USE OF FADE MITIGATION TECHNIQUES FOR BROADCASTING AND NEWS GATHERING SATELLITE APPLICATIONS IN KA BAND

Frédéric Cornet, Caroline Bazile and Alban Duverdier
Centre National d'Etudes Spatiales
18, avenue Edouard Belin – 31401 TOULOUSE Cedex 4
Tel: (+33)561283369 – Mail: Frederic.Cornet@cnes.fr

ABSTRACT: In the design of future broadcasting and news gathering applications in Ka Band satellite communication systems, propagation impairments have an important impact. Their consideration with a traditional approach leads to high fixed link budget margins. It is nevertheless possible to adapt the system depending on attenuation fluctuations, especially for uplink. Among these techniques, the paper presents first the use of spatial diversity for gateways design applied to a broadcasting uplink. The case of a news gathering uplink is then considered and the use of a modulation/coding schemes switch is proposed with a new evaluation approach of the resulting system availability.

INTRODUCTION

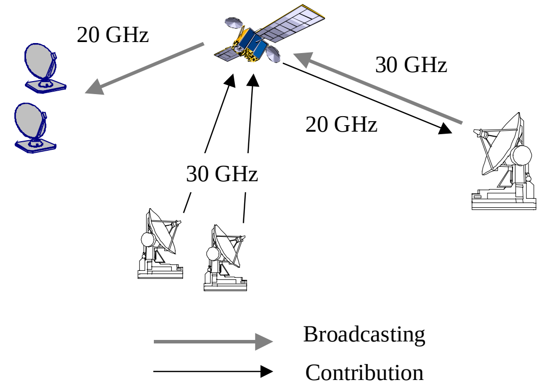
With the increasing demand on high data rates for satellite telecommunications systems, the use of Ka band is now commonly foreseen with a 30GHz uplink and a 20GHz downlink. It is especially the case for broadcasting and news gathering applications in a near future.

As the use of Ka band frequencies implies very high propagation impairments, traditional approaches that consider fixed margins to design systems are not possible any more. It is then more interesting to adapt the system depending on attenuation fluctuations, especially for uplink. We will use the term Fade Mitigation Techniques (FMT) to designate these adaptation methods. The aim of the paper is to present such techniques in the context of broadcasting and news gathering uplink and to evaluate their performances.

The first part of the paper presents the broadcasting/news gathering system architecture and defines the main parameters that evaluate the system performances. Then, we present a technique adapted to broadcasting, spatial diversity for gateways design. In the third part, we consider a news gathering link using a modulation/coding schemes switch and we introduce a new evaluation approach of the resulting system availability.

I. SYSTEM ARCHITECTURE AND MAIN PARAMETERS

In this paper, a typical broadcasting and news gathering system is considered, where news gathering is used to collect contributions.

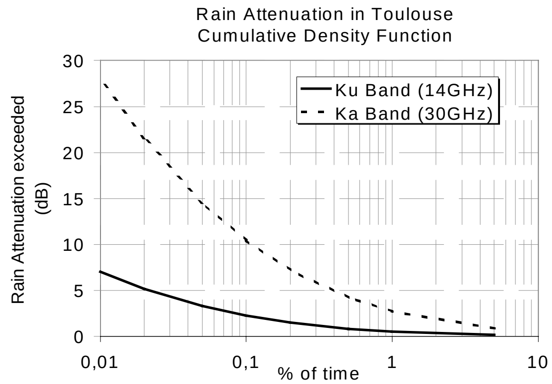


It is constituted by one gateway and terminals. Most of the terminals are receive-only user terminals whereas the others are dedicated to contribution applications. Both contribution and broadcasting links are considered in Ka band, i.e. 30GHz on the uplink and 20GHz on the downlink.

In such a system, Quasi-Error Free (QEF) transmissions are usually considered. It is realized on a given link for a required signal to noise ratio. Besides, the system quality is characterized by an availability depending on time and space. The percentage of time where the required signal to noise ratio is exceeded is called time availability. The percentage of the coverage where this time availability is granted is called spatial availability.

To ensure availability of the service, satellite communications systems designers have especially to consider the effects of atmospheric phenomena. In Ka-Band and higher frequencies, signal fades are principally due to atmospheric gases and rain. Water vapor and oxygen affect the radio-link permanently whereas rain occurs typically between 3% and 10% of time in temperate climate. So, system margins are defined to mitigate, first, the whole atmospheric gazes attenuation and, then, most of the rain attenuation.

