# A G.709 Optical Transport Network Tutorial

Guylain Barlow, Product Manager, Innocor Ltd.
7 Mill Street, P.O. Box 1363, Almonte, ON, Canada, K0A 1A0 www.innocor.com
gbarlow@innocor.com

The amount of data traffic relative to voice traffic on optical networks and the total traffic volume keeps increasing.[1] These factors are the drivers behind emerging, flexible technologies to supplement the mature, voice optimized, SONET/SDH transport infrastructure and help manage network complexity. At the edge of the network, where data and voice combine in a common infrastructure, new data-centric applications have emerged. An example is the combination of virtual concatenation (VCAT), which provides flexible bandwidth groupings for SONET/SDH, Link Capacity Adjustment Scheme (LCAS), which provides dynamic bandwidth settings, and Generic Framing Procedures (GFP), which provides a protocol agnostic frame container[2, 3, 4]. In the transport core, bandwidth requirements spawned the creation of the Optical Transport Network (OTN) described in general terms in ITU-T G.872[5]. ITU-T G.709 provides the network interface definitions.[6]

G.709 improves transport network performance and facilitates the evolution to higher backbone bandwidths. The G.709 OTN frame includes transport overhead that provides operation, administration, and maintenance capabilities, and Forward Error Correction (FEC). The FEC helps reduce the number of transmission errors on noisy links, which enables the deployment of longer optical spans. This tutorial focuses on the digital applications of G.709.

## Interfaces and Payload

G.709 defines standard interfaces and rates. These rates have been derived from the existing SONET/SDH rates where the G.709 overhead and FEC information have been taken into account. The resulting interfaces thus operate at line rates, roughly 7% higher, than the corresponding SONET/SDH that becomes the OTN payload. **Table 1** lists the G.709 line rates and the matching SONET/SDH interfaces. An additional interface type, which is not part of the G.709 recommendation, applies to 10 Gigabit Ethernet LAN clients. In this case, the same overhead structure and FEC is applied resulting in a line rate of 11.095Gbps.

| G.709 Interface | Line Rate | Corresponding SONET/SDH Rate | Line Rate |
|---|---|---|---|
| OTU-1 | 2.666 Gbps | OC-48/STM-16 | 2.488 Gbps |
| OTU-2 | 10.709 Gbps | OC-192/STM-64 | 9.953 Gbps |
| OTU-3 | 43.018 Gbps | OC-768/STM-256 | 39.813 Gbps |

Table 1

**Figure 1** illustrates the three parts that constitute the G.709 OTN frame; namely the overhead, the payload, and the FEC. There is no direct correlation between the size of a G.709 frame and that of a SONET/SDH frame. As an example, transmitting a single OC-192 frame takes about eleven OTU-2 frames. The SONET/SDH payload clients, also referred to as constant bit rate (CBR), are accompanied by stuff bytes in the amount of 64 and 128 per frame in the case of OTU-2 and OTU-3 respectively. These additional bytes leave room to support the multiplexing of multiple G.709 lower transmission rate signals. For example, four individual OTU-1 signals may be combined, with their FEC stripped and minor overhead modifications, and interleaved into the payload of an OTU-2 frame. The OTN is protocol agnostic as it supports payload types other than SONET/SDH and multiplexed G.709 signals. More specifically, native data protocols such as Asynchronous Transfer Mode (ATM), and Generic Framing Procedures (GFP) can be mapped directly into the payload area of the G.709 frame.

Though the initial development efforts focus on SONET/SDH clients, G.709 also considers the management of optical wavelengths for wave-division multiplexing (WDM). At present, simple wavelength identification can be provided in the existing G.709 overhead. The implementation of additional dedicated overhead for optical channels is for future standardization.

