Analysis of ITU-R Performance and Characterization of Ku Band Satellite Downlink Signals during Rainy Season over Chennai Region of India

Sanjeev SURESH, M. Ganesh MADHAN, Maharaj SIVARAJ, S. PARASURAMAN

Dept. of Electronics Engineering, Madras Institute of Technology Campus, Anna University, Chennai 600 044, India.

sanjeevsuresh90in@gmail.com, mganesh@annauniv.edu, ashanthicpt@gmail.com, parasuramanmit@gamil.com

Abstract. *In this paper, we present the analysis of Ku band satellite signal reception during rainy season over Chennai region, India (Latitude: 12° 56' 60 N, Longitude: 80° 7' 60 E). We also examine the effectiveness of International Telecommunication Union – Radio communication (ITU-R) model in predicting the rainfall induced attenuation in Ku band, over this region. An improved Simulink model for Digital Video Broadcast – Satellite (DVB-S2) downlink channel incorporating rain attenuation and Cross Polarization Discrimination (XPD) effects is developed to study the rain attenuation effects, by introducing the experimental data in the ITU-R model pertaining to that region. Based on the improved model, a Monte Carlo simulation of the DVB-S2 signal link is carried out and the performance is analyzed by received constellation and Bit Error Rate (BER) parameters.*

Keywords

ITU-R, Ku band, DVB-S2, DTH, Simulink, Monte Carlo simulation.

1. Introduction

Recent advances in satellite based digital television systems has led to the drastic increase in the utilization of the Ku band frequency spectrum for direct to home broadcasting (DTH) of these television signals. With several operators utilizing this frequency band and due to the ever increasing demand, it becomes essential to study the key effects and causes of signal distortion and attenuation at such frequencies. At these frequencies, atmospheric effects influence the characteristics of the signal. Amongst different atmospheric effects, attenuation due to rainfall is the most significant and is directly responsible for link outages of a Ku band signal [1]. Further, the effect of water on the antenna surface is also found to provide significant attenuation at higher frequencies [2]. Several models, both empirical and non-empirical have been suggested to model the effects of rainfall on Ku Band signals [3] – [9]. Measurement of the effects of rain such as attenuation and depolarization typically involve calculation of parameters such as effective path length, rainfall intensity and specific attenuation. In this paper, ITU-R recommendations were used to theoretically estimate rain attenuation and cross polarization discrimination. Calculation of rain rate was done with the help of the Rice Holmberg model [9]. Further, the approach suggested in Bhattacharya et al [3] is followed, where rain attenuation data is synthesized from available metrological data. The required metrological data was readily obtained from the Indian Metrological department [10]. In our previous paper [11], the experimental study of rain effect was carried out and compared with the theoretical predications of ITU-R. It is observed that the ITU-R model seems to under estimate the rain attenuation in Chennai region. Mandeep [12] has also reported such deviations from theoretical rainfall attenuation predictions, for Equatorial regions. DVB-S2 is the standard evolved for aatellite based high quality Direct to Home (DTH) TV broadcast services [13]. In DTH applications, detailed propagation studies are required to provide insight in to performance, availability and quality of service. Rain fade margin is an important parameter that has to be considered in the link design. As the rainfall characteristics vary from one region to other, detailed link models incorporating regional rain attenuation parameters become mandatory. Many authors [4] – [8], have investigated the signal attenuation due to rainfall, at different frequencies, but the effect of such attenuation on the performance of a digital satellite based TV broadcast has not been investigated thoroughly. Recently, Simulink® based models have gained importance due to its reduced complexity and scalability and are widely used to study communication systems performance [14]. Simple satellite based DVB link models were used to study different techniques for down link reception [15]. Even in Simulink tool box [16], detailed attenuation blocks like rain fall, cross polarization effects, which are very important in link analysis, are not available. Hence we attempt to incorporate rain attenuation and cross polarisation discrimination effects in the existing DVB–S2 Simulink model. As a test case, experimental rain attenuation values corresponding to the earth space path over Chennai region of India, is incorporated and received satellite signal performance is studied in terms of BER and constellation diagrams. Such analysis becomes vital for the design of Ku band satellite receivers with appropriate rain fade margins, for different geographical locations. The proposed model can accommodate rain attenuation values of the region of interest and predict the rain induced impairments in the satellite down link, relevant to the region of study. Further performance study with different modulations can be easily carried out with this approach.

