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MISSION DATA DOWNLINK IN K/KA-BAND: SUMMARY RESULTS OF THE ATMOSPHERIC PROPAGATION EFFECTS IN THE DOWNLINK AVAILABILITY

For Future Programmes, EUMETSAT evaluated the relevant band allocations in 18.1 and 26.5 GHz (K and Ka-Band) to downlink the instrument data (because of the associated data volumes and rates). As these bands are recognised to be fade prone, it is naturally derived a need to secure the downlink from the satellites implying the provision of margins in the design of the system. As any system margin, this needs to be balanced with the resource implications that the implementation of the margin will imply. In telecommunication systems this led to look for alternatives to mitigate the fading effects. Fade mitigation techniques are described in the literature and have been evaluated in previous systems (e.g. by NASA and ESA) that have allowed ITU, for instance, deriving statistical models that are currently used by telecommunications operators when planning systems in these bands. However, these statistical models have been derived for average year and allow system planning for quality of service (QoS) in telecommunications systems also expressed in percentage of unavailability (errored seconds) over an average year.

In the case of the Meteorological satellites, the downlink from the instrument (s) contains data that have a temporal dimension (or even a repeat cycle concept), in the order of minutes, that needs to be taken into consideration when processing the data and that is subject to timeliness requirements when generating and making the different levels of processed products available to the user community. In this sense, there is a short term component in the data that it is not well covered by the long term (average year) statistical modelling done for telecommunication systems. In order to better understand the short term component of the fading in these bands, and the potential benefits of site diversity as a fading mitigation technique, EUMETSAT is currently performing a study for characterising the short term behaviour of a "mission data downlink" signal in this band. The study is using a beacon (19.3 GHz) provided by a telecommunications satellite but ITU models can be used for frequency scale the results. The study contains two reception sites so the improvement achieved by site diversity is also covered. The case example of MTG (@ Phase B1) is used to model the problem and derive results (e.g. data downlink yearly availability is stated to be 99.9% which corresponds to atmospheric attenuation margin of approx 6 dB @ 19.3 GHz).

This Working Paper summarizes the logic that has been followed in the study and its preliminary results, and it is aimed to inform CGMS members about the activities performed by EUMETSAT in the area of the CGMS WG-I on telecommunications techniques that could be of relevance for future systems using these frequency bands (18.1 and/or 26.5 GHz).

Mission data downlink in K/Ka-Band: Summary results of the atmospheric propagation effects in the downlink availability

1 INTRODUCTION

The increase in the number and demanding requirements for the future meteorological and climate related missions (in general this is also applicable to all Earth Observation missions) are driving the design of the corresponding instruments to data volumes and rates that are no compatible with the traditional bands used in previous programmes (L and X-Band) by CGMS members, at least for EUMETSAT.

As a response to this, EUMETSAT is evaluating the use of the relevant band allocations in 18 and 26.5 GHz (K and Ka-Band) to downlink the instrument data for Future Programmes. As these bands are recognised to be fade prone, it is naturally derived a need to secure the downlink from the satellites implying the provision of margins in the design of the system. As any system margin, this needs to be balanced with the resource implications that the implementation of the margin will imply. In telecommunication systems this led to look for alternatives to mitigate the fading effects. Fade mitigation techniques are described in the literature and have been evaluated in previous systems (e.g. by NASA and ESA) that have allowed ITU, for instance, deriving statistical models that are currently used by telecommunications operators when planning systems in these bands.

However, these statistical models have been derived for average year and allow system planning for quality of service (QoS) in telecommunications systems also expressed in percentage of unavailability (errored seconds) over an average year.

In the case of the Meteorological satellites, the downlink from the instrument(s) contains data that have a temporal dimension (or even a repeat cycle concept), in the order of minutes, that needs to be taken into consideration when processing the data and that is subject to timeliness requirements when generating and making the different levels of processed products available to the user community. In this sense, there is a short term component in the data that it is not well covered by the long term (average year) statistical modelling done for telecommunication systems.

In order to better understand the short term component of the fading in these bands, and the potential benefits of site diversity as a fading mitigation technique, EUMETSAT is currently performing a study for characterising the short term behaviour of a “mission data downlink” signal in this band. The study is using a fixed K-Band frequency available from a beacon provided by a telecommunications satellite, at 19.3 GHz, but ITU models can be used for frequency scaling the results. The study contains two reception sites so the improvement achieved by site diversity is also covered. The case example of MTG (@ Phase B1) is used to model the problem and derive results (e.g. data downlink yearly availability is stated to be 99.9% which corresponds to atmospheric attenuation margin of approx 6 dB @ 19.3 GHz).