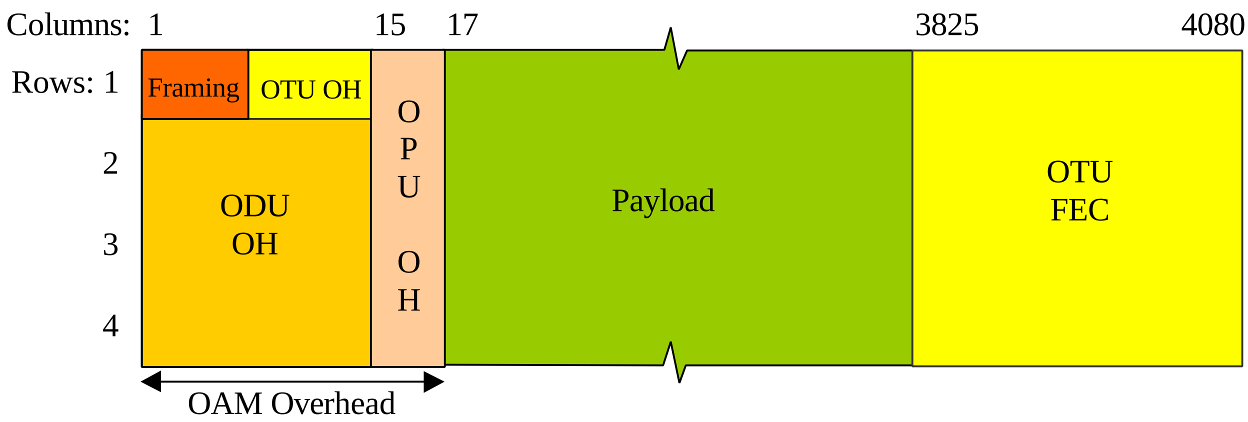


Figure 1

## Forward error correction

*FEC is one of the main justifications behind G.709*. It uses a Reed-Solomon (RS) code to produce redundant information that gets concatenated with the signal to be transmitted. This additional information is used on the receive interface to help identify and correct transmission errors. The RS encoding was chosen because of its low complexity, relatively high error correction capability and low error burst sensitivity.

The G.709 FEC separates the frame data into 16 data streams, where up to 8 errored bytes can be corrected per stream. **Figure 2** illustrates this process where each row is split into sub-rows. The protocol uses one overhead byte and 238 data bytes to compute 16 parity bytes to form 255 byte blocks—the RS(255,239) algorithm.

Two key advantages are achieved by interleaving the information. First, the encoding rate of each stream is reduced relative to the line transmission rate and second, it reduces the sensitivity to bursts of error. The interleaving combined with the inherent correction strength of the RS(255,239) algorithm enables the correction of transmission bursts of up to 128 consecutive errored bytes. As a result, G.709's contiguous burst error correcting capability is enhanced 16 times above the capacity of the RS(255,239) algorithm.

