Cost-efficient design of hybrid network for video transmission in tropical areas

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***Abstract*— This paper aims at providing different cost-efficient solutions for the channel impairments in tropical areas. In order to extend service to isolated areas, we propose hybrid architecture based on DVB-S2/RCS+WiFi networks. In this scenario the satellite channel is affected by deep rain events that do not allow ACM modes to protect data. Moreover, the delay in the ACM reaction to fade changes can affect the quality of the video transmission. In order to avoid the QoS reduction, we focus on different Fading Mitigation Techniques (FMT), designing a multi-layer scheme protection, using LL-FEC and AL-FEC in higher layers, and optimizing the intervention threshold and super-frame length in the physical layer.**

Keywords-component; DVB-S2, WiFi, LL-FEC, AL-FEC, Hybrid network, Tropical, video streaming

I. INTRODUCTION

The necessity of providing broadband connectivity to low-densely populated areas has given rise to a big interest for hybrid networks, especially those composed of a satellite backhaul and a wireless terrestrial network. In this paper, we focus on a DVB-S2/RCS system with Adaptive Coding and Modulation (ACM) for the satellite link and a Wi-Fi network for the indoor terrestrial wireless link. Fig. 1 depicts the considered scenario, which reproduces the hybrid network used to give service to small villages along the Amazon River [1]. The video stream is transmitted by the video stream server to the satellite transmitter, which broadcasts it to the satellite network. Each satellite receiver broadcasts the video stream to a terrestrial indoor wireless network. For the Amazon scenario considered here, the satellite link is the bottleneck of the system in terms of capacity, since the users in the indoor WiFi network are fixed; consequently, the terrestrial link condition has no impact on the overall conditions of the hybrid channel.

In [3] the authors show that, for some rain events, the DVB-S2 ACM modes can not cope with the deepest attenuations, as exemplified in Fig. 2, where the E_b/N_0 of the tropical rain is below the intervention threshold of the minimum ACM mode, which is -1.5 dB for a 10^{-7} QEF FEC (Quasi Error Free Packet Error Rate). In this paper, we propose to use (for the forward link) the Link Layer FEC (LL-FEC) that have been recently standardised in DVB-RCS Mobile (DVB-RCS+M) following the DVB policies of re-using already standard solutions.

However, since the maximum size of FEC frames is limited, and deep fading duration can be in the order of seconds, we additionally propose an Application Layer FEC solution (AL-FEC) like the one standardized for DVB-H (Handheld) and DVB-SH (DVB Satellite to Handheld), where FEC frames are allowed to be larger. Since the error protection we propose causes a noticeable delay, it cannot be used for real-time applications, which is why we focus on video streaming applications. In this paper we also demonstrate that, during the rain event, the delay in the ACM reaction to fade changes can affect the Quality of Service (QoS) of a multicast video streaming. Specifically, there is a noticeable delay (RTT of about $2 \cdot 250$ms plus DVB super-frame length) from the moment an RCS Terrestrial (RCST) detects an ongoing fade event to when it receives from the NCC the transmission with the modulation and coding rates appropriate to cope with the increased atmospheric attenuation. We verify that the LL-FEC, tuning of super-frame (SF) length and the intervention threshold are useful to compensate for the packet errors introduced by the ACM switching delay.

Therefore, this work aims at demonstrating the improvement in QoS of the video transmitted in the hybrid network by using the proposed techniques and shows how to make efficient use of bandwidth in order to reduce costs in Amazon areas. The main parameters evaluated for this purpose are the packet error rate, the delay, and the bandwidth overhead due to the use of the proposed techniques. The received video will be evaluated by using the PSNR (Peak Signal to Noise Ratio) metric.

The paper is organized as follows. Section II presents our hybrid scenario based on DVB-S2+WiFi. A description of the framework and the performance of different FMT considered herein, such as LL-FEC and AL-FEC, is carried out in section III. The simulation platform is presented in section IV, where also the results will be analyzed in detail for different setting configurations. Finally, in the conclusions, we identify the achievements of the paper and the issues to be addressed in the future.

