Distinction between HAPS and LEO Satellite Communications under Dust and Sand Storms Levels and other Attenuations

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Summary

Satellite communication for high altitude platform stations (HAPS) and low earth orbit (LEO) systems suffer from dust and sand (DU&SA) storms in the desert regions such as Saudi Arabia. These attenuations have a distorting effect on signal fidelity at high frequency of operations. This results signal to noise ratio (SNR) to dramatically decreasing and leads to wireless transmission error. The main focus in this paper is to propose common relations between HAPS and LEO 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 LEO 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 gaseous effects for different frequency, and propagation angle to provide system operations with a predicted vision of satellite parameters' values. Skillful decision and control system (SD&CS) is proposed to control applied parameters that lead to improve satellite network performance and to get the ultimate receiving wireless signal under bad weather condition.

Key words:
Dust and Sand (DU&SA), Gaseous Attenuations, Satellite Communications Networks, Signal to Noise Ratio (SNR), and Skillful Decision and Control System (SD&CS).

1. Introduction

Communication networks operating at high frequency suffer from different weather conditions. These attenuations can dramatically drop signal level and result in the quality of service (QoS) dropping and thus, unrecovered receiving signal errors. These propagation impairments can be presented by dust and sand (DU&SA) and other gaseous conditions mostly in desert areas. These attenuation are considered a dominant impairment, in Saudi Arabia and other areas, for satellite communication operating above 8 *GHz*. Figure 1 represents the operation of low earth orbit (LEO) and high altitude platform stations (HAPS) communication networks under DU&SA storms [1]–[4].

It is essential to know the characteristics and performance of attenuations to improve end to end satellite communications. International Telecommunication Union Radio Communications (ITU – R) provides values for some parameters that are used to compute the values of different weather attenuations. This data is useful for any desired location.

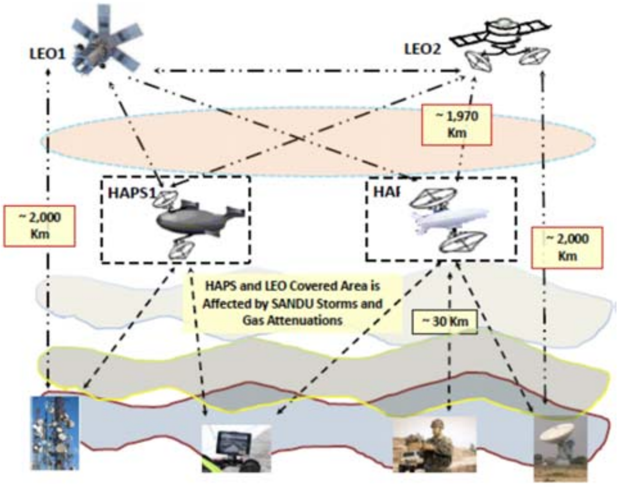

Fig. 1 DU&SA storms effects on HAPS and LEO signal propagation.

Researchers are investigating on LEO and HAPS satellite networks the impact of different weather characteristics. Both systems use fast internet access and low latency [2], [4]–[6]. Most of literature work present in satellite systems and networks by using uniform particular size distribution within the storm or specific angle cases. Some works have been done for HAPS systems without stating DU&SA's effect [7]–[12], while two were done for HAPS under DU&SA weather conditions [1], [13]. Some advantages of HAPS over LEO are reducing the high cost involved in building satellites and launching them, serve and focus into crowded areas, fast internet connection, face trouble with DU&SA and other attenuations.

The impact of atmospheric attenuation becomes more significant for signals having shorter wavelengths which observe more attenuation and scattering from particles of DU&SA as per our case in the radio path. The effectiveness of precision offered by any technical solution is dependent on proper prediction and identification of all the radio attenuation causing factors. Authors in [8] used the approach of adding a vertical path adjustment factor to measure attenuation is presented. This paper generalizes the concepts of [8], [14], [15] and presents three dimensional

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relationships of average dust particle size variations with respect to different reference visibilities, dust particular size, and heights. Afterward, the methods to get precise attenuation and SNR measures have been presented based on the mentioned parameters. This scheme for modeling, estimation and proposing would be helpful in optimizing the radio resources and implementing the cost effective link budgets for satellite links while maintaining the end-to-end QoS requirements.

