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International Telecommunication Union
Standardization Sector

Recommendation

ITU-T G.709.1 (03/2024)

SERIES G: Transmission systems and media, digital systems and networks

Digital terminal equipments – General

Flexible OTN common elements

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Recommendation ITU-T G.709.1

Flexible OTN common elements

Summary

Recommendation ITU-T G.709.1 specifies common elements and signal structures used by various types of flexible optical transport network (FlexO) interfaces.

Edition 3.0 removes short-reach interfaces which are moved to Recommendation ITU-T G.709.5. This Recommendation is renamed and focuses on common FlexO elements.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
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3.0	ITU-T G.709.1	2024-03-08	15	11.1002/1000/15810

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FOREWORD

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The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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Recommendation ITU-T G.709.1

Flexible OTN common elements

1 Scope

This Recommendation specifies common elements and signal structures used by various types of flexible optical transport network (FlexO) interfaces, both for single vendor applications and multi-vendor interoperable applications. Such definitions include FlexO frame, FlexO instance interleaving, mapping procedures to FlexO-n(e) and FlexO overhead. FlexO interfaces support bonding (i.e., grouping) of multiple interfaces such that one or more client signals (e.g., OTUCn or Ethernet) can be transferred via one or more optical tributary signals (OTSi) over one or more physical interfaces. Interoperable short-reach and long-reach interfaces are defined in other Recommendations such as [ITU-T G.709.3], [ITU-T G.709.5] and [ITU-T G.709.6].

In addition, some introduction material for the various short and long-reach applications is included.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.698.2] Recommendation ITU-T G.698.2 (2018), *Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces.*

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2020), *Interfaces for the optical transport network*.

[ITU-T G.709.3] Recommendation ITU-T G.709.3 (2024), *Flexible OTN B100G long-reach interfaces*.

[ITU-T G.709.5] Recommendation ITU-T G.709.5 (2024), *Flexible OTN short-reach interfaces*.

[ITU-T G.709.6] Recommendation ITU-T G.709.6 (2024), *Flexible OTN B400G long-reach interfaces*.

[ITU-T G.798] Recommendation ITU-T G.798 (2023), *Characteristics of optical transport network hierarchy equipment functional blocks*.

[ITU-T G.872] Recommendation ITU-T G.872 (2024), *Architecture of the optical transport network*.

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2024), *Optical transport network physical layer interfaces*.

[ITU-T G.7041] Recommendation ITU-T G.7041/Y.1303 (2016), *Generic framing procedure*.

[ITU-T G.8260] Recommendation ITU-T G.8260 (2022), *Definitions and terminology for synchronization in packet networks*.

[IEEE 802.3] IEEE Std. 802.3-2022, *IEEE Standard for Ethernet.*

[IEEE 802.3df]	IEEE Std. 802.3df-2023, *IEEE Standard for Ethernet Amendment 9: Media Access Control Parameters for 800 Gb/s and Physical Layers and Management Parameters for 400 Gb/s and 800 Gb/s Operation*
[NIST SP 800-38D]	National Institute of Standards and Technology (2007), *Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC.*
[OIF FlexE]	Optical Interworking Forum, OIF (2021), *FlexEthernet Implementation Agreement 2.2*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 Terms defined in [ITU-T G.709]:

– completely standardized OTUCn (OTUCn)

– optical transport network (OTN)

3.1.2 cipher text [b-ITU-T X.800]: Data produced through the use of encipherment. The semantic content of the resulting data is not available.

3.1.3 confidentiality [b-ITU-T X.800]: The property that information is not made available or disclosed to unauthorized individuals, entities, or processes.

3.1.4 encryption [b-ITU-T X.800]: The cryptographic transformation of data to produce ciphertext.

3.1.5 integrity [b-ITU-T X.800]: The property that data has not been altered or destroyed in an unauthorized manner.

3.1.6 key [b-ITU-T X.800]: A sequence of symbols that controls the operations of encipherment and decipherment.

3.1.7 plaintext [b-ISO/IEC 18033-3]: Unenciphered information.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 FlexO: Information structure with a specific bit rate and frame format, consisting of overhead and payload, intended to be used in a group.

3.2.2 FlexO-n: Information structure consisting of a group of n ($n \geq 1$) FlexO instances for the transport of OTUCn and Ethernet clients.

3.2.3 FlexO-x: Information structure consisting of x ($x \geq 1$) interleaved FlexO instances, intended to be used in a group with m ($m = \lceil n/x \rceil$) instances for the transport of client signals such as OTUCn or Ethernet. The order x signifies the FlexO-x interface rate in units of 100G.

3.2.4 FlexO-x-<int>: Information structure consisting of a FlexO-x plus FEC parity and possibly DSP framing. In some instances, <int> name indicates modulation type.

3.2.5 FlexO-x-<int> interface: Refers to an individual member interface that is part of a FlexO-x-<int>-m interface group.

NOTE – The terms "member" and "PHY" are often used to refer to a FlexO-x-<int> interface.

3.2.6 FlexO-x-<int>-m interface group: Refers to the group of m × FlexO-x-<int> interfaces.

NOTE – The text may use "FlexO group" as short-hand for FlexO-x-<int>-m interface group.

3.2.7 FOICx.k-<int>: Refers to a FlexO-x-<int> interface using k parallel lanes.

NOTE – "FOICx.k" is the FlexO equivalent of "OTLk.m" for OTUk as defined in [ITU-T G.709].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AAD	Additional Authenticated Data
AIS	Alarm Indication Signal
AMi	Alignment Marker of index i
AM	Alignment Mechanism
AT	Authentication Tag
B100G	Beyond 100G
B400G	Beyond 400G
BIP	Bit Interleaved Parity
BMP	Bit-synchronous Mapping Procedure
BOH	Basic Overhead Field
CFP2	C (100G) Form-factor Pluggable Optical Module, form factor type 2
CRC	Cyclic Redundancy Check
CSF	Client Signal Fail
CST	Cipher Suite Type
CSTAT	Client status
EOH	Extended Overhead Field
FA	Frame Alignment
FAS	Frame Alignment Signal
FBA	FEC Block Alignment
FCC0/1	FlexO Communications Channel 0 or 1
FEC	Forward Error Correction
FlexE	Flexible Ethernet
FlexO	Flexible Optical Transport Network
FN	Frame Number
FS	Fixed Stuff
GFP	Generic Framing Procedure
GID	Group Identification
GMP	Generic Mapping Procedure
IA	Implementation Agreement
IID	FlexO Instance Identification
IV	Initialization Vector
KCC	Key exchange Communication Channel

KI	Key Index
LCK	Locked
LD	Local Degrade
LF	Local Fault
LSB	Least Significant Bit
MAP	FlexO Map field
MDI	Media Dependent Interface
MFAS	Multi-Frame Alignment Signal
MNT	Maintenance
MS	Multiplexed Section
MSB	Most Significant Bit
ODU	Optical Data Unit
OFEC	Open FEC
OH	Overhead
OPU	Optical Payload Unit
OSMC	OTN Synchronization Messaging Channel
OTL	Optical Transport Lane
OTN	Optical Transport Network
OTSi	Optical Tributary Signal
OTU	Optical Transport Unit
OTUCn	OTU order Cn
PCS	Physical Coding Sublayer
PHY	Physical Layer
PRBS	Pseudo Random Binary Sequence
PT	Payload type
PTP	Precision Time Protocol
QSFP28	Quad (100G) Small Form-factor Pluggable
RD	Remote degrade
RES	Reserved for Future International Standardization
RPF	Remote Physical Layer Fault
RS	Reed-Solomon
RSTAT	Regen Status
SSM	Synchronization Status Message
STAT	FlexO Status
RTTI	Regen Trail Trace Identifier
WDM	Wavelength Division Multiplexing

5 Conventions

This Recommendation uses the following conventions:

Names of information structures and interfaces

The terms FlexO-n, FlexO-x, FlexO-x-<int>, FlexO-x-<int>-m, and FOICx.k-<int> are used to refer to FlexO information structures and interfaces that are optimized for OTN bit rates.

n: The index "n" is used to represent the number of FlexO instances that are in a FlexO group.

x: The index "x" is used to represent the bit rate of the FlexO interface, in 100G increments. For example, x=1 for 100G, x=2 for 200G, x=4 for 400G, etc.

(e): When used as FlexO-x(e), it is short-hand for "or" (e.g., FlexO-x or FlexO-xe), with the "e" meaning optimized for Ethernet payloads. Same short-hand concept is used for FlexO-n(e).

m: The index "m" is used to represent the number of interfaces in a FlexO group. m is also used to represent the number of bits in a block of data/stuff in client mappings.

k: The index "k" is used to represent the number of lanes on an FOICx.k-<int> interface.

<int>: The <int> placeholder is used by specific short-reach and long-reach interface Recommendations to provide a unique name to the interface. The interface can be identified by a FEC type or a combination of FEC type and modulation type.

Transmission order: The order of transmission of information in all the diagrams in this Recommendation is first from left to right and then from top to bottom. Within each byte the most significant bit is transmitted first. The most significant bit (bit 1) is illustrated on the left side of all diagrams.

Value of reserved bit(s): The value of an overhead bit, which is reserved for future international standardization, shall be set to "0".

Value of non-sourced bit(s): Unless stated otherwise, any non-sourced bits shall be set to "0".

6 Introduction and applications

Flexible optical transport network (FlexO) interface groups (FlexO-x(e)-<int>-m) are defined for a variety of applications. They complement [ITU-T G.709], by providing interfaces for OTUCn transport as well as interfaces for Ethernet optimized transport. A FlexO-x-<int>-m interface group provides modularity by bonding standard-rate interfaces (e.g., 100G and 400G), over which the OTUCn clients are adapted and multiplexed. A FlexO-xe-<int>-m interface group is optimized for adapting and multiplexing Ethernet clients.

A FlexO-x(e)-<int>-m interface provides FEC, scrambling, bit alignment as well as operational, administrative and maintenance overhead. Common elements of the information structure (e.g., FlexO-x) can be leveraged for functionally standardized single vendor interfaces. Fully standardized multi-vendor interoperable interfaces are also defined in companion FlexO Recommendations for both short-reach and long-reach applications.

FlexO instance rates are designed to support reuse of 100G pluggable modules that also support OTU4 as specified in [ITU-T G.709].

A FlexO-x(e)-<int>-m interface group:

– provides an interoperable system OTN interface;
– enables higher capacity clients (e.g., ODUflex and OTUCn), by means of bonding m interfaces in a group;
– provides a FEC tailored for the application;
– provides optional encryption at the FlexO layer;

– provides interface rate modularity and flexibility;
– provides a frame, alignment, deskew, group management, management communication channel and such functions that are not associated with the client signal;
– enables regeneration applications.

6.1 Short-reach FlexO interfaces

Short-reach interfaces are specified in [ITU-T G.709.5] using a Reed-Solomon forward error correction or RS FEC typical of similar Ethernet interfaces and are intended to support multi-vendor interoperable connectivity. Short-reach interfaces are often supported on direct detect multi-lane modules such as QSFP28, QSFPDD, OSFP and CFP2. Short-reach interfaces only support OTUCn clients, and do not include Ethernet optimized variants.

NOTE – The logical signal format of FlexO short-reach interface (FOICx.k-RS) can be reused on a system internal interface (interoperable component-to-component interface) specified in [b-ITU-T G-Sup.58].

Example applications are provided in Appendix I.

6.2 Long-reach FlexO interfaces

Long-reach applications can be both single vendor and multi-vendor interoperable. The multi-vendor long-reach FlexO interfaces are fully specified in [ITU-T G.709.3] for B100G rates of 100G-400G (FlexO-x with x =1, 2 and 4) and [ITU-T G.709.6] for B400G rates of 400G-800G (FlexO-x with x =4 and 8). In order to mitigate the impairments of accumulated noise, these interfaces use forward error correction (FEC) schemes with a higher coding gain than the FEC type deployed in FlexO short-reach interfaces. Long-reach FlexO interfaces are typically used with wavelength division multiplexing (WDM) and are based on coherent detection.

Example applications are shown in Appendix II.

7 Structure and processes

This clause introduces the functions associated with a FlexO-x(e)-<int>-m interface group and the basic signal structure, processes and atomic functions associated with the common FlexO elements across different types of interfaces.

7.1 Basic signal structure

The FlexO-x(e)-<int>-m interface group architecture is specified in [ITU-T G.872]. The information structure for FlexO-x(e)-<int>-m interface group is represented by information containment relationships and flows.

The principal information containment relationship for a FlexO-x(e)-<int>-m group interface is described in Figure 7-1. One or many client signals (OTUCn or Ethernet) are mapped into a FlexO-n(e) signal. The n FlexO instances from the FlexO-n(e) signal are mapped into m (m ≤ n) FlexO-x-<int> interfaces. Each FlexO-x-<int> interface contains one or more FlexO instances from the FlexO-n(e) signal. Finally, forward error correction (FEC) adaptation consists of adding FEC parity bits, and appropriate padding. The details of FEC adaptation are beyond the scope of this Recommendation.

In scenarios involving mapping of FlexO-n(e) into a FlexO-x(e)-<int>-m group interface and n < (m × x), some instances are marked unequipped as described in clause 10.

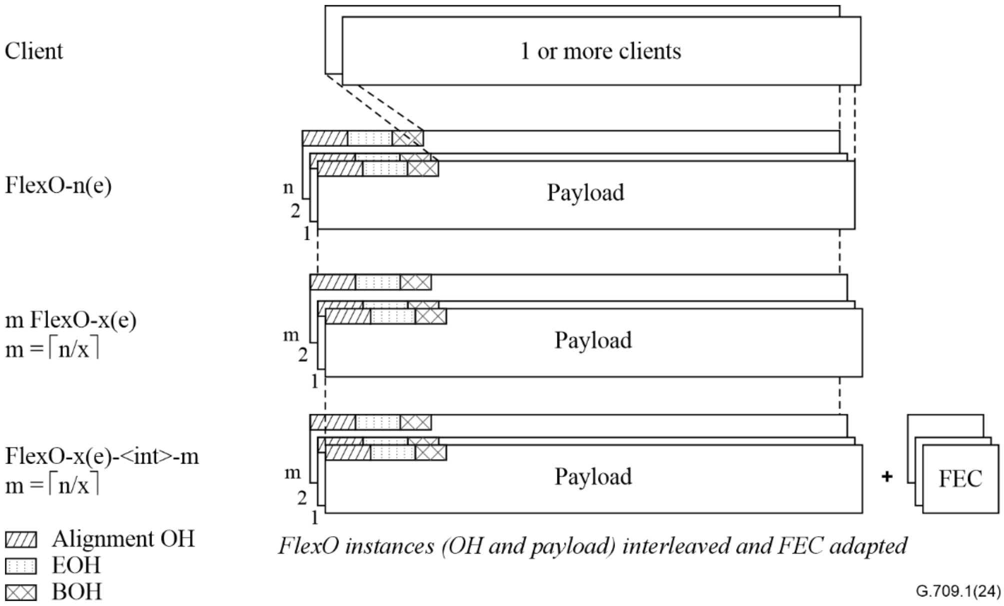

Figure 7-1 – FlexO-x(e) principal information containment relationship

7.2 Processing and information flow

Functions, processes and information flows are more formally specified in [ITU-T G.798].

8 FlexO frame and maintenance

A FlexO frame is associated with a FlexO-x(e)-<int> interface and is independent of client structures carried within the FlexO payload. A FlexO frame structure can be used for FlexO-x or Ethernet optimized FlexO-xe interfaces.

A FlexO frame consists of a frame alignment mechanism field (AM), extended overhead field (EOH), basic overhead field (BOH) and payload area.

The FlexO frames carried over m interfaces of a FlexO-x(e)-<int>-m interface group are frame/multi-frame aligned at the source.

8.1 Frame structure

The FlexO frame structure is shown in Figure 8-1 and consists of 128 rows by 5,140 1-bit columns. It contains a frame alignment mechanism field (AM) in row 1, columns 1 to 480, an extended overhead field (EOH) in row 1, columns 481 to 960, a basic overhead field (BOH) in row 1 columns 961 to 1280 and a (128 × 5140 – 1280 = 656640 bit) payload area in the remainder of the frame.

NOTE – The FlexO frame structure is derived from 100Gbit/s Ethernet clause 91 [IEEE 802.3] FEC alignment and lane architecture, without any 66b alignment or 256b/257b transcoding functions.

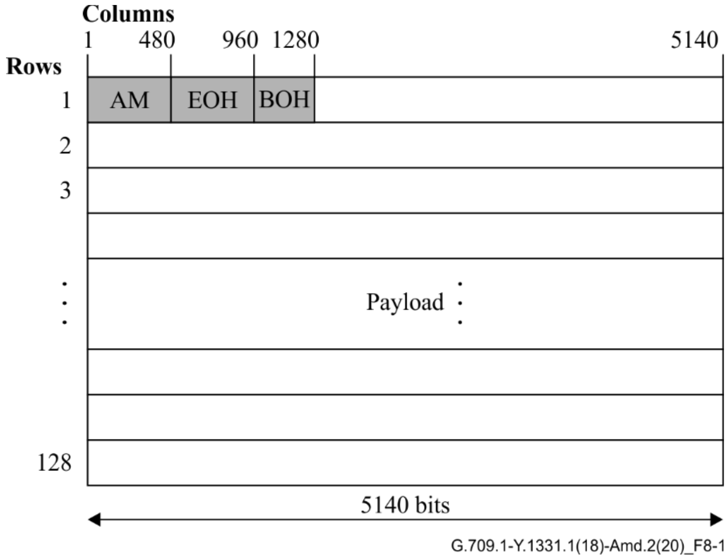

Figure 8-1 – FlexO frame structure

8.2 Multi-frame structure

In order to provide space for additional OH fields, an 8-frame FlexO multi-frame structure is defined. It uses the three least significant bits of the multi-frame alignment signal (MFAS) overhead to identify the eight frames within the multi-frame.

The multi-frame payload structure details are defined in clause 10.

8.3 Bit rates and frame periods

The bit rates and tolerances of the FlexO signal interfaces are defined in Table 8-1.

Table 8-1 – FlexO-n(e) bit rates

Interface Type	FlexO-n(e) nominal bit rate	FlexO-n(e) bit-rate tolerance
FlexO-n	n × 491384/462961 × 99 532 800 kbit/s	±20 ppm
FlexO-ne	n × 21845/25984 × 766 × 156 250 kbit/s	±20 ppm
NOTE 1 – The nominal FlexO-n bit rate is approximately: n × 105 643 510.782 kbit/s. The FlexO-n bit rate can be derived from the OTUC bit rate as follows: 4112/4097 × n × OTUC bit rate = 4112/4097 × 239/226 × n × 99 532 800 kbit/s. NOTE 2 – The nominal FlexO-ne bit rate is approximately: n × 100 622 438.327 kbit/s. The FlexO-ne bit rate can be derived from 156M Ethernet clock multiple as follows: n × 514/544 x 1445/1624 × 766 × 156 250 kbit/s.		

The frame and multi-frame periods of the FlexO signal interfaces are defined in Table 8-2.

Table 8-2 – FlexO-n(e) frame and multi-frame periods

Interface Type	Frame period (Note)	8-frame multi-frame period (Note)	4-frame multi-frame period (Note)
FlexO-n	~6.228 µs	49.822 µs	24.911 µs
FlexO-ne	~6.539 µs	52.310 µs	26.155 µs
NOTE – The period is an approximated value, rounded to 3 decimal places.			

FlexO maintenance signals such as alarm indication signal (AIS) and locked (LCK), are generated using a local clock.

8.4 FlexO-x(e) frame structure

This section defines generic z-bit interleaving for FlexO-x(e)-<int> interfaces with x > 1. The value of z is interface specific and defined by [ITU-T G.709.3], [ITU-T G.709.5] and [ITU-T G.709.6].

The FlexO-1(e) frame structure is equal to the FlexO instance frame structure as shown in Figure 8-1.

The FlexO-x(e) frame structure is shown in Figure 8-2 and consists of x × 64 rows by 10280 1-bit columns. The x FlexO instances are z-bit interleaved into the FlexO-x(e) frame in order from lowest identification (IID) to highest IID.

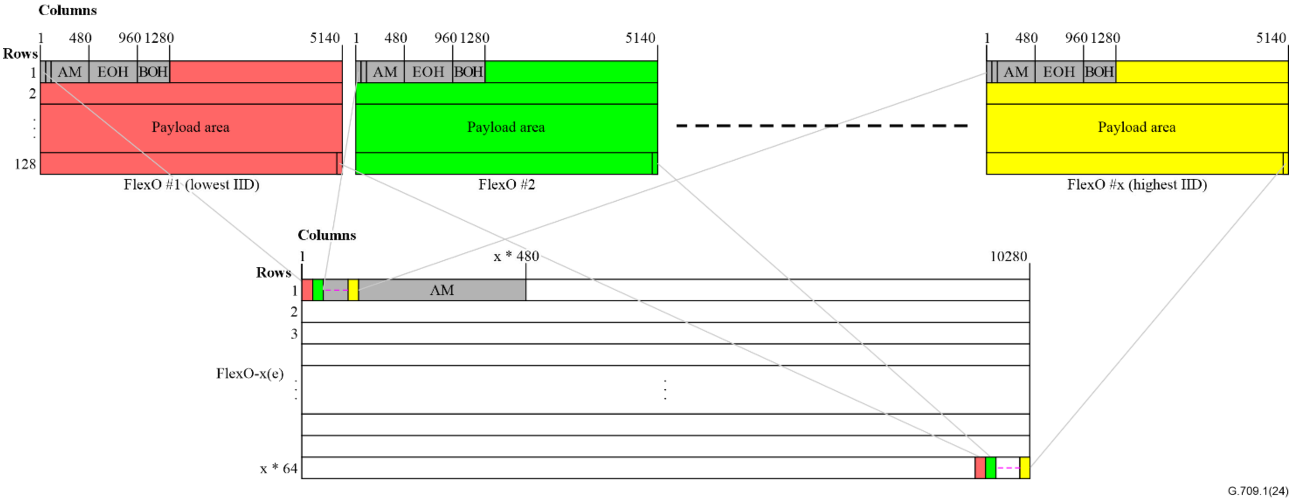

Figure 8-2 – FlexO-x(e) frame structure

8.5 FlexO maintenance

FlexO maintenance states are indicated in the maintenance (MTN) field of the STAT overhead as described in clause 9.2.3.3.

LCK and AIS definitions and behaviour are the same as [ITU-T G.709]. An alarm indication signal (AIS) is a signal sent downstream as an indication that an upstream defect has been detected. An AIS signal is generated in an adaptation sink function. An AIS signal is detected in a trail termination sink function to suppress defects or failures that would otherwise be detected as a consequence of the interruption of the transport of the original signal at an upstream point. A locked (LCK) is a signal sent downstream as an indication that upstream the connection is "locked", and no signal has passed through. An LCK signal is generated in an adaptation source or sink function. An LCK signal is detected in a trail termination sink function.

