Influence of HAPS and GEO Satellite under SANDU Layering and Gas Attenuations

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Summary
Satellite communication for high altitude platform stations (HAPS) and geostationary orbit (GEO) systems suffers from sand and dust (SANDU) storms in desert and arid regions. The focus of this paper is to propose common relations between HAPS and GEO for the atmospheric impairments affecting the satellite communication networks operating above Ku-band crossing the propagation path. A double phase three-dimensional relationship for HAPS and GEO systems is then presented. The comparison model present the analysis of atmospheric attenuation with specific focus on sand and dust based on particular size, visibility, adding gas effects for different frequency, and propagation angle to provide systems' operations with a predicted vision of satellite parameters' values. Thus, the proposed system provides wide range of selecting applicable parameters, under different weather conditions, in order to achieve better SNR for satellite communication.

Key words:
Control and Decision System (CADS), Sand and Dust (SANDU), Skillful Atmospheric Aware Model (SAAM), Satellite Networks, Signal to Noise Ratio (SNR)

1. Introduction

Satellite systems at high speed along with means of coverage extension and emergency connections under disasters weather condition is highly demanded. However, atmospheric attenuation cause minimum quality of service (QoS) and thus receiving signal errors. It differs according to earth location and is presented as atmospheric conditions such as dust and sand in desert areas. Figure 1 represents the operation of high altitude platform stations (HAPS) and geostationary orbit (GEO) communication systems under sand and dust (SANDU) storms [1–4].

In this paper, the satellite propagation path takes into account level presentation of dust and sand distributions within the storms beside other atmospheric conditions.

Researchers are investigating the impact of different weather characteristics based on different given database and weather factors on GEO and HAPS satellite networks [5–9]. Most of literature work present GEO systems by using uniform size distribution of SANDU particle within the storms or specific angle cases. Some works have been done for HAPS systems without mentioning the SANDU's effect [10,11], while one was done for HAPS under SANDU weather conditions [12]. Some advantages of HAPS over GEO are reducing the high cost involved in building satellites and launching them, serve and focus into crowded areas, face troubles with SANDU attenuations, and avoid the delay associated with GEO satellite systems. Therefore, research face some challenges to control the satellite network resources availability that are affected by SANDU storms.

This paper introduces a method to enhance dust and gaseous attenuation models, presented in [13,14] and (ITUR P.676 and ITU–R P.1510). It provides better estimation for GEO and HAPS signal level under severe SANDU storms. In addition, a math simulation is proposed for SANDU attenuation with frequency, visibility, SANDU size, and angle. These results will fit into skillful system for analysis and take the necessary action to improve bit error rate [13–17].

The remaining sections of this paper are as follows: In section 2, an introduction to SANDU measured database and layering concept. In Section 3, QoS for satellite systems followed by analysis and simulation of SANDU and gas attenuations. In Section 4, skillful atmospheric aware model (SAAM) is presented. Section 5 presents simulation results and discussions of SNR improvement. Finally, conclusions and future work are presented in Section 6.

2. Layering Concept on SANDU

SANDU storms are being observed in desert and dry areas such as Saudi Arabia, and other countries. These storms have varying speeds and maximum altitudes depending upon regions. SANDU depends upon the visibility. In other words, visibility decrease with more dust storms intensity. Storms can attain altitudes up to 5.0 Km. Thus, a different approach to model these storms and existing way to get measurements have been defined. Two-dimensional model based on side and top view models of dust storm being discussed in [3,7,18].

The concept of SANDU storm layering is proposed to HAPS and GEO satellite communications. Thus, the intensity of the particles within the storm is randomly distributed according horizontal and vertical expansions.

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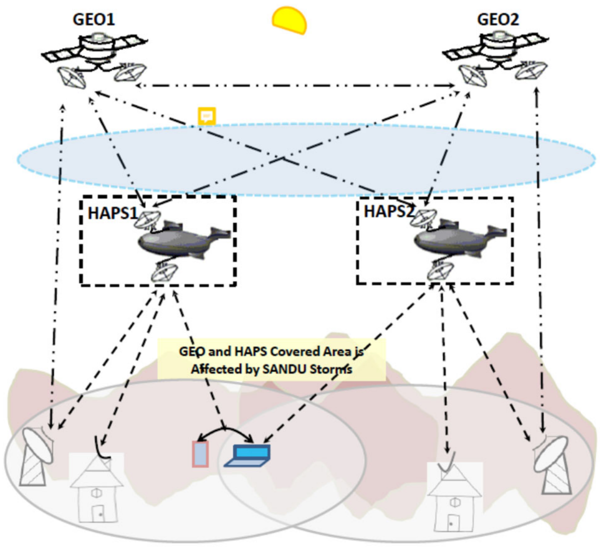

Fig. 1 SANDU storms effects on HAPS and GEO signal propagation.