This paper introduces a method to enhance gaseous attenuation models, presented in (ITU–R P.676 and ITU–R P.1510), by improving computational efficiency and prediction accuracy for different atmospheric parameters based on weather database at different sites, and frequencies [16]. In addition, a three dimensional relationship is proposed for DU&SA attenuations with visibility, particle size, frequency and propagation angle. These results will supply the proposed skillful atmospheric aware model networking parameters such as link and queuing skillful decision and control system (SD&CS) with a mechanism to better estimate satellite characteristics. These derived parameters will then enable the adaptive SD&CS to maintain QoS and service agreements by controlling signal power, position, transmission frequency, propagation angle, signal rate, coding and modulation schemes in the presence of storms. Moreover, the proposed method can be used to build up a flexible system based on optimized algorithms and core computing skillful control and decision system which takes into account challenging propagation environments and the need to extend deterministic models to predict parameters relevant to the simulation of communications systems. It will promptly adjust to new signal changes through the interconnected network entities before storm weather effect actually manifest themselves to maintain end-to-end bit error rate (BER) requirements [3], [14]–[18]. Simulation results for SNR with both of total estimated attenuations and transmit power are presented to show the performance improvements.

The remaining sections of this paper are: Section 2, introduction to DU&SA measured database and different levels concept. Section 3, atmospheric attenuation impacted LEO and HAPS satellite networks followed by analysis and simulation of DU&SA and other attenuations. Section 4, SNR calculations and improvement and SD&CS for satellite systems are presented. Section 5, presents simulation results and analysis. Finally, a conclusion and future research are presented in Section 6.

2. DU&SA Database

DU&SA storms are very common meteorological phenomenon being observed in desert such as Saudi Arabia, Iraq, Sudan, Libya, Nevada, etc. [6], [18].

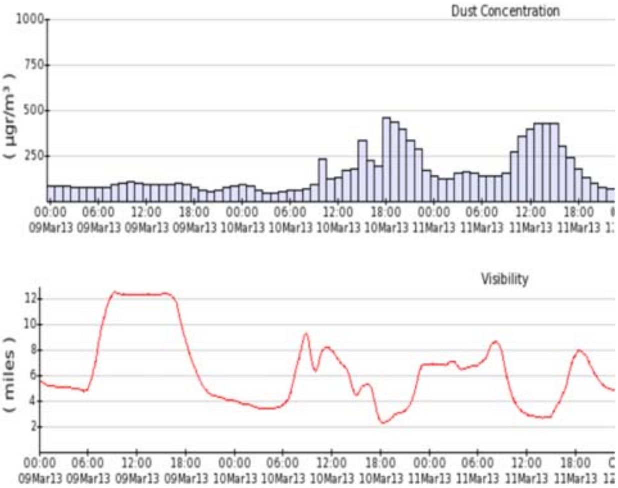

Fig. 2 Sample of DU&SA concentration vs visibility at Dhahran station, Saudi Arabia.

Figures 2 shows measured data for dust concentration, compared to visibility at Dhahran, Saudi Arabia location (Lat. = 26.311, Lon. = 50.130). The sample data showed dust concentration variations from around 75 to 480 $\mu gr/m^3$ with visibility variations from 2 to 12 *miles*. These measurements were randomly selected over a specific period of time of DU&SA season under temperature ranges from 10 to 30 °C, wind speed at 10 *m* ranges from 4 to 10 m/s, relative humidity at 2 *m* ranges from 0 to 90 %, and sea level pressure ranges from 1002 to 1018 *hPa*.