2. Simulink Model

In DTH applications, detailed rain fall attenuation models are required to provide insight in to performance and quality of service [12]. As typical modulations used for DVB-S2 applications include Quadrature Phase Shift Keying (QPSK) and 8 Phase Shift Keying (PSK) [13], we include these modulations in our simulation. In conventional Simulink(R) based analysis of satellite channels, only Additive White Gaussian (AWGN) model for noise effects are included. We enhance the model by adding rain attenuation, path loss and Cross Polarization Discrimination (XPD). Fig. 1 describes the complete blocks used to model the satellite down link channel. These blocks along with the conventional Simulink based DVB-S2 transmitter and receiver blocks are used to perform the simulations of a DVB-S2 downlink. As conventional transmitter and receiver modeling approaches are well documented in the literature, we have not provided them here.

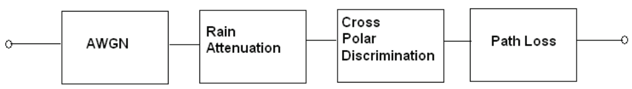

Fig. 1. Block diagram for improved DVB-S2 channel model.

The DVB- S2 transmitter block comprises of a random number generator, a Bose Chaudhuri Hocquenghem (BCH) encoder, a Low-density parity-check (LDPC) encoder, a block interleaver, and a modulator (QPSK) / Quadrature Amplitude Modulation (QAM)). The channel is represented by an AWGN model along with an attenuation block, which can be configured to introduce attenuation as calculated from the ITU-R model or values measured experimentally at the receiver site. There is also a XPD block, which creates cross polar depolarization effect as calculated from the ITU-R model. The receiver consists of a demodulator followed by first the LDPC decoder and then the BCH decoder. The received data is then suitably compared to the input data to calculate BER and Frame Error rates as required.

3. Methodology

The entire study was performed at Anna University - MIT Campus, Chennai, where the experimental setup was installed in order to study the event. The rainfall rate was then utilized to estimate the theoretical rainfall attenuation suffered by the signal as per the ITU-R global model for attenuation. The same model was then used to develop estimates of Cross Polarization Discrimination.

The ITU-R model [1] calculates specific attenuation as per the following equation:

$$\gamma = kR^{\alpha} \tag{1}$$

where γ is the specific attenuation due to rainfall, dependent on R, the rainrate (mm/hr.) in the given region. Also, k and α denote the regression coefficients, which are dependent on frequency, temperature, drop spectral density and polarization of radio wave. Apart from the specific attenuation, the model also requires calculation of effective path length $L_{effective}$, which is calculated from (2), given below.

$$L_{effective} = L_r v \tag{2}$$

where

$$L_r = \left(L_g r_P\right) / \cos\theta \tag{3}$$

in which

$$L_g = \left(L_s\right)\cos\theta \, . \tag{4}$$

In the above equations L_s, r, θ and v, represent Effective Slant Path, effective rain rate, elevation angle (in degrees) and vertical adjustment factor respectively. The slant path is itself calculated from the rain height with the help of ITU recommendation 839.1 [1]. With the above formulae, the expression for rain attenuation as a function of rain exceedence is also given in the ITU R recommendation and calculated as

$$A_{0.01} = \gamma L_{effective} \tag{5}$$

where, $A_{0.01}$ = attenuation exceeded for 0.01 % time in an average year.

The ITU-R model [1] is based on Laws and Parson's drop size distribution for specific attenuation. Ajayi [17] deduces the constants ("k" and "α" in (1)) for specific attenuation based on log normal drop size data for the tropical regions [18]. This approach is also used to compare the rain induced attenuation.

The Cross Polarization discrimination due to rain is defined as ratio of received power on the transmitted polarization over the received power in the orthogonal polarization.

The calculation of Cross Polarization Discrimination (C_{tot}) from rain attenuation characteristics is based on ITU-R 736-3 [19], and given in (6)

$$C_{tot} = C_{\theta} + C_{\tau} + C_f + C_{\sigma} - C_A \tag{6}$$

where, C_θ, C_τ, C_f, C_σ and C_A denote cross polarization discrimination due to elevation angle dependent term, polarization improvement factor dependent on tilt angle, frequency dependent term, rain drop canting angle dependent term and rain attenuation dependent term respectively. The parameters, contributing for C_{tot}, are given by the following expressions.

$$C_f = 30(\log f), \tag{7}$$

$$C_A = 12.8 f^{0.19} \log A_p, \tag{8}$$

$$C_\tau = -10\log(1-0.484(1+\cos 4\tau)), \tag{9}$$

$$C_\theta = -40\log(\cos\theta), \tag{10}$$

$$C_\sigma = 0.052\sigma^2. \tag{11}$$

Using the ITU-R recommendations and subsequent formulas, attenuation for different exceedence percentages can be obtained. A Matlab® code was developed for this calculation and the typical exceedence curve for Chennai region is determined as shown in Fig. 2.

