KA-BAND FEEDER LINK
FOR A MOBILE LOW EARTH ORBIT SATELLITE SYSTEM

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INTRODUCTION

In this paper the effects of atmospheric impairments on the feeder link of a Low Earth Orbit (LEO) satellite system are studied. The study has been carried out in the framework of the European project COST 255 "Radiowave Propagation Modelling for New Satcom Services at Ku-Band and Above". The best statistical models identified during this activity are applied to a LEO system very similar to the first operational LEO communication system "IRIDIUM" with the aim of calculating impairment statistics. The propagation effects studied in the analysis comprise oxygen, water vapour, cloud and rain attenuation as well as scintillation.

SYSTEM DESCRIPTION

The test system is a LEO satellite system, the advantages of which are low necessary transmission power, small propagation delay and high spectral efficiency due to low orbit height. This allows the use of hand-held terminals. The system comprises a constellation of 66 satellites at an altitude of 780 km. The 66 satellites are equally distributed on 6 orbital planes each containing 11 satellites. The planes are inclined by 86° with respect to the equatorial plane. The system is designed to guarantee a minimum elevation angle of 8° above the horizon with at least one satellite visible to the user at any time. Each satellite generates a cluster of 48 cells on the earth surface formed by phased array L-band antennas. The studied feeder link operates in the frequency band from 29.1 to 29.3 GHz on the uplink and 19.4 to 19.6 GHz on the downlink. Modulation type is QPSK with a projected data rate of 12.5 Mbit/s on the feeder link. The BER objective is 10^{-6} for data transmission. The link is protected with a convolutional code of rate ½ and is projected to be available 99.8 % of the time. Fade mitigation techniques are used to improve the service availability: uplink power control with a dynamic range of about 25 dB, as well as downlink power control with a dynamic range of about 13 dB (in addition to 3.3 dB clear sky margin). For the study of the feeder link the site of the European gateway in Fucino (41° 58' North, 12° 35' East), Italy has been chosen.

APPROACH OF THE STUDY

Conventional propagation studies were mostly carried out to generate a Cumulative Distribution Function (CDF) of attenuation on a link between an Earth station and a geostationary satellite, which is characterised by a fixed elevation. Here, the considered system is made up with a LEO constellation, which leads to a varying elevation angle that has to be taken into account when establishing the CDF. This can be done with the introduction of the Elevation Probability Distribution Function (PDF) of the link.
A procedure to calculate long-term statistics of impairments has been detailed in the new ITU-R draft Rec. P 618-6 [1]. This procedure recommends to firstly determine the PDF of elevation angles of one satellite from a given Earth station and secondly to calculate the CDF of impairment corresponding to each elevation angle increment. Consecutively is calculated for each elevation angle the time percentage, that a certain impairment level is exceeded (product of the probability to have this elevation by the percentage of time this impairment is exceeded). Finally, the percentage values corresponding to all the elevation angle increments are summed up for a fixed impairment level. This method is used in the following to determine the CDF of impairment for the feeder link of the test system.

GENERATION OF ELEVATION TIME SERIES AND STATISTICS

As outlined in the previous section the PDF of elevation angle statistics is needed to generate realistic impairment statistics. For this purpose the SaCoS (Satellite Communication Simulator) developed at ComNets at Aachen University of Technology has been used. By simulating the orbital movement of the 66 satellites of the IRIDIUM system, elevation angle statistics as seen from the Fucino gateway station, have been generated. Different satellite selection strategies are implemented in the simulator. In this case it has been assumed that always the satellite with the highest elevation is connected to the gateway. The resulting PDF is illustrated in Fig. 1.

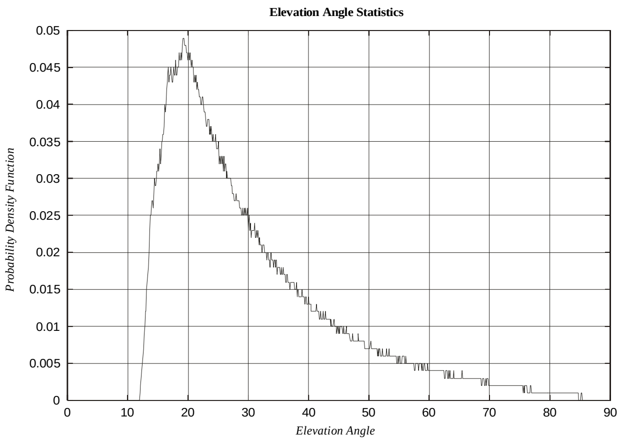

Fig. 1 Probability Density Function of elevation angles

SELECTION OF PROPAGATION MODELS

The studied propagation effects can be classified on the one hand in clear sky effects: oxygen, water vapour and cloud attenuation as well as scintillation, and on the other hand rain attenuation. The influence of depolarisation will not be studied in the following.

