OTN Tutorial

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OTN Network

Intra-domain Interfaces (IaDI)

Carrier B domain

Vendor B1 domain

Vendor B2 domain

Interdomain interfaces (IrDI)

Carrier A domain

Carrier C domain

End-to-end OTN-standard service management
OTN Layers

- **OTS** – Monitors optical span connections between NEs
- **OMS** – Monitors connections between NEs with optical multiplexing functions
- **OCh** – Transports client signals between 3R (Reamplification, Reshaping, Retiming) regeneration points
- **OTU** – Monitors electrical span connections between MultiService Transport Platforms (MSTPs)
- **ODU** – Monitors end-to-end client path
Information Containment Relationships

<table>
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<th>Frame Alignment</th>
<th>OTUk Specific Overhead</th>
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<td>OPUk Specific Overhead</td>
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<tr>
<td>OPU Payload (Client)</td>
<td>FEC</td>
</tr>
</tbody>
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OTUk = OCh Payload

OTUk section

OTUk = OCh Payload

ODUk TCM OH

ODUk path

OPUk

OPUk OH

Client

OPUk OH

Client

OPUk

ODUk

ODUk PM OH

ODUk path

ODUk tandem connection

ODUk

ODUk TCM OH

ODUk
OTM-n.m Information Containment

- **OTM**: Optical Transport Module
- **OCG**: Optical Carrier Group
- **OMU**: Optical Multiplex Unit
- **OOS**: OTM Overhead Signal
- **OCC**: Optical Channel Carrier

**n**: used to represent the order of the OTM, OTS, OMS, OPS, OCG, OMU. n represents the maximum number of wavelengths that can be supported at the lowest bit rate supported on the wavelength.

**m**: used to represent the bit rate or set of bit rates supported on the interface. This is one or more digits "k", where each "k" represents a particular bit rate.
**Information Containment Relationships**

- **OTM-0.m** – Single channel without an assigned specific color

  - OChr
  - OTUk = OCh Payload
  - OTM-0.m
  - OPS0

- **OTM-nr.m** – OTM Interface with reduced functionality

  - OChr
  - OTUk = OCh Payload

- **OCG-nr.m**
  - OCCp
  - OCCp
  - OCCp
  - OCCp
  - OCCp

- **OTM-nr.m**
  - OPSn
OTM-0.mvn
Information Containment Relationships

OTUk section
- OTUk OH
- ODUk
- FEC

OT Lanes
- OTLk.n #0
- OTLk.n #1
- OTLk.n #n-1

OTLCG
- OTLCp
- OTLCp
- OTLCp

OTM-0.mvn
- OPSMnk

OTLCG: Optical Transport Lane Carrier Group
Adaptation of OTU3/4 over Multichannel I/F

- This mechanism is designed to allow the use of the optical modules being developed for IEEE 40GBASE-R and 100GBASE-R signals for short-reach client-side OTU3 and OTU4 interfaces, respectively.

- OTU3 signals may be carried over parallel interfaces consisting of four lanes.

- OTU4 signals may be carried over parallel interfaces consisting of four or ten lanes, which are formed by bit multiplexing of 20 logical lanes.

- The OTU3 and OTU4 frames are inversely multiplexed over physical/logical lanes on a 16-byte boundary aligned with the OTUk frame
  - The OTUk frame is divided into 1020 groups of 16-bytes.
OTU3 16-byte Increment Frame Distribution

- Each 16-byte increment of an OTU3 frame is distributed, round robin, to each of the four physical lanes. On each OTU3 frame boundary, the lane assignments are rotated.
- OTU3 lane rotation and assignment is determined by the two LSB of the MFAS.
- The pattern repeats every 64 bytes until the end of the OTU3 frame. The following frame will use a different lane assignment according to the MFAS.
- The two LSB of the MFAS will be the same in each FAS on a particular lane, which allows the lane to be identified.
- Since the MFAS cycles through 256 distinct values, the lanes can be deskewed and reassembled by the receiver as long as the total skew does not exceed 127 OTU3 frame periods (approximately 385μs).
OTU4 16-byte Increment Distribution

- Each 16-byte increment of a frame is distributed, round robin, to each of the 20 logical lanes. On each frame boundary, the lane assignments are rotated.
- Since only 32 out of 48 bits of the FAS are checked for frame alignment, the 3rd OA2 byte position is assigned as a logical lane marker (LLM).
- Since 240 is the largest multiple of 20 that can be represented by 8 bits in order to maximize skew detection range the lane marker value will increment on successive frames from 0-239.
- In mapping from lanes back to the OTU4 frame, the 6th byte of each OTU4 frame which was borrowed for lane marking is restored to the value OA2.

