Kenya

3.3 Choice of Antenna

The deployment of long distance Wi-Fi based links demands use of high gain directional antenna whose characteristics and features have been pre-determined. Most microwave systems utilize parabolic dish antennas because of their high gain advantage. This antenna comprises of a driven element and a passive spherical reflector. The driven element, often called the antenna feed, may be a wire dipole antenna. The reflector size is dictated by the wavelength of the signal to be transmitted or received and is usually in the order of several wavelengths. The driven element must be positioned at the exact focal point of the parabola-shaped reflector. At this position, it receives the converged narrow beam of the electromagnetic waves that bounce off the reflector, which is thereafter fed to the Wi-Fi radio either through a coaxial line feed or the radio is connected at the focal point of the reflector. For this work, Ubiquiti Rocket-dish antenna and MIMO Airmax radio were used.

3.4 Antenna height and Fresnel zone clearance

The line of sight path is divided into different regions, called Fresnel zones that accommodate varying velocities of the transmitted signal. Fresnel zone is an elliptical region surrounding the straight path (LOS) between the transmitting and receiving antennas and is caused by diffraction of the signal at a circular aperture(Flickenger, 2008) as illustrated in Figure 4 below.

Radio waves travel in a straight line unless obstructed. When there are reflecting surfaces within an even Fresnel zone, the radio waves reflected from these surfaces arrive out of phase with the line of sight signal causing destructive interference and hence signal degradation. When the reflection off a surface is in an odd Fresnel zone, the interference is constructive leading to improved signal quality (Outmesguine, 2004). A clear first Fresnel zone allows the transmitted signal to travel with very little attenuation. It is free when the midpoint of the ellipse is free and clear of obstruction at least 0.6 of the radius. To achieve best results, the radius of the elliptical shape should be calculated in order to determine the height of the antenna towers.

Fresnel losses may be as high as 20dB if large objects and obstructions are present in the line of sight. However, if at least the first 0.6 Fresnel zone is free of such objects, then Fresnel losses of approximately 6dB can be avoided. Whereas attempts may be made to attain clear line of sight by electing antennas on very high towers, the degradation of microwave frequencies with height, due to ground reflections cancelling out the signal, becomes the drawback that must be contended.

The rule of the thumb with Fresnel considerations is to keep at least 60% of first Fresnel zone unobstructed to achieve acceptable signal strength and tolerable signal attenuation. A formula to be used in calculating the Fresnel zone radius clearance is shown in equation (3.1)

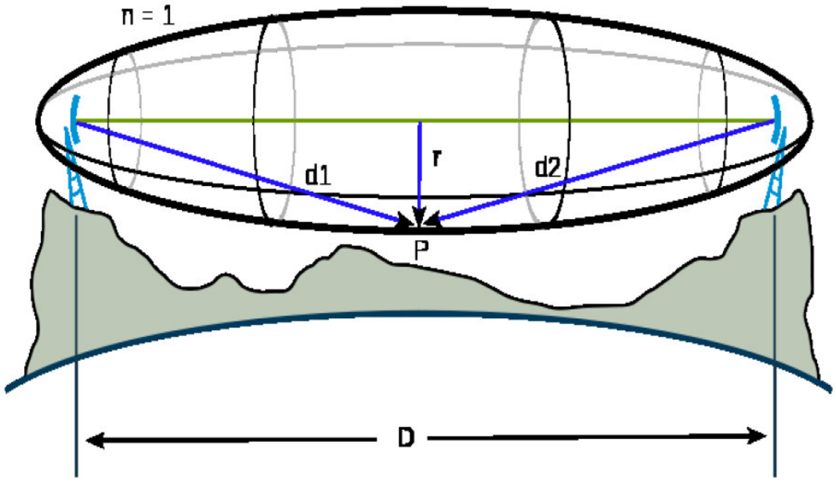

Figure 4: Detailed illustration of Fresnel zone and associated dimensions (Outmesguine, 2004)

$$h = 17.32\sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}}$$ (Farahmand and Webber, 2012) (3.1)