II. SYSTEM MODEL

We consider a GEO (Geostationary Earth Orbit) Multibeam Broadband Satellite (MBS) link with a DVB-S2/RCS [4, 5] air interface. DVB-S2 incorporates ACM on a time slot basis, chosen on the base of the SNIR (Signal-to-Noise-plus-Interference Ratio) at the destination terminal. Therefore, TDM/FDM (hybrid Time and Frequency Division Multiplexing) is implemented, and each time slot transmits a DVB-S2 physical layer packet, which has constant amount of coded symbols but an ACM mode dependant number of information bits and symbols with consequent variable transmission time. Only 23 out of 27 ACM modes proposed in the standard [4] are considered in order to obtain a coding gain between modes of about 1dB. We assume transmission in the Ka band (20-30 GHz) and therefore rain is the most affecting atmospheric event. The Wi-Fi access point is in charge of utilizing the limited radio spectrum resources efficiently. On the satellite side, the RCST measures the downlink attenuation and signals it to the NCC, which in turn adapts the transmission parameters to the observed fading.

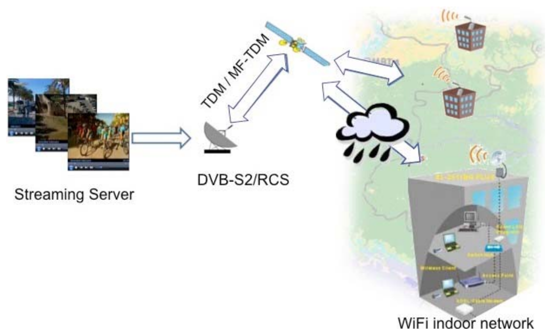

Figure 1. The video server broadcasts a video stream to the indoor wireless network by means of a satellite network

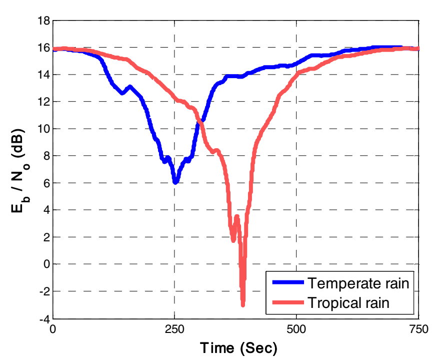

Figure 2. Examples of channel conditions caued by a rain event in Temperate and Tropical areas.

The combination of these two technologies is useful to enable connectivity in non-urban areas. It is one of the solutions that are envisaged in the context of the BRASIL project in order to provide different types of network access to villages along the Amazon River.

III. Fade Mitigation Techniques

To compensate for signal outages, the application of erasure-based FEC codes extending the time diversity is a well-known method. Generally, the larger the time-diversity, the higher the efficiency of the system, as signal outages can be averaged out more easily. Two codes have been proposed for high layer error correction: Reed-Solomon (RS) and Raptor codes. RS codes had commonly been used if only small dimension block codes are required, and are applied in the first generation of DVB family of standards, e.g. in DVB-C, DVB-S or DVB-H. On the other hand, Raptor Codes have been proposed lately and introduced into standards. In contrast to RS codes, they provide more flexibility, larger blocks of coded data, and lower decoding complexity. Raptor codes have therefore been adopted in the latest DVB standards, e.g. within DVB-H for file delivery and DVB-IPTV.

Fig. 3 shows a high-level protocol stack highlighting the usage of FEC codes for DVB services over IP-based networks [6]. In the physical layer we can find the well known Turbo codes and LDPC codes used in the ACM scheme. At the data link layer, DVB has adopted a LL-FEC (MPE-FEC) in DVB-H, which has been later standardized for DVB-RCS+M. However, during the DVB-SH standardization activities, it was recognized that for satellite-to-handheld services, the MPE-FEC is not sufficient. Therefore, it was decided to specify a multi-burst link layer FEC framework referred to as Inter-Burst FEC (IFEC). Finally, an AL-FEC may be applied at the Application or Transport layers as in 3GPP's Multimedia Broadcasting/Multicast Services (MBMS) or IPDC file delivery over DVB-H based on the Raptor codes.

