EVALUATION OF RADIO LINK DESIGN WITH DIFFERENT MODULATION AND ANTENNA SCHEMES

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ABSTRACT

This article is devoted to microwave radio link design in order to provide communication between two locations and based on modelling of different radio link solutions with different modulation techniques, different antenna dimensions etc. by using PathLoss program software. Path loss test tool and modulation techniques for 256 quadrature amplitude modulation (QAM), 64 QAM, 16 QAM, and 4 QAM have been used in order to perform simultaneous simulations so that the best correlation of stated variables are characterized for the project. The variables are then simulated with various antenna sizes for the best throughput of 155 Mbit/s data transfer. Another design consideration for achieving better radio link availability and less transmission path interruption is to use automatic Adaptive Modulation feature of selected radio link equipment to fight against adverse weather. Adaptive Modulation can lower modulation level from 16 QAM in our study to 4 QAM level and this allows even smaller interruption time (0.18 minute) but with a bit smaller capacity (80 Mbps) for this short adverse weather conditions period. In this study, the locations where we are unable to reach via fiber are considered for wireless transmission links. In the practical part of this study different modulation techniques and antenna sizes were analyzed in order to provide the most efficient way of data transmission.

KEYWORDS*: Radio link; design; modulation; antenna*

1.0 INTRODUCTION

Since ancient times, one of the principal needs of people has been to communicate. This need created interest in devising communication systems for sending messages from one place to another. The advent of high performance computer

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processors brought many advantages for digital communications over that of analog. These benefits include more features, easy storage and faster processing. These caused huge amount of information, which is increasing exponentially every year, to be carried over communication networks.

The message into a signal that can be sent over a communication channel; the channel distorts the signal and adds noise to it; and the receiver processes the noisy received signal to extract the message. Thus, communication systems design must be based on a sound understanding of signals, and the systems that shape them (Stremler, 1990).

Optical communication systems have taken a monumental leap in the last 20 years in terms of the capacity provided by them. With the recent advances in technologies related to high speed optoelectronic devices, and advanced modulation formats, single channel capacities of upto 100 Gb/s are in development for metro and core Networks (Gnauck and Winzer, 2004; Gnauck and Winzer, 2005; Van den Borne et al., 2008; Zaldívar-Huerta et al., 2015; Tripathi, 2016). The aim of the study is to provide the highest throughput between radio link. locations using available modulation techniques. The study was conducted in Ankara with technical support from Türk Telekom and Milens. In order to do this, a simulation where one can take different parameters like modulation technique, antenna size into consideration and model a formula. So the idea is to find the best correlation of the parameters for the objective of providing the best service to the computers in radio link designed locations.

2.0 METHODOLOGY

Path loss test tool and modulation techniques for 256 QAM, 64 QAM, 16 QAM and 4 QAM have been used in order to perform simultaneous simulations so that best correlation of stated variables are characterized for the project. The variables are then simulated with various antenna sizes for the best throughput of 155 Mbit/s data transfer. We used path loss software (Pathloss, 2011) to design link budget using shuttle radar topography mission (SRTM). PathLoss program software requires exact geographical coordinates of two radio link end points and by using SRTM Digital Elevation Model information of the Earth (high-resolution digital topographic database of Earth), calculates Line of Sight (LoS) status and link budget by taking into account free space loss, rain loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption.

2.1 Path Loss Radio Link Definitions for Sample Link

Firstly geographical coordinates information for two sites where more than 100 Mbps transmission capacity required is entered into a PathLoss software tool, as Site 1 and Site 2 by using their Longitude and Latitude values. SRTM database which PathLoss software is getting terrain data, yields the height information as 1178.3 m for Site 1 and 1027 m for Site 2. Tower height is considered as 30 m which is the common practice in microwave radio link applications (Ghasemi et al., 2013). PathLoss tool has another screen for analyzing exact LoS status where the height profile between Site 1 and Site 2 can be graphically and tabular seen (Figure 1).

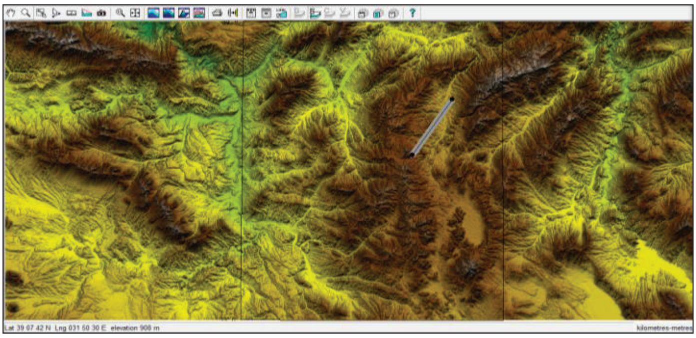
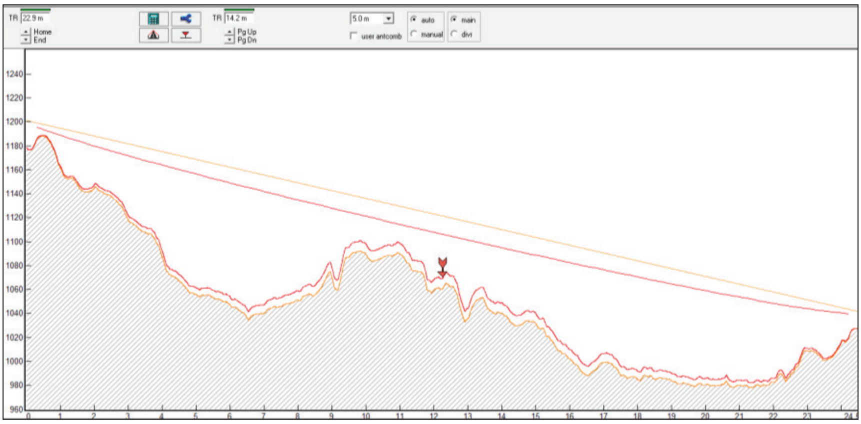


Figure 1. Clutter Backdrop and terrain data

Figure 2 shows the exact LoS status for the selected antenna heights of Site 1 and Site 2. Antenna height parameter is editable and depending on tower defined maximum height, can be adjusted to have optimal LoS. In this study, antenna height for Site 1 is taken as 22.9 m and for Site 2 as 14.2 m.



TR 22.9 m

TR 14.2 m

5.0 m

☐ user antcomb

● auto ○ manual

● main ○ divr

Figure 2. Antenna Heights

3.0 RESULTS AND DISCUSSION

Next sections use this antenna height assumption and by changing modulation and antenna types, the overall radio link availability values with different transmission capacities are evaluated for five different radio link designs.