Thus, the visibility is almost minimum at the middle, and increase around the horizontal/vertical start and end level. Thus, intensity distributions within SANDU is presented on multi-layers from the ground up to the top level [3,8]. It exemplifies their physical appearance for different layers. SANDU distribution can be presented as a wide bell function with high concentration in the middle and decrease around both edges.

3. Satellite Networks Analysis with Atmospheric Attenuations

Satellite networks directly affected by different attenuations at high operational frequency with little effect once frequency decreases. This section proposes new layering method for SANDU for calculating the attenuation that contained various visibility and particle size distributions. Some signal propagation parameters are achieved by applying software that uses data given by ITU–R for these attenuations at any point on earth, for different satellite parameters as per [4,19].

3.1 Analysis and Simulation for SANDU Attenuation

SANDU storm formation can be divided into multiple layers. Each layer has visibility different for the other [3,19]. For better performance, the visibility windows should be adjusted to a certain value that will not complicate the communication networks. Expression (1) represents different SANDU levels within the storm:

$$h_m = h_{(m-1)} \left[\frac{V_m}{V_{(m-1)}}\right]^{3.85}, \qquad (1)$$

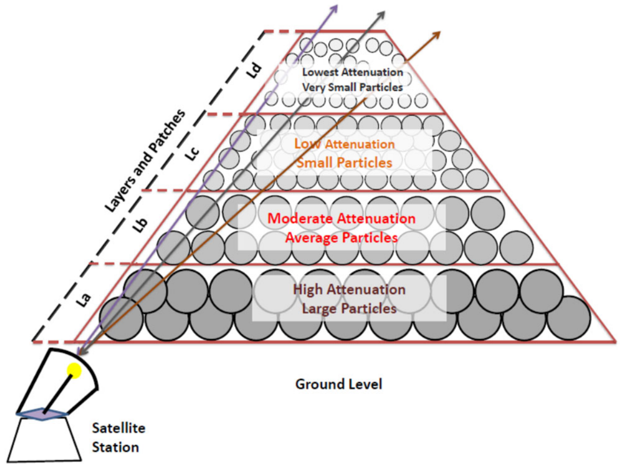

Fig. 2 SANDU particle-size distributions at different levels.

where $V_{(m-1)}$ and $h_{(m-1)}$ are the height and visibility respectively, and (m) represents number of layers. Equation (1) is adjusted to calculate different levels of visibility with respect to different heights:

$$V_m = V_{(m-1)} \left[\frac{h_m}{h_{(m-1)}}\right]^{0.26}, \qquad (2)$$

SANDU can have different characteristics for permittivity and dust sizes for different regions, Fig. 2 reveals an appropriate dust size variation inside SANDU storm, represented by four layers La, Lb, Lc and Ld. This figure shows wireless signal propagating along the storm passing through different layers that contained various visibilities according to SANDU particles sizes. Notice that, most of large particles stay close to ground, while the small particles are able to fly away. In addition, storms concentrations presented by large and small SANDU particles lead to increase scattering effect at different levels. Depending on SANDU storm location, height, etc., simulations can select the number of necessary layers starting from three up to ten layers and each layer may vary from 10 m up to 3 Km as shown in Fig. 2.

Moreover, the variation of visibility with height is presented in Fig. 3 where SANDU storm is divided into four layers. Therefore, for first layer, the visibility was 6.653 Km at 100 m height with layering and decreases to 5.987 Km without layering. Also at the third layer, the visibility at 500 m height was 8.293 Km with layering and 7.967 Km without layering, respectively as shown in Fig. 3. Thus, improvement of visibility calculations lead to appropriate results in SANDU attenuation and satellite communications.

For better estimation, designer should decrease at low level the layer size since the particles are large and increase it around 1.5 Km up to the end of the storm. Thus, the layer numbers should be well selected based on SANDU storms for better communications.

