QoS Improvement Using Intelligent Algorithm under Dynamic Tropical Weather for Earth-Space Satellite Applications

Joseph S. Ojo, Vincent A. Akpan, Oladayo G. Ajileye, Olalekan L, Ojo

Abstract**—**In this paper, the intelligent algorithm (IA) that is capable of adapting to dynamical tropical weather conditions is proposed based on fuzzy logic techniques. The IA effectively interacts with the quality of service (QoS) criteria irrespective of the dynamic tropical weather to achieve improvement in the satellite links. To achieve this, an adaptive network-based fuzzy inference system (ANFIS) has been adopted. The algorithm is capable of interacting with the weather fluctuation to generate appropriate improvement to the satellite QoS for efficient services to the customers. 5-year (2012-2016) rainfall rate of one-minute integration time series data has been used to derive fading based on ITU-R P. 618-12 propagation models. The data are obtained from the measurement undertaken by the Communication Research Group (CRG), Physics Department, Federal University of Technology, Akure, Nigeria. The rain attenuation and signal-to-noise ratio (SNR) were derived for frequency between Ku and V-band and propagation angle with respect to different transmitting power. The simulated results show a substantial reduction in SNR especially for application in the area of digital video broadcast-second generation coding modulation satellite networks.

Keywords**—**Fuzzy logic, intelligent algorithm, Nigeria, QoS, satellite applications, tropical weather.

I. Introduction

In recent times, application of satellite services continue to gain tremendous significance because of its wide area coverage, point to multi-point approach and vast sensors for numerous services. In order to rate the effectiveness of the satellite networks, a measurable tool termed QoS must be considered. Satellite services' major problem is the short period of visibility as a result of the altitude. Other problems may arise as a result of the reduction in the SNR due to atmospheric weather along the propagation link. Signal propagation for satellite networks has a long path from the source to the destination. Therefore, it is immensely susceptible to attenuation mainly caused by weather factors for different satellite functions and service providers [1]. The major atmospheric and weather related factors of signal attenuation were rain fade, gaseous absorption, cloud and fog attenuation and tropospheric scintillation [2]. These are referred to as the hydrometeors. Among them, the effect of attenuation due to rain becomes a major problem especially at frequencies above 10 GHz [3]-[8]. Signal absorption and scattering along the propagation path are usually associated with rain attenuation especially at the receiving end. Energy arises from the signal are usually absorbed and scattered due to rain droplets. This results into reduction in its power level depending on sizes, intensity and shape of the drops. In the absence of long-term measured attenuation data over a specific location, rain rate statistics of 1-minute integration is generally used. The result obtained from the prediction usually serves as the equivalent rain-induced attenuation in the given link.

Rain attenuation is a function of frequency, probability of signal availability p, propagation angle θ, polarization tilt angle and raindrop temperature. Other major factors are the intensity of the rain and raindrop size distribution. Most of the time, the signal at the receiving terminal may be lost completely because of the excessive effect of rain-induced attenuation. This may be due to the fact that the receiving terminal cannot adjust to the situation on its own. In addition, the hubs of the satellite repeating terminal have not been designed to support the receiving terminal in such situation. It is, therefore, imperative to design an algorithm that can intelligently manage the situation when the need arises.

As a result of the importance of QoS in satellite applications to the customers, several studies have been carried out worldwide based on the mathematical models. These have not necessarily yielded good result [9], [10]. However, in recent times, the adoption of intelligent techniques is now being introduced to achieve good QoS that can meet customer service level agreements (SLAs) [11]-[17]. However, the adaptability of the intelligent technique can achieve better results based on local data since the rain that contributed significantly to signal degradation is location dependent.

In this paper, IA based on ANFIS has been employed to improve the reliability of QoS that can meet the customer SLAs. To illustrate the performance of the proposed method, a dynamic simulation technique based on the ANFIS methods using Fuzzy logic was adopted. The ANFIS makes use of real-time training that can interact with the Eutelsat 36B satellite link configurations as well as the location weather data.

The remaining part of the paper is arranged as follows: Section II discusses the setup and data used, while Section III provides information on the approach adopted. Section IV

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presents a case study to demonstrate the performance of the proposed method as well as the results and discussion; followed by the concluding remarks in Section V.