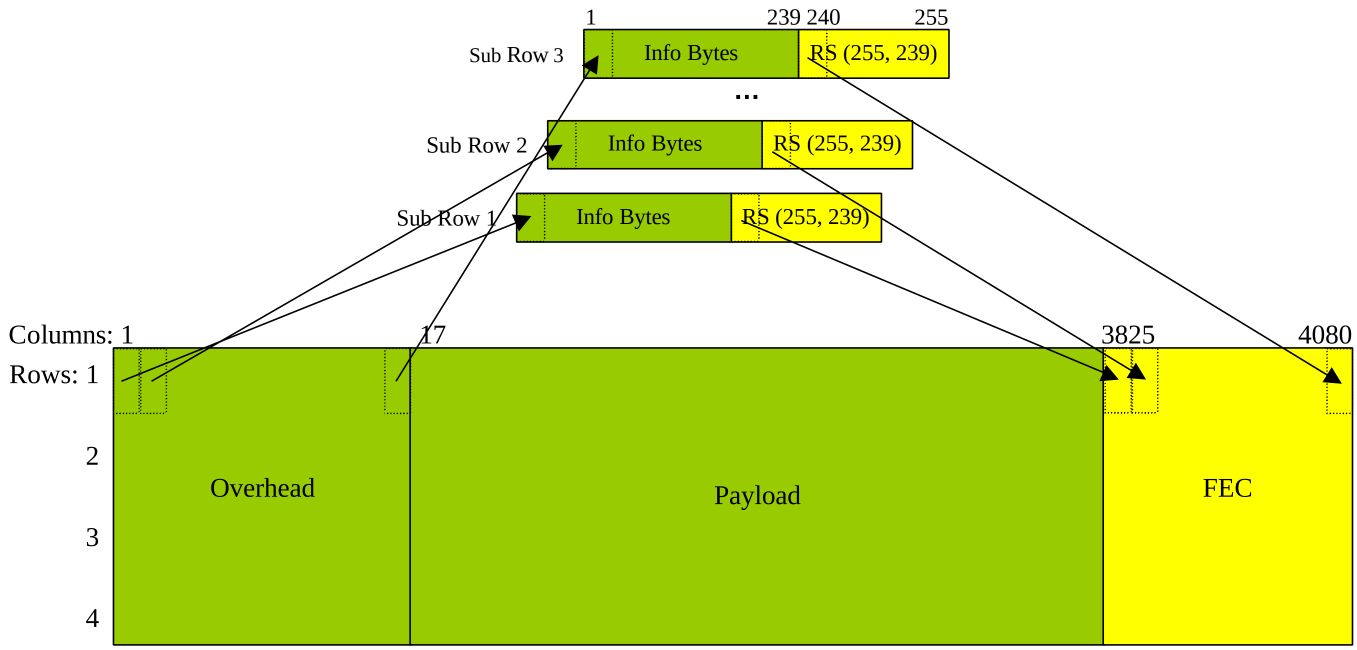


Figure 2

**Figure 3** illustrates the coding gain achieved with FEC relative to the Bit Error Rate (BER). At high BER, the effectiveness of the FEC decreases relative to a signal without FEC. This is quantified using the coding gain, which is described as the power decrease required to maintain the same BER as that achieved without FEC encoding. At low BER such as $10^{-12}$ or 1 errored bit per terabit, G.709 achieves around 5.4dB of optical coding gain[7,8]. In actual facts, this translates into longer optical spans using the same optical launch power. *The FEC can be used as a warning tool for degrading signals since an increase in the number of corrected symbols indicates a deteriorating link.* These signs can be present even before any system faults or alarms, later described, are detected. G.709 supports the option to turn FEC off in which case the FEC field is filled with zeroes.

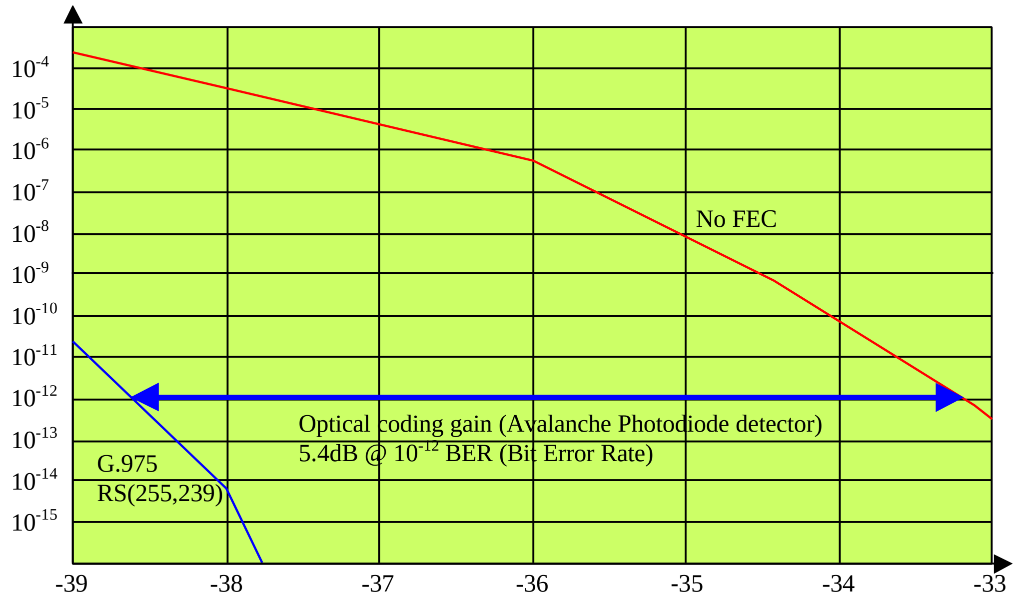


Figure 3

## Overhead

Figure 1 shows the OAM overhead and its three parts: the Optical channel Transport Unit (OTU), Optical channel Data Unit (ODU), and Optical channel Payload Unit (OPU). The OTU structure, which includes the FEC, provides supervisory functions and conditions the signal for transport between optical channel termination points where re-timing, reshaping, and regeneration takes place. The ODU provides end-to-end path supervision and supports tandem connection monitoring while the OPU supports the adaptation of client signals for transport over an optical channel. **Figure 4** shows sample OTU, ODU, and OPU termination points in an OTN network.