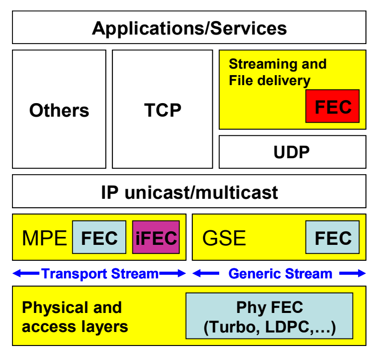

Figure 3. FEC location in the protocol stack

A. LL-FEC Framework

DVB has adopted a LL-FEC in DVB-H at the data link layer (MPE Layer) referred to as MPE-FEC. At the time when DVB-H was specified, only RS codes were available, and therefore, the MPE-FEC is based on RS codes. FEC operations are performed in the DVB-H link layer as illustrated in Fig. 4 and the processes are fully defined in [7]. For an ideal memory-less erasure channel with symbol erasure probability ε, P_e is the residual PER of RS(n, k) code and can be computed as

$$P_e \cong \varepsilon\left(1-\sum_{i-1}^{n-k}\binom{n}{i}\varepsilon^i(1-\varepsilon)^{n-i}\right) \tag{1}$$

For RS(255, 191) in DVB-H, n=255 and k=191. However, the code, which can also be punctured and shortened such that any k can be used with $0 < k \le 191$ and $n = k$+255-191.

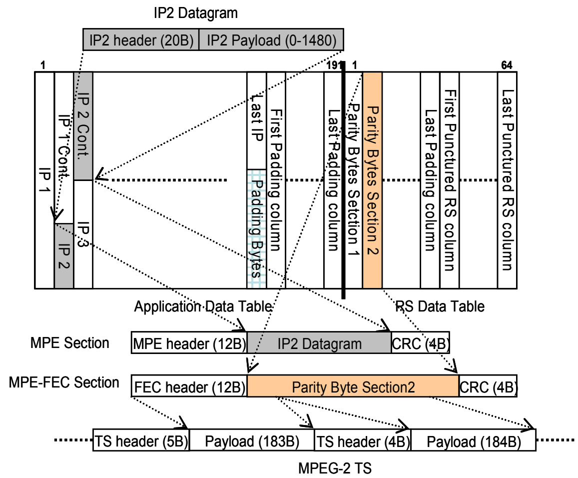

Figure 4. MPE-FEC Frame and the MPE encapsulation process

Our purpose it not only to avoid the loss of packets due to the ACM delay reaction when the attenuation of the rain event is changing, but also when the ACM modes can not cope with deepest attenuations. However, one of the main drawbacks when using this framework for DVB-S2 is the size of the MPE-FEC frame, which is not big enough to protect against long burst errors since the number of address signaling bits for the Application Data Table (ADT) and RS data table is only 18 bits [7].

B. AL-FEC Framework and Intervention threshold

In order to protect from the longest error bursts (deep attenuations can be in the order of seconds), which LL-FEC can not recover, we propose to use an AL-FEC. It can be activated before the rain attenuation exceeds the threshold of the lowest ACM mode, and thus data can be protected during heaviest conditions, otherwise all data will be lost. Note that AL-FEC provides the same error correction capability as LL-FEC for a given coding rate, but the key is that it can provide protection across several error bursts, rather than across a single burst as with MPE-FEC.

As an alternative or a complement to the LL-FEC, we consider a simple threshold-based algorithm, where the NCC changes the ACM mode when the standardized threshold of DVB-S2 is reached, with a given margin thr_m (in dB). We will compare both alternatives in terms of PER and available bandwidth.