LCK is specified as a repeating "0101 0101" pattern and AIS is specified as a repeating "1111 1111" in the entire FlexO payload, BOH, EOH and AM as shown in Figure 8-3.

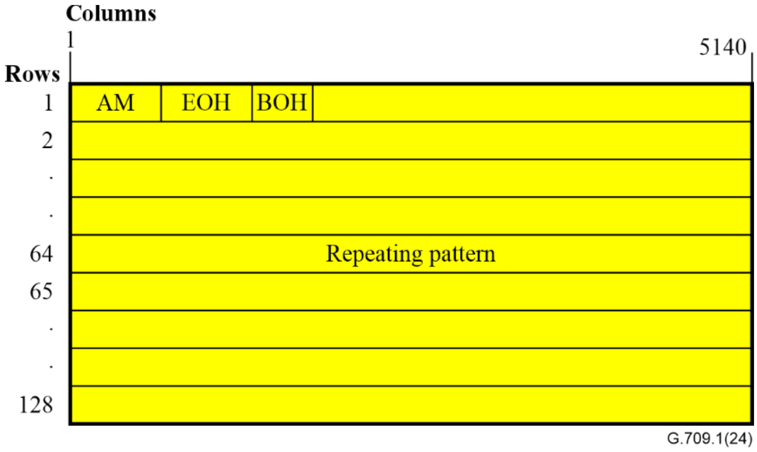

Figure 8-3 – FlexO AIS/LCK squelch

Before they are presented at the optical transport network (OTN) interface, the LCK and AIS FlexO signals are extended with AM, the MFAS and cyclic redundancy check (CRC) fields from the BOH, and may also get extended by regenerator fields from EOH and FCC1 field from BOH. This is dependent on the functionality between the LCK and AIS insertion points, and the OTN interface. The presence of LCK and AIS is detected by monitoring the MNT bits in the STAT overhead field.

9 Overhead

The FlexO frame overhead consists of alignment mechanism field (AM), basic overhead (BOH) and extended overhead (EOH). FlexO total overhead fields in an elementary FlexO frame consist of 1,280 bits per FlexO instance, 480 bits for AM, 480 bits for EOH and 320 bits for BOH.

The aggregate frame of a higher rate FlexO-x(e)-<int> interface is constructed by interleaving multiple FlexO frame instances.

An overview of FlexO frame overhead areas is presented in Figure 9-1.

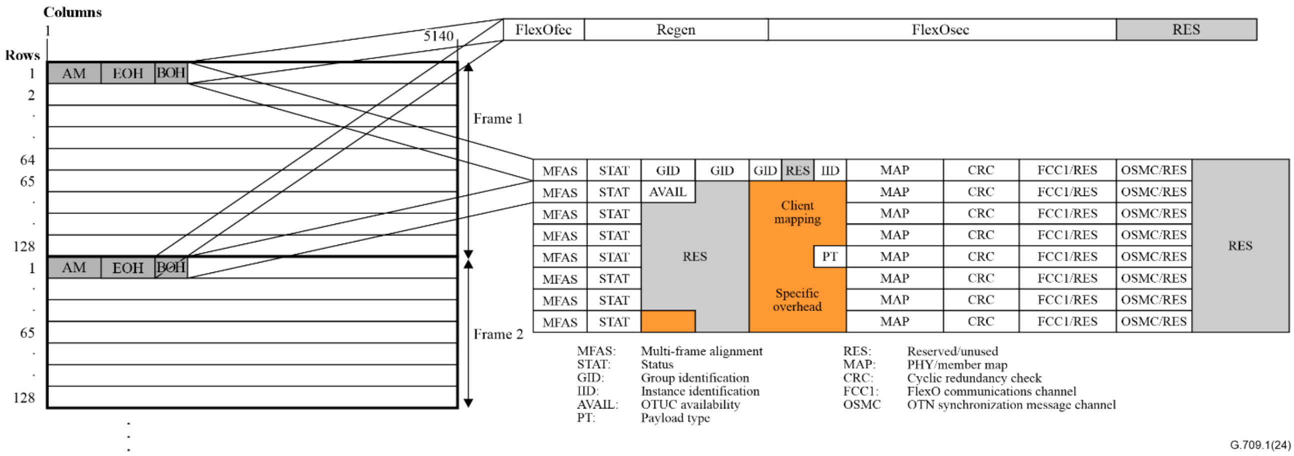

Figure 9-1 – Overhead overview

9.1 Alignment mechanism

The alignment mechanism details are interface specific and outside the scope of this Recommendation.

9.2 Basic overhead (BOH) description

The FlexO BOH field is contained in the 320 bits following the FlexO frame EOH field. The BOH structure amounts to 2,560 bits (320 bytes) and is distributed across an 8-frame multi-frame, as shown in Figure 9-2. Each frame contains 40 BOH bytes.

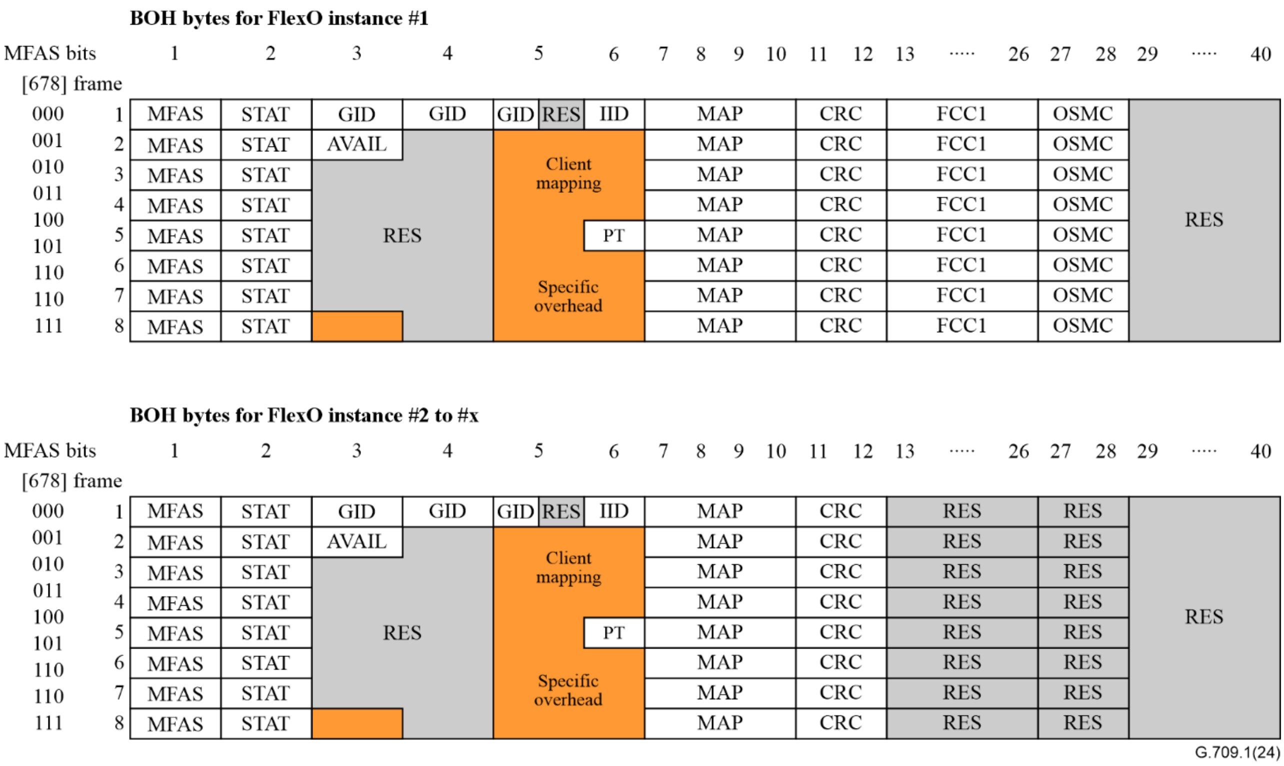

Figure 9-2 – FlexO BOH structure

The FlexO BOH field contains the following subfields (see Figure 9-2):

– multi-frame alignment signal (MFAS)

– status (STAT)

– group management overhead including:
  - group identification (GID)
  - FlexO instance identification (IID)
  - FlexO map (MAP)

– payload overhead including:
  - payload type (PT)
  - client mapping specific
  - OTUC availability (AVAIL) – defined in clause 9.2.6.1

– cyclic redundancy check (CRC)

– FlexO management communication channel (FCC1)

– OTN synchronization message channel (OSMC)

– bits reserved for future international standardization (RES)

9.2.1 Multi-frame alignment signal (MFAS)

An 8-bit (1 byte) multi-frame alignment signal field is provided and incremented in every FlexO frame. This MFAS field counts 0x00 to 0xFF and provides a 256-frame FlexO multi-frame.

This central multi-frame is used to lock 2-frame, 4-frame, 8-frame, 16-frame, 32-frame, etc. multi-frame structures of overhead and payload structure to the principal frame. The MFAS sequence is shown in Figure 9-3.

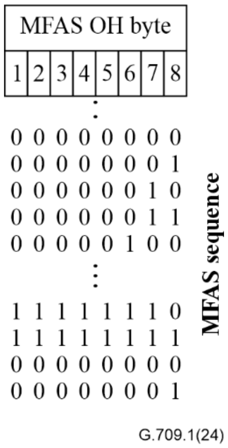

Figure 9-3 – Multi-frame alignment signal overhead

The MFAS field is located in all FlexO frames, in overhead byte 1 immediately following the AM.

9.2.2 Group management overhead

9.2.2.1 Group identification (GID)

A 20-bit (2.5 bytes) FlexO group identification (GID) field is provided to indicate the interface group instance that the FlexO-x(e)-<int> interface is a member of. The GID provides the ability to check at the receive side that the interface belongs to the intended FlexO group.

The GID field is located in frame 1, in overhead bytes 3, 4 and 5.

The same FlexO group identification value is used in both directions of transport.

Non-zero values for GID are valid and the value of "0" is reserved for this field.

A FlexO instance is marked as unequipped with its FlexO GID value default to "0" when it does not belong to any FlexO-n group and so does not carry any client signal in its payload. A FlexO-x(e)-<int> interface that is not part of any group carries unequipped FlexO instances.

9.2.2.2 FlexO instance identification (IID)

A FlexO-x(e)-<int>-m interface group is composed of m FlexO-x(e)-<int> interfaces, also referred to as members. An 8-bit (1 byte) IID field is provided to uniquely identify each FlexO instance of a group and the order of each instance and member in the group. This information is required in the reordering process.

The IID values of the interfaces in a FlexO group are not necessarily arranged consecutively. The IID values indicate the order of the interfaces within the FlexO group, from low to high. The first FlexO-x(e)-<int> interface in the group is the one with the lowest IID value(s).

The FlexO instances identification value(s) (IID) within a FlexO-x(e)-<int> interface shall all be larger than the IID value(s) within the prior FlexO-x(e)-<int> interface in the group, and shall all be smaller than the IID value(s) within the next FlexO-x(e)-<int> interface in the group.

The IID field is located in frame 1, in overhead byte 6. The values "0" and "255" are reserved for this field.

The same FlexO instance identification value is used in both directions of transport.

9.2.2.3 FlexO map (MAP)

A 256-bit (32 bytes) field is provided to indicate the members belonging to the group. Each bit in the field, is set to "1" indicating that an instance is part of the group. The bit position of the MAP corresponds to the IID set for the member FlexO-x(e)-<int> interface, with the most significant bit (MSB) corresponding to lowest numbered IID. The remaining unused fields in the MAP are set to "0". The full MAP is sent and received on all members of the group.

The MAP field is located in all frames of all FlexO instances in a group, in overhead bytes 7, 8, 9 and 10. As shown in Figure 9-4, bit 2 of overhead byte 7 in frame 1 is associated with IID#1 and bit 7 of overhead byte 10 in frame 8 is associated with IID #254. Additionally, bit 1 of overhead byte 7 in frame 1, and bit 8 of overhead byte 10 in frame 8 are reserved.

Frame / MAP bytes	7								8								9								10							
1	RES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	32	33	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
3	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
4	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
5	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
6	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
7	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
8	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	245	246	247	248	249	250	251	252	253	254	RES

G.709.1(24)

Figure 9-4 – FlexO MAP field

9.2.3 Status (STAT)

An 8-bit (1 byte) field, as shown in Figure 9-5, is provided for general purpose status indication for the FlexO instance.

– Remote fault (RF)

– Maintenance (MNT)

– Reserved (RES)

Bits	1	2	3	4	5	6	7	8
	RF	MNT			RES			

G.709.1(24)

Figure 9-5 – FlexO BOH STAT field

The STAT field is located in all frames, in overhead byte 2 as shown in Figure 9-2.

NOTE – Implementations developed prior to Edition 2.5 of this Recommendation do not support the MNT field, those bits are Reserved. Previous Editions also only have RPF field in the first instance, and this has been repurposed in Edition 2.5 to the RF field in all instances.

9.2.3.1 Remote fault (RF)

For section monitoring, a single bit remote fault (RF) indication conveys the signal fail status detected at the remote FlexO sink function in the upstream direction.

RF is set to "1" to indicate a remote fault/defect indication; otherwise, it is set to "0".

NOTE – Editions prior to 2.5 of this Recommendation referred to this field as remote physical layer fault (RPF).

9.2.3.2 Reserved (RES)

Four bits of the STAT byte are reserved for future international standardization as shown in Figure 9-5. These bits are set to "0".

9.2.3.3 Maintenance (MNT)

Three bits of the STAT byte are used for signalling maintenance states.

– 000 – Normal operation

– 111 – AIS

– 101 – LCK

NOTE – 100 value is reserved due to FlexOsec squelch pattern.

9.2.4 Payload overhead

The FlexO payload overhead consists of: OTUC availability (AVAIL), payload type (PT) and client mapping specific overhead as shown in Figure 9-2.

9.2.4.1 OTUC availability (AVAIL)

The AVAIL field is unused and should be set to a value of 1 for FlexO-1-RS 100G interfaces. For other cases it is reserved.

The AVAIL field is located in frame 2, in overhead byte 3.

9.2.4.2 Payload type (PT)

A one-byte FlexO payload type signal is defined to indicate the composition of the FlexO payload signal. The PT field is located in frame 5, in basic overhead byte 6 in all n FlexO instances. The code points are defined in Table 9-1.

Table 9-1 – FlexO payload type code points

MSB 1 2 3 4	LSB 5 6 7 8	Hex code (Note 1)	Interpretation
0 0 0 0	0 0 0 0	00	BMP mapping OTUCn into FlexO-n
0 0 0 0	0 0 0 1	01	Experimental mapping (Note 2)
0 0 0 0	0 0 1 0	02	GMP mapping OTUCn into FlexO-n
0 0 0 0	0 1 0 0	04	*Reserved for FlexOsec SquelchText value*
0 0 0 0	0 1 0 1	05	GMP mapping Ethernet into FlexO-ne
0 1 0 0	0 0 0 0	40	*Reserved OIF 800ZR mapping and multiplexing of Ethernet clients*
0 1 0 0	0 0 0 1	41	*Reserved OIF 800ZR PRBS test pattern*
1 0 0 0	x x x x	80-8F	*Reserved codes for proprietary use (Note 3)*
0 1 0 1	0 1 0 1	55	*Reserved for FlexO LCK maintenance signal, see clause 8.5*
1 1 1 1	1 1 1 0	FE	PRBS test pattern, see clause 10.5
1 1 1 1	1 1 1 1	FF	*Reserved for FlexO AIS maintenance signals, see clause 8.5*
NOTE 1 – There are 230 spare codes left for future international standardization. Refer to Annex A of [b-ITU-T G.806] for the procedure to obtain one of these codes for a new payload type. NOTE 2 – Value "01" is only to be used for experimental activities in cases where a mapping code is not defined in this table. Refer to Annex A of [b-ITU-T G.806] for more information on the use of this code. NOTE 3 – These 16 code values will not be subject to further standardization. Refer to Annex A of [b-ITU-T G.806] for more information on the use of these codes.			

9.2.4.3 Client specific overhead allocation

Fourteen bytes are reserved in the FlexO basic overhead for the client mapping specific overhead. These bytes are located in rows 2 to 8, basic overhead byte 5; rows 2 to 4 and 6 to 8, basic overhead byte 6; and row 8, basic overhead byte 3.

The use of these bytes depends on the specific client signal mapping and is activated per PT configuration.

9.2.5 Cyclic redundancy check (CRC)

The CRC-16 (2 bytes) is located in overhead bytes 11 and 12 of each FlexO frame. The CRC protects the integrity of the OH fields in bytes 2 to 10 and excludes the MFAS, OSMC and FCC1 fields. The CRC-16 uses the $G(x) = x^{16} + x^6 + x^5 + x^3 + 1$ generator polynomial and is calculated as follows:

1) The overhead bytes 2 to 10 of the OH frame are taken in network byte order, most significant bit first, to form a 72-bit pattern representing the coefficients of a polynomial $M(x)$ of degree 71.
2) $M(x)$ is multiplied by x^{16} and divided (modulo 2) by $G(x)$, producing a remainder $R(x)$ of degree 15 or less.
3) The coefficients of $R(x)$ are considered to be a 16-bit sequence, where x^{15} is the most significant bit.
4) This 16-bit sequence is the CRC-16 where the first bit of the CRC-16 to be transmitted is the coefficient of x^{15} and the last bit transmitted is the coefficient of x^0.

The demapper process performs steps 1-3 in the same manner as the mapper process, except that here, the $M(x)$ polynomial of step 1 includes the CRC-16 bits in received order and has degree 87. In the absence of bit errors, the remainder shall be 0.

9.2.6 FlexO management communications channel (FCC1)

An 896-bit (112 bytes) field per multi-frame is provided for a FlexO-x(e)-<int> interface generic management communications channel. As shown in Figure 9-6, these fields are allocated across all 8 frames of the multi-frame of the first FlexO instance. This provides a clear channel. Format and content of the management channel is outside the scope of this recommendation.

The FCC1 field is located in all frames, in overhead bytes 13 to 26. If unused, the management channel shall be filled with all-0s prior to scrambling. The FCC1 bytes provide a communication channel per FlexO-x(e)-<int> interface with an approximate bandwidth of ~18 Mbit/s.

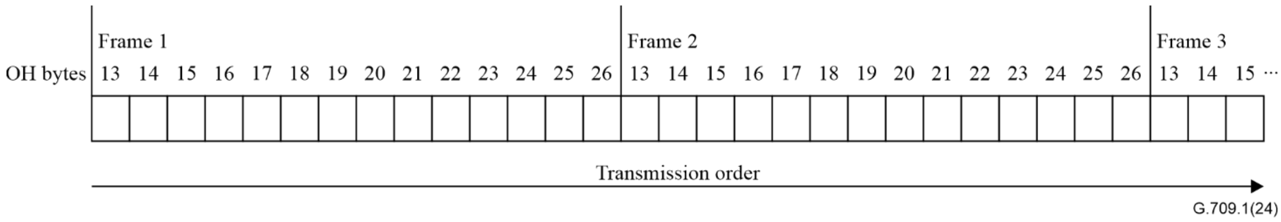

Figure 9-6 – FCC1 transmission order

NOTE – Editions prior to 2.5 of this Recommendation referred to this field as FCC.

9.2.7 FlexO reserved overhead (RES)

112.5 bytes of the FlexO basic overhead field in the FlexO multi-frame structure are reserved for future international standardization. These bytes/bits are located in frame 1/byte 5, frame 2/byte 4, frames 3 to 7/bytes 3 to 4, frame 8 byte 4 and frames 1 to 8/bytes 29 to 40. These bytes/bits are set to all-0s prior to scrambling.

9.2.8 OTN synchronization message channel (OSMC)

A 128-bit (16 bytes) field per multi-frame is provided for an OTN synchronization message channel (OSMC). As shown in Figure 9-2, these are allocated across all eight frames of the multi-frame. This field provides a clear channel, to transport synchronization status message (SSM) and precision time protocol (PTP) messages.

The OSMC is only defined on the first FlexO instance (lowest IID value) of a FlexO-x(e)-<int>-m interface group.

The OSMC field is located in all frames, in overhead bytes 27 and 28. If unused, the OTN synchronization message channel bytes shall be filled with all-0s prior to scrambling. The OSMC bytes are combined to provide a messaging channel, as illustrated in Figure 9-7, with an approximate bandwidth of 2.56 Mbit/s per 100G interface.

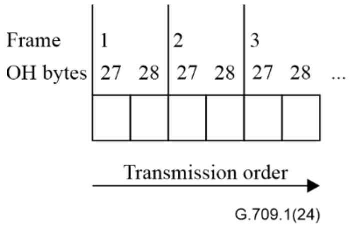

Figure 9-7 – OSMC transmission order

The SSM and PTP messages within a FlexO instance are encapsulated into generic framing procedure frame-mapped (GFP-F) frames as specified in [ITU-T G.7041]. PTP event messages are timestamped and after encapsulation into GFP-F frames, they are inserted into the OSMC as specified in this clause. GFP-F encapsulated SSM messages (and PTP non-event messages) are inserted into the OSMC at the earliest opportunity. Generic framing procedure (GFP) idle frames may be inserted between successive GFP frames.

The mapping of GFP frames is performed by aligning the byte structure of every GFP frame with the byte of the OSMC overhead field. Since the GFP frames are of variable length and may be longer than 16 bytes, a GFP frame may cross the FlexO multi-frame boundary.

9.2.8.1 Generation of event message timestamp

The message timestamp point [ITU-T G.8260] for a PTP event message transported over the OSMC shall be the 32-frame multi-frame event (corresponding to MFAS[4:8] = 00000) preceding the beginning of the GFP frame, in which the PTP event message is carried. Since the GFP frames may be longer than 64 bytes, a frame may cross the FlexO 32-frame multi-frame boundary. Figure 9-8 shows a timestamp diagram example and the relationship to the GFP frames (PTP message).

All PTP event messages are timestamped on egress and ingress interfaces. The timestamp shall be the time at which the event message timestamp point passes the reference plane [ITU-T G.8260] marking the boundary between the PTP node (i.e., OTN node) and the network.

