MPE/ULE-FEC vs GSE-FEC Efficiency Comparison of IP Datagram Transmission over DVB-S2

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[Abstract] In this paper, the transport efficiency of Multi Protocol Encapsulation (MPE), Unidirectional Lightweight Encapsulation (ULE) and Generic Stream Encapsulation (GSE) for typical IP packet sizes is compared. Moreover, the aggregated efficiency when applying packet-level forward error correction (PL-FEC) with MPE, ULE and GSE is also analyzed. MPE-FEC is the mechanism used by DVB-H whereas GSE-FEC is our proposed modification to be used in DVB-S2. A layered efficiency calculation model is presented in order to simplify the computation. The performance of GSE-FEC is also analyzed when adopted by the IP traffic and DiffServ Classes with different modulations and coding rates (ModCods). Theoretical analysis and simulation revealed that GSE-FEC is more efficient than MPE-FEC and ULE-FEC for DVB-S2 networks.

Nomenclature

η_{Cod}	=	the spectral efficiency of the coding rate
η_{Mod}	=	the spectral efficiency of the modulation
η_{punct}	=	the efficiency of puncturing RS columns
$p(L_{IP})$	=	the probability distribution of the IP packet size
L_{PL}	=	the size of payload (Byte)
L_{TM}	=	the transmitted bits after encapsulation (Byte)
L_{IP}	=	the size of the IP datagram (Byte)
L_H	=	the size of the Header (Byte)
L_{CRC}	=	the size of the CRC (Byte)
ψ_{TOT}	=	the total efficiency of DVB-S2
$\bar{\psi}_{TOT}$	=	the average total efficiency of DVB-S2
ψ_{FEC_Matrix}	=	the FEC Matrix Framing efficiency
ψ_{Encap}	=	the encapsulation efficiency of MPE, ULE or GSE
ψ_{MAC}	=	the MAC layer efficiency of DVB-S2
ψ_{PHY}	=	the PHY layer efficiency of DVB-S2
$S(\eta_{Mod})$	=	the number of slots in the FLFrame

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I. Introduction

DVB-S2 is the second-generation DVB specification for broadband satellite applications,[1] developed after the success of the first generation specifications of DVB-S (shown in Ref. 2) for broadcasting and DVB-DSNG (shown in Ref. 3) for satellite news gathering and contribution services, benefiting from the technological achievements of the last decade. It has been designed for:

1) Broadcast Services for standard definition TV and High-Definition TV (HDTV).
2) Interactive Services including Internet Access for consumer applications.
3) Professional Applications, such as Digital Television (DTV) contribution and News Gathering, TV distribution to terrestrial Very High Frequency/UltraHigh Frequency (VHF/UHF) transmitters, Data Content distribution and Internet Trunking.

The DVB-S2 standard has been specified around three key concepts: best transmission performance, total flexibility and reasonable receiver complexity. It is a specification for next-generation digital satellite transmission emerging from technical ad-hoc DVB working groups. It should progressively complement DVB-S aiming at offering new services and improving capacity dramatically.

The encapsulation of DVB-S2, unlike DVB-S, allows for several input stream formats. In addition to MPEG transport streams (TS), generic streams (GS) are encompassed by the standard. The DVB-S2 standard introduces generic stream transport method not only for providing digital TV services, but also as technology for building IP networks and dedicated data streaming.

Multi Protocol Encapsulation (MPE) is widely used in current DVB-S systems for encapsulating Internet Protocol (IP) datagrams over MPEG-TS, which is based on the Digital Storage Media Command and Control (DSM-CC).[4] MPEG-TS is used in almost all contemporary digital broadcasting systems, including the DVB and the standards of Advanced Television Systems Committee (ATSC) family as the format of baseband data, organized in a statistically multiplexed sequence of fixed-size, 188-byte TS Packets. Initially intended to convey MPEG-2 encoded audio and video streams, the MPEG-2 TS was eventually used also for the transport of IP traffic, with the adaptation method introduced in Ref. 5 and named as Multi Protocol Encapsulation. The adoption of MPE accented the role of DTV platforms as access networks for IP-based broadband data and multimedia services.[6] Broadcasters have the potential to use a part of the capacity of the broadcast channel to include unicast or multicast IP traffic along with the audiovisual streams.[4] What is more, state-of-the-art broadcasting technologies, such as DVB-H or DVB-S2 are IP-oriented and actually expected to carry exclusively IP data rather than MPEG-2 content.

