HAPs Communication in Saudi Arabia under Dusty Weather Conditions

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Abstract **– Technology is improving rapidly. One of the most revolutionary communication technologies that appears to be convincing and efficient is called High Altitude Platform (HAP). As any other wireless communication system, a main degrading factor of HAP Station (HAPS) propagation channel in desert and semi-desert areas is the dust storm attenuation. This attenuation increases with an increasing operational frequency and is prominent in the frequency bands above 10 GHz which is used for HAPS communications. This paper investigates the effect of dust attenuation on the reliability of the HAPs system. Also, based on a close scrutiny of the existing dust attenuation models, this paper proposes some modifications to an existing dust attenuation model to comply with the real dust phenomenon. In this paper, a platform altitude of 22 km with a minimum elevation angle of** 20 **were considered. The analysis showed that the dust attenuation degraded the signal to noise ratio by around 20 dB at Ka frequency band. As a result, an appropriate intelligent attenuation mitigation technique was then suggested.**

Keywords **– High Altitude Platform Stations (HAPS), Permittivity indices, quality of service, dust and sand storms, satellite networks, signal to noise ratio.**

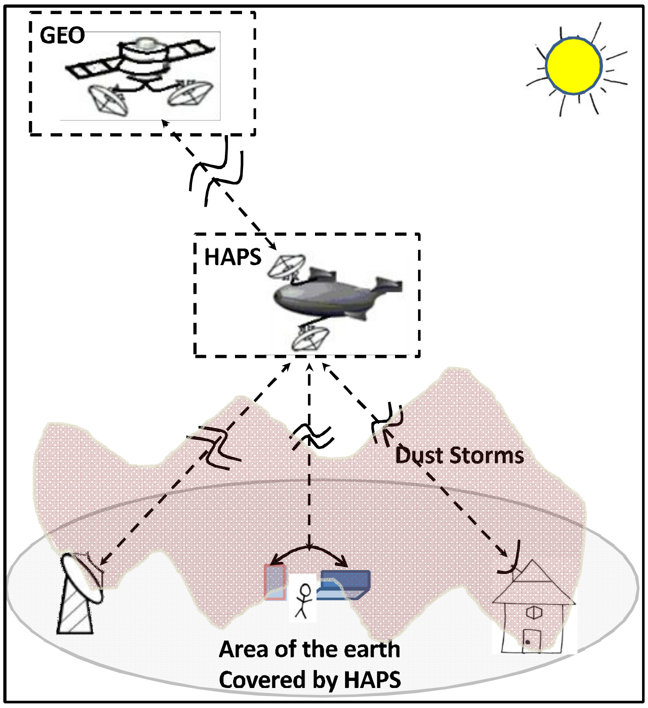

Fig. 1: Effects of Dust and Sand Storms on HAPs Communications

I. Introduction

HAP communication in certain areas was considered the alternative to satellites. High Altitude Platform Stations (HAPS) is an emerging wireless access technology which uses balloons or aircrafts at a specified altitudes ranging between 17 and 50 km to provide wireless services. In spite of the advantages of satellite systems, unequivocal disadvantages including the high cost involved in building satellites and launching them, and the changing technical requirements for non-GEO satellite systems, or the delays associated with GEO satellite systems [1]–[6]. Terrestrial systems on the other hand, have also some pitfalls: the deployment of terrestrial mobile networks is expensive, have potential health hazards and the environmental impacts, are looming problems. This is why the High Altitude Platform Stations (HAPS) technology became superior. HAPS, also known as stratospheric repeaters, is the technology for providing wireless narrow band and broadband telecommunication and broadcasting services, particularly in remote rural areas where the deployment of terrestrial network infrastructure is not only difficult, but costly as well. The HAPS provide these services to users using either aircraft (manned or unmanned) or lighter-than-airships (LTA) [7], [8]. These platforms are reusable and positioned at stratospheric altitudes, from $20\ km$ to $50\ km$ approximately. This new concept of wireless access avoids some of the drawbacks of existing systems both Satellites and Terrestrial, while bringing a number of innovative advantages. The HAPS deployment is rapid and gradual, maintenance is easy and they can be re-configured and re-allocated. Round-trip delay is less than 0.5 ms. and is environmentally friendly [7]–[11]. Moreover, the HAPS can be easily integrated with the existing satellite and terrestrial systems as depicted in Figure 1.