II. Setup and Data

The experimental site for the present study is the Federal University of Technology, Akure, Nigeria (henceforth be referred to as AKURE) 7.3043° N, 5.1370° E. 5-year (2012-2016) rainfall rate of one-minute integration time series data has been obtained with an automatic weather station -Davis 6250 Vantage Vue. The indoor unit of the equipment is housed in the scintillation laboratory of the CRG while the outdoor unit is placed in the observatory garden. The time series precipitation data were collected using a self-emptying tipping bucket with a resolution of 0.2 mm per tip. The precipitation instrument is part of the Integrated Sensor Suit-ISS associated with the vantage Vue. The sensor gauge has an accuracy of about 2% up to rain rate of 250 mm/hr. The gauge also has measuring range between 2 and 400 mm/h. Details of measurement methodology and rain rate processing used in the present study are fully discussed in [18], [19] and therefore not reiterated here due to paucity of space. Similarly, the CRG concurrently carries out measurement of attenuation due to rain at the Ku-band frequency. The Ku-band signal from EUTELSAT W4/W7 beacon receiver satellite is received through a 0.9 m offset parabolic dish placed at an elevation angle of 53.2^o to the down converter. The down-converted signal from the beacon receiver via a low noise block amplifier can then be fed to a digital satellite meter and a spectrum analyzer. The signal received is continuously logged into a computer unit. A detailed description is available in [19] and is not reiterated here due to paucity of space.

III. Methodology

This section discusses various methodology adopted.

A. Prediction of Rain-induced Attenuation

The attenuation due to rain is calculated using [20] according to the steps as outlined in the recommendation. Some of the steps are stated below while full details are available on the recommendations.

The specific attenuation, γ0.01 (dB/km) is obtained from the rain rate, 0.01% of the time in an average year as [20]:

$$\gamma_{0.01} = kR_{0.01}^{\alpha} \quad (1)$$

The parameters k and α are frequency, polarization, elevation angle, and tilt angle dependent. It can be derived based on information as in [21]. Rain attenuation at 0.01% of an average year, $A_{0.01}$ may then be obtained using:

$$A_{0.01} = \gamma_R Le \quad \text{(dB)} \quad (2)$$

where Le is the effective path length through rain (km). The 0.01% of an average year has been chosen based on the fact that a good system must provide at least 99.99% reliability for customer satisfaction [20].

Attenuation due to rain at other percentage of interest (A_p) can also be calculated using:

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-\left[0.655+0.033\ln(p)-0.045\ln(A_{0.01})-z\sin\theta(1-P)\right]} \quad (3)$$

where p is the percentage probability of interest and z can be obtained as:

$$\text{For } p \geq 1\%, \quad z = 0 \quad (4)$$

while for $p < 1\%$

$$z = 0 \qquad for\ |\Phi| \geq 36^o$$

$$z = -0.005\left(|\Phi| - 36\right)\ for\ \theta \geq 25^o \text{ and } |\phi| < 36^o$$

$$z = -0.005\left(\Phi - 36\right) + 1.8 - 4.25\sin\theta, \quad for\ \theta < 25^o \text{ and } |\Phi| < 36^o \quad (5)$$

We have also adopted frequency scaling techniques to span the application for V-band frequencies. Based on an approximation method as specified in [20], we can estimate the total attenuation behavior for the whole range of applicable frequencies by using a fixed sample frequency (Fi). Thus, rain attenuation as a function of frequency (f) is calculated as:

$$A_2(f_2) = A_1\left(\varphi_2/\varphi_1\right)^{1-H(\varphi_1,\varphi_2,A_1)} \quad (6)$$

$$\varphi(f) = \frac{f^2}{1+10^{-4}f^2} \quad (7)$$

and

$$H(\varphi_1,\varphi_2,A_1) = 1.12\times10^{-2}\left(\frac{\varphi_2}{\varphi_1}\right)^{0.5}\left(\varphi_1 A_1\right)^{0.55} \quad (8)$$

where A_1 and A_2 are the equivalent values of excess attenuation (dB) at frequencies f_1 and f_2 (GHz) respectively. It then implies that once we have rain-induced attenuation at any lower frequency, we can then estimate the equivalent higher frequencies until desired frequency is achieved. Thus, the dependence of statistics of attenuation on propagation angle, probability of occurrence, polarization, frequency and rainfall rate can be investigated.

B. Signal to Noise Ratio

SNR is the measure of the strength of the signal as a function of attenuation and background noise, usually measured in decibels (dB) as:

$$SNR = \frac{P_t G_t G_c}{KTBAL_{sys}}\left(\frac{\lambda_0}{4\pi d}\right)^2 \quad (9)$$

where G_t and G_r are transmitting and receiving antenna gain respectively, P_t is the transmitting power (W), λ_0 is the free-space wavelength (m), K is the Boltzmann constant with value $1.38x10^{-23}$ J/K, T is the temperature (K), A is the attenuation (dB), B is the bandwidth (Hz), $F$is the noise factor (unit less), L_{sys} is the system loss in ratio (unit less) and d is the range (m).

