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Design of Short Haul High Capacity Intra City Microwave Access Link for Transport of Cellular Traffic

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Abstract: *India is one of the largest Telecom services providing country. After the Telecom sector liberalization (1995) cellular Traffic in India started increasing day by day. This increase in cellular traffic severely impacted mobile Access and Backhaul Network. Consequent to this, Indian Mobile operators were forced to augment their Mobile Access and Backhaul Network. While optical Fibre Network met the Backhaul requirement, it did not meet Access Network requirements due to extremely high Fibre Optic Cable laying cost in dense urban areas and due to more deployment time. Consequent to this Mobile Operators started looking for an alternative cost effective media to provide Abis traffic connectivity between BTS's (Base Trans receiver station).Microwave media emerged as alternative medium for Access connectivity. The design approach for intra-city Access Microwave (MW) link is different from long haul inter-city links. In majority of the cases hop lengths of Access Links vary from less than a KM to 5KMs. However in Rural areas short haul MW link hop length may be more than 10KMs. This article discusses the various aspects that are to be considered for designing Short haul Microwave Access links.*

Keywords: *Cellular, Mobile backhaul, Short-haul, Access. Microwave links, PDH, SDH, TDM, Abis, Optical Fibre, Tower, Microwave link availability, Performance*

1. Introduction

Figure: 1 indicates typical Mobile backhaul architecture including short haul Access, Fibre Backhaul, Fibre Aggregation (National Long distance) and Fibre core Network (Metro Network)

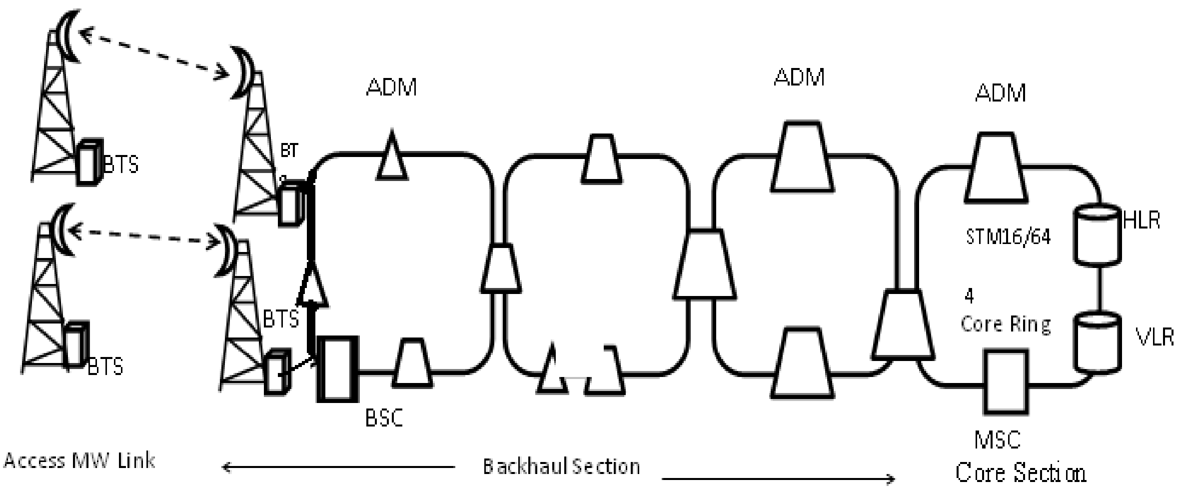

Fig1. *Mobile Backhaul Network*

In India ninety per cent of Mobile Network Access connectivity is built using Microwave links operating in the band of 15/18/23 GHz. In India as per the Government regulation 6/7/8 GHz Microwave (MW) spectrum can only be used for building long haul inter-city MW links of hop lengths greater than 15 KMs. Short Haul Access links are deployed to provide Abis traffic connectivity between BTS 's and between BTS to BSC's. In general, in Urban areas hop lengths of