Event message timestamps are generated at the FlexO Access Point. The message timestamp point is specified below as the 32-frame FlexO multi-frame event corresponding to MFAS[4:8] = 00000. For this application, the FlexO multi-frame event is defined as when the first bit of the first alignment mechanism (AM), corresponding to MFAS[4:8] = 00000 frame, on a lane crosses between the PTP node (i.e., OTN node) and the network (i.e., the analogous point to Ethernet MDI). In the case of a multi-lane PHY, the PTP path data delay is measured from the beginning of the AM field at the reference plane, which is equivalent to Ethernet MDI of the lane with the maximum media propagation delay. In practice:

– On egress interfaces, since the AM fields for all lanes are transmitted at the same time conceptually, any AMs can be used for timestamping.

– On ingress interfaces, AM fields are present in all the lanes, but different lanes may be skewed from each other. The last received AM across all the lanes shall be used for timestamping.

NOTE 1 – The first byte of a GFP (PTP event message) frame is inserted into the FlexO OSMC between 4 and 31 frames after the 32-frame multi-frame boundary.

NOTE 2 – The guard band of four frames is defined to simplify implementation.

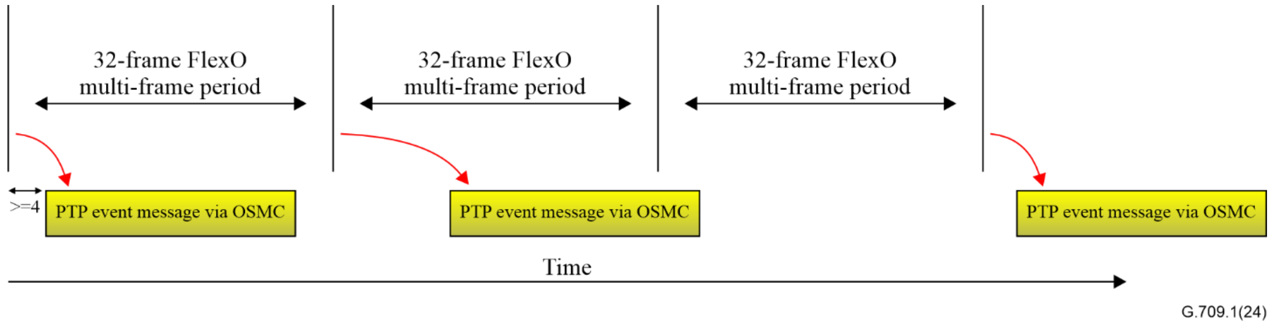

Figure 9-8 – Timing diagram example for OSMC

NOTE 3 – This time synchronization over FlexO-x-RS interface implementation does not generate event message timestamps using a point other than the message timestamp point [ITU-T G.8260].

In this time synchronization over FlexO-x-RS interface implementation, the timestamps are generated at a point removed from the reference plane. Furthermore, the time offset from the reference plane is likely to be different for inbound and outbound event messages. To meet the requirement of this clause, the generated timestamps should be corrected for these offsets. Figure 19 in [b-IEEE 1588] illustrates these offsets. Based on this model, the appropriate corrections are as follows:

<egressTimestamp> = <egressMeasuredTimestamp> + egressLatency

<ingressTimestamp> = <ingressMeasuredTimestamp> – ingressLatency

where the actual timestamps <egressTimestamp> and <ingressTimestamp> measured at the reference plane are computed from the detected, i.e., measured, timestamps by their respective latencies. Failure to make these corrections results in a time offset between the follower and leader.

The PTP timestamp is associated with the first FlexO instance (lowest IID value) of a FlexO-x(e)-<int>-m interface group.

9.3 Extended overhead (EOH) description

The FlexO EOH field is contained in the 480 bits (60 bytes) following the FlexO frame AM field. The EOH overhead does not use the 8-frame multi-frame. The EOH structure is shown in Figure 9-9.

NOTE – FlexO extended overhead was specified as FlexO PAD in Editions 1.0 to 2.2 of this Recommendation.

Extended overhead that is not used for a specific application contains the all-0's pattern.

FlexO extended overhead applications include FlexOfec, FlexOsec and regen. Further applications may be defined in future editions of this Recommendation.

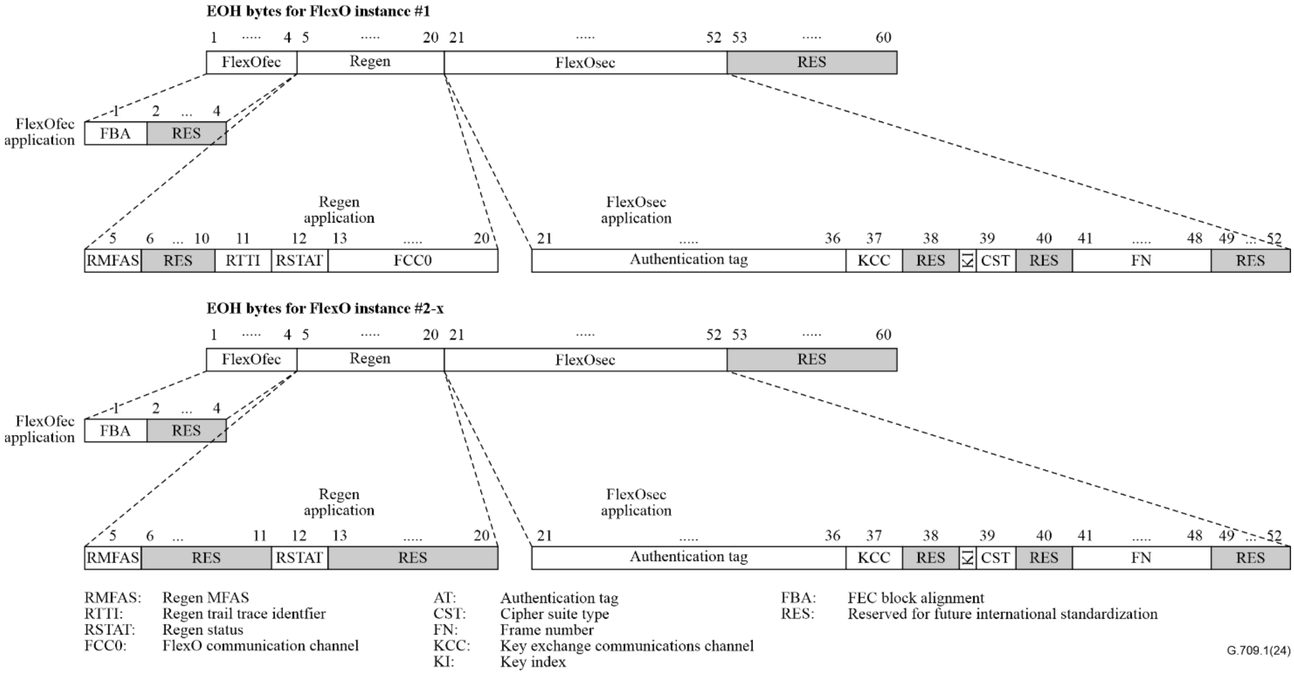

Figure 9-9 – FlexO extended overhead

9.3.1 FlexOfec overhead

FlexOfec overhead application in this Edition is associated with the staircase FEC (SC FEC) specified in [ITU-T G.709.3].

9.3.1.1 Staircase FEC block alignment (FBA) field

Figure 9-9 shows the "FBA" overhead byte in byte 1 of the extended overhead field. Refer to [ITU-T G.709.3] for the FBA specification.

9.3.2 FlexOsec overhead

FlexOsec provides secure communications between two FlexO interfaces which are interconnected by an unsecured fibre, a point-to-point optical line system or an optical network. An authenticated and authorized FlexO security entity within each FlexO interface uses the unsecured transmission through the fibre, point-to-point optical line system or optical network to provide the secure transmission to its FlexO client.

The FlexOsec overhead is specific and defined for all FlexO instances within a FlexO group interface. The FlexOsec overhead is illustrated in Figure 9-9 and contains the following fields:

– Authentication tag (AT)
– Frame number (FN)
– Key index (KI)
– Cipher suite type (CST)
– Key exchange communication channel (KCC)
– Bits reserved for future international standardization (RES)

9.3.2.1 Authentication tag (AT)

A 128-bit (16 byte) authentication tag field is provided to secure the integrity of transport of the bits in a FlexO frame. The cryptographic algorithms used to generate the integrity value and the various portions of the authenticated FlexO frame depend on the cipher suite type used. Additional details can be found in Annex A.

The AT overhead field is used individually per FlexO instance within a group interface. An authentication tag calculated over (portions of) a FlexO instance #i frame #j is inserted in the following FlexO instance #i frame #j+1.

The AT field is located in bytes 21 to 36 of the extended overhead field.

9.3.2.2 Frame number (FN)

A 64-bit (8 byte) frame number field is provided to synchronize the invocation counters on both ends of a FlexOsec connection. The use of FN as invocation counter and initialization vector (IV) construction is specific to the cipher suite type and further defined in Annex A. An IV is a nonce that is associated with an invocation of authenticated encryption on a particular plaintext and additional authenticated data (AAD).

The FlexOsec frame number is also used to create a 4-frame FlexOsec multi-frame which is separate to the FlexO MFAS multi-frame. FN is applicable to the current FlexO frame. FN increments by 1 on every FlexO frame, however on key change events FN is assumed to be reset to 0.

The FN field is located in bytes 41 to 48 of the extended overhead field.

9.3.2.3 Key index (KI)

A 2-bit key index field is provided for an in-band mechanism to coordinate use of keys on both ends. At the source, the KI value increments on key change/roll events. The value of KI is constant across 4-frame FlexOsec multi-frames and increments on multi-frame boundaries as defined by FN [63 ,64] = 00. The value of KI in the current multi-frame #k indicates the key to be used starting at the next multi-frame #k+1. Figure 9-10 shows key index boundaries.

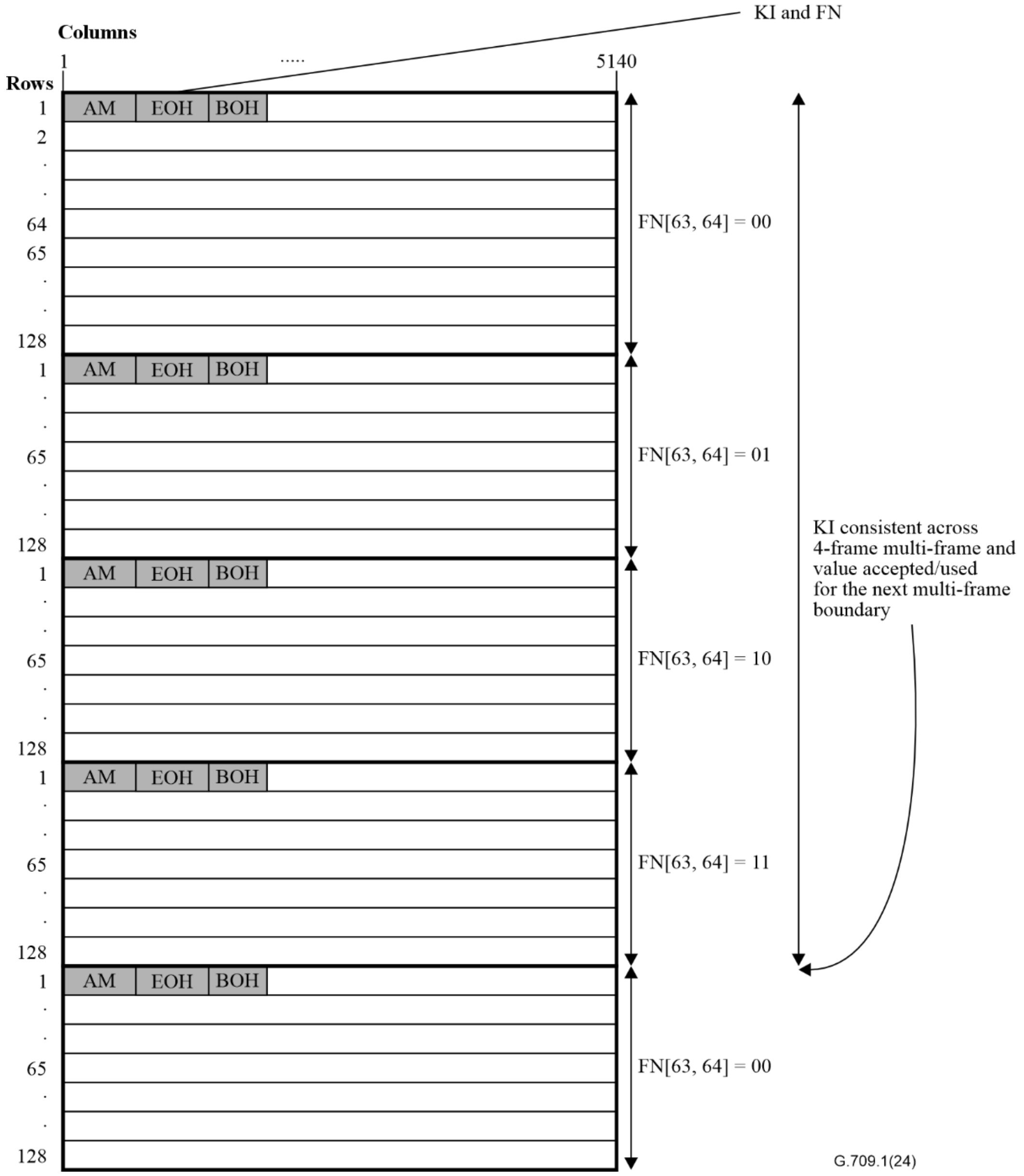

Figure 9-10 – Key index boundaries

The key index is used to select among 4 possible keys as shown in Table 9-2.

Table 9-2 – Key index coding

KI bits [12]	Interpretation
00	Key #0
01	Key #1
10	Key #2
11	Key #3

The KI field is located in bits 1 and 2 of byte 39 of the extended overhead field.

9.3.2.4 Cipher suite type (CST)

A 6-bit cipher suite type field is provided to identify and distinguish different types of ciphers (including absence of cipher), profiles or applications. The code points are defined in Table 9-3. Code point value 000000 indicates that there is no source FlexOsec.

The CST field is located in bits 3 to 8 of byte 39 of the extended overhead field.

Table 9-3 – Cipher suite type code points

CST bits [123456]	Interpretation
0 0 0 0 0 0	*No source FlexOsec*
0 0 0 0 0 1	GCM-AES-256 FlexOsec without OH encryption. Refer to Annex A.1.
0 0 0 0 1 0 – 1 1 0 1 1 1	Codepoints reserved for future standardized cryptographic cipher suites (defined by national or international standards bodies or government agencies) for use with FlexO.
0 1 0 1 0 1	*Reserved for FlexO LCK maintenance signal, see clause 8.5*
1 1 1 0 0 0 – 1 1 1 1 1 0	*Reserved codes for proprietary use (Note)*
1 1 1 1 1 1	*Reserved for FlexO AIS maintenance signal, see clause 8.5*
NOTE – These 7 code values will not be subject to further standardization.	

9.3.2.5 Key exchange communication channel (KCC)

An optional 8-bit (1 byte) key exchange communication channel field is provided to exchange key agreement protocols in-band using FlexO overhead.

The KCC field is located in byte 37 of the extended overhead field.

NOTE 1 – Key agreement protocols may be vendor, operator or user specific for the case that multi-vendor, multi-operator or multi-user interoperability is not required.

NOTE 2 – KCC is only present in the first FlexO instance of each FlexO-x(e)-<int> interface.

9.3.2.6 Reserved (RES)

6 bytes of the FlexOsec overhead area are reserved for future international standardization. These are located in bytes 38, 40, 49, 50, 51 and 52. These bytes/bits are set to all-0s.

9.3.3 FlexO regeneration overhead (regen)

Regen overhead is used to enable FlexO regeneration functions and is terminated on every interface.

NOTE – Implementations developed prior to Edition 2.5 of this Recommendation do not support the regen overhead and associated functions.

The regen overhead is illustrated in Figure 9-9 and contains the following fields:

– Regen multi-frame alignment signal (RMFAS)
– Regen status (RSTAT)
– Regen trail trace identifier (RTTI)
– FlexO regen communication channel (FCC0)

9.3.3.1 Regen multi-frame alignment signal (RMFAS)

An 8-bit (1 byte) regen multi-frame alignment signal field is provided and incremented in every FlexO frame. This RMFAS field counts 0x00 to 0xFF and provides a 256-frame FlexO multi-frame. This multi-frame is used to lock 2-frame, 4-frame, 8-frame, 16-frame, 32-frame, etc. multi-frame structures of overhead to the FlexO frame. The RMFAS sequence is identical to what is shown in Figure 9-3 for the MFAS. The RMFAS (EOH) and MFAS (BOH) increment independently.

9.3.3.2 Regen status (RSTAT)

An 8-bit (1 byte) field, as shown in Figure 9-11, is provided for general purpose status indication.

– Remote fault indication (RF)
– Local and remote degrades (LD, RD)
– Reserve (RES)

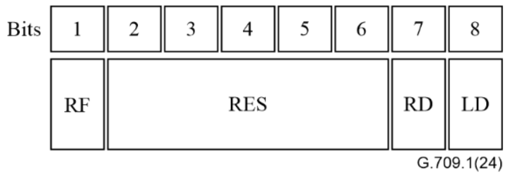

Figure 9-11 – FlexO EOH RSTAT field

The RSTAT field is located in all frames, in EOH byte 12 as shown in Figure 9-9.

9.3.3.2.1 Remote fault indication (RF)

For regen section monitoring, a single bit remote fault indication (RF) conveys the signal fail status detected at the remote FlexO sink function in the upstream direction.

RF is set to "1" to indicate a remote defect indication; otherwise, it is set to "0".

9.3.3.2.2 Degrade indication (LD/RD)

The 2-bit link degrade indication field is defined to indicate the quality of the FlexO-x(e)-<int> interface. Local and remote degrade (LD and RD) fields are asserted and set to "1" on detection of terminated FlexO-x(e)-<int> pre-FEC BER link degrade; otherwise they are set to "0". LD is propagated in the forward direction and can cover multiple regen spans. RD is propagated in the backwards direction and only covers a single FlexO-x(e)-<int> interface span.

NOTE – Annex C.2 illustrates the propagation of LD/RD in RSTAT for the case of multiple optical links and the interworking with the native indications in an Ethernet client link.

9.3.3.2.3 Reserved (RES)

Five bits of the RSTAT byte are reserved for future international standardization as shown in Figure 9-11. These bits are set to "0".

9.3.3.3 Regen trail trace identifier (RTTI)

For FlexO section monitoring, a one byte regen trail trace identifier (RTTI) overhead is defined to transport the 64-byte RTTI signal specified in clause 15.2 and Figure 15-4 of [ITU-T G.709].

The FlexO-x(e)-<int> interface contains one RTTI overhead in the first instance as shown in Figure 9-9.

The 64-byte RTTI signal shall be aligned with the FlexO regen multi-frame (RMFAS). Byte 0 of the 64-byte RTTI signal shall be present when the value of the FlexO RMFAS is xx00 0000.

9.3.3.4 FlexO regen communication channel (FCC0)

A 64-bit (8 bytes) field per frame is provided for a FlexO-x(e)-<int> interface regen generic management communications channel. As shown in Figure 9-9, this field is located in the EOH in byte locations 13 to 20 of the first FlexO instance.

The FCC0 bytes provide a communication channel per FlexO-x(e)-<int> interface with an approximate bandwidth of ~10 Mbit/s.

10 FlexO mapping procedures

FlexO payload can be mapped with different clients, such as OTUCn, Ethernet and pseudo random binary sequence (PRBS).

10.1 BMP mapping of OTUCn client into FlexO-n

The n OTUC instances of a single OTUCn are mapped to a single FlexO-n (group of n FlexO instances). For the reordering of FlexO members and deskewing of the OTUCn client after demapping from FlexO-n, see clause 10.4.1.

An OTUCn is mapped in order into n FlexO instances with ascending IID values.

10.1.1 Distributing OTUCn and combining OTUC instances

An OTUCn frame structure is specified in clause 11.3 [ITU-T G.709] and contains n instances of OTUC frame structures. As shown in Figure 10-1, the FlexO source adaptation consists of splitting the OTUCn frame into n × OTUC instances. Similarly, the sink adaptation combines n × OTUC instances into an OTUCn. A single OTUC instance is then associated to a FlexO instance, and multiple FlexO instances are associated to a FlexO-n.

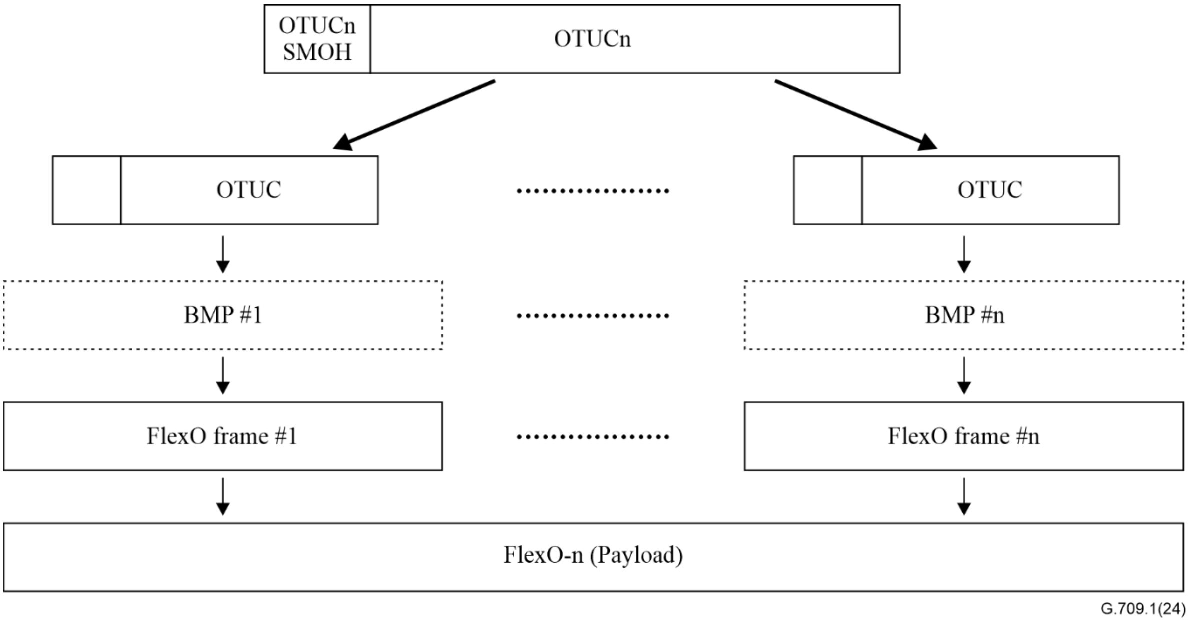

Figure 10-1 – OTUCn distributed into FlexO-n

10.1.2 FlexO multi-frame payload

For bit-synchronous mapping procedure (BMP), fixed stuffing is used to pad the OTUCn up to a FlexO-n rate. In order to pad the payload area, an 8-frame FlexO multi-frame structure is defined. It uses the three least significant bits of the multi-frame alignment signal (MFAS) overhead to identify the eight frames within the multi-frame.