IV. RESULTS

A. Simulation Platform

A Multilayer Protection simulation platform has been developed in order to quickly assess the performance of different parameter configurations without repeating the time-consuming physical layer simulations (see Fig. 5). Given that this performance assessment entails many layers, specifically from the physical to the network layers of the protocol stack, a modular approach has been considered. The ACM switch Physical-Layer module, which generates the time series of satellite channel attenuations, interfaces with the Link Layer simulator. In the PHY settings module, intervention threshold and super-frame length are chosen. The simulator takes stream of IP packets as input and applies the MPE-FEC encoding technique as described in [5], generating an MPEG-2 TS by encapsulating Multi-Protocol Encapsulation (MPE) sections and MPE-FEC sections. At this point, the output of the physical-layer simulator is used to mark the MPEG-2 Transport Stream (TS) packets as correctly received or being erroneous. Next, the MPE-FEC decoding process is applied by reconstructing columns of the FEC matrix applying the correction capabilities of different FEC codes (RS or Raptor). The sequence of IP packets affected by the unreliable columns is obtained and the PER at the IP level is computed. The MPEG2-TS time series are sent to the corruption block, where the original video is corrupted with erasures due to the channel. Finally, PSNR is computed by comparing both videos; original and corrupted.

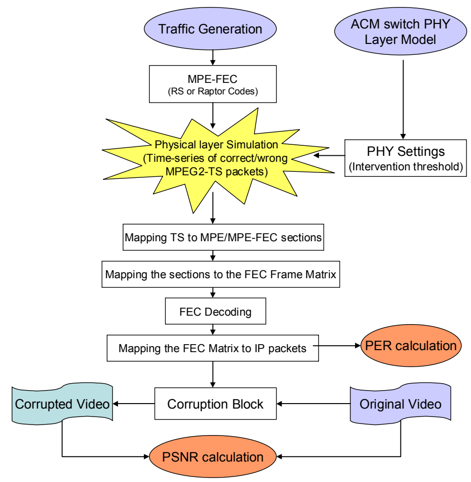

Figure 5. Simulation Flow diagram

The introduced LL-FEC framework allows a significant variability in terms of parameter settings. The amount of data (bits), that can be protected with target delay τ_{ll}, can be computed as $S_{protect} = \tau_{ll} B_s M r_{phy} r_{ll}$. Where B_s is the symbol rate, M (modulation order) and r_{phy} (physical layer coding rate) depend on the selected ACM, and r_{ll} is LL-FEC coding rate.

B. Result Analysis

A data rate of 530 kb/s has been chosen to study the performance of the video streaming application. First of all, in Fig. 6, we evaluate performance in terms of PER versus intervention threshold, for different super-frame length durations. No FEC is used for this simulation. As expected, the PER is strongly affected by the SF length (SF_{dur}). In particular, decreasing the SF length, the ACM delay decreases and consequently the PER, without significantly increasing the bandwidth on the forward link. Moreover, by increasing the intervention threshold, the PER is reduced (more than 50% of reduction for 0.2 dB), even for low values of thr_m. Note that, for values bigger than 0.5 dB, the PER is not reduced, because the system can not recover all the packet losses due to the deep fading.

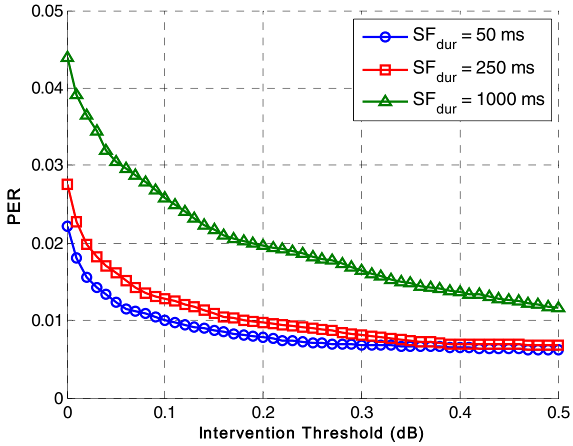

Figure 6. PER as a function of intervention threshold and for different super-frame length durations (no FEC)

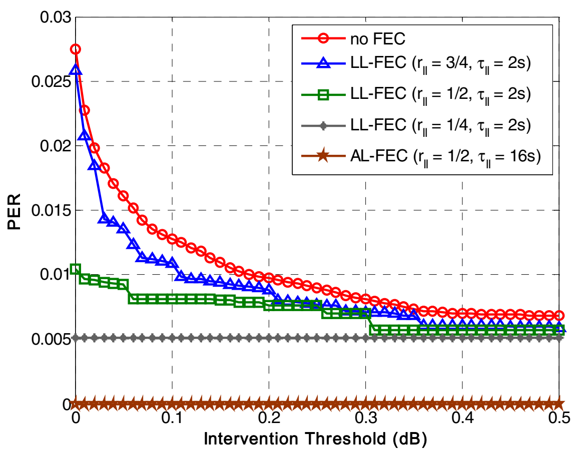

Figure 7. PER as a function of intervention thresholds and for different FEC code rates using RS (SF_{dur} = 250 ms)