Access links vary from less than a KM to 5 KMs, However in Rural areas hop lengths of Access Links may go up to 15 KMs. Access Links are short haul Intra City Links and Long haul links are Intercity Links built using high capacity Radios with large Antennas operating in 6/7/8 GHz band. In most of the cases Traffic requirement per BTS would 1 E1 (2Mbps) to 2 E1 (4Mbps), hence Access links are built using PDH (Plesiochronous) Radios. These radios are of 16E1(34Mbps) capacity with QPSK modulation to limit the transmission RF bandwidth to 28 MHz, with a Transmit power of around +21dBm and receiver sensitivity of -82 dBm. Traffic from each BTS is collected by the PDH links and handed over to BSC (Base station controller). One PDH Link can carry traffic pertaining to 8/16 BTS's. Traffic from different Access MW links are groomed at Optical Fiber Access rings of capacity STM1 (155Mbps)/STM4 (622Mbps).These fiber rings are built using either STM1 (63E1's) or STM4 (252E1's) SDH Multiplexers. In General STM1 access rings are subtended to STM 4 rings. These Access Fiber rings carry enroute BTS/BSC traffic and operate as collector rings for BTS's and BSC's.STM1/4, Fiber Optic Access collector rings are deployed along major roads in a City subtended by Short Haul MW links. Similarly STM1/STM4 Access/collector fiber rings are subtended on to STM16 aggregate Fiber rings built using STM16 (2.5Gbps) Multiplexers. A large City will have many STM16 optical fiber rings. STM16 rings are deployed around the city and act as both collector and Aggregate rings grooming the traffic, and are ultimately subtended on to STM 64 National Long distance Rings. These Rings are built using STM64 (10Gbps) Multiplexer, These STM64 rings act as core/Metro rings as well as National Long distance Optical fiber links carrying traffic from one state to another state. In general NLD links are DWDM links. Fig 2 indicates typical Short Haul MW Access link, MW link between one BTS to another BTS is established using BTS towers itself. In most of the cases BTS's are located on roof tops of the two/ three or or multistoried buildings, inside a shelter. Short haul MW links consists of 5M to 20M RT (roof top towers) erected on buildings of height 3M to 20M and 0.3M to 1.2M Parabolic Dish Antennas, MW radio consists of two parts ODU(outdoor unit) which houses RF Trans receiver and is directly mounted behind Parabolic Dish Antenna and IDU(Indoor Unit) which contains Modem ,Multiplexer and IF units. IDU is mounted inside a shelter which is mounted close to the Antenna on the building roof top. ODU and IDU are interconnected by Low loss Foam dielectric IF(intermediate Frequency) cable. As the hop distances in Urban Areas is very short Access MW links can be built with antennas of size 0.3M to 0.9M in most of the cases