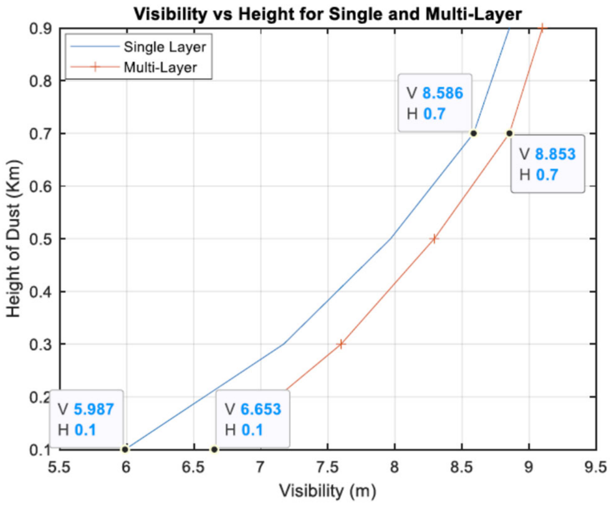

Fig. 3 Visibility under SANDU with height for single and multiple layers.

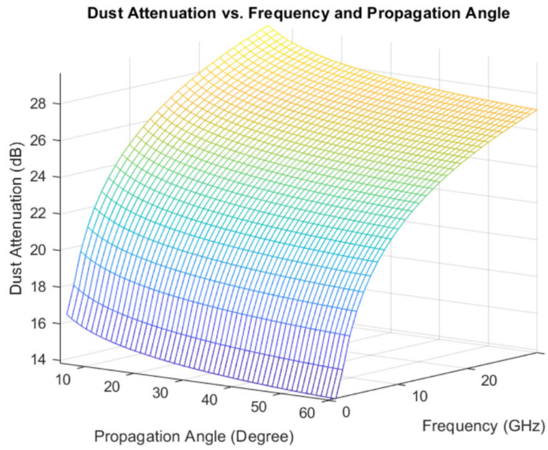

Fig. 4 SANDU attenuation.

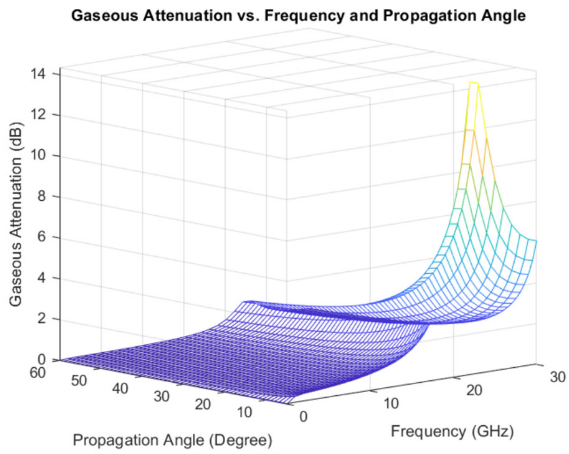

Fig. 5 Gaseous attenuation.

3.1.1 SANDU Distribution

SANDU storm may have uncorrelated distributions according to different locations, wind speed, etc. For example, the spherical shapes of SANDU, used in desert and other regions, have a diameter between 10 – 90 μm and 90 – 150 μm, respectively [6].

3.1.2 Modeling of SANDU

This section present SANDU modeling for layering the storms into multiple layers. Each layer has its specific attenuation based on the concentration of SANDU and elevation. The total SANDU attenuation based on consumed level can be represented by:

$$A_{pl} = \left[\frac{567}{Vr_e^2\lambda}\right]\left[\frac{\varepsilon''}{(\varepsilon'+2)^2+\varepsilon''^2}\right]\sum_l^N P_l r_l^3 \quad (3)$$

$$A_{SANDU} = \sum_l^N A_{Pl} \quad (4)$$

Thus, SANDU simulation results of Eq. (3) and Eq. (4) are presented in a form of mesh view as per Fig. 4. Visibility starts from 100 m at low level and increases to 5.0 Km or 6.0 Km where satellite signals leave the storm. The summary of dielectric constants values are listed in [8]. The presented model computes SANDU attenuation based on different visibilities and SANDU particles sizes.

