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Encapsulation and Framing Efficiency of DVB-S2 Satellite Systems

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I. INTRODUCTION

Current DVB-S and DVB-DSNG standards, make use of concatenated Reed-Solomon and Viterbi Forward Error Correction schemes. These techniques do not fully exploit the available bandwidth and are about 4 dB away from the theoretical Shannon limit. Moreover, with the shift of allocated transmission bands to upper frequencies, solutions based only on increasing the number of bits-per-second-per-Hz for some fixed link budget margin is no longer sufficient due to the strongly demanding characteristics of the propagation channel.

DVB-S2 is a specification for next-generation digital satellite transmission emerging from technical ad-hoc DVB working groups. It should progressively complement the 9 years old DVB-S aiming at offering new services and improving capacity dramatically. DVB-S2 standardizes a number of configurations and applications areas. This paper focuses on the DVB-S2 interactive data service in which the use of ACM has been set as normative. The following is based on the draft [1].

It is important to highlight that the physical layer design addressed by the DVB-S2 technical committee has been driven by the synergy pursued between broadcast and unicast systems and at the same time by the very low bit error rates (10^{-11}) required by broadcast transmissions. For this reason both the DVB-S2 ACM configurations and the encapsulation process of DVB-S2 differ considerably of ACM implementations in terrestrial access systems [2].

This paper is structured as follows. Firstly, the DVB-S2 ACM subsystem is briefly described. Secondly, a layered model of the DVB-S2 air interface is presented. Thirdly, encapsulation and framing efficiency are defined and a layered encapsulation model is obtained. Finally, a number of numerical results are presented on both the layered and the overall efficiency. The last section presents the main conclusions of the paper.

II. DESCRIPTION OF THE DVB-S2 ADAPTIVE CODING AND MODULATION SUBSYTEM

The functional block diagram of the DVB-S2 encapsulation/framing (at the transmitter side) is shown in Fig. 1. It is shown that unlike DVB-S, the second generation of the standard allows for several input stream formats. In addition to MPEG transport stream, generic streams (IP in Fig. 1) are encompassed by the standard. When this second configuration is selected, MPEG Transport Stream rules do not apply and different encapsulation protocols with improved efficiency can be used as an alternative to the Multi Protocol Encapsulation (MPE) [3]. IP datagrams can also be directly mapped on the transmission frame.

The mode adaptation subsytem implements the merging policy, which refers to the application dependent packet scheduling. For unicast systems with multiple input streams the standard considers the possibility of performing a round robin polling with a time out for the user packets in each buffer. However, additional different policies can be implemented. Dummy frames are inserted and transmitted in case of empty buffers.