Also, Fig. 3 presents real DU&SA storm divided into four levels including ground, X, Y and Z within a rectangular storm – container ranging from earth level up to 8 *Km*. Usually, these storms emanates from strong wind blows causing the dust particles to get suspended in the atmosphere. These storms have varying maximum altitudes depending upon specific regional characteristics and wind blow speeds. Severity of dust storms depends upon the visibility. Dust storms can attain altitudes of 5.0 *Km* or more in the atmosphere. Thus, a different approach to model these storms and methods to get precise attenuation measurements have been defined. The concept of different levels for DU&SA storm is proposed to HAPS and LEO satellite communications [1], [14].

3. Analysis of Atmospheric Attenuations

The atmospheric attenuations based on different attenuation formation will be presented by multiple levels.

a) DU&SA Attenuation

Each level constitutes its specific point attenuation on the microwave signal depending on the measurement of visibility as well as the equivalent dust particles radii.

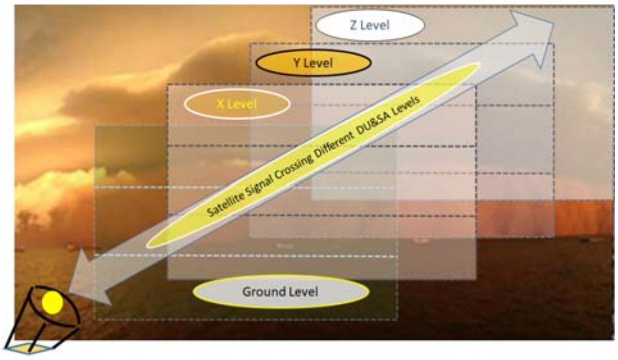

Fig. 2 Different levels sample of DU&SA storm.

Equation (1) can be used in a recursive manner to make the visibility based levels in DU&SA storm:

$$h_1 = h_{(l-1)} \left[\frac{V_m}{V_{(l-1)}}\right]^{3.85}, \quad (1)$$

$h_{(l-1)}$ and $V_{(l-1)}$ are the reference height and visibility respectively, and the suffix (l) indicates different DU&SA levels. This equation can be adapted to find various levels of visibility associated with different heights:

$$V_l = V_{(l-1)} \left[\frac{h_l}{h_{(l-1)}}\right]^{0.26} \quad (2)$$

Creating an effective generic storm model is a challenge, since DU&SA particles from different regions have different characteristics such as relative permittivity and average dust particle sizes [1]. Note that, large particle size mostly exist at low level will block satellite signal.

$$A_{p-level} = \left[\frac{567}{V r_e^2 \lambda}\right] \left[\frac{\varepsilon''}{(\varepsilon'+2)^2+\varepsilon''^2}\right] \sum_l^N P_l\, r_l^3 \quad (3)$$

$$A_{SANDU} = \sum_l^N A_{P-level} \quad (4)$$

These individual level attenuations are then summed up as presented in (3) and (4) reaching the end of the storm which can be discovered by attaining certain lower bound of visibility comparable to visibility in free space [6], [14].

Thus, the simulation results of DU&SA will be added to other weather attenuations. The results depict almost 100 *m* visibility at the earth station, which keeps on increasing between 0 to 8 *Km* at the point where transmitted signal gets out of the DU&SA influenced region. A strategy presented above is devised to slice off the whole DU&SA storm into several levels according to visibility. The dielectric constants values are listed in Table 1. In such case, the proposed model takes into account a range of visibilities with several DU&SA particles sizes along with altitude dependent distributions for all the particles sizes to compute its respective attenuations.

b) Gaseous Attenuation

Gaseous attenuations are presented by the gas molecules and its absorption that are present in the atmosphere. Note that, the path length which varies between HAPS and LEO communications.

TABLE 2: Listing of dielectric constants at various frequencies measured by [6].

DIELECTRIC CONSTANTS			
Freq. GHz	**Soil Type**	ε'	ε''
1 – 3 24 – 37	Loam	3.5 2.88	0.14 0.3529
3 – 10.5	Clay, silt	5.73	0.474
10.5 – 14	Sand	3.9	0.62
14 – 24	Sad	3.8	0.65

Analytical solutions for gaseous attenuation are presented in [16], [19], [20]. The results present the effect by summing all significant resonance lines for dry air, slant path equivalent to height, and propagation angle up to 70 degrees. This section computes the gas attenuation based on different propagation angles and frequencies as:

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

$A_0 = h_0.\gamma_0\ dB$ and $A_w = h_w.\gamma_w\ dB$. The parameters used to estimate gaseous attenuations are given by ITU–R P.676. Thus, the attenuations are:

$A_{DU\&SA}(\theta, f)$: Eqs. (3) - (4) estimate DU&SA attenuation.

