Performance Analysis of E-Band 70/80 GHz Frequency Segment for Point to Point Gigabit Connectivity

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Abstract

The commercial viability for E-Band spectrum has attracted a lot of research for the last decade in order to find economic wireless gigabit connectivity that can complement fiber optic cable. This paper has analyzed the usefulness of E-Band point-to-point microwave link in providing wireless backhaul capacities comparable to that of fiber optic cable. In particular, microwave links that utilize the E-band frequencies were set up in three different cities in Kenya i.e. Mombasa (Latitude 04 01 24.10 S, Longitude 039 37 35.10 E) and validated the acceptable propagation and performance of millimeter wave links at E-Band frequencies for distances within and well above the promised limits in the existing literature. Daily occurrences of signal losses closely match the rainfall pattern, and this has been used to further validate the practicality of the experiments. These experiments were successful in verifying that E-Band can be used in Kenya for short range backhaul connectivity and in slightly over stretched path lengths of 3-6 km under clear atmospheric conditions.

1. Introduction

The data usage in major cities has increased and so is the demand for a better infrastructure to support the requirements. Fiber network remains the most obvious options when the question of customer premise connectivity arises and even when considering a backhaul solution for GPON solutions and even small to medium data centers due to nearly unlimited bandwidth. However, fiber optics cable has its own limitations in terms of cost, maintenance and implementation lead time especially when the timelines are short. Application for way leaves, trenching among many other procedural requirements make fiber optics cable only a long term solution and its long MTTR provides the need to have a complimentary solution that may not match its capability in terms of bandwidth but close enough to meet demand expectations.

E-band spectrum has for a long time dominated the millimeter frequency transmission solutions literatures owing to the wide bandwidth available and its relatively low atmospheric absorption compared to the neighbouring spectrum bands. Even though E-Band has relatively short wave lengths that cannot penetrate solid and obstacles, this is a common characteristic for nearly all millimeter wave transmission solutions which can only operate on line of sight for point to point transmission [1]. In addition, all frequencies above 10GHz are affected by rain fade making the propagation characteristics nearly the same. Unlike free space optics, E-Band is not subject to fog, dust, air turbulence or any other atmospheric impairment that can take down optical links for hours over regular cycles [1].

Systems designed at 70/80 GHz provide 10 GHz bandwidth that is far much more than what is currently available on the lower point to point transmission frequencies from 6-42 GHz. The higher frequencies antennas are designed with pencil like highly directive beam width that not only provides high gain to compensate for high free space loss but also provide the high discrimination required that makes it easy to plan so many links within a dense network without suffering from adjacent channel interferences [2].
The E-Band licensing adopted is “light licensing” so that users only pay for a reasonably small administration fee to the regulating authorities. This licensing model provides full interference protection and also makes the economics of gigabit connectivity attractive [2].

2. Theoretical Analysis

2.1 Free Space Loss

Free space loss is the expected attenuation of an electromagnetic wave signal as it travels away from the source. When a signal radiates from the antenna, it spreads out over an increasingly larger distance. As the area covered increases, the power intensity (the amount of power per unit area) decreases. This effectively weakens the electromagnetic wave signal. When calculating the link budget, it is important to obtain the FSL first in order to determine the link feasibility. The FSL is given as [12]

$$FSL = \left(\frac{4\pi d}{\lambda}\right)^2$$

$$= \left(\frac{4\pi d f}{c}\right)^2 \qquad (1)$$

Where:

- f is the transmission frequency in (MHz)
- d is the path length between the transmitting and receiving antennas in (KM)
- c is the speed of light, given as 2.99792458×10^8 m/s

$$FSL(dB) = 10log_{10}\left(\frac{4\pi df}{c}\right)^2$$

$$= 20log_{10}\left(\frac{4\pi df}{c}\right)$$

$$= 20log_{10}\left(\frac{4\pi}{c}\right) + 20log_{10}d + 20log_{10}f$$

$$= 20log_{10}d + 20log_{10}f + 32.44$$

The above formula complies with ITU-R P.525 [12], free space attenuation calculation for point-to point microwave transmission links in all frequency bands permitted by ITU-R frequency sector.