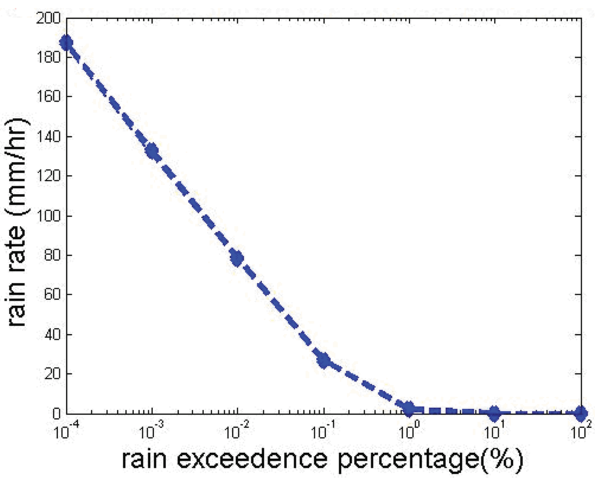

Fig. 2. Year-round rain exceedence curve for Chennai region as calculated using ITU-R recommendation.

As it can clearly be seen, higher rain rates are pretty rare and hardly account for 0.01 to 0.001 % of an entire year. It is during such times of the year that maximum attenuation due to rainfall can be studied best.

4. Experimental

The exact co-ordinates of Chennai are 130° N, 80° E. To receive Ku band signals, a typical satellite receiver along with a 2 feet Ku band dish antenna was used. The dish antenna receives signals from the INSAT 4B satellite which is located at 93.5° East longitude. The satellite receiver obtains the Intermediate Frequency (IF) signal (Frequency range 0.95 to 2.05 GHz) from the Low Noise Block Converter (LNBC). The IF signals are provided from satellite receiver loop out and fed to a spectrum analyzer, which is used to measure the signal level. The experimental set up is shown in Fig. 3. An Agilent E4402B, 3 GHz spectrum analyzer was used to record samples of the viewed spectrum over finite periods of time. A typical IF signal spectrum under clear sky conditions is shown in Fig. 4.

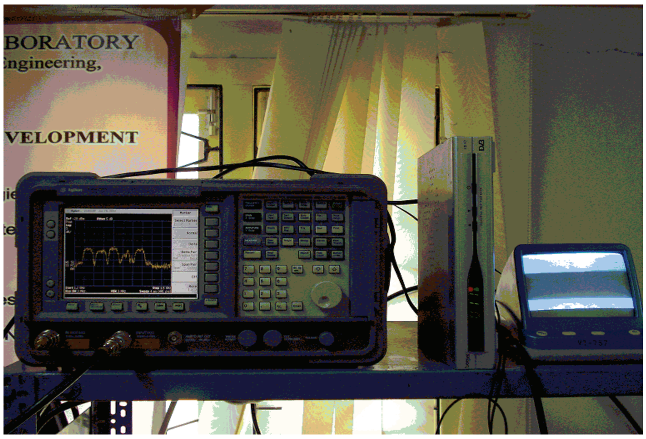

Fig. 3. Experimental set up.

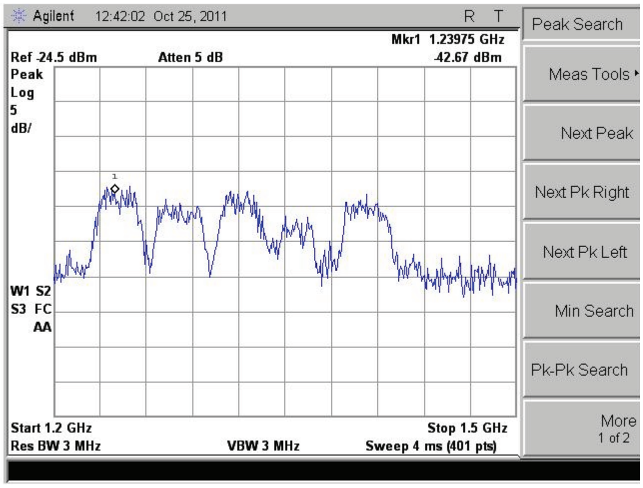

Fig. 4. Typical DTH IF signal spectrum (clear sky).

The setup is then used to obtain data for signal power during events of rainfall. The corresponding rain statistics are obtained from the Indian Metrological Department website [10] and are used to run the theoretical models.