This study, therefore, focuses on analyzing the characteristics of atmospheric propagation in frequencies similar to those in which future EUMETSAT Programmes will/might work, namely:

- The effects of the atmosphere regarding signal fading and degradation (attenuation and noise increase);
- The statistical behaviour (especially short term duration –in the order of seconds to minutes) of the fade dynamics in the link;
- The necessary margin for a given availability taking into account a repeat-cycle concept (in the order of minutes);
- Analyse the benefits of site diversity as a fade mitigation technique for a GEO satellite like MTG (this part of the study is of little relevance to LEO satellites –at least in the way it has been conceived).

Site diversity is a technique used for mitigating the effects of rain attenuation in bands that are particularly vulnerable to such impairments (e.g. 18.1 or 26.5 GHz bands) and is based on the reception of the desired signal from different stations, separated by some tens of Kms. Traditional approaches using site diversity predict which one of the two site diverse stations will be "available" and activate it for data reception for the corresponding period of time. In the specific case of this study, the concept of site diversity has been further refined and corresponds to the concurrent use of two site diverse stations that do receive the satellite signal continuously and provide the instrument data to the processing centre that performs a data consolidation function (filling the gaps and removing duplications based on the parallel copies coming from both stations) before being delivered to the L1 processors. This is expected to have the result of an improvement in terms of the completeness and short term availability of the consolidated data stream that shall be reflected in the end-to-end system availability for the different L1 (and therefore also L2) products. According to ITU, the gain improvement by duplicating the receivers asymptotically increases with distance, rain cells are considered to be uncorrelated after few Kms of distance, and the maximum distance to the stations is normally determined by the associated communications costs. For this study, one receiver has been deployed at EUMETSAT headquarters in Darmstadt, Germany (Site-1), and the second one has been collocated at the MSG Primary Ground Station at Usingen, Germany (Site-2). The baseline distance between both sites is around 50 km.

2 SYSTEM IMPLEMENTATION

For carrying out the test, an existing signal from a GEO communications satellite has been chosen. For the sake of deriving valid statistics with simple algorithms, this signal is a beacon (unmodulated carrier). The closest beacon found is coming from SIRIUS-4 satellite, located at located at 4.8°E and with a frequency of 19.3 GHz. Using the model detailed in ITU-R P.618-9, it is possible to scale the results from 19.3 GHz to, say, 18.1 or 26.5 GHz.

The deployed system consists of two identical receivers (one per site). Each receiver tracks the same beacon signal and samples beacon power levels and close-to-carrier noise power (thus deriving C/N_0 figures). Measurements are performed using a Spectrum Analyser controlled by a software routine in charge of automatically triggering the changes to spectrum analyser configuration, performing the measurements, collecting the results and storing the data in a PC. The receiver is provided with a noise source for calibrating the variations in the LNB gain and noise figure caused, mainly, by temperature variations. The systems are synchronized by

NTP allowing adequate time correlation and post processing of the samples taken by both systems. Based on the measurements provided by both sites, the diversity combination is computed as the maximum value (of C/N_0) between synchronised C/N_0 measurements (from both sites and for each sample).

3 MAIN RESULTS WITH AND WITHOUT SITE DIVERSITY

Measurements are being collected in Site-1 since October 2008. After completing system adjustments, the second receiver was deployed in Site-2 in February 2009 and since then both terminals are used to gather data.

As an example of the measurements performed by the system, Figure 1 shows the C/N_0 measured in Site-1 during the whole month of May 2009. As can be seen, there are rain episodes in which the attenuation reaches more than 20 dB below the average level. The same has been done for Site-2 and shown in Figure 2. In this case, the deepest attenuation is around 15 dB below the average level.

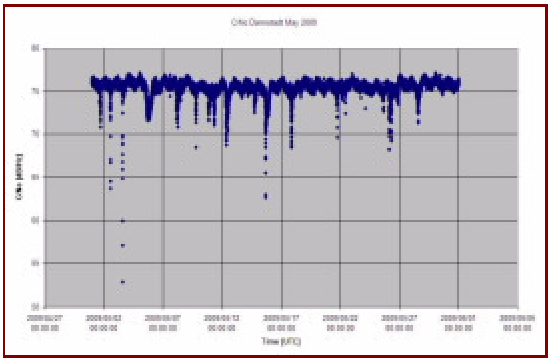

Figure 1 – C/N_0 measurements in Site-1 (time series May 2009)