Example of free space loss for 23GHz and 80GHz link over a 3km path length will thus be;
For 23GHz

$$FSL(dB) = 20log_{10}d + 20log_{10}f + 32.44$$

$$= 20log_{10}3 + 20log_{10}23000 + 32.44$$

$$= 20 \times 0.4771 + 20 \times 4.3617 + 32.44$$

$$= 9.542 + 87.234 + 32.44$$

$$= 129.216dB$$

For 80GHz

$$FSL(dB) = 20log_{10}d + 20log_{10}f + 32.44$$

$$= 20log_{10}3 + 20log_{10}80000 + 32.44$$

$$= 20 \times 0.4771 + 20 \times 4.9031 + 32.44$$

$$= 9.542 + 98.062 + 32.44$$

$$= 140.044dB$$

From the two values it is evident that at E-Band the free space attenuation is higher compared to the lower frequency bands. Thus the lower frequency bands have better radio propagation characteristics than their E-Band counter parts. However, at E-Band frequencies the antenna has a pencil like beam which increases its directivity and gain. This antenna characteristic compensates for the high free space loss and gives E-Band enough EIRP that can enable it to perform considerably well in the same propagations conditions as 23 GHz band.

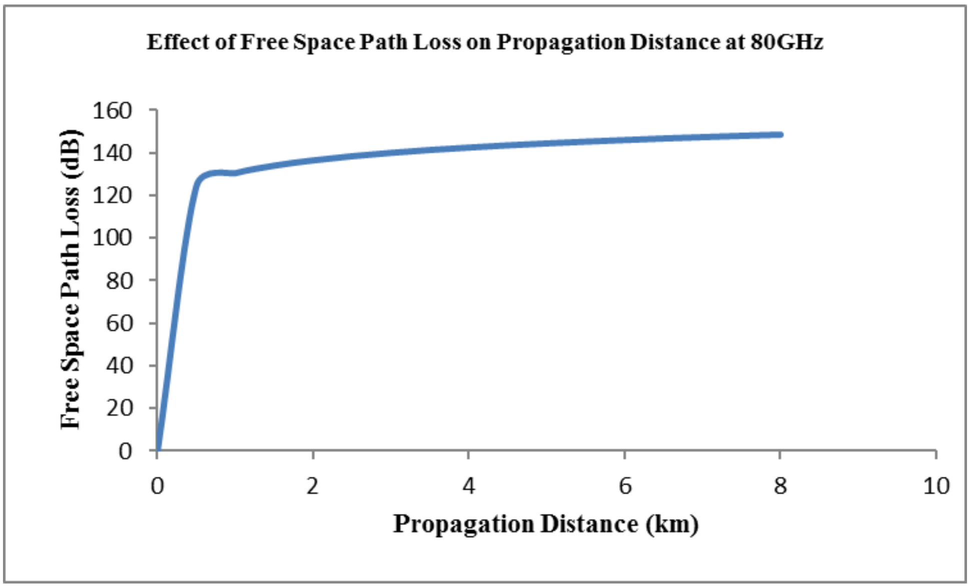

Fig 1 Graph of FSL as a function of propagation distance at 80GHz [12]

2.2 Rainfall (Precipitation) Attenuation

Rain attenuation greatly affects the performance (availability) of a microwave link. In this paper, we analyze the effect of rain attenuation on transmission performance of an E-Band link. Rain specific attenuation is estimated by the equation;

$$\gamma_R = kR^{\alpha} \qquad (2)$$

Where γ_R(dB/km) is the specific rain-related attenuation and R (mm/hour) is the rain rate parameter differentiating the intensity of a rain fall and may be obtained through a set of specified values given in ITU-R Recommendation P.837-1. The coefficients k and α are frequency and polarization dependent and may be obtained from a set of specified values given in ITU-R Recommendation P.838-1.

To estimate rain attenuation, the propagation distance is used to account for the distribution of the rain cells. Attenuation is given by;

$A = \gamma_R . D$, where D is the propagation distance

(3)

Rain attenuation tends to reduce the propagation range of a microwave link.

3. Link Planning and Implementation

NEC iPASSO EX E-Band links were implemented in Kenya at the coastal city, Mombasa (Latitude 04 01 24.10 S, Longitude 039 37 35.10 E) and performance data collected for a period of 3 months. Pathloss 4.0, a microwave link planning and design software tool was used for link engineering.

