ENERGY EFFICIENT BROADBAND SATELLITE COMMUNICATION SYSTEMS DESIGN AT FREQUENCIES ABOVE 10 GHZ

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Abstract

Tropospheric attenuation is the dominant fading mechanism for modern broadband satellite communication systems operating at high frequency bands (above 10GHz). A very significant aspect of the effective design of such systems is the minimization of the consumed energy leading to Green Satellite Communications. In this contribution we discuss how Fade Mitigation Techniques (FMTs) can be used both to counteract the tropospheric attenuation and to minimize the consumed power, satisfying the required Quality of Service (QoS). 3year rainfall rate experimental data, used for the generation of channel dynamics are derived from two raingauges placed at Athens. FMTs design is based on the aforementioned statistics. Furthermore we examine a simulated pico-scale diversity scheme and we present statistics of the dynamic diversity gain for various satellite link characteristics.

1. INTRODUCTION

In modern satellite communication systems, the reliable design is constrained by the radio propagation effects, the interference and the noise that are inherently present in all radio systems [1], [2]. New and rate demanding broadband satellite application have been evolved and have led to the employment of higher frequency bands. The current satellite communications use GEO satellites for fixed satellite services and usually employ Ku (12/14GHz) and Ka (20/30GHz) bands. These frequency bands are used either for direct-to-user (DTU) applications, for broadcasting satellite applications, or for feeder links and satellite backhaul networks. Next-generation low Earth orbit (LEO) satellite systems will also operate at higher frequencies, i.e., Ka-band due to high available bandwidth and the congestion of conventional frequency bands, such as X-band and Ku-band. These frequency bands for NGEO satellites may be used either for Earth-observation links or telecommunication links. However, there are numerous activities mostly from European Space Agency for the exploitation of Q/V (33-50GHz) and W (75-110GHz) bands. Q/V band is proposed either for feeder links or for direct-to-user applications, while W band is studied for feeder links and backhauling applications. Satellite communication systems in these high frequency bands are severely affected by atmospheric phenomena and especially rain. A very significant aspect of the design of broadband satellite systems is the compensation of atmospheric phenomena minimizing at the same time the power consumption leading to "Green Satellite Communications".

The fade margin namely the system gain that ensures the specified Quality of Service (QoS) of the satellite link must be much greater in order to compensate the transmission and propagation impairments for satellite communications operating at frequencies much more 10GHz. The larger fade margins are not feasible of technical and economic reasons. The cost of the ground station would increase dramatically and significantly also increase the power consumption.

In order to satisfy the QoS requirements and with a view to exploit higher millimetre wave frequencies, a small fraction of time is significant for system design. Due to the fact that total attenuation induced into the system can take high values for this small fraction of time, the application of a high fixed power margin to deal with total attenuation (especially rain attenuation) does not give the optimum and efficient engineering solution as this extra power will remain unexploited for the greatest time percentage of the year. Consequently, Fade Mitigation Techniques (FMTs) are proposed in order to protect the system from atmospheric attenuation and to operate at smaller fade margins (higher energy efficiency). The FMTs used are categorized into the following three major classifications: i) Power Control Techniques, ii) Link adaptation techniques (Adaptive Coding and Modulation-ACM and Data Rate Reduction) and iii) Diversity techniques (Site, orbital, time and frequency).

In this contribution, we present how to design energy efficient FMTs. Then in Section III rainfall data for 3 years as measured by two tipping buckets placed at the National Technical University of Athens, NTUA Zografou campus (37.98ºN, 23.79ºE) with separation distance 387m are used for the generation of channel dynamics. More specifically the data are transformed into rainfall rate time series and then used as inputs in the synthetic storm technique (SST) [3] and they transformed into rain attenuation time series. In this paper the results for two hypothetical links at Ka (20GHz) and Q (40 GHz) bands located in Athens (GR) are exhibited.

Furthermore, we investigate the dynamic properties in pico-scale site diversity, for different frequencies and elevation angles and we present statistics of the dynamic diversity gain.

2. ENERGY EFFICIENT FMTS

Satellite channel dynamics are of prominent importance for the efficient design of high frequency satellite links. In this section the exploitation of channel dynamics and the dynamic fade margin for advanced FMTs are used with a view to achieving green satellite communication systems will be pinpointed. Satellite channel dynamics is the considered the value of the induced tropospheric attenuation.