Rain attenuation increases significantly with frequencies, especially for uplink transmissions. This effect is illustrated by the following figure that presents the cumulative density function of rain attenuation in Toulouse in Ku (14GHz) and Ka (30GHz) bands computed with the ITU-R P.618-7 models [1].

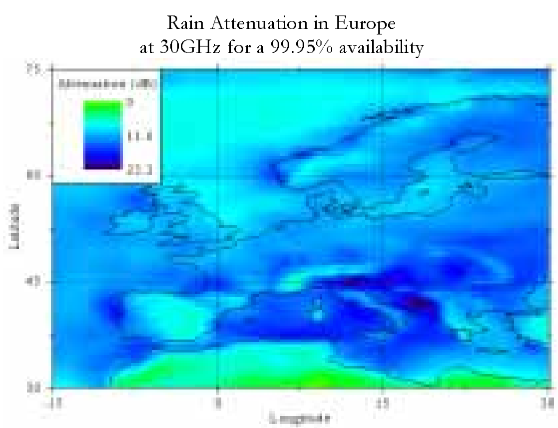


We can see that, for a 7dB margin, the availability reduces from 99.99% in Ku band to 99.79% in Ka band. In an other way, the 99.99% availability requires a margin of 7dB in Ku band and 28dB in Ka band. With a traditional approach, it would be necessary to use expensive gateways (very large antennas, large power transmitters and low noise receivers) for broadcasting and to reduce terminal bit rate for contribution.

In this paper, we will focus on alternative ways to mitigate rain attenuation on uplink transmissions based on the adaptation of this link regarding to attenuation fluctuations. Considering the previous results, the challenge is to design the broadcasting gateway-satellite link with an availability of 99.95% and the contribution terminal-satellite link with an availability of 99.9%.

II. BROADCASTING: SPATIAL DIVERSITY FOR GATEWAY DESIGN

To design a 99.95% availability link for broadcasting, we compute the rain attenuation exceeded during 0.05% of an average year. The map below presents the variation of this parameter at 30GHz in Europe using the ITU-R P.618-7 model [1]:



Rain attenuation can reach 23dB in Europe for this system configuration. It is then judicious to place the gateway where rain attenuation is the lowest possible. However, most of the time, systems designers have not this possibility. To be in a representative case, we assume that the gateway is based in Toulouse. Indeed, it corresponds to a rain attenuation of 14dB at 30GHz which is a typical value in Europe as shown on the map.

In this paper, we propose to use spatial diversity with two gateways to ensure a 99.95% system availability. To define the distance between the gateways, we use the ITU-R P.618-7 recommendation introducing diversity gain and diversity improvement factor.

The diversity gain is the difference in dB between the attenuation on a single-site link and a link with spatial diversity for the same time availability. It is obtained by the ITU-R model:

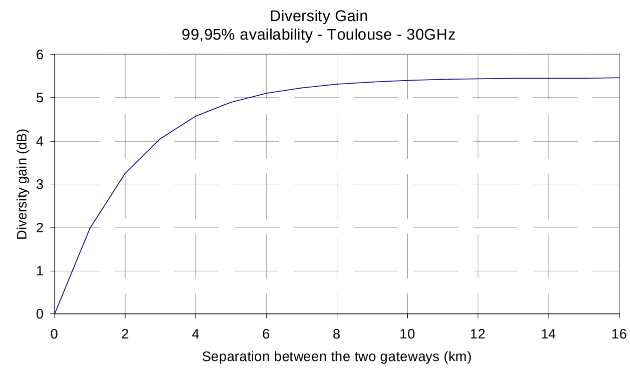
$$G = a\left(1-e^{-bd}\right)\left(1+0.006\theta\right)\left(1+0.002\psi\right)e^{-0.025f} \quad (1)$$

where

$$a = 0.78A - 1.94\left(1-e^{-0.11A}\right),\ b = 0.59\left(1-e^{-0.1A}\right)$$

with f frequency (GHz), θ elevation angle (°), d separation between the two sites (km), A attenuation for a single site (dB) and ψ angle (°) made by the azimuth of the link and the baseline between the two sites (ψ≤90°).