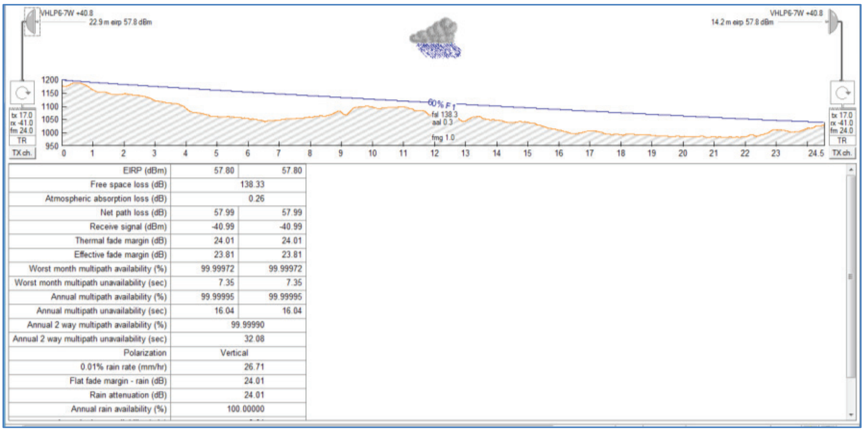
3.1 Design Simulation - 1

Various design simulations are studied for achieving the highest radio link capacity while still satisfying the high transmission availability values. All radio link models are based on commercial microwave equipment manufacturers (DragonWave Inc.) Harmony Radio product family, which has a wide range of microwave radios that start from 3.5 GHz to 42 GHz and variable spectrum which can be adjusted between 3.5 to 56 MHz channel bandwidth. For all radio link calculations, PathLoss IP radio model of 8 GHz Dragonwave Harmony Radio is used and antenna is selected from Andrew Corporation (VHLP series, frequency range 7125 MHz – 8500 MHz) with various diameters but with single polarization in order to be able to decide on optimal design.

For the Simulation -1, Harmony Radio with 256 QAM modulation and 56 MHz channel bandwidth is considered together with 1.8m antenna. Harmony Radio can provide a transmit power of TX = 17 dBm for this mode, and antenna gain is 40.8 dBm for 1.8m antenna. This results in an EIRP (Equivalent Isotropically

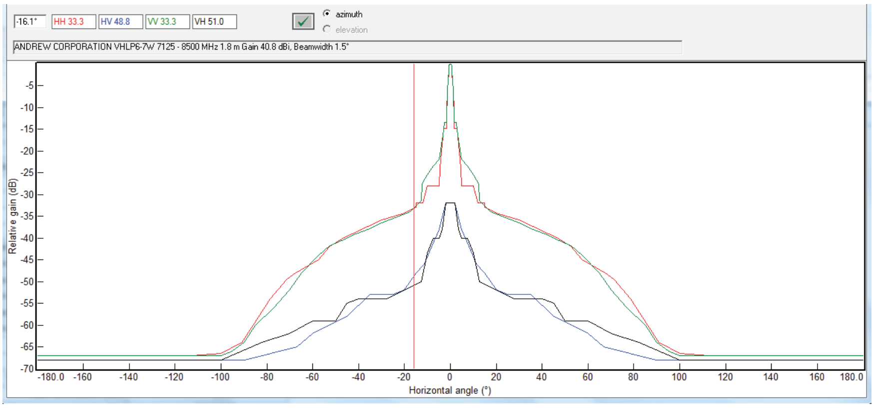
Radiated Power) value of 57.8 dBm for both end points in Site 1 and Site 2. If we consider additional antenna gain of 40.8 dBm on the receiving site as well, total gain budget of 98.6 dBm becomes available both for Site 1 and Site 2. At this modulation level Harmony Radio has a receiver sensitivity of 65 dBm so, if we consider the free space loss of 138.33 dBm (for a distance of 24.54 km) and Atmospheric absorption loss of 0.26 dBm and Field margin of 1 dBm, we end up with receive signal of -40.99 dBm (which is safely in line with -65 dBm receiver sensitivity). This allows for quite sufficient thermal fade margin of 24 dB, which in turn provides a good overall transmission link availability (Annual rain + multipath availability: 99.99990 %).

Figures 3 and 4 shows consecutively the transmission analysis screen with calculated attenuation values, selected antenna model and radio model with gain values and the antenna pattern for 1.8 m 8 GHz single polarized antenna. Table 1 provides detailed information for Radio and Antenna model used in this simulation and related threshold and gain values to achieve a BER ratio of 10-6.



EIRP (dBm)	57.80	57.80
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Net path loss (dB)	57.99	57.99
Receive signal (dBm)	-40.99	-40.99
Thermal fade margin (dB)	24.01	24.01
Effective fade margin (dB)	23.81	23.81
Worst month multipath availability (%)	99.99972	99.99972
Worst month multipath unavailability (sec)	7.35	7.35
Annual multipath availability (%)	99.99995	99.99995
Annual multipath unavailability (sec)	16.04	16.04
Annual 2 way multipath availability (%)	99.99990	
Annual 2 way multipath unavailability (sec)	32.08	
Polarization	Vertical	
0.01% rain rate (mm/hr)	26.71	
Flat fade margin - rain (dB)	24.01	
Rain attenuation (dB)	24.01	
Annual rain availability (%)	100.00000	

Figure 3. Transmission Analysis 1



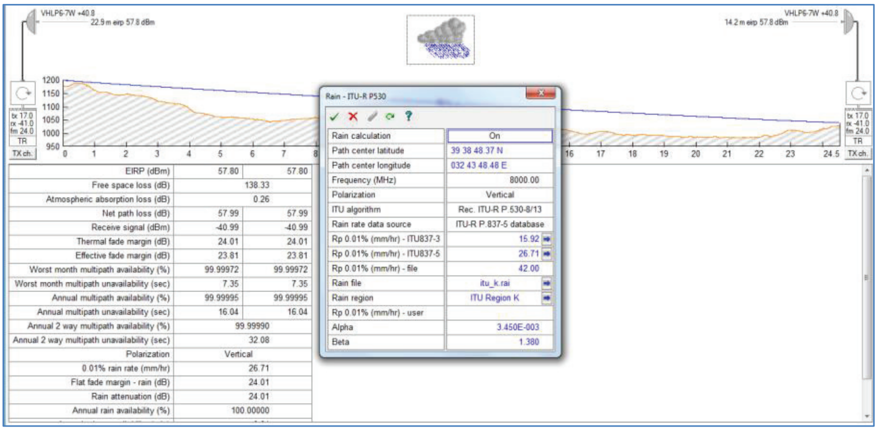
ANDREW CORPORATION VHLP6-7W 7125 - 8500 MHz 1.8 m Gain 40.8 dBi, Beamwidth 1.5°

