Analysis and Implementation of Encapsulation Schemes for Baseband Frame of DVB-S2 Satellite Modulator

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ABSTRACT
This paper presents the analysis and implementation of encapsulation schemes for baseband frame of DVB-S2 satellite modulator. As convergence is the main issue in broadcast communications, encapsulation schemes enable the carriage of network layer packets over DVB networks in an effective manner. In order to meet the requirements of different complex stages of the DVB-S2 baseband signal flow, the presented encapsulation schemes are efficient. Efficiency of encapsulation schemes under different criteria of DVB-S2 baseband frame is calculated. The baseband frame is first simulated & implemented on Xilinx ISE software tool for hardware realization. The framing model is tested on Zynq based Xilinx Field programmable Gate array (FPGA) Development Platform.

General Terms
DVB-S2, encapsulation, FPGA

Keywords
MPE, ULE, Transport stream, GSE, Baseband frames

1. INTRODUCTION
DVB-S2 is the second generation standard for satellite broadcasting, developed by the Digital Video Broadcasting (DVB) Project as a successor of worldwide known DVB-S standard [1] [14]. This architecture is designed for broadband satellite applications such as digital television or radio, as well as interactive services such as Internet access or content distribution. The first generation digital video broadcast systems, DVB-S has adopted a MPEG-2 data structure, which is optimized for the broadcast delivery of digital television data and not for transporting IP packets. Multi Protocol Encapsulation (MPE) and Unidirectional Lightweight Protocol (ULE) adopt MPEG-2 TS format [3], whereas Generic Stream Encapsulation (GSE) provides a more flexible solution for DVB-S2 by deflecting double encapsulation overhead[6].

DVB-S2 provides several functionalities of physical layer such as modulation and synchronization, and also of link layer such as coding, multiplexing and concatenation. It implements the most recent modulations and channel coding with the use of QPSK, 8PSK, 16APSK, 32APSK and especially concatenated Bose-Chaudhuri- Hocquenghem (BCH) and Low Density Parity Check (LDPC) codes. The LDPC code rate can be chosen among 11 values [1]. A powerful FEC system allows Quasi-Error-Free operation at about 0.7 dB to 1 dB from the Shannon limit, depending on the transmission mode [1] [2]. DVB-S2 improves bandwidth efficiency over DVB-S by 30% [1]. It also defines the Generic Stream (GS) as a method of packet-based data carriage without MPEG-2 TS encoding.

In this paper, the implementation of framing for DVB-S2 modulator is investigated. In Section 2, the encapsulation schemes viz. MPE, ULE and GSE that are used for the framing are presented. Section 3 presents the comparisons of frame overhead and efficiency calculations. Section 4 is devoted to the explanation of implementation methodology and results. The final conclusions are drawn in section 5.

2. ENCAPSULATIONS OVER DVB-S2
2.1 MPEG-2 Transmission Networks
DVB broadcast networks are part of MPEG-2 transmission networks. These networks utilize the MPEG-2 Transport Stream (TS) as a common mechanism for combining elementary video, audio, and auxiliary data streams of television programs into a single or multiple Transport Streams for carriage over error prone transmission links. The protocol has been designed for efficiency and simplicity of implementation in high bandwidth broadcast applications.

2.2 Multi-Protocol Encapsulation
Multi-Protocol Encapsulation (MPE) protocol is a standard method to carry IP packets over MPEG-2 TS as a native to DVB-S. It inherits Section data structure with a default header size of 12 bytes. Fig.1 and 3 show the format of an MPE Section. The header includes various fields such as 6 Address bytes, a 12-bit Section Length field, 2 bits each for Payload Scrambling Control (PSC) and Address Scrambling Control (ASC) and an 8 byte LLC/SNAP Flag that indicates the presence of IEEE 802.2 Logical Link Control/Subnetwork Access Point (LLC/SNAP) field following the header. The Address bytes may carry an IEEE 802 address identifier and support the delivery of packets to individual receivers.