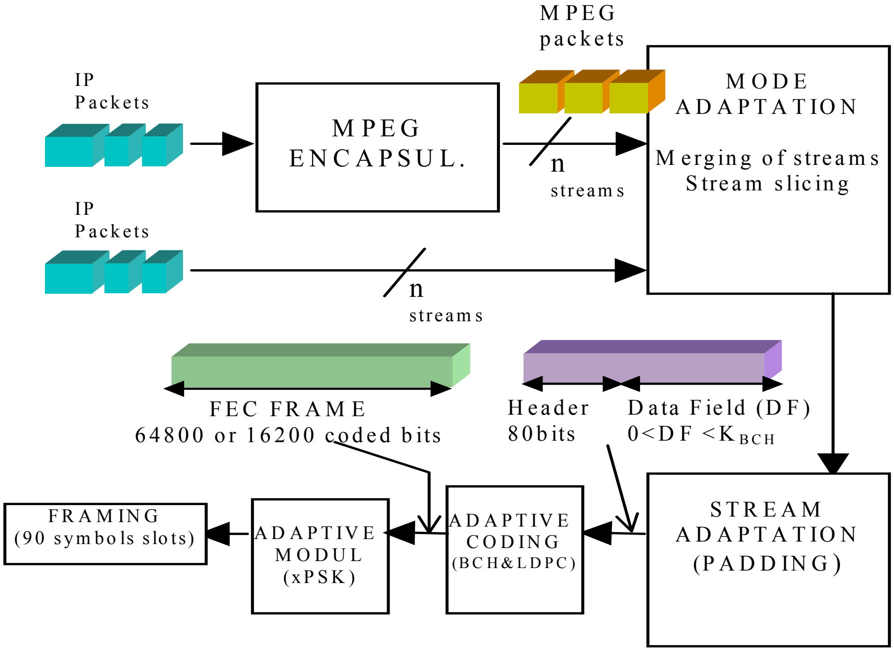

Figure 1. Block diagram of the DVB-S2 encapsulation/framing

The data field is composed by DFL (Data Field Length) bits, where $K_{BCH} -80 \geq DFL \geq 0$. K_{BCH} is the BCH uncoded block length, which is dependent on the FECFRAME length (normal or short) and on the coding rate, and 80 bits is the BBHEADER length. While for broadcasting and DSNG applications the data field is filled to his maximum capacity (K_{BCH} -80 bits), for unicast applications the data field may include an integer number of user packets. This allows for correct recovery of the user information when adaptive coding and modulation is utilized. As a consequence, padding is required to complete the constant length (K_{BCH}) BBFRAME. This also happens whenever available data is not sufficient to fill the BBFRAME.

The stream adaptation subsystem is responsible for providing padding in case $DFL < K_{BCH} -80$, and scrambling the information at the encoder input. Next, the BBFRAME is sent as input to the FEC encoder, composed by the concatenation of the BCH outer encoder and of the LDPC inner encoder. The parity check bits are appended to the frame, which is then processed by the channel interleaver. In unicast systems, the output FECFRAME can have short (16200 bits encoded bits) or normal length (64800 coded bits). Mapping into QPSK, 8PSK, 16APSK and 32APSK is then applied. When ACM is used, coding rate and modulation format may be changed frame-by-frame.

The modulated symbols are inserted in a regular physical layer frame structure, composed of fixed length slots of 90 symbols. The final transmitted frame (PLFRAME) is obtained by adding the PLHEADER, which occupies one extra slot and carries the information related to the frame type and to the physical layer mode.

When ACM systems are considered, pilot symbols can be inserted in the physical layer frame structure for carrier synchronization and channel estimation purposes. In fact, phase recovery for 8PSK and higher modulation orders with the specified phase noise appears very difficult without any pilot. Besides, in ACM system, the key issue is that the receiver is in general able to decode only a part of the entire stream, and precisely only the frames where transmission parameters are compatible with user channel conditions. In this context, pilot symbols both allow for carrier recovery without knowledge of the frame data and prevent the need for frame re-acquisition when the current frame data are not correctly decoded. Pilot symbol insertion in DVB-S2 signal is optional, but pilot switching on a frame-by-frame basis is not permitted.

III. DVB-S2 LAYERED ENCAPSULATION ARCHITECTURE

In this section the particular case of IP datagrams encapsulated over DVB-S2 is addressed. The capsule of DVB-S2 is called BBFRAME (in information bits) or FECFRAME (in coded bits) as it is was explained in the previous sections and is shown in the overall layered architecture of the air interface presented in Figure 2