Power Control Techniques: In a power control system the transmitted power is defined according to the current state of propagation impairments and especially the rain attenuation value. For example, while the attenuation induced by rain increases above a certain threshold (margin) then the transmitted power will also increase to compensate the rain attenuation impairments. In Figure 1 a snapshot of rain attenuation with various threshold values are presented. Therefore, in order to design energy efficient systems and to minimize the outage probability, these power thresholds must be accurately selected for the high frequency links. Moreover for the time that rain attenuation is above the various power thresholds the channel dynamics are real crucial. These statistics among others, give information in order to define the time needed to use a certain power to compensate rain attenuation or the time needed to change to a higher or lower transmitted power in order to keep the system available.

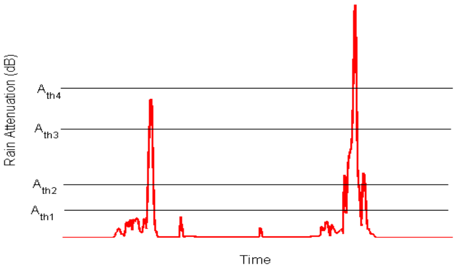


Figure 1. Rain attenuation events

Link adaptation techniques: The design of these techniques is very similar with the one is followed for the power control systems. The optimum rain attenuation thresholds for changing the various ACM and DRR schemes must be accurately defined. Moreover, channel dynamics must be exploited so as the time that the satellite link will remain in each ACM and DRR scheme and the time required to move from one scheme to the other is estimated. Consequently the maximization of the spectral efficiency and the minimization of the outage is achieved which turns on the reduction of consumed power.

Diversity techniques: First of all there is the time diversity technique which can be applied for delay tolerant services. In these technique data are transmitted when the fading is not strong. Therefor channel dynamics are needed to define among others the retransmit time, i.e. the time interval between the first try to transmit the data where there was high rain attenuation until the time that the data will finally transmitted, the attenuation threshold etc. The optimum estimation of such metrics can be proved really important for the energy efficiency.

Secondly, site diversity technique even in small distances can be applied. In this scheme more than one ground stations used to compensate the rain attenuation. The signal is received via different stations where it is likely each station faces different impairments. Channel dynamics are used for the diversity system so as the dynamic diversity gain is accurately estimated. As bigger as the diversity gain is so less power will be consumed.

Moreover, frequency diversity can be used. During the normal conditions high frequencies will be used while lower frequencies are preferred when rain attenuation exceeds certain thresholds.

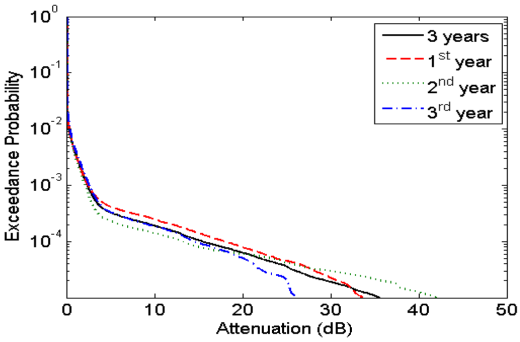
Furthermore Orbital diversity is used to compensate the induced rain attenuation in accordance with the reduction of consumed power. Different satellites with different elevation angles are used for the same station. For the effective and reliable design of these systems channel dynamics must be computed so as the diversity gain is estimated.

3. NUMERICAL RESULTS

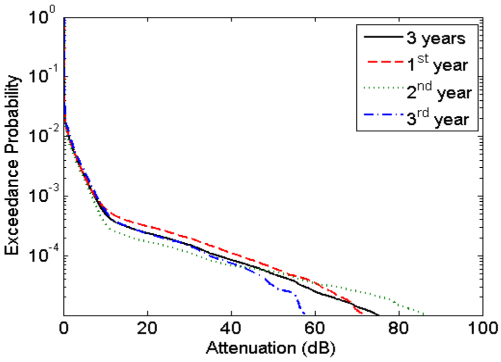
In this section the numerical results for hypothetical links at 20 GHz and 40 GHz are presented. The data used are derived from two rainfall rate measuring devices.