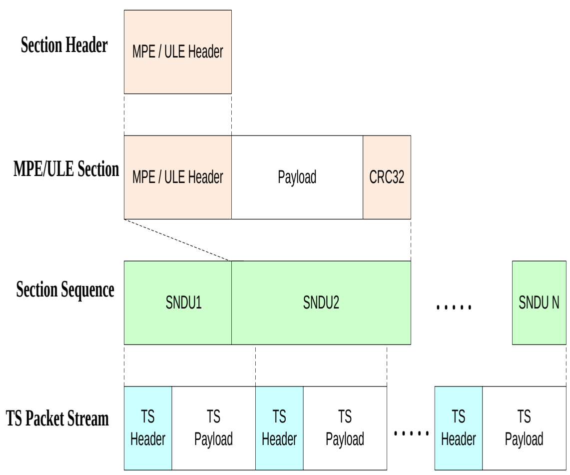

Fig 1. Overview of Transport System

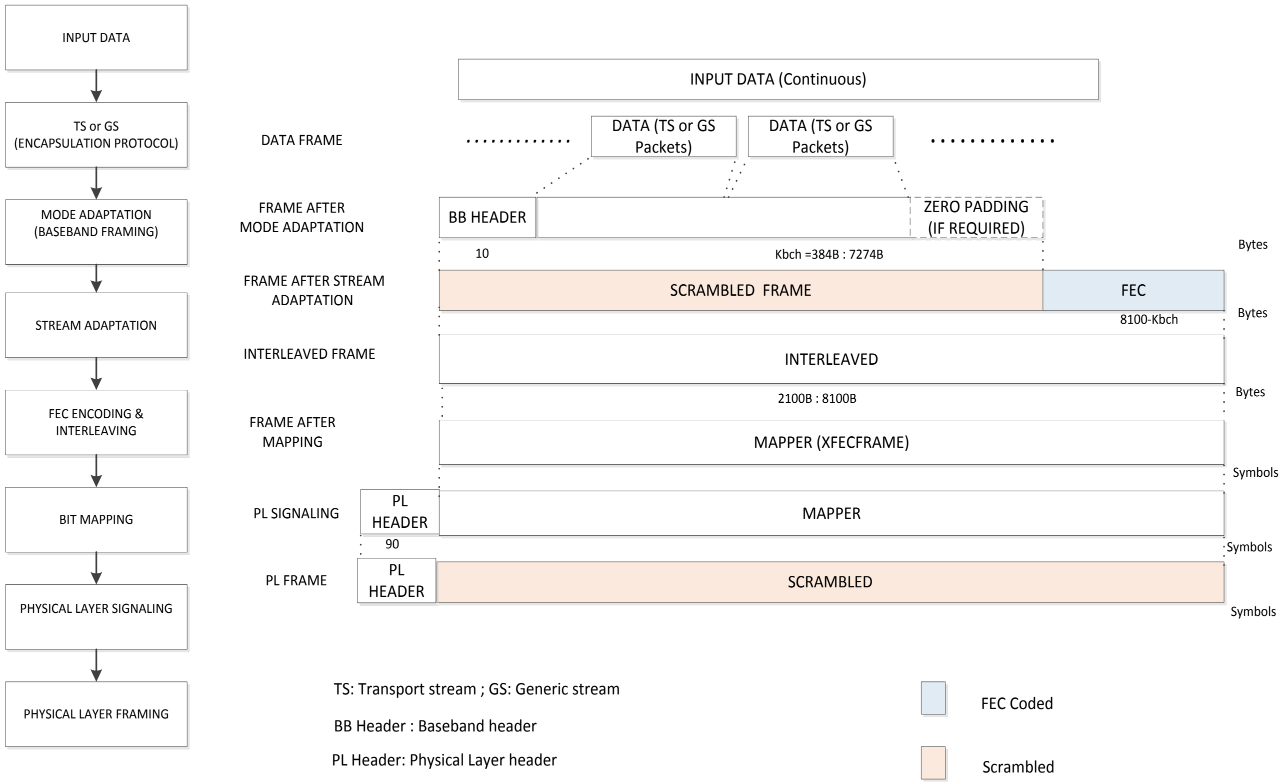

Fig 2. Overview of DVB-S2 Frame Format

The number of bytes used for receiver addressing can be controlled via signaling [12]. The Section Length field specifies the size of an encapsulated packet. The LLC/SNAP field can be used to carry non IP protocol data [4]. The last four bytes within the payload of an MPE Section are reserved for a CRC-32, which provides the verification of correct reassembly of Sections and the detection of bit errors if any. Both section packing and padding modes are supported in MPE. Padding may be required when no data is scheduled for transmission.