$A_{Gas}(\theta, f)$: Eq. (5) estimates gaseous attenuation.

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

$$A_{WAG}(\theta, f) = A_{\text{DU\&SA}}(\theta, f) + A_{Gas}(\theta, f). \quad (6)$$

The result of (6) for atmospheric attenuation presented by the available measurement and estimated data for all latitudes for the prediction of visibilities, DU&SA size, and gaseous attenuation values at any ground station location, propagation angle up to 50 degree, and frequency up to 30 *GHz* is shown in Fig. 4.

Also, free space loss should be presented while estimating signal transmission from station to HAPS or LEO satellite and vice versa. Free space loss presented as a function of frequency by:

$$A_{FSL}(f) = (4.\pi.d/\lambda)^2, \quad (7)$$

The wavelength λ and *d* is around 2,000 *Km* for LEO and 30 *Km* for HAPS distance between transmitter and receiver. It is also a function of the propagation angle (θ) for the line path linked between earth station and HAPS or LEO satellite. Free space means surface free of electrical charge, uniform distribution extent in all directions, carries with no current, [21], [22].

Thus, total attenuations $A_T(\theta, f)$ is given by:

$$A_T(\theta, f) = A_{SA\&DU}(\theta, f) + A_{Gas}(\theta, f) + A_{FSL}(\theta, f). \quad (8)$$

The total attenuation represented in (8) is used to compare both HAPS and LEO satellite for different locations, particle concentration and visibilities, propagation angle, frequency and different DU&SA levels, as shown in Fig. 5.

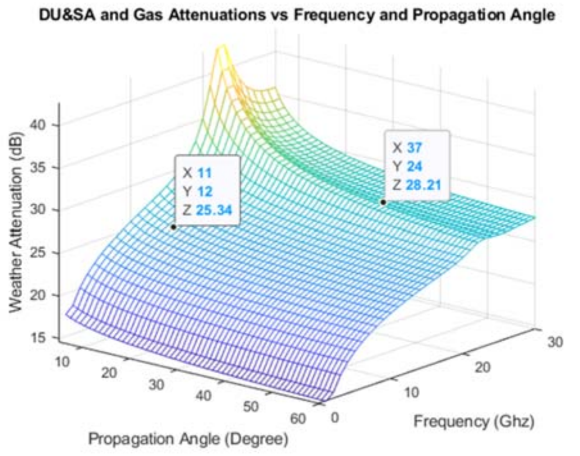

Fig. 4 Atmospheric results based on DU&SA and gaseous attenuation.

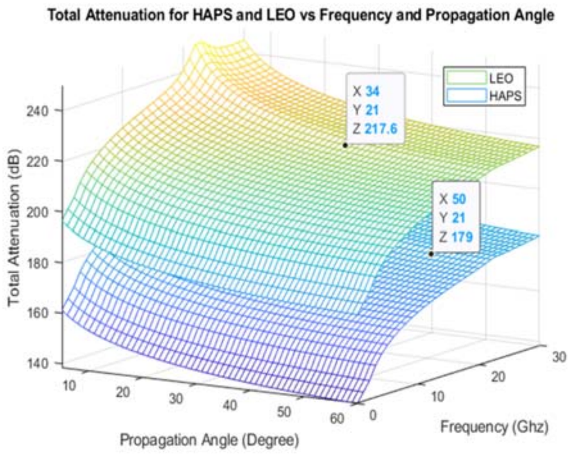

Fig. 5 Total attenuation for HAPS and LEO.

Therefore, due to the dominance of different effects and the inconsistent availability of test data, some variations of errors occur across the distribution of different probabilities. HAPS and LEO attenuations according to analysis and simulation are mostly come from free space loss, as signal propagation faces the same amount of DU&SA and gas attenuation while traveling from the same location applying the same frequency and propagation angle.