4.1 Measurement Case I

Measurements were carried out during a rainfall event (17/8/2010), to determine the rain induced attenuation. The measured attenuation, estimated attenuation (ITU) calculated using (1) – (5) and attenution calculated using Ajayi's [17] model, are all evalauted during a typical rainfall event, and tabulated in Tab. 1. The experimental attenuation is calculated by subtracting the clear sky signal power (-43.74 dBm) from the measured value at that instant.

Time (PM)	Rain Rate (mm/hr)	Measured Attenuation (dB)	Estimated Attenuation (dB)	
			ITU Model	Ajayi 's Model
5:25	0	0	0	0
5:32	0	0	0	0
5:35	5	1	0.53	0.95
5:40	15	2.6	2.06	2.45
5:45	5	1.23	0.53	0.95
5:50	5	0.49	0.53	0.95
5:55	5	0.64	0.53	0.95
6:00	0	0	0	0
6:10	10	1.63	1.25	1.57
6:20	15	3.1	2.06	2.45
6:30	60	11.94	11.27	11.58
6:32	48	9	8.58	8.74
6:34	40	6.24	6.85	6.65
6:35	25	4.11	3.91	3.85
6:40	17	2.25	2.93	2.35
6:45	5	0.79	0.53	0.95

Tab. 1. Measured and estimated attenuation values.

A graph is plotted in Fig. 5 to show the relation between rain attenuation and rainfall intensity. Also, the measured attenuation, estimated attenuation values calculated using ITU model and Ajayi's model are also plotted in Fig. 6. It is observed that the ITU model underestimates the attenuation due to rain in the Chennai region. This may be due to the fact that α and *k* coefficients used in the ITU-R model are not specific to the requirements of the Chennai region. It is also found that the modified model suggested by Ajayi [17], provides data very close to the measured attenuation. The deviations of the ITU model and Ajayi's model with respect to measured values are plotted in Fig. 7.

A graph showing the deviations in the case of ITU and Ajayi's model with respect to measured attenuation is plotted in Fig. 7.

It is observed that the Ajayi's model [17] provides better estimate compared to the ITU model. However, for best estimate, models with optimum value of regression coeffcients should obtained from large number of experimental data pertaining to the region of interest. Especially in tropical regions, similar deviations have been oberved by Mandeep et al [7].

4.2 Measurement Case II

In another experiment conducted recently, a satellite signal meter (Sefram Model 7805) is used in the place of the spectrum analyser, to measure the Carrier to Noise Ratio (CNR) and Bit Error Rate (BER) parameters. The measurment parameters in the meter are set as follows:

- Downlink frequency: 11.1517 GHz,
- Sampling rate: 27.5 Ms/s,
- Modulation: QPSK,
- Code rate: ¾,
- Polarisation: Vertical.

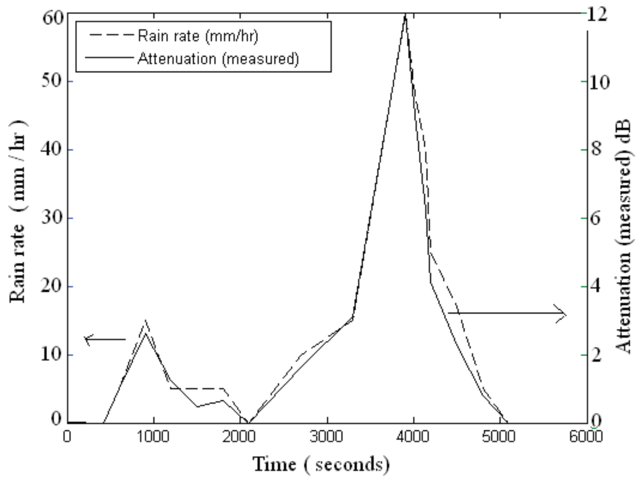

Fig. 5. Rain attenuation and Rain rate with time instants.

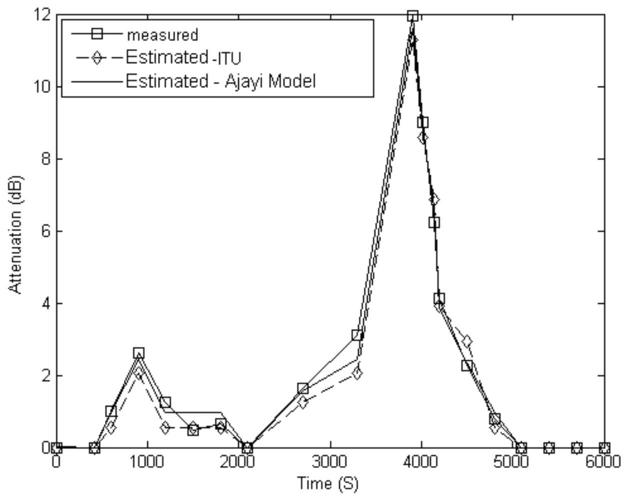

Fig. 6. Rain attenuation measured, ITU model and Ajayi's model.