Table ID (0x3E)	Flags	Section Length	MAC 6,5	Flags & Section Number	MAC 4,3,2,1	LLC/SNAP (Optional)
1B		3B	5B	8B	12B	20B

Fig.3 MPE Header Format

2.3 Unidirectional Lightweight Encapsulation

The Unidirectional Lightweight Encapsulation (ULE) protocol is an alternative to MPE which is a lightweight and extensible solution for carrying IPv4, IPv6 and Protocol Data Units (PDUs) over MPEG-2 transmission networks. The ULE packet format is outlined in fig 4. Protocol fields include a 15 bit ULE Sub-Network Data Unit (SNDU) Length identifier, a 16-bit protocol/next-header Type field, a 6 byte Network Point of Attachment (NPA) address or Label whose presence is indicated via a Destination Absent (D) bit, and a CRC-32 for error protection. NPA is like an IEEE 802.3 MAC address and is used to identify the receivers within the network [4]. The Type field supports the set of Ether Type code points defined by IEEE 802.3/Ethernet II specifications [10]. ULE has adopted the fragmentation mechanism defined for MPEG-2 Sections. ULE SNDUs (Sub Network Data Units) may be contiguously mapped into TS cells as shown in fig. 1.

D	Length	Payload Type	Destination NPA (Optional)
1b	2B	4B	10B

Fig. 4 ULE Header Format

2.4 Generic Stream Encapsulation

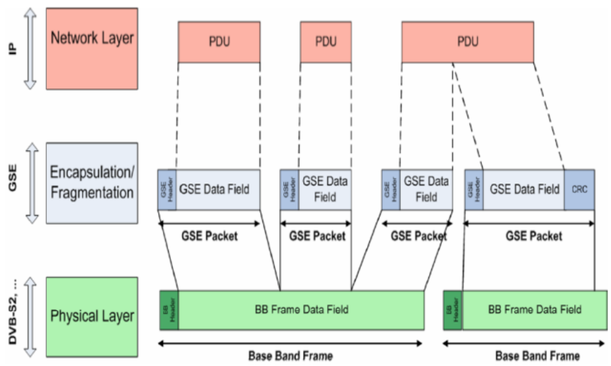

Fig.5 Overview of Generic Stream for DVB-S2 [6]

The Generic Stream Encapsulation (GSE) protocol has been designed as an efficient, lightweight and extensible encapsulation mechanism for GS transmission over DVB-S2 broadcast links. It inherits the ULE protocol and shares the same extension header mechanism as that of ULE. In comparison with ULE, some noticeable changes have been added such as Fragmentation Identifier and label. The label may be optionally reduced to a shorter 3 byte address format or it may be omitted by label reusing within a baseband frame [6]. A flexible payload fragmentation mechanism is available for GSE, which allows pre-emption of high priority data due to QoS demands. A CRC is omitted from unfragmented GSE SNDUs. Thus, the CRC is responsible for the detection of reassembly errors but not for the detection of bit errors. GSE fragmentation is quite independent of the baseband frame format. Still GSE packets must not cross any baseband frame boundaries [12].

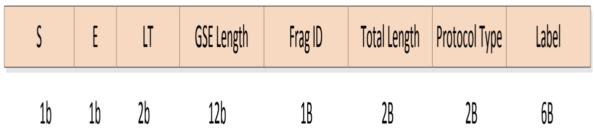

Fig.6 GSE Header Format

Fig. 6 shows the general format of GSE packets, while fig.5exemplifies the mapping of GSE packetized streams and into baseband frames. The GSE header contains a Start (S) and End (E) bit to indicate whether the current GSE packet contains an entire PDU or the start of packet, continuity or an end of payload data. For scheduling of GSE packets a 1 byte fragmentation identifier (Frag ID) is present in GSE packets containing fragmented payload data which provides a multiplexing ability up to 256 logical channels [6]. For each such channel data may be independently scheduled for transmission. This may be particularly advantageous to fill the remaining space of an incomplete baseband frame with partial content of a low-priority PDU. The 2 bit Label Type (LT) field of GSE packets has significance only for full GSE packets or GSE start packets, and indicates the length of NPA address i.e. 0, 3 or 6 bytes. It also signifies whether the Label from the previous GSE packet within the current baseband frame is to be taken. The 12 bit Packet Length field refers to the size of the GSE packet with a maximum value of 4KB compared to ULE [6]. For GSE packets containing payload fragments, a Total Length field identifies the length of the complete payload.