This tendency towards the convergence of the worlds of digital broadcasting and IP-based telecommunications has initiated research efforts towards a more efficient and flexible encapsulation protocol.[7] The IP-over-DVB (IPDVB) working group of IETF has proposed an improvement of MPE, namely the Unidirectional Lightweight Encapsulation (ULE, formerly Ultra Light Encapsulation).[8-10] In comparison to MPE, ULE offers simplicity, improved efficiency, native IPv6/MPLS (Multi Protocol Label Switching) support and greater flexibility via optional Extension Headers. ULE has been adopted by IETF as a “Request for Comments” (RFC) document.

Anther alternative protocol is Generic Stream Encapsulation (GSE), which is designed for the transmission of IPv4 datagrams and other network protocol packets directly over the DVB-S2 Generic Stream.[1] The protocol specifies an encapsulation format and fragmentation over DVB-S2 baseband frames (BBFrames), the size of which is variable ranging from 384B to 7274B. The encapsulation part of GSE relies in some fundamental design choices of ULE. GSE uses the same Type Field as ULE that allows it to carry additional header information to assist in network/Receiver processing, but specifies a generic fragmentation method, a different base encapsulation format and another processing method because of the substantially different underlying link-layer.

Forward Error Correction (FEC) will be likely introduced in applications where signal reception shows high Packet Loss Ratio (PLR). Such high PLR may be caused for example by the repeated presence of obstacles, such as the power arches in the railway. With the FEC about 25% of TS or GS data will be allocated to parity overhead, because 64 columns of FEC frame (255 columns) are used to pad RS data. The protocol of MPE-FEC is introduced in Ref. 5 and Ref. 11. The issues of MPE efficiency have been studied by some papers from different angles. In Ref. 12, the authors compared two different schemes (padding and packing) of stuffing at the end of TS packet. The transport efficiency of MPE and ULE has been analyzed in Ref. 8, 9 and 13 over MPEG-2/DVB networks. In Ref. 10, a network simulation model is built to compare the performance of MPE and ULE. The layered model of DVB-S2 has been studied in Ref. 14.

In this paper, the efficiency of MPE, ULE and GSE is compared for typical IP packet sizes. Moreover, we also analyze the aggregated efficiency when applying packet-level forward error correction (PL-FEC) at MPE, ULE and GSE. The efficiency of DiffServ is also analyzed using GSE-FEC over DVB-S2 network. The intention of this paper is to compare the transport efficiency of MPE-FEC, ULE-FEC and GSE-FEC for IP transmission and to present the characteristics of GSE-FEC used in IP traffic and DiffServ classes over DVB-S2 networks. The rest of this paper is organized as follows. Section II analyses the encapsulation procedure for each protocol and outlines the benefits of GSE for DVB-S2. Section III presents a layered efficiency calculation model to compute the encapsulation efficiency for each protocol. Section IV defines the simulation parameters and compares the results of encapsulation efficiency for each protocol over DVB-S2 networks. Section V concludes the paper.

II. Encapsulation Protocol Overview

A. Multi Protocol Encapsulation

MPE has already been world-widely adopted in both IP/MPEG-2 Gateways and decapsulators/receivers, as being the only IP-to-MPEG-2 encapsulation protocol for almost a decade. Using MPE, each IP packet arriving at an MPEG Encapsulation Gateway has an MPE header attached to form a network layer packet named Protocol Data Unit (PDU). The entire PDU is then fragmented to form a series of MPEG-2 TS Packets. Since IP packets are of variable size, it is reasonable to expect most IP packets will be placed in a series of TS packets. A one-bit Payload Unit Start Indicator (PUSI) in the TS packet header and one-byte PTR after the TS header indicate a specific TS packet carries the start of a new TS Packet payload.

The basic MPE header format carries a MAC destination address, but no payload type field. This leads to the assumption in most current Receiver driver software that the payload is IPv4. If the payload is other IPv4, such as IPv6 packet, a type field is required to de-multiplex the received packets. In MPE, this requires the inclusion of the optional Logical Link Control/Sub-Network Access Point (LLC/SNAP) header (4 bytes).

In most cases, the end of an IP packet does not precisely align to the end of a TS packet payload, one or more bytes will typically be free and may be unused (Padding) or used to carry a subsequent packet (Packing). Encapsulators and the corresponding receivers may use either mechanism, but must choose the same one. TS packet padding is the default mechanism within MPE.

As shown in Fig.1, the structure of MPE Subnetwork Data Unit (SNDU) section, the main drawback of MPE is the inclusion of several MPEG specific fields in the section header, which in fact can as well be omitted. Moreover, the declaration of the receiver MAC address, which is not always necessary, since the TS is itself a sub-network layer and the traffic is already divided in logical channels, is mandatory in MPE, adding an overhead of 6 more bytes. Another issue is the absence of the declaration of type of data contained in the SNDU. MPE offers the option of either having a pure IP payload (no discrimination between v4 and v6), or carrying the data with an LLC/SNAP header. Thus, there is no uniform representation of the type of the encapsulated data, as it exists e.g. in Ethernet framing with the Type field.