Figure 4. Transmission Analysis for Antenna 1.8 m

Table 1. Radio and Antenna Model

Antenna (VHLP6-7W)			**Radio (08HR56HET348v01)**		
Antenna diameter (m)	1.83	1.83	Emission Designator	56MOD7WET	56MOD7WET
Antenna height (m)	22.93	14.22	TX power (watts)	0.05	0.05
Antenna gain (dBi)	40.80	40.80	TX Power (dBm)	17.00	17.00
Antenna 3 dB beamwidth H (^{0})	1.50	1.50	RX threshold criteria	1E-6 BER	1E-6 BER
Antenna 3 dB beamwidth E (^{0})	1.50	1.50	RX threshold level (dBm)	-65.00	-65.00
True azimuth (^{0})	32.58	212.68	Max. Receive signal (dBm)	-21.00	-21.00
Vertical angle (^{0})	-0.46	0.29	Dispersive fade margin (dB)	37.27	37.27

Figure 5 shows the rain loss related PathLoss tool values for the selected geographical area, ITU-T Region K is automatically selected by using ITU algorithm Rec. ITU-R P.530-8/13 for 8 GHz frequency. Used rain rate data source is ITU-R P.837-5 database. Figure 6 has the other path profile data and fading factor for this radio link. Some parameters like “inland path classification”, “Use over water modifications” and “Over water classification” are selected according to geographical data and map info for this specific link. Multipath fading method - Rec. ITU-R P.530-7/ 8 is applied for this link analysis.

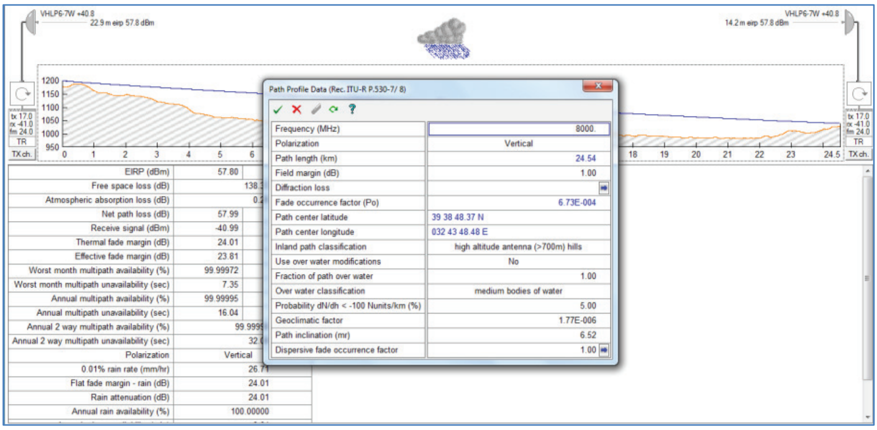


EIRP (dBm)	57.80	57.80
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Net path loss (dB)	57.99	57.99
Receive signal (dBm)	-40.99	-40.99
Thermal fade margin (dB)	24.01	24.01
Effective fade margin (dB)	23.81	23.81
Worst month multipath availability (%)	99.99972	99.99972
Worst month multipath unavailability (sec)	7.35	7.35
Annual multipath availability (%)	99.99995	99.99995
Annual multipath unavailability (sec)	16.04	16.04
Annual 2 way multipath availability (%)	99.99990	
Annual 2 way multipath unavailability (sec)	32.08	
Polarization	Vertical	
0.01% rain rate (mm/hr)	26.71	
Flat fade margin - rain (dB)	24.01	
Rain attenuation (dB)	24.01	
Annual rain availability (%)	100.00000	

Rain - ITU-R P530

Rain calculation	On
Path center latitude	39 38 48.37 N
Path center longitude	032 43 48.48 E
Frequency (MHz)	8000.00
Polarization	Vertical
ITU algorithm	Rec. ITU-R P.530-8/13
Rain rate data source	ITU-R P.837-5 database
Rp 0.01% (mm/hr) - ITU837-3	15.92
Rp 0.01% (mm/hr) - ITU837-5	26.71
Rp 0.01% (mm/hr) - file	42.00
Rain file	itu_k.rai
Rain region	ITU Region K
Rp 0.01% (mm/hr) - user	
Alpha	3.450E-003
Beta	1.380

Figure 5. Transmission Analysis for rain loss



EIRP (dBm)	57.80
Free space loss (dB)	138.3
Atmospheric absorption loss (dB)	0.2
Net path loss (dB)	57.99
Receive signal (dBm)	-40.99
Thermal fade margin (dB)	24.01
Effective fade margin (dB)	23.81
Worst month multipath availability (%)	99.99972
Worst month multipath unavailability (sec)	7.35
Annual multipath availability (%)	99.99995
Annual multipath unavailability (sec)	16.04
Annual 2 way multipath availability (%)	99.9999
Annual 2 way multipath unavailability (sec)	32.
Polarization	Vertical
0.01% rain rate (mm/hr)	26.71
Flat fade margin - rain (dB)	24.01
Rain attenuation (dB)	24.01
Annual rain availability (%)	100.00000

Path Profile Data (Rec. ITU-R P.530-7/ 8)

Frequency (MHz)	8000.
Polarization	Vertical
Path length (km)	24.54
Field margin (dB)	1.00
Diffraction loss	
Fade occurrence factor (Po)	6.73E-004
Path center latitude	39 38 48.37 N
Path center longitude	032 43 48.48 E
Inland path classification	high altitude antenna (>700m) hills
Use over water modifications	No
Fraction of path over water	1.00
Over water classification	medium bodies of water
Probability dN/dh < -100 Nunits/km (%)	5.00
Geoclimatic factor	1.77E-006
Path inclination (mr)	6.52
Dispersive fade occurrence factor	1.00

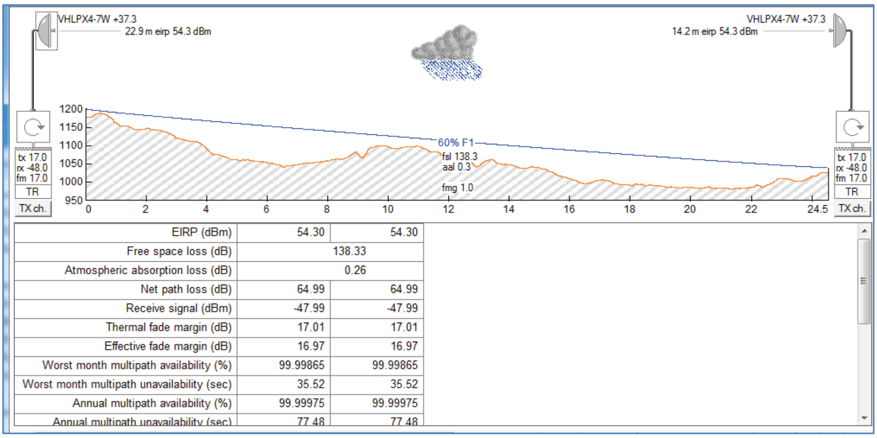
Figure 6. Transmission Analysis for path profile data

Radio Specification for 256 QAM modulation level, PathLoss program uses the specified values of TX_POWER and RX_THRESHOLD values specific for this microwave radio. Table 2 summarizes the radio link result and annual availability values for 1.8 m antenna, 56 MHz spectrum bandwidth and 256 QAM modulation for the whole year and shows the effect of rain and multipath related extra losses.