Where h is the Fresnel radius at a point just above potential obstruction
f is the frequency of the Wi-Fi signal in GHz
d_1 is the distance (km) from transmitting antenna to point just above potential obstruction
d_2 is the distance (km) from receiving antenna to point just above potential obstruction

Considering the 5.3km, Shama Hostels to Resource centre, link and assuming the land is perfectly flat, then the antenna towers height would be calculated as follows:

Given the frequency of operation $f = 5.8$ GHz and the distances d_1 and d_2 are assumed to be equal and the highest potential obstacle is located at the midpoint ($d_1 = d_2 = 2.65$km), then the antenna tower heights would be given by

$$h = 17.32\sqrt{\frac{2.65 \times 2.65}{5.8(2.65 + 2.65)}} = 8.27 Meters \tag{3.2}$$

From these calculations, it is clear that a minimum antenna mast height on each side was 8 meters. However, the assumption is obviously inaccurate and the most likely scenario is that the antenna mast is located at an elevated point. This gives the advantage of reduced height requirements. For the work that was carried out, detachable antenna mast of seven to ten meters were used. As shown in Figure 3 above, the terrain for all of the six links resembled it or varied very insignificantly. This means that the 60% Fresnel zone clearance was met for all the links.

3.5Link Budget Considerations

Link budget requirements demands proper calculation of the gain of the antennas used as well as the sensitivity of the Wi-Fi radios to achieve required signal strengths. The overall goal is ensure that the signal strength at the transmitter meets the threshold required by the sensitivity of the receiver. Several parameters, as listed below, are considered and varied for the threshold to be met.

- **Effective transmitting power (P_{eff})** which is equal to Wi-Fi radio transmit power, P_t (dBm) plus the antenna gain, G_t (dBi) less the cable and transmitter feeder losses, TFL (dB)
- **Free space loss, *fsl* (dB)** is the loss of signal strength in free space
- **Effective receiving sensibility, S_{eff}** which is equal to Receive antenna gain, G_r (dBi) less receiver feeder loss, RFL (dB) and Wi-Fi radio sensitivity, S (dBm)

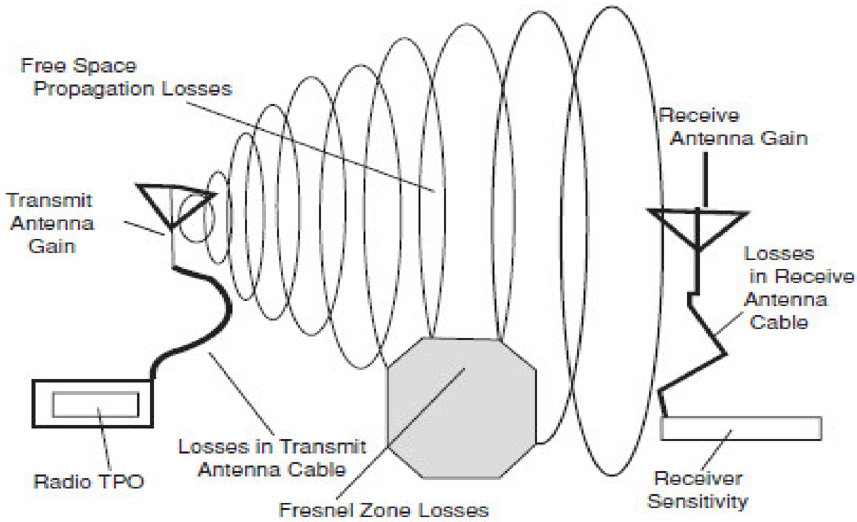

Figure 5: Illustration of link budget parameters [9]

Taking a practical scenario of the Dedan Kimathi Resource Centre to Shama Hostels Link, Nodes A-C, the link budget is calculated as follows