For the practical purposes as related to the application for digital communication, the SNR is determined based on bit energy-to-noise ratio E_b/N_o. E_b/N_o determines the effectiveness of a signal for digital communication with a specified bandwidth. The transmitting side of the satellite is also measured in terms of the equivalent isotopically radiated power (EIRP) and the figure of merit (G/T). Hence, (9) is synonymous with E_b/N_o as [16], [22]-[24]:

$$SNR = E_b / N_o(dB) = EIRP + G/T(dB/T) - A(dB) - L_{sys} - 10\log R_B(dB)) \quad (10)$$

where R_B is the bit rate and all other terms retain the usual meaning. Simulation Based on IA-ANFIS for Optimization of SNR

C. Simulation Based on IA-ANFIS for Optimization of SNR

Simulation of the IA based on fuzzy logic was done using MATLAB/Simulink tool for optimization of the link availability to achieve good QoS. The fuzzy logic has been based on the ANFIS scheme using the Fuzzy inference system (FIS) as the foundation platform [25]. Fuzzy logic is a tool that applies fuzzy sets using a Membership Function (MF). The MF defines how each point in the input space is mapped to a membership value between 0 and 1 based on curves. MF also assigns different degree of membership in a set of any element that belongs to the universe of discourse [26], [27].

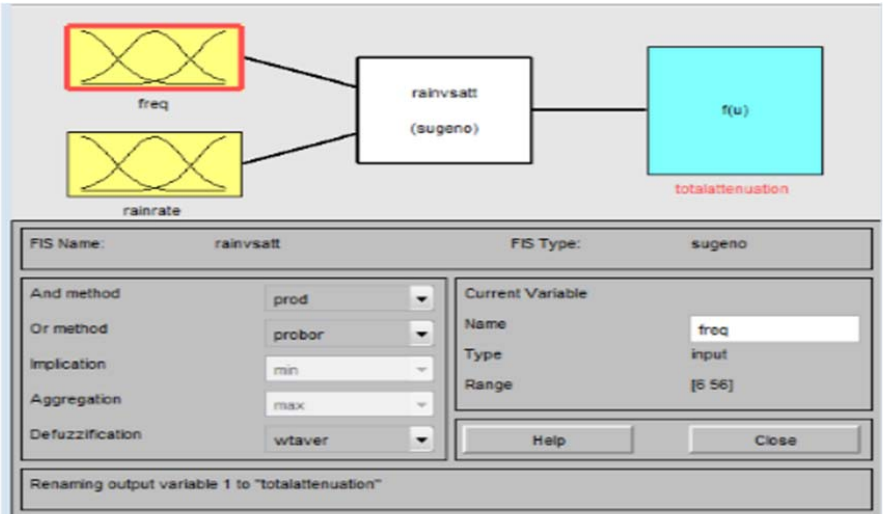

Fig. 1 A typical FIS editor for rain attenuation values at different rain rates and frequencies

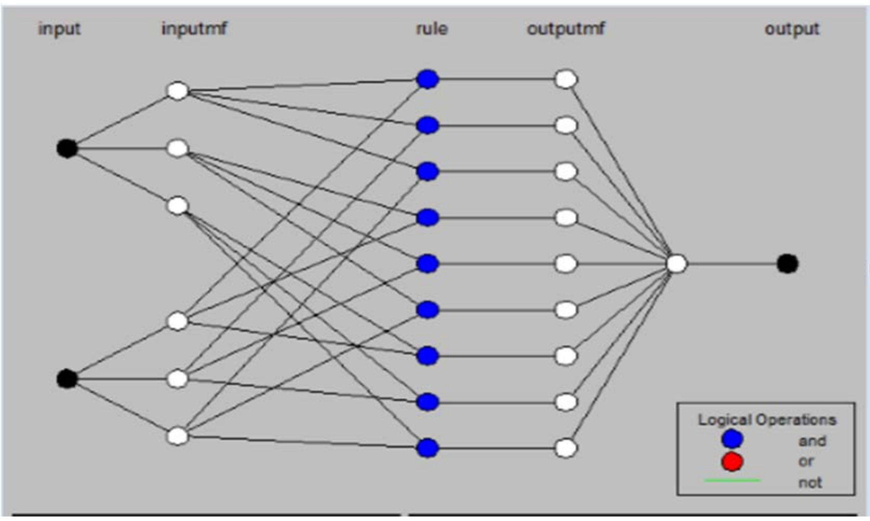

Fig. 2 A typical ANFIS model structure for rain attenuation values at different rain rates and frequencies.