Parameters	**Mombasa**	
	Link 1	**Link 2**
Link Path Length	6.12km	0.49km
Transmit Frequency (MHz)	81125	81125
Receive Frequency (MHz)	71125	71125
Duplex Spacing (MHz)	10000	10000
RF Channel Spacing	250MHz	250MHz
Modulation	16QAM	16QAM
Ethernet Bandwidth (Mbps)	799	799
Antenna Size (m)	0.6	0.3
Antenna Gain (dBi)	50.5	43.5
Transmit Power (dBm)	13	13
RX Level (dBm)	-40.93	-35.57
Fade Margin (dBm)	22.07	38.43
Design Availability (%)	99.867	100
Equipment Type	NEC	NEC

Table 1 Link planning and design parameters

4. Results and Observations

Link 2 with a shorter path length had a good performance without registering a single error during the period of monitoring.

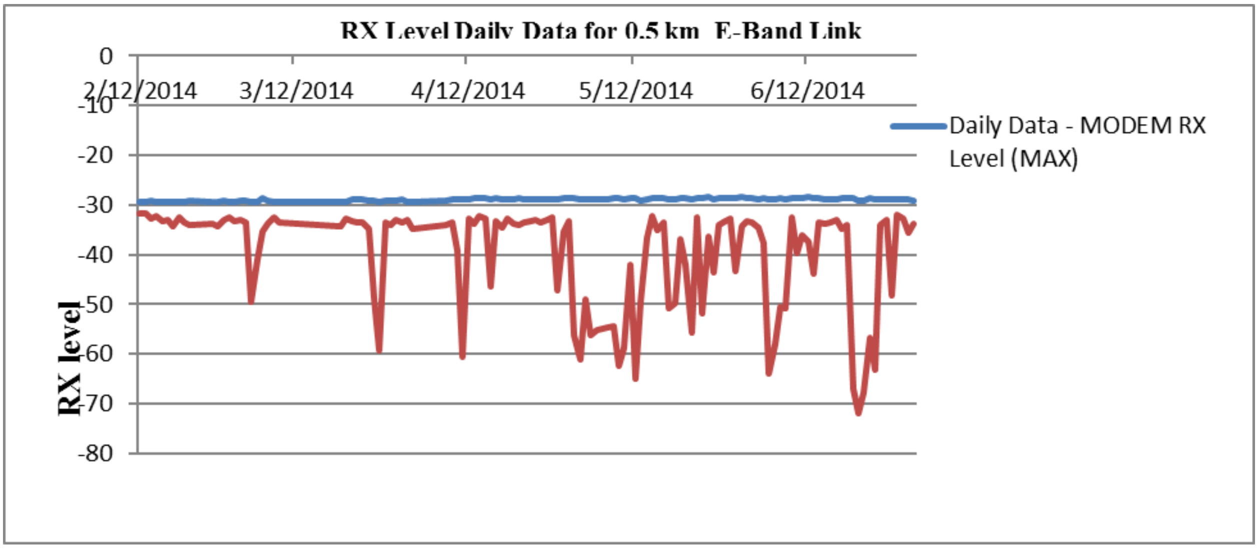

Fig 2 Daily maximum and minimum RX levels for link 2

Link 1 of a longer path length equally performed well but registered periods of errored and unavailable seconds.