Site 1 to Site 2 radio link design with the specified modulation and antenna type results in an overall link availability value of 99.99990% (including annual rain and multipath related effects) which means 0.54 minutes of interruption of traffic for one year. With 56 MHz spectrum bandwidth and 256 QAM modulation level, a high traffic capacity of 348 Mbps is achievable between Site 1 and Site 2 with very limited interruption annually.

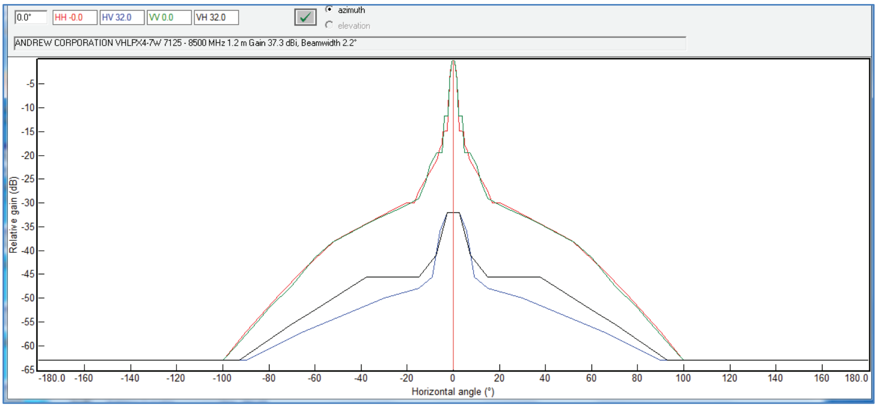
3.2 Design Simulation - 2

For the Simulation -2, Harmony Radio with 256 QAM modulation and 56 MHz channel bandwidth is considered together with 1.2 m antenna. Harmony Radio can provide a transmit power of TX = 17 dBm for this mode, and antenna gain is 37.3 dBm for 1.2 m antenna. This results in an EIRP (Equivalent Isotropically Radiated Power) value of 54.3 dBm for both end points in Site 1 and Site 2. If we consider additional antenna gain of 37.3 dBm on the receiving site as well, total gain budget of 138.33 dBm becomes available both for Site 1 and Site 2. At this modulation level Harmony Radio has a receiver sensitivity of 65 dBm so, if we consider the free space loss of 138.33 dBm (for a distance of 24.54 km) and Atmospheric absorption loss of 0.26 dBm and Field margin of 1 dBm, we end up with receive signal of -47.99 dBm (which is safely in line with -65 dBm receiver sensitivity). This allows for quite sufficient thermal fade margin of 17 dB, which in turn provides a good overall transmission link availability (Annual rain + multipath availability : 99.99947 %). Figure 7 and 8 show consecutively the transmission analysis screen with calculated attenuation values, selected antenna model and radio model with gain values and the antenna pattern for 1.2 m 8 GHz single polarized antenna.



EIRP (dBm)	54.30	54.30
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Net path loss (dB)	64.99	64.99
Receive signal (dBm)	-47.99	-47.99
Thermal fade margin (dB)	17.01	17.01
Effective fade margin (dB)	16.97	16.97
Worst month multipath availability (%)	99.99865	99.99865
Worst month multipath unavailability (sec)	35.52	35.52
Annual multipath availability (%)	99.99975	99.99975
Annual multipath unavailability (sec)	77.48	77.48

Figure 7. Transmission Analysis 2, Pathloss Calculation with 1.2 m Antenna



0.0° HH -0.0 HV 32.0 VV 0.0 VH 32.0

● azimuth
○ elevation

ANDREW CORPORATION VHLPX4-7W 7125 - 8500 MHz 1.2 m Gain 37.3 dBi, Beamwidth 2.2°

Figure 8. Transmission Analysis 2 for Antenna 1.2 m

Table 3 summarizes the radio link result and annual availability values for 1.2 m antenna, 56 MHz spectrum bandwidth and 256 QAM modulation for the whole year and shows the effect of rain and multipath related extra losses. Site 1 to Site 2 radio link design with the specified modulation and antenna type results in an overall link availability value of 99.99947 % (including annual rain and multipath related effects) which means 2.40 minutes of interruption of traffic for one year. With 56 MHz spectrum bandwidth and 256 QAM modulation level, a high traffic capacity of 348 Mbps is achievable between Site 1 and Site 2 with very limited interruption annually.

Table 3. Design 2 Result

	Site 1	**Site 2**
True azimuth (°)	32.58	212.68
Vertical angle (°)	-0.46	0.29
Elevation (m)	1178.30	1026.99
Tower height (m)	30.00	30.00
Antenna model	VHLPX4-7W (TR)	VHLPX4-7W (TR)
Antenna file name	vhlpx4-7w	vhlpx4-7w
Antenna gain (dBi)	37.30	37.30
Antenna height (m)	22.93	14.22
Frequency (MHz)	8000.00	
Polarization	Vertical	
Path length (km)	24.54	
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	

(continued)