- The LOS link length of 5.3 Km
- The curvature of the earth is 0.55 Meters
- The highest obstacle is 10meters at midpoint
- The frequency of operation is 5.8GHz
- The Fresnel radius was calculated to be 11.29Meters (with 40% blockage allowance)
- The **free space loss** is defined by $fsl = (\frac{4\pi r}{\lambda})^2$ and in dB $fsl = 10\log(\frac{4\pi r}{\lambda})^2 dB$ where λ is the wavelength of the transmitted signal in meters obtained from $\lambda = \frac{c}{f}$ with $c = 3 \times 10^8 ms^{-1}$ and $f = 5.8GHz$ giving $\lambda = \frac{3 \times 10^8}{5.8 \times 10^9} = 0.052 meters$

Therefore free space path loss $fsl = (\frac{0.052}{4\pi \times 5.8 \times 10^9})^{-2} = 1.409 \times 10^{12}$ which when expressed in decibels becomes $fsl = 10\log(1.658 \times 10^{12}) = 121.4dB$

Since most MIMO Wi-Fi radios at 5.8GHz have transmit power capped at, $P_t = 27dBm\ (500mW)$, receive sensitivity of approximately -75dBm and approximating the cable and connector losses to 5dB, then the effective transmit power P_{eff} can be expressed as

$$P_{eff} = P_t - TFL + G_t = 27dBm - 5dB + G_t \quad (3.3)$$

Where TFL is the transmitter feeder loss approximated as equal to 5dB and G_t is the transmit antenna gain.

The effective receiver sensibility S_{eff} is given by

$$S_{eff} = G_r - RFL - S = G_r - 5dB - -75dBm \quad (3.4)$$

and finally the link budget dictates that the signal strength at the receiver is given by

$$P_r = P_{eff} + S_{eff} - fsl \quad (3.5)$$

Since it is possible to set the two antennas have the same gain and in order to achieve a strong link, a 6dB signal strength margin is set as threshold. Thus the major design consideration is the antenna gain and by the above calculations, the link budget for the Shama Hostels - DeKUT link, A-C, is obtained as from equation (3.5)

$$6dBm = 27dBm - 5dB + G_t + G_r - 5dB - -75dBm - 121.4dB \quad (3.6)$$

Since $G_t = G_r$, then it is possible to evaluate the their values from (3.6) as

$$6dBm - 27dBm + 5dB + 5dB + -75dBm + 122.2dB = G_t + G_r = 36.2dBi \quad (3.7)$$

And from (3.7)

$$G_t = G_r = 18.1dBi \quad (3.8)$$

Thus, the antenna gain is evaluated as above and given by 18.1dBi. The 30dBi antennas used clearly exceeded this gain.

3.6 Antenna Alignment

While the antenna alignment is an enormous research task by itself(Subramanian et al., 2006), way beyond the scope of this research, a simplified approach of antenna alignment was used. Since the link distances were relatively short, the antenna alignment was majorly performed to achieve azimuth plane alignment first and then a little tilting of the antenna masts to achieve elevation plane alignment.

The Ubiquiti antennas have an inbuilt software based frequency spectrum analyzer that was used to perform antenna alignment. It produces different beep sounds depending on the signal strength received. When for instance the antennas are completely out of alignment, the received signal strength was in the range of -96dBm and less. As the antenna masts are rotated in the azimuth plane and tilted in elevation plane, the received signal strength rises to the best achievable. For most of the links, the best alignment produced signal strength in the range of -20dBm to -68dBm depending on the link length. Figure 2 shows the interface of the software based spectrum analyzer used in the antenna alignment.