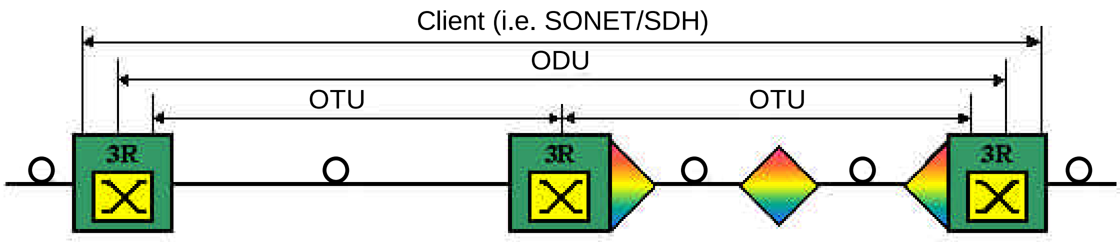


Figure 4

**Figure 5** illustrates the framing bytes and the non-FEC portion of the OTU. The framing bytes are used in transmission systems to delineate G.709 frames, in other words to determine where frames start and end. There are two functionally distinct framing fields. The Frame Alignment Signal (FAS) bytes contain a static value of '0xF6F6F6282828' while the MFAS is a Multi-frame Alignment Signal. MFAS is continuously incremented frame after frame from 0 to 255. This is useful in multi-frame structures where the full meaning of a message is determined by collecting information over a fixed period covering 64 or 256 frames. The FAS and MFAS bytes are not scrambled unlike the rest of the OTU structure. The purpose of scrambling is to ensure sufficient bit state transitions for clock recovery purposes and to reduce the likeliness of FAS byte duplication.

In the OTU, the Trail Trace Identifier (TTI) byte, which is part of the Section Monitoring (SM) overhead, is an example of a multi-frame signal. It contains information on network elements in the form of Source and Destination Access Point Identifiers (SAPI, DAPI). In addition, the SM has a BIP-8 field and a byte for alarm signals, which are further described in the fault and alarms section. The OTU also contains the General Communications Channel field (GCC0) which resembles the DCC (Data Communications Channel) from SONET/SDH. The GCC function is currently undefined but it will likely be used for functions such as network management[9] or control plane signaling for a protocol like Generic Multi-Protocol Label Switching (G-MPLS)[10]. The reserved (RES) fields found throughout the overhead are set aside for future use.