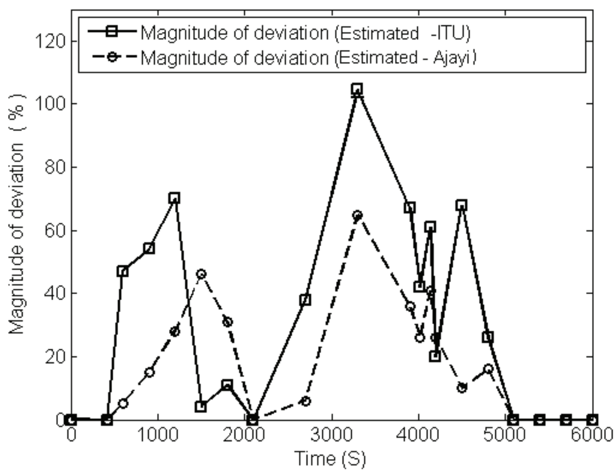

Fig. 7. Deviations from measured attenuation.

Under normal, clear sky conditions, signal meter shows a level of -38 dBm. The corresponding CNR, BER before and after Viterbi decoding was found to be 8.9 dB, 3.1E-3 and 1E-9, respectively. The Modulation Error Ratio (MER) was around 9.1 dB. During rainfall event, measurements have been carried out and the data is tabulated (Tab. 2). It is observed that during moderate rain fall, up till the received signal level reaches -41.5 dBm, the link parameters could be measured. As the rain rate increases, attenuation also increases leading to decrease of CNR below 4 dB. In the case of measured CNR of 5.1, a BER of 3E-4 is observed after Viterbi decoding. This value coincides well with the DVB standard, which states that the onset of link failure occurs around 5.46 dB, corresponding to BER of 1E-6.

Sl No	Time	Rain Attenuation Measured (dB)	Signal level (dBm)	CNR dB	BER	VBER	MER (dB)
1	18.20	1.6	-39.6	5.1	1E-4	3E-4	5
2	18.21	3.5	-41.5	4.0	1E-3	2E-3	4
3	18.23	4.2	-42.2	3.6	1	1	N.A.
4	18.24	6.0	-44	2.7	1	1	N.A.
5	18.25	17	-55	1.5	1	1	N.A.
6	18.26	18	-56	1.2	1	1	N.A.
7	18.27	15	-53	1.7	1	1	N.A.
8	18.28	19	-57	1.0	1	1	N.A.
9	18.29	19	-57	1.0	1	1	N.A.
10	18.30	21	-59	0.8	1	1	N.A.

Tab. 2. Rain attenuation vs Signal Parameters.

Under higher rainfall rate, the receiver is unable to decode the data and the BER becomes maximum, i.e., 1. Further, the MER value could not be decoded by the receiver, indicated as Not Available (N.A.) in Tab. 2. A minimun CNR of 0.8 dB is observed for an attenuation of 21 dB, during that event.

5. Simulation Results

The DVB -S2 SIMULINK model shown in Fig. 1, was used to simulate the satellite down link. The effects of both attenuation and cross polarization discrimination, on the received signal was analyzed by using detailed Monte Carlo simulations. The mathematical equations representing rain fall effects, provided in (1) – (10) are employed for the simulation. The rainfall data pertaining to rainfall event on 17/8/2010 was used for the simulation. Typical DVB-S2 modulation schemes, viz. ½ QPSK and 8 PSK2/3, are considered for the study. The plot of the in-phase component of the signal versus the quadrature component, decimated by a factor, is used to examine the signal constellations under the impact of rain attenuation. The input constellation for the QPSK case consists of 4 defined points at the centre of each quadrant. The demodulated, equalized and sampled in phase and quadrature phase components are found to form a cluster due to channel impairments such as noise, attenuation and XPD.

Fig. 8(a) and (b) shows the received constellation in the case of 1/2 QPSK and 8 PSK2/3 modulations schemes respectively.