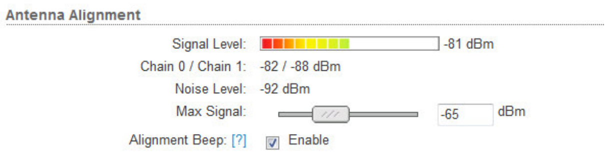

Figure 6: Software based Spectrum analyzer

3.7 Data Collection

The general objective of this research was to validate the usability of the UNII-3 Wi-Fi frequencies in establishing long distance point-to-point links. Initially, at least six links were to be tested for consistency and proof of variability of the achievable throughput and any possible packet losses or un-anticipated causes of any link performance degradation. Each link was to meet the above mentioned design factors and considerations; each link had clear line of site, with at least 60% Fresnel clearance, the gains of the antennas did meet the minimum threshold as defined in the link budget calculations. Each node had a parabolic dish antenna and a Wi-

Fi radio. For this work, an off-the-shelf commercial antenna, Ubiquiti Rocket Dish 30dBi antenna was used. This antenna comes with a Wi-Fi radio whose MAC protocol has been modified from the usual CSMA/CA based protocol to a proprietary TDMA based protocol called, Airmax.

Data collection was done for the six links mentioned, all independently of each other. Two independent factors and their effect on the achievable throughput were investigated. These are the channel width and link distance. The objective was to determine how and to what extent each of these affects achievable throughput and their correlation. The research question meant to find out whether the achievable throughput is dependent on the link and whether there is any significant correlation between the link distances and the channel width. Further, whether the effect of channel width is the same for all the link distance or whether there are link lengths when its effect is more or less pronounced was explored.

For each link, a file of 1.17GB was transferred across the link from the access point node to the station node. This was repeated for different parameter values, that is, when channel width was at 40MHz, 20MHz, 10MHz and 5MHz. the observed values of the achievable throughput for each channel width were recorded and tabulated. This was repeated for the six links.

4. Results and Discussions

It was observed that as long as the line of site was free of obstructions, the link establishment was rather easy and straightforward. The link displayed different characteristics for different parameter settings. Since the antennas used allowed four values of channel width to be set, the widest channel width gave the best results. Average values in the range of 96Mbps to 106Mbps were recorded for each of the six links when the channel width was set at 40MHz. In fact, it was later noted that this average value was relatively capped at these same values for all the links by the inferior Ethernet drivers installed in one of the laptops used in the tests. This means that each of the links were capable of achieving higher throughputs way above the 100Mbps mark recorded. This will be shown in a later paper when experiments are repeated with superior-drivers laptops.

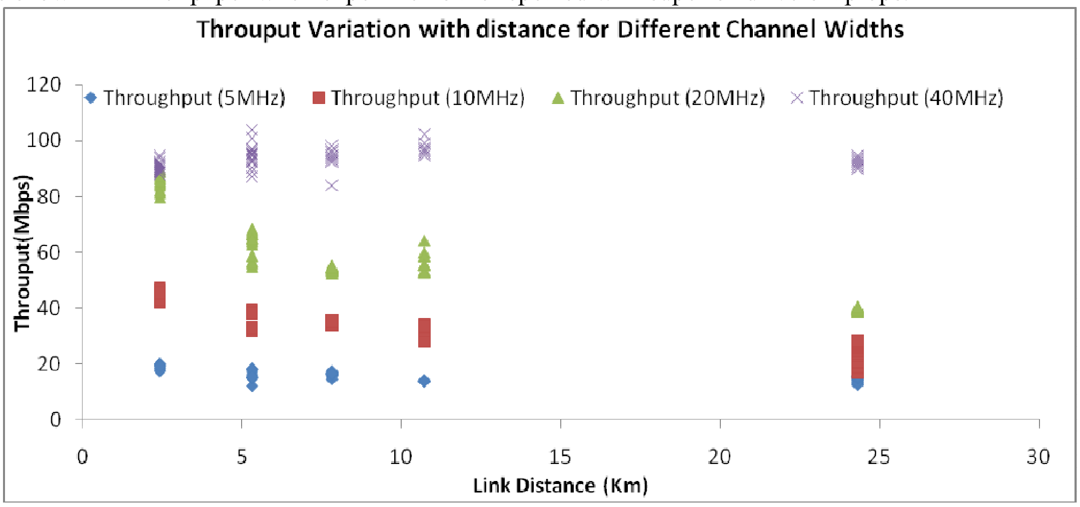

Figure 7: Graph showing interrelationship between Distance and Channel width and their effect on throughput