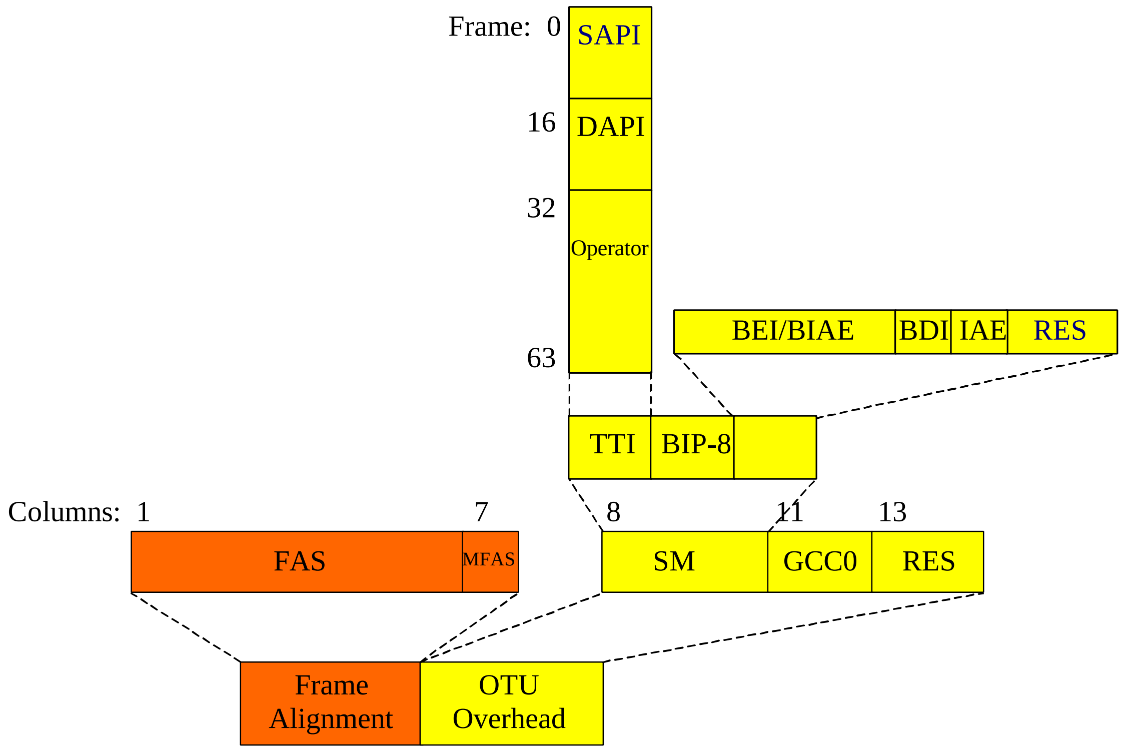


Figure 5

The greatest number of overhead fields is found in the ODU, illustrated in figure 6, where a notable feature are the Tandem Connection Monitoring (TCM) fields. The TCM ACT field is reserved for future use to enable the activation/deactivation of TCM channels. There are six TCMi (TCM1-6) fields defined for use by network operators for management functions. They contain elements quite similar to the SM including a TTI, BIP-8, and alarm capabilities that are discussed in the next section. The termination points of each TCMi can be defined within an operator's network, across a large public network at the user network interface points, or at protection switching points.

The Path Monitoring (PM) is a structure analogous to the SM and TCMi except that its purpose is to provide connection end-to-end monitoring. It also contains a TTI, BIP-8 and alarm capabilities. The automatic protection switching and protection communication channel (APS/PCC) currently supports linear switching, as opposed to ring. Recommendations on the APS protocol are found in G.873.1[11]. APS is supported on different monitoring levels, more specifically: on the ODU path, on any of the TCMi, or based on SNC/I, which is a subnetwork connection with inherent monitoring typically used to protect a path segment. The applicable APS level is derived from the actual value of the three least significant bits of the MFAS.

The experimental overhead (EXP) is not standardized and can be used freely by vendors and network operators while the GCC1 and GCC2 are very similar to the GCC0 except that they apply to the ODU. The Fault Type and Fault Location reporting communication channel (FTFL) is a 256 byte multi-frame structure used to monitor path level faults. The structure is divided into forward and backward directions that can indicate either no fault (value of '0'), signal fail '1', or signal degrade '2' accompanied with an operator identifier. The signal fail indication is used to trigger alarms as described in the next section. The signal degrade information can be used in the protection switching process.