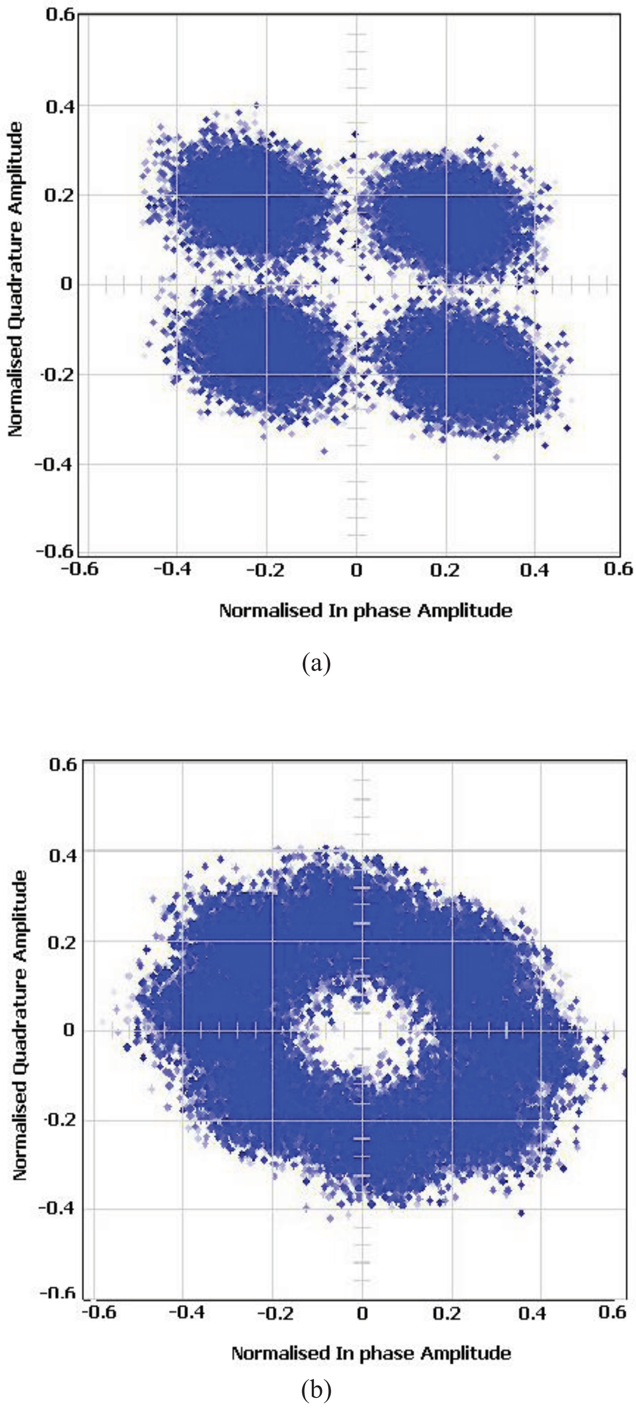

Fig. 8. Received constellation during a severe rain fall event; (a) 1/2 QPSK. (b) 8 PSK2/3.

Further the variation of BER with E_b/N_o (Energy per bit to noise density ratio) is also determined under clear sky and different attenuation conditions. Figs. 9 and 10 show the BER plot of the 1/2 QPSK and 8 PSK 2/3 modulations.

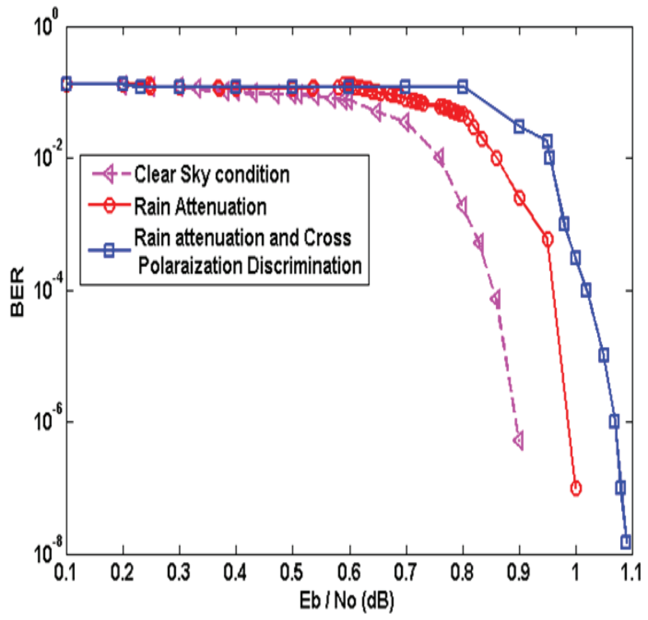

Fig. 9. BER Curves for 1/2 QPSK.