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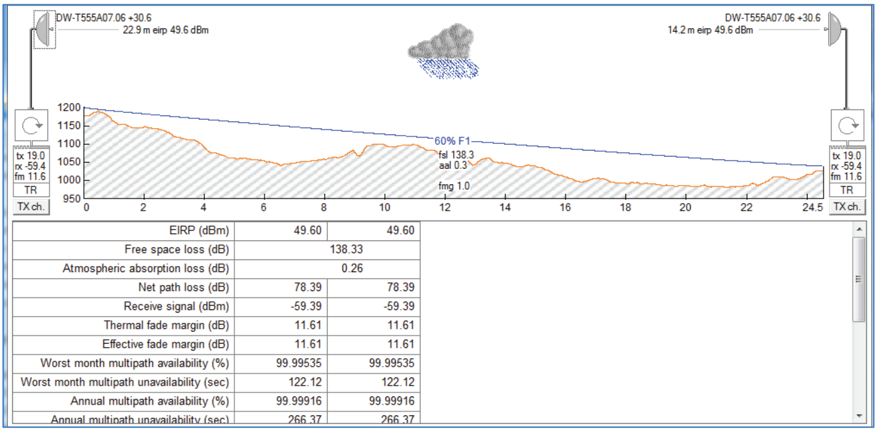
Field margin (dB)	1.00	
Net path loss (dB)	64.99	64.99
Radio model	08HR56HET348v01	08HR56HET348v01
Radio file name	08hr56het348v01	08hr56het348v01
TX power (dBm)	17.00	17.00
Emission designator	56M0D7WET	56M0D7WET
EIRP (dBm)	54.30	54.30
RX threshold criteria	1E-6 BER	1E-6 BER
RX threshold level (dBm)	-65.00	-65.00
Receive signal (dBm)	-47.99	-47.99
Thermal fade margin (dB)	17.01	17.01
Dispersive fade margin (dB)	37.27	37.27
Dispersive fade occurrence factor	1.00	
Effective fade margin (dB)	16.97	
Geoclimatic factor	1.768E-006	
Path inclination (mr)	6.52	
Fade occurrence factor (Po)	6.731E-004	
Worst month multipath availability (%)	99.99865	99.99865
Worst month multipath unavailability (sec)	35.52	35.52
Annual multipath availability (%)	99.99975	99.99975
Annual multipath unavailability (sec)	77.48	77.48
Annual 2 way multipath availability (%)	99.99951	
Annual 2 way multipath unavailability (sec)	154.95	
Polarization	Vertical	
0.01% rain rate (mm/hr)	26.71	
Flat fade margin - rain (dB)	17.01	
Rain attenuation (dB)	17.01	
Annual rain availability (%)	99.99996	
Annual rain unavailability (min)	0.22	
Annual rain + multipath availability (%)	**99.99947**	
Annual rain + multipath unavailability (min)	**2.80**	

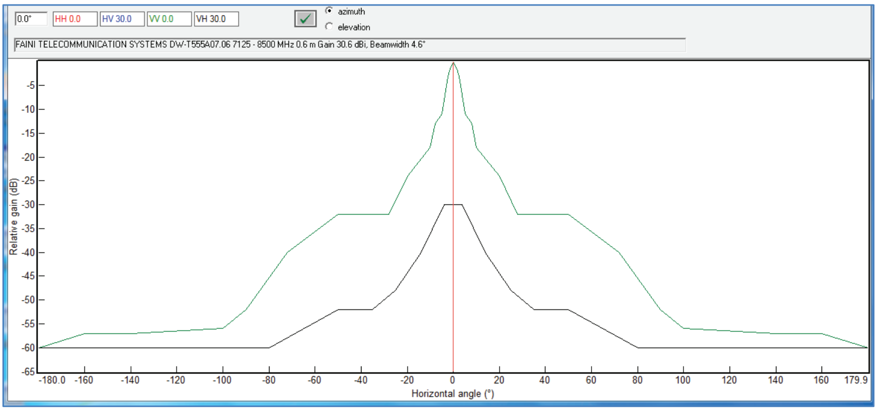
3.3 Design Simulation - 3

For the Simulation -3, Harmony Radio with 64 QAM modulation and 56 MHz channel bandwidth is considered together with 0.6 m antenna. Harmony Radio can provide a transmit power of TX = 19 dBm for this mode, and antenna gain is 30.6 dBm for 0.6m antenna. This results in an Equivalent Isotropically Radiated Power (EIRP) value of 49.6 dBm for both end points in Site 1 and Site 2. If we consider additional antenna gain of 30.6 dBm on the receiving site as well, total gain budget of 138.33 dBm becomes available both for Site 1 and Site 2. At this modulation level Harmony Radio has a receiver sensitivity of 65 dBm so, if we consider the free space loss of 138,33 dBm (for a distance of 24.54 km) and Atmospheric absorption loss of 0.26 dBm and Field margin of 1 dBm, we end up with receive signal of -59.39 (which is safely in line with -65 dBm receiver sensitivity). This allows for quite sufficient thermal fade margin of 11.61 dB, which in turn provides a good overall transmission link availability (Annual rain + multipath availability: 99.99804 %). Figures 9 and 10 show consecutively the transmission analysis screen with calculated attenuation values, selected antenna model and radio model with gain values and the antenna pattern for 0.6 m 8 GHz single polarized antenna.



EIRP (dBm)	49.60	49.60
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Net path loss (dB)	78.39	78.39
Receive signal (dBm)	-59.39	-59.39
Thermal fade margin (dB)	11.61	11.61
Effective fade margin (dB)	11.61	11.61
Worst month multipath availability (%)	99.99535	99.99535
Worst month multipath unavailability (sec)	122.12	122.12
Annual multipath availability (%)	99.99916	99.99916
Annual multipath unavailability (sec)	266.37	266.37

Figure 9. Transmission Analysis 3, Pathloss Calculation with 0.6 m Antenna and 64 QAM modulation


0.0° HH 0.0 HV 30.0 VV 0.0 VH 30.0 ☑ ● azimuth ○ elevation

FAINI TELECOMMUNICATION SYSTEMS DW-T555A07.06 7125 - 8500 MHz 0.6 m Gain 30.6 dBi, Beamwidth 4.6°

Figure 10. Transmission Analysis 3 for Antenna 0.6 m a 64 QAM modulation

Table 4 summarizes the radio link result and annual availability values for 0.6m antenna, 56 MHz spectrum bandwidth and 64 QAM modulation for the whole year and shows the effect of rain and multipath related extra losses. Site 1 to Site 2 radio link design with the specified modulation and antenna type results in an overall link availability value of 99.99804 % (including annual rain and multipath related effects) which means 10.30 minutes of interruption of traffic for one year. With 56 MHz spectrum bandwidth and 64 QAM modulation level, a high traffic capacity of 254 Mbps is achievable between Site 1 and Site 2 with very limited interruption annually.