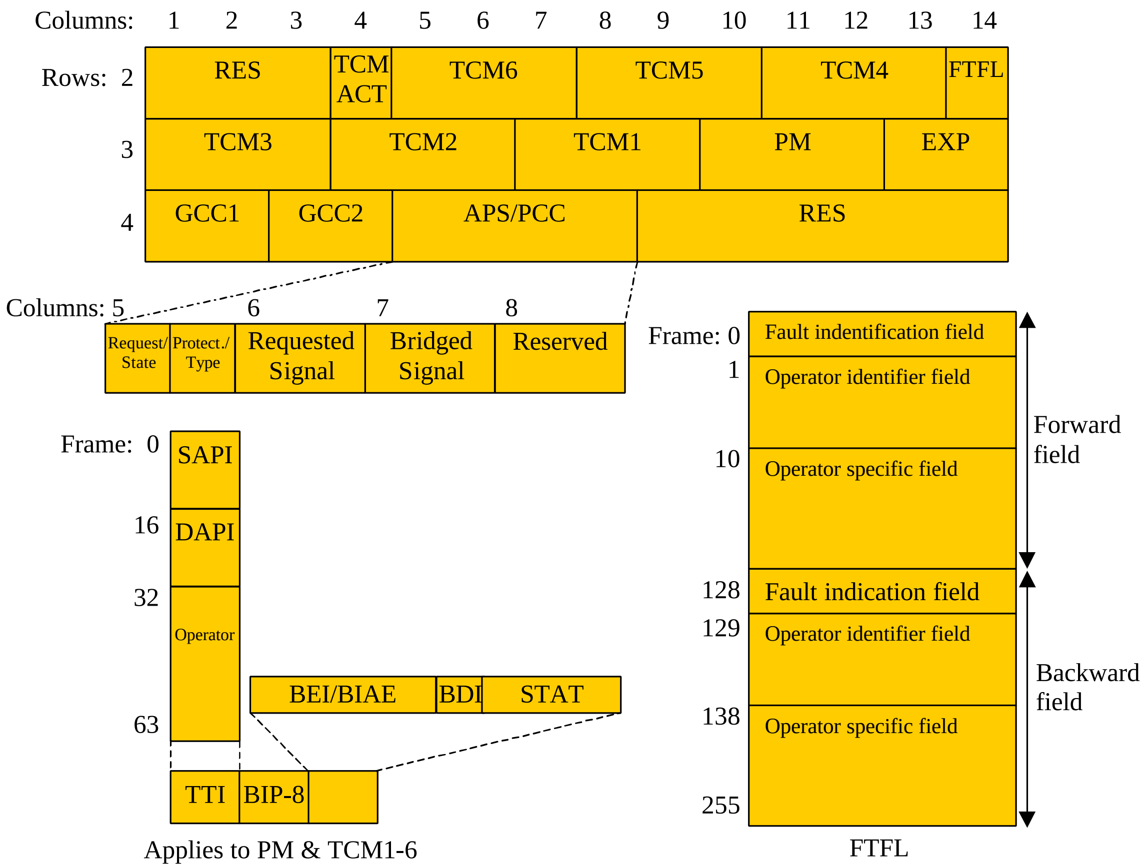


Figure 6

**Figure 7** illustrates the OPU overhead. The Justification Control (JC) bytes provide for payload movements inside the OTN frame. This can occur when line and client clock sources are asynchronous. G.709 also supports synchronous clocking where the payload is fixed relative to the overhead. There are three JC bytes where majority voting, meaning two out of three, is sufficient to carry out justification events. Positive justification events cause one of the payload bytes, identified as the Position Justification Opportunity (PJO), to not contain payload information as the event occurs. Conversely, during a negative justification event, the NJO byte will temporarily carry part of the payload information.

The Payload Structure Identifier (PSI) is a 256-byte multi-frame structure. It contains the Payload Type (PT), which identifies the payload content such as asynchronous SONET/SDH, ATM, or GFP. Virtual concatenation, which groups multiple OPU interfaces into a single OPU that runs at a higher rate, is a function supported by G.709. An advantage of virtual concatenation is that the channels within a group can travel on different physical paths through a network, before being joined back together, and carry an overall payload corresponding to a higher transmission rate. In this case, the PT is set to a value of '06', and the vcPT indicates the actual payload type. The PT byte can also specify that an ODU multiplex structure, discussed earlier, is carried in the payload. This enables the multiplexing of multiple tributaries into a higher rate structure.

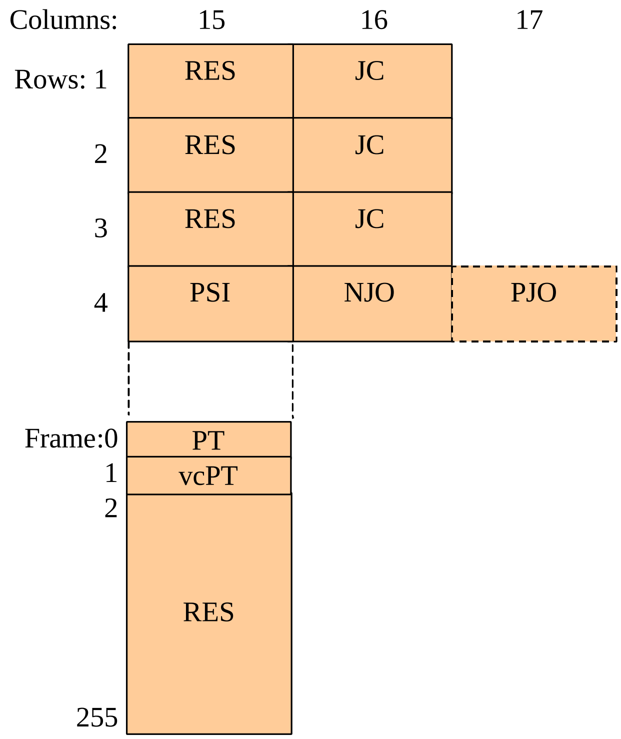
Columns:
15
16
17
Rows: 1
RES
JC
2
RES
JC
3
RES
JC
4
PSI
NJO
PJO
Frame:0
PT
1
vcPT
2
RES
255