However, if any of these factors changes such as miss-estimation of DU&SA storms, receiving signal would be totally different. Better estimation of these attenuations will be an asset to support skillful system to decide and control satellite parameters.

4. Skillful Model for SNR

This section describes different computational techniques to provide decision and control (D&C) with an accurate view for modeling satellite propagation environments, and procedure for improving accuracy for the atmospheric attenuations with SNR calculations using different methods.

a) SNR Calculation

SNR is a measure of signal strength for applicable satellite signal relative to signal attenuations and noise. A better estimation for SNR values calculated under different atmospheric attenuations is proposed as follows:

TABLE 2: Noise temperature in antenna.

T_A (Kelvin)		
Hemispherical terminal antenna	290 360 400	At night Cloudy sky Clear sky with sunshine
Directional terminal antenna	3 – 10 ≈ 80 10^5….10^4	Space from earth at 90˚elev. Space from earth at 10˚elev. Sun (1…10 *GHz*)
Directional satellite antenna	290	Earth from space

Thermal noise power density is: $N_0 = K\,.T$ and $T = T_a + T_r$. The noise temperature of the antenna ranges from 290 ~ 400 K based on satellite and terminal antennas as shown in Table 2, where:

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

$N_r \approx 0.7 - 2.0\ dB$. Thus, SNR can be estimated from:

$$\frac{C}{N_0} = \frac{P_r}{K\,.\,T} = P_t + G_t - A_T + G_r - K - T\ dBHz, \qquad (10)$$

$$\text{SNR} = \frac{C}{N} = \frac{C}{N_0\,.\,B_r}\ dB, \qquad (11)$$

P_t and G_t, P_r and G_r are signal power and antenna gain at transmitter and receiver sides, respectively. $A_{TA} = A_{WA} + A_{FS}$. Where A_{FS} represents the free space loss calculated from (7), N (noise power) = $K.T.Br$ where B_r is noise of equivalent bandwidth.

b) SD&CS's Tasks

A SD&CS has to perceive its environment, to act rationally toward its assigned tasks, and to interact with other agents.

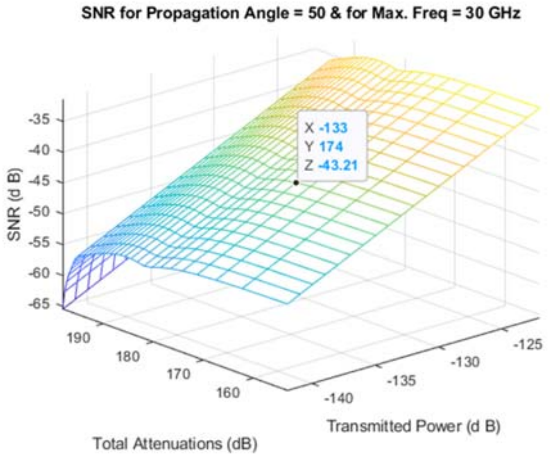

Fig. 6 Output SNR for LEO Satellite System.

The assigned tasks for this system are used to improve SNR according to weather's variation. These capabilities are covered by topics such as power, visibility, storm intensity, modulation, coding, and data rate, etc. The system rely on satellite parameter variations, training knowledge, various problem solving, and search engine. Using the core SD&CS for satellite communication networks as shown in Fig. 7, designers are able to predict individual components in a cohesive manner for an enhanced D&C. The derived parameter values, being fed through D&C to improve estimated SNR, will enable the SD&CS to maintain QoS by controlling satellite signal power, frequency, modulation, coding, and data rate under unpredictable weather conditions. The proposed method builds up a flexible SD&CS based on core computing of the adaptive skillful model – that would be controlled by the predicted weather database. Such system will proficiently search to overcome the atmospheric attenuation and thus improve signal performance. This periodically computed attenuation will keep updating our knowledge input to the SD&CS through the gate of D&C block. Moreover, this high level architecture for SD&CS – which is based on atmospheric attenuation, DU&SA size, power, modulation, and coding information along with other parameters – is used to estimate the optimal decision for satellite communication systems. Such system will proficiently search for different combinations of input control variables to minimize estimated attenuation effect and maximize channel robustness and efficiency by improving signal to noise ratio SNR [23], [24].