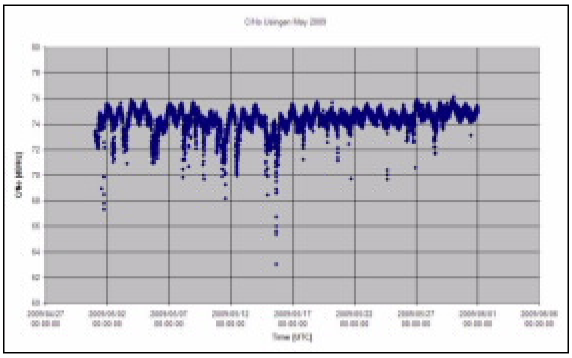

Figure 2 – C/N_0 measurements in Site-2 (time series May 2009)

After the diversity combination (Figure 3), there is a significant improvement in the C/N_0 of the consolidated signal and the gain in availability depends on the reference availability selected for the system (i.e. theoretical rain margin) and on the rain conditions of each site during the observation period (i.e. actual C/N_0 degradation in the period).

In the specific case of the study, the assumption is that a 6 dB margin is allocated for rain, (i.e. 99.9% @19.3 GHz for these two sites in Germany following ITU-R P.618-9). During the particular case of May 2009, the signal received in Site-1 had a measured availability of around 99.84% (99.88% for the Site-2 system). This means that in May none of the sites reached a timely availability at the required value (99.9%). With diversity however, the measured availability reaches 99.98%.

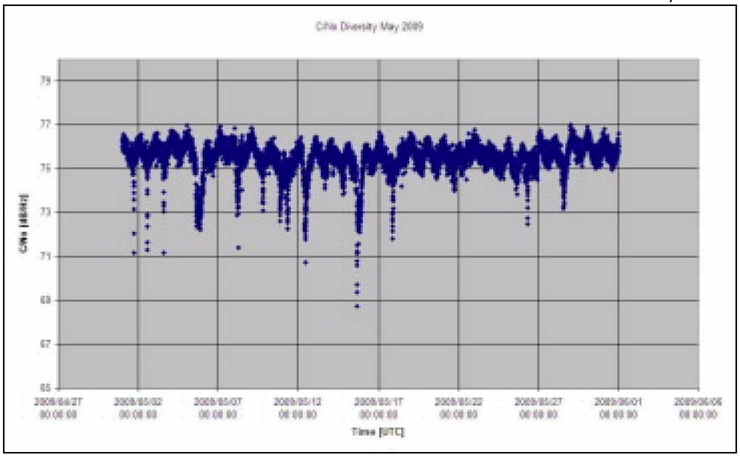

Figure 3 – Site diversity C/N$_0$ after combination (time series May 2009)

Nevertheless, it is necessary to emphasize that, in the cases in which rain cells are large enough to simultaneously affect both sites (and this may happen as seen in May 2009 measurements), site diversity is not able to completely resolve the reception problem and therefore is not achieving 100% availability. Such cases, although rarely observed in the duration of the study, do occur. This is illustrated in Figure 4, in which the total duration and total number of fade events below the 6 dB margin, after the site diversity combination function, are shown for all the existing repeat cycle slots (10 minutes) for May 2009. In this case, even if most of the events present individually at each site were solved by site diversity (see correlated fade events below 6 dB from the average level in Figure 1 and Figure 2), there are some events that were correlated in time in both sites and thus unable to be solved by the consolidation function. The most interesting study case is the one determining the number of “lost” repeat cycles (i.e. C/N$_0$ below the link budget margin -6 dB in our study case) with and without site diversity and the consolidation function. Again, the case of May 2009 is very illustrative, as it includes all the possible combinations of reception results at both sites:

- Site-1 with low availability but Site-2 with high availability, thus high availability after diversity combination.
- Site-1 and Site-2 with low availability but showing fade events to be uncorrelated, thus high availability after diversity combination.
- Site-1 and Site-2 with low availability and with fade events correlated (occurring simultaneously), thus low availability after diversity combination. Nevertheless, in this case, a slight improvement is achieved.

Figure 5 shows the daily availability (as amount of time of the day in which the signal level is above the margin, 6 dB in this case), with all the above identified cases clearly depicted in red: 3, 9 and 15, respectively.

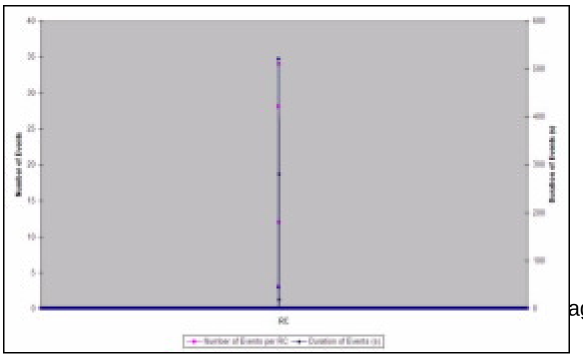

Figure 4 – Repeat Cycle-based number and duration of fade events greater than 6 dB in the site diversity case for May 2009.