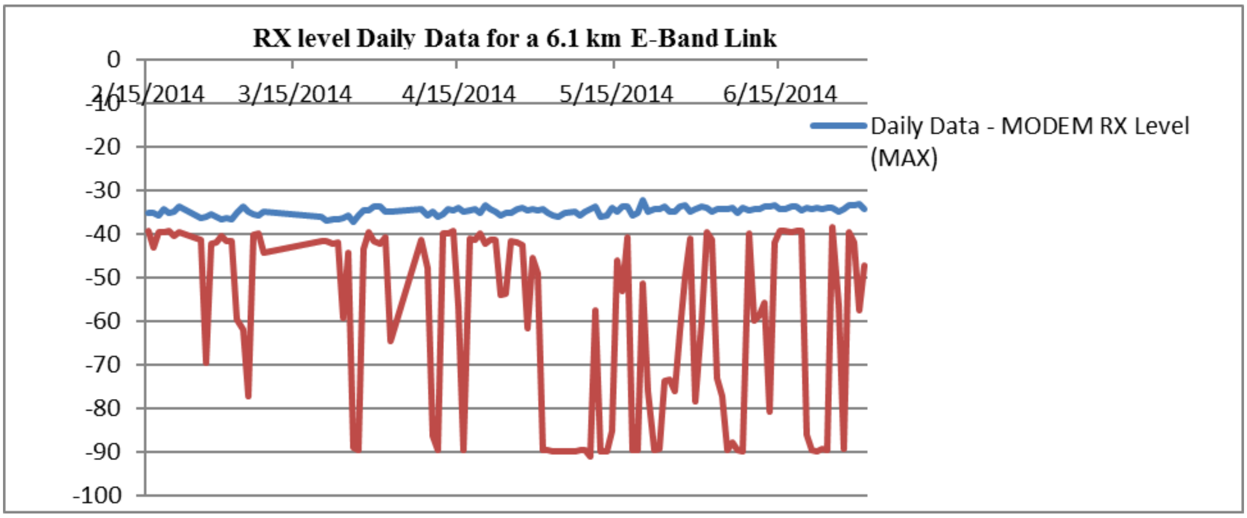

Fig 3 Daily maximum and minimum RX levels for link 1

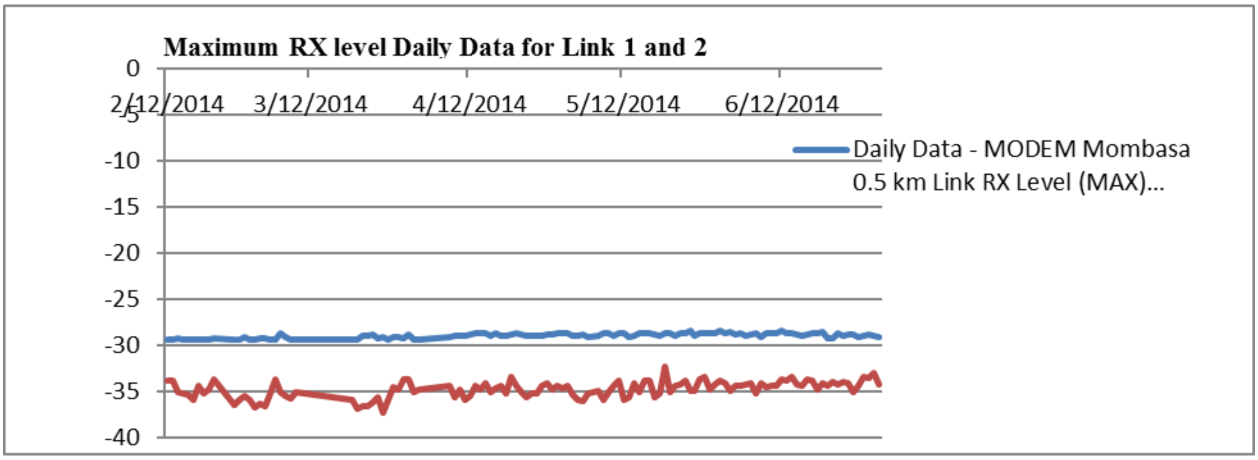

Fig 4 Comparison of maximum RX levels for links 1 and 2

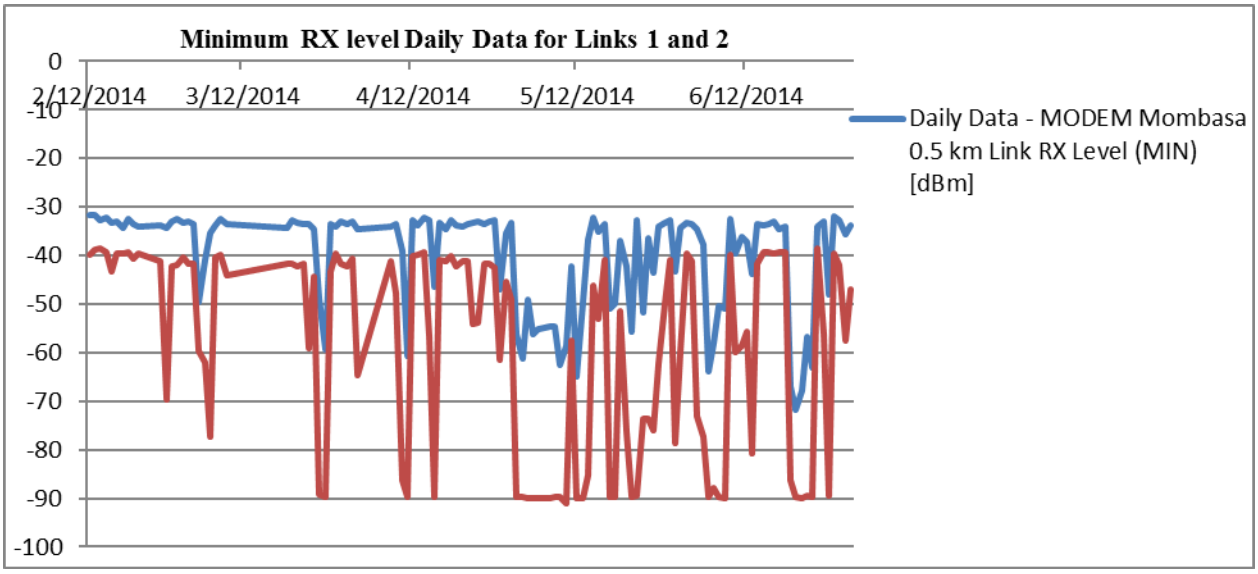

Fig 5 Comparison of minimum RX levels for links 1 and 2

The following graphs were plotted and observations made on link performances in comparison to daily rainfall