3.2 Analysis and Simulation for Gaseous Attenuation

The gas molecules and its absorption that are present in the atmosphere [14,20] present gaseous attenuations. Note that, the path length that varies between HAPS and GEO communications. Analytical solutions for gaseous attenuation are presented in [13,14,20]. The results presented the effect by summing all significant resonance lines for dry air, slant path equivalent to height, and propagation angle up to 75 degrees.

This section computes the gas attenuation based on different propagation angles and frequencies as:

$$A_G(\theta, f) = \frac{A_0+A_w}{sin\theta}\ dB, \quad (5)$$

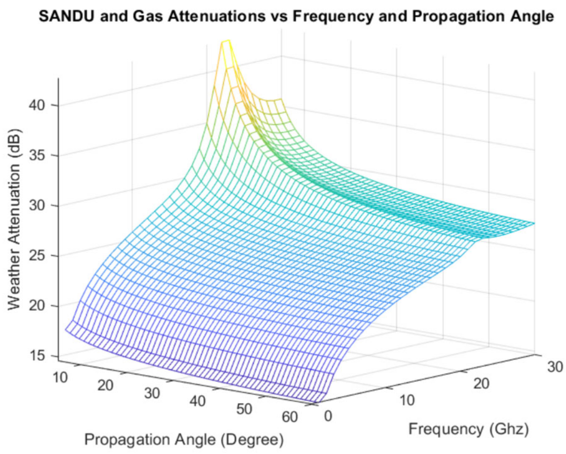

Fig. 6 Atmospheric attenuation.

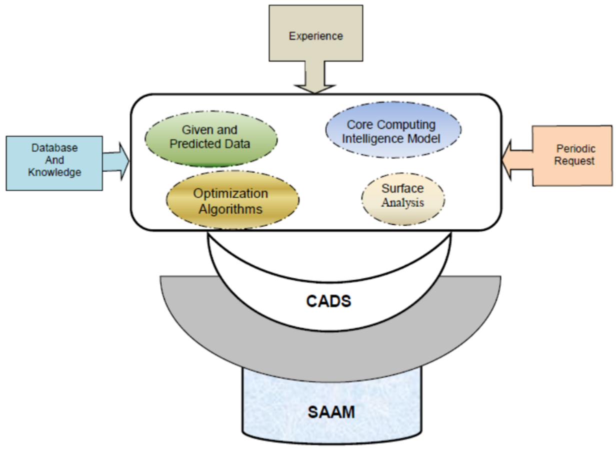

Fig. 7 Control and decision system (CADS).

where $A_0 = h_0 \cdot \gamma_0\ dB$ and $A_w = h_w \cdot \gamma_w\ dB$. The parameters used to estimate gaseous attenuations are given by ITU–R P. 676. Thus, Fig. 5 shows the approximate gaseous attenuation values at any ground station location, propagation angles and frequency.

3.3 Atmospheric Attenuation Analysis and Simulation

Estimation of atmospheric attenuations are represented by SANDU and gas using weather signal data with ITU–R propagation models combined with mathematical methods and other characteristics. Atmospheric attenuations for systems operation above 10 GHz is presented in Fig. 6 [1,4, 13,15,21].

This method provides a useful way to improve satellite signal based on the diagnostic view for SANDU and gaseous attenuations. The required input parameters for the above attenuations are:

$A_{SANDU}(\theta, f)$: SANDU attenuation as estimated in (4).
$A_G(\theta, f)$: Gaseous attenuation as estimated in [14] and [20].

A general method for calculating atmospheric attenuations $A_{WA}(\theta, f)$ that includes all of SANDU and gas attenuations is given by:

$$A_{WA}(\theta, f) = A_{SANDU}(\theta, f) + A_G(\theta, f). \qquad (6)$$

The results of (6) for atmospheric attenuation with different variables is presented in Fig. 6. Free space loss with different frequencies for signal transmission from earth station to HAPS or GEO satellite is presented as:

$$A_{FS}(f) = (4.\pi.d/\lambda)^2 \qquad (7)$$

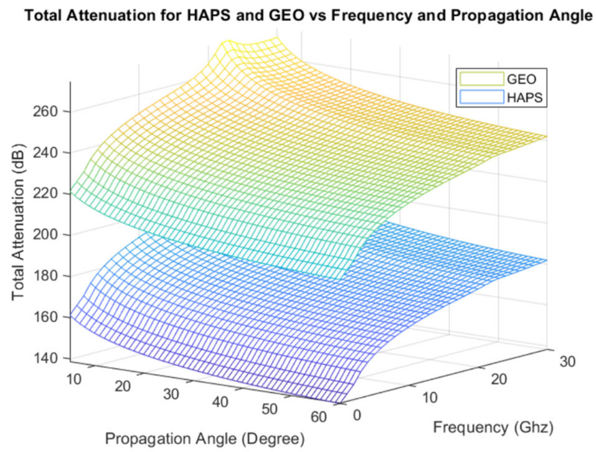

Fig. 8 Total attenuation for HAPS and GEO.

where d is the distance between ground station and satellite which is around 36,000 Km for GEO and 30 Km for HAPS.

Thus, total attenuations $A_{TA}(\theta, f)$ is given by:

$$A_{TA}(\theta, f) = A_{SANDU}(\theta, f) + A_G(\theta, f) + A_{FS}(\theta, f). \quad (8)$$

The total attenuation represented in Eq. (8) is used to compare both HAPS and GEO satellite results. The output is shown in Fig. 8. Note that, the difference between attenuation levels for HAPS and GEO mostly come from free space loss, as signal propagation faces the same amount of SANDU and gaseous attenuation while traveling from the same location and applying the same angle and frequency of operation. However, if any of these factors changes, the estimation should be different.

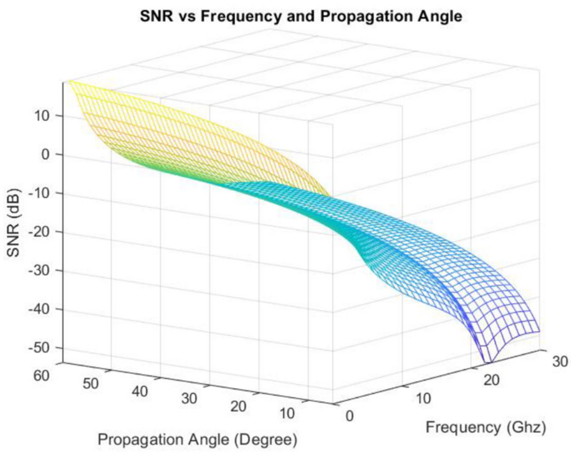

Fig. 9 SNR affected by different attenuations.

4. Skillful Satellite Systems

A computational technique is described to support control and decision system (CADS) that supply the proposed skillful atmospheric aware model (SAAM) for an accurate view for modeling satellite propagation environments. This research applied SAAM which is presented in [8] with such update and modification in its multi-levels and blocks to fit with different input data, parameters and operating systems to improve accuracy for estimating atmospheric attenuations and better SNR.

4.1 Role of SAAM

A SAAM is used to collect and analyze input data and come up with an approved SNR level. The CADS system shown in Fig. 7 is located on top of SAAM system as shown in Fig. 11. Both systems collaborate to provide better satellite communications under different weather conditions. This high-level presentation and structure of CADS and SAAM work to estimate the optimal selection for satellite systems using SANDU size, power level, modulation/coding database and other requested parameters, which result an improving end to end communications.

Thus, SAAM includes heuristic search and planning algorithms, machine learning techniques, sensing and ac action problems, formalisms for given representation, such as function variation of various satellite parameters based on unpredicted weather attenuations [8,22].

4.2 SNR Calculation

This section computes SNR under different atmospheric attenuations is proposed as follows:

$$T_r(\text{Noise temperature}) = \left(10^{\frac{N_r}{10}} - 1\right) \ . \ 290. \qquad (9)$$

where $N_r \approx 0.7 - 2\ dB$. $N_0 = K \ . \ T$ represents thermal noise power spectral density, K = –228.6 *dBWs/K* and temperature of noise $T = T_r + T_a$, where T_r and T_a represents the effective receiver and antenna noise temperature, respectively. Therefore, ratio between signal and noise power spectral density is:

$$\frac{C}{N_0} = \frac{P_r}{K\ .\ T} = \frac{P_t\ .\ G_t}{A_{TA}} . \frac{G}{K\ .\ T} = \frac{EIPR}{A_{TA}} . \frac{G_r}{K\ .\ T}\ dB, \qquad 10)$$