The FlexO multi-frame structure is shown in Figure 10-2. The multi-frame contains seven fixed stuff (FS) locations in the payload area of FlexO frames, each containing 1,280 bits. These fixed-stuff locations are located in row 65, columns 1 to 1,280 of the first seven frames within the multi-frame. The last frame within the multi-frame does not contain fixed stuff.

The fixed stuff bits are filled with all-0s and are not checked at the receiver sink function.

The FlexO multi-frame payload, excluding the FS locations, consists of 5,244,160 bits (655,520 bytes) out of the total 5,263,360 bits (657,920 bytes) per FlexO multi-frame.

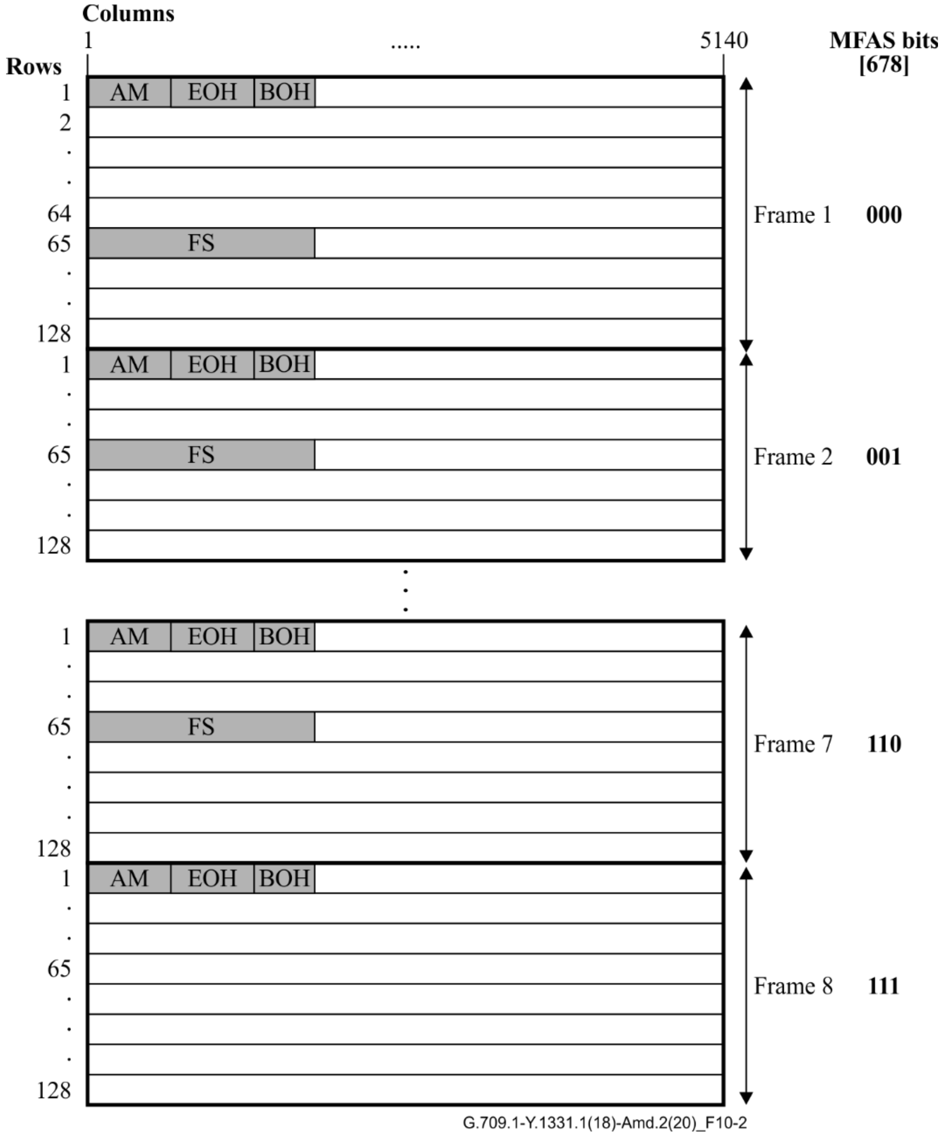

Figure 10-2 – FlexO BMP multi-frame structure

The FlexO multi-frame payload area is divided in 128-bit blocks. The 128-bit blocks are aligned to the start of a FlexO payload area (following AM, EOH and BOH). The FlexO frame payload consists of 5,120 blocks (frame #1-7 of the multi-frame, with fixed stuff payload) and 5,130 blocks (frame eight of the multi-frame, without fixed stuffing).

NOTE – This 128-bit (16-byte) word/block alignment of the 100G OTUC is analogous to the 66b block alignment of a 100G Ethernet PCS stream that is kept through the clause 91 [IEEE 802.3] adaptation process.

10.1.3 Mapping of OTUC into FlexO multi-frame payload

Groups of 128 successive bits (16 bytes) of the OTUC signal are mapped into a 128-bit block of the FlexO frame payload area using a bit-synchronous mapping procedure (BMP) control mechanism as specified in clause 17 of [ITU-T G.709]. The 128-bit group of OTUC is aligned to the OTUC frame structure.

The OTUC frame structure is floating in respect to the FlexO frame.

The serial bit stream of an OTUC signal is inserted into the FlexO frame payload so that the bits will be transmitted on the FlexO-x-<int> interface in the same order that they were received at the input of the mapper function.

In clause 8.3, the shown bit rate ratio between FlexO frame and the OTUC client is 4112/4097. The bit rate of the OTUC signal (with up to ±20 ppm bit-rate tolerance) is 1/n the bit rate of the OTUCn client specified in [ITU-T G.709] Table 7-1.

10.1.3.1 Mapping of OTUC into FlexO frame

There exists a one-to-one relationship between an OTUC and a FlexO instance. The FlexO payload area is segmented in 128-bit blocks. The OTUC is mapped in contiguous 128-bit segments.

There are (5,140×128×8 – 1,280×15) / (239×16×8×4) ~= 42.86 OTUC frames per FlexO multi-frame. The numerator is the number of payload bits in the FlexO multi-frame, which is computed based on the number of bits in the multi-frame (5140 bits per row times 128 rows per frame times 8 frames per multi-frame) minus the bits used for overhead or fixed stuff – 8 instances of 1280 bits of overhead in the multi-frame, plus 7 instances of 1280 bits of fixed stuff. The denominator is the number of bits per OTUC frame, which would be more clearly expressed as 3824 bytes/row × 8 bits/byte × 4 rows/frame. This results in ~5 OTUC frames per FlexO frame, or a new OTUC frame every ~24 FlexO frame rows, as shown in Figure 10-3.

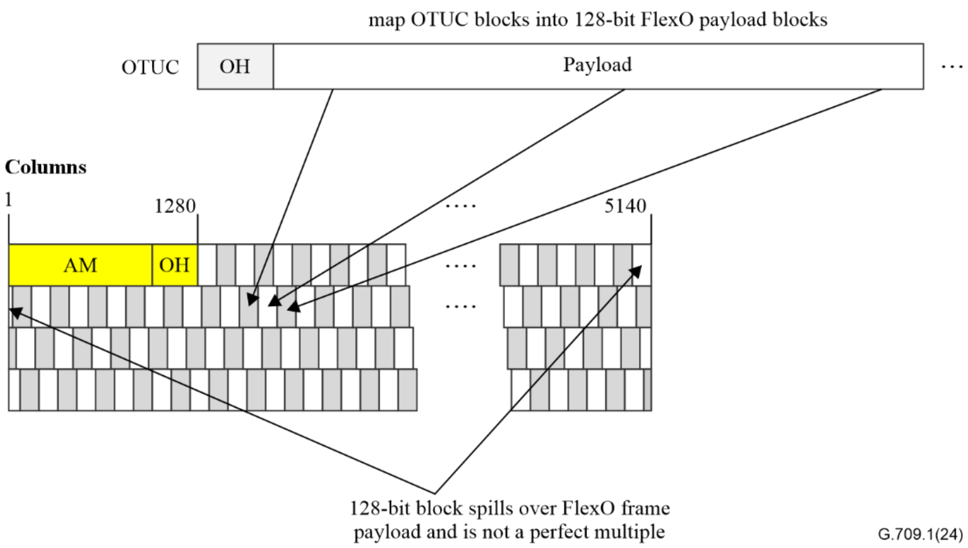

Figure 10-3 – OTUC mapped into 100G FlexO frame payload

The FlexO frame payload does not divide elegantly into 128-bit blocks in a single row. The block will spill over and cross row boundaries as shown in Figure 10-3. The 128-bit alignment is always consistent across FlexO frames and the first 128-bit block starts immediately following the overhead area.

During a signal fail condition of the incoming OTUCn signal, this failed incoming signal will contain the OTUCn-AIS signal as specified in clause 16.4.2 of [ITU-T G.709]. This OTUCn-AIS is then mapped into the n FlexO instances payload.

10.1.4 Client mapping specific overhead

The client mapping specific overhead shown in Figure 9-2 is not used for OTUCn BMP mapping and reserved.

10.2 GMP mapping of Ethernet clients into FlexO-ne

One or more Ethernet clients (with up to ±100 ppm bit-rate tolerance) can be mapped directly to n FlexO instances (FlexO-ne) using generic mapping procedure (GMP). The n FlexO frames are phase-locked and multi-frame aligned. Table 10-2 specifies the Ethernet clients defined by this mapping procedure.

For each Ethernet client and prior to mapping, the mapper shall first recover the 257b client stream, which is referred to as the OTN reference signal.

For 100GBASE-R clients, the bit interleaved parity (BIP) counters in the alignment markers are discarded. Because 100GBASE-R does scrambling prior to 257b transcoding, there is no descrambling performed for these clients.

For 200GBASE-R and 400GBASE-R clients, the am_sf<2:0> bits are extracted from the alignment markers prior to their removal and the 257b blocks are descrambled per clause 119.2.4.3 of [IEEE 802.3].

For 800GBASE-R client, the am_sf<2:0> bits are extracted from the alignment markers prior to their removal, ORed together between both 400G flows and the two 257b streams are descrambled (400G flow 0 and 400G flow 1) without alignment markers as per clause 172.2.4.2 of [IEEE 802.3df].

At the demapper, the inverse processes are performed. For 200GE/400GE/800GE client types, the 257b blocks are scrambled following the procedures in clause 119.2.4.3 of [IEEE 802.3] and the am_sf<2:0> fields extracted from the received FlexO frame overhead fields are processed as described in CSTAT clause 10.2.3.3 and inserted in the appropriate locations in the alignment marker fields. For 100GE clients the BIP counters are recomputed and inserted. For 100GE clients, no scrambling is performed (the blocks are intrinsically scrambled).

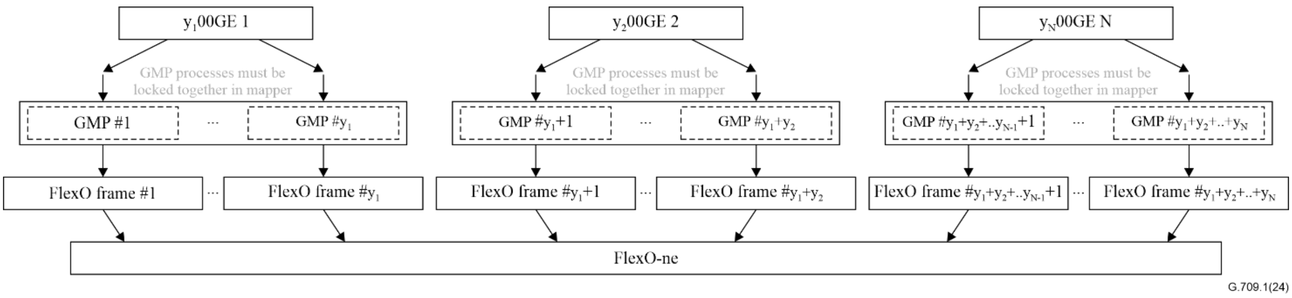

Figure 10-4 – Mapping of Ethernet clients using GMP

For 100GBASE-R (100GE) clients, the 257b stream is mapped directly into the payload area of the corresponding FlexO instance.

For y00GBASE-R (y=2,4,8) clients, the 257b stream is split on a 257b block basis, in a round-robin fashion into y 100G 257b streams which are mapped into the payload areas of the corresponding y FlexO instances.

10.2.1 FlexO frame and 4-frame multi-frame payload structure

The FlexO frame payload area is divided in 257-bit payload blocks (see Figure 10-5). A 5b padding (following AM, EOH and BOH) is used to align to 257-bit multiples. The 257-bit payload blocks are aligned to the start of a FlexO payload following the 5b padding area. The FlexO frame payload contains 2555 257-bit blocks.

NOTE – There is no fixed stuff in frames 1 to 7 of the FlexO 8-frame multi-frame in this mapping.

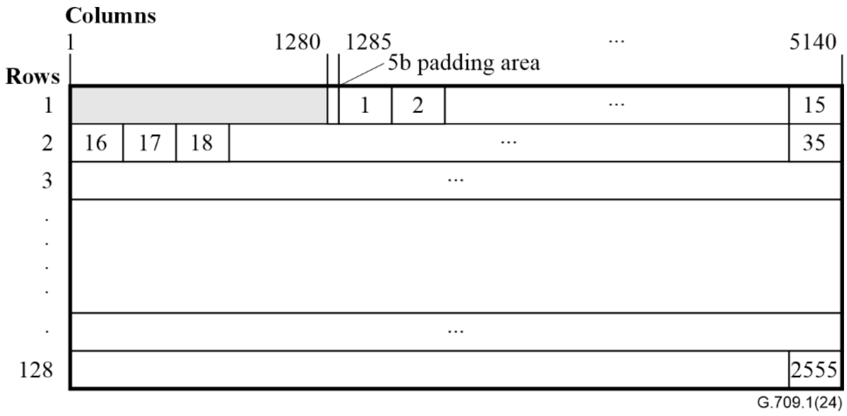

Figure 10-5 – FlexO frame showing payload with 257b blocks

The FlexO payload 4-frame multi-frame structure with 257-bit payload blocks in the payload area for the mapping of Ethernet client signals is illustrated in Figure 10-6. This per server payload area consists of 10220 257-bit blocks for Ethernet client mapping. Note that a y00GE client is GMP mapped over y phase-locked and 4-frame multi-frame aligned FlexO instances, so its server payload area actually consists of 10220 × [y × 257]-bit blocks.

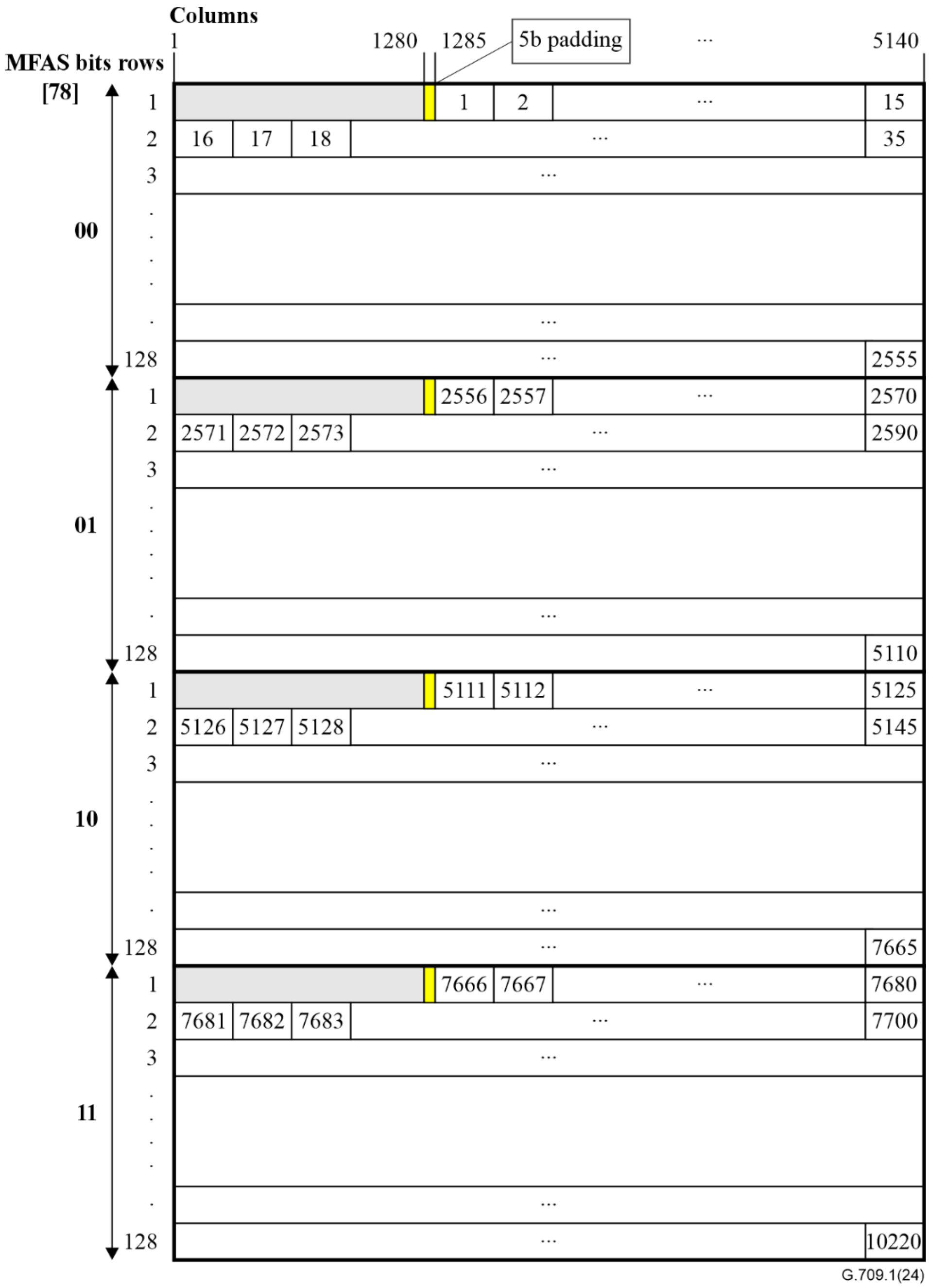

Figure 10-6 – FlexO instance payload 4-frame multi-frame structure with 257-bit payload blocks for the GMP mapping of Ethernet client signal

The FlexO-ne payload bit rate is defined in Table 10-1.

Table 10-1 – FlexO-ne payload bit rates

Interface Type	FlexO-ne payload nominal bit rate	FlexO-n(e) payload bit-rate tolerance
FlexO-ne	n × 1594685/1900544 × 766 × 156 250 kbit/s	±20 ppm
NOTE – The nominal FlexO-ne payload bit rate is approximately: n × 100 425 910.128 kbit/s. The FlexO-ne payload bit rate can be derived from 156M Ethernet clock multiple as follows: n × 511/512 × 514/544 × 1445/1624 × 766 × 156 250 kbit/s.		

10.2.2 Ethernet client

Each adapted and mapped Ethernet client is a sequence of 257B blocks, with alignment markers removed.

In the mapping (source) direction, the Ethernet clients are recovered using a similar process as described in [IEEE 802.3] clause 91 for 100GBASE-R, clause 119 for 200GBASE-R/400GBASE-R and clause 172 for 800GBASE-R. The lane(s) of the physical interface are bit-deinterleaved into logical lanes of 26 562 500 kbit/s. Lane alignment marker lock is acquired on each PCS lane, allowing lane deskew and reorder, and for FEC code word synchronization and error correction. The mapper shall extract the FEC parity bits and alignment markers, and performs descrambling (except for 100GBASE-R clients). The 257B/256B encoded signal is adapted into the FlexO-ne payload. Uncorrectable FEC code words shall be replaced with error control blocks in transcoded 257B block format. The order and bit ordering of these blocks shall match the ordering in the signal prior to FEC decoding. For 100GBASE-R clients, the alignment markers contain BIP counters which are discarded along with the alignment markers. The client am_sf<2:0> bits are extracted for 200GBASE-R/400GBASE-R/800GBASE-R client types prior to alignment marker removal for transmission in the overhead fields of the FlexO frame and the 257B blocks are descrambled following the procedures in clause 119.2.4.3 of [IEEE 802.3] standard.

The inverse process is implemented in the demapping (sink) direction. For 200GBASE-R/400GBASE-R client types, the 257b blocks are scrambled following the procedures in clause 119.2.4.3 of [IEEE 802.3] and the am_sf<2:0> fields extracted from the received FlexO frame overhead fields are processed as described in CSTAT clause 10.2.3.3 and inserted in the appropriate locations in the alignment markers. For 100GBASE-R clients the BIP counters are recomputed and inserted. For 100GBASE-R clients, no scrambling is performed (the blocks are intrinsically scrambled). For 800GBASE-R, the 257B client data blocks are then deinterleaved into 400G flow 0 and 400G flow 1, to retrieve the 800GBASE-R client stream at the OTN reference signal as specified in clause 172.2.4.2 of [IEEE 802.3df]. Scrambling is performed and alignment markers and FEC parity bits are inserted on each 400G flow prior to the 800GBASE-R PCS lane distribution and interleaving into physical lanes at the PMA interface.

The bit rates of the FlexO-ne Ethernet clients are listed in Table 10-2 and the corresponding replacement signals are listed in Table 10-3.

Table 10-2 – FlexO-ne Ethernet clients

Client signal	Nominal bit rate (kbit/s)	Bit-rate tolerance (ppm)
100GBASE-R	16383/16384 × 100 390 625	±100
200GBASE-R	20479/20480 × 200 781 250	±100
400GBASE-R	20479/20480 × 401 562 500	±100
800GBASE-R (Note)	2 × 20479/20480 × 401 562 500	±50
NOTE – This signal represents two aligned and unscrambled 256B/257B encoded 400G flows (400G flow 0 and 400G flow 1), without alignment markers.		

Table 10-3 – Replacement signal for FlexO-ne Ethernet clients

Client signal	Replacement signal	Bit-rate tolerance (ppm)
100GBASE-R	Scrambled LF (Note 1)	±100
200GBASE-R	LF (Note 1)	±100
400GBASE-R	LF (Note 1)	±100
800GBASE-R	LF (Note 2)	±50
NOTE 1 – The replacement signal for a 100GBASE-R, 200GBASE-R and 400GBASE-R signal is a continuous stream of LF sequence ordered sets encoded according to Figure 82-5 of [IEEE 802.3] using control block type 0x4B. 257B transcoding plus alignment marker insertion will be performed on the stream in the demapping direction. 200GBASE-R/400GBASE-R signals are then scrambled. NOTE 2 – The replacement signal for an 800GBASE-R signal is a continuous stream of LF sequence ordered sets encoded according to Figure 82-5 of [IEEE 802.3] using control block type 0x4B and then 256B/257B transcoded as specified in clause 119.2.4.2 of [IEEE 802.3]. 257-bit blocks deinterleaving into two aligned 400G flows and alignment marker insertion will be performed on these two aligned 400G streams of 257-bit blocks in the demapping direction after which these signals are scrambled.		