It can be stressed from Fig. 7 that PER estimated without using the proposed techniques (thr_m = 0 and no FEC) and using a SF_{dur} of 250 ms, is 2.8%. In this figure, we are carrying out multi-layer protection with high layer FEC and intervention threshold. We show that a FEC coding rate of 3/4 and a target delay of 2s are not enough to significantly reduce the packet loss for low values of thr_m, and we need lower codes. For the lowest-rate code (1/4), we verify that LL-FEC can recover the corrupted bits due to the ACM switched delay, but can not recover the residual packet loss (0.5%) due to the deep fading event. For bigger delay values of τ_{ll}, the PER is reduced, however, the maximum delay allowed for the LL-FEC settings is 4s due to the address signaling bits (limited to 18), as explained in section III. Thus, we have tested the AL-FEC, by using a modified LL-FEC platform. We have increased the τ_{ll} delay, and as Fig. 7 shows, the PER has been reduced to 0. We conclude that AL-FEC should be introduced to mitigate this type of tropical channel conditions, since it can provide protection for time spans of several seconds. We plan to investigate this issue using a detailed AL-FEC simulator.

In order to make efficient use of bandwidth, we also investigate the trade-off between PER and bandwidth efficiency. By using the combination of r_{ll} = ½ and thr_m = 0.5 dB we obtain a PER similar to what we obtain using only r_{ll} = ¼. In the second case, in terms of bandwidth efficiency, we are using 25% more of bandwidth due to the code rate than in the other case. That is because the LL-FEC is applied during all the time. However, regarding the thr_m = 0.5 dB, as Fig. 8 shows, only 0.2% of bandwidth is used (for the 250ms frame-length duration case). Therefore, by using intervention threshold instead of strongest codes, we have a gain of 24.8% of bandwidth with similar PER results. The bandwidth efficiency from Fig. 8 is found as follows: we compute the mean spectral efficiency used during all rain event when the ACM mode changes by thr_m dB before the standardized threshold [4], and we normalize with respect to mean spectral efficiency when using thr_m = 0. As demonstrated, intervention threshold not only achieves similar results to the strongest codes of LL-FEC, but also allows more available bandwidth.

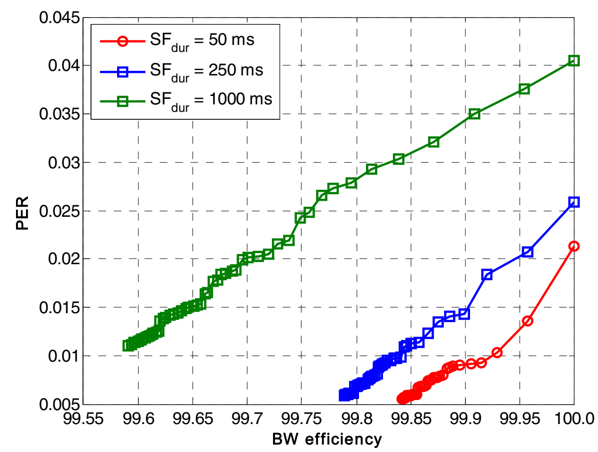

Figure 8. PER as a function of the BW efficiency of the intervention threshold and for different super-frame length durations (no FEC)

C. *Video quality evaluation*

In this Section we show the performance of our recovery technique, in terms of video quality estimation, by using the trace produced by our simulation and extracting the video stream at the end-users. We consider the well-known Akiyo video samples [8], by evaluating the video quality at the end-users versus the network overhead. To this purpose we compare the video samples received by the end-users with the transmitted original video by using the standard PSNR metric [9]. The PSNR of a picture P is expressed as:

$$PSNR = 10 \log \frac{\left(2^n - 1\right)^2}{\sqrt{MSE(P)}} \tag{2}$$

where n is the number of bits used to represent each pixel, and $MSE(P)$ is the Mean Squared Error:

$$MSE(P) = \frac{1}{w * h} \cdot \sum_{i=1}^{N} \left(P_i^o - P_i^c\right)^2 \tag{3}$$

where $[w, h]$ are the picture dimensions, while P_i^o and P_i^c are the original and the corrupted video pictures, respectively.