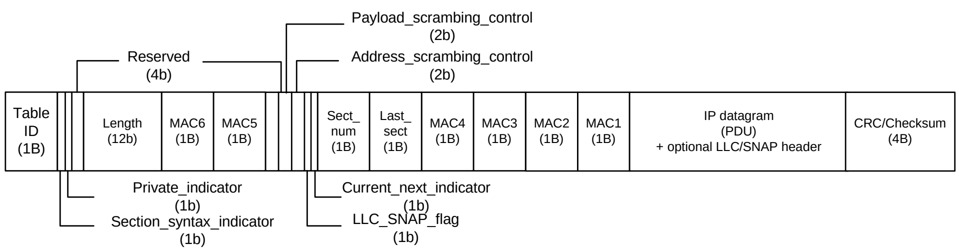

Figure 1 Structure of the MPE SNDU section

MPE-FEC is the mechanism used by DVB-H,[11] which is introduced in order to support reception in situations of high PLR on the MPE section level. The use of MPE-FEC is not mandatory and is defined separately for each elementary stream in the TS. For each elementary stream it is possible to choose whether or not MPE-FEC is used, and if it is used, to choose the trade-off between FEC overhead and RF performance. The MPE-FEC Frame is arranged as a matrix with 255 columns and a flexible number of rows. The number of rows is specified at header and the value is variable. Figure 2 shows the structure of the MPE-FEC frame.

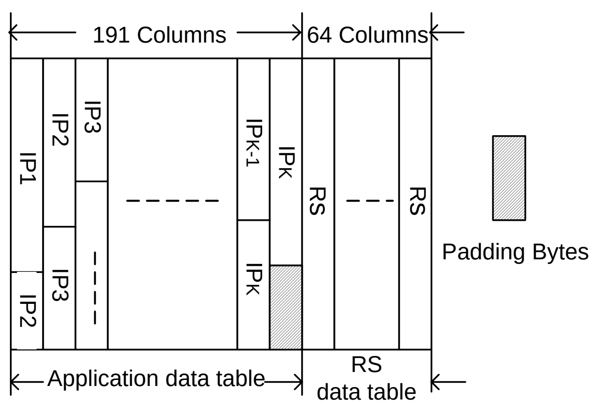

Figure 2 The structure of the MPE-FEC Frame

B. Unidirectional Lightweight Encapsulation

ULE is an alternative encapsulation method to MPE, providing simplicity, efficiency and configurability. It was designed with the aim of making the encapsulation process as lightweight as possible without sacrificing flexibility.

It follows the approach of “data piping” i.e. directly mapping the PDU into the TS payload, adding only a small header. ULE header contains just a Length field which declares the length of the SNDU, and a Type field which has the same functionality with that of Ethernet i.e. it declares the type of the payload. Thanks to the Type field, ULE provides native support for state-of-the-art network protocols, such as IPv6 and MPLS. Depending on the value of this field, the PDU can be an IPv4 datagram, IPv6 datagram, MPLS and so on.

The ULE header can also include a 6-byte destination address corresponding to the receiver’s Network Point of Attachment (NPA). The NPA address (which can correspond to the receiver’s MAC) is used to uniquely identify a receiver in the MPEG-2 transmission network and is mandatory only in the case that the PDU is to be processed by a receiver-router, which will further forward it to its final destination. If this is not the case and the data is directly received by the destination terminal, this field can be omitted and filtering can be performed at IP level.

If there is additional SNDU-level signaling which cannot be carried in the existing header fields, ULE provides the option of adding one or more Extension Headers after the standard header and before the PDU, carrying the data which are needed. Finally, a CRC-32 tail is appended (as in MPE) to ensure proper reception and synchronization. Figure 3 shows the structure of the ULE SNDU section. The framing has become as lightweight as possible (comparing with Fig.1), retaining only the necessary fields for proper de-encapsulation and forwarding of the IP datagram. After framing, the ULE SNDU is mapped to the payload of MPEG-2 TS packets. In the case that the SNDU length is not an integer multiple of the TS payload and the stuffing techniques of Padding or Packing can be employed.