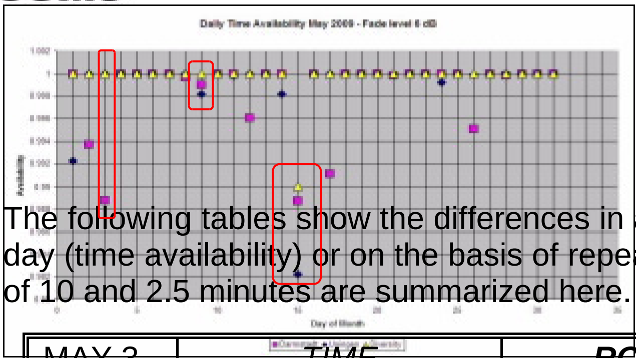

Figure 5 - Daily Time Availability for the two sites and 3 configurations for May 2009

The following tables show the differences in availability, when computed for the whole day (time availability) or on the basis of repeat cycles. For convenience, repeat cycles of 10 and 2.5 minutes are summarized here.

MAY 3	*TIME AVAILABILITY*	***RC 10 MIN***		***RC 2.5 MIN***	
		Availability	*# RC lost*	*Availability*	*# RC lost*
Site-1	**99.8791 %**	**97.9167%**	**3**	**98.2639 %**	**10**
Site-2	100%	100%	0	100%	0
Diversity	**100%**	**100%**	**0**	**100%**	**0**

Table 1 – Daily and RC availability for the study case of May 3, 2009

In the first case (Table 1), site diversity is capable of achieving 100% availability due to the fact that one of the sites is completely available, despite the other one is not. Depending on the duration of the repeat cycles, between 3 and 10 would be lost if no site diversity would have been implemented.

MAY 9	*TIME AVAILABILITY*	***RC 10 MIN***		***RC 2.5 MIN***	
		Availability	*# RC lost*	*Availability*	*# RC lost*
Site-1	**99.8996 %**	**98.6111%**	**2**	**99.4792%**	**3**
Site-2	**99.8146%**	**99.3056%**	**1**	**99.4792%**	**3**
Diversity	**100%**	**100%**	**0**	**100%**	**0**

Table 2 – Daily and RC availability for the study case of May 9, 2009

In the second case (Table 2), site diversity is capable of achieving 100% availability due to the fact fading events were uncorrelated in both receivers, even if both of them were below full availability. Depending on the duration of the repeat cycles and the location of the reception antenna, during this day between 1 and 3 repeat cycles would be lost if no site diversity would have been implemented.

MAY 15	*TIME AVAILABILITY*	***RC 10 MIN***		***RC 2.5 MIN***	
		Availability	*# RC lost*	*Availability*	*# RC lost*
Site-1	**98.8739 %**	**97.2222%**	**4**	**97.9167%**	**12**
Site-2	**98.2201 %**	**95.8333%**	**6**	**97.0486%**	**17**
Diversity	**99.0026 %**	**97.2222%**	**4**	**98.0903%**	**11**

Table 3 – Daily and RC availability for the study case of May 15, 2009

In the third case (Table 3), site diversity is not capable of achieving 100% availability, as the fading events were correlated in both receivers. Nevertheless, it is possible to increase the availability with regards to the standalone configurations. Regarding the number of lost repeat cycles, in the 10 minutes case it was not possible to save any of the ones lost by the Site-1 receiver. On the other hand, for the 2.5 minute case at least one whole repeat cycle has been recovered.

4 SUMMARY

This study confirms that for frequency bands in the area of interest of EUMETSAT Future Programmes (18.1 and 26.5 GHz), when looking into satellite to ground link budget availability figures, the availability defined on the basis of days or even minutes (repeat cycle for GEO satellites or pass concept for LEO satellites) may significantly differ from the values derived from ITU models (referred as average year basis or to a 'worst month concept'). The consolidated outcome of this study, expected to be completed after the winter season of 2009-2010, is intended to be used for supporting system design decision within EUMETSAT for future programmes.

Additionally, the site diversity implementation with receivers in two different sites in Germany (as case demonstrators), separated around 50Kms in a N-S axis, confirms sufficient decoupling among rain cells for minimising any potential influence on both slant-paths at the same time, and therefore secures a significant improvement on the link budget availability figures (for the case study). In line with theoretical models and expectations, it has been shown that site diversity is not capable of securing 100% availability in K/Ka-Band and that there are cases in which simultaneous rain events happen in the slant-path to both receivers. Such events are rare and sparse but do occur, as it is shown in the graphs.

CGMS is invited to take note of the current status of the presented study being performed by EUMETSAT in the frame of Future Programmes and to provide comments regarding similar or related experiences.