10.2.3 Client mapping specific overhead

The client mapping specific overhead shown in Figure 9-2 consists of a multiplex structure identifier (MSI), justification control (JC1-JC6) and client status (CSTAT) overhead as shown in Figure 10-7. The FlexO overhead locations are present in each FlexO instance.

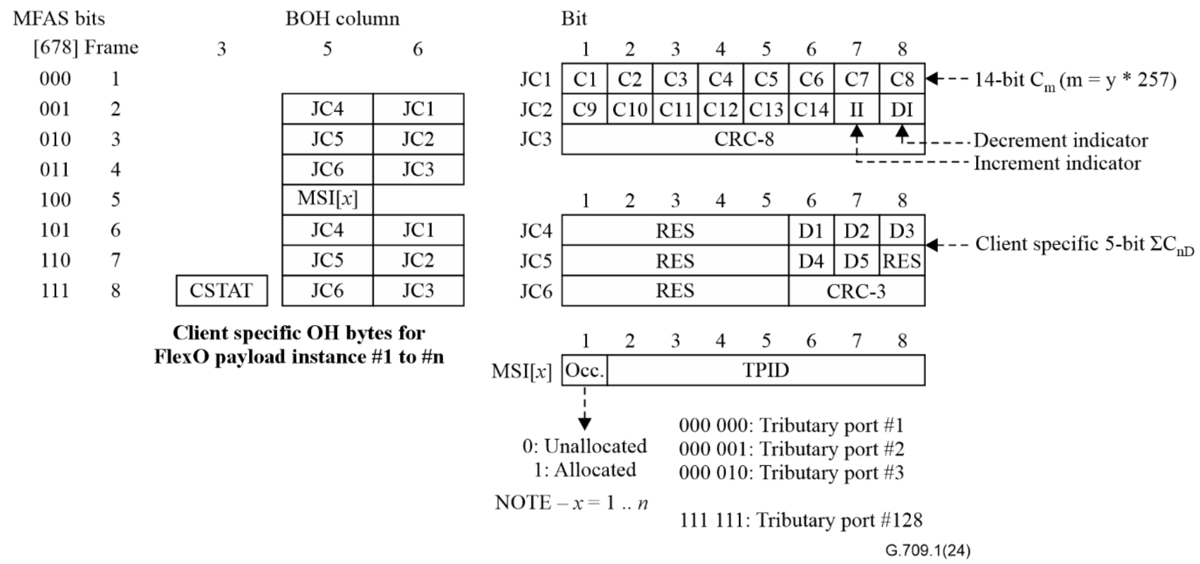

Figure 10-7 – Client mapping specific overhead for mapping Ethernet to FlexO-ne

10.2.3.1 FlexO multiplex structure identifier (MSI)

The FlexO multiplex structure identifier (MSI) overhead is located in frame 5, in overhead byte 5 in all n FlexO frames, as illustrated in Figure 10-8. The MSI indicates the Ethernet content of each FlexO instance payload. One byte is used for each FlexO instance.

– The FlexO occupation (OCC) bit 1 indicates if the FlexO instance payload is allocated or unallocated.

– The tributary port identifier (TPID) in bits 2 to 8 indicates the tributary port number of the Ethernet client which is being transported in this FlexO instance; Ethernet tributary ports are numbered 1 to 128. The value is set to all-0s when the occupation bit has the value 0 (FlexO instance is unallocated).

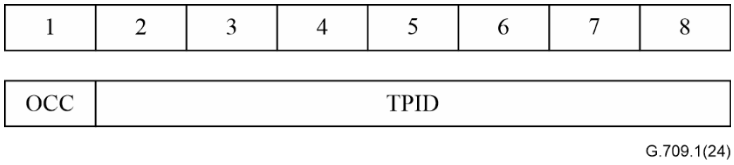

Figure 10-8 – Ethernet GMP MSI

10.2.3.2 FlexO justification overhead (JC)

GMP overhead is carried once per 4-frame multi-frame in bytes JC1-JC6. The 14-bit $C_m(t)$ (i.e., m-bit block count value) is carried in bits C1-14 of JC1 and JC2 (C1=MSB, …, C14=LSB) and the encoded 5-bit $\Sigma C_{nD}(t)$ (cumulative value of $C_{nD}(t)$) is carried in bit D1-D5 of JC4 and JC5 (D1=MSB, … D5=LSB).

$C_m(t)$ shall be protected with a CRC8 (carried in JC3 OH byte) and $\Sigma C_{nD}(t)$ shall be protected with a CRC3 (carried in the four LSBs of JC6 OH byte). Note that because a set of JC1-JC6 bytes are per 4-frame multi-frame, they appear twice in the 8-frame multi-frame shown in Figure 10-7.

10.2.3.3 Client status (CSTAT)

An 8-bit (1 byte) field, as shown in Figure 10-9, is provided for general purpose status indication.

– Client signal fail (CSF)

– Maintenance (MNT)

– Client local and remote degrades (LD, RD)

– Reserved (RES)

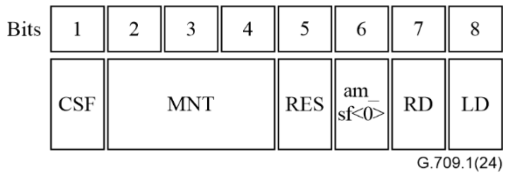

Figure 10-9 – Ethernet GMP CSTAT field

10.2.3.3.1 Client signal fail (CSF)

The client signal fail (CSF) bit is set to "1" to indicate that an incoming client fault was detected; otherwise it is set to "0". The client signal fail (CSF) bit indicates forward signal fail status detected at the local RX client interface in the downstream direction. The replacement signal for client fault conditions is Ethernet local fault (LF) as defined in [IEEE 802.3] generated using a local clock and shown in Table 10-3.

10.2.3.3.2 Reserved (RES)

One bit of the CSTAT byte is reserved for future international standardization as shown in Figure 10-9. This bit is set to "0".

10.2.3.3.3 Maintenance (MNT)

Three bits of the CSTAT byte are used for signalling maintenance states.

– 000 – Normal operation

– 101 – LCK

NOTE – 100 value is reserved due to FlexOsec squelch pattern.

A locked (LCK) is a signal sent downstream as an indication that upstream the connection is "locked". The replacement signal for client locked maintenance is Ethernet local fault (LF) as defined in [IEEE 802.3] generated using a local clock.

10.2.3.3.4 Client degrade indication (LD/RD)

The 3-bit host link degrade indication field is defined to indicate to the downstream device the quality of the client. This is transparently passed from the client's terminated alignment markers, which are referred to as am_sf<0> (reserved), am_sf<1> (remote degrade RD) and am_sf<2> (local degrade LD).

These are only applicable to 200GBASE-R, 400GBASE-R and 800GBASE-R clients. These are applied as described in Annex C.

10.2.4 Mapping of *y*00GBASE-R client into y FlexO instances of a FlexO-ne

The mapping of an *y*00GBASE-R signal (with up to ±100 or ±50 ppm bit-rate tolerance) into *y* FlexO payload instances of a FlexO-ne is performed by means of a generic mapping procedure as specified in Annex D of [ITU-T G.709] and Annex B in this Recommendation.

The *y* FlexO payload instances of a FlexO-ne are created from a locally generated clock (within the limits specified in Table 8-3), which is independent of the *y*00GBASE-R signal.

The *y*00GBASE-R signal is adapted to the locally generated *y* FlexO payload instances of a FlexO-ne clock by means of a generic mapping procedure (GMP) as specified in Annex D [ITU-T G.709]. The value of n in c_n and $C_n(t)$ and $C_{nD}(t)$ is specified in Annex B.

A group of *y* successive *y*00GBASE-R 257-bit words is mapped into a group of *y* successive FlexO payload instances of a FlexO-ne 257-bit words.

NOTE 1 – The 257-bit word alignment of the *y*00GBASE-R is preserved through the mapping procedure; e.g., the position of the first 257 bits of the *y*00GBASE-R is always located after an integer number of 257-bit words from the start of the *y* FlexO payload instances of a FlexO-ne structure.

For the case of y00GBASE-R signals, the generic mapping process generates once per *y* FlexO payload instances of a FlexO-ne multi-frame the $C_m(t)$ and $C_{nD}(t)$ information according to Annex D [ITU-T G.709] and encodes this information in the *y* FlexO payload instances of a FlexO-ne justification control overhead JC1/JC2/JC3 and JC4/JC5/JC6. For clients which are split across multiple FlexO payload instances of a FlexO-ne the mappers are locked and the JC bytes are replicated and present in all FlexO instances carrying the client.

The support for n-bit timing information (ΣC_{nD}) in the JC4/JC5/JC6 OH is required.

During a signal fail condition of the incoming *y*00GBASE-R signal, this failed incoming signal will contain the *y*00GBASE-R replacement signal as specified in Table 10-3. This *y*00GBASE-R replacement signal is then mapped into the *y* FlexO payload instances of a FlexO-ne.

The y 100G streams of a client signal are mapped to the *y* FlexO payload instances of a FlexO-ne structure as y 100G aligned 257b block streams. The payload area for this mapping consists of the payload of the aligned 4-frame multi-frames of y FlexO instances in ascending IID order. Groups of m consecutive bits of the client are mapped into m bits of the y aligned 4-frame multi-frame payload areas under control of the GMP data/stuff control mechanism. Each group of m in the y aligned 4-frame multi-frame payload areas may carry either m client bits or m stuff bits. The stuff bits shall be transmitted as zeros and shall be ignored on receive.

The equations and values of the GMP parameters m, $C_{m,nom}$, $C_{m,min}$, $C_{m,max}$, n, $C_{n,nom}$, $C_{n,min}$ and $C_{n,max}$ for *y*00GBASE-R client into "y FlexO payload instances of a FlexO-ne" are specified in Table B.1.

GMP is a positional mapping with non-fixed stuff locations. The stuff locations within the payload are determined using a delta-sigma algorithm based on the $C_m(t)$ value.

For information only, Table 10-4 shows the location of the "stuff" GMP blocks for a few specific C_m values.

Table 10-4 – GMP stuff locations

C_m	locations
10220	N/A
10219	1
10218	1, 5111
10217	1, 3407, 6814
10216	1, 2556, 5111, 7666
10215	1, 2045, 4089, 6133, 8177
10214	1, 1704, 3407, 5111, 6814, 8517

The de-mapping process decodes $C_m(t)$ and $C_{nD}(t)$ from JC1/JC2/JC3 and JC4/JC5/JC6 and interprets $C_m(t)$ and $C_{nD}(t)$ according to Annex B. CRC-8 shall be used to protect against an error in bits 1 to 8 of the JC1, JC2, JC3 signals. CRC-3 shall be used to protect against an error in bits 6 to 8 of JC4, JC5, JC6 signals.

A group of *y* successive *y*00GBASE-R 257-bit words is de-mapped from a group of *y* successive FlexO payload instances of a FlexO-ne 257-bit blocks.

During a signal fail condition of the incoming FlexO-ne signal the *y*00GBASE-R replacement signal pattern as specified in Table 10-3 is generated as a replacement signal for the lost *y*00GBASE-R signal.

10.3 GMP mapping of OTUCn clients into FlexO-n

This clause specifies the multiplexing of $OTUCn_i$ into FlexO-*n* payload using a client agnostic generic mapping procedure (GMP).

This $OTUCn_i$ into FlexO-n payload multiplexing is performed by means of asynchronous mapping of $OTUCn_i$ into n_i FlexO payload instances using GMP.

The FlexO-n supports up to n different $OTUCn_i$ signals.

A set of n FlexO instances (FlexO-n) may carry multiple $OTUCn_i$ (i = 1..N) signals via GMP. In the most general case, the $n = n_1 + n_2 + .. + n_N$ OTUC instances of the $OTUCn_i$ (i = 1..N) are mapped to a FlexO-n. For the reordering of FlexO members and deskewing of each $OTUCn_i$ client after demapping from FlexO-n, see Clause 10.1.4.

An $OTUCn_i$ is mapped in order into n_i FlexO instances with ascending IID values.

10.3.1 Distributing $OTUCn_i$ and combining OTUC instances

An OTUCn frame structure is specified in clause 11.3 of [ITU-T G.709] and contains n synchronous instances of OTUC frame structures. As shown in Figure 10-10, the $OTUCn_i$ multiplexing consists of splitting each of the $OTUCn_i$ frames into $n_i \times$ OTUC instances and then the mapping of each OTUC instance in a FlexO instance under control of a GMP process. The n_i GMP processes associated with one $OTUCn_i$ may be locked together at the $OTUCn_i$ to FlexO mapper, or could be operated independently. At the demapper, each GMP process is operated independently.

Similarly, the $OTUCn_i$ demultiplexing consists of extracting each OTUC instance from its FlexO instance under control of a GMP process and combining the $n_i \times$ OTUC instances of each $OTUCn_i$ into the $OTUCn_i$.

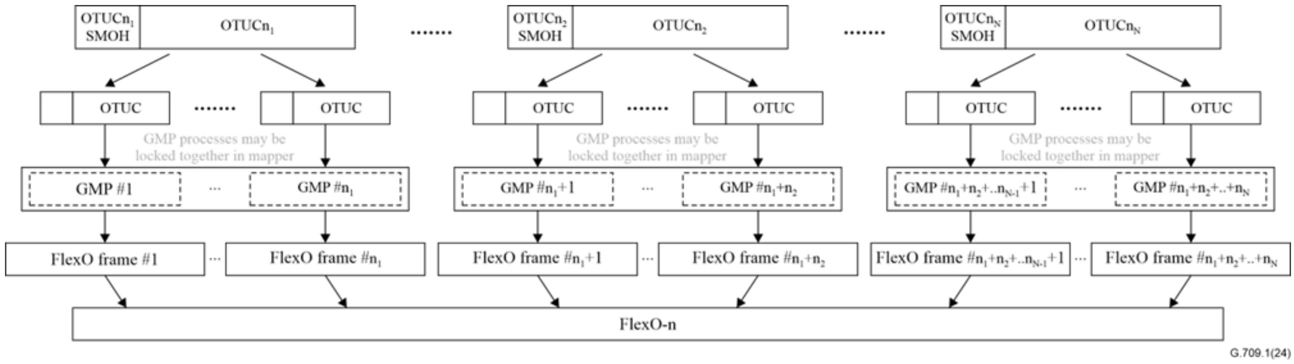

Figure 10-10 – Mapping multiple OTUCni clients onto FlexO-n

10.3.2 FlexO frame and 4-frame multi-frame payload structure

The FlexO frame payload area is divided in 256-bit payload blocks (see Figure 10-11). The 256-bit payload blocks are aligned to the start of a FlexO payload area (following AM, EOH and BOH). The FlexO frame payload consists of 2565 256-bit blocks.

NOTE – There is no fixed stuff in frames 1 to 7 of the FlexO 8-frame multi-frame in this mapping.

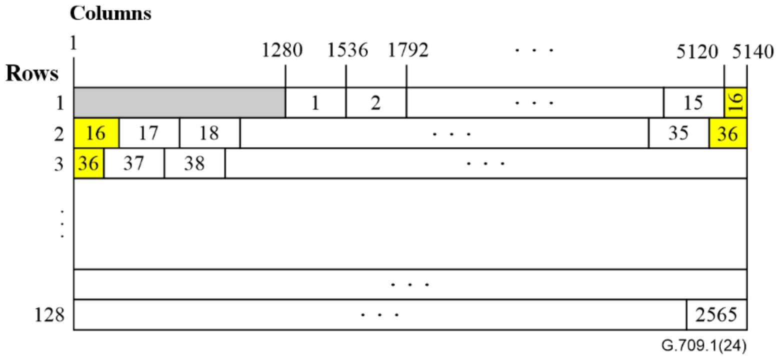

Figure 10-11 – FlexO frame payload structure with 256-bit payload blocks

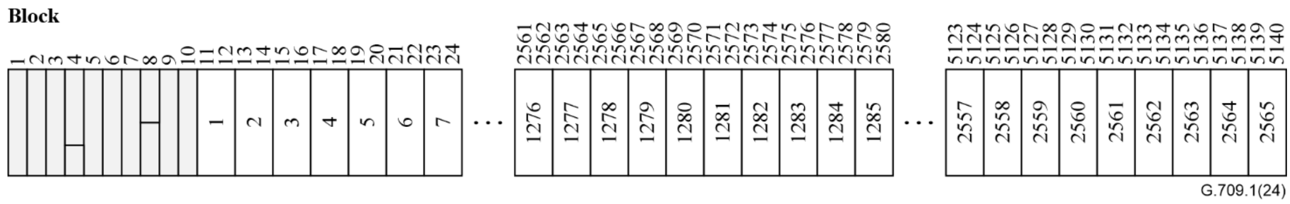

Figure 10-12 – FlexO frame payload structure in 128-bit block format with 256-bit GMP blocks

The FlexO payload 4-frame multi-frame structure with 256-bit payload blocks in the payload area for the mapping of an OTUC client signal is illustrated in Figures 10-13 and 10-14. The payload area consists of 10,260 256-bit blocks.

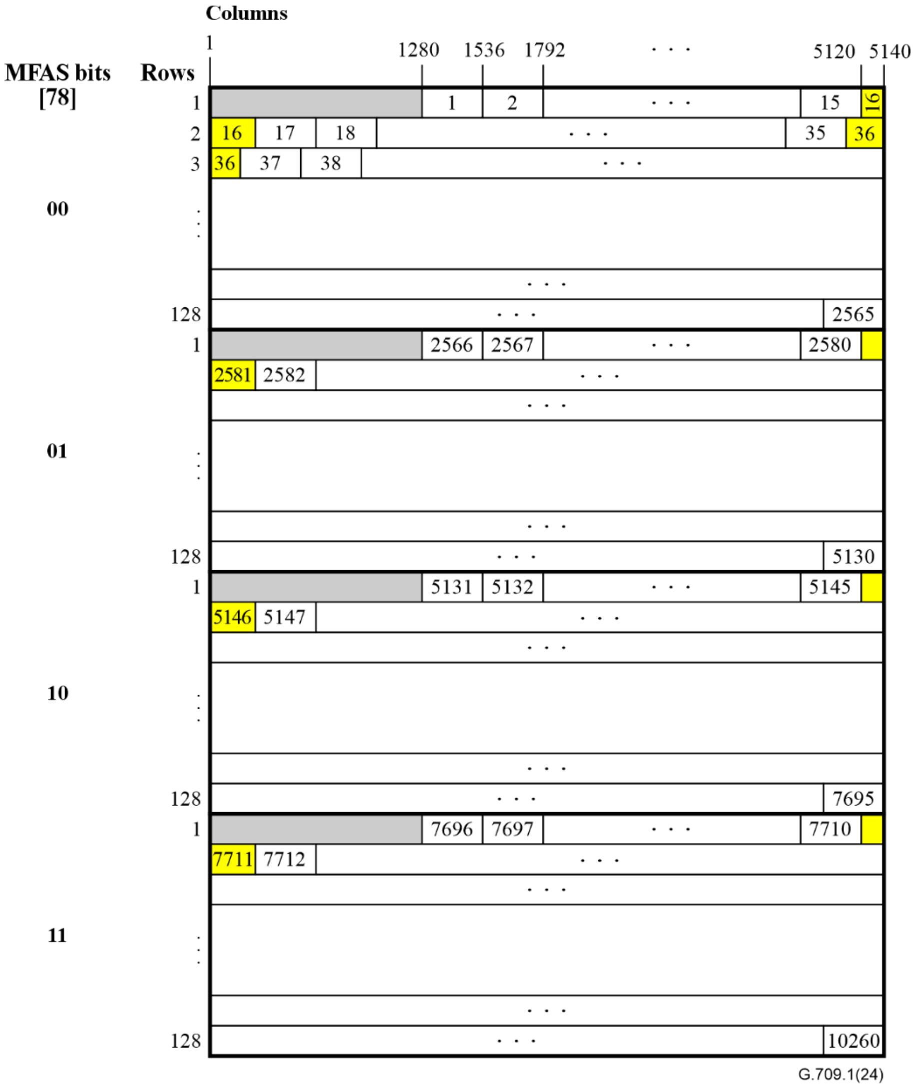

Figure 10-13 – FlexO payload 4-frame multi-frame structure with 256-bit payload blocks for the GMP mapping of an OTUC client signal

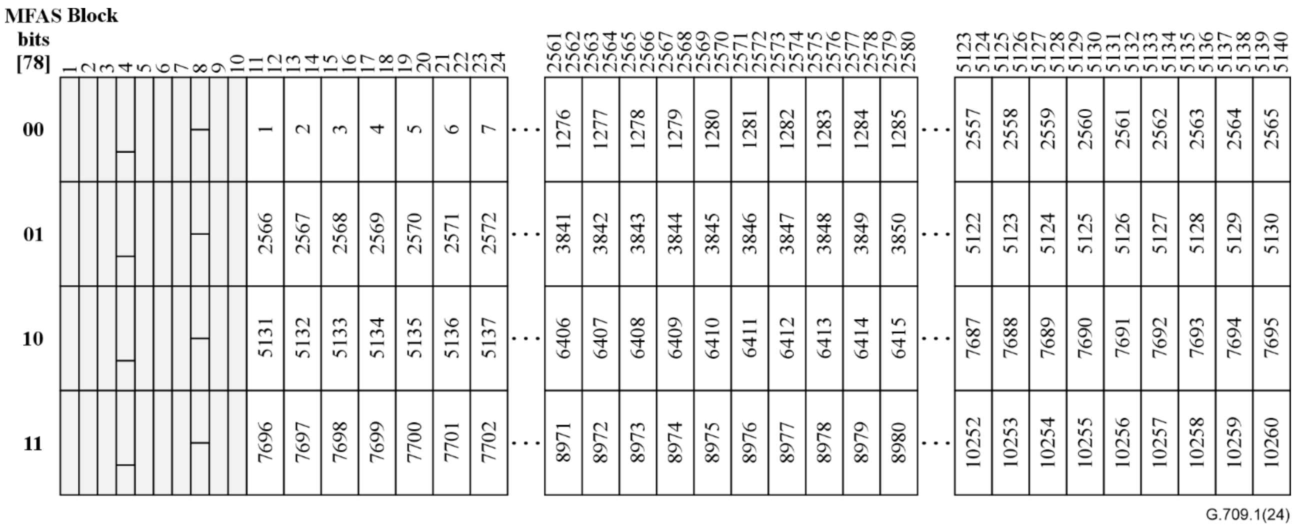

Figure 10-14 – FlexO payload 4-frame multi-frame structure in 128-bit block format with 256-bit payload blocks for the GMP mapping of an OTUC client signal

The FlexO-n payload bit rate is defined in Table 10-5.