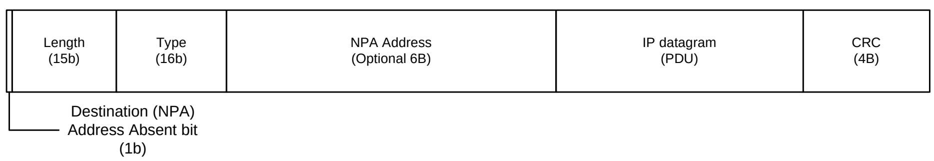

Figure 3 Structure of the ULE SNDU section

Figure 3 shows the structure of the ULE SNDU section. Comparing with MPE, it is sufficient to demonstrate the simplicity introduced by lightweight header. By reducing the framing fields only to the necessary ones, ULE saves bandwidth and processing time at the encapsulator.

C. Generic Stream Encapsulation

Anther alternative lightweight encapsulation protocol to MPE is GSE, which is designed specially for DVB-S2 networks and allows TS Packets to be sent as GSE SNDU sections.

GSE protocol allows for direct encapsulation of IP and other network-layer packets over DVB-S2 physical layer frames. The encapsulation and fragmentation of IP datagrams for transport over DVB-S2 Generic Streams have been defined in Ref. 12. Firstly, the PDUs are encapsulated in SNDUs by adding the SNDU header and optional checksum bytes. The structure of PDU and SNDU are illustrated in Fig.4. Then the SNDU sections are encapsulated in one or more GS units. Each GS unit is made of GS header and Data Field. The size of GS header ranges from 2B to 5B depending on the PDU fragmented or not. The length of GS Date Field is variable ranging from 1B to 4kB, because the size of IP packets and the number of GS units in each SNDU section are both variable. Figure 4 also shows the encapsulation of SNDUs and the structure of GS units.

The size of SNDU header ranges from 2B to 8B because the part of Label (3B or 6B) is optional and Protocol field (2B) is mandatory. CRC32 (4B) will be attached at the end of the last GS unit if SNDU section is encapsulated in several GS units as shown in Fig.4.

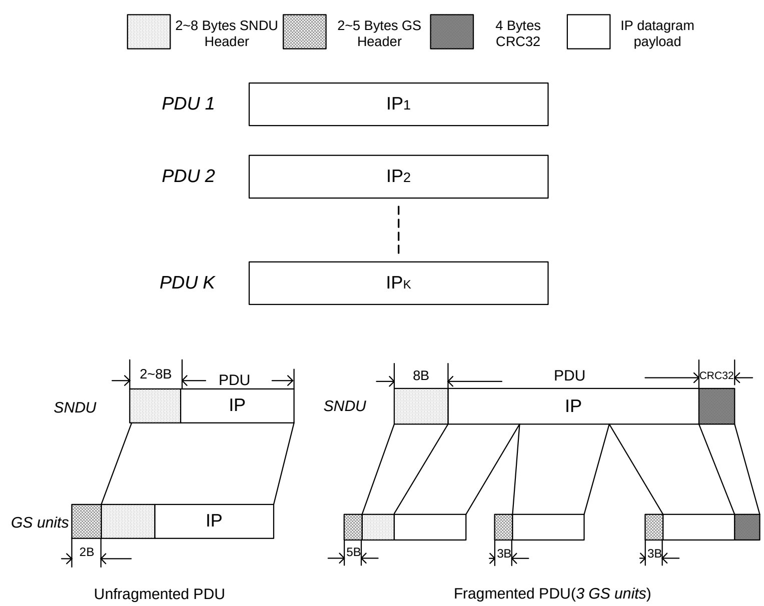

Figure 4 The structure of PDU, SNDU and GS units

The SNDU is transmitted over a DVB-S2 link by placing it either in a single GS which is sent in one BBFrame, or if required, a PDU may be fragmented into several GS units, which are sent in one or a series of BBFrames. The size of BBFrames varies from 384 bytes to 7274 bytes. Adaptive Coding and Modulation (ACM) allows for changing ModCods on-the-fly and in accordance with the link quality perceived at the receivers. Consequently the receiver will be able to demodulate and decode only those BBFrames whose ModCods matches the perceived link quality. The DVB-S2 standard permits an encapsulator to transmit different network layer packets destined to a specific receiver into BBFrames with different ModCods, and feedback from the receiver about its link quality may trigger ModCods changes at any time. The 10B header of a BBFrame carries the length of the Datafield, but it is different to the 4B header of a TS packet, does neither include the PUSI nor a Transport Error Indicator (TEI), GS units will resemble its own Start and End Indicator for reassembly of encapsulated units instead. The structure of BBFrames is shown in Fig.5.