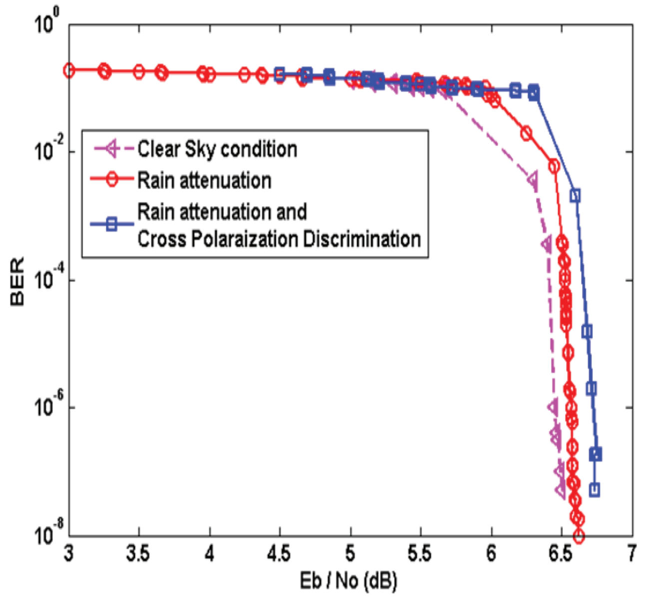

Fig. 10. BER Curves for 8PSK 2/3.

The simulation shows that in order to meet a basic requirement having BER less than 10^{-6} requires the E_b/N_o to be greater than 0.89 dB and 6.46 dB, in the case of 1/2 QPSK and 8 PSK systems.

The Eb/No required by the system to maintain a minimum BER of 10^{-6} is calculated and tabulated in Tab. 3. The simulation results for the clear sky case and the Eb/No requirement are in agreement with the DVB standards [20]. It is observed that a minimum Eb/ No of 1.06 dB and 6.68 dB are required in the case of 1/2 QPSK and 8 PSK schemes, under rain fall conditions. It can be shown that during the worst case scenario, the Eb/No drop much below this threshold thus making the system prone to black-outs.

Modulation Type	Clear Sky (dB)	Rain attenuation (dB)	Rain attenuation and Cross polar discrimination (dB)
1/2 QPSK	0.89	0.98	1.06
8 PSK 2/3	6.46	6.566	6.68

Tab. 3. Min Eb/No required for BER of 10^{-6} under various atmospheric conditions.

6. Conclusion

In this paper, rain attenuation for Ku band DTH signals was measured, calculated with ITU and Ajayi's models. It is observed that Ajayi's model provides better rain attenuation estimate for the region under study. Experimental values of CNR for proper decoding, under rainfall conditions were determined. An improved SIMULINK model for DVB-S2 link is also developed incorporating rain attenuation and cross polar depolarization effects in the channel. Based on the model, Monte Carlo simulations on the rain effect on the performance of 1/2 QPSK and 8 PSK2/3 signal transmission are carried out. Constellation diagrams of the received signals were used to evaluate the signal conditions. Further, BER plots for various values of Eb/No depicting the real channel situations were determined and conditions for minimum BER of 10^{-6} is estimated for various atmospheric conditions. The results were found to agree with the values reported in the literature, thereby validating our simulation methodology. This approach can be easily extended to any region of study and for other modulation formats too.

References

[1] *ITU-R Recommendation P. 618-7: Propagation Data and Prediction Methods Required for the Design of Earth-Space Telecommuni-cation Systems*. Geneva (Switzerland): International Telecommunication Union, 2005.

[2] MANDEEP, J. S. Analysis effect of water on a Ka-band antenna. *Progress in Electromagnetic Research Letters*, 2009, vol. 9, p. 49 - 57.

[3] BHATTACHARYA, R., DAS, R., GUHA, R., BARMAN, S. D., BHATTACHARYA, A. B. Variability of millimeter wave rain attenuation and rain prediction: A survey. *Indian Journal of Space and Radio Physics*, 2007, vol. 36, no. 4, p. 325 - 344.

[4] MAITRA, A., CHAKRAVARTY, K., BHATTACHARYA, S., BAGCHI, S. Propagation studies at Ku band over an earth-space at Kolkata. *Indian Journal of Radio and Space Physics*, 2007, vol. 36, no. 5, p. 363 - 368.