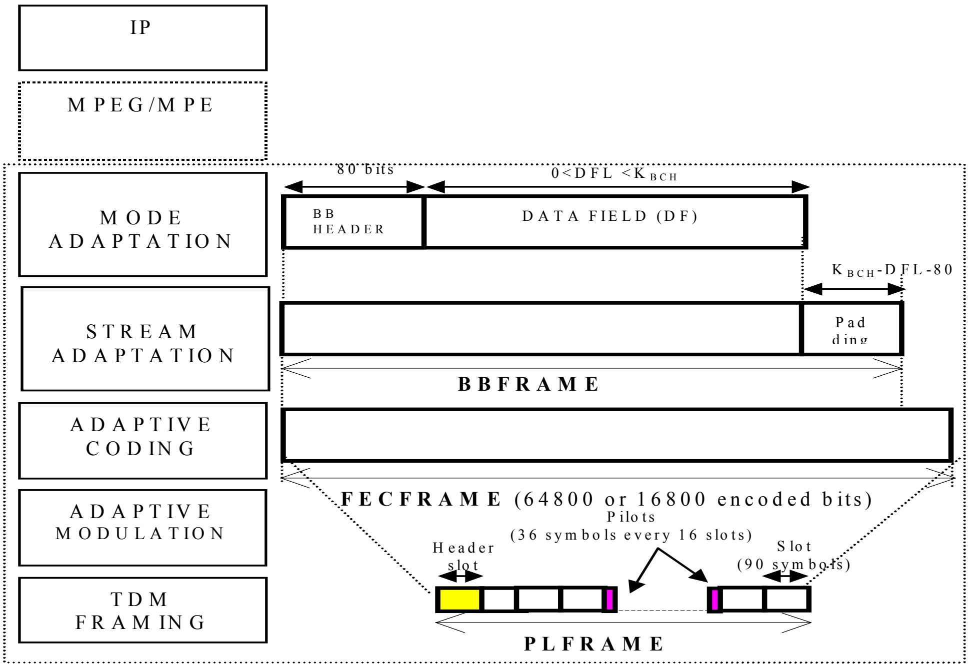

Figure 2. Air interface architecture of the DVB-S2 using ACM

IV. DEFINITION OF LAYERED ENCAPSULATION EFFICIENCY

In order to estimate the encapsulation efficiency of IP packets, a layered fashion is proposed following the corresponding layered architecture from the IP layer down to the transmitted bearing signal shown in Fig. 2. In principle the efficiency can be defined in different ways. We decide on using the following one which is the same (only inversed) given in [3]:

$$\psi_i(\eta, L_i) = \frac{payload\ bits\ (layer\ i)}{total\ transferred\ bits\ (layer\ i)} \qquad (1)$$

where the dependency on the spectral efficiency, η, and on the packet length, L_i, on a per-layer *i*-th basis is explicit. Note that the packet to be encapsulated at layer *i*-th is the packet delivered by the layer (*i-1*)-th.

From the layered air interface architecture shown in Figure 1, it can be distinguished between the encapsulation that takes place out of the DVB-S2 sub-system and the encapsulation performed within it so as the total encapsulation efficiency can be expressed as follows

$$\psi_{tot}(\eta_{COD},\eta_{MOD},L_{IP},L)=\psi_{MPEG/MPE}(L_{IP})\psi_{DVB-S2}(\eta_{COD},\eta_{MOD},L) \quad (2)$$

where η_{COD} is the LDPC coding rate and η_{MOD} is the spectral efficiency due to the modulation (number of bits carried by a constellation symbol). Note that the MPEG/MPE efficiency depends on the IP packet size, L_{IP}, while the DVB-S2 efficiency depends on the packet size entering the DVB-S2 ACM subsystem, L. The efficiency of the MPEG encapsulation, $\psi_{MPEG/MPE}(L_{IP})$, equates one if IP packets are encapsulated directly on the DVB-S2, and in this case $L_{IP} = L$. It should be noted that any encapsulation other than MPEG is allowed by the standard for unicast applications.

The encapsulation performed within the DVB-S2 subsystem is actually performed in two steps and therefore can be expressed as follows

$$\psi_{DVB-S2}(\eta_{COD},\eta_{MOD},L)=\psi_{MS}(\eta_{COD},L)\psi_{framing}(\eta_{MOD}) \quad (3)$$

Recall that $L=L_{IP}$ if IP is directly encapsulated over DVB-S2. The first step takes place during the Mode and Stream adaptation where the input stream is adapted to the encoder input block and therefore the efficiency depends on the used coding rate, $\psi_{MS}(\eta_{COD},L)$. The second one takes place during the framing and in this case the efficiency depends only on the used modulation $\psi_{framing}(\eta_{MOD})$ as the FECFRAME is independent from the coding rate and packet length. It should be understood that framing efficiency does not depend on the packet length since the overhead introduced in the framing process (pilot symbols, signaling information) only depends on the modulated symbols resulting from modulating the encoded bits. Therefore, the framing efficiency can be simply computed as the ratio of data and total transmitted symbols

$$\psi_{framing}(\eta)=\frac{data\,symbols(\eta)}{total\,transmitted\,symbols(\eta)} \quad (4)$$

V. NUMERICAL RESULTS

A. DVB-S2 ENCAPSULATION, $\psi_{DVB-S2}(\eta_{COD},\eta_{MOD},L)$

Figure 3 shows $\psi_{MS}(\eta_{COD},L)$ when only one single IP packet is directly encapsulated. It can be observed that the large size of the DVB-S2 capsules yield an important consequence in the encapsulation process since in order to achieve reasonable encapsulation efficiency, different users must be multiplexed.