This study tries to investigate the link performance of HAPS communication system during heavy dust storms and proposes an appropriate attenuation mitigation technique.

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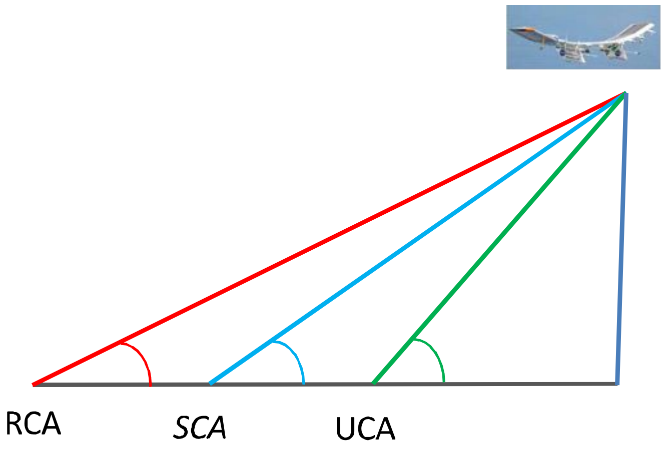

Fig. 2: HAPS Different Coverage Area

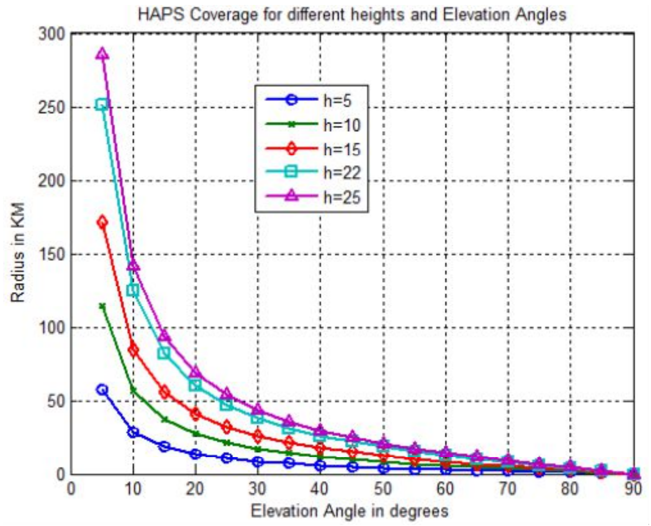

Fig. 3: Variation of Radius and Elevation Angle with Different Altitude

II. Study's Problem

Most of the existing wireless communication technologies including satellites and terrestrial, suffer from immobility and high installation costs. Therefore, a technology which is relatively cost effective, and which can easily be moved depending on the demand while observing the required quality of service is urgently needed. With such technology a more convenient way of information provision can be realized with as low cost as possible. Definitely, the choice will be HAPS technology. To ensure the quality of services, the communication link has to be analyzed and set to the appropriate operating parameters. For the technology to be adopted in desert and semi-desert countries like Saudi Arabia, dust attenuation should have a special attention in the link budget.

III. Research Methods

A. HAPS System Geometry

HAP is intended to provide wireless narrow band and broadband telecommunication services (i.e. internet, cellular services) with either airships or aircrafts, which are located in the stratosphere at $20 - 25$ km of altitude having a fixed position with respect to the ground [7]. The footprint and hence the coverage area of HAPS communication system is uniquely defined by the accepted minimum elevation angle and its height.

The ITU-R defines three coverage areas: urban area coverage (UAC), suburban area coverage (SAC) and rural area coverage (RAC). These areas are determined by the subscribers location in terms of the distance from the sub-platform point (SPP). These radii locations are shown in Figure 2, while the effect of changing elevation angle and the platform height is given in Figure 3, where h represents height above ground level. The simulated plot demonstrates how the HAPS footprint shrinks as the minimum elevation angle increases [8]. It is worth noting that ITU-R recommends the use of minimum elevation angles 5, 10 and 20 for C, Ku and Ka bands respectively.