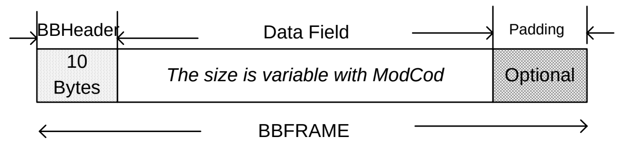

Figure 5 The structure of BBFrame

GSE-FEC is a modification of MPE-FEC mechanism to use in DVB-S2. The PL-FEC is applied in DVB-S2 using the same logic as in DVB-H, that is to say, it is applied on the IP datagrams. The GSE-FEC matrix is constructed with IP datagrams in the left-hand side (191 columns) and parity byte (RS data) on the right-hand side (64 columns without puncturing) as Fig.2 shows. Thus about 25% of GS data will be allocated to parity overhead.

III. Definition of the Encapsulation Efficiency

In order to estimate the packet level encapsulation efficiency for transporting IP packets over DVB-S2 networks, a layered simulation model is presented in Fig.6. Traditionally, the encapsulation efficiency is defined using Eq. (1).

$$\psi = \frac{L_{PL}}{L_{TM}} \tag{1}$$

where L_{PL} and L_{TM} are payload bits and total transmitted bits after encapsulation respectively.

Considering the layered conception shown in Fig.6, the total efficiency of DVB-S2 can be expressed using Eq. (2).

$$\psi_{TOT}(L_{IP},\eta_{punct},\eta_{Cod},\eta_{Mod}) = \psi_{FEC\_Matrix}(L_{IP},\eta_{punct})\psi_{Encap}(L_{IP})\psi_{MAC}(L_{IP},\eta_{Cod})\psi_{PHY}(\eta_{Mod}) \tag{2}$$

where the total efficiency is composed of four parts: ψ_{FEC_Matrix}, ψ_{Encap}, ψ_{MAC} and ψ_{PHY}, which are the FEC matrix framing efficiency, encapsulation efficiency for MPE, ULE or GSE, MAC layer framing efficiency and PHY layer efficiency respectively. And L_{IP} is the packet size of IP datagram. η_{punct}, η_{Cod} and η_{Mod} are the puncturing column efficiency, coding rate, and modulation spectral efficiency.

Regarding the effect of the statistical distribution of the IP packet size for different Quality of Service (QoS), the efficiency of Eq. (2) can be rewritten as follows:

$$\bar{\psi}_{TOT}(\eta_{punct},\eta_{Cod},\eta_{Mod}) = \sum_{L_{IP}} \psi_{TOT}(L_{IP},\eta_{punct},\eta_{Cod},\eta_{Mod})\, p(L_{IP}) \tag{3}$$

Each part of the total efficiency can be expressed using the following equations.

$$\psi_{FEC\_Matrix}(L_{IP},\eta_{punct}) = \frac{L_{PL-Matrix}(L_{IP})}{L_{PL-Matrix}(L_{IP}) + L_{RS}(\eta_{punct}) + L_{Matrix-padding}} \tag{4}$$

$$\psi_{Encap}(L_{IP}) = \frac{L_{PL-Encap}(L_{IP})}{L_{PL-Encap}(L_{IP}) + L_{H-Encap} + L_{CRC}} \tag{5}$$

$$\psi_{MAC}(L_{IP},\eta_{Cod}) = \frac{L_{PL-BBFrame}(L_{IP},\eta_{Cod})}{L_{PL-BBFrame}(L_{IP},\eta_{Cod}) + L_{H-BBFrame} + L_{CRC} + L_{BBFrame-padding}} \tag{6}$$

$$\psi_{PHY}(\eta_{Mod}) = \frac{90S(\eta_{Mod})}{90(S(\eta_{Mod})+1)+36\,\mathrm{int}\left\{\frac{S(\eta_{Mod})-1}{16}\right\}} \tag{7}$$

where L_{RS} and L_{CRC} are the size of RS data and CRC data. $L_{H-Encap}$ is size of the SNDU header and MPE, ULE or GSE header. $L_{H-BBFrame}$ is the size of BBFrame header. $L_{PL-Matrix}$ and $L_{PL-BBFrame}$ are the size of the FEC Matrix payload and BBFrame payload. The packets of the MAC layer are presented as BBFrames in DVB-S2. The PHY layer efficiency of DVB-S2 depends on the modulation scheme. The packets of the Physical layer are a stream of FLFrames. The FLFrame is composed of an FLHeader and an integer number $S(\eta_{Mod})$ of slots, each slot contain 90 symbols. And pilot blocks (optional) insert every 16 slots to help receiver synchronization, and each pilot block is composed of 36 pilot symbols. Table 1 presents the PHYFraming efficiency with normal FECFRAME (64800 bits) for different Modulation type.[14] The efficiency is very close to 100%. Therefore, the total efficiency of DVB-S2 network can be approximated without considering the spectral efficiency of Modulation. Therefore, Eq. (2) and (3) can be approximated as Eq. (8) and (9).