The figure below presents the diversity gain obtained for our study case for various separation distances:



Beyond 10km, the separation distance increase do not improve significantly the diversity gain. Indeed, a typical rain cell diameter is 10km, so rain attenuation correlation is very low for higher values of separation. A good choice of separation is 10km which is nearly the shortest distance corresponding to the maximum diversity gain.

Using this figure, the diversity gain obtained for two gateways distant of 10km is 5.4dB: in this case, the spatial diversity leads to only 9.1dB margins for each of the two gateways instead of 14.5dB for a single site.

The second ITU-R model consists in the computation of the diversity improvement factor. This factor is defined as the ratio of single-site unavailability (p_1) by diversity unavailability (p_2) and can be computed by:

$$I = \frac{p_1}{p_2} = 1 + \frac{10^{-2} d^{1.33}}{p_1} \Rightarrow d = \left(10^2 p_1 \frac{p_1 - p_2}{p_2}\right)^{\frac{1}{1.33}} \quad (2)$$

where d is the separation between the two gateways (in km).

Considering the same configuration as above, we can compute the lowest separation distance to ensure 99.95% of availability at 30GHz with a 9.1dB margin for each site. Using the ITU-R P. 618-7 rain attenuation model, the availability corresponding to a 9.1dB attenuation is equal to 99.87% of an average year. Then, with p_1=0.13% and p_2=0.05% in equation (2), we obtain a separation distance between two gateways of 9.8km that improves the availability from 99.87% to 99.95%.

To conclude, both approaches (diversity gain and diversity improvement factor) are in this case coherent in Ka Band and lead to the same conclusion: for a 99.95% availability link at 30GHz, the use of spatial diversity with 10km separation site distance leads to an improvement of 5.4dB with a remaining rain margin of 9.1dB.

III. CONTRIBUTION: WAVE FORM ADAPTATION FOR USER TERMINALS

To ensure an availability of 99.9% on the contribution link from terminal to satellite, rain margins must be around 10dB in Europe. A static dimensioning of the system would be very constraining on the link budget and synonymous of a low bit rate transmission.

In order to increase the average bit rate, we present here a possible adaptation of modulation and coding depending on meteorological conditions. First, the system is defined with a low margin privileging the efficiency of the modulation and coding scheme. Then, rain attenuations are mitigated by means of successive rate reductions. Notice that time response of FMT control loop and demodulation algorithms have not been considered.

A fixed access to the network is considered, in which each user has a constant available frequency bandwidth. The symbol rate is as a consequence fixed, and the useful bit rate depends on the scheme chosen. When we change the modulation/coding scheme, we have a double gain in the link budget. On the one hand, the the required E_b/N_0 is reduced. On the other hand, with a given C/N_0, the corresponding E_b/N_0 obtained will increase with the ratio of the data-rates. The total gain in dB can be written as follow:

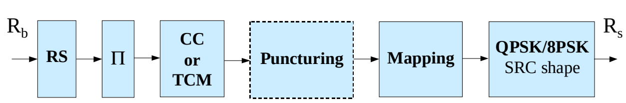
$$\Delta\left(\frac{E_b}{N_0}\right) = \Delta\left(\frac{E_b}{N_0}\right)_{required} + 10\log\left(\frac{R_{b1}}{R_{b2}}\right) \quad (3)$$

where R_{b1} and R_{b2} are the bit rates before and after switch.

III.1. Switch technique definition

The solution proposed in this paper switches between three modulation/coding schemes defined in the DVB-DSNG [2] standard: 8PSK5/6, QPSK5/6 and QPSK1/2. This standard is commonly used for contribution applications and offers a high diversity of modulation/coding schemes. A DVB-DSNG modem is indeed based on QPSK, 8PSK, and 16QAM modulations and on a concatenated coding scheme consisting of convolutional/pragmatic trellis-code modulation inner codes and Reed-Solomon (RS) outer code.

The DVB-DSNG solution is presented on the following figure:



We can note that the 16QAM schemes have not been chosen for our system, because of the important back-off (typically 3dB) necessary on the terminal amplifier that makes the link budget difficult to ensure.

The required Eb/N_0 for QEF transmission and spectral efficiencies of these three schemes are summarized in the following table:

	$(Eb/N_0)_r$	Rb/Rs
8PSK5/6	8.9dB	2.3
QPSK5/6	6.0dB	1.53
QPSK1/2	4.5dB	0.92

We can notice that the signal to noise ratio required for 8PSK5/6 is around 12dB. In a 4-colours reuse beam pattern, current Ka antenna isolation characteristics are not sufficient to reach such a ratio on all the antenna coverage.

