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Combined Effects of Atmospheric Propagastion on link Availability of Non-Geostationary Satellite at Ka-Band in Arid Climate

التأثير الجوي المركب على مدى توفر وصلة الأقمار الصناعية غير ثابتة المدار عند نطاق Ka في المناطق الجافة

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Abstract: Earth-to-space links are affected by several atmospheric impairments which may have different degrees of correlation or statistical dependence. For non-Geostationary Satellite Orbit (GSO) links operating at Ka-band in the arid climate of the Kingdom of Saudi Arabia (KSA), it is found that attenuation due to rain is the dominant source of propagation impairment (about 78% at 8o elevation and 0.01% time is exceeded). The effect of dust contributes the minimum source (less than 0.2%). However, the contribution of all other sources other than rain cannot be neglected (about 32%).

Key words: Atmospheric Propagation, Link availability, Nongeostationary, Aridzone.

المستخلص: تعرض هذه الورقة تأثير العوامل الجوية على اتصالات أنظمة الأقمار الاصطناعية المتنقلة غير ثابتة المدار، عند ترددات نطاق ما فوق ka، في المناطق التي يتميز معظم مناخها بالجفاف. قياساً على أحدث معلومات الباحثين. تقدم الدراسة وصفا لطرق التنبؤ واستخدامها للحصول على تقدير لاضمحلال انتشار الموجات عند نطاق ka، نتيجة لمختلف العوامل الجوية. وقد تم استخدام بيانات العوامل الجويةبعد القياس محليا. ومن ثم مقارنة تأثير العوامل الجوية المختلفة بالنسبة لبعضها، وكذلك التنبؤ بالتأثير المُركب لهذه العوامل مجتمعة. وأتضح من البحث أن الأمطار هي السبب الغالب لاضمحلال انتشار الموجات (حوالي 78% من مصادر الاضمحلال عند درجة ارتفاع 8 درجات 0.01% من الوقت خلال السنة)، بينما تأثير الغبار هو الأقل(0.2% من مصادر الاضمحلال). إلا أنه لا يمكن إهمال تأثير العوامل الجوية الأخرى (غير الأمطار) على الاضمحلال (32%).

كلمات مدخلية: العوامل الجوية، توفر، وصلة الأقمار الصناعية، غير الثابته، المناطق الجافة.

Introduction

Satellite services using non Geostaionary Satalite Orbit (GSOs) are expected to grow rapidly in the coming years with emerging information technology applications such as mobile satellite communications and multimedia systems. Moreover, with the congestion of C (4/8 GHz) and Ku (12/18 GHz) bands, satellite services are moving to Ka-band (20/30 GHz). Higher frequency bands have the advantages of enabling users to have small terminals and providing broad bandwidth. However, atmospheric propagation impairments increase as the frequency is increased, and link availability at Ka-band may be affected by several impairments (ITU Handbook 1996).

These sources of impairments may have some sort of correlation or dependence. For example, the correlation between cloud attenuation in the presence of rain attenuation is one. However there may be cloud but not precipitation. In an arid climate, the probability of rain attenuation just after a dust storm may correlate (ITU Handbook 1996).

(Dissanayake *et. al* 1997) proposed a model for (GSO) satellites with a low elevation angle and frequency of 4 to 35 GHz, using a direct summation and rms summation of attenuations caused by atmospheric gasses, precipitation, cloud, melting layer, scintillation and low angle fading. Equiprobable summation of cumulative distribution functions represents the worst case and assumes total dependence of the effects, while the convolution summation assumes statistical independence between sources of attenuation. Convolution summation is a condition that is more realistic and the result is less than the equiprobable case. Equiprobable and convolution summation are considered the upper and lower bounds respectively of the combined effects of attenuation due to different sources. Other methods fall between the two bounds.

In this paper, the effects of atmospheric gases, rain, cloud and dust on non-(GSO) links operating at Ka-band in the arid climate of the Kingdom of Saudi Arabia are analyzed and the combined effects are discussed and presented.

Methodology

There are some variations in the attenuation modeling of atmospheric effects on earth satellite propagation. However, they all depend on, among other effects, angles of elevation (ITU Handbook, 1996), (Ippolito, and Russell,1993), and (Brussaard and Rogers, 1990). In non-(GSO) satellite earth terminals, the angle of elevation changes with time. A procedure has been proposed for the calculation of elevation angle variation with time for a non-(GSO) satellite system passing over the location of the gateway (Al-Ruwais and Sultan, 2005). This procedure is based on the constellation parameters of a moving satellite (Brussaard and Rogers,1990).