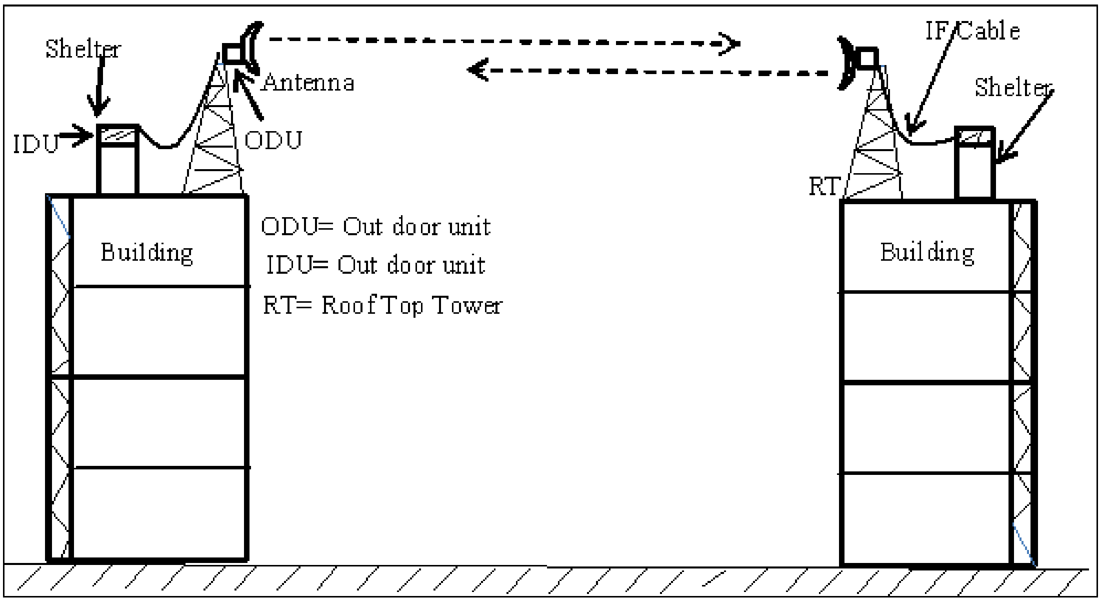

Fig2. *Typical Short haul MW link*

Most of the Access Mw links are PDH links with 16E1 (34 Mbps) capacity. Wherever more number of BTS's are to be served SDH links of capacity 63E1 (155mbps) are deployed. However Receive sensitivity of SDH radio(-68 dBm) is almost 20 dB less than the PDH radios, hence distance covered by SDH radio's would be two to three times less than the PDH radios for the same antenna sizes. Hence to cover the same distance SDH radio require large Antenna sizes PDH radios can withstand high interference signals and are suitable for deployment in urban areas where frequency interference is a major concern and for better reuse of MW spectrum. Alternatively where large No. of BTS's are to be provided traffic connectivity, Modulation rate of SDH radios 128 QAM (to limit 155Mbps in 28 MHz BW). ITU-R has defined various performance parameters (ITU-TG826) and outage objectives (ITU-R1703) which are to be met by MW links. Individual cellular operators define their own performance and availability objectives (Based on ITU) for their MW Access and Mobile Back haul Network. MW frequencies above 10GHz are severely affected by rain attenuation. The amount of rain fade will be equivalent to rain fall rate rather than total amount of rain fall. Sufficient fade margin to combat rain attenuation to be provided while designing the Access MW links. Unlike long haul MW links, short haul MW Access links are not affected by the refractivity gradient variations in the lower part of the troposphere of the atmosphere. Since hop lengths of the MW Access links are very less compared to Long haul Links, short haul Access links may not be severely affected by anomalous propagation effects radio waves in the atmosphere like sub refraction, super refraction, and other impairments like elevated layer reflections, multipath fading to the ground reflections. Hence impact of these factors need not be considered while designing short haul MW Access links. However diffraction loss due to obstructions lying on the MW path like buildings, water tanks, hoardings and other manmade structures are of serious concerns for planning the Access MW links. Hence excess rain attenuation and diffraction loss due to obstructions lying on the path are to be considered for short haul MW Access link design.

2. MICROWAVE PROPAGATION

As Microwaves travel in the lower part of Atmosphere, MW paths whether short haul or long haul are subjected to atmospheric variations.

2.1 Free Space Transmission Loss

Free space propagation refers to propagation of radio waves in homogeneous, ideal dielectric medium, also considered as least possible attenuation between Transmitter and Receiver