IPv4 statistics are quite well-known, at least in the IP backbone [4]. In general, a high percentage of the packets represent a small percentage of the volume, which means that small packets are far more numerous.

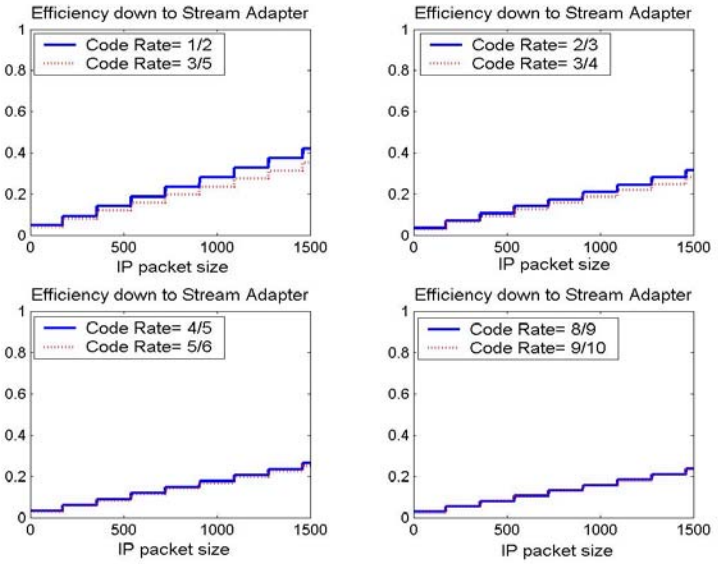

Figure 3. IP encapsulation efficiency in the Mode and Stream adaptation, $\psi_{MS}(\eta_{COD}, L)$ when only 1 packet is encapsulated

In particular, three leading packets sizes gather 60% of the packets and 70% of the volume: ~40, ~500 and 1500 bytes. The explanation of this is the implementation of the TCP protocol. The small packets are TCP acknowledgments or control segments. The medium size ones come from implementations of TCP/IP not using Path MTU Discovery [6]. The effect of not using this protocol is that the sender ignores the maximum packet size that can get through the route to the receiver. Thus, the packet size is set to the default size, which is 512 bytes. Finally, the 1500 bytes packet is characteristic of the Ethernet.

As an example, Figure 4 shows the efficiency when only packets of 40 or only of 512 bytes (552 after adding the IP header) are encapsulated altogether. It is apparent that short FECFRAME is less efficient for those particular yet most likely packet sizes.

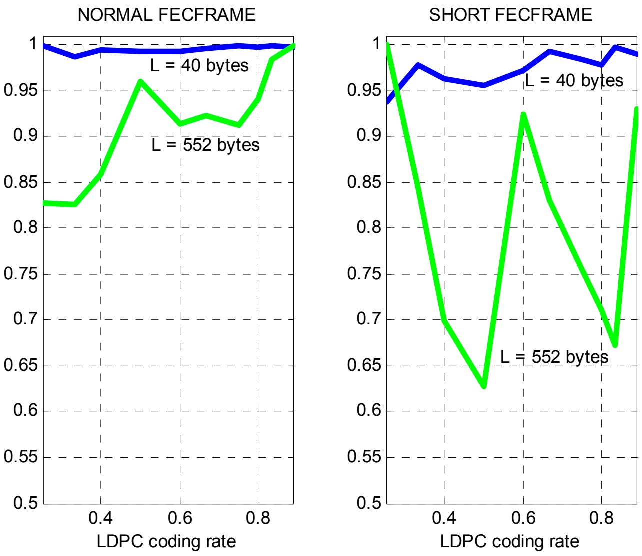

Figure 4. $\psi_{MS}(\eta_{COD}, L = 40bytes)$, $\psi_{MS}(\eta_{COD}, L = 552bytes)$ for normal and short FECFRAME configurations