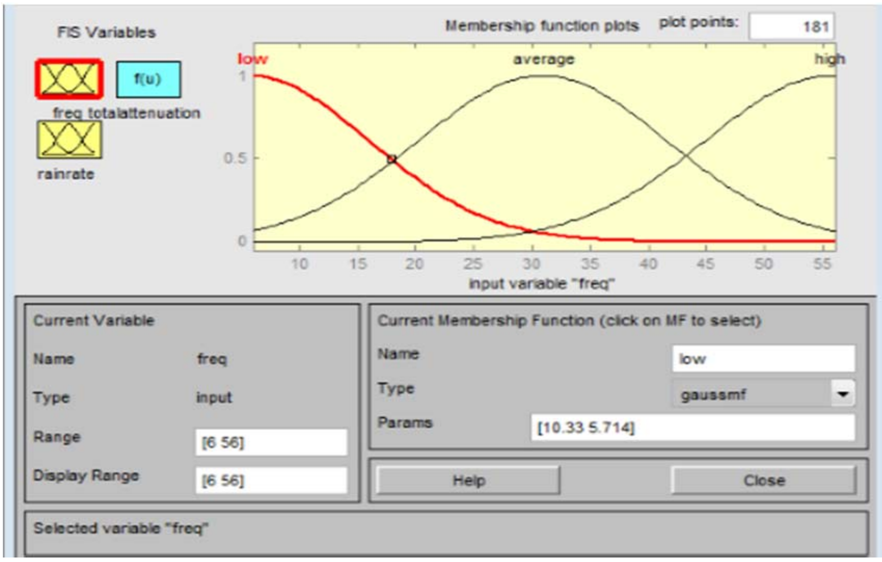

Fig. 3 A typical MF for rain attenuation values at different rain rates and frequencies

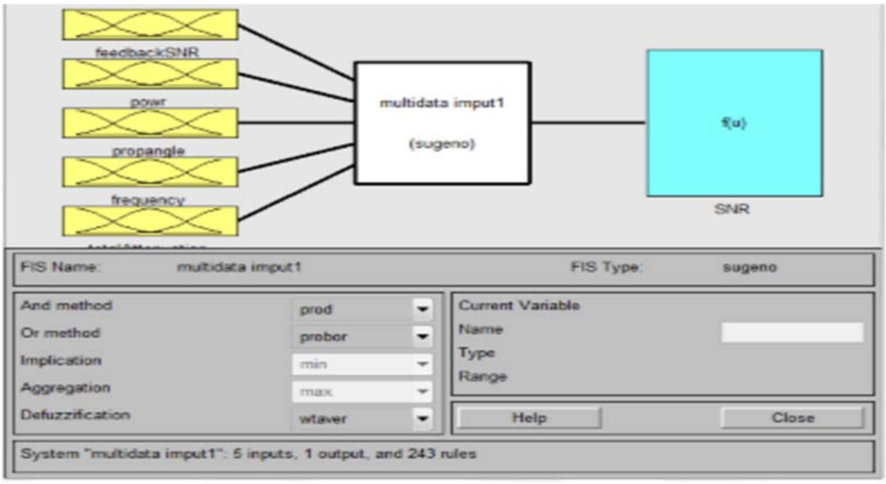

Fig. 4 FIS editor for the analysis of attenuation, power, propagation angle, frequency, feedback SNR and SNR

Based on the principle stated above, the IA will iteratively interact with the input signal criteria (propagation angles, frequency, frame size and the estimated SNR) to activate the weighted modulation – QSPK and QAM. The process will continue based on the weather conditions, configuration settings, and tolerance margins of the system until it reaches the optimal value (threshold level) [14]. Depending on the SNR values got, the algorithm will either increase the transmitting power or adopt the next step. This decision will continue until a desirable output value is achieved. Generated values of propagation angles, frequency, and rain attenuation values were loaded from the workspace into the database of the Neuro-fuzzy designer as input to undergo different stages. The first stage analyses the rain attenuation at different rain rates and frequency to examine the variation and the effect, based on different MF s and some governing rules. It analyses the rain attenuation further as a function of propagation angle and rain rate in order to examine the variation and the effect based on different MF s with some governing rules. The estimated SNR was also generated at different frequency, attenuation, power rating and propagation angle based on different MFs. Some governing rules are fixed to examine the negative effect caused by increasing the frequency and attenuation on SNR. Figs. 1-3 present typical FIS editor, ANFIS model structure and MF respectively, for rain attenuation values at different rain rates and frequencies.