<table>
<thead>
<tr>
<th>Lane</th>
<th>LLM MOD 20 = 0</th>
<th>Rotate</th>
<th>LLM MOD 20 = 1</th>
<th>Rotate</th>
<th>LLM MOD 20 = 18</th>
<th>Rotate</th>
<th>LLM MOD 19 = 0</th>
<th>Rotate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1:16 (FAS)</td>
<td>321:33</td>
<td>6</td>
<td>16001:1601</td>
<td>6</td>
<td>305:320</td>
<td>16001:1601</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>17:32</td>
<td>337:35</td>
<td>2</td>
<td>16017:1603</td>
<td>2</td>
<td>1:16 (FAS)</td>
<td>16017:1603</td>
<td>2</td>
</tr>
<tr>
<td>19</td>
<td>305:320</td>
<td>625:64</td>
<td>0</td>
<td>16305:1632</td>
<td>0</td>
<td>289:304</td>
<td>16305:1632</td>
<td>0</td>
</tr>
</tbody>
</table>

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- The OTUk forward error correction (FEC) contains the Reed-Solomon RS(255,239) FEC codes.
  - If no FEC is used, fixed stuff bytes (all-0s pattern) are to be used.
- For interworking of FEC with non-FEC equipment, the FEC supporting equipment shall disable the FEC decoder and ignore the FEC area.
The forward error correction for the OTU-k uses 16-byte interleaved codecs using a Reed-Solomon S(255,239) code. The RS(255,239) code operates on byte symbols.

The FEC can correct up to 8 symbol errors in the FEC code word.

The FEC can detect up to 16 symbol errors in the FEC code word in error detection mode.
Enhanced FECs – Super FECs

- Defined in ITU-T G.975.1 - Forward Error Correction for DWDM submarine systems.
  - Defines super FEC codes that have higher correction ability than RS (255,239).
- Performance parameters for super FEC codes:
  - Correction ability
  - Redundancy ratio
  - Latency
Correction Strength

- **BER characteristics**
  - BER characteristic for FEC: Decoder input signal BER / Corrected output signal BER.
    - BER improvement by FEC indicates the FEC correction ability.

- **Coding Gain**
  - For randomly distributed errors within the encoded line signal, a FEC decoder reduces the line BER-in (Bin) to a required reference BER (Bref) value within the payload signal.
    - Coding gain accordingly is defined as Bin / Bref.

- **Net Coding Gain (NCG)**
  - Code Rate: The code rate $R$ is the ratio of bit rate without FEC to bit rate with FEC, $R<1$.
    - NCG is characterized by both the code rate $R$ and the maximum allowable BER-in (Bin) which can be reduced to a reference BERout=Bref by applying the FEC algorithm.

- **Q Limit**
  - Q limit means the minimum required Q factor of the input signal which still allows the receiver decision circuit to achieve a reference BER (Bref ≈ BERout).
  - The Q factor is the signal-to-noise ratio at the decision circuit in voltage or current
    - $Q = (\mu_1-\mu_0)/(\sigma_1+\sigma_0)$
Popular Enhanced FECs

I.4
- RS(1023,1007) outer code, BCH (2047,1952) inner code
- Low latency

<table>
<thead>
<tr>
<th>Input BER</th>
<th>Output BER</th>
<th>Net Coding Gain [dB]</th>
<th>Coding Gain [dB]</th>
<th>Q Limit [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.23x10^{-3}</td>
<td>10^{-13}</td>
<td>8.03</td>
<td>8.31</td>
<td>9.0775</td>
</tr>
<tr>
<td>2.20x10^{-3}</td>
<td>10^{-14}</td>
<td>8.34</td>
<td>8.62</td>
<td>9.0906</td>
</tr>
<tr>
<td>2.17x10^{-3}</td>
<td>10^{-15}</td>
<td>8.67</td>
<td>8.95</td>
<td>9.1034</td>
</tr>
</tbody>
</table>

I.7 - Two orthogonally concatenated BCH codes
- 3 options of the same scheme:
  - Option 1: ITU-T G.709 compliant framing (7% overhead)
  - Options 2, 3: High performance with 11% and 25% FEC overhead.
- Option 1: For 10 Gbps payloads the latency is ~100μs.