Framing is organized in units of 90 symbols (slot) such as after modulation the coded and modulated FECFRAME occupies exactly an integer number of slots. A header is inserted for receiver configuration occupying exactly one slot. Pilots (36 symbols) are inserted every 16 units of 90 symbols (slots). The framing efficiency in therefore given by

$$\psi_{framing}(\eta_{MOD}) = \frac{datasymbols(\eta_{MOD})}{datasymbols(\eta_{MOD}) + 90 + \frac{90S(\eta_{MOD})}{\left\lceil 90(S(\eta_{MOD})+1) + P\,\mathrm{int}\left\{\frac{(S(\eta_{MOD})-1)}{16}\right\}\right\rceil}} \qquad (5)$$

where $S(\eta_{MOD})$ is the number of slots used for the given modulation and P corresponds to the 36 symbols of the pilot. Note that the spectral efficiency in (5) refers only to the modulation.

η_{MOD} (bits/s/Hz)	$\psi_{framing}(\eta_{MOD})$	
	NORMAL FECFRAME	SHORT FECFRAME
2	99.72	98.90
3	99.58	98.36
4	99.45	97.83
5	99.31	97.3

Table 1. Framing efficiency.

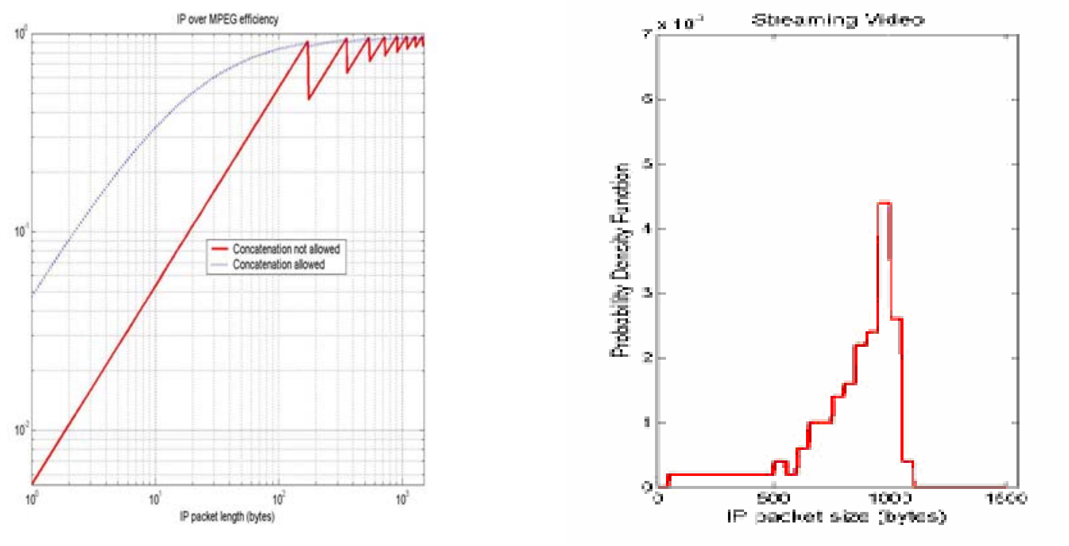

Figure 5. (a) IP over MPEG encapsulation efficiency $\psi_{MPEG/MPE}(L_{IP})$ (b) Probability Density Function of IP sizes of streaming video traffic

Table 1 gives the framing efficiency for the different modulation efficienciesy and it can be seen that the dependency with the spectral efficiency is quite low and therefore the total efficiency can be approximated as follows

$$\psi_{tot}(\eta_{COD}, L_{IP}, L) = \psi_{MPEG/MPE}(L_{IP})\psi_{DVB-S2}(\eta_{COD}, L) \qquad (6)$$

B. TOTAL ENCAPSULATION, $\psi_{tot}(\eta_{COD}, L)$

IP over MPEG encapsulation is currently performed via the Multi Protocol Encapsulation MPE, which allows concatenating IP packets [3]. The two following different approaches are possible:

- MPEG/MPE encapsulation
- MPEG-TS-based transmission

Only the first case is assumed here, IP packets are encapsulated into MPEG packets according to [3]. However, no MPEG transport stream is assumed for transmission although such a case is also encompassed by the standard. This case requires a number of intermediate operations (not shown in Fig. 1) in order to comply with the TS rules, essentially related to maintain constant delay and rate since transport streams have been aimed for TV programs transmission.