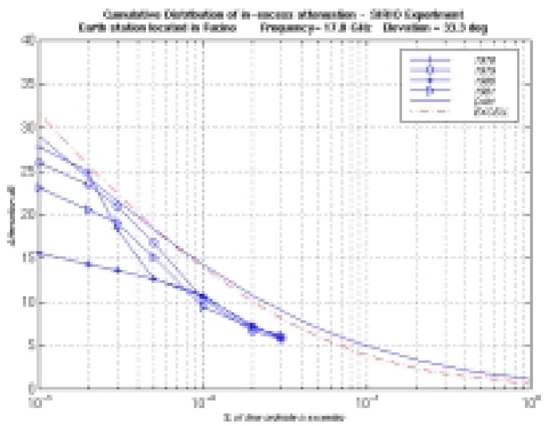

Fig. 2 Comparison prediction / measurements

Selecting the most appropriate propagation model is achieved through a comparison with measurements carried out during the SIRIO experiment in Fucino between 1978 and 1981. The SIRIO results considered here were produced from in-excess attenuation measurements of a 17.8 GHz beacon signal, realised with an Earth station (antenna diameter of 17 m) located in Fucino [2]. The large diameter of this Earth station allows to avoid to take into account for scintillation effects, so only rain attenuation prediction models can be tested. Four years of data are available (see Fig. 2). Among these four years, three CDFs exhibit a similar behaviour (1978, 1979 and 1981), whereas the 1980 CDF presents a particular one. However, this effect is encountered only for time percentages lower than 0.005 % of the time, which concerns rare strong events, and does not correspond to a possible availability target of the considered link.

CDFs of measured rain attenuation are then compared to results obtained with both DAH model (now ITU-R recommendation P 618-6) and EXCELL model [3], in which the CDF of rain rate is established with the Climpara model [4]. Although the measured CDF does not exceed time percentages higher than 0.04 % of the time, it can be inferred from Fig. 2 that the accuracy of both prediction models is relatively good. The model used for rain attenuation in the following will be the one adopted by ITU-R.

As far as clear sky effects are concerned the following propagation models have been chosen based on COST 255 results: for oxygen attenuation the Salonen model [5], for water vapour attenuation also the Salonen model [5], for cloud attenuation ITU-R Recommendation P 840-2 and for clear sky scintillation the Van de Kamp model [6].

SIMULATION RESULTS

Each calculation is performed using radiometeorological parameters (temperature, integrated water vapour content, integrated liquid water content, integrated liquid water content of heavy clouds, rain rate for 0.01 % of an average year) obtained for Fucino from Climpara maps [4]. Simulations are carried out for all possible elevation angles to derive the conditional CDF of impairments with the procedure described above. In addition, conditional CDFs are compared with CDFs obtained for the corresponding minimum, maximum and mean fixed elevation angles (cf. Fig. 3 and following).

Simulations have been carried out for the higher frequency of the uplink at 29.3 GHz and associated results are presented at Fig. 3 and Fig. 4.