In this paper, the height of the platforms were defined to be 22 km taking into account the ITU-R recommendations and the wind behavior. From the geometry, the corresponding slant path and the coverage radius were found to be 64.324 km and 60.445 km respectively as shown in Figure 4.

B. HAP Altitude and Wind speed

The Earths atmosphere consists of several distinct layers with the troposphere being the lowest one. The troposphere extends from the Earths surface to approximately 11 km in altitude, depending on the season and geographic location. In the troposphere, the air temperature generally decreases with height. The air pressure also decreases, from about 1000 hPa at sea level to around 200 hPa at a 10 km altitude [8]. The stratosphere is the next layer, ranging from 10 to 50 km in altitude. The stratosphere is characterized by a high static stability, associated with a temperature increase, related to height and relatively mild winds. There are no clouds in the stratosphere, which could allow clean solar energy to be used without atmospheric pollution.

Figure 5 helps designers to select the ultimate location for HAPS in the space. Thus, it shows how wind speed, atmospheric pressure and temperature vary with altitude at different layers of the atmosphere. The wind speed varies according to the season, geographic location and temperature gradient. It is clear from the figure that the wind speed is highest at altitudes of about 10 and 50 km and designers should avoid these altitudes. Thus, at altitudes of 20 and 30 km, the air masses are relatively stationary, with very slow winds [8]. This allows the location of quasi-stationary high altitude platforms (HAPs) to be best positioned at altitudes

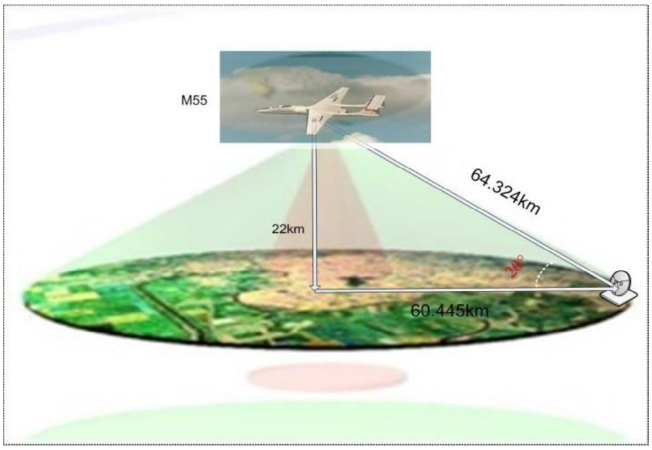

Fig. 4: HAPS Approximate Geometry

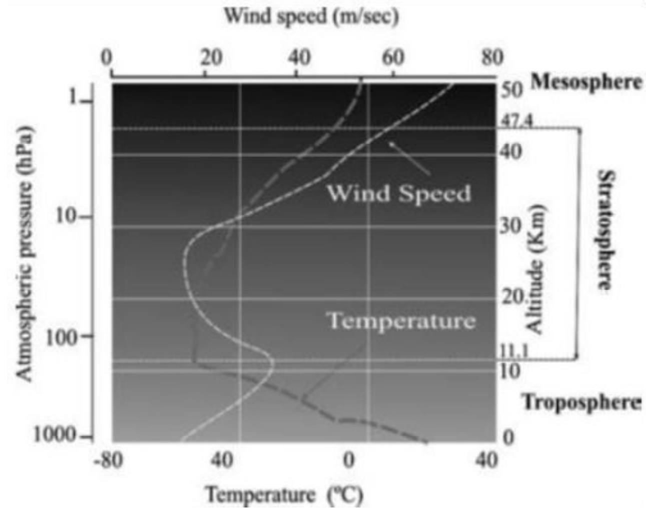

Fig. 5: Variation of Wind Speed with Altitude [8]

between 17 and 25 km. At these heights, platforms can succeed in maintaining station-keeping, flying against the wind without excessive power demands.