3. COMPARISONS & EFFICIENCY CALCULATIONS

3.1 Overhead Comparison

The amount of overhead is a function of the size and time at which of the IP packets are being sent [4]. For small packet size, GSE and ULE have a major advantage over MPE as many small packets can be packed in a single cell. The overhead may vary for the same encapsulation protocol according to application area and introduction of respective optional header fields. Baseband frame if a function of Kbch i.e. BCH uncoded block length [1] which is an aggregation of 10B baseband header and baseband payload data. It is mandatory to meet the standard Kbch value according to LDPC code rate [1]. The maximum number of MPEG-2 packets per baseband frame is calculated according to (1). Table 1 shows the overhead comparisons.

Number of packets in BBFrame = (Kbch-Size of Baseband header)/Size of packet. (1)

Number of TS packets= (Kbch-80)/1504

Table 1: Summary of encapsulation overheads

Encapsulation Header Type	Overhead (Bytes)	Header Fields & Function
MPE	12+4=16	No LLC/SNAP header; No ether type
	12+8+4=24	With LLC/SNAP header; Ether type allowed
ULE	4+4=8	D=1; omitting Destination Receiver address
	4+6+4=14	D=0; including Destination address
GSE	7.5	S=E=1:Single packet without fragmentation
	10	S=E=0 : with fragmentation ID & 3B label
	13	S=E=0 : with fragmentation ID & 6B label
	10+4=14	S=0,E=1 : Last Packet; with fragmentation ID & 3B label
	13+4=17	S=0,E=1 : Last Packet; with fragmentation ID & 6B label

Table 2 shows the number of MPEG-2 TS packets that can be equipped in short (16200 bits) and normal (64800 bits) size frames. Increase in modulation and coding rate i.e. MODCOD, leads to more TS packet content per baseband frame. Hence the choice of normal FEC frame size can be useful. The numbers of TS packets are independent of modulation scheme, but depend on LDPC code rate. As GSE is flexible to comprise a number of packets up to 4KB, the number of GS packets per baseband frame is also tangible. From Table 2 it can be recommended to have a choice of higher modulation & coding scheme.

3.2 Transmission Efficiency

An important characteristic of any encapsulation protocol is its Transport efficiency. Transport efficiency of any encapsulation protocol is a function of size of network layer packet and the included overhead bytes. Table 1 shows the amount of overhead for MPE, ULE and GSE under different scenarios. The available bandwidth capacity should be exploited at its peak, and should not be cut down in unnecessary overhead. Section packing mode can lead to lesser overhead than section padding mode for efficient bandwidth usage.

Table 2: Maximum number of TS packets per baseband frame

Modulation & Code rate (MODCOD)		BCH Uncoded Block Length (Kbch bits)		Useful Data Per FEC Frame		Number of TS Packets	
		Short	**Normal**	**Short**	**Normal**	**Short**	**Normal**
QPSK	1/4	3072	16008	2992	15928	1	10
	1/3	5232	21408	5152	21328	3	14
	2/5	6312	25728	6232	25648	4	17
	1/2	7032	32208	6952	32128	4	21
	3/5	9552	38688	9472	38608	6	25
	2/3	10632	43040	10552	42960	7	28
	3/4	11712	48408	11632	48328	7	32
	4/5	12432	51648	12352	51568	8	21
	5/6	13152	53840	13072	53760	8	35
	8/9	14232	57472	14152	57392	9	38
	9/10	NA	58192	NA	58112	NA	38
8PSK	3/5	9552	38688	9472	38608	6	25
	2/3	10632	43040	10552	42960	7	28
	3/4	11712	48408	11632	48328	7	32
	5/6	13152	53840	12352	51568	8	21
	8/9	14232	57472	14152	57392	9	38
	9/10	NA	58192	NA	58112	NA	38
16APSK	2/3	10632	43040	10552	42960	7	28
	3/4	11712	43408	11632	48328	7	32
	4/5	12432	51648	12352	51568	8	21
	5/6	13152	53840	13072	53760	8	35
	8/9	14232	57472	14152	57392	9	38
	9/10	NA	58192	NA	58112	NA	38
32APSK	3/4	11712	48408	11632	48328	7	32
	4/5	12432	51648	12352	51568	8	21
	5/6	13152	53840	13072	53760	8	35
	8/9	14232	57472	14152	57392	9	38
	9/10	NA	58192	NA	58112	NA	38

Transmission efficiency = (Encapsulated payload bytes) / (Transmitted bytes) (2)

Efficiency for encapsulation scheme = (Packet Length)/ (Length of SNDU+ Overhead).