data obtained from the meteorological department of Kenya. Data from MOMBASA PORT REITZ AIRPORT STATION was used for links performance analysis.

The shorter hop had 100% availability even with the presence of rainfall for the entire duration of performance monitoring.

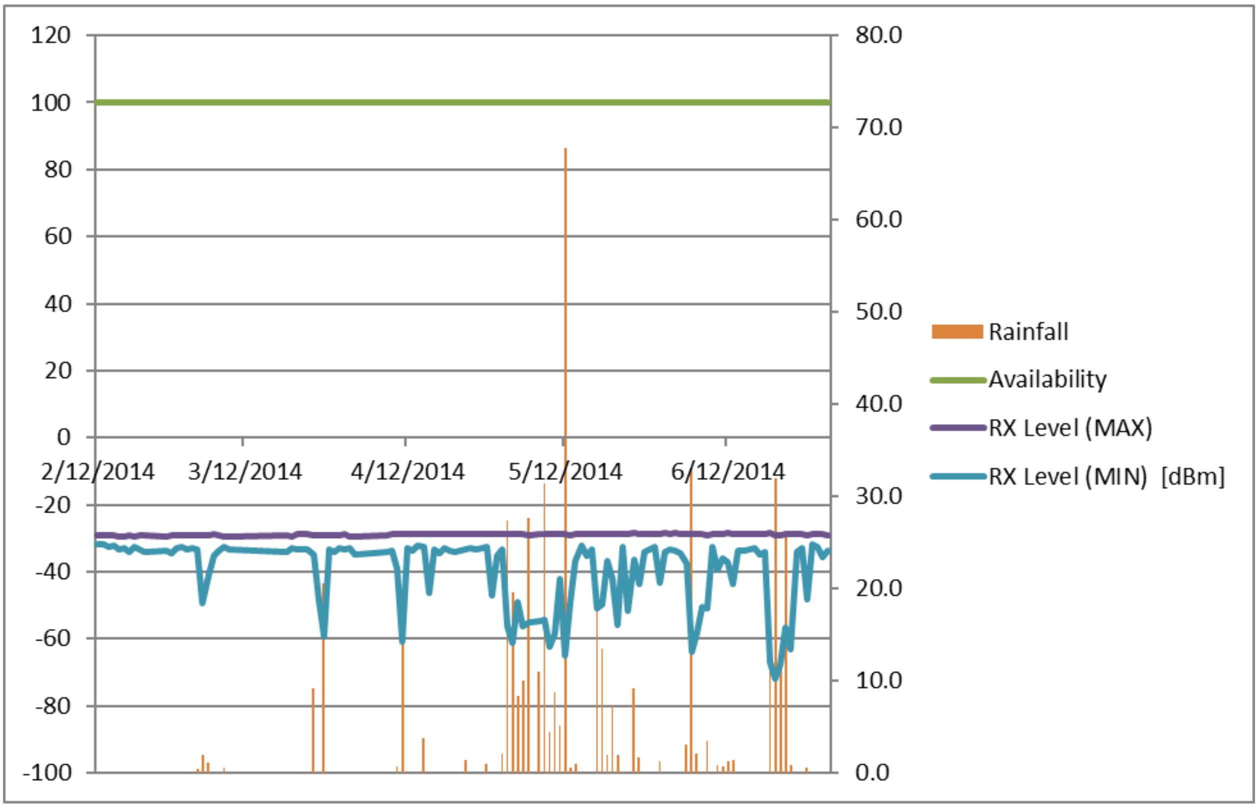

Fig 6 Comparison of RX levels and Availability with daily rainfall data for link 2