Table 4. Design 3 Result

	Site 1	**Site 2**
True azimuth (°)	32.58	212.68
Vertical angle (°)	-0.46	0.29
Elevation (m)	1178.30	1026.99
Tower height (m)	30.00	30.00
Antenna model	DW-T555A07.06 (TR)	DW-T555A07.06 (TR)
Antenna file name	thp_06_071_s_wb	thp_06_071_s_wb
Antenna gain (dBi)	30.60	30.60
Antenna height (m)	22.93	14.22
Frequency (MHz)	8000.00	
Polarization	Vertical	
Path length (km)	24.54	
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Field margin (dB)	1.00	
Net path loss (dB)	78.39	78.39
Radio model	08HR56HET254v01	08HR56HET254v01
Radio file name	08hr56het254v01	08hr56het254v01
TX power (dBm)	19.00	19.00
Emission designator	56M0D7WET	56M0D7WET
EIRP (dBm)	49.60	49.60
RX threshold criteria	1E-6 BER	1E-6 BER
RX threshold level (dBm)	-71.00	-71.00
Receive signal (dBm)	-59.39	-59.39
Thermal fade margin (dB)	11.61	11.61
Dispersive fade margin (dB)	42.17	42.17
Dispersive fade occurrence factor		1.00

(continued)

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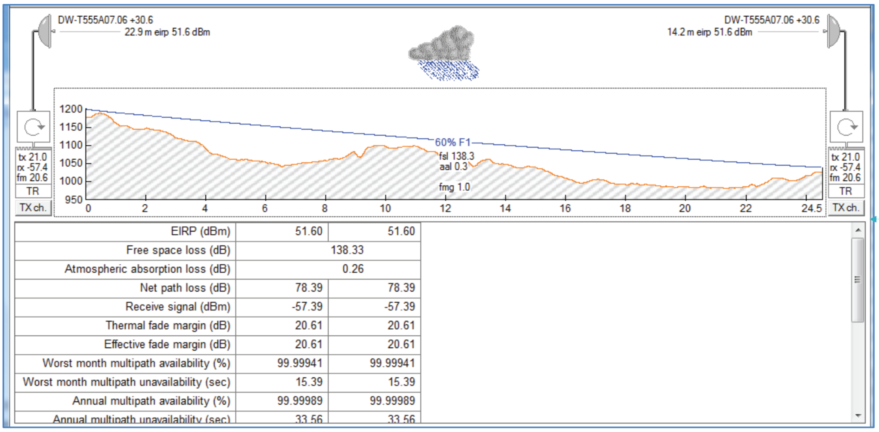
Effective fade margin (dB)	11.61	11.61
Geoclimatic factor	1.768E-006	
Path inclination (mr)	6.52	
Fade occurrence factor (Po)	6.731E-004	
Worst month multipath availability (%)	99.99535	99.99535
Worst month multipath unavailability (sec)	122.12	122.12
Annual multipath availability (%)	99.99916	99.99916
Annual multipath unavailability (sec)	266.37	266.37
Annual 2 way multipath availability (%)	99.99831	
Annual 2 way multipath unavailability (sec)	532.74	
Polarization	Vertical	
0.01% rain rate (mm/hr)	26.71	
Flat fade margin - rain (dB)	11.61	
Rain attenuation (dB)	11.61	
Annual rain availability (%)	99.99973	
Annual rain unavailability (min)	1.42	
Annual rain + multipath availability (%)	**99.99804**	
Annual rain + multipath unavailability (min)	**10.30**	

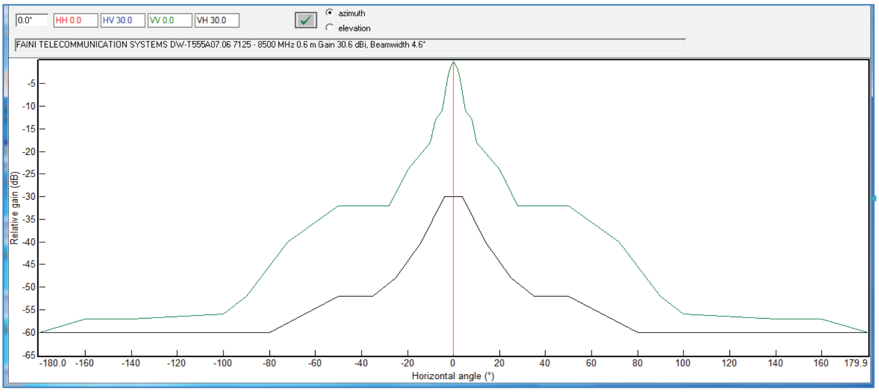
3.4 Design Simulation - 4

For the Simulation -4, Harmony Radio with 16 QAM modulation and 56 MHz channel bandwidth is considered together with 0.6 m antenna. Harmony Radio can provide a transmit power of TX = 21 dBm for this mode, and antenna gain is 30.6 dBm for 0.6 m antenna. This results in an EIRP (Equivalent Isotropically Radiated Power) value of 51.6 dBm for both end points in Site 1 and Site 2. If we consider additional antenna gain of 30.6 dBm on the receiving site as well, total gain budget of 138.33 dBm become available both for Site 1 and Site 2. At this modulation level Harmony Radio has a receiver sensitivity of 65 dBm so, if we consider the free space loss of 138.33 dBm (for a distance of 24.54 km) and Atmospheric absorption loss of 0.26 dBm and Field margin of 1 dBm, we end up with receive signal of -57.39 (which is safely in line with -65 dBm receiver sensitivity). This allows for quite sufficient thermal fade margin of 20.61dB, which in turn provides a good overall transmission link availability (Annual rain + multipath availability: 99.99978 %). Figures 11 and 12 show consecutively the transmission analysis screen with calculated attenuation values, selected antenna model and radio model with gain values and the antenna pattern for 0.6 m 8 GHz single polarized antenna.



EIRP (dBm)	51.60	51.60
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Net path loss (dB)	78.39	78.39
Receive signal (dBm)	-57.39	-57.39
Thermal fade margin (dB)	20.61	20.61
Effective fade margin (dB)	20.61	20.61
Worst month multipath availability (%)	99.99941	99.99941
Worst month multipath unavailability (sec)	15.39	15.39
Annual multipath availability (%)	99.99989	99.99989
Annual multipath unavailability (sec)	33.56	33.56

Figure 11. Transmission Analysis 4, Pathloss Calculation with 0.6 m Antenna and 16 QAM



0.0° HH 0.0 HV 30.0 VV 0.0 VH 30.0

● azimuth
○ elevation

FAINI TELECOMMUNICATION SYSTEMS DW-T555A07.06 7125 - 8500 MHz 0.6 m Gain 30.6 dBi, Beamwidth 4.6°

Figure 12. Transmission Analysis 4 for Antenna 0.6 m and 16 QAM

Table 5 summarizes the radio link result and annual availability values for 0.6 m antenna, 56 MHz spectrum bandwidth and 16 QAM modulation for the whole year and shows the effect of rain and multipath related extra losses.

Site 1 to Site 2 radio link design with the specified modulation and antenna type results in an overall link availability value of 99.99978 % (including annual rain and multipath related effects) which means 1.18 minutes of interruption of traffic for one year. With 56 MHz spectrum bandwidth and 16 QAM modulation level, traffic capacity of 160 Mbps is achievable between Site 1 and Site 2 with very limited interruption annually.