Table 3 shows the formulae for calculating the lengths of SNDU for MPE, ULE and GSE. Efficiency can be calculated using (2).

Table 3: Formulae for SNDU length calculation

Type	Criteria	Length of SNDU
MPE	No LLC/SNAP	$(\text{Packet Length} + 16) \times \frac{188}{184}$
	With LLC/SNAP	$(\text{Packet Length} + 24) \times \frac{188}{184}$
ULE	No NPA	$(\text{Packet Length} + 8) \times \frac{188}{184}$
	With NPA	$(\text{Packet Length} + 14) \times \frac{188}{184}$
GSE	Frag ID = 0	$(\text{Packet Length} + 4 + \text{Label}) \times \frac{\text{BBFrame}}{(\text{BBFrame}-10)}$
	Frag ID > 1	$(\text{Packet Length} + 8 + \text{Label}) \times \frac{\text{BBFrame}}{(\text{BBFrame}-10)}$

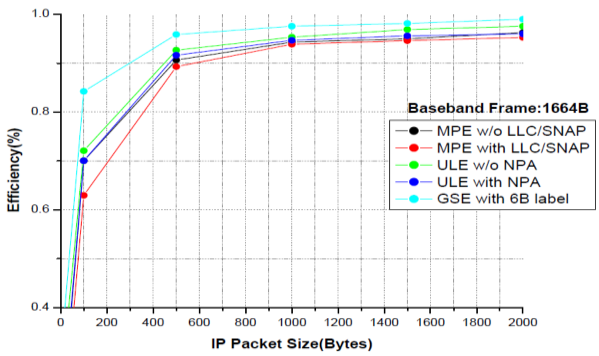

Fig. 7 Efficiency comparison for MPE, ULE & GSE in BBFrame of 1164 Bytes

Fig. 7 and 8 show the efficiency comparisons for different encapsulation schemes under varying IP packet sizes. For efficiency analysis, the sample calculations are done for LDPC code rate of 3/4 and baseband frame of size 1164 bytes and 6730 bytes respectively, including 10 byte baseband header. GSE outputs are mapped directly onto baseband frame whereas MPE and ULE add the extra amount of overhead to output of baseband frame. From fig. 7 and 8, the efficiency of GSE is ~98% and that of MPE, ULE are ~95% and ~96% respectively.

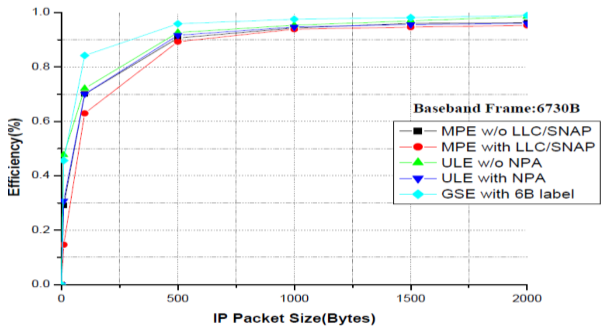

Fig. 8 Efficiency comparison for MPE, ULE & GSE in BBFrame of 6730 Bytes

4. Hardware Implementation & Results

4.1 Baseband Frame Specifications

The specifications considered for baseband framing are:

- Operation Mode: Constant Coding & modulation
- Encapsulation schemes: MPE, ULE, GSE
- Modulation: 32APSK, Code rate: 3/4
- MODCOD: 24
- Input stream: Single TS or GS
- FECFrame size: 64800bits
- Kbch: 43408bits