C. Propagation Effects

The propagation loss for earth-HAP path in the Ka band mainly consists of the following contributions: free-space loss (L_p), rain attenuation (L_r), dust attenuation (L_d), atmospheric gases attenuation (L_g), attenuation by tropospheric scintillation (L_s) and attenuation due to clouds (L_c) [12]. However, in arid and semi-arid environments, only path loss and dust attenuation are of great significant.

1) Free-Space Loss: The free space path loss (L_p) is given by:

$$L_p = 10 \cdot log(4\pi d/\lambda)^2, \tag{1}$$

where λ is the wavelength of the RF signal, and is the distance between the antennas of the ground station and the HAP antenna operating at inclination angle (θ) that is given by:

$$d = h_{HAP}/sin\theta \tag{2}$$

2) Dust Attenuation: According to [12], [13], dust storms can potentially result in serious attenuation in signal level especially at Ku band and higher frequencies with direct impact on telecommunications system performance. Basically, dust storms are significant meteorological phenomenon characterized by strong winds and dust-filled air over an extensive area. They are common in arid and semi-arid regions [9]. There is a number of different models that have been proposed for dust attenuation estimation, taking into account the variation of visibility, particle size and concentration of the dust particles. An attractive model for the attenuation was proposed by [9], [11], [13] as:

$$A_P = \left[\frac{567}{V r_e \lambda}\right] \left[\frac{\varepsilon''}{(\varepsilon' + 2)^2 + \varepsilon''^2}\right] \sum_i^N p_i r_i^3, \tag{3}$$

where A_p, is the point attenuation in dB/km, ε' and ε'' are respectively the real and imaginary dielectric constant component, r_e is the equivalent particle size, λ wavelength of the signal, V is the visibility given by:

$$V = V_0 \left[\frac{h}{h_0}\right]^{0.26}, \tag{4}$$

where V_0 is the visibility at the reference height h_0. The variations of the V and h are illustrated in Figure 6.

However, the model does not consider the height of the dust storm and therefore, it is not confined to the storm height. For that reason, a new model was developed in attempt to improve the existing one considering the dust height and maximum visibility. The model is confined to the dust region only as shown in Figure 7.

$$V = V_m exp\left[-3.6 \frac{h_0}{h}\right], \tag{5}$$

where

$$V_m = V_0 \left[\frac{h_1}{h_0}\right]^{0.26} \tag{6}$$

h_1 is the storm height while other variables carry their usual meanings.

According to [13], the total attenuation, A_T is obtained from the following expression

$$A_T = r_v \times d \times A_p \tag{7}$$

r_v is the vertical path adjustment factor and all other symbols carry their usual meanings. The vertical path adjustment is estimated using the following relation [13] as:

$$r_v = \frac{h_0^{0.26} \times h_1^{0.74}}{0.74 \times \ d \ \times \ (\sin\theta)^{1.74}} \tag{8}$$

It is clear from the expression that, r_v is a function of the inclination angle, θ, height of the storm, h_1, reference