As can be seen from figure 7 above, channel width has greatest impact on throughput for short distance links while the effect diminishes with increased link lengths. As observed above, the 40MHz channel width is not properly represented by the observed throughput values, due to Ethernet throttling as mentioned earlier. Therefore, in figure 8 below, the values recorded in the settings are omitted in the graph. The resulting graphs correctly illustrate the above-mentioned handicap, as shown in figure 8.

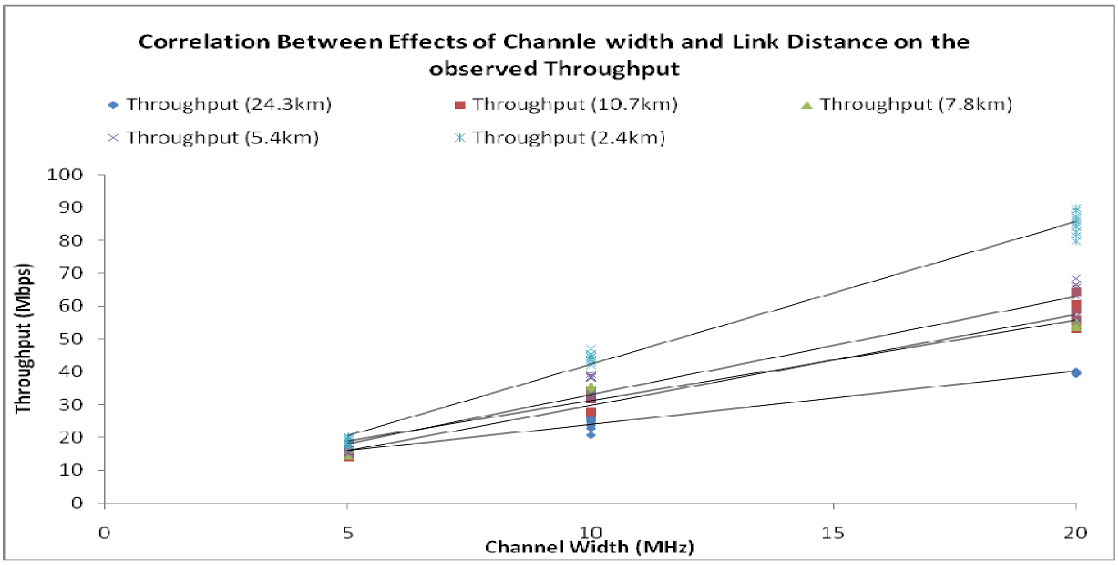

Figure 8: Effect of Channel Width on Throughout for Different Link Distances

The interrelationship between these variables may then be explained best by a linear regression model whose equation is

$$\zeta = 16.633 - 0.632d + 2.154\varpi \tag{3.9}$$

Where ζ it throughput
d is the distance and
ω is the cannel width
This is a best fit bivariate regression model with the following parameters

Table 1: Regression Statistics

Regression Statistics	
Multiple R	0.97
R Square	0.94
Adjusted R Square	0.94
Standard Error	7.60
Observations	256.00

						0.95		0.99
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 99%***	***Upper 99%***
Intercept	16.63	1.04	15.96	0.00	14.58	18.68	13.93	19.34
distance	-0.63	0.07	-9.33	0.00	-0.77	-0.50	-0.81	-0.46
channel width	2.15	0.04	60.75	0.00	2.08	2.22	2.06	2.25

As can be seen in Table 1, throughput and channel width have a positive linear relationship, while the distance and throughput have negative linear relationship. The adjusted R value of 0.94, as seen in the regression statistics table above means that 94% of the change in the observed throughput can be explained by the two dependent variables: distance and channel width. At 95% confidence interval, the slope of the throughput – channel width linear relationship is between 2.08 and 2.22 while that of throughput-distance lies between -0.77 and -0.5.