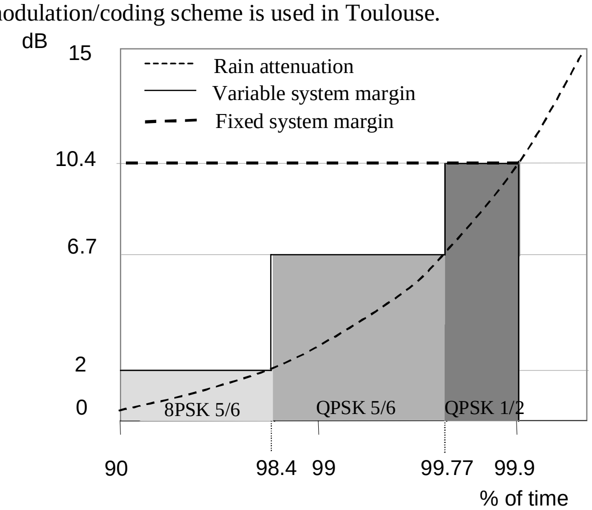
The values of required (Eb/N_0) are issued from the standard, and take into account implementation margins. From equation (3), we obtain the following gains:

Switch	$\Delta\left(\frac{E_b}{N_0}\right)$
8PSK5/6 → QPSK5/6	4.7dB
QPSK5/6 → QPSK1/2	3.7dB

The overall gain is then 8.4dB.

Let us choose a nominal margin of 2dB, comparable to those commonly used in Ku band. The corresponding modulation associated is 8PSK5/6. When the rain attenuation exceeds 2dB, a switch to QPSK5/6 is operated, the second switch happening when 6.7dB of rain attenuation is exceeded.

The following figure shows for which time percentage each modulation/coding scheme is used in Toulouse.



The spectral efficiency gain of this variable bit rate versus a fixed bit rate system appears clearly for the example of Toulouse:

Capacity gain factor	% time
2.5	98.4
1.67	1.37
1	0.13

For a given bandwidth allocated per user, the improvement of user average bit rate is significant and can be quantified by the following factor:

$$G_u = \frac{2.3*0.984 + 1.53*0.0137 + 0.92*0.0013}{0.92*0.999} = 2.486 \quad (4)$$

III.2 Space-time dilemma

Time availability has been computed above for a given location. This parameter fluctuates depending on geographical position. System designers need a complete view of the system availability which includes both temporal and spatial percentages. For a given margin, a trade-off has to be found between time availability and coverage. Such choices are presented hereafter introducing original time availability maps for a given margin deduced from ITU rain attenuation models.

The relationship between the rain attenuation A_{001} exceeded during 0.01% of time, the unavailability p and the corresponding value of rain attenuation A_p exceeded during p % of an average year is defined in ITU R P.618 7 recommendation by:

$$A_p = A_{001}\left(\frac{p}{0.01}\right)^{-\left(0.655+0.033\ln(p)-0.045\ln(A_{001})-\beta(1-p)\sin\theta\right)} \quad (5)$$

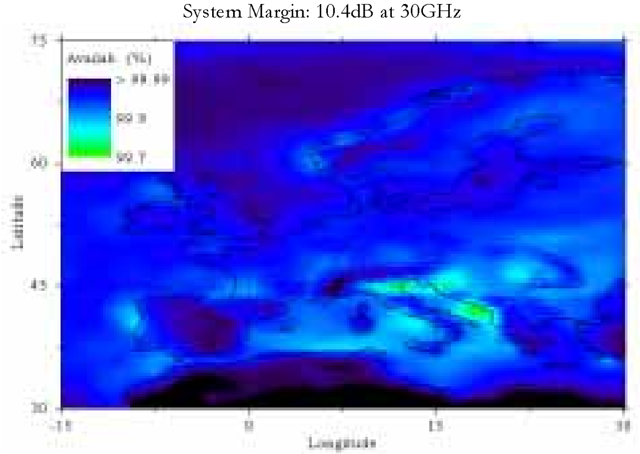
with

$$\begin{cases} \beta = 0 \quad if\ p \geq 1\%\ or\ |\varphi| \geq 36° \\ \beta = -0.005(|\varphi|-36) \quad if\ \ p < 1\%\ and\ |\varphi| < 36°\ and\ \theta \geq 25° \\ \beta = -0.005(|\varphi|-36)+1.8-4.25\sin\theta \end{cases}$$

and φ terminal latitude and θ elevation angle.