Table 1 The number of slots and Physical Layer efficiency with different Modulation type

η_{Mod}	$S(\eta_{Mod})$	$\psi_{PHY}(\eta_{Mod})$
2(QPSK)	360	99.72%
3(8PSK)	240	99.59%
4(16APSK)	180	99.45%
5(32APSK)	144	99.31%

$$\psi_{TOT}(L_{IP},\eta_{punct},\eta_{Cod}) \approx \psi_{FEC\_Matrix}(L_{IP},\eta_{punct})\psi_{Encap}(L_{IP})\psi_{MAC}(L_{IP},\eta_{Cod}) \tag{8}$$

$$\bar{\psi}_{TOT}(\eta_{punct},\eta_{Cod}) \approx \sum_{L_{IP}} \psi_{TOT}(L_{IP},\eta_{punct},\eta_{Cod})\,p(L_{IP}) \tag{9}$$

The FEC matrix framing efficiency ψ_{FEC_Matrix} will be 75% without using padding columns and puncturing RS columns, which is affected by the size of IP datagram and puncturing column efficiency. ψ_{FEC_Matrix} can be improved by introduce the conception of puncturing RS columns or appropriate size of IP packet. But puncturing columns will deteriorate the performance of the receiver because of the less FEC bytes attached. Therefore, it should balance the performance and efficiency here.

ψ_{Encap} is calculated when IP datagrams are encapsulated as PDU, SNDU and then fragmented as TS packets for MPE and ULE or GS units for GSE. For MPE and ULE, ψ_{Encap} is affected by the size of SNDU header and IP packets, also affected by the type of stuffing schematic (padding or packing) used at the end of each TS packet. The larger size of IP packet the better, because each IP datagram is encapsulated as one SNDU. For GSE, anther factor affects ψ_{Encap} is the number of GS units encapsulating each SNDU. The more GS units the worse because of much more overhead introduced by the GS header.

ψ_{MAC} is affected by the Coding rate and statistical distribution of the IP packets.

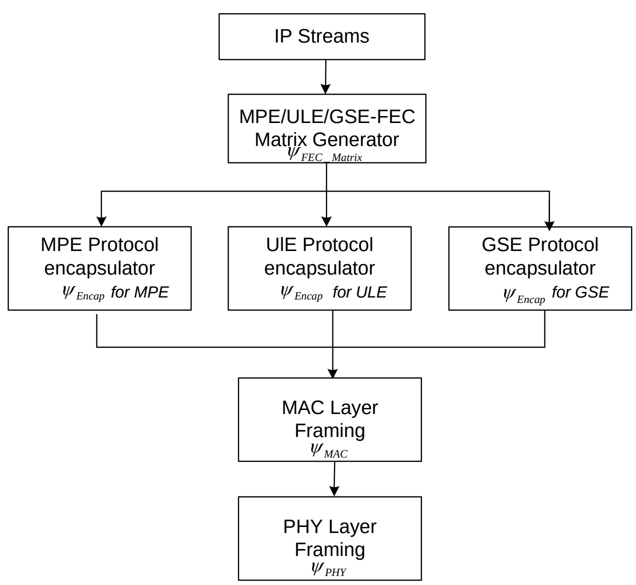

Figure 6 The flow chat of the Encapsulation Efficiency

IV. Simulation Description

In this paper, the simulation is done in MATLAB. The efficiency of MPE, ULE and GSE with FEC is computed over DVB-S2 using the model presented in section III. The size of IP datagram ranges from 10B to 2000B when comparing the efficiency of these three encapsulation protocols. And the typical IP packet sizes (shown in table 2) for DiffServ Classes are also simulated. Two different types of stuffing schematic, padding and puncturing, are simulated and compared for MPE and ULE protocol. The number of rows of the FEC matrix is 1024 (Byte), which makes the total FEC frame 2M bits.

Figure 7 presents the efficiency of GSE-FEC with different number of GS units fragmented by the SNDU section. The efficiency first increases and then drops for any size of IP datagram. Because the padding is dominant when the number of GS unit is small and the overhead of total GS header is dominant when the number of GS unit is large. So an optimal number of GS unit exist when fragmenting each SNDU section. The efficiency of MPE-FEC, ULE-FEC and GSE-FEC is shown in Fig.8. It's clear that the result of all the types is below 75% because of the FEC framing, and padding mode is worse than packing. The efficiency fluctuates with packet size, is the same for these three protocols. The zigzag efficiency for padding mode results from the fixed size of TS packet (188B) and the efficiency will be maximized when the SNDU fits exactly into an integer number of TS packets.