Table 10-5 – FlexO-n payload bit rates

Interface type	FlexO-n payload nominal bit rate	FlexO-n payload bit-rate tolerance
FlexO-n	n × 490428/462961 × 99 532 800 kbit/s	±20 ppm
NOTE – The nominal FlexO-n payload bit rate is approximately: n × 105 437 978.660 kbit/s. The FlexO-n payload bit rate can be derived from the OTUC bit rate as follows: n × 513/514 × 4112/4097 × OTUC bit rate = n × 513/514 × 4112/4097 × 239/226 × 99 532 800 kbit/s		

10.3.3 Client mapping specific overhead

For OTUCn multiplexing, the mapping specific overhead consists of a multiplex structure identifier (MSI) and justification control (JC1-JC6) overhead. The FlexO MSI and JC1-JC6 overhead locations are illustrated in Figure 10-15 and are present in each FlexO instance of the group of n = $n_1 + n_2 + .. + n_N$ FlexO instances.

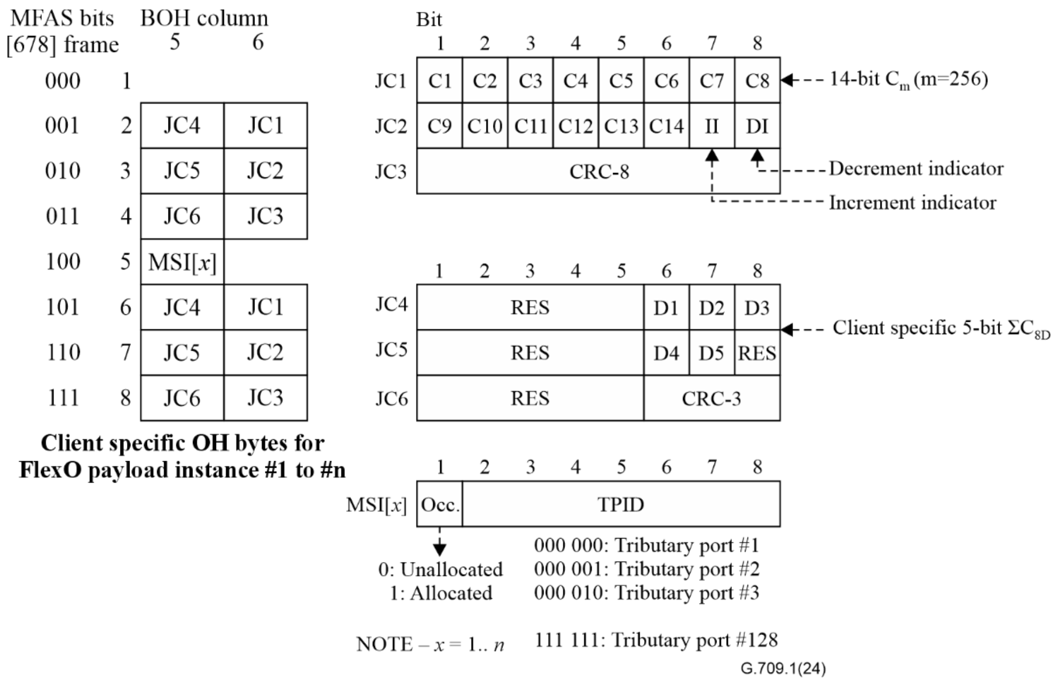

Figure 10-15 – FlexO multiplex and justification overhead

10.3.3.1 FlexO multiplex structure identifier (MSI)

The FlexO multiplex structure identifier (MSI) overhead, which encodes the OTUC multiplex structure in the FlexO-n payload is located in frame 5, in overhead byte 5 in all n FlexO frames, as illustrated in Figure 10-15. The MSI indicates the OTUC content of each FlexO instance payload. One byte is used for each FlexO instance.

- The FlexO occupation bit 1 indicates if the FlexO instance payload is allocated or unallocated.
- The tributary port identifier in bits 2 to 8 indicates the tributary port number of the OTUCn$_i$ of which an OTUC instance is being transported in this FlexO instance; for the case of a OTUCn$_i$ carried in two or more FlexO instances a flexible assignment of tributary port to FlexO instance is possible. OTUCn$_i$ tributary ports are numbered 1 to N. The value is set to all-0s when the occupation bit has the value 0 (FlexO instance is unallocated).

10.3.3.2 FlexO justification overhead

The FlexO justification control overhead (JOH), which carry GMP justification control overhead, is located in frames 2, 3, 4, 6, 7 and 8 in overhead bytes 5 and 6 in all n FlexO frames, as illustrated in Figure 10-15. It consists of two groups of six bytes of justification control: JC1, JC2, JC3 and JC4, JC5, JC6.

The JC1, JC2 and JC3 bytes consist of a 14-bit $C_m(t)$ field (bits C1 (MSB), C2, .., C14 (LSB)), a 1-bit increment indicator (II) field, a 1-bit decrement indicator (DI) field and a 8-bit CRC-8 field which contains an error check code over the JC1, JC2 and JC3 bytes.

The JC4, JC5 and JC6 bytes consist of a 5-bit ΣC_{nD} field (bits D1, D2, .., D5), a 3-bit CRC-3 field which contains an error check code over bits 6 to 8 in the JC4, JC5 and JC6 fields and sixteen bits reserved for future international standardization (RES).

The value of 'm' in C_m is 256.

The value of 'n' represents the timing granularity of the GMP C_n parameter, which is also present in ΣC_{nD}. The value of n is 8.

The value of C_m controls the distribution of groups of two 128-bit OTUC data blocks into 256-bit GMP blocks in the FlexO payload. Refer to Annex D of [ITU-T G.709] and Annex B for further specification of this process.

The value of ΣC_{nD} provides additional 'n'-bit timing information, which is necessary to control the jitter and wander performance experienced by the OTUC signal.

The value of C_n (i.e., number of client n-bit data entities per FlexO payload 4-frame multi-frame) is computed as follows: $C_n(t) = m/n \times C_m(t) + (\Sigma C_{nD}(t) - \Sigma C_{nD}(t-1))$. Note that the value C_{nD} is effectively an indication of the amount of data in the mapper's virtual queue that it could not send during that multi-frame due to it being less than a 256-bit word. For the case where the value of ΣC_{nD} in a multi-frame 't' is corrupted, it is possible to recover from such error in the next multi-frame 't+1'.

10.3.4 Mapping of OTUCn$_i$ into n$_i$ FlexO instances of a FlexO-n

The mapping of an OTUCn$_i$ signal (with up to ±20 ppm bit-rate tolerance) into n_i FlexO instances payload is performed by means of a generic mapping procedure.

The n_i FlexO payload instances are created from a locally generated clock (within the limits specified in Table 8-3), which is independent of the OTUCn$_i$ signal.

Specifically, an OTUC instance of an OTUCn$_i$ is mapped into a FlexO instance payload of the n_i FlexO instances payload. The bit rate of the OTUC instance is $1/n_i$ the bit rate of the OTUCn$_i$ client specified in [ITU-T G.709] Table 7 1.

An OTUC signal is adapted to the locally generated FlexO instance payload clock by means of a generic mapping procedure (GMP) as specified in Annex D [ITU-T G.709]. The value of n in c_n and $C_n(t)$ and $C_{nD}(t)$ is specified in Annex B.

An OTUC 32-byte (256-bit) word is mapped into a FlexO payload instance 32-byte (256-bit) word.

NOTE 1 – The 32-byte word alignment of the OTU*C* is preserved through the mapping procedure; e.g., the position of the first 32 bytes of the OTU*C* is always located after an integer number of 32-byte words from the start of the FlexO payload instance structure.

For the case of OTUC signals, the generic mapping process generates once per FlexO payload instance multi-frame the $C_m(t)$ and $C_{nD}(t)$ information according to Annex D [ITU-T G.709] and encodes this information in the FlexO payload instance justification control overhead JC1/JC2/JC3 and JC4/JC5/JC6. The de-mapping process decodes $C_m(t)$ and $C_{nD}(t)$ from JC1/JC2/JC3 and JC4/JC5/JC6 and interprets $C_m(t)$ and $C_{nD}(t)$ according to Annex B. CRC-8 shall be used to protect against an error in bits 1 to 8 of the JC1, JC2, JC3 signals. CRC-3 shall be used to protect against an error in bits 6 to 8 of JC4, JC5, JC6 signals.

During a signal fail condition of the incoming OTUCn$_i$ signal, this failed incoming signal will contain the OTUCn$_i$-AIS signal as specified in clause 16.4.2 of [ITU-T G.709]. This OTUCn$_i$-AIS is then mapped into the n$_i$ FlexO instances payload.

An OTUC 32-byte word is de-mapped from a FlexO payload instance 32-byte block.

The equations and values of GMP parameters m, $C_{m,nom}$, $C_{m,min}$, $C_{m,max}$, n, $C_{n,nom}$, $C_{n,min}$ and $C_{n,max}$ for OTUCn$_i$ client into FlexO-n$_i$ payload area are specified in Table B.1.

10.3.4.1 Mapping OTUC into FlexO instance payload

Groups of 32-byte/256-bit words of the OTUC signal are mapped into a 32-byte block of the FlexO instance payload area under control of the GMP data/stuff control mechanism. Each 32-byte block in the FlexO instance payload area may either carry an OTUC 32-byte word, or carry a stuff 32-byte word. The value of the stuff bytes is set to all-0s.

The 32-byte blocks in the FlexO instance payload area are numbered from 1 to 10260.

The FlexO instance payload 32-byte numbering for GMP 32-byte (m-bit) blocks is illustrated in Figures 10-12 and 10-13.

10.4 FlexO-n group alignment and deskewing

10.4.1 Alignment and deskewing of OTUCn clients

FlexO members are identified within a FlexO-n group and reordered using GID, MAP and IID FlexO BOH field.

For OTUCn BMP and GMP mappings defined in clauses 10.1 and 10.3, deskewing in the sink process is performed between OTUC frames within the group, using OTUC FAS as specified in [ITU-T G.709].

The OTUC frame skew requirements are intended to account for variations due to digital mapping and cable lengths. The skew tolerance requirements are specified in [ITU-T G.709.3], [ITU-T G.709.5] and [ITU-T G.709.6].

During a signal fail condition of the incoming FlexO-n signal or if the OTUCn deskewing has failed, the OTUCn-AIS pattern as specified in clause 16.4.2 [ITU-T G.709] is generated as a replacement signal for the lost OTUCn signal.

10.5 FlexO payload PRBS test pattern

A framed FlexO PRBS test pattern is used for validating FlexO-x(e)-<int> interfaces through links and regens. The required PRBS31 is per [IEEE 802.3] with the initial generator state (see Figure 10-16) being all 1's.

– The PRBS polynomial pattern is inserted per FlexO instance, replicated in all instances on a FlexO-x(e)-<int> interface.
– The PRBS pattern will be identified by a unique payload type identifier as shown in Table 9-1.
– The PRBS in the source is inserted in the full payload area shown in Figure 8-1. Stuffing or padding used by mapping procedures is ignored (overwritten) when PRBS is used.
– The PRBS in the sink is monitored from the FlexO payload area. The PRBS checker shall recover and verify the PRBS31 sequence.

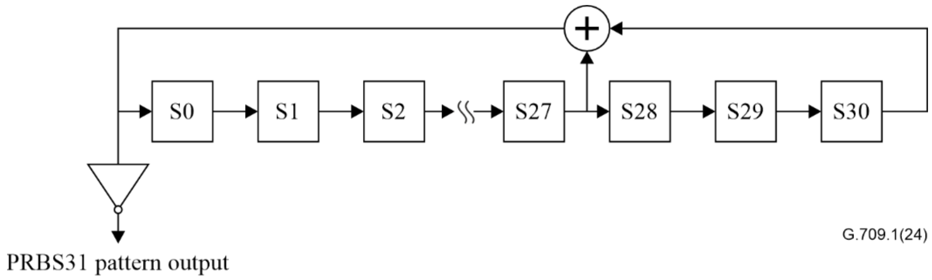

Figure 10-16 – FlexO PRBS

10.5.1 Client mapping specific overhead

The client mapping specific overhead shown in Figure 9-2 is not used for PRBS test pattern and reserved.

Annex A

FlexOsec encryption and authentication

(This annex forms an integral part of this Recommendation.)

This annex specifies encryption and authentication of fixed-length FlexO frame structures. It contains specific authentication and encryption process details for the different cipher suite types (profiles).

A cipher suite type is an interoperable specification of cryptographic algorithms together with the values of parameters (e.g., key size) to be used by those algorithms. Specification of the cryptographic functions required by FlexOsec in terms of cipher suite types increase interoperability by providing a clear default and a limited number of alternatives.

A.1 GCM-AES-256 frame payload encryption

The GCM-AES-256 cipher suite corresponds to CST value of 000001 as shown in Table 9-3. This profile is based on cryptographic algorithms and processes as defined in [NIST SP 800-38D].

In this cipher suite type, the FlexO frame payload is encrypted for confidentiality as shown in Figure A.1. The FlexO frame payload along with BOH and a subset of EOH are authenticated for integrity as shown in Figure A.2.

In the FlexOsec scheme, confidentiality and integrity are applied individually per FlexO instance. The frame format discussed is this annex is prior to FEC adaptation and FlexO-x interface interleaving.

A.1.1 GCM-AES-256 confidentiality (encryption)

The bits in the FlexO frame payload area are encrypted prior to transmission for cases where confidentiality on the interface is required, as illustrated in Figure A.1. These bits correspond to the FlexO frame payload area and are excluding AM, EOH and BOH fields. For the purpose of FlexOsec application, the FlexO frame structure can be represented as 5140 × 128-bit fixed-length blocks. An alternate representation using 128-bit blocks is shown in Figure A.2.

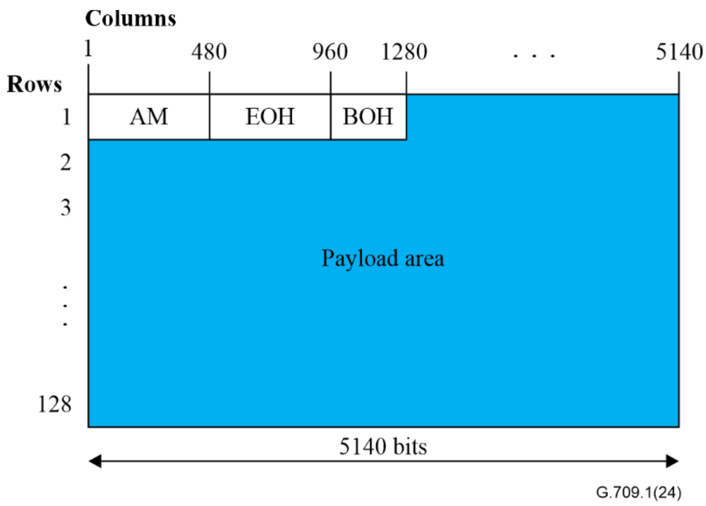

Figure A.1 – FlexO frame encryption

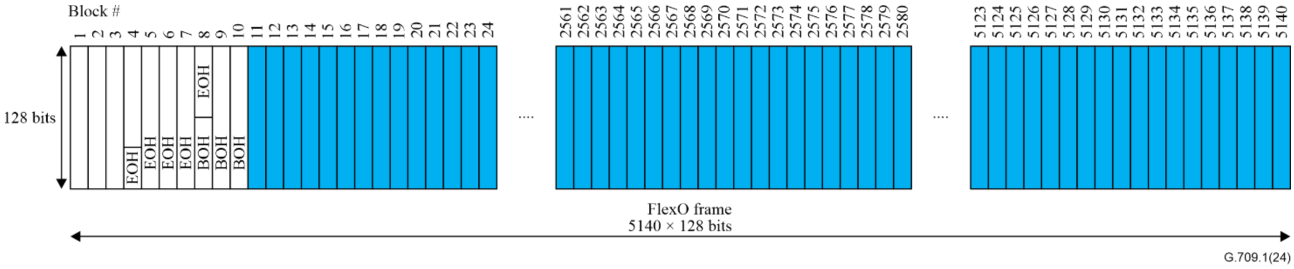

Figure A.2 – FlexO frame encryption (128-bit representation)

A.1.2 GCM-AES-256 integrity (authentication)

The bits in the FlexO frame payload area, BOH and subset of the EOH are authenticated prior to transmission for cases where the integrity of the information on the interface is required, as illustrated in Figure A.3. An alternate representation using 128-bit blocks is shown in Figure A.4. The authentication starts at bit 769 (in the EOH), which corresponds to the 7th 128-bit word, and runs until the end of the frame.

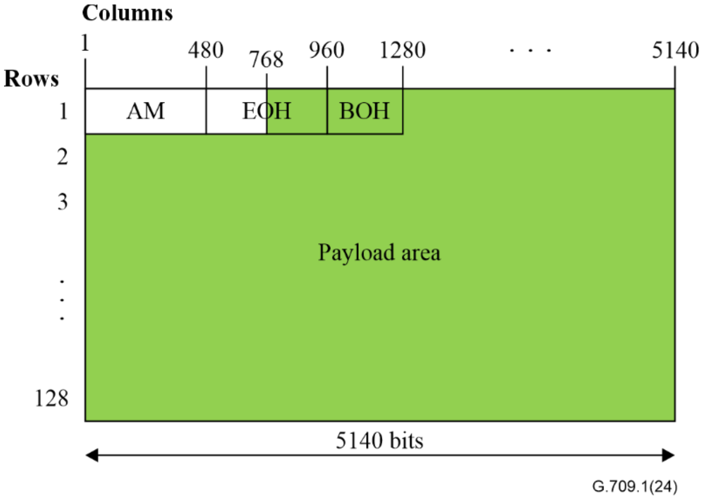

Figure A.3 – FlexO frame authentication

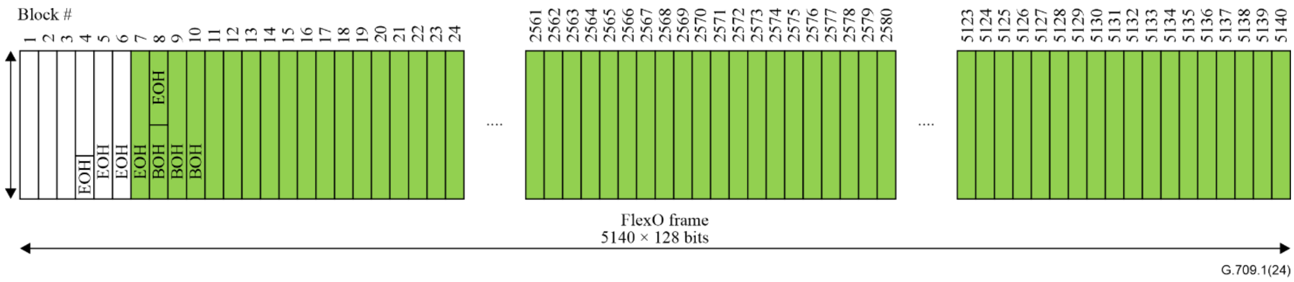

Figure A.4 – FlexO frame authentication (128-bit representation)

An authentication tag (AT) is created using algorithms specified in clause A.1.2, with 128-bit words from the FlexO instance #i frame #j. The AT is then inserted in the next EOH of FlexO instance #i frame #j+1. The authentication tag is unique to each FlexO instance.

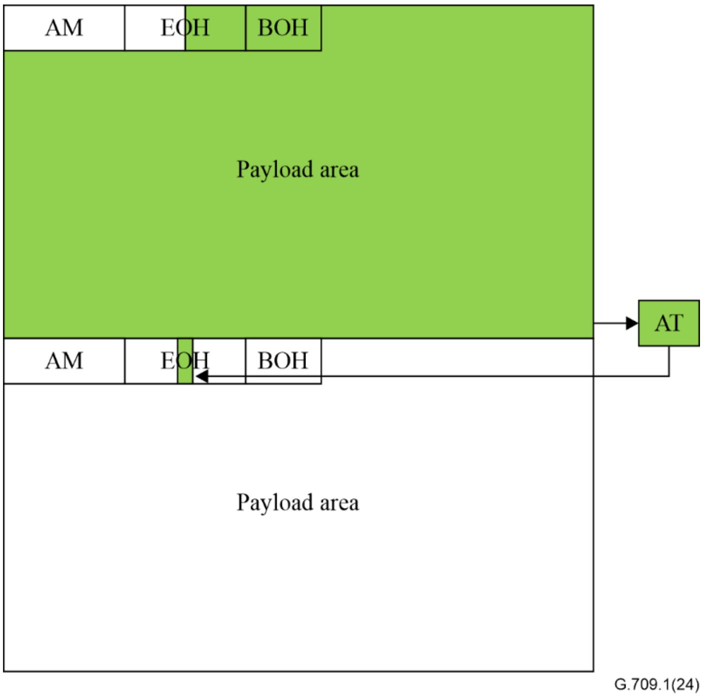

Figure A.5 – FlexO AT insertion

In the process flow, some values in the FlexOsec overhead are inserted after AT calculation (algorithm) in the source functions and before in the sink functions. Some OH values will be assumed as all-0s for the AT algorithms and these are reflected in Table A.1. Figure A.5 shows FlexO AT insertion.

Table A.1 – FlexOsec OH AT calculation

FlexOsec OH field	Tag calculation	Note
Authentication tag (AT)	Not part of tag calculation	
Frame number (FN)	Use FN value	
Key index (KI)	Use KI value	
Cipher suite type (CST)	Use CST value	
KCC	All-0s	KCC inserted after tag calculation
Reserved (RES)	All-0s	

Since the AT value of a current frame (n) is presented in the following frame (n+1), buffering of a FlexO frame could optionally be required for some applications that discard frames that have failed integrity check (authentication failures). The individual frames can be optionally replaced with a repeating SquelchText = 0x04 byte pattern replacing the area covered by authentication as shown in Figure A.3. Figure A.6 shows per instance FlexO processing.