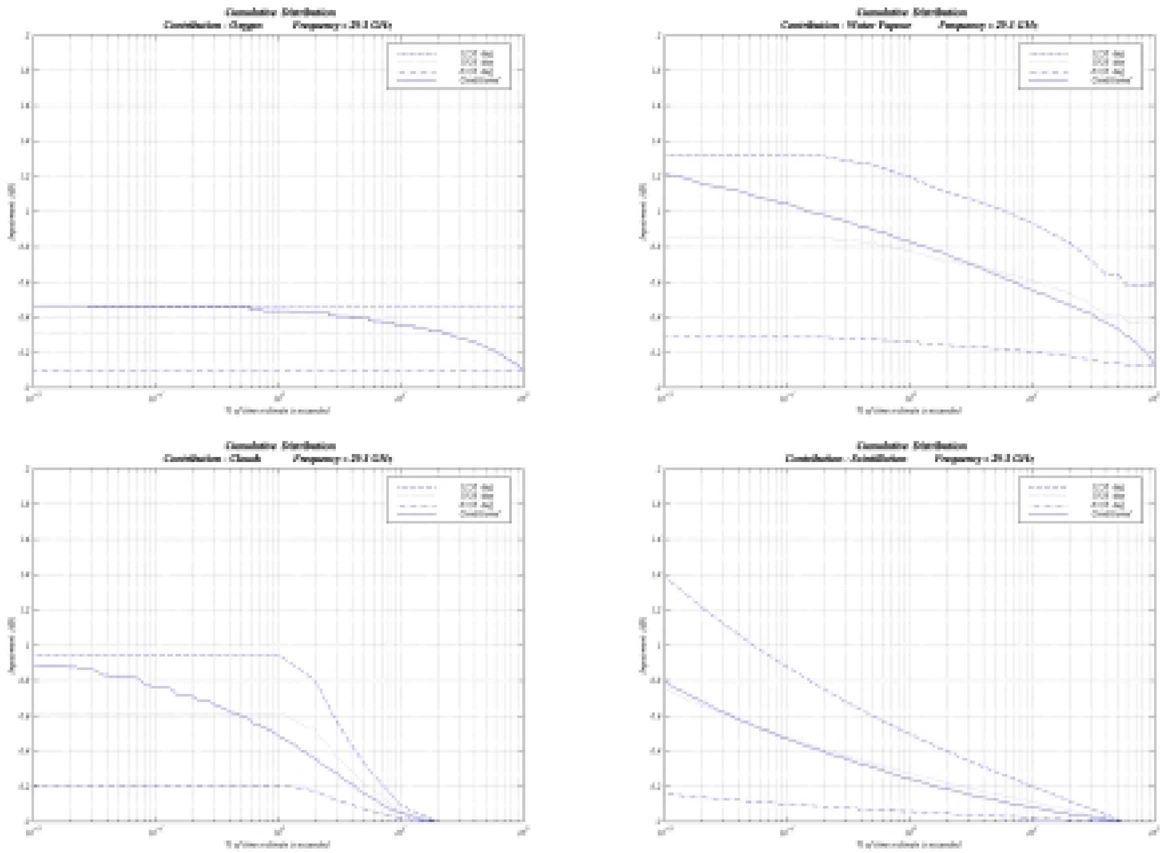

Fig. 3 Influence of clear sky effects on the uplink

From clear sky effect calculations given at Fig. 3 it can be inferred that for the availability target of 99.8 % of the time, the separate contributions to total impairment are 0.5 dB for oxygen, 1 dB for water vapour, 0.7 dB for clouds and 0.4 dB for scintillation, which leads to a global impairment in clear sky conditions of 2.6 dB.

When submitted to rain, attenuation on the uplink can reach 10 dB for 99.8 % of the time (see Fig. 4, left). It is worth noting that this rain attenuation is significantly less than the designed dynamic range for Up-Link Power Control (16 dB). Regarding combination of effects in Fig. 4, right, it appears that total attenuation exceeded for 99.8 % of the time is not higher than 11 dB for the gateway located in Fucino. Therefore the dynamic range of the system margin allows the system to compensate up to 29.3 dB (26 dB from ULPC and 3.3 dB from clear sky margin) on the uplink and leads to improve the system availability on the uplink to a value better than 99.99 % (< 0.01 % outage).

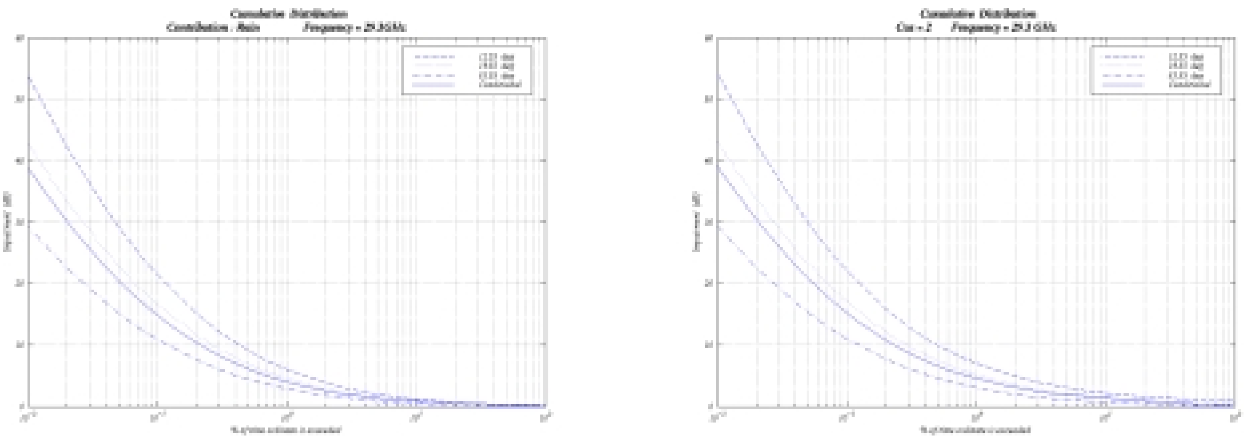

Fig. 4 Influence of rain attenuation on the uplink (left) and combination of effects for the uplink (right)