The MPE encapsulation is performed as follows: the stream is divided in SNDU (Sub Network Data Units) containing a header in bytes of 2 (length), 2 (type) and 4 (CRC). The SNDU is encapsulated into a series of MPEG-2 transport stream packets belonging to the same logical TS channel. The 184 bytes of the TS payload are filled and a MPEG-2 header of 4 bytes is added containing a packet identifier (PID) of 13 bits to identify the TS channel. If another SNDU is available, the encapsulator should fill with that the empty room in the TS payload; to indicate that the packet carries the start of a SNDU the payload unit start indicator (PUSI) in the MPEG header should be set to one.

The TS packet that carries the last byte of the SNDU must carry an adaptation field of 4 bytes and the 2 bits of the Adaptation Field Control (AFC) in the MPEG header should be consequently set to one. If another SNDU is not available the remaining space in the TS payload should be stuffed with padding bits. Figure 5 shows the MPEG encapsulation efficiency as a function of the IP packet length showing the incurred losses when concatenation of packets is not allowed and also when MPE is used.

Regarding the effect of the statistical distribution of the IP packet length on the encapsulation efficiency, it is possible to compute analytically for the MPEG/MPE case by averaging as follows

$$\overline{\psi}_{MPEG/MPE} = \sum_{L\min}^{L\max} \psi_{MPEG/MPE}(L_{IP})p(L_{IP}) \qquad (6)$$

where $\psi_{MPEG/MPE}(L_{IP})$ is plotted in Fig. 5(a) and p(L_{IP}) is plotted in Fig. 5(b) for Streaming Video traffic[5]. Table 2 shows the average values both when packet concatenation is not allowed and when it is (PUSI is 0 or 1 respectively).

	$\overline{\psi}_{MPEG/MPE}$	
	PUSI=0	PUSI=1
All packet sizes equally distributed	0.80	0.90
Video streaming packet size distribution	0.87	0.93

Table 2. MPEG/MPE weighted encapsulation efficiency.

It should be noted that multiplexing of users could be preformed in two different ways, either according to the destination address (PID) or to the physical layer requirements. In the first case, MPE protocol can be applied thus increasing MPEG efficiency (see Table 2). In the second case, MPE protocol could only be used in its current version by coordinating PID and physical layer.

Fig. 6 shows the total encapsulation efficiency considering MPEG/MPE and PUSI=0 encapsulation on top of DVB-S2 for the packets sizes shown in Fig. 4. It can be observed that for such a worst case of no concatenation of packets, the minimum efficiencies are 85% and 75% for the normal and short FECFRAME respectively. If aggregation were possible (PUSI=1), there is an increase of 5%.

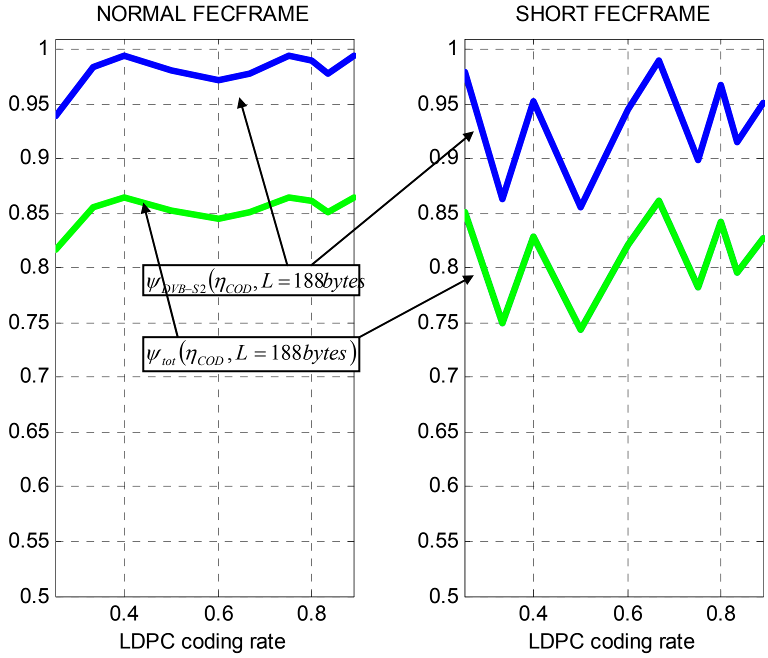

Figure 6. Comparison of total and DVB-S2 encapsulation efficiencies when using MPEG/MPE (PUSI=0) and streaming video traffic.