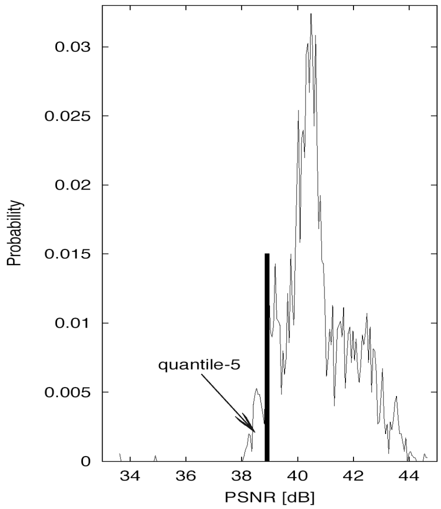

Figure 9. PMF of the received video with LL-FEC with r_{ll} = ¼ , τ_{ll} = 2s, thr_m= 0dB and SF_{dur} of 250 ms.

The PSNR can be used as a good indicator of the variation of the video quality when the content and coded are fixed across the test conditions [10], for this reason we compare the performance of the proposed error recovery technique by using Akiyo's sequence, encoded at an average PSNR of 46 dB.

Fig. 9 shows the Probability Mass Function (PMF) of the received video with a LL-FEC with r_{ll} = ¼ and τ_{ll} = 2s. As we can see, the PSNR is below 39 with a probability equal to 5% (quantile 0.05); this means that for the 5% of time the quality of the streaming video is below 39 dB, which is the threshold to consider good video quality. Fig. 10 shows the quantile 0.05 of the PSNR as a function of LL-FEC configurations using RS (SF_{dur} = 250 ms and no threshold optimization (thr_m = 0 dB)). The results show that the quantile 0.05, when we apply link layer coding rate equal to ¼ with τ_{ll} = 2s or more, is greater that 39 and thus the quality of the video is acceptable.

V. Conclusions

In the paper, we have proposed multi-layer protection solutions in order to cope with the requisites of heavy atmospheric conditions of tropical areas. In particular, LL-FEC and AL-FEC has been considered has high layer error protection. We have also proposed to add an intervention threshold.

LL-FEC and intervention threshold have been demonstrated to allow the transmission of good video quality, since they avoid packet losses during the ACM delay reaction. However, the threshold performance shows that it can achieve almost the same PER reduction as the strongest high layer codes, but with higher bandwidth efficiency gain. On the other hand, we show that AL-FEC allow to protect data during deep fading events of several tens of seconds.

Future work includes the development of more complex intervention threshold analysis, including channel prediction. And also a detailed study of the AL-FEC performance for video streaming applications.

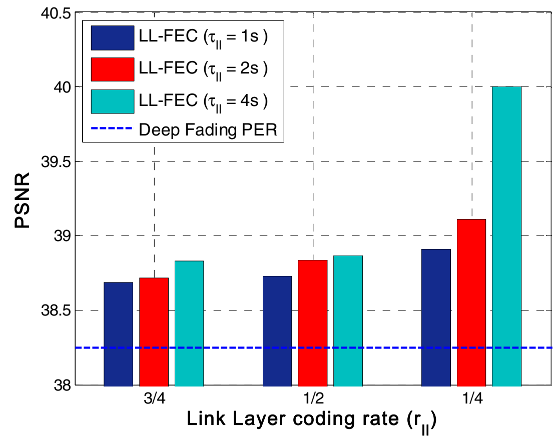

Figure 10. PSNR for different LL-FEC configurations using RS (SF_{dur} = 250 ms and no threshold optimization (thr_m=0))

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