Table 5. Design 4 Result

	Site 1	Site 2
True azimuth (°)	32.58	212.68
Vertical angle (°)	-0.46	0.29
Elevation (m)	1178.30	1026.99
Tower height (m)	30.00	30.00
Antenna model	DW-T555A07.06 (TR)	DW-T555A07.06 (TR)
Antenna file name	thp_06_071_s_wb	thp_06_071_s_wb
Antenna gain (dBi)	30.60	30.60
Antenna height (m)	22.93	14.22
Frequency (MHz)	8000.00	
Polarization	Vertical	
Path length (km)	24.54	
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Field margin (dB)	1.00	
Net path loss (dB)	78.39	78.39
Radio model	08HR56HET161v01	08HR56HET161v01
Radio file name	08hr56het161v01	08hr56het161v01
TX power (dBm)	21.00	21.00
Emission designator	56M0D7WET	56M0D7WET
EIRP (dBm)	51.60	51.60
RX threshold criteria	1E-6 BER	1E-6 BER
RX threshold level (dBm)	-78.00	-78.00
Receive signal (dBm)	-57.39	-57.39
Thermal fade margin (dB)	20.61	20.61
Dispersive fade margin (dB)	48.11	48.11
Dispersive fade occurrence factor	1.00	
Effective fade margin (dB)	20.61	20.61
Geoclimatic factor	1.768E-006	
Path inclination (mr)	6.52	
Fade occurrence factor (Po)	6.731E-004	
Worst month multipath availability (%)	99.99941	99.99941
Worst month multipath unavailability (sec)	15.39	15.39
Annual multipath availability (%)	99.99989	99.99989
Annual multipath unavailability (sec)	33.56	33.56
Annual 2 way multipath availability (%)	99.99979	
Annual 2 way multipath unavailability (sec)	67.13	
Polarization	Vertical	

(continued)

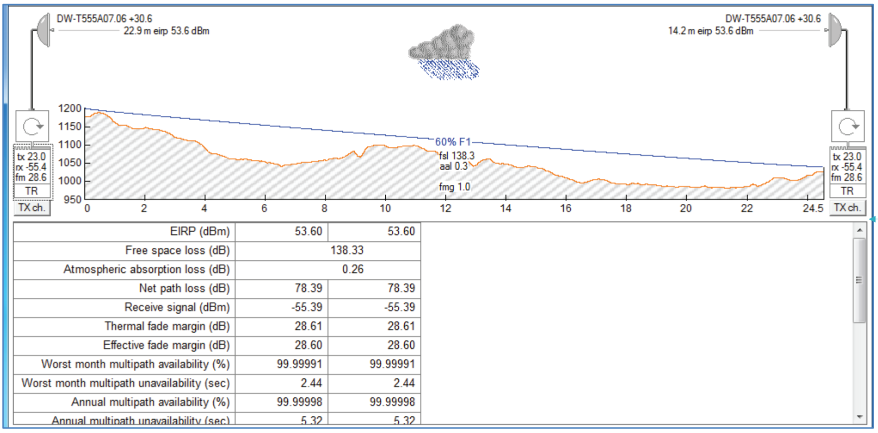
(continued)

0.01% rain rate (mm/hr)	26.71
Flat fade margin - rain (dB)	20.61
Rain attenuation (dB)	20.61
Annual rain availability (%)	99.99999
Annual rain unavailability (min)	0.06
Annual rain + multipath availability (%)	**99.99978**
Annual rain + multipath unavailability (min)	**1.18**

3.5 Design Simulation - 5

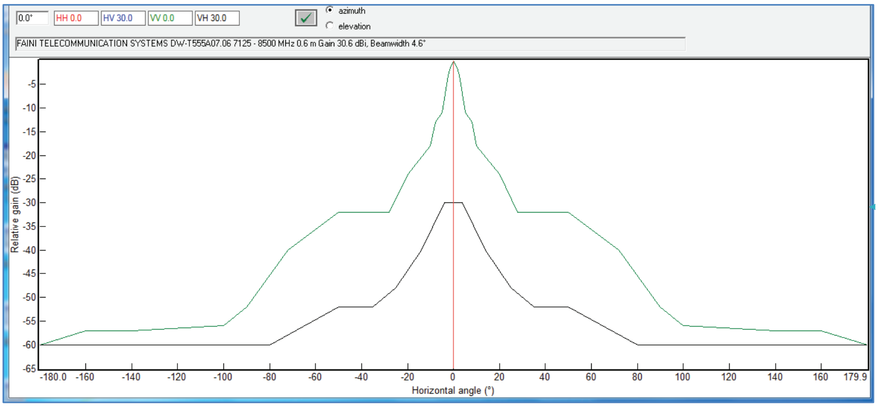
For the Simulation - 4, Harmony Radio with 4 QAM modulation and 56 MHz channel bandwidth is considered together with 0.6 m antenna. Harmony Radio can provide a transmit power of TX = 23 dBm for this mode, and antenna gain is 30.6 dBm for 0.6 m antenna. This results in an Equivalent Isotropically Radiated Power (EIRP) value of 53.6 dBm for both end points in Site 1 and Site 2. If we consider additional antenna gain of 30.6 dBm on the receiving site as well, total gain budget of 138.33 dBm becomes available both for Site 1 and Site 2. At this modulation level Harmony Radio has a receiver sensitivity of 65 dBm so, if we consider the free space loss of 138.33 dBm (for a distance of 24.54 km) and Atmospheric absorption loss of 0.26 dBm and Field margin of 1dBm, we end up with receive signal about -55.39 (which is safely in line with -65 dBm receiver sensitivity). This allows for quite sufficient thermal fade margin of 28.61 dB, which in turn provides a good overall transmission link availability (Annual rain + multipath availability: 99.99977 %).

Figures 13 and 14 show consecutively the transmission analysis screen with calculated attenuation values, selected antenna model and radio model with gain values and the antenna pattern for 0.6 m 8 GHz single polarized antenna.



EIRP (dBm)	53.60	53.60
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Net path loss (dB)	78.39	78.39
Receive signal (dBm)	-55.39	-55.39
Thermal fade margin (dB)	28.61	28.61
Effective fade margin (dB)	28.60	28.60
Worst month multipath availability (%)	99.99991	99.99991
Worst month multipath unavailability (sec)	2.44	2.44
Annual multipath availability (%)	99.99998	99.99998
Annual multipath unavailability (sec)	5.32	5.32

Figure 13. Transmission Analysis 5, Pathloss Calculation with 0.6 m Antenna and 4 QAM modulation


0.0° HH 0.0 HV 30.0 VV 0.0 VH 30.0

● azimuth
○ elevation

FAINI TELECOMMUNICATION SYSTEMS DW-T555A07.06 7125 - 8500 MHz 0.6 m Gain 30.6 dBi, Beamwidth 4.6°

Figure 14. Transmission Analysis 5 for Antenna 0.6 m and 4 QAM modulation

Table 6 summarizes the radio link result and annual availability values for 0.6 m antenna, 56 MHz spectrum bandwidth and 4 QAM modulation for the whole year and shows the effect of rain and multipath related extra loss.