<table>
<thead>
<tr>
<th>Input BER</th>
<th>Output BER</th>
<th>Net Coding Gain [dB]</th>
<th>Coding Gain [dB]</th>
<th>Q Limit [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00x10^{-3}</td>
<td>10^{-13}</td>
<td>7.82</td>
<td>8.14</td>
<td>9.18</td>
</tr>
<tr>
<td>1.62x10^{-3}</td>
<td>10^{-14}</td>
<td>7.98</td>
<td>8.29</td>
<td>9.38</td>
</tr>
<tr>
<td>1.30x10^{-3}</td>
<td>10^{-15}</td>
<td>8.09</td>
<td>8.41</td>
<td>9.58</td>
</tr>
</tbody>
</table>
OTM Overhead Signal (OOS)

- The OOS consists of the OTS, OMS and OCh overhead.
- The format, structure and bit rate of the OOS is not defined.
- The OOS is transported via an Optical Supervisory Channel (OSC).
  - A special wavelength

OTSn
  - TTI
  - BDI-O
  - BDI-P
  - PMI

OMSn
  - FDI-O
  - FDI-P
  - PMI

OCh
  - FDI-O
  - FDI-P
  - OCI

General management communications
OTS OH Description

- **OTS Trail Trace Identifier (TTI)**
  - Transports a 64-byte TTI

- **OTS Backward Defect Indication – Payload (BDI-P)**
  - Upstream indication of the OTSn payload signal fail status detected in the OTSn termination sink function.

- **OTS Backward Defect Indication – Overhead (BDI-O)**
  - Upstream indication of the OTSn overhead signal fail status detected in the OTSn termination sink function.

- **OTS Payload Missing Indication (PMI)**
  - Downstream indication that at the source point of the OTS signal no payload is added. Suppresses the consequential Loss of Signal condition.
OMS OH Description

• OMS Forward Defect Indication – Payload (FDI-P)
  – Downstream indication of the OMSn payload signal status (normal or failed).

• OMS Forward Defect Indication – Overhead (FDI-O)
  – Downstream indication of the OMSn overhead signal status (normal or failed).

• OMS Backward Defect Indication – Payload (BDI-P)
  – Upstream indication of the OMSn payload signal fail status at the OMSn termination sink function.

• OMS Backward Defect Indication – Overhead (BDI-O)
  – Upstream indication of the OMSn overhead signal fail status at the OMSn termination sink function.

• OMS Payload Missing Indication (PMI)
  – Downstream indication that none of the source OCCp's contain an optical channel signal. Suppresses consequential Loss of Signal condition.
OCh OH description

- **OCh Forward Defect Indication – Payload (FDI-P)**
  - Downstream indication of the OCh payload signal status (normal or failed).

- **OCh Forward Defect Indication – Overhead (FDI-O)**
  - Downstream indication of the OCh overhead signal status (normal or failed).

- **OCh Open Connection Indication (OCI)**
  - Downstream indication that in a matrix connection is open as a result of a management command.
  - The consequential OCh Loss of Signal condition can be accordingly correlated.
The OTUk frame alignment shall be found by searching for the OA1, OA2 FAS bytes contained in the OTUk frame. The process has two states, out-of-frame (OOF) and in-frame (IF).

In the OOF state, the framing pattern searched for shall be a 4-byte subset of the OA1 and OA2 bytes. The IF shall be entered if this subset is found and confirmed one frame period later.

In the IF state, the frame signal shall be continuously checked with the presumed frame start position for correct alignment. The framing pattern checked for shall be the OA1OA2OA2 pattern (bytes 3, 4 and 5 of the first row of the OTUk frame). The OOF state shall be entered if this subset is not found at the correct position in 5 consecutive frames.

The frame start shall be maintained during the OOF state.