As an example of a non-(GSO) satellite, the Iridium has been selected. To the best of our knowledge, the North American Aerospace Defense Command, (NORAD) 2-line elements set TLE parameters of other Ka-band non-GSO satellites are not available in available literature. However, the proposed method for calculating the angle of elevation for a single Iridium satellite could be applied for the other satellites with their corresponding TLE parameters (www.http://celestrak.com/NORAD/elements/).

Figure (1) shows the results of calculating the variation of the percentage of time during which an earth station at Riyadh will "see" the Iridium satellite with variations in the angle of elevation (q) (Al-Ruwais and Sultan ,2005).

1. Absorption due to atmospheric gases:

Absorption due to atmospheric gases depends on frequency, angle of elevation, altitude above sea level and absolute humidity. Its importance increases with frequency increases above 10GHz, particularly for a low angle of elevation. Absorption by atmospheric gases is calculated as a function of elevation angles of the satellite link (ITU, Rec. ITU-R P.618-8, 2003), (ITU, Rec. ITU-R P.676, 2001), (ITU, Rec. ITU-R P.836-3, 2001). It is assumed that the mean water density r= 7.5 gm/m^3 at a height h_s= 0.6 km (Riyadh City), while the equivalent height of dry air h_o = 6 km for clear air and the equivalent height of water vapor h_{wo} = 1.6 km for clear air and 2.1 km during rain, and that the operating frequency f = 20 GHz.

The attenuation due to gas absorption A_g for elevation angle (ϑ) is calculated as:

Ag = (C1+C2)/(sin(q)) dB
C_1 = $\gamma 0 * h_o * \exp(-h_s/h_o)$ dB
C2 = $\gamma_w * h_{wo}$ dB
$\gamma 0$ = specific surface attenuation for dry air dB/km
γ_w = specific surface attenuation for water vapor dB/km

Most of the variation in gaseous absorption arises from the lognormal distribution of water vapor (Dissanayake *et. al.* A ,1997).

(2) Rain attenuation:

The rain attenuation exceeded for 0.01 of an average year is calculated following the procedure shown in the reference (Al-Ruwais and Sultan 2005) as a function of the angle of elevation from 10 to 80 degrees and f=20 GHz for the rain climatic region of Riyadh City. A measured rain climatic region is employed in

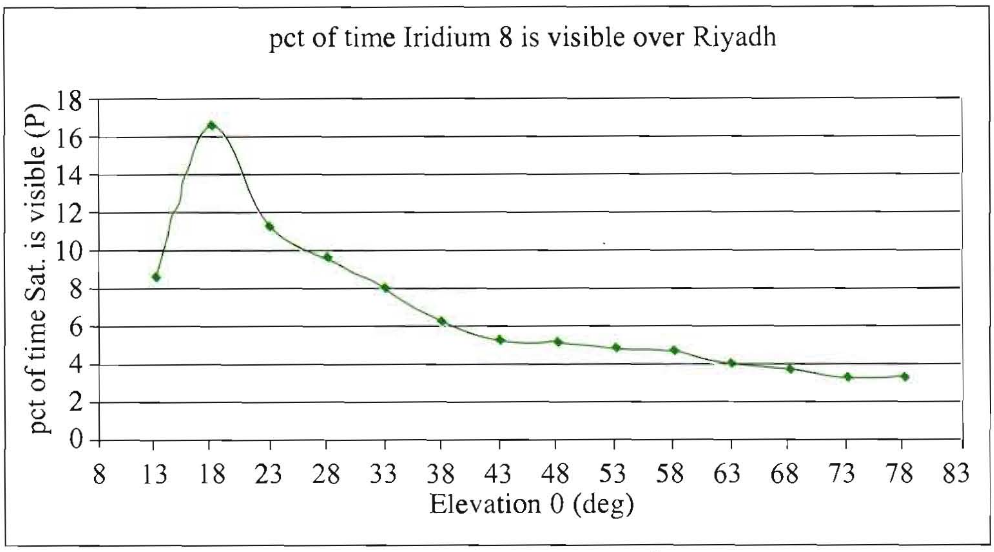


Fig. (1). Percentage of time an earth station at Riyadh for an Iridium satellite.

this work, which has been developed locally for Saudi Arabia (Ali A.A. *et. al.* 1986).