Table 6. Design 5 Result

	Site 1	**Site 2**
True azimuth (°)	32.58	212.68
Vertical angle (°)	-0.46	0.29
Elevation (m)	1178.30	1026.99
Tower height (m)	30.00	30.00
Antenna model	DW-T555A07.06 (TR)	DW-T555A07.06 (TR)
Antenna file name	thp_06_071_s_wb	thp_06_071_s_wb
Antenna gain (dBi)	30.60	30.60
Antenna height (m)	22.93	14.22
Frequency (MHz)	8000.00	
Polarization	Vertical	
Path length (km)	24.54	
Free space loss (dB)	138.33	
Atmospheric absorption loss (dB)	0.26	
Field margin (dB)	1.00	
Net path loss (dB)	78.39	78.39
Radio model	08HR56HET080v01	08HR56HET080v01
Radio file name	08hr56het080v01	08hr56het080v01
TX power (dBm)	23.00	23.00
Emission designator	56M0D7WET	56M0D7WET
EIRP (dBm)	53.60	53.60
RX threshold criteria	1E-6 BER	1E-6 BER
RX threshold level (dBm)	-84.00	-84.00
Receive signal (dBm)	-55.39	-55.39
Thermal fade margin (dB)	28.61	28.61
Dispersive fade margin (dB)	55.08	55.08
Dispersive fade occurrence factor	1.00	
Effective fade margin (dB)	28.60	28.60
Geoclimatic factor	1.768E-006	
Path inclination (mr)	6.52	
Fade occurrence factor (Po)	6.731E-004	
Worst month multipath availability (%)	99.99991	99.99991
Worst month multipath unavailability (sec)	2.44	2.44
Annual multipath availability (%)	99.99998	99.99998
Annual multipath unavailability (sec)	5.32	5.32
Annual 2 way multipath availability (%)	99.99997	
Annual 2 way multipath unavailability (sec)	10.64	
Polarization	Vertical	

(continued)

(continued)

0.01% rain rate (mm/hr)	26.71
Flat fade margin - rain (dB)	28.61
Rain attenuation (dB)	28.61
Annual rain availability (%)	100.00000
Annual rain unavailability (min)	0.00
Annual rain + multipath availability (%)	**99.99997**
Annual rain + multipath unavailability (min)	**0.18**

Site 1 to Site 2 radio link design with the specified modulation and antenna type results in an overall link availability value of 99.99997 % (including annual rain and multipath related effects) which means 0.18 minutes of interruption of traffic for one year. With 56 MHz spectrum bandwidth and 4 QAM modulation level, traffic capacity of 80Mbps is achievable between Site 1 and Site 2 with very limited interruption annually.

Table 7 summarizes the various radio link design results studied with different modulation and antenna schemes and provides overall annual availability value, related free space loss, rain loss and multipath fading effects. As the purpose of the traffic calculation is to provide 155 Mbps traffic capacity, the minimal antenna dimension and acceptable interruption rate are considered for optimal design.

Table 7. R/L Total Result

			1.Design	2.Design	3.Design	4.Design	5.Design
Frequency Band	Channel Band	The Values Obtained	256QAM Antenna Height 1.8m	256QAM Antenna Height 1.2m	64QAM Antenna Height 0.6m	16QAM Antenna Height 0.6m	4QAM Antenna Height 0.6m
7125-8500 MHz	56 MHz	Annual rain + multipath availability (%)	99.9999	99.99947	99.99804	99.99978	99.99997
		Annual rain + multipath unavailability (min)	0.54	2.8	10.3	1.18	0.18
		Tx and Rx Data Rate (MHz)	348	348	254	160	80
		EIRP (dBm)	57.8	54.3	49.6	51.6	53.6

4.0 CONCLUSION

Radio Link Design Study -4 with 16 QAM modulation and with 0.6 m Antenna is considered as the suitable one with annual interruption time of 1.18 minutes. The obvious reason for this selection is its ability to transport 155 Mbps traffic smoothly and at the same time allowing to use a considerably small diameter antenna of 0.6 m. Small diameter antennas are very favorable to use when possible because of its small aperture for wind and tower that results in considerably less tower leasing costs. Some studies show that using smaller antennas can provide up to 75 % savings in tower leasing costs over a five years period which is sometimes equal to the cost of radio link equipment itself.

Another design consideration for achieving better radio link availability and less transmission path interruption is to use an automatic Adaptive Modulation feature of selected radio link equipment to fight against adverse weather conditions. Adaptive Modulation can lower modulation level from 16 QAM in our study to 4 QAM level and this allows even much smaller interruption time (0.18 minute) but with a bit smaller capacity (80 Mbps) for this short adverse weather conditions period.

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REFERENCES

Ghasemi, A., Abedi, A., & Ghasemi, F. (2013). *Propagation engineering in radio links design*. New York: Springer Science & Business Media.

Gnauck, A.H. & Winzer, P. (2005). Optical Phase-shift-keyed transmission. *Journal of Lightwave Technology*, 23(1):115-130.

Gnauck, A.H., Winzer, P.J., Chandrasekhar, S. & Dorrer, C. (2004). Spectrally efficient (0.8 b/s/Hz) 1-Tb/s (25 x 42.7 Gb/s) RZ-DQPSK transmission over 28 100-km SSMF spans with 7 optical add/drops. *Proceeding of Optical Fiber Communication Conference*, Paper Th4.4.1.

Pathloss. (2011). Pathloss 4. Versão 4. Canadá, 2008. Disponível em: . Acesso em: 20 mar. 2011.

Stremler, F. G. (1990). *Introduction to Communication Systems, 3rd Edition*. USA: Addison-Wesley.

Tripathi, D. K. (2016). Design and performance evaluations with optical comparator link. *Engineering Science and Technology, an International Journal*, 20(1):89-94.

Van den Borne, D., Jansen, S.L., Gottwald, E., Schmidt, E.D., Khoe, G.D. & de Waardt, H. (2008). DQPSK modulation for robust optical transmission. *Proceeding of Optical Fiber Communications Conference*, paper OMQ1.

Zaldívar-Huerta, I. E., García-Juárez, A., Pérez-Montaña, D. F., Hernández-Nava, P., & Vera-Marquina, A. (2015). Proposal and performance evaluation of a Fiber-To-The-Antenna system for video distribution operating in the S-band. *Optics & Laser Technology*, 71: 89-94.