We can invert the formula above and compute the unavailability p corresponding to a system margin A_p with an iterative process. The availability map at 30GHz obtained for the 10.4dB margin is presented bellow.

Availability in Europe for a 13°E satellite
System Margin: 10.4dB at 30GHz

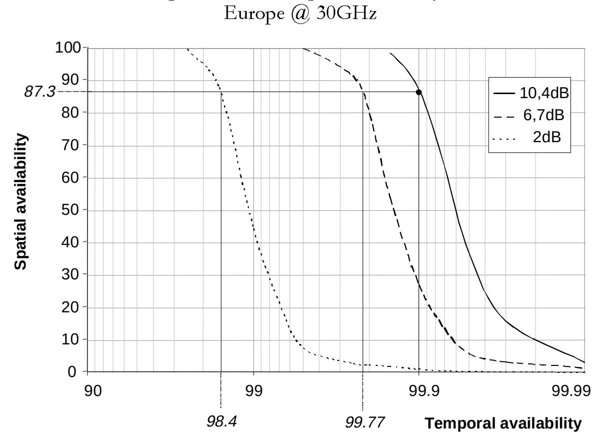


To be more representative, antenna gain and coverage should be taken into account in the availability computation.

The same maps for 2dB and 6.7dB margins would also visualize the time spent in the different switch modes.

We can extract from these maps the coverage percentage where a given time availability is ensured. Plotting this percentage, called spatial availability versus time availability shows the possible choices to quantify the system availability. The following figure presents these curves for 10.4, 6.7, and 2dB margins in Europe.

Spatial versus temporal availability
Europe @ 30GHz



System designers can first use the 10.4dB margin curve to choose the temporal availability and the spatial availability that define their system availability. Then, the two other curves give the percentages of time spent in each modulation/coding mode, for the terminal positions where the 99.9% availability is granted. For example, for Europe with 10.4dB margin, the 99.9% time availability can be granted on 87.3% of the map. The minimum time percentages spent in 8PSK5/6, QPSK5/6 and QPSK1/2 are respectively 98.4%, 1.37% and 0.13% of an average year in the considered area.

A mean time availability on the map can also be obtained by integrating the time availability over the spatial availability presented in the map above. The three values computed correspond to the spatial average of time percentages spent under each attenuation margin. They can be used to calculate an average spectral efficiency on the whole map, which takes into account both spatial and time variations.

$$\overline{R}_{b\,europe} = (0.9889*2.3+0.0094*1.53+0.0009*0.92)*R_s = 2.29*R_s \quad (6)$$

The same calculation for a fixed bit-rate system using QPSK1/2 gives an average bit rate of $0.919*R_s$.

CONCLUSION

The application of FMT to the case of broadcasting and news gathering system uplinks has been analyzed in the paper, and the performances improvements have been quantified.

For gateways design in broadcasting systems, it has been shown that spatial diversity can highly reduce the system margin: An improvement of 5.4dB has been obtained for a 99.95% availability link at 30GHz with two 10km distant gateways in a representative location in Europe.

For contribution uplink, a switch between three modulation/coding schemes defined in DVB-DSNG standard has been proposed. A 8.4 dB margin gain between 8PSK5/6 and QPSK1/2 is obtained. The resulting system performances have been analyzed with a new evaluation approach in terms of time/spatial availability, average spectral efficiency.

To compare the total capacity of the considered variable bit rate and fixed bit-rate systems, it is necessary to take into account the antenna coverage characteristics. Antenna coverage and gain should also be integrated in the computation of maps and spatial availability. Besides, switch durations haven't been treated in the paper but play a central role in the definition of FMT: the impact of time response of demodulation algorithms and detection/prediction of rain attenuation remains to be studied.

REFERENCES

[1] ITU-R P.618-7 (02/01) "Propagation data and prediction methods required for the design of Earth-space telecommunication systems"

[2] ETSI EN 301 210 v1.1.1 (03/01) "Digital Video Broadcasting (DVB); framing structure, channel coding and modulation for digital satellite news gathering (DSNG) and other contribution applications by satellite