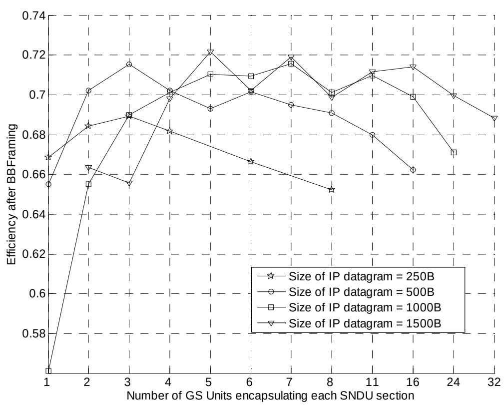

Figure 7 The Efficiency of GSE-FEC over BBFraming with different number of GS units

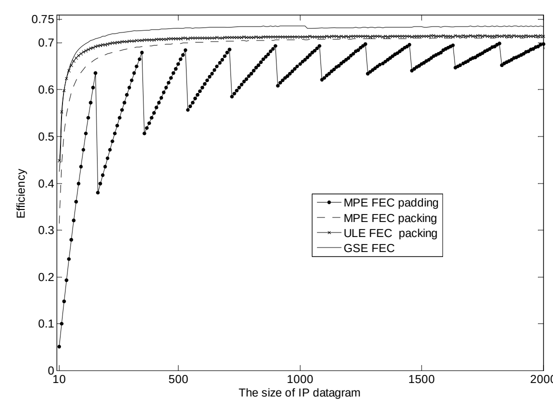

Figure 8 The Efficiency of GSE-FEC, ULE-FEC and MPE-FEC ($\psi_{TOT}(L_{IP}, \eta_{punct} = 0, \eta_{Cod} = 3/4)$)

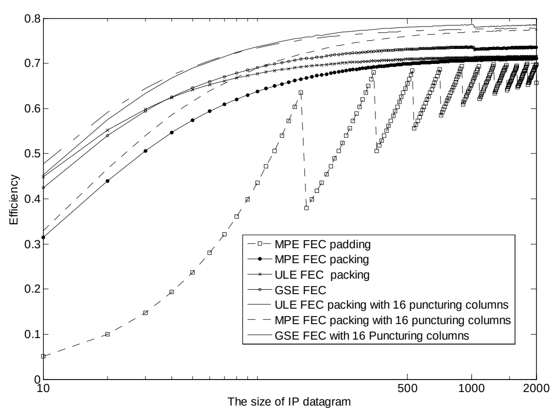

Figure 9 The Efficiency of GSE-FEC, ULE-FEC and MPE-FEC with and without puncturing RS columns ($\psi_{TOT}(L_{IP}, \eta_{punct} = 0 \; or \; 16, \eta_{Cod} = 3/4)$)

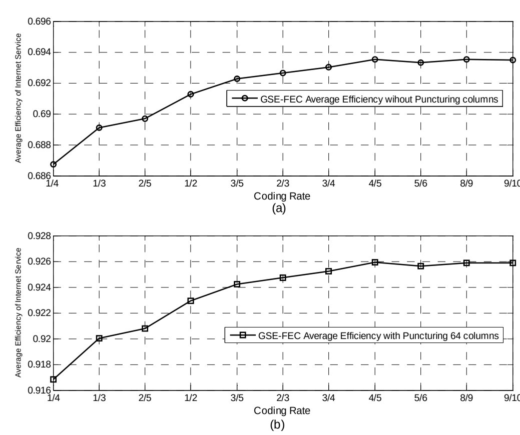

Figure 10 The Average Efficiency of Internet Service with different Coding Rate using GSE-FEC
(a) $\bar{\psi}_{TOT}(\eta_{punct} = 0, \eta_{Cod})$ **(b)** $\bar{\psi}_{TOT}(\eta_{punct} = 64, \eta_{Cod})$

The conception of puncturing RS columns is conducted in Fig.9 and Fig.10 in order to decrease overhead introduced by the RS data. It's clear that puncturing will increase efficiency because the punctured RS columns are not transmitted. A decreased level appears at Fig.8 and Fig.9 when the size of IP datagram is larger than 1024B due to the number of the column is fixed at 1024 and the efficiency will be maximized when the size of IP datagram is exactly 1024B.

Figure 10 shows the average efficiency of IP traffic with different Coding Rates. And the efficiency is computed using the Eq. 9 with GSE-FEC encapsulation. The probability distribution of IP packet size of IP traffic is shown in Fig.11, which is referred in Ref. 15. The efficiency increases with the increasing of coding rate, which can be explained that the higher coding rate the larger size of Data Field for the BBFrame (shown in Fig.5). Therefore, the overhead will decrease because of more payload datagram encapsulated in each BBFrame. However, the influence of the coding rate is less than IP packet size and puncturing efficiency. The efficiency increases only 0.7% when Coding Rates change from 1/4 to 9/10. Therefore, the total efficiency in Eq. (8) and (9) can be simplified as Eq. (10) and (11) without considering Coding Rates.