For the improvements stage, the IA also undergoes different stages in order to improve and maintain the QoS. The various values of generated SNR, power, frequency, propagation and attenuation were first imputed into FLC, follow by training the input data, checked and tested to regulate the error rate and authenticate the imputed data. Subsequently, the ANFIS generated about 243 rules to control the SNR based on five MF s of each of the imputed data. A typical FIS editor for the analysis of attenuation, power, propagation angle, frequency, feedback SNR and SNR is presented in Fig. 4

In summary, various stages involved are: (i) creating a database based on input/output pairs (ii) creating rules for each of the data pairs based on the appropriate mode and number of fuzzy sets (iii) setting aside the conflicting rules (iv) formulating the inference engine and (v) decision stages.

IV. Results and Discussion

This section presents information on the results obtained through experimental and simulations.

A. Testing Model Results with Experimental

In order to test the suitability of the main imputed data-rain attenuation, a comparison between measured attenuation and the predicted based on ITU model are presented in Fig. 5 for the Ku-band frequency. We observed that good correlation existed between the measured and the predicted values especially at higher time percentage of an average year. This is to establish the result earlier observed by [16] using data from the same site. However, using more years of continuous measurement, there is also good correlation at lower time percentage of an average year ($p < 0.1\%$) with a reasonable percentage deviation. For example, the measured rain attenuation values are 13.7 and 21.3 dB at 0.01% and 0.001% of the time respectively, while the equivalent values obtained using ITU model are 11.3 and 19.4 dB respectively. The implication is that, the ITU model underestimates measured attenuation values by about -10.2 and -8.9 respectively based on average relative errors [28]. We can therefore presume that ITU model closely agrees with the measurements based on a relatively lower deviation. However, the present result deviated with those got by [16] that ITU model overestimates the rain-induced attenuation in the same site. This might be due to the Moupfouma attenuation model adopted for the attenuation prediction as well as the number of the measured attenuation used.

B. Influence of Rain-Induced Attenuation on Frequency

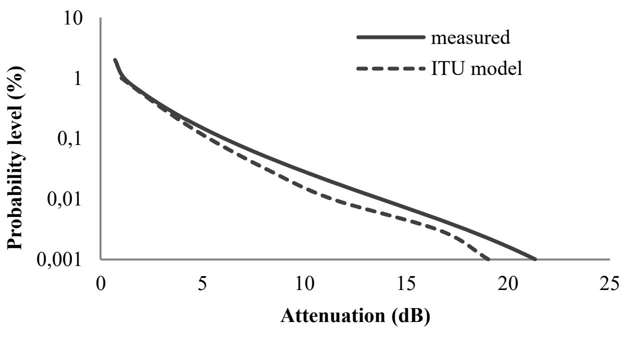

Fig. 5 Comparison between measured and predicted attenuation

Having tested the suitability of the attenuation values used as one of the main data, Fig. 6 presents the influence of rain rate and rain-induced attenuation obtained using ITU model on different transmission frequencies. The results show that as operating frequency increases from Ku-band to higher frequency bands, the effect of attenuation arises as increasing in the rain rate becomes severe. This is due to the contributions of the raindrops on higher frequencies leading to more absorption or scattering of signals. For example, at 10 GHz frequency and rain rate of 2 mm/hr, the estimated attenuation value is about 15.30 dB. However, using the same frequency and rain rate of about 8 mm/hr, the attenuation due to rain is about 16.20 dB. Also, at the high frequency of 30 GHz and rain rate of about 14.3 mm/hr, the attenuation is as high as 54.90 db. The implication is that signal reception from the satellite will be severely attenuated as the frequency increases.

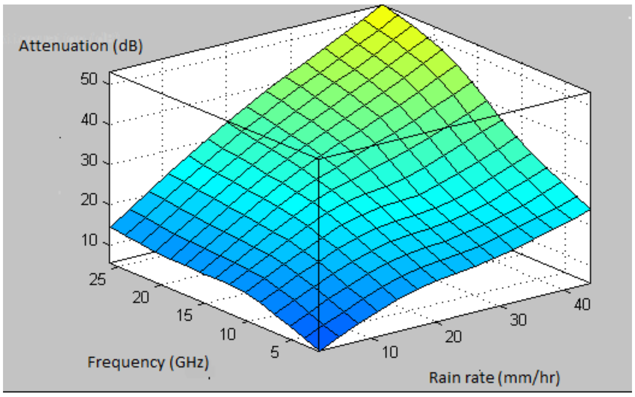

Fig. 6 Influence of rain rate and rain-induced attenuation on different transmission frequencies

C. Influence of Propagation Angle and Operating Frequency

The influence of rain-induced attenuation was also tested for different propagation angles and different operating frequency as depicted in Fig. 7. We observed that rain-induced attenuation of lower dB occurred at low propagation angles (10-30 dB) with respect to variation in frequencies. However, as propagation angle increases to above 30 dB, the attenuation encountered with the propagation path increases and reaching the peak at 40 GHz frequencies. The implication is that propagation angle should also be considered during the link budgeting to ensure signal optimization especially at higher frequency band.