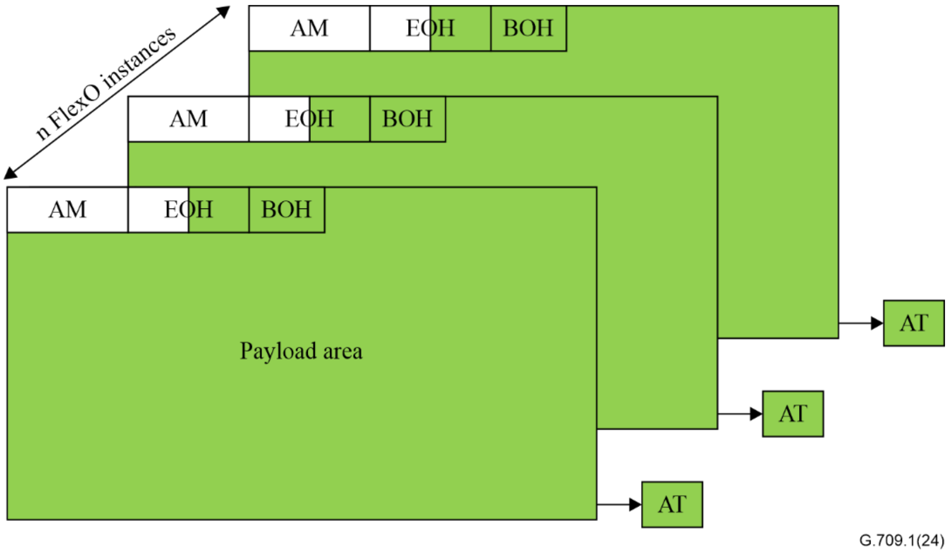

Figure A.6 – Per instance FlexO processing

A.1.3 IV construction

The 96-bit initial vector for this cipher suite type is based on deterministic construction as defined in clause 8.2.1 of [NIST SP 800-38D]. In order to promote interoperability for the default IV length of 96 bits, the leading (i.e., leftmost) 32 bits of the IV hold a user configurable fixed identifier and the trailing (i.e., rightmost) 64 bits hold the invocation field, which is the frame number (FN).

NOTE – The construction described in this clause meets the total number of invocation requirements as specified in clause 8.3 of [NIST SP 800-38D].

A.1.4 GCM-AES-256 algorithms

The authenticated encryption and authenticated decryption algorithms for this cipher suite type are based on the GCM specifications in clause 7 of [NIST SP 800-38D]. These are referred to as algorithms 4 and 5, for the authenticated encryption and authenticated decryption functions, respectively. The specifications include the inputs, the outputs, the steps of the algorithm, diagrams, and summaries. The GCM-AES-256 parameters are listed in Table A.2.

Table A.2 – GCM-AES-256 parameters

Parameter	Name	Length
C	CipherText	656640 bits (5130 × 128 bits)
P	PlainText	656640 bits (5130 × 128 bits)
A	Additional authenticated data	512 bits (4 × 128 bits)
T	Authentication tag (referred to as AT in recommendation)	128 bits
K	Key	256 bits
IV	Initial vector	96 bits

Figure A.7 shows how the FlexO frame bits are processed with respective cryptographic algorithms. There are three inputs into the NIST authenticated encryption algorithm referred to as algorithm 4: J0, AAD and P (plaintext). The first bits transmitted are the leftmost bits in the figure.

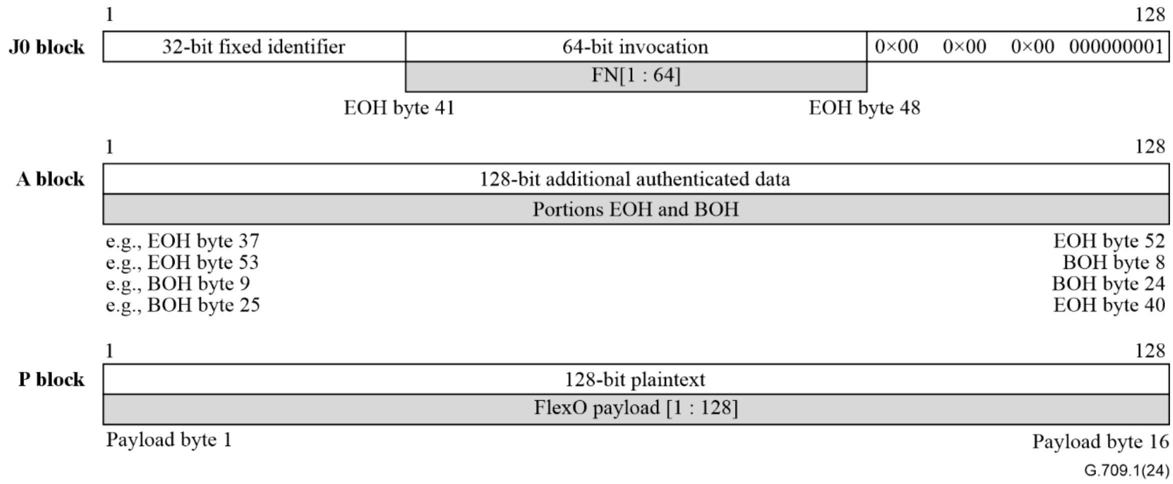

Figure A.7 – FlexOsec bit ordering

Annex B

Applying generic mapping procedure principles in a FlexO-n(e)

(This annex forms an integral part of this Recommendation.)

This annex complements Annex D in [ITU-T G.709] with FlexO specific aspects. It presents application principles of GMP within the FlexO cases when a client is mapped into a FlexO-n(e) payload.

B.1 Applying GMP in a FlexO-n(e)

Clauses 10.2 and 10.3 of this Recommendation specify GMP as the asynchronous generic mapping method for the mapping of Ethernet and OTN client signals into a FlexO-n(e). Asynchronous mappings have a timing granularity n as shown in Table B.1.

B.1.1 Mapping granularity

257y-bit granularity mapping

Clause 10.2 of this Recommendation specifies that the mapping of Ethernet bits into the payload of an FlexO-ne is performed with 257 × y-bit (257y-bit) granularity, where y is the number of FlexO payload instances occupied by the client signal, as shown in Table D.1 of [ITU-T G.709]. The value of m discussed in clause D.2 of [ITU-T G.709] is 257 × y. The remaining $C_{nD}(t)$ data entities are signalled in the justification overhead as additional timing/phase information.

The corresponding c_m, $C_m(t)$, c_{nD} and $C_{nD}(t)$ values can be calculated using equations D-12 through D-15 in [ITU-T G.709], with m = 257 × y.

The FlexO 257y-bit granularity uses the 14-bit $C_m(t)$ described in clause B.1.2.1, with the corresponding 5-bit $\sum C_{nD}(t)$ described in clause B.1.3.1.

256n_i-bit/32n_i-byte granularity mapping

Clause 10.3 of this Recommendation specifies that the mapping of OTUCn_i bits into the payload of n_i FlexO instances of an FlexO-n is performed with 256-bit (32-byte) granularity per OTUC/FlexO instance, as shown in Table B.1. The value of m discussed in clause D.2 of [ITU-T G.709] is 256. The remaining $C_{nD}(t)$ data entities are signalled in the justification overhead as additional timing/phase information.

The corresponding c_m, $C_m(t)$, c_{nD} and $C_{nD}(t)$ values can be calculated using equations D-12 through D-15 in [ITU-T G.709], with m = 256.

The FlexO 32_i-byte granularity uses the 14-bit $C_m(t)$ described in the example below in clause D.3.2.2 of [ITU-T G.709] with the corresponding 5-bit $\sum C_{nD}(t)$ described in clause D.3.3.2 of [ITU-T G.709].

Values of GMP parameters for FlexO servers

The values for n, m, f_{client}, f_{server}, T_{server}, B_{server}, O_{server}, P_{server}, $f_{n,server}$, $P_{n,server}$, $P_{m,server}$ and ΣC_{nD} are specified in Table B.1.

Table B.1 – FlexO-n(e) GMP parameters

GMP parameter	Equations	*y*00GBASE-R into y FlexO payload instances of a FlexO-ne	OTUC into FlexO instance payload
n		y × 8.03125 100GBASE-R: 8.03125 × 1 = 8.03125 200GBASE-R: 8.03125 × 2 = 16.0625 400GBASE-R: 8.03125 × 4 = 32.125 800GBASE-R: 8.03125 × 8 = 64.25	8
m		m = 257 × y 100GBASE-R: 257 × 1 = 257 200GBASE-R: 257 × 2 = 514 400GBASE-R: 257 × 4 = 1028 800GBASE-R: 257 × 8 = 2056	m = 256
f_{client}		Ethernet nominal bit rate (Table 10-2) 100GBASE-R: 100,384,497,642.517 bit/s 200GBASE-R: 2 × 100,385,723,114.014 bit/s 400GBASE-R: 4 × 100,385,723,114.014 bit/s 800GBASE-R: 8 × 100,385,723,114.014 bit/s	OTUC nominal bit rate (1/n_i × OTUCn_i bit rate specified Table 7-1 [ITU-T G.709]) 105,258,138,053.097 bit/s
$f_{client\_tolerance}$		Ethernet tolerance (Table 10-2) 100GBASE-R: 100 ppm 200GBASE-R: 100 ppm 400GBASE-R: 100 ppm 800GBASE-R: 50 ppm	OTUCn_i tolerance (Table 7-1 of [ITU-T G.709]) 20 ppm
f_{server}		FlexO-ne nominal bit rate (Table 8-1) y × 100,622,438,327.432 bit/s	FlexO nominal bit rate (Table 8-1) 105,643,510,782.118
$f_{server\_tolerance}$		FlexO-ne tolerance (Table 8-1) 20 ppm	FlexO tolerance (Table 8-1) 20 ppm
T_{server}		FlexO-ne 4-frame period (Table 8-2) ~26.155 µs	FlexO 4-frame period (Table 8-2) ~24.911 µs
B_{server}		y × 10240 × 257 bits = y × 2,631,680 bits	10280 × 256 bits = 2,631,680 bits
O_{server}		y × 20 × 257 bits = y × 5,140 bits	20 × 256 bits = 5120 bits
P_{server} = $P_{n,server}$		10220 × 257 bits / 8.03125 = 10220 × 32 = 327,040 n-bits	10260 × 256 bits / n = 10260 × 32 = 328,320 n-bits
$f_{p,server}$		y × FlexO payload instances bit rate and tolerance (Table 10-1) y × 100,425,910,127.574 bit/s	FlexO payload bit rate and tolerance (Table 10-5) 105,437,978,659.973 bit/s
$P_{m,server}$		10220 m-bits	10260 m-bits
ΣC_{nD} range		0 to +31	0 to +31

Table B.1 – FlexO-n(e) GMP parameters

GMP parameter	Equations	*y*00GBASE-R into y FlexO payload instances of a FlexO-ne	OTUC into FlexO instance payload
$C_{m,nom}$	$c_{m,nom} = \left(\frac{f_{client\_nom} \times P\ m,server}{fp,server\_nom}\right)$	100GBASE-R: 10 215.785 y00GBASE-R: 10 215.910 (y = 2,4,8)	10242.5
$C_{m,min}$ (note)	$c_{m,min} = c_{m,nom} \times \left(\frac{1 - fclient\_tolerance}{1 + fp,server\_tolerance}\right)$ $C_{m,min} = \lfloor c_{m,min} \rfloor$	100GBASE-R: 10 214.559 y00GBASE-R: 10 214.684 (y = 2,4) 800GBASE-R: 10 215.195	10 242.090
$C_{m,max}$ (note)	$c_{m,max} = c_{m,nom} \times \left(\frac{1 + fclient_{tolerance}}{1 - fpserver_{tolerance}}\right)$ $C_{m,max} = \lceil c_{m,max} \rceil$	100GBASE-R: 10 217.011 y00GBASE-R: 10 217.136 (y = 2,4) 800GBASE-R: 10 216.625	10 242.910
$C_{n,nom}$	$c_{n,nom} = \left(\frac{fclient_{nom} \times Pn,server}{fpserver,nom}\right)$	100GBASE-R: 326 905.139 y00GBASE-R: 326 909.130 (y = 2,4,8)	327 760
$C_{n,min}$ (note)	$c_{n,min} = c_{n,nom} \times \left(\frac{1 - fclient_{tolerance}}{1 + fpserver_{tolerance}}\right)$ $C_{n,min} = \lfloor c_{n,min} \rfloor$	100GBASE-R: 326 865.9111 y00GBASE-R: 326 869.902 (y = 2,4) 800GBASE-R : 326 886.247	327 746.890
$C_{n,max}$ (note)	$c_{n,max} = c_{n,nom} \times \left(\frac{1 + fclient_{tolerance}}{1 - fpserver_{tolerance}}\right)$ $C_{n,max} = \lceil c_{n,max} \rceil$	100GBASE-R: 326 944.368 y00GBASE-R: 326 948.360 (y = 2,4) 800GBASE-R : 327 773.111	327 773.111
NOTE – $C_{m,min}$, $C_{n,min}$, $C_{m,max}$ and $C_{n,max}$ values represent the boundaries of client and server payload ppm offset combinations (i.e., min. client/max. payload and max. client/min. payload). In steady state, given instances of client and server payload offset combinations should not result in generated C_m and C_n values throughout this range but rather should be within as small a range as possible. Under transient ppm offset conditions (e.g., replacement signal to normal signal), it is possible that C_n and C_m values outside the range $C_{n,min}$ to $C_{n,max}$ and $C_{m,min}$ to $C_{m,max}$ may be generated and a GMP de-mapper should be tolerant of such occurrences.			

B.1.2 FlexO $C_m(t)$ encoding and decoding

$C_m(t)$ is encoded in the FlexO justification control bytes JC1, JC2 and JC3 specified in clause 10.2.3 and 10.3.3 of this Recommendation for the 14-bit count.

B.1.2.1 FlexO $C_m(t)$ encoding and decoding for FlexO-ne and FlexO-n

The encoding of $C_m(t)$ into bytes JC1 and JC2 for FlexO-n(e) is defined using the 14-bit count field of Table B.2. An "I" entry in the table indicates an inversion of that bit. A CRC-8 in JC3 verifies whether the transmitted $C_m(t)$ value has been received correctly.

Table B.2 – 14-bit $C_m(t)$ increment and decrement indicator patterns

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	II	DI	Change
U	U	U	U	U	U	U	U	U	U	U	U	U	U	0	0	0
I	U	I	U	I	U	I	U	I	U	I	U	I	U	1	0	+1
U	I	U	I	U	I	U	I	U	I	U	I	U	I	0	1	–1
U	I	I	U	U	I	I	U	U	I	I	U	U	I	1	0	+2
I	U	U	I	I	U	U	I	I	U	U	I	I	U	0	1	–2
binary value														1	1	More than +2/–2
NOTE: – I indicates inverted Cj bit – U indicates unchanged Cj bit																

The CRC-8 located in JC3 is calculated over the JC1 and JC2 bits. The CRC-8 uses the $G(x) = x^8 + x^3 + x^2 + 1$ generator polynomial, and is calculated as follows:

1) The JC1 and JC2 octets are taken in network octet order, most significant bit first, to form a 16-bit pattern representing the coefficients of a polynomial *M(x)* of degree 15.

2) *M(x)* is multiplied by x^8 and divided (modulo 2) by *G(x)*, producing a remainder *R(x)* of degree 7 or less.

3) The coefficients of *R(x)* are considered to be an 8-bit sequence, where x^7 is the most significant bit.

4) This 8-bit sequence is the CRC-8 where the first bit of the CRC-8 to be transmitted is the coefficient of x^7 and the last bit transmitted is the coefficient of x^0.

The demapper process performs steps 1-3 in the same manner as the mapper process, except that here, the *M(x)* polynomial of step 1 includes the CRC bits of JC3, resulting in *M(x)* having degree 23. In the absence of bit errors, the remainder shall be 0000 0000.

A parallel logic implementation of the source CRC-8 associated with the 14-bit $C_m(t)$ encoding of Table B.2 is illustrated in Appendix VI of [ITU-T G.709].

Figure D.7 in [ITU-T G.709] is applied to the GMP sink synchronization for the 14-bit $C_m(t)$. When II ≠ DI in frame *i*, the Hunt state is determined by the values of the II and DI bits and the count least significant bit (LSB) (C14) in frame *i*. When frame *i*+1 is received, Figure D.7 in [ITU-T G.709] synchronization state machine "S" state interpretation associated with the 14-bit count field is specified in Table B.3.

Table B.3 – "S" state interpretation (see Figure D.7) with 14-bit C_m

S state	Interpretation/Action
S+2	Count = C1-C14 after inverting C2, C3, C6, C7, C10, C11, & C14; Increment +2 for the next frame
S+1	Count = C1-C14 after inverting C1, C3, C5, C7, C9, C11, & C13; Increment +1 for the next frame
S-1	Count = C1-C14 after inverting C2, C4, C6, C8, C10, C12, & C14; Decrement -1 for next frame
S-2	Count = C1-C14 after inverting C1, C4, C5, C8, C9, C12, C13; Decrement -2 for next frame

When synchronized, the GMP sink uses the updated $C_m(t)$ value to extract the client data from the next FlexO-n tributary unit frame as described above in clause D.2.2 in [ITU-T G.709], interpreting the received JC octets according to the inversion patterns of Table B.2.

B.1.3 FlexO $\Sigma C_{nD}(t)$ encoding and decoding

B.1.3.1 $\Sigma C_{nD}(t)$ encoding and decoding for FlexO-n(e)

The cumulative value of $C_{nD}(t)$ ($\Sigma C_{nD}(t)$) is encoded in bits 4-8 of the FlexO justification control bytes JC4, JC5 and JC6. Bits D1 to D10 in JC4 and JC5 carry the value of $\Sigma C_{nD}(t)$. Bit D1 carries the most significant bit and bit D10 carries the least significant bit.

The CRC-3 is calculated over bits 6-8 in JC4 and JC5. The CRC-3 uses the $G(x) = x^3 + x^2 + 1$ generator polynomial, and is calculated as follows:

1) The JC4 bits 6-8 and JC5 bits 6-8 are taken in network transmission order, most significant bit first, to form a 6-bit pattern representing the coefficients of a polynomial $M(x)$ of degree 5.
2) $M(x)$ is multiplied by x^3 and divided (modulo 2) by $G(x)$, producing a remainder $R(x)$ of degree 2 or less.
3) The coefficients of $R(x)$ are considered to be a 3-bit sequence, where x^2 is the most significant bit.
4) This 3-bit sequence is the CRC-3 where the first bit of the CRC-3 to be transmitted is the coefficient of x^2 and the last bit transmitted is the coefficient of x^0.

The demapper process performs steps 1-3 in the same manner as the mapper process. In the absence of bit errors, the remainder shall be 000.

NOTE – Refer to clause 6.2.8 of [b-ITU-T G.7044] for a parallel logic implementation of CRC-3. Replace RCOH1 and RCOH2 bits 1-3 by JC4 and JC5 bits 6-8.

Annex C

Transporting Ethernet client and Regen local degrade and remote degrade

(This annex forms an integral part of this Recommendation.)

C.1 Ethernet client CSTAT LD/RD

IP routers may support a "soft reroute" feature, which will direct IP traffic away from an optical link that experiences an increased number of forward error correction (FEC) errors on that optical link. 200G, 400G and 800G Gbit/s Ethernet interfaces that are compliant with [IEEE 802.3] will be able to support this feature. This application is described in more detail in Annex K of [ITU-T G.709].

[IEEE 802.3] has specified three bits in the alignment marker field (am_sf<2:0>) to carry link status information to support this feature. Bit am_sf<2> is defined as a remote degrade (RD) signal, bit am_sf<1> is defined as a local degrade (LD) signal and bit am_sf<0> is reserved. In the case of 800G Ethernet, the am_sf<2:0> bits are duplicated and present in the two 400G PCS streams (flow 0 and flow 1) alignment marker fields.

Note that in both Figures C.1 and C.2 router B includes the optional extender sublayer (XS) comprising a PHY XS connected to a DTE XS over an AUI.