$$\frac{C}{N_0} = P_t + G_t - A_{TA} + G_r - K - T\ dBHz, \qquad (11)$$

where P_t, G_t and P_r, G_r are transmitted and gained at transmitter and receiver sides respectively. $A_{TA} = A_{WA} + A_{FS}$. Where A_{FS} represents the free space loss calculated from (7). Also, $N = N_0 \ . \ B_r = K \ . \ T$. Br noise power, and (B_r) is the noise bandwidth. Therefore, SNR is introduced:

$$\text{SNR} = \frac{C}{N} = \frac{C}{N_0\ .\ B_r}\ dB \qquad (12)$$

The SNR according to GEO system under SANDU and gas attenuations is shown in Fig. 9.

4.3 CADS Optimization

CADS contains different parameters used to feed SAAM for better system performance. It maintains improved QoS by calibrating satellite parameters according to different weather conditions.

The proposed method for SANDU and Gas attenuations contained a flexible SAAM connected with computing core and skillful model can be controlled by the estimated or predicted weather database. The system look into different ways or given prospective of input variables shown in the first level of Fig. 11 in order to limit attenuation to minimum values and thus improve SNR and QoS. The CADS keep updating system's knowledge for attenuation variations that will be SAAM's main input. Also, SNR serve as a feedback to our SAAM by modifying input control variables for better communications.

4.4 SNR Adjustment

The traditional method used to improve SNR is to increase the power level. However, this method can help up to a certain level based on safety conditions. Therefore, in this section, an updated version of SAAM is introduced, as shown in Fig. 11 to improve SNR and thus system throughput under SANDU and gaseous weather conditions. Therefore, by calibrating satellite's parameters such as transmitted signal power, data rate, code/modulation and location if possible, designers are able to come up with better signal propagation under unpredictable atmospheric conditions. The adjusted SNR calculation is given by:

$$\frac{E_s}{N_0}(A, P) = P_t + G_t - A_{TA} + G_r - K - T - R_s\ dB \quad (13)$$

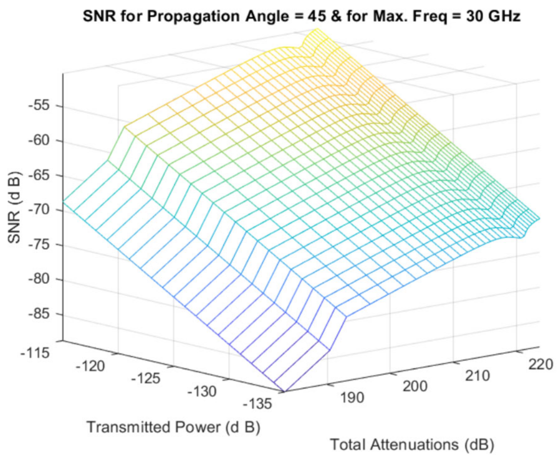

Fig. 10 Output SNR.

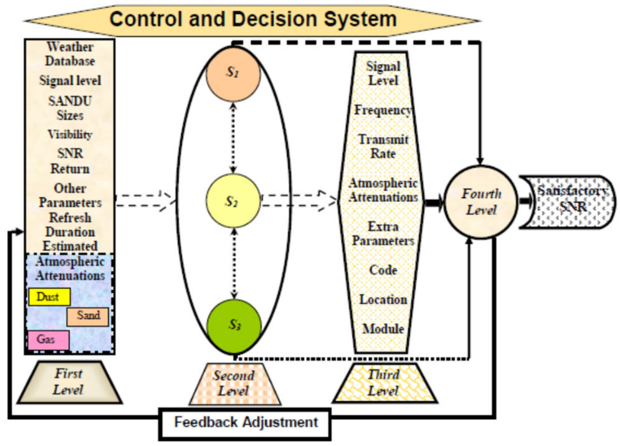

Fig. 11 SAAM for satellite systems.

Fig. 10 shows the output results for SNR before adjustments. Thus, Fig. 11 collected, controlled and analyzed different parameters to prevent signal loss due to SANDU and gaseous attenuations. The function of each level is represented as following:

System holds input signal parameters in the first level.

Where data rate, angle of operation, SNR values, along with other parameters, were compared against SNR acceptable proposed level.