4.2 Hardware Implementation & Testing

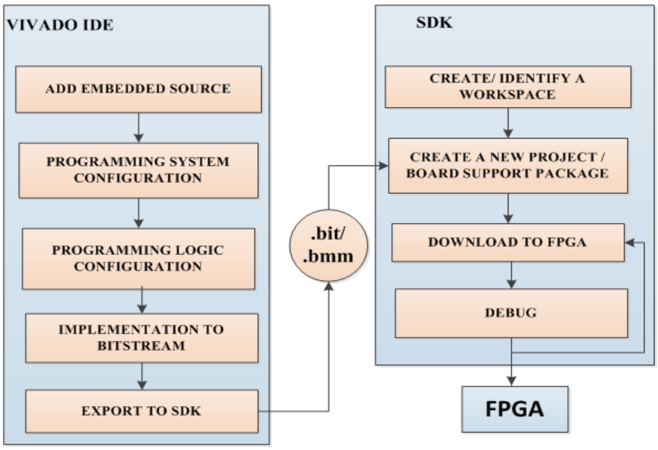

Fig. 9 Hardware Implementation Flow

Vivado IP integrator design suite is used for creating hardware specific platform, PS configuration and constraints assignments whereas Xilinx Software Development Kit is used for application development. Hardware implementation is done on Zynq based FPGA development board i.e. ZedBoard that has Zynq SoC with Cortex-A9 core [13]. The implementation flow is shown in fig. 9 and fig. 10 shows the setup used for testing of baseband frame. Baseband frame is given to modem for testing using ZedBoard which is ported with baseband code. Transmitted and received data are compared using Oscilloscope and Digital Logic Analyzer.

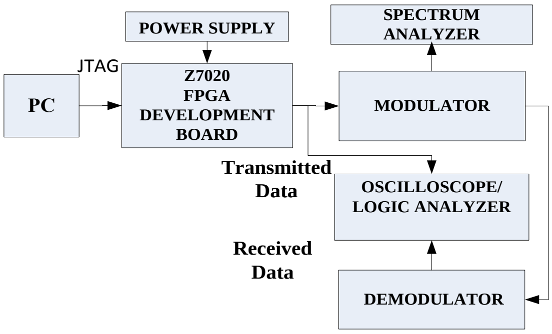

Fig 10: Test setup

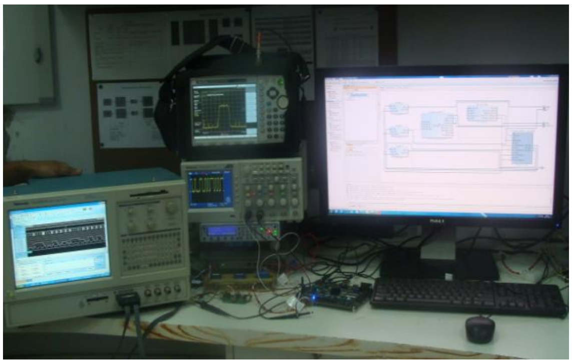

Fig 11: Actual Test setup

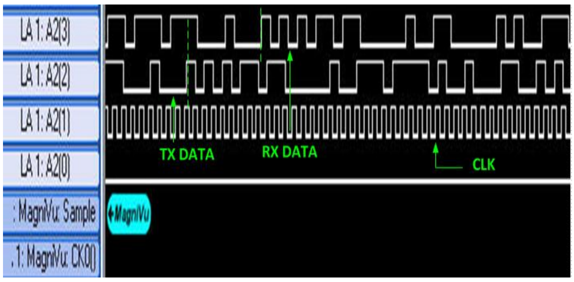

Fig 12: Logic Analyzer Results

5. CONCLUSIONS

In this paper different encapsulation schemes are discussed in order to optimize data transmission and bandwidth capacity over DVB-S2 baseband frame. Efficiency calculations are performed on MPE, ULE and GSE, which show that GSE is more efficient than other encapsulation schemes. The efficiency gain of GSE ranges from 1% to 4%. Hence GSE provides efficient broadcasting over other two encapsulation protocols. The configurability and efficiency introduced by GSE in DVB-S2 gives significant advantage over DVB-S. Ideally transmitted and received baseband frames should be same. This is verified successfully. Further work will be to implement the baseband frame for Variable Coding & Modulation (VCM) as well as Adaptive Coding & Modulation (ACM) modes of DVB-S2.

6. ACKNOWLEDGMENTS

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