These devices are placed inside NTUA Zografou campus with 387 m separation distance. The resolution of rain gauges (tipping buckets) is 0.2 mm per tip. From rain gauge the rain fall amount per tip is measured and according to the methodology presented in [3] the rainfall rate series in mm/h with integration time of 1 min are calculated. Then Synthetic Storm Technique is used for the estimation of attenuation time series. This method takes into account the elevation angle of the link the frequency and the storm speed among others. Regarding the coefficients of specific rain attenuation and the rain height we have used the ITU-R P.838-3 and ITU-R P. 839-4 respectively. The average storm speed is assumed 14.25 m/s as derived from meteorological data in Athens, Greece. The availability of the rainfall rate data in both rain gauges is 100%.

In the following figures the Complementary Cumulative Distribution Function (CCDF) of rain attenuation, derived from the simulated rain attenuation time series from the first device at the operating frequencies are presented. The height of ground station is 0.21 km while the elevation angle is 46 deg. These statistics are proved extremely important for the calculation of the dynamic fade margin of a station. Moreover it can be easily observed the rain attenuation is extremely dependent of the operation frequency.



(a)



(b)

Figure 2. CCDF rain attenuation: (a) 20 GHz, (b) 40 GHz

Now using the data for both rain gauges which have 387 m separation distance the CCDF of dynamic diversity gain will be computed. Dynamic diversity gain is given [4]:

$$G_D(t) = A_{ref}(t) - A_{joint}(t) \tag{1}$$

This expression defines diversity gain on temporal domain where A_{ref} is the rain attenuation induced in a single satellite slant path used as reference while A_{joint} is:

$$A_{joint}(t) = \min(A_1(t), \ldots A_N(t)) \tag{2}$$

where A_i with i=1,…N is the induced rain attenuation in each link used in the diversity scenario. The reception scheme is considered as a selection combining scheme [1]. In Figure 3 the CCDF of dynamic diversity gain for the two operating frequencies is presented. It can be pinpointed that even in such small separation distance there is significant diversity gain. Moreover the dynamic diversity gain dependency on frequency is made explicit

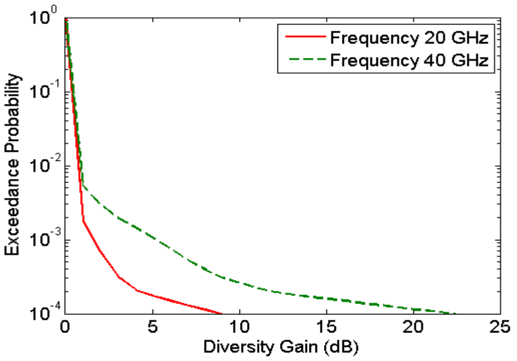


Figure 3. CCDF of dynamic diversity gain for two operating frequencies at 20 and 40 respectively

In Figure 4 the CCDF of dynamic diversity gain for two elevation angles 46deg and 35deg is presented. Frequency is assumed to be 20 GHz. It can be pinpointed that dynamic diversity gain is higher for lower elevation angles.

From Figures 3 and 4 it can be easily observed that the reduction of consumed power can be achieved using effective diversity techniques.

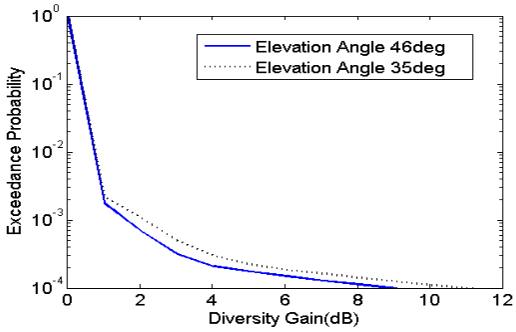


Figure 4. CCDF of dynamic diversity gain for two elevation angles 46deg and 35deg and operating frequency at 20 GHz

7. CONCLUSION

In this contribution we exploit statistical propagation models and simulated total attenuation data for the design of energy efficient FMTs in modern broadband satellite communication systems. FMTs are proposed in order to protect the system from atmospheric attenuation and reduce the power consumption

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