Free space loss is given by *92.4+20 log d=20 log f, dB, where*

d = distance of transmitter and receiver in KM's, and f= frequency in GHz

2.2 Line of Sight and Earth Bulge

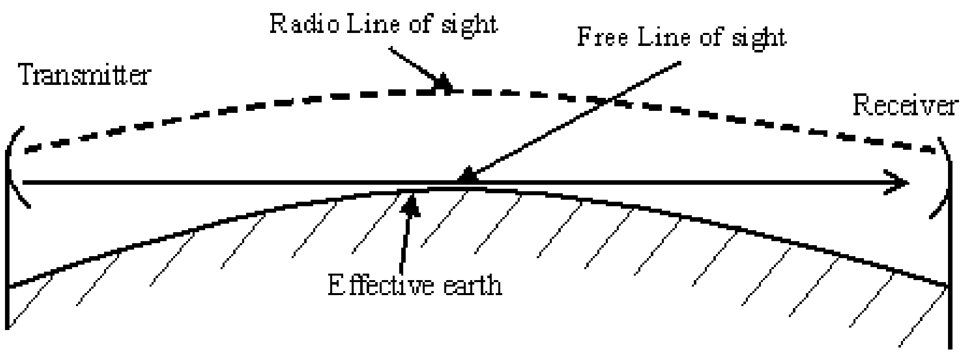

Fig3. *Line of Sight and effective earth radius*

Earth atmosphere impacts propagation of radio waves in different ways. Radio waves travel with different velocities in the atmosphere due to variation in the refractivity gradients in the atmosphere, which causes refraction. Due to refraction Radio waves bend slightly downwards causing radio waves to travel more than the straight line, hence Radio line of sight is more than the geometrical line of sight.

This additional travel of radio waves is factored as, earth radius factor 'k' or earth bulge. Value of 'k' = 4/3 for normal atmosphere. Effective earth radius is defined as *Re*

$Re = k \cdot R,$

Where Re = Effective earth radius, R= True earth Radius =6370 KMs, and k = effective earth radius factor

2.3 Fresnel Zone

Obstacles falling on the MW path and close to the MW path (LOS) cause attenuation to the electromagnetic waves. It is customary to define Fresnel zone around the line of sight path. First Fresnel zone is defined as ellipsoid with its focal points at the antennas on both ends of the path. Fresnel zone diameter increases with frequency of operation.

Fig 4 defines Fresnel zone relationship = $d3+d4-d = \lambda/2$

First Fresnel Zone radius $rF= 17.3 \{(d1.d2) / f.d\}^{1/2}$ Where, rF= First Fresnel zone radius in M,

d1= distance from the first focal point (antenna) to the point interest in KM

d2= distance from the second focal point (focal Antenna) to the point interest in KM

d= Total distance between the focal points (antennas) in KMs, f= frequency of operation in GHz