3. Cloud attenuation:

It has been shown (ITU, Rec. ITU-R P.676-5 2001), (Gerace and Smith 1990)] that cloud models are based on Rayleigh scattering, Mie absorption theories and empirical data. Attenuation results tend to agree at frequencies below 40 GHz for light and medium cloud conditions. The properties of cloud, such as vertical extent, horizontal extent, water content and percentage of time the cloud exist over a land, differ according to their types. For heavy clouds and above 10 GHz, the different models diverge from each other (Asoka, Allnut, and Haidara 1997). The attenuation due to cloud is calculated as (Brussaard and Rogers 1990):

$A_c = \alpha c * h^c / \sin(q)$ dB

h_c = vertical extent of cloud (2.0 km for cumulus cloud)

In addition, the specific attenuation is obtained using Rayleigh approximation as:

$$\alpha_c = 0.4343 * \frac{3\pi \; \mathrm{Im}E}{32} C_w \qquad \mathrm{dB/km}$$

λ = wavelength

$\mathrm{Im}E = \text{imaginary } \frac{1-\epsilon}{2+\epsilon}$

ϵ = Complex dielectric constant of water;

C_w = cloud water content (assumed 0.6 g/m3);

4. Dust attenuation:

Generally, the cited literatures ignore the attenuation due to dust storms where dry permittivity of dust particles is assumed. On the other hand, using soil permittivity to quantify the permittivity of moist suspended dust particles will overestimate the predicted attenuation. It can be shown that airborne dust particles adsorb moisture from the air according to the adsorption polarization theory (Gregg and Sing 1982), which results in an increase in the permittivity of dust particles with an increase in humidity. Using this theory, it was shown that the specific attenuation α_d due to humid dust storms increases exponentially with increasing relative humidity (RH %) according to (Sultan 1990).

Vo = visibility during dust storm; Km

$\alpha_d = \{1.26(\xi f\,(V_o)^{-\gamma}\}\exp(0.22\,(RH\%)$; $40\% < RH\% < 90\%$

$\xi = 10^{-6}$ at Riyadh (kg/m³) km

$\gamma = 1$;

From practical observation, It can be assumed that the visibility distance caused by airborne dust does not exceed 0.03 km for 0.1% of time. It is also assumed that in the worst case scenario, the relative humidity reaches 90% and the height of the storm is typically hd = 1km. The slant path attenuation due to dust is given by:

$Ad = \alpha d * h_d / \sin(\theta)$; dB

5. Prediction of Combined Attenuation and Total System Availability:

In the case of non-(GSO) satellite systems, a variable is introduced that represents the percentage of time the non-(GSO) satellite is visible over the earth station as a function of the elevation angle. For a given propagation impairment level, the percentage of time that a level is exceeded is found for each elevation angle. For rain, the ratio of this value relative to the attenuation at 0.01% of time of the year (p%) can be calculated using an empirical formula [ITU-R-618-5 (2003)]. However, in case of combined attenuation due to different sources of impairments, this formula is not valid. In this work, the combined attenuation is calculated for different percentages of time, and a mathematical model that represents the relation between the percentage of time and the attenuation for each angle of elevation is found. The model is employed to determine the percentage of time that a certain combined attenuation level is exceeded. For the calculation of the total system availability, the time variation of the elevation angle obtained previously is multiplied by the percentage of availability for a given propagation margin and for each elevation angle and by adding up the results.

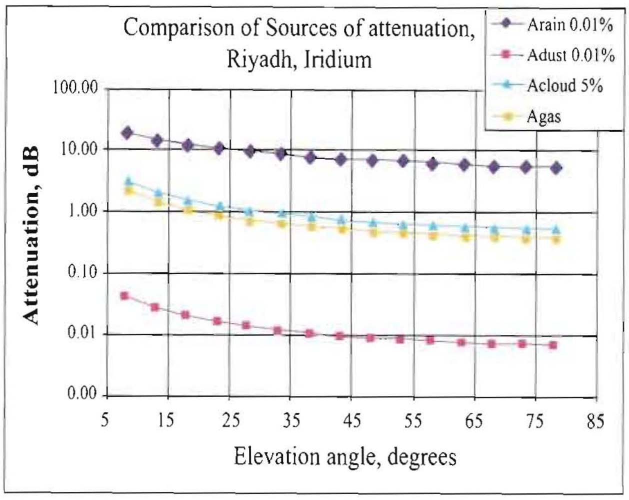
Discussion and Results

(I) Figure (2) shows a comparison of the values of attenuation due to atmospheric gases, dust, cloud and rain over Riyadh for an Iridium satellite as a function of the angle of elevation. It can be said that attenuation due to rain is the dominant source of propagation impairment in arid climate (about 78% at 8o elevation and p=0.01%), while the effect of dust contributes the minimum (less than 0.2%). However, the sum of all other sources other than rain cannot be neglected (about 32%).

(II) Figure (3) shows the values of the combined attenuation due to atmospheric gases, dust, cloud and rain at Riyadh for the Iridium satellite as a function of the angle of elevation, and for different (p%).