5. CONCLUSION

It was observed that as long as the basic requirements for setting up Wi-Fi based long distance point to point links were met, and then link establishment was straightforward. These basic requirements were clear line of sight with at least 60% first Fresnel zone clearance, the link budget requirements of antenna gain and Wi-Fi radio sensitivity Simplified antenna alignment is achievable with minor vertical tilting and horizontal rotation of the antenna masts. This was possible with the use of software-based frequency spectrum analyzer that comes integrated with the Ubiquiti Wi-Fi radios.

Airmax, a TDMA based MAC protocol, that runs in the Ubiquiti Wi-Fi radios is capable of providing throughput of 100Mbps or higher. It was noted that link distance has very minimal effect (as low as -0.5 change in throughput per unit distance, with the channel width held constant) on the achievable throughput as explained in the equation(3.9).

In other words, this paper demonstrated a simplified model of a test-bed that may be used to provide broadband internet in rural areas. The observed peak throughput values of 90+Mbps can meet the demands of an entire village of 1000+ simultaneous users assuming 256kbps bandwidth may be utilized by 2-5 users at any given time. This is true since most users in the village will use the bandwidth to primarily access web pages, access emails, visit and share in social sites and rarely download one or two files in a day. This justifies the bandwidth requirement of 100kbps per an average user in a rural area of a developing country.

6. References

Aguayo, D., Bicket, J., Biswas, S., Couto, D.S.J.D. and Morris, R. (2005) 'Architecture and Evaluation of the MIT Roofnet Mesh Network', MOBICOM.

Bhagwat, P., Raman, B. and Sanghi, D. (2004) 'Turning 802.11 Inside-Out', ACM SIGCOMM Computer Communication Review, New York, NY, USA, 33-38.

Chebrolu, K., Raman, B. and Sen, S. (Sep, 2006) 'Long-Distance 802.11b Links: Performance Measurements and Experience.', 12th Annual International Conference on Mobile Computing and Networking (MOBICOM).

Farahmand, A. and Webber, M. (2012) *Improvised wireless networking*.

Flickenger, R. (2008) *Wireless Networking in the Developing World*, 2nd edition.

Flickenger, R., Okay, S., Pietrosemoli, E., Zennaro, M. and Fonda, C. (2008) 'Very Long Distance Wi-Fi Networks', The second ACM SIGCOMM workshop on Networked systems for developing regions, Seattle, USA, 1-6.

Outmesguine, M. (2004) *M. Outmesguine, Wi-Fi Toys: 15 Cool Wireless Projects for Home, Office, and Entertainment*, 1st edition, Wiley Publishing, Inc.

Patra, R., S., N., Surana, S., Sheth, A., Subramanian, L. and Brewer, E. (April, 2007) 'WiLDNet: Design and Implementation of High Performance WiFi Based Long Distance Networks.', USENIX NSDI.

Raman, B. and Chebrolu, K. (2005) 'Design and Evaluation of a new MAC Protocol for Long Distance 802.11 Mesh Networks', 11th Annual International Conference on Mobile Computing and Networking pape, 156-169.

Raman, B. and Chebrolu, K. (2007) 'Experiences in using Wi-Fi for Rural Internet in India', *IEEE Communications Magazine,* , vol. Special Issue on New Directions In Networking Technologies In Emerging Economies, Jan.

Sheth, A., Nedevschi, S., Patra, R., Surana, S. and Brewer, E. (2007) 'Packet Loss Characterization in WiFi-based Long Distance Networks', *IEEE Communications Magazine*, vol. 2, pp. 311-320.

Subramanian, L., Surana, S., Patra, R., Nedevschi, S., Ho, M. and Brewer, E. (2006) 'Rethinking Wireless for the Developing World', 5th Workshop on Hot Topics in Networks (HotNets).

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