Figure 7

## Faults and Alarms

The main fault indicators relating to the framing bytes—Out of Frame (OOF), Loss of Frame (LOF), Out of Multiframe (OOM), and Loss of Multi-frame (LMF)—are detected using the overhead bytes; additional information can be obtained from G.798.[12]
The protocol enters the OOF state if it fails to find an FAS sub-pattern (FAS bytes 3, 4, and 5) for five consecutive frames. Similarly, OOM is declared when the received MFAS is out of sequence for five consecutive frames. LOF and LOM are the resulting indicators when the OOF or OOM states have been constantly observed for 3 ms respectively.

There are several indicators derived from the OTU SM and ODU PM and TCMi structures. For example, Trace Identifier Mismatch (TIM) is raised when the received SAPI and/or DAPI values found in the TTI do not match the expected, pre-provisioned values. The detection of a frame slip, which can occur at the OTU or ODU Tandem Connection Monitoring (TCM), generates an Incoming Alignment Error (IAE) in the downstream direction. For OTU, the IAE bit resides in the SM while for the ODU TCMi, the 3 bit value of '010' in the Status (STAT) field indicates IAE. A corresponding BIAE is inserted in the upstream direction by specifying bits '1011' in the BEI/BIAE SM or TCMi fields. Concerning the STAT field applicable to the ODU TCMi, the Loss of Tandem Connection (LTC) condition is declared when the tandem connection is in use and the received value in the TCMi STAT field is "000". The STAT value for an active TCM without an IAE condition is '001'.

The ODU SM, ODU PM, and ODU TCMi all contain a BIP-8 and a BEI field. The BIP-8 values are byte-oriented parity checks that cover the OPU and client payload of the G.709 frame. The parity values are computed before the FEC is applied in the transmit direction and after in the receive direction. The BIP-8 values are inserted in the BIP-8 field of the 2nd frame following calculation. Each BIP-8's maximum bit error rate detection capability is 8 bits per 15,240 bytes corresponding to a rate of 6.56X10-5. The BEI field is used for the back reporting, in the upstream direction, of the number of BIP-8 errored blocks. A block is equivalent to a frame.

Three maintenance signals are available at the ODU, they are the AIS (Alarm Indication Signal), Locked defect (LCK), and Open Connection Indication (OCI). The LCK maintenance signal is generated on operator request to perform out-of-service tests. It is a repeating '01010101' pattern that fills the ODU, OPU, and payload. An open connection generates the OCI maintenance signal, which is a repeating '01100110' pattern that also fills the ODU, OPU, and payload. The AIS is an all 1's pattern that fills the ODU except for the FTFL, OPU, and payload. It is a forwarded signal in the downstream direction sent as a response to a signal fail indication, such as in the FTFL or an incoming ODU-AIS. In the upstream direction the response to continuity, connectivity and maintenance signals, such as AIS, is a Backward Defect Indication (BDI) signal indicated by a bit found in the PM, TCMi, or SM for the OTU. BDI is raised as an alarm when it has been received for five consecutive frames. The BDI and AIS also exist at the OTU layer, where the AIS is a 2047-bit polynomial sequence, called PN-11, that covers the full OTU frame including the framing bytes. In a practical example[13], the OTU-AIS would be sent as a response to a loss of signal.

At the OPU level, a Payload Mismatch (PLM) is declared when the received payload type (PT) differs from the expected, pre-provisioned PT value.

### Summary

G.709 has opened the door to standardized internetworking within an OTN framework. The initial thrust focuses on SONET/SDH payloads to take advantage of forward error correction capabilities. The G.709 recommendation is forward looking since it enables developments in the areas of tributary mapping, virtual concatenation, and the support of data protocols such as GFP. G.709 addresses the fundamental issues of bandwidth scalability and enabling high transmission rates, up to 40Gigabits/second, in addition to providing high signal integrity in long haul networks.

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Guylain Barlow is the product manager for the test and measurements division at Innocor. He has been involved in telecommunications for the past 15 years after graduating in Electrical Engineering from the University of Sherbrooke. He has worked as an application specialist at Simbol Test Systems where he focused on optical/WDM testing. Previously, he spent 10 years at Nortel Networks where he designed and engineered ATM/IP data networks and voice networks. His roles have included technical presentations at conferences and overseas assignments.