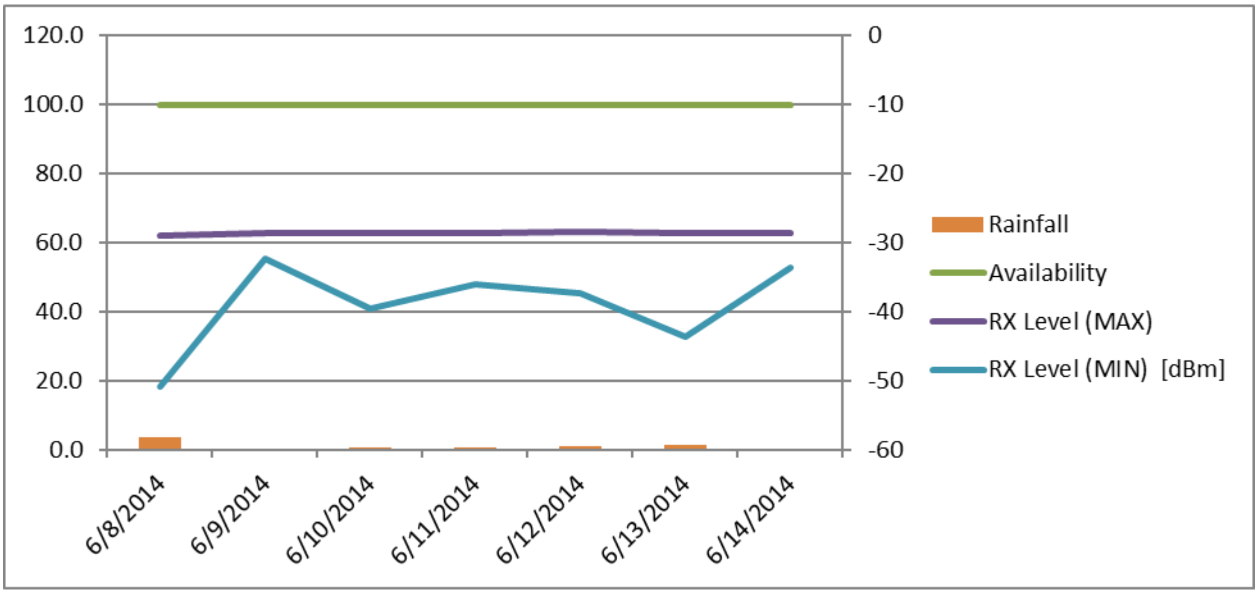

Fig 7 One week comparison of RX levels and Availability with daily rainfall data for link 2