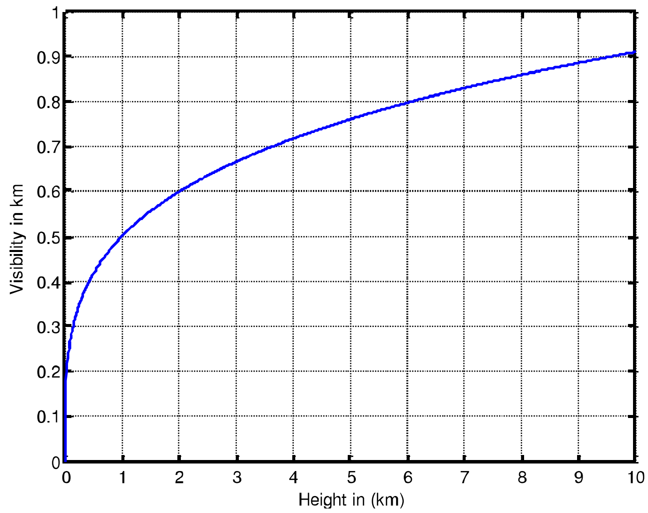

Fig. 6: Variation of Visibility with The Height

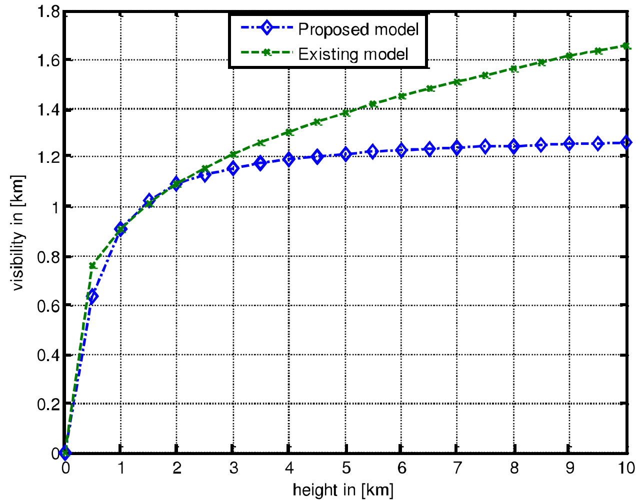

Fig. 7: Comparison between the Two Dust Models

height h_0 and the slant path, d. The variation of r_v with the inclination angle and frequency are depicted in Figure 8.

From the above analysis, the HAP operating point was found to be $\theta = 20°$, $d = 11.7\ km$ corresponding to $r_v = 1.146$ as summarized in Table I. Then, the values for total attenuation were obtained by going through (1) to (8) for existing model, and for varying visibilities with different heights (h) for the proposed model.

D. Link Budget Analysis

By definition, the HAP link budget M is the margin between the required carrier-to-noise ratio, $(C/N)_r$, and the available carrier-to-noise ratio, $(C/N)_a$, given by:

$$M = \left(\frac{C}{N}\right)_a - \left(\frac{C}{N}\right)_r, \quad (9)$$

where $(C/N)_r$ depends on the service requirements, including the specified bit energy-to-noise density ratio E_b/N_0, required data rate R_b, the transmission bandwidth B of the carrier, the modulation scheme and the coding gain G_{coding} of the system [12] as:

$$\left(\frac{C}{N}\right)_r = \left(\frac{E_b}{N_0}\right)_r + \left(\frac{R_b}{B}\right)_r - G_{coding}\ dB. \quad (10)$$

$(C/N)_r$ is assumed to be 10 dB. While $(C/N)_a$ is determined from the transmitter's effective isotropic radiated power $EIRP$, the channel propagation losses, and the characteristics of the receiver [12] is given by:

$$\left(\frac{C}{N}\right)_a = \mathrm{EIRP} - \mathrm{A_T} + \mathrm{G_r} - (\mathrm{k} + \mathrm{T_s} + \mathrm{B} + \mathrm{L_r})\ dB, \quad (11)$$

where G_r and L_r are the receiving antenna gain and receiver loss. Also, T_s and k are noise temperature of the receiver and the Boltzmann's constant. From the above equation, the link performance is highly affected by the attenuation assuming other parameters remain constant. The signal-to-noise ratio is reduced notably as the dust attenuation increases.

TABLE I: HAPS Operating Point.

Frequency $[GHz]$	A_p(dB/km) Proposed Model	A_p(dB/km) Existing Model
31	1.462	1.2549
28	1.3205	1.1334
Elevation angle $\theta = 20$, Slant height $L = 11.7\ km$, and vertical adjustment $r_v = 1.146$		

E. Fading Mitigation Techniques

Some researchers including [3], [9], [11] proposed the use of intelligent mitigation schemes for signal to noise ratio (SNR) improvement. The mitigation techniques that were applied to compensate the attenuation impairment during heavy attenuation period, including Automatic Transmit Power Control ($ATPC$), and space diversity such that whenever a heavy storm condition is experienced, then the traffic can be re-routed via the second back haul link. The latter is ineffective as far as mobile HAPS communication system is concerned. $ATPC$ technique does not only serve as mitigation technique during a heavy storm, but it provides cost effectiveness as well. The system will be transmitting power according to the demand. By knowing the required performance such as weather prediction, the system will maintain appropriate SNR level by changing the transmitted power according to the demand. The automatic power control mechanism is used whereby the transmit power changes as the dust attenuation changes and it transmits the minimum power during the clear air condition. However, once weather attenuation increases and power factor reaches its limits, other parameters should be updated to maintain SNR values above minimum (threshold) signal level that is needed for costumer's satisfaction and acceptable communication performance.