D. Influence of Attenuation and Transmitting Power on SNR

Figs. 8 (a) and (b) show some typical results based on the influence of the attenuation and varying transmitting power on outputs SNR at 12 and 40 GHz frequency respectively.

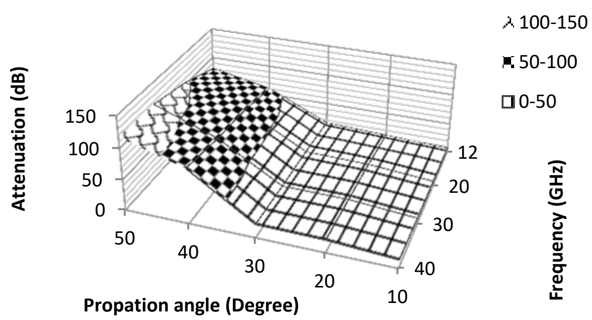

Fig. 7 Influence of rain-induced attenuation and propagation angles on different operating frequencies

The result is necessary to discover the extent of SNR of the propagation paths prior to the execution of IA on the link. As presented in Fig. 8, as the transmitting power (range between -70 and -25 dB) increases as well as increasing the attenuation along the propagation paths, the SNR also increases. The implication is that, the noise power becomes much greater than the signal power as the attenuation increases. For example, at the specified transmitting power, the SNR generated ranges between -66 and -36 dB for 12 GHz frequency (Fig. 8 (a)) and -106 to -46 dB at 40 GHz frequency (Fig. 8 (b)). Theoretically, increasing the transmitting power may reduce the effect of noise at the receiving end leading to reduction in the probability of errors; however, this may not be advisable due to the physical and cost implications. An intelligent device is, therefore, needed to interact with the system criteria under a dynamic atmospheric weather condition to achieve signal optimization.

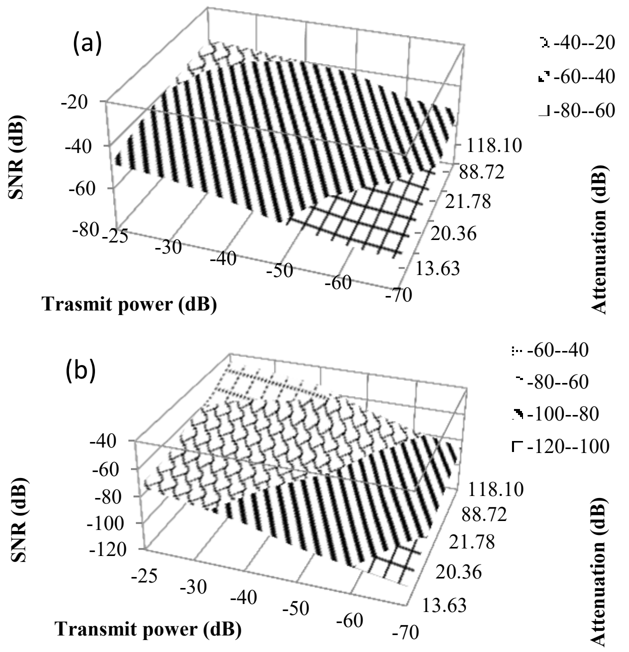

Fig. 8 Typical result based on the influence of the attenuation and varying transmitting power on output SNR at (a) 12 and (b) 40 GHz frequency.

E. Adjusted Power and SNR Based on Rain-Induced Attenuation

Optimizing the signal under dynamic weather condition by improving the SNR and transmitting power through the new IA is presented in Fig. 9. For example, Fig. 9 (a) presents typical result of signal optimization under bad weather condition at Ku-band frequency based on IA over QAM modulation scheme by keeping the initial attenuation ranges constant. The results generated by adopting the IA scheme shows that, the transmitting power now ranges between ~ -26 and -12 dB and adjusted SNR between -26 and 4 dB. The same trend could be seen when applied to 40 GHz frequencies (Fig. 9 (b)), although with different improvement values in both transmitting power and SNR. Consequently, the algorithm effectively evaluated the up-link power control for improvement in SNR and yielding good QoS at the receiving end. Irrespective of the associated weather dynamics along the propagation link. The result further suggested that the compensation needed for the up-link power gain may not necessarily be too high even under dynamic weather. Because, reducing the bit rate can enhance the energy per bit to noise power density ratio, which eventually improves the bit error rate performance.