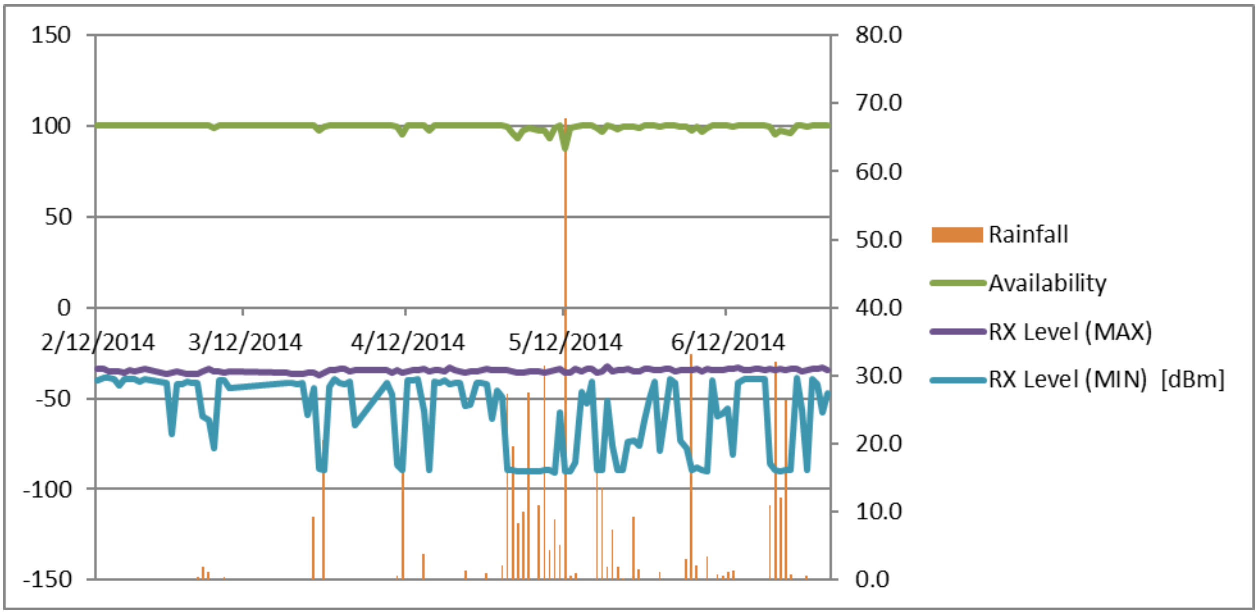

Fig 8 Comparison of RX levels and Availability with daily rainfall data for link 1

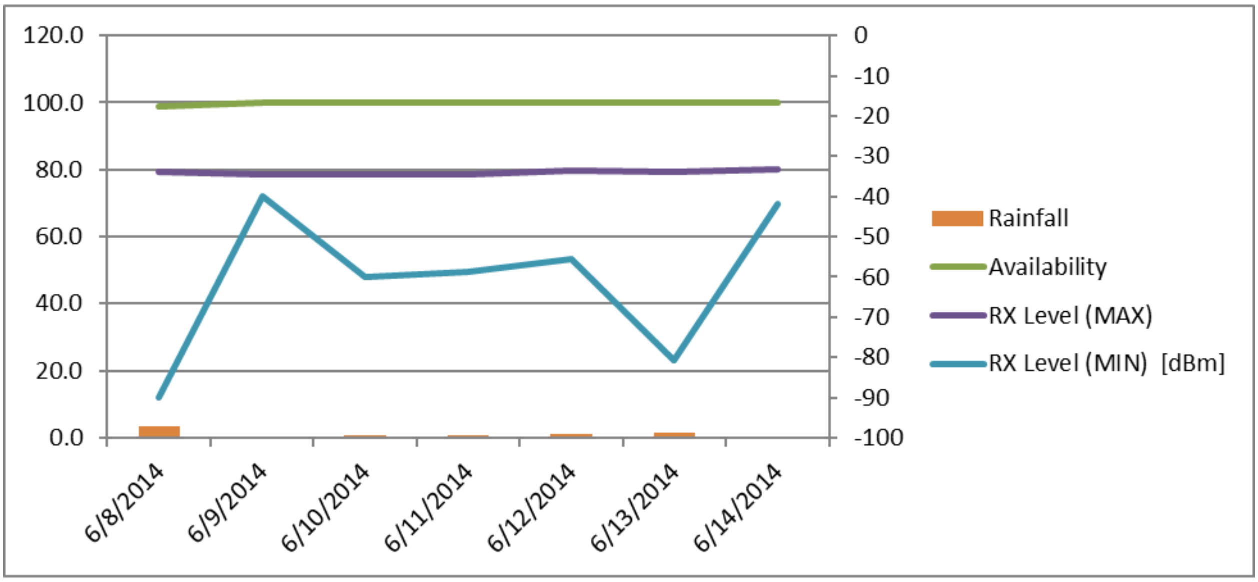

Fig 9 One-week comparison of RX levels and Availability with daily rainfall data for link 1

5. Analysis

The maximum power for E-Band used was 16dBm at QPSK meaning it matches more less the same power capability of equipment used for 15 and 23Ghz. Due to high antenna directivity and with proper link alignment, a strong performance was achieved on both links with the 6km hop achieving a maximum receive signal level of -35dBm under clear atmospheric conditions. It can therefore be seen that the highly directive antenna is one of the biggest asset in overcoming the high free space loss for E-Band communication systems.