[5] GARCI- LOPEZ, J. A., HERNANDO, J. M., SELGA, J. M. Simple rain attenuation prediction method for satellite radio links. *IEEE Transactions on Antennas and Propagation*, 1982, vol. 36, no. 3, p. 460 - 465.

[6] CRANE, R. K. Comparative evaluation of several rain attenuation models. *Radio Science*, 1985, vol. 20, p. 843 - 863.

[7] MANDEEP, J. S., ALNUTT, J. E. Rain attenuation predictions at Ku band in south-east Asian countries. *Progress in Electromagnetic Research*, 2007, vol. 76, p. 65 - 74.

[8] MOUPFOUMA, P. Improvement of rain attenuation prediction methods for terrestrial microwave links. *IEEE Transaction on Antennas and Propagation*, 1984, vol. 32, no. 12, p. 1368 - 1372.

[9] RICE, P., HOLMBERG, N. Cumulative time statistics of surface point rainfall rates. *IEEE Transactions on Communication*, 1973, vol. 21, no. 10, p. 1131 - 1136.

[10] Indian Meterological Department. *Rainfall Data, June – December 2010.* [Online] Available at http:www.imdchennai.gov.in/np2.htm.

[11] SURESH, S., MADHAN, G. M. An experimental study of rain attenuation at Ku band frequencies for an earth space over Chennai. *IJCA International Journal of Computer Applications*, 2011, no. 6, p. 1 - 5.

[12] MANDEEP, J. S. Equatorial rainfall measurement on Ku band satellite communication downlink. *Progress in Electromagnetic Research*, 2007, vol.76, p. 195 - 200.

[13] MORELLO, A., MIGNONE, V. DVB- S2: The second generation standard for satellite broad band services. *Proceedings of the IEEE*, 2006, vol. 94, no. 1, p. 210 - 227.

[14] LIU, X., XIONG, X., YANG, P. Modeling and simulation for IDMA systems based on Simulink. In *Proceedings of Pacific Asia conference on Circuits, Communications and Systems (PACCS)*, Chengdu (China), 2009, p. 213 - 216.

[15] RONGA, L. S., DEL RE, E., GANDON, F. Link co-operation technique for DVB- S2 down link reception with mobile terminals. *Satellite communication and Navigation Systems*, 2008, vol. 4, p. 561 - 572.

[16] Mathworks, Inc. *DVB- S2 – Simulink Demo*. [Online] Available at: http://www.mathworks.com

[17] AJAYI, G. O. Characteristics of rain-induced attenuation and phase shift at cm and mm waves using a tropical raindrop size distribution model. *International Journal of Infrared and Millimeter Waves*, 1985, vol. 6, no. 8, p. 771 - 806.

[18] AJAYI, G. O., RODERIC, A., OLSEN, L. Modeling of a tropical raindrop size distribution for microwave and millimetre wave applications. *Radio Science*, 1985, vol. 20, no. 2, p. 193 – 202.

[19] *ITU-R Recommendation S.736-3: Estimation of Polarization Discrimination in Calculations of Interference between Geostationary-Satellite Networks in the Fixed-Satellite Service*. Geneva (Switzerland): International Telecommunication Union, 1997.

[20] *ETSI EN 302 307, v. 1.2.1.: Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Services, News Gathering and Other Broadband Satellite Applications (DVB-S2).* European Telecommunications Standards Institute, 2009.

About Authors …

Sanjeev SURESH received the B.E. degree in Electronics and Communication Engineering from the Anna University, Chennai, India. He is currently a Master's student at University of California, Los Angeles, specializing in VLSI technology.

M. Ganesh MADHAN, received his B.E degree (1993) in Electronics and Communication Engineering from Madurai Kamaraj University, India, M.E degree (1995) in Optical Communications from College of Engg, Guindy, Anna University, India. He was a CSIR Junior Research Fellow at Anna University for a short period and subsequently joined as a lecturer in the same institute. He worked in the area of semiconductor laser diodes, and obtained Ph.D degree in 2001. Currently he is an Associate. Professor of Electronics Engineering at the Madras Institute of Technology campus of Anna University, Chennai, India. He has about 50 Journal and conference papers to his credit. His current research interests include design, modeling of opto-electronic devices, RF and optical communication systems.

Mahraj SIVARAJ received the B.E. degree in Electronics and Communication Engineering from the Anna University, Chennai, India. He is currently working as an application engineer in Chennai.

S. PARASURAMAN received the B.E. degree in Electronics and Communication Engineering from the Anna University, Chennai, India. He is currently working as an Engineer in Infosys Technologies, Chennai, India.