c) SNR Improvement

Several factors such as power, modulation, etc., can play an immense role in improving SNR and in maximizing system throughput and availability of the link. In this section, a new proposed SD&CS is introduced, as shown in Fig. 7, to overcome different weather conditions. Thus, by controlling the above mentioned factors that supply the SD&CS, a path is given to allow an efficient mechanism to better estimate satellite's networking parameters such as link and queuing characteristics. These derived parameters would enable the SD&CS to maintain SNR by adaptively adjusting signal power, transmission rate, coding, and modulation under unpredictable weather conditions. As$_s$ $Es = C - R_s\, dB$, where transmission rate $R_s = 1 / T_s$ and energy–to–noise power density per symbol is:

$$\frac{E_s}{N_0}(A,P) = P_t + G_t - A_{TA} + G_r - K - T - R_s\, dB. \quad (12)$$

Fig. 6 shows the output results for SNR before adjustment. Thus, Fig. 7 illustrates a manner for changing parameters of the communication system in order to overcome the deteriorating effect of atmospheric impairments, and to increase reliability of the data transmitted throughout the channel.

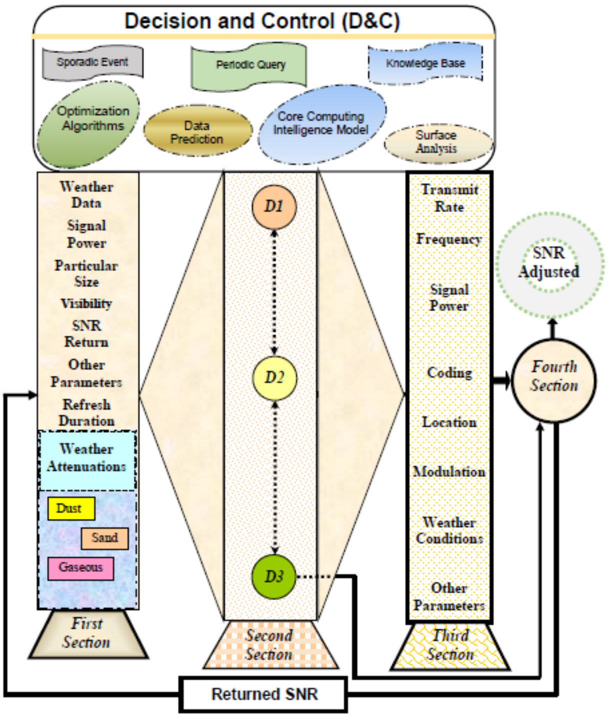

Fig. 7 SD&CS for satellite communication networks.

In the first section, the system holds input signal parameters such as frame size, propagation angle, SNR estimated values, etc., that were compared against SNR threshold level in a single database. The result should be greater than or at least equal to this level.

In the second section, based on SNR value, either the SD&CS will decide to increase transmit power up to a maximum limit of –30 *dB* (0 *dBm*) in order to reach the desired level and stop the simulation or to skip to the next section. Next, SNR value will be checked among modulation and coding values recorded in the system. If this value can be reached by using any of the mentioned table combinations, then the system will go to the last section.

In the last section, the system will compromise among different SNR achieved outputs and make decision based on the skillful controller according to available parameters and requirements. The given feedback will keep looping until a satisfactory value is reached. Thus, the system has capabilities to change data rate, frame size, frequency, etc. in order to adjust SNR in cases such as unpredicted storm weather condition by using refresh duration that is located in the first section.