IV. Results Discussion

From Table II, the performance of the system was promising in clear sky and dusty conditions. In case of clear weather, the only degrading component was the path loss. The available carrier-to-noise ratios were found to be $34.84\ dB$ and $29.48\ dB$ for the uplink and the downlink respectively. However, during the dust storm condition, the signal-to-noise ratios were drastically reduced to $15.24\ dB$ and $11.78\ dB$ respectively for the uplink and the downlink, keeping other parameters constant. With the increasing transmit power during the heavy storm conditions, the system can provide the required services with relatively good quality of service. In this paper the transmitted power was assumed to be $0\ dBm$ and the results were satisfactory. Thus, a much better result is expected if the transmit power can be raised.

TABLE II: Clear sky and Dust Condition belong to the HAPS Communications Link Budget Analysis for Elevation Angle of 20°.

Different Satellite Parameters	Uplink Clear/Dusty Weather	Downlink Clear/Dusty Weather
Frequency	31GHz	28GHz
Bandwidth	20MHz	20MHz
Transmitting Antenna		
Transmitted Power	5dBm	0dBm
Feeder Loss	0.5dB	0.5dB
Transmitter Gain	40dB	20dB
EIRP	44.5dBm	19.5dBm
Transmission range	64.324km	64.324km
FSL	158.4dB	157.5dB
Dust Attenuation	0dB/19.6dB	0dB/17.7dB
Atmospheric Loss	0.5dB	0.5dB
Receiving Antenna		
Receiver Gain	20dB	40dB
Feeder Loss	0.5dB	0.5dB
Received Power	-94.9dBm/ -114.5dBm	-99.0dBm/ -116.7dBm
Technical Loss	0.5dB	0.5dB
Noise Power		
Noise Temperature	300K	400K
Boltzmann's constant	-228.6 dBW/K/Hz	-228.6 dBW/K/Hz
Noise Power	-130.8dBm	-129.5dBm
Available Carrier to Noise ratio	34.8dB/ 15.24dB	29.4dB/ 11.78dB
Required Carrier to Noise ratio	10dB	10dB
Margin for Clear/Dusty	24.84dB/ 5.24dB	19.48dB/ 1.77dB

V. Conclusion

This paper investigates the link reliability during the dust storm scenario. It was found that the link margin dropped tremendously due to the fading effect of dust storms and it can destroy the signal at certain levels. Though the system at this level can be considered operational, but only an extra attenuation of around $2\ dB$ can make the system

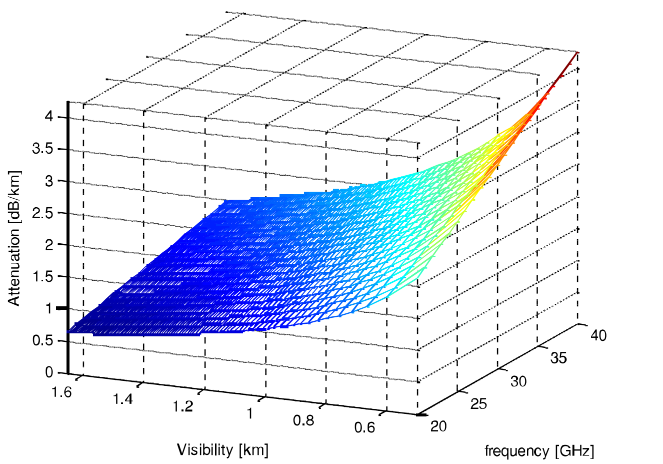

Fig. 8: Vertical attenuation with Inclination and Slant Height

unreliable. However, with the application of automatic power transmission, the required quality of service can be maintained.

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