Some OTUk and ODUk overhead signals span multiple OTUk/ODUk frames requiring multiframe alignment processing to be performed. OTUk/ODUk overhead signals may use this central multiframe to lock their 2-frame, 32-frame, etc., multiframe to the principal frame.
OTN Overhead - PM

16 bytes overhead

* PS: Payload Specific

TTI
- BIP-8
- BEI
- BDI
- STAT

<table>
<thead>
<tr>
<th>STAT</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>Reserved for future international standardization</td>
</tr>
<tr>
<td>001</td>
<td>Normal Path signal</td>
</tr>
<tr>
<td>010</td>
<td>Reserved for future international standardization</td>
</tr>
<tr>
<td>011</td>
<td>Reserved for future international standardization</td>
</tr>
<tr>
<td>100</td>
<td>Reserved for future international standardization</td>
</tr>
<tr>
<td>101</td>
<td>Maintenance signal: ODUk-LCK</td>
</tr>
<tr>
<td>110</td>
<td>Maintenance signal: ODUk-OCI</td>
</tr>
<tr>
<td>111</td>
<td>Maintenance signal: ODUk-AIS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAS</td>
<td>DM</td>
</tr>
<tr>
<td>MFAS</td>
<td>TCM/ACT</td>
</tr>
<tr>
<td>SM</td>
<td>TCM6, TCM5, TCM4</td>
</tr>
<tr>
<td>GCC0</td>
<td>FTFL, PS*</td>
</tr>
<tr>
<td>GCC1</td>
<td>Reserved</td>
</tr>
<tr>
<td>GCC2</td>
<td>APS/PCC</td>
</tr>
<tr>
<td>Reserved</td>
<td>PS, PSI</td>
</tr>
</tbody>
</table>

TTI Bit Positions:
- 0: 0x00
- 16: DAPI
- 32: Operator Specific

Reserved Bit Positions:
- 0: SAPI
- 15: DAPI
- 31: DAPI
- 63: Operator Specific
## OTN Overhead - TCM

### Payload Specific (PS)

<table>
<thead>
<tr>
<th>STAT</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>No source TC</td>
</tr>
<tr>
<td>001</td>
<td>In use without IAE</td>
</tr>
<tr>
<td>010</td>
<td>In use with IAE</td>
</tr>
<tr>
<td>011</td>
<td>Reserved for future international standardization</td>
</tr>
<tr>
<td>100</td>
<td>Reserved for future international standardization</td>
</tr>
<tr>
<td>101</td>
<td>Maintenance signal: ODUk-LCK</td>
</tr>
<tr>
<td>110</td>
<td>Maintenance signal: ODUk-OCI</td>
</tr>
<tr>
<td>111</td>
<td>Maintenance signal: ODUk-AIS</td>
</tr>
</tbody>
</table>

###含まれ้นครั้งที่มีผลต่อสัญญาณข้อมูล (TCM)

- **Reserved**: ช่องที่ไม่ใช้งาน
- **DM**: ช่องเติมข้อมูลไม่แน่นอน
- **TCM/ACT**: ช่องตัวบ่งชี้ TCM และ ACT
- **TCM6**: ช่อง TCM ที่ 6
- **TCM5**: ช่อง TCM ที่ 5
- **TCM4**: ช่อง TCM ที่ 4
- **FTFL**: ช่อง TCM ที่ 5
- **PS**: ช่อง Payload Specific
- **PSI**: ช่อง Payload Specific
- **APS/PCC**: ช่อง APS/PCC
- **GCC1**: ช่อง GCC ที่ 1
- **GCC2**: ช่อง GCC ที่ 2

### Other Fields

- **TTI**: Time to Identify (TTI)
- **BIP-8**: Bit Interleaved parity-8 (BIP-8)
- **BEI/BIAE**: Bit Error Indicator/Bad Indicator (BEI/BIAE)
- **BDI**: Bit Direction Identifier (BDI)
- **STAT**: Status
Example: TCM Overhead Assignment

- ODUk leased circuit: The user may be assigned 1 level of TCM, the service provider 1 level of TCM and network operators up to 4 levels of TCM.
- This would result in the following TCM OH allocation:
  - User: TCM1 field between the two user subnetworks, and TCM1..TCM6 within its own subnetwork
  - Service provider (SP): TCM2 overhead field between two UNIs
  - Network operators NO1, NO2, NO3: TCM3, TCM4, TCM5, TCM6.
    - Note that NO2 cannot use TCM5 and TCM6 in the connection through the domain of NO4
  - NO4: TCM5, TCM6
OTN Overhead - FTFL