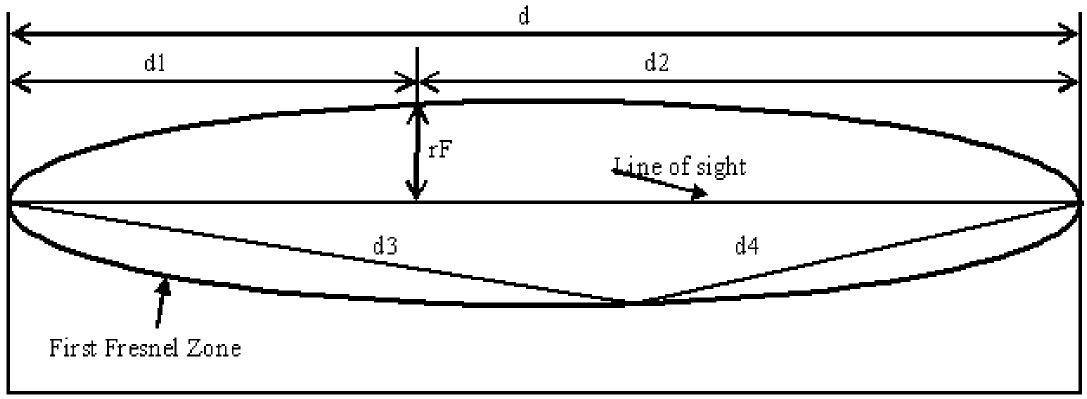

Fig4. *Fresnel Zone Radius*

3. SHORT HAUL MW LINK DESIGN METHODOLOGY

Following are the steps followed for designing short haul MW Link

a. Network Creation & number of hops estimation

b. Estimation of traffic capacity per BTS/Node B and total Capacity of MW Link

c. Route survey

d. Terrain Generation of individual hops

e. Estimation of Tower heights

f. Link Engineering

3.1 Network Creation

A Network diagram is created by entering the site coordinates (latitudes and Longitudes) which are to be provided MW connectivity in to the Pathloss tool. Many software tools are available for carrying out MW Link engineering out of them Pathloss tool is widely used. Fig 5 indicates a Typical MW network diagram formed by interconnecting 8 Sites (BTS locations). This consists of 7 hops.

Number of Hops = Total number of sites-1

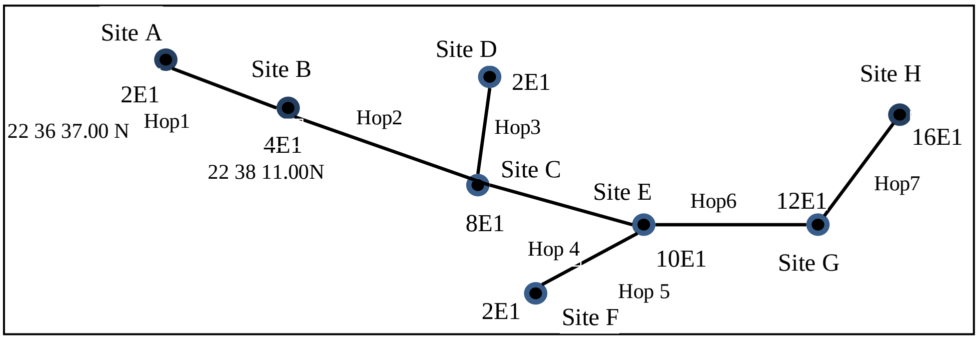

Fig5. *Typical MW Network diagram*

3.2 Estimation of Traffic and Radio Capacity

Capacity of the Microwave link is calculated by summation of individual E1's that are to be carried from each BTS sites progressively from start to end. Table I indicates typical Traffic dropping table.

Table1. *Estimation of Traffic Capacity Per BTS and Total Capacity of Mw Link*

Site	*SiteA/ Starting*	*Site A-B*	*Site B- C*	*Site C-D/Spur*	*Site D-E*	*Site E-F/Spur*	*Site G-H*	*SiteH/ terminating*
No E1's	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*

3.3 Route Survey

Purpose of Path profile generation is to find out availability LOS is available between the two locations which are to be connected by MW and for ensuring sufficient clearance above the obstacles falling on the LOS path. It is a plot of elevation of the earth as a function of distance along the path. Route survey is carried out for all the hops. Data is collected by physical site visit and route walk along the LOS path. Differential GPS, Altimeters & Binoculars are used for data collection. Heights of the obstacles are recorded using Altimeters. GPS is used for recording the elevation and coordinates of Buildings trees and other obstacles falling on the LOS path

3.4 Terrain Generation of Individual Hops

Path profile data recorded (earth elevation and heights of the obstructions) is entered in to the Pathloss tool along with the heights of the two building where MW link to be deployed. Terrain data of the path profile is indicated in fig 6