Moving to the second level, according to estimated SNR, either SAAM will decide to increase signal power, which is limited by safety system, or to move to final diagnostic.

In the next level, SNR value will be checked according to the system's availability for coding and modulation. The threshold value for SNR should be reached, otherwise the simulation will go to the last level.

In the final step, attained SNR values will be compromised according to SAAM parameters and the system will decide based on the available parameters and requirements. Finally, a feedback loop can run for a limited period using refresh system duration until reaching satisfactory SNR level.

Figures 10 and 12 show SNR ranges before and after treatment for GEO communications. Thus, SNR is used to fall between (–81.25 ~ –51.12) dB as per Fig. 10, for signal power from (–135 ~ –115) dB, and was transformed after system decision mechanism to fall within given database for modulation and coding. The improved SNR ranges from (–20.0 ~ 31.1) dB with power ranges from (–78 ~ –44) dB, and total attenuations, before and after adjustment, ranges from (186 ~ 222.5) dB. As mentioned earlier, once power reaches it limits other parameters such as modulation and coding should match in order to adjust SNR as per Fig. 12.This system allowed to jump among given parameters fed into the system in order to achieve desired target. As a result, designers with reasonable flexibility are able to improve SNR results using SAAM for wireless systems.

5. Simulation Results

The atmospheric attenuations were estimated for HAPS and GEO. The simulation presented in Fig. 3 for SANDU existing non-layering model of dealing with storms and for proposed layering model. The results provide an appropriate variation between both methods according to the estimation of atmospheric attenuations. Also, a double three dimension for both systems were presented in Fig. 8. This results came from estimating both SANDU and gas attenuations for high frequency as presented in Fig. 4 to Fig. 12. Therefore, an accurate skillful engine that is controlled by input parameters and decision system is introduced in Fig. 11 to overcome wireless communications problems and returned SNR values for activating satellite elements to its optimal values under different atmospheric conditions.

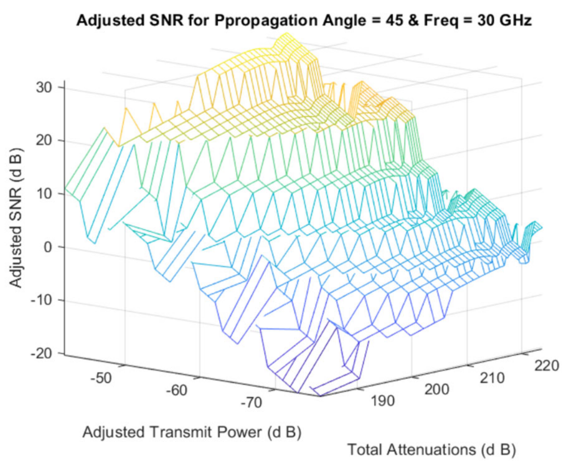

Fig. 12 Output adjusted SNR.

Thus, SAAM function is presented by checking SNR level according to atmospheric situation and react intelligently based on the given input parameters to improve signal transmission performance. Also, a feedback loop shown in 11 is introduced to provide designers with reasonable signal recovery that satisfies the minimum acceptable level resulted in the adjustment between Fig. 4 and Fig. 12.

The author wrote different programs using MATLAB to analyze the performance of the satellite system. Resulted in two and three-dimensional results for SANDU layering, SANDU and gas attenuation, and output results for the communication satellite systems.

6. Conclusions and Future Work

Satellite networks in general are affected by atmospheric attenuations. A full analysis for SANDU layering for GEO and HAPS is presented for better attenuation estimation. The results of layering aside with other attenuation on GEO and HAPS satellite networks and ITU–R database belong to Saudi Arabia ground terminal, can be an immense help for selecting satellite networks parameters and its characteristics. Also, the proposed CADS includes some intelligent and historical data and background to provide an accurate view, with other presented database and parameters, for SAAM system to overcome the impact of atmospheric attenuations. Therefore, designers are able to have a clear and flexible view of signal propagation, its implementation and monitoring for level variations using SAAM model. System flexibility is presented by adaptively selecting location, frequency, signal modulation and coding, angle, signal level and transmission rate to achieve required satellite system's throughput, SNR and QoS under unpredicted atmospheric conditions.

Future work will focus on simulation of SANDU under thunderstorm and other weather attenuations at different location on earth.

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