Figures 6 and 8 show a comparison for the outputs of SNR ranges before and after modification for LEO communications, respectively. Thus, before modification SNR used to fall between (~ –65.0 to ~ –31.54) *dB*, for power transmits from (~ –142 to ~ –122) *dB*, as output of Fig. 6. And was transformed after intelligent decision mechanism to fall within modulation and coding boundaries

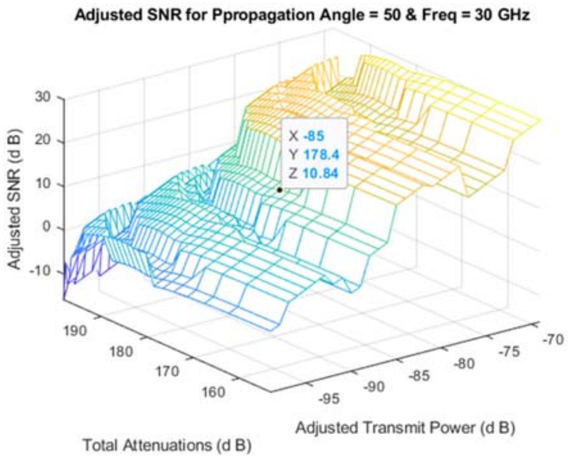

Fig. 8 Output Improved SNR for LEO Satellite System.

of allowable used database. The adjusted output for SNR ranges from (~ –16.09 to ~ +30.22) to (~ –99.0 to ~ –69.0) *dB* for transmitted power, and (~153.0 to 197.8) *dB* for attenuations in both results. Note that, there is a limit for increasing transmit power up to around –30 *dB*. Once this value has been reached, modulation and coding selections should match in order to adjust SNR as per Fig. 8. Consequently, this figure shows throughput enhancements for wireless communication systems. They also create a robust SD&CS by allowing designers to work with flexible ranges by applying various combinations of satellite signal parameters for any unpredictable weather conditions.

5. Simulation and Analysis

The predicted atmospheric attenuations were estimated for HAPS and LEO, in the previous sections, at any location on earth for different operational frequency values, visibilities, and for a wide range of propagation angles. These schemes provide appropriate results for high frequencies of operations as presented in Fig. 4 to Fig. 8.

Moreover, these results are the key factors in implementing an accurate skillful engine that act to improve end-to-end wireless communications for different weather conditions. This simulation pilots an enhanced back propagation learning algorithm that is used to iteratively tune the skillful controller technique with returned SNR values for activating the weighted modulation/code point to its optimal values, depending on actual or predicted weather conditions, configuration settings and tolerance or safety margins for SLAs commitment as shown in Fig. 7.

Thus, the simulated SD&CS checks out various combinations for different input variables based on given threshold signal level at each section and conveys intelligently the ultimate value for SNR. Therefore, the implemented skillful engine will proficiently search for the blend of available signal parameters in the presence of unpredicted channel attenuations. It will then provide us with reasonable signal recovery that satisfies at least the minimum threshold level as shown in Fig. 8.

The results are done by using MATLAB simulations. Different programs were written to collect database information from different sources such as ITU–R. It is used to implement the three dimensional results for DU&SA and gaseous attenuations, and to run the skillful engine in order to present the desired output for the communication satellite systems.

6. Conclusions and Future Works

Sand, dust, and other atmospheric properties can have a distorting effect on the performance of satellite communication systems. Predicting channel attenuation due to atmospheric conditions can enable mitigation planning by adaptively selecting appropriate propagation parameters such as modulation and coding etc. This paper presented a method to estimate dust, sand, and other attenuations using the signal–weather database taken in Saudi Arabian and from ITU–R propagation models combined with bi–linear interpolation, gateway, and ground terminal characteristics. A three dimensional relationship was presented for these attenuations with both frequency and propagation angles to provide the D&C with a mechanism to have an accurate view of satellite's parameters. The proposed SD&CS can provide designers with a perceptible view of approximated atmospheric attenuation values by giving them the flexibility at any location to apply various combinations of modulation, coding, transmission power, and transmission rate, for all propagation angles, and for any frequency ranges, in order to maximize satellite system's throughput and QoS for variant weather conditions. Simulation results were presented to show the effectiveness of the proposed methods.

Future work will focus on simulation of DU&SA under thunderstorm and other weather attenuations at different locations on earth.

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