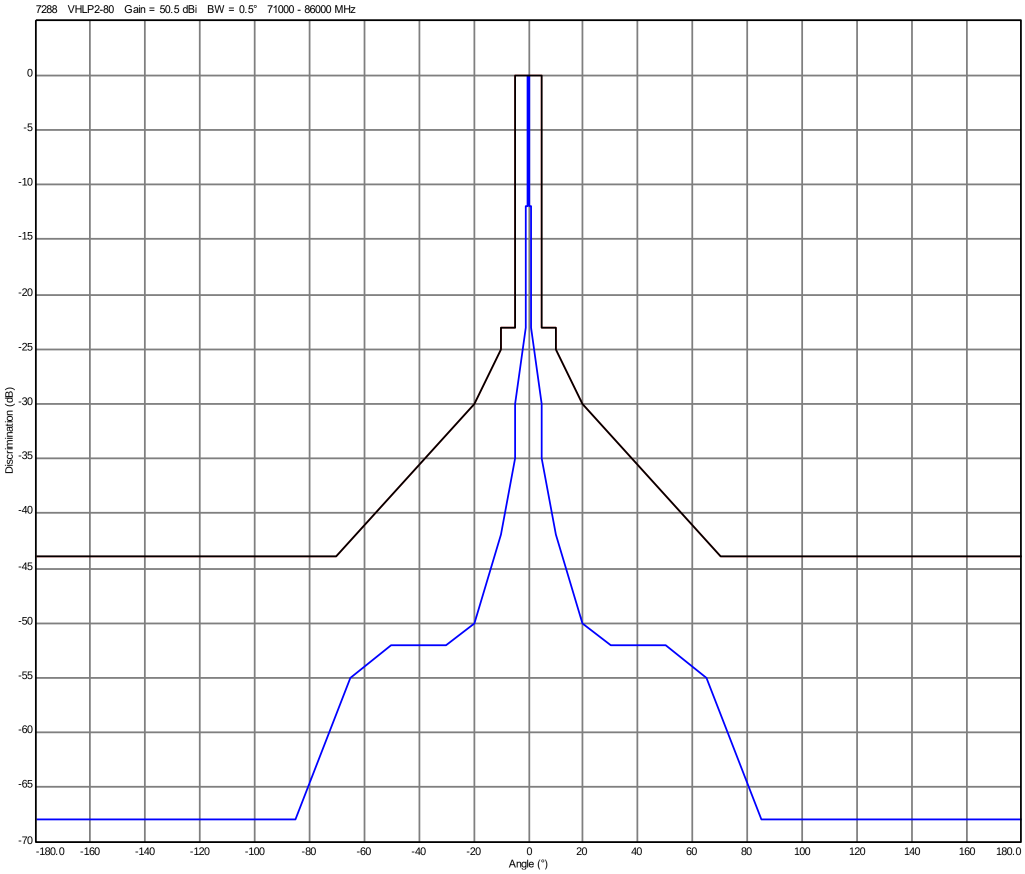

Fig 10 Radiation Pattern envelope of a 0.6 m (2ft) E-Band antenna

It was also noted that none of the links registered even a single error at a received signal level of -70 dBm. All the links operated well without effects on the customer traffic while operating at received signal levels of between -63 and -70 dBm. The highly sensitive receiver thus helps in achieving a high fade margin to overcome fading due to bad atmospheric conditions.

The notable difference in the maximum received signal levels for the two links in Mombasa shows the effect of propagation distance on free space loss. As the link propagation distance increases the free space loss increases as well. Thus in as much as the longer link had a bigger antenna and gain, the additional 7 dBi gain was not enough to compensate for the 22 dB free space loss difference. The free space loss equation at 80GHz shows that there is a 22 dB increase in free space attenuation when the link distance is increased from 0.5 km to 6 km. the result also obeys the inverse square law where power decreases inversely as the square of the distance. Rainfall attenuation is a function of frequency and distance of propagation. Thus an increase in the path length coupled with high frequencies results in high rain attenuation that affects the availability of a microwave link and this explains the reason why the longer hop suffered most during rainfall periods. In order to make the link more robust, the modulation scheme can be reduced to QPSK and channel bandwidth increased to 500 MHz to ensure capacity is not compromised.

6. Conclusion

The purpose of this case study was to demonstrate the possibility of obtaining acceptable and sustainable performance of E-Band links in Kenya with an aim to open up high spectrum opportunities in this frequency band for alternative high data rate backhaul solutions. It has been proved that E-Band link can perform very well in path lengths of up to 3km and beyond this range under clear weather conditions. The good receiver sensitivity of E-Band equipment has seen the links work under very low received signal levels. This together with the high antenna gain has made it possible for equipment in this frequency band to be able to operate on higher path lengths of up to 6km or even more under clear weather conditions.

Acknowledgement

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