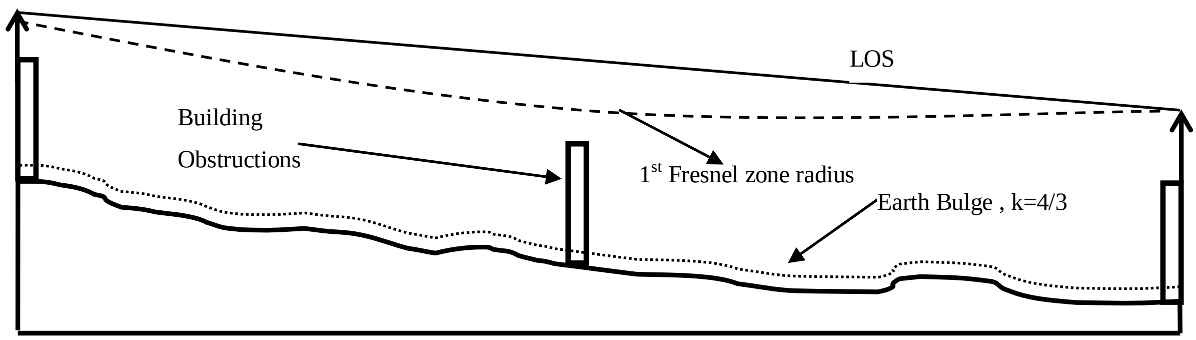

Fig6. *Terrain data*

3.5 Estimation of Tower Height

Suitable tower heights are entered in to the path loss tool and Line of sight line is drawn between the two sites (interconnecting top most points of the roof top towers) in such a way that line of sight clears all the obstructions falling on the path, if not tower heights are readjusted to ensure LOS is above all the obstructions.

3.6 Earth Bulge & Fresnel Zone Clearances

Tower heights are again readjusted to achieve clearances for both earth bulge and 100 % clearance for first Fresnel zone radius. Since hop lengths of most of the short haul links are less than 5KMs, it is sufficient is LOS clearance is verified for k value of 4/3, as the extent of radio wave bending due to refraction is quite less when compared to Long-haul paths (15 to 30 KMs).Table II indicates earth bulge values for different hop length, maximum earth bulge is noticed at the center of the MW path *.It can be seen from the table that earth bulge figures for hops less than 5Kms is just 0.65M. Hence Earth bulge factor may not be considered for hop lengths less than 5Kms.* Table III indicates Fresnel zone diameter for different Access frequencies and hop lengths .It can be seen that maximum clearance to be given for 15 GHz Links

TableII. *Maximum Earth Bulge for Different Hop Distances For K=4/3*

Erath Bulge								
Hop Length in KM	*15KM*	*10KM*	*8KM*	*5KM*	*3KM*	*2KM*	*1KM*	*0.5KM*
Earth Bulge in M , K=4/3	*5.89M*	*2.62M*	*1.67M*	*0.65M*	*0.24M*	*0.1M*	*0.03M*	*0.01M*

TableIII. *Maximum Fresnel Zone Radii for Different Hop Lenghts and Frquencies*

	Hop Length							
Frequency	***15KM***	***10KM***	***8KM***	***5KM***	***3KM***	***2KM***	***1KM***	***0.5KM***
15 GHz	*8.65M*	*7.0M*	*6.3M*	*5.0M*	*3.9M*	*3.16M*	*2.23M*	*1.6M*
18 GHz			*5.77M*	*4.56M*	*3.53M*	*2.88M*	*2.04M*	*1.44M*
23 GHz				*4.03M*	*3.12M*	*2.55M*	*1.8M*	*1.28M*

3.7 Link Engineering

Link Engineering or Link budget is prepared to estimate the received signal level (RSL) during non-fading time. Received signal level (RSL) varies over time due to variation in the propagation conditions of the MW path. This variation of RSL over a time is called fading. Fade margin is required to ensure proper operation of the MW link even under sever climatic and topological situations, so that RSL is always above the receiver threshold level. Receiver threshold level of a MW radio is defined as the minimum receive signal level required at the input of the radio receiver to produce a BER of $1x10^{-6}$

Fade margin = Nominal RSL – Rx (threshold)

Receive signal (RSL) = Pt - Lc + Gtx - Lo + Grx -FSL

Where Pt = Transmitter power output at the Antenna input, Lc = Feeder cable Loss,