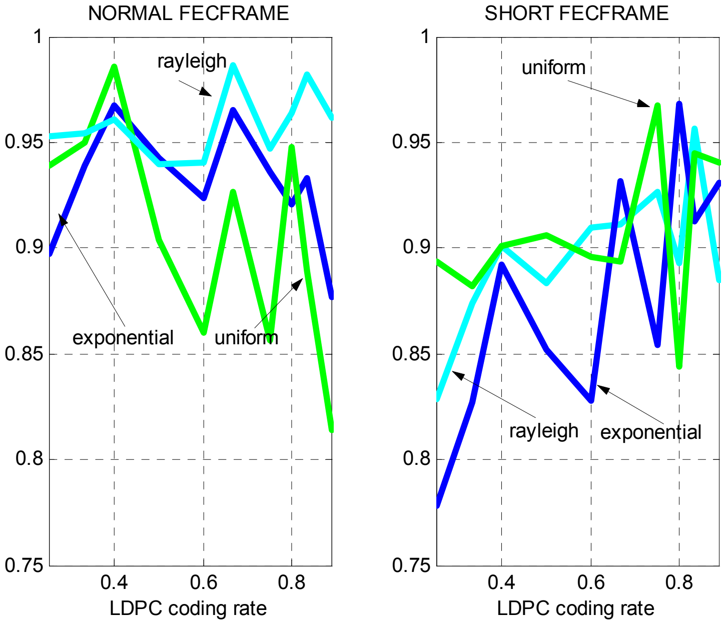

Figure 7. DVB-S2 encapsulation efficiency when L is distributed following exponential, uniform and rayleigh distributions with mean 100 bytes .

Finally, Fig. 7 shows the effect of multiplexing packets of different sizes. Packet sizes are assumed to follow three different statistical distributions with the same mean of 100 bytes: exponential, uniform and rayleigh. It is observed that in all cases the minimum encapsulation efficiencies are not far from the efficiencies achieved when using MPEG/MPEG but the values show a larger deviation with the coding rate.

VI. CONCLUSIONS

A methodology has been presented to analyze encapsulation and framing efficiency of the DVB-S2 subsystem that implements adaptive physical layer. Preliminary results have been obtained that are summarized as follows. Due to the large length of the DVB-S2 capsules, users must be multiplexed according to the required physical layer. It has been shown that encapsulating most likely IP packet sizes, using Normal FECFRAME capsules of 64800 coded bits shows better efficiency than Short FECFRAME capsules of 16800 coded bits. Moreover, the latter is highly variable with the coding rate. The total efficiency has also been computed, which takes account of the encapsulation performed on top of the DVB-S2 subsystem, i.e. packets entering DVB-S2 are already encapsulated. In this paper it has been assumed a MPEG/MPE encapsulation, which introduces a dependency with the IP packet size distribution. Measured packet size distribution of streaming video has been considered as an illustrative case; the total efficiency has been found to be above 85% for the normal FECFRAME case and above 75% for the short FECFRAME case (Fig. 6) when IP packets are not concatenated (MPE PUSI bit indicator set to zero). In case they are (MPE PUSI bit indicator set to one) efficiency increases up to 90% and 80 % for the normal and short FECFRAME respectively.

Finally, the effect of multiplexing packets of different sizes on the efficiency is also presented. It is shown that the average efficiency is in the order of the one achieved when using MPEG/MPE but the values show a larger deviation with the coding rate. In this case on the other hand, additional procedures implementing fragmentation should be considered (adaptation layer).

A paramount final remark should be noted. No traffic dynamics have been assumed throughout the paper thus considering the optimistic case of having always packets available to be sent. Actual encapsulation efficiency will depend on the specific traffic dynamics of the application of interest.

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