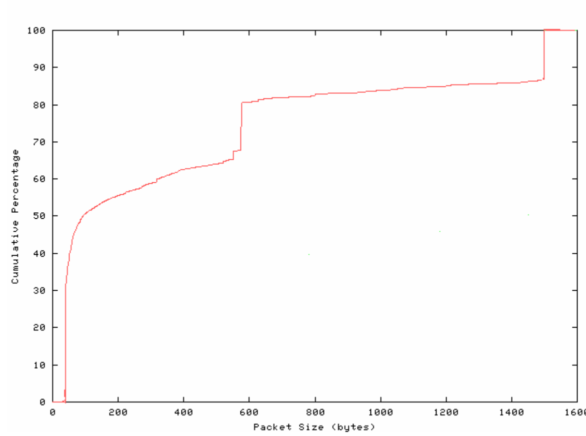

Figure 11 The Cumulative Distribution of Packet Sizes of IP traffic

$$\psi_{TOT}(L_{IP},\eta_{punct}) \approx \psi_{FEC\_Matrix}(L_{IP},\eta_{punct})\psi_{Encap}(L_{IP})\psi_{MAC}(L_{IP}) \quad (10)$$

$$\bar{\psi}_{TOT}(\eta_{punct}) \approx \sum_{L_{IP}} \psi_{TOT}(L_{IP},\eta_{punct})\, p(L_{IP}) \quad (11)$$

Table 2 is the typical packet size for DiffServ classes,[16] the efficiency varies from the DiffServ classes, such as Assured Forwarding (AF), Expedited Forwarding (EF) and Best Effort (BE). Table 3 is the efficiency of GSE-FEC with different ModCods for DiffServ classes. The results show that BE has the best efficiency because the efficiency is proportional with the packet size as Fig.8 and Fig.9 shows. And the efficiency for all DiffServ Classes can be improved with puncturing columns.

Table 2 Packet size definitions for DiffServ classes

DiffServ-Class	*Class Name*	*Packet Size*
EF	Premium	60 Byte
AF Class 1(AF1)	Gold	40 Byte
AF Class 2(AF2)	Silver	552 Byte
AF Class 3(AF3)	Bronze	576 Byte
BE	Best-Effort	1500 Byte

Table 3 The efficiency of DiffServ classes with different ModCod using GSE-FEC encapsulation ($\psi_{TOT}(L_{IP},\eta_{punct}=0 \text{ or } 64,\eta_{Cod})$)

	ModCods		*DiffServ Classes*				
	Modulation	*Coding Rate*	*EF*	*AF1*	*AF2*	*AF3*	*BE*
Without Puncturing Columns	*QPSK*	*1/4*	0.6500	0.6194	0.7251	0.7254	0.7273
	8PSK	*3/5*	0.6580	0.6225	0.7299	0.7302	0.7321
	16APSK	*3/4*	0.6575	0.6234	0.7298	0.7300	0.7320
	32APSK	*8/9*	0.6573	0.6224	0.7292	0.7294	0.7314
Puncturing 64 Columns	*QPSK*	*1/4*	0.8678	0.8269	0.9681	0.9685	0.9710
	8PSK	*3/5*	0.8785	0.8311	0.9745	0.9749	0.9774
	16APSK	*3/4*	0.8778	0.8323	0.9743	0.9746	0.9773
	32APSK	*8/9*	0.8775	0.8310	0.9735	0.9738	0.9765

V. Conclusion

In this paper, PL-FEC is applied at three different encapsulation protocols MPE, ULE and GSE. A layered efficiency calculation model is presented in order to compute the transport efficiency of MPE-FEC ULE-FEC and GSE-FEC over DVB-S2 networks. The performance of GSE-FEC is also analyzed when adopted by the IP traffic and DiffServ Classes with different ModCods. The results show that the total efficiency of DVB-S2 network has a low relation with ModCods and can be approximated as a function only with the distribution of IP packet size and puncturing efficiency. The theoretical analysis and comparison of the simulation results revealed that GSE-FEC is more efficient than MPE-FEC and ULE-FEC for DVB-S2 networks. The efficiency of GSE-FEC can be also improved by puncturing RS columns. The results show that the efficiency is improved about 5% with puncturing 16 RS columns and 25% with puncturing 64 RS columns. But the number of punctured RS columns should be designed precisely because it will deteriorate the performance of the receive systems.

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