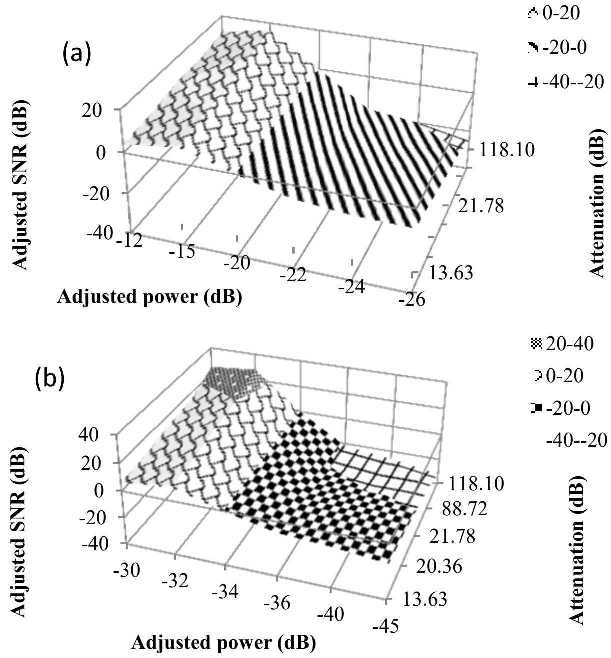

Fig. 9 Typical result signal optimization under bad weather condition at (a) 12 and (b) 40 GHz frequency based on IA over QAM modulation scheme

V. Conclusion

This paper has proposed an adaptive intelligent algorithm for optimizing signal along propagation links under a dynamic tropical weather conditions. Based on this study, we found out that adopting IA with ANFIS for modeling signal, good QoS could be successfully demonstrated. Although there are other theoretical models; however, for this study we have proposed that IA with ANFIS could be applied for good QoS to meet customers' SLAs. This will yield reasonable performance because of the ability to achieve a single-valued output or a decision associated with the output. Testing the main weather imputed data (attenuation) with the experiment shows that ITU model closely agrees with the measurements based on a relatively lower deviation. The influence of propagation angle and attenuation on operating frequency shows that, as propagation angle increases to above 30 dB, the attenuation encountered along the propagation path also increases. This trend continues until it reaches the peak at 40 GHz. The result on the influence of attenuation and transmitting power over SNR also shows that; the noise power becomes much greater than the signal power as the attenuation increases. Simulation results finally suggest that the algorithm can effectively evaluate the up-link power control for improvement in SNR and yielding good QoS at the receiving end irrespective of the associated weather dynamics along the propagation path.

REFERENCES

[1] A.W. Dissanayake, J.E Allnutt, and F Haidara, "A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths," *IEEE Trans on Antennas & Propagation,* vol. 45, no. 10, pp. 1546-1558, 1997

[2] S. Katiyar, *A textbook on Satellite communication*, 3rd ed., published by S. K. Kataria and Sons, New Delhi, 2013.

[3] R. K, Crane, "Prediction of the effects of rain on satellite communication systems" in *Proc. of the IEEE,* 1977, vol. 65, no. 3, pp. 456-474.

[4] C. Capsoni, F. Fedi, C. Magistroni, A. Pawlina, and A. Paraboni A. "Data and theory for a new model of the horizontal structure of rain cells for propagation applications, Radio Science, vol. 22, no. 33, pp. 395-404, 1987.

[5] L. J Ippolito. "Propagation effects and system performance considerations for satellite communications above 10 GHz," *Proc. of the IEEE, Global Telecommunications Conference, 1990, and Exhibition. 'Communications: Connecting the Future'*, GLOBECOM '90, 2-5 December, 1990.

[6] X. Boulanger, G., Benjamin, L. Casadebaig, and C. Laurent. "Four Years of Total Attenuation Statistics of Earth-Space Propagation Experiments at Ka-Band in Toulouse", *IEEE Transactions on Antennas and Propagation,* vol. 63 no. 5, pp. 2203-2214, 2015

[7] S Shrestha and D. Choi Rain attenuation statistics over millimeter wave bands in South Korea, Journal of Atmospheric and Solar-Terrestrial Physics, vol. 152–153, Pp 1-10, 2017

[8] J. S, Ojo, "Geo-spatial distribution of cloud cover and influence of cloud induced attenuation and noise temperature on satellite signal propagation over Nigeria" *Advances in Space Research*, vol 59, no. 10, pp. 2611-2622, 2017

[9] .S.C. Lu, "Quality of service for personal satellite multimedia"*, IEEE Seminar on Personal Broadband Satellite* (Ref. No. 2002/059), Jan. 2002, London U.K, 10.1049/ic:20020021. 2002.

[10] L. Ki-Dong, "Variable-target admission control for nonstationary handover traffic in LEO satellite networks", *IEEE Transactions on Vehicular Technology,* vol: 54, no 1, pp. 127 – 135, 2005.