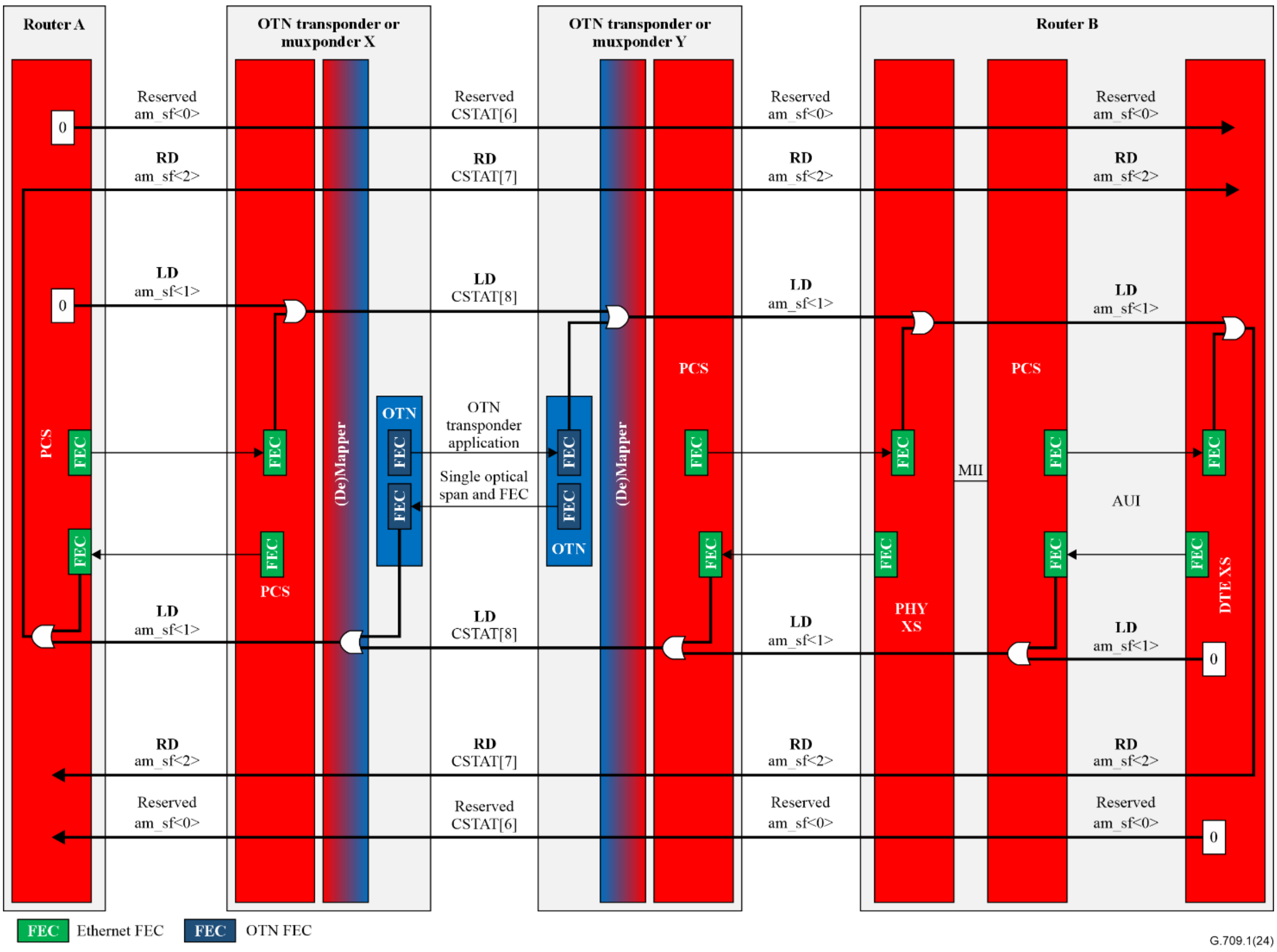

Figure C.1 – Local/remote degrade interworking between router and OTN muxponders/transponders for 200G/400G Ethernet

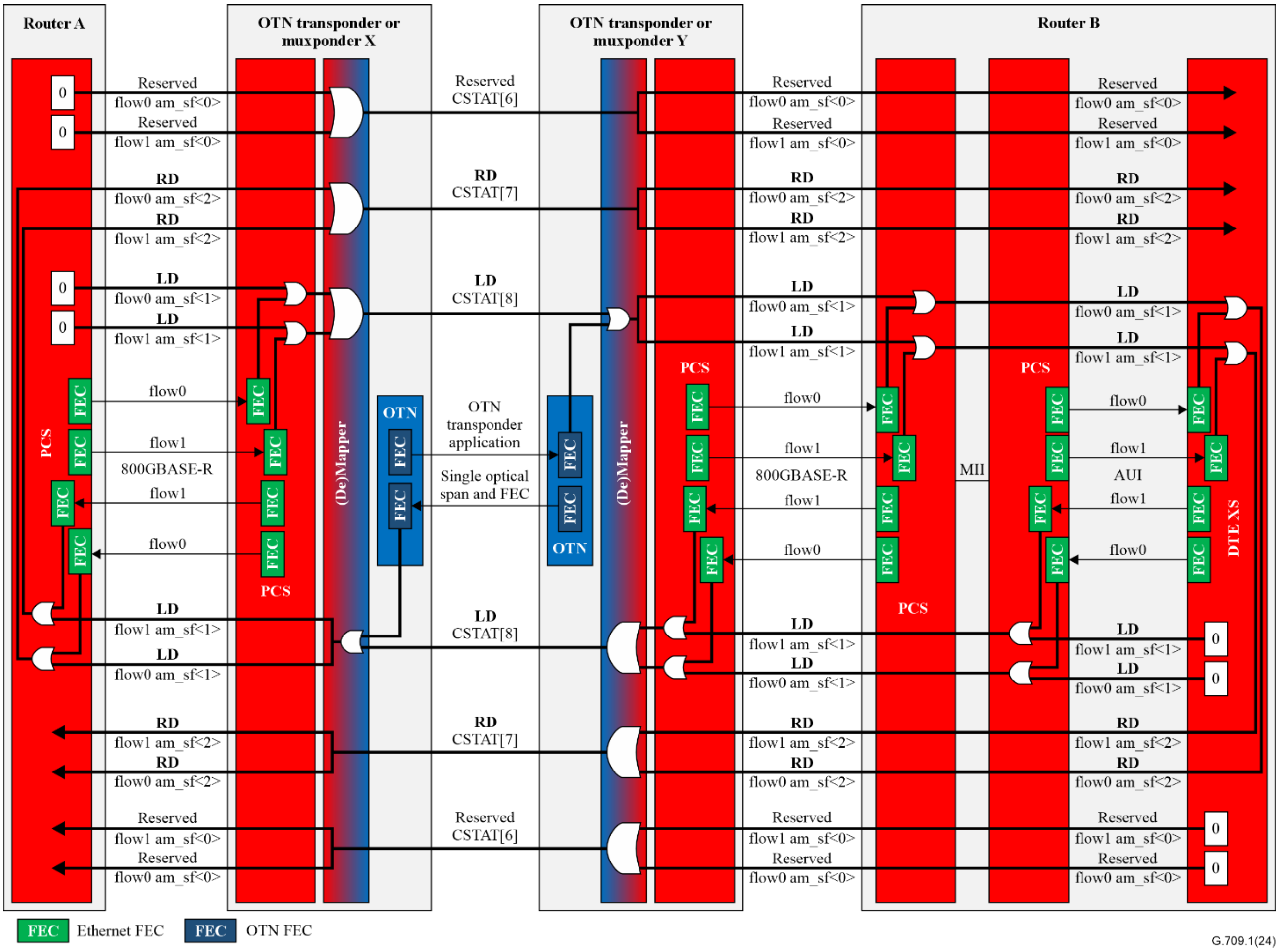

Figure C.2 – Local/remote degrade interworking between router and OTN muxponders/transponders for 800G Ethernet

The use case for 200GE and 400GE is illustrated in Figure C.1 and for 800GE in Figure C.2. The OTN muxponders/transponders X and Y can forward the information in the reserved (am_sf<0>) and RD (am_sf<2>) bits between ingress and egress muxponder/transponder. For 800G Ethernet client mapping illustrated in Figure C.2, the two sets of am_sf<2:0> values bits extracted from the two 400G PCS streams (flow 0 and flow 1) and present at the client interface shall be ORed to form a single set of am_sf<2:0> for further processing. The figures illustrate a single instance of client and CSTAT field, but muxponder designs may have multiple clients, whereas transponders would have a single client. The information in am_sf can be carried in CSTAT FlexO overhead using corresponding fields. The additional processing comprises the OR'ing of the LD status in the am_sf<1> bits of a 200GE, 400GE or 800GE signal with the local Ethernet pre-FEC BER link degrade status in the ingress transponder (X). In the egress transponder (Y), additional processing comprises the OR'ing of the LD status in CSTAT overhead bit of the FlexO signal with the local OTN pre-FEC BER link degrade status in the transponder (details defined by [ITU-T G.798]). The resulting LD status is then carried in the am_sf<1> bit of the 200GE, 400GE or 800GE signal. Note that in the case of 800 Gbit/s Ethernet signal, the single set of am_sf<2:0> bits value generated from the OTN demapping processes is duplicated towards both 400G flows (flow 0 and flow 1) at the client interface to be carried in both sets of alignment markers.

C.2 Ethernet client CSTAT and Regen RSTAT LD/RD

The RSTAT field also contains LD/RD status bits and the use case is illustrated in Figure C.3. The OTN muxponder/transponder X is connected to a regen node. At a regen node, the received RSTAT[8] LD is ORed with the OTN pre-FEC BER link degrade status.

In the opposite direction, muxponder/transponder X is terminating the FlexO section and demapping the Ethernet client; the received RSTAT[8] LD, as the received CSTAT[8] LD and OTN pre-FEC BER link degrade status are ORed to generate the Ethernet client's am-sf<1> field as described in clause C.1.

The RSTAT[7] RD field is only used for a single regen span. It is asserted in the reverse direction when a pre-FEC OTN link degrade is detected as shown in Figure C.3.

Client Ethernet CSTAT LD/RD is fully transparent to the FlexO regen section. The CSTAT[7] RD signal and corresponding Ethernet client RD am_sf<2> signal are not shown in Figure C.3 for clarity.

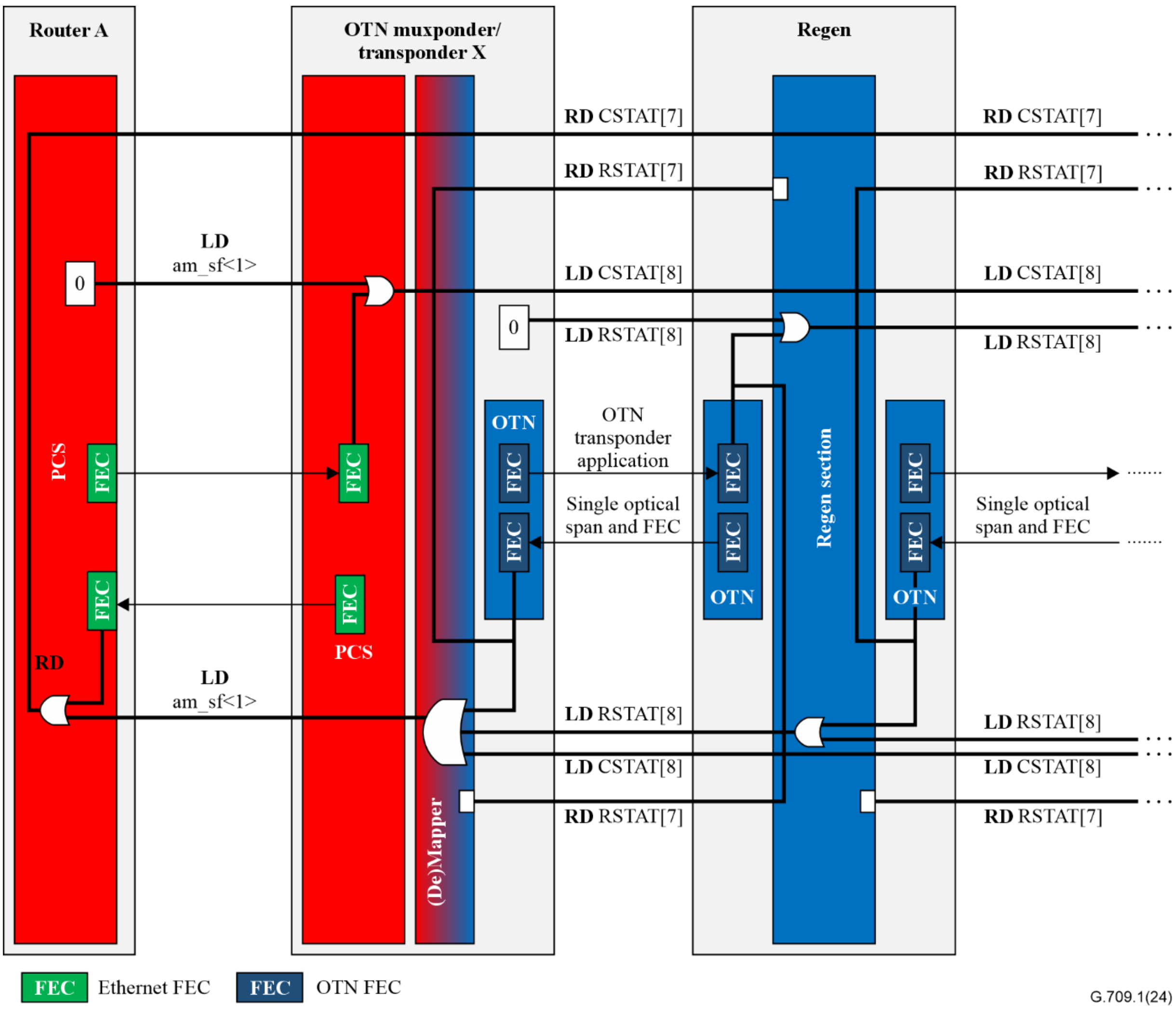

Figure C.3 – Local/remote degrade interworking with regens

Appendix I

Example short-reach applications

(This appendix does not form an integral part of this Recommendation.)

FlexO-x-RS-m interface group can be used for a variety of applications. Example applications for a FlexO-x-RS interface are shown in Figure I.1 and Figure I.2. An interoperable interface might represent an OTN handoff between router (R) and transport (T) nodes, or could be a handoff between different administrative domains.

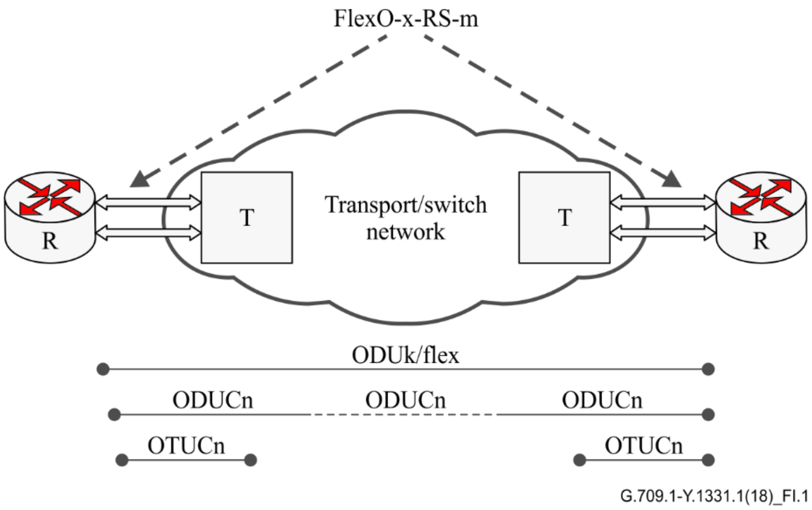

Figure I.1 – Example FlexO-x-RS handoff router-transport

The R-T topology is used in Figure I.1, to draw an analogy between FlexO-x-RS and FlexE use cases presented in [OIF FlexE]. The ODUk/flex (which can be a rate higher than 100Gbit/s) is the transport service (path) and maintenance entity in the OTN transport/switch network. The ODUCn/OTUCn is the section and FlexO-x-RS provides the interfacing capabilities (e.g., FEC, bonding and scrambling).

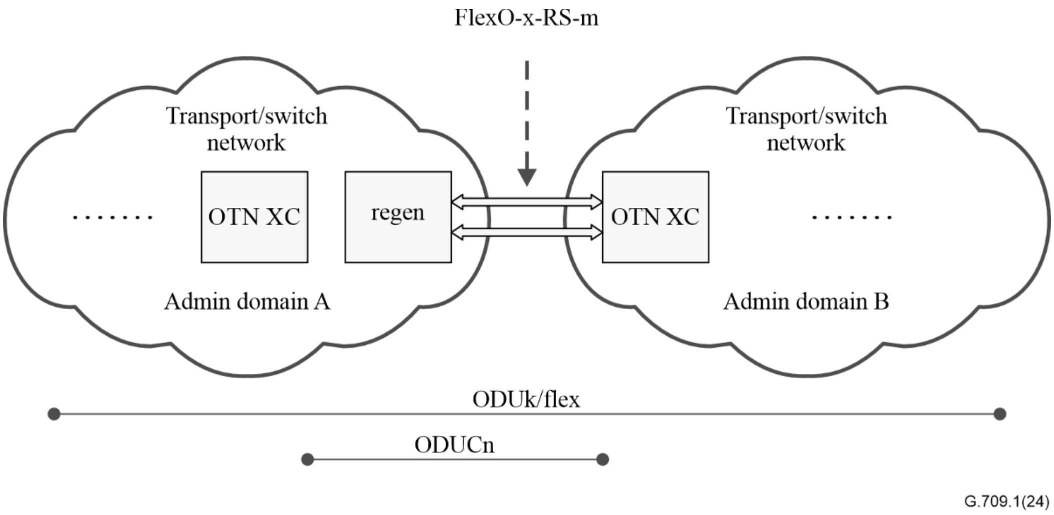

Figure I.2 – Example FlexO-x-RS inter-domain handoff

The example of Figure I.2 shows a FlexO-x-RS inter-domain interface used as a handoff between two OTN switch/transport administrative domains (A and B). The administrative domains can represent different carriers, different equipment vendors within a carrier or different segments (metro vs core) within a carrier.

Appendix II

Example long-reach applications

(This appendix does not form an integral part of this Recommendation.)

FlexO-x(e)-<int> (<int> = DO-modulation or DSH-modulation) group interfaces can be used for a variety of applications.

Example applications for a FlexO-x(e)-<int>-m interface group are shown in Figure II.1 and Figure II.2. Such an interface group might represent an OTN handoff between router (R) and transport (T) nodes within one administrative domain or could be a handoff between OTN equipment of different vendors in one administrative domain.

Optical transport networks are typically subdivided into metro and core where the core interconnects metro networks. Transport services may stay in one metro network or they may extend over different ones. In the latter case they may be passed through the core network.

Network elements in the metro network play different roles such as metro/core gateway, edge towards customer and transit nodes. The customer facing functions lead to some diversity of client interfaces. Network elements from different vendors may be used to serve this broad scope of functions. FlexO long-reach interfaces could be used to interconnect network elements of different vendors or the same vendor.

Figure II.1 illustrates an OTN core network with associated metro networks. The figure shows:

– packet switching nodes (labelled Router) of vendor Z interconnected with the router of vendor X using a FlexO-x(e)-<int>-m interface group

– OTN ODU cross connect nodes with electrical switch fabric (labelled EXC) of vendor Z interconnected with EXC of either Z or vendor X using a FlexO-x-<int>-m interface group

– interconnection of the above EXC or router nodes through a metro OTN network which connects with a backbone/core network of the same vendor X, thereby allowing a single management domain

– interconnection of EXC or router nodes from the same vendor X, establishing a path over which the OCh or OTSiA overhead can be exchanged (via the OCC, internal to the network and not illustrated) as specified in [ITU-T G.872], [ITU-T G.709] and [b-ITU-T G.7712] enabling end-to-end optical path monitoring

– interconnection in backbone/core network is also possible if the FlexO-x(e)-<int> FEC is adequate.

Details of the optical paths supporting the FlexO-x(e)-<int> signals are defined in [ITU-T G.698.2].

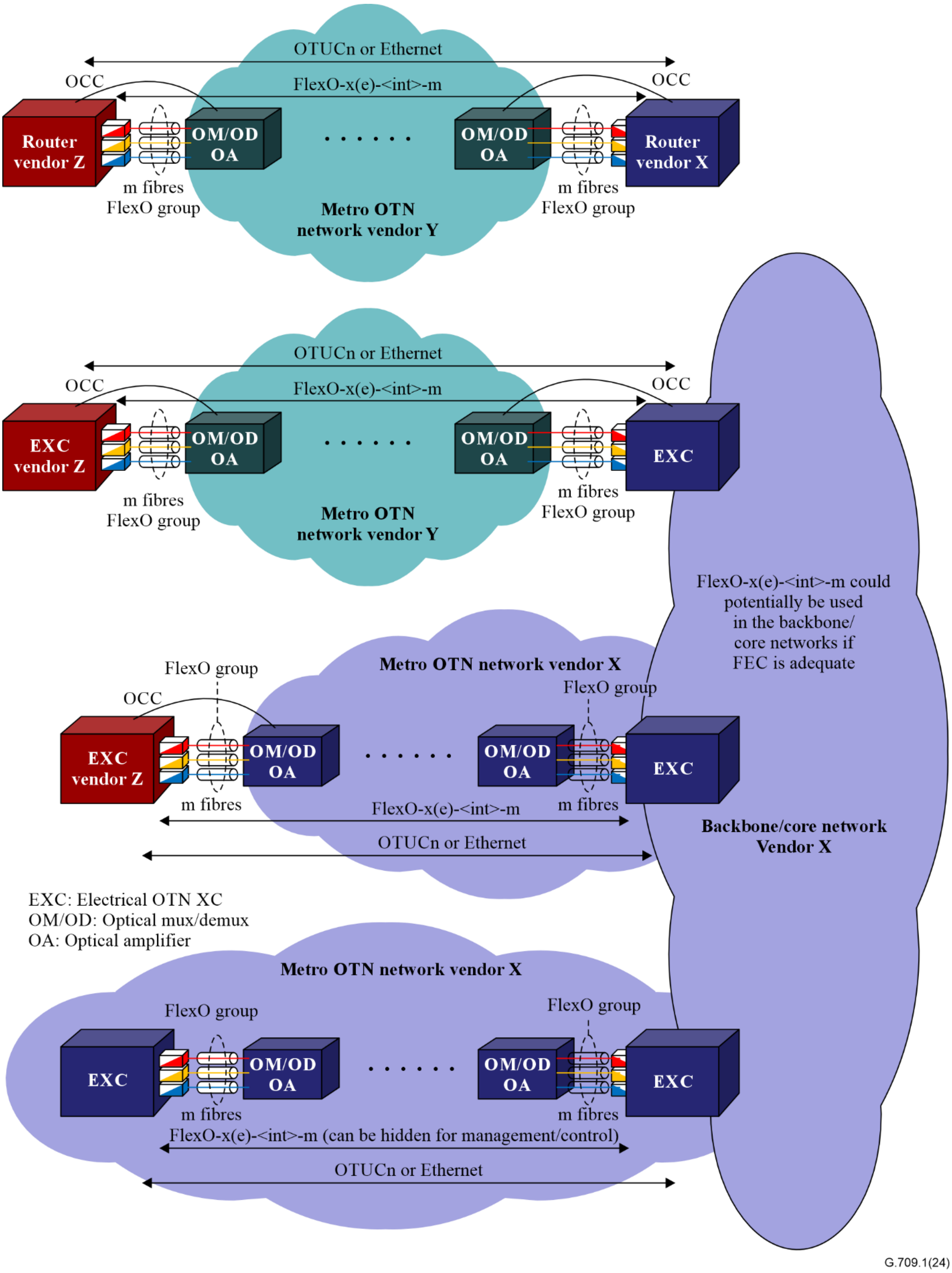

Figure II.1 – Example FlexO-x-<int>-m deployments in one administrative domain

Figure II.2 illustrates interconnection of the EXC or router nodes through a set of m point-to-point fibres, establishing an inter-domain group interface beyond the distances supported by the FlexO-x-RS-m specified in [ITU-T G.709.5] and [ITU-T G.959.1].

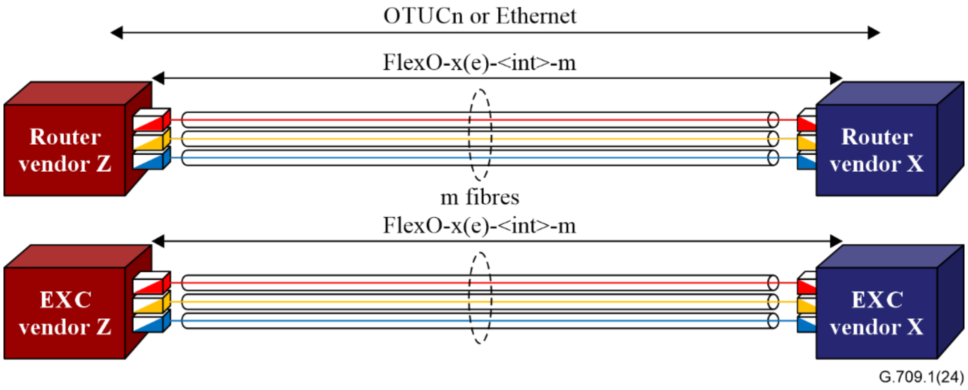

Figure II.2 – Example FlexO-x(e)-<int>-m deployments establishing an inter-domain group interface beyond the distances supported by the FlexO-x-RS-m

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