Since the rain is the dominant source of attenuation, it is reflected in the behaviour of the variation of combined attenuation for p% range from 0.01% to 1%.

(III) Figure (4) shows the system availability of the non-(GSO) satellite (Iridium) over Riyadh due to the combined effects of atmospheric gases, dust, cloud and rain. It is assumed that the correlation between those sources is one, i.e. worst-case. On the same plot, the system availability due to rain only is shown for comparison.



Legend: Arain 0.01: attenuation due to rain at 0.01% of time.

Fig. (2). Comparison of different sources of propagation impairments at the shown percentage of time.

Conclusion

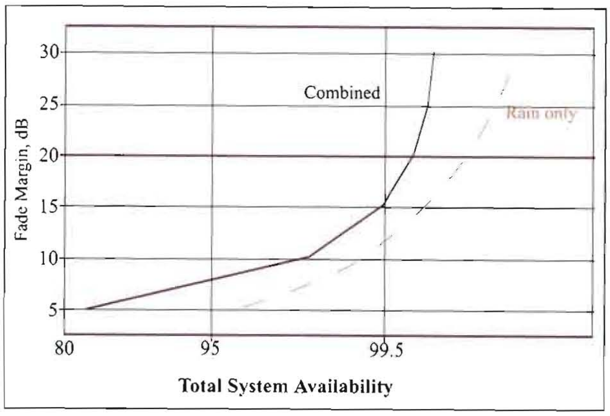


Fig. (4) Total system availability duer to combined impairments for Iridium over Riyadh.

It is found that attenuation due to rain is the dominant source of propagation impairment in an arid climate (about 78% at 8° elevation and p=0.01%), while the effect of dust contributes the minimum (less than 0.2%). However, the contribution of the sum of all other sources other than rain cannot be neglected (about 32%).

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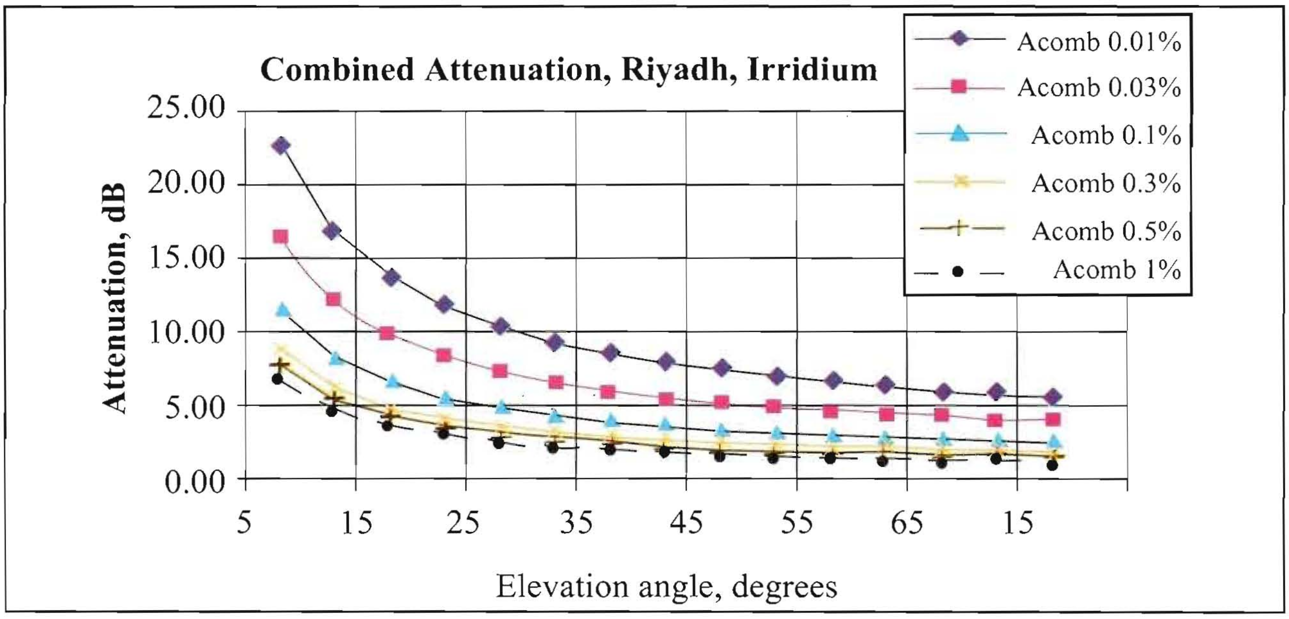

Legend: Acomb0.01: combined attenuation due to rain at 0.01% of time.

Fig. (3). Combined attenuation as a function of elevation angle and shown percentage of time.

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