[11] M Saraireh, R. Saatchi, S. Al-Khayatt and R Strachan, "Assessment and improvement of quality of service in wireless networks using fuzzy and hybrid genetic-fuzzy approaches," *Artificial Intelligent Review*, 27, pp. 95–111, 2008.

[12] K Harb, Omair Butt, Samir Abdul-Jauwad, Abdul-Aziz M. Al-Yami, "Systems Adaptation for Satellite Signal under Dust, Sand and Gaseous Attenuations*", Journal of Wireless Networking and Communications*, vol.3, no.3, pp. 39-49, 2013.

[13] R. Z Dhafer, S. Thulfiqar Aldeen A. AL Wahab (2013), "Simplified the QoS Factor for the Adhoc Network sing Fuzzy Technique" *Int. J. Communications*, *Network and System Sciences*, vol. 6, pp. 381-387, 2013.

[14] J.S Ojo and P.A Owolawi, "Prediction of Time-series Rain Attenuation based on Rain Rate using Synthetic Storm Techniques over a Subtropical Region. Southern Africa Telecommunication Networks and Applications (SATNAC-2014) conference proceedings, at Boardwalk, Port Elizabeth, Eastern Cape, South Africa, 31 August - 3 September 2014, 67 – 71.

[15] I. M Atta-ur-Rahman. Qureshib, A. N Malikc and M. T. Naseema. "QoS and rate enhancement in DVB-S2 using fuzzy rule based system", *Journal of Intelligent & Fuzzy Systems*, vol. 30, no. 2, pp. 801–810, 2016.

[16] I. Adegbidin, P.A Owolawi, and M.O Odhiambo, "Intelligent Weather Awareness Technique for Mitigating Propagation Impairment at SHF and EHF Satellite Network System in a Tropical Climate", Research Journal of the South African Institute of Electrical Engineers), vol. 107, no.3, pp. 136 – 145, 2016.

[17] H. S. Asad, K.K Richard and H. Gongsheng, "Hybrid Adaptive Modeling to Enhance Robustness of Real-Time Optimization", *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, vol:11, no 4, pp. 348-352, 2017.

[18] O. O. Obiyemi, J. S. Ojo, and T. S. Ibiyemi "Performance Analysis of Rain Rate Models for Microwave Propagation Designs over Tropical Climate*," Progress in Electromagnetics Research M*, vol. 39, pp. 115–122, 2014.

[19] O.M, Durodola, J. S Ojo, and M. O Ajewole, (2017) "Performance of Ku-Band Satellite Signals Received during Rainy Condition in two low Latitude Tropical locations of Nigeria", *Adamawa State University Journal of Scientific Research*, vol. 1, no.5, pp. 1-17, 2017.

[20] ITU-Rec. P 618-12,"Propagation data and prediction method required for the design of earth-space telecommunication systems, "Radio wave propagation, International Telecommunication Union Recommendation ITU-R P.6I8-12, 2012.

[21] ITU-Rec. P 838-3. Specific attenuation model for rain for use in prediction methods, International Telecommunication Union Recommendation ITU-R P.838-5, 2005.

[22] E., Lutz, M Werner, and A Jahn.: Satellite systems for personal and broadband communications. Springer, New York, 2000.

[23] K Harb., F. R Yu., P. Dakhal, and A. Srinivasan, "An intelligent QoS control system for satellite networks based on Markovian weather," *Proc. of IEEE 72nd Conference on Vehicular Technology (VTC)*'201O Fall, 6-9 September, 2010, Ottawa, ON, Canada.

[24] A. M. Al-Saegh, A Sali, J. S Mandeep, A. Ismail, Abdulmajeed HJ Al-Jumaily, and C. Gomes: Atmospheric Propagation Model for Satellite Communications, *MATLAB Applications for the Practical Engineer*, publisher, Intech, 249-275, 2014.

[25] C.C Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller - I, 11,*" IEEE Transactions on Systems. Man. and Cybernetics*, vol. 20, no. 2, pp. 404-435 1990.

[26] L. A., Zadeh, "Fuzzy Sets, Usuality and Commonsense Reasoning," *EECS Technical Report, University of California, Berkeley.1985.*

[27] B Khoshnevisan, R. Shahin , O. Mahmoud and M. Hossein (2014): Development of an intelligent system based on ANFIS for predicting wheat grain yield on the basis of energy inputs, Information Processing in Agriculture 1, pp. 14–22, 2014.

[28] ITU-R P. 311-15 'Acquisition, presentation and analysis of data in studies of tropospheric propagation. Recommendations, 2013.