For the downlink simulations have also been carried out for the higher frequency at 19.6 GHz. It is found that for the availability target of 99.8 % of the time, the separate contributions to total impairment are 0.3 dB for oxygen, 1.2 dB for water vapour, 0.35 dB for clouds and 0.35 dB for scintillation, which leads to a global impairment in clear sky conditions of 2.2 dB. When submitted to rain, attenuation on the downlink can reach 4 dB for 99.8 % of the time. It is worth noting that this rain attenuation is significantly less than the designed dynamic range due to the ability to increase satellite EIRP in rain conditions (from 15.1 dBW to 28.1 dBW).

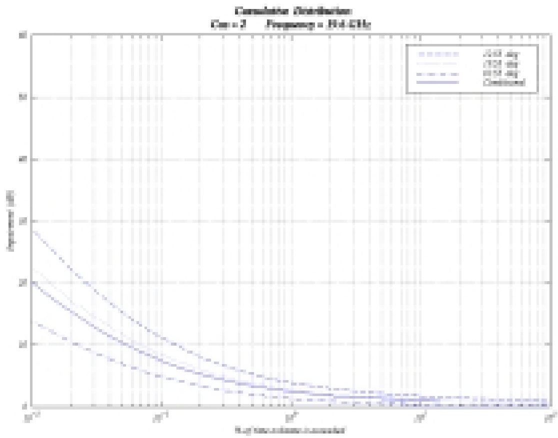

Fig. 5 Combination of effects for the downlink

Regarding combination of effects on the downlink in Fig. 5, it appears that total attenuation exceeded for 99.8 % of the time is not higher than 5 dB for the Earth station located in Fucino. Therefore the dynamic range of EIRP adjustment added to the clear sky margin allows the system to compensate up to 16.3 dB (13 dB for DLPC and 3.3 dB for clear sky margin) on the downlink and could lead to improve the system availability on the downlink to a value better than 99.98 % (< 0.02 % outage).

CONCLUSION

Availability due to propagation conditions has been evaluated for a LEO feeder link using best conventional models tested by COST 255 and checked (for rain attenuation) with SIRIO 18 GHz beacon data collected in Fucino.
Conditional CDFs of total impairments have been established for both up and downlinks. It has been inferred from this analysis that the considered feeder link should comply with the availability target of 99.8 % for both links, taking into account a clear sky static margin of 3.3 dB (for each link) and a dynamic margin due to the use of Fade Mitigation Techniques (26 dB for Up Link Power Control and 13 dB for Down Link Power Control). More precisely, assuming a perfect FMT control loop behaviour, the whole margins implemented in the system should allow to reach availability values better than 99.99 % for the uplink and better than 99.98 % for the downlink.
Eventually, it appears that the considered feeder link simulated in this analysis is rather over-designed for an availability target of 99.8 % and for a gateway located in Fucino. But it has to be taken into account that other gateways around the globe may be situated in regions with less favourable climatic conditions. Besides, the practical availability supplied by the system will be essentially conditioned by the performance of the link established with the mobile.

REFERENCES

[1] ITU-R, “Propagation data and prediction methods required for Earth-Space telecommunications systems”, *CCIR Rec., Propagation in non-ionised media*, RPN serie, Rec. 618-6, Geneva 1994.

[2] COST 205, “Prediction of rain attenuation statistics from point rainfall intensity data”, *Alta Frequenza*, vol. LIV, nº 3, 1985.

[3] C. Capsoni, F. Fedi, C. Magistroni, A. Paraboni, “Data and theory for a new model of the horizontal structure of rain cells for propagation applications”, *Radio Science*, Vol. 22, n 3, 1987.

[4] P. Poiares-Baptista, E. Salonen, “Review of rainfall rate modelling and mapping”, *Climpara’98*, Ottawa, Canada, 1998.

[5] E. Salonen, S. Karhu, P. Jokela, W. Zhang, S. Uppala, H. Aulamo, S. Sarkkula, P. Poiares Baptista, “Modelling and calculation of atmospheric attenuation for low-fade-margin satellite communications”, *ESA Journal*, vol. 16, n° 3, 1992.

[6] M. Van de Kamp, J. Tervonen, E. Salonen, P. Poiares Baptista, “Improved models for long-term prediction of tropospheric scintillation on slant paths”, *IEEE Transactions on antennas and propagation*, vol. 47 nº 2, February 1999.