Gtx = Transmit Antenna gain, Lo = other losses (siting losses etc), Grx = Receive Antenna gain

FSL = Free space path loss is given by FSL= 92.4+ 20Logd +20logf

Where d = distance between the transmitter and receiver in KMs and f is the operating frequency in GHz

As indicated earlier Rain attenuation is a major concern for designing short haul MW Access Links operating in the frequency bands15/18/23 GHz Since most of the India's region is falls under Tropical climate attenuation due to rain is a major concern. Rain attenuation cause flat fading and is short term and can vary from 30 dB to 70 dB for depending upon the frequency of operation and hop length. Sufficient flat fade margin to be provided using large Antennas up to 1.2M size to combat rain fading. Horizontal polarization is impacted more compared to vertical polarization. ITU has provided world rain regions according to rain fall rates, which is exceeded for 0.01% of the time(ITU-R 837). Fade margin should be equal to the MW path attenuation that corresponds to a rainfall rate that is exceeded for 0.01% of the time. India's region Region falls under 95mm raim fall rate which is ITU N region. and next higher rain rate is115mm/Hr (ITU Q region)

Main objective of Link Engineering is to find out the availability of the link. Different methods are followed for availability calculations. ITUR 530 methods are popular. These methods estimate the probability of Multipath and rain fade depth (dB) exceeding the designed Fade margin either by 1% or 0.1%or 0.01% of the time (over one year), Factors like terrain roughness, Geoclimatic factor, path length, path inclination, frequency, fade margin are considered for availability calculations, For short haul link availability calculations multipath effects can be ignored due to short hop lengths and higher frequency band of operation(15/18/23GHz)

The fade probability P that the fade depth F dB exceeded in the worst month is indicated below

$$P=K.d^{3.3}.f^{0.93}.(1+\epsilon_p)^{-1.1}.\theta^{1.2}.10^{-F/10}$$

K= Geo climatic factor, d= path length in KMs, f=frequency in GHz,

ϵp =Path inclination in mili radians,

θ= Average grazing angle in mili radians, Corresponding to a 4/3 earth radius factor,

F=effective fade margin in dB, K is estimated from the percentage of time PL that the average refractivity

12 20 03.84

076 39 7.88

Gradient in the lowest 100m of the atmosphere is less than-100N units/Km,

TableIV. *Maximum Fresnel Zone Radii for Different Hop Lenghts and Frquencies*

S. No	Site Name	Coordinates	Elevation M	Azimuth degree	Building height M	Tower height M	Antenna height M	Hop distance Km	Antenna size M	Radio Type	Frequency in MHz	Polarization	RSL dBm
1	*NR Mohalla1*	*12 19 35.25 076 3 49.50*	*740.17*	*356.81*	*30*	*15*	*45*	*0.9*	*0.6*	*STM 1*	*15075*	*V*	*-26.0*
	To St Joseph	*12 20 03.84 076 39 7.88*	*730.01*	*176.81*	*35*	*10*	*45*		*0.6*	*STM 1*	*14655*	*V*	*-26.0*

Table IV indicates Link Engineering report of a Short haul High capacity (STM1/155Mbps) SDH Access MW link of 0.9M link designed to achieve 99.99% availability , with a Fade margin of 42dB to with stand 115mm rain fall rate , The Radio is an SDH radio with Transmit power of +21dBm

4. CONCLUSION

It is possible to design High availability(greater than 99.99% availability) short haul MW Links in 15/18/23 GHz bands conforming to ITU performance standards and to with stand high rain fall rate in tropical countries like India. It can be seen from Table II and III that for designing short haul links conventional earth bulge factors need not considered up to 5KM hop length. In addition Fresnel zone clearances can also be ignored for very shorter hop lengths. *What is important is to maintain a minimum of 35 dB rain fade margin, to mitigate rain attenuation* and *Multipath path effects for short haul MW links design need not be considered*

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