16 bytes overhead

Fault Indication

Definition

0x00  No Fault
0x01  Signal Fault
0x02  Signal Degrad
0x03 to 0xFF  Reserved

Country Code

National Segment Code

Geographic/Political CC  ICC  Null
G/PCC  ICC  Null
G/PCC  ICC  Null
G/PCC  ICC  Null
G/PCC  ITU Carrier Code (ICC)  Null

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### OTN Overhead – APS/PCC

**16 bytes overhead**

<table>
<thead>
<tr>
<th>FAS</th>
<th>MFAS</th>
<th>SM</th>
<th>GCC0</th>
<th>Reserved</th>
<th>PS*</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>DM</td>
<td>TDM/ACT</td>
<td>TCM6</td>
<td>TCM5</td>
<td>TCM4</td>
<td>FTFL</td>
</tr>
<tr>
<td>TCM3</td>
<td>TCM2</td>
<td>TCM1</td>
<td>PM</td>
<td>EXP</td>
<td>PS</td>
<td>PS</td>
</tr>
<tr>
<td>GCC1</td>
<td>GCC2</td>
<td>APS/PCC</td>
<td>Reserved</td>
<td></td>
<td>PSI</td>
<td>PS</td>
</tr>
</tbody>
</table>

**MFAS LSBs**

<table>
<thead>
<tr>
<th>000</th>
<th>001</th>
<th>010</th>
<th>011</th>
<th>100</th>
<th>101</th>
<th>110</th>
<th>111</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODUk Path</td>
<td>ODUk TCM1</td>
<td>ODUk TCM2</td>
<td>ODUk TCM3</td>
<td>ODUk TCM4</td>
<td>ODUk TCM5</td>
<td>ODUk TCM6</td>
<td>ODUk server layer trail (OTUk or HO ODUk)</td>
</tr>
</tbody>
</table>

*PS: Payload Specific*

Connection Monitoring Level

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OTN Overhead - PT

<table>
<thead>
<tr>
<th>Offset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x01</td>
<td>Experimental</td>
</tr>
<tr>
<td>0x02</td>
<td>Asynchronous CBR</td>
</tr>
<tr>
<td>0x03</td>
<td>Bit synchronous CBR</td>
</tr>
<tr>
<td>0x04</td>
<td>ATM</td>
</tr>
<tr>
<td>0x05</td>
<td>GFP</td>
</tr>
<tr>
<td>0x06</td>
<td>Virtual Concatenated</td>
</tr>
<tr>
<td>0x07</td>
<td>1000BASE-X into ODU0</td>
</tr>
<tr>
<td>0x08</td>
<td>FC-1200 into ODU2e</td>
</tr>
<tr>
<td>0x09</td>
<td>GFP into Extended OPU2 payload</td>
</tr>
<tr>
<td>0x0A</td>
<td>STM-1 into ODU0</td>
</tr>
<tr>
<td>0x0B</td>
<td>STM-4 into ODU0</td>
</tr>
<tr>
<td>0x0C</td>
<td>FC-100 into ODU0</td>
</tr>
<tr>
<td>0x0D</td>
<td>FC-200 into ODU1</td>
</tr>
<tr>
<td>0x0E</td>
<td>FC-400 into ODUflex</td>
</tr>
<tr>
<td>0x0F</td>
<td>FC-800 into ODUflex</td>
</tr>
<tr>
<td>0x10</td>
<td>Bit stream with octet timing</td>
</tr>
<tr>
<td>0x11</td>
<td>Bit stream without octet timing</td>
</tr>
<tr>
<td>0x20</td>
<td>ODU multiplex structure supporting ODTUjk only</td>
</tr>
<tr>
<td>0x21</td>
<td>ODU multiplex structure supporting ODTUk.ts or ODTUk.ts and ODTUjk</td>
</tr>
<tr>
<td>0x55</td>
<td>Not Available (Maintenance LCK signal)</td>
</tr>
<tr>
<td>0x66</td>
<td>Not Available (Maintenance OCI signal)</td>
</tr>
<tr>
<td>0x80-0x8F</td>
<td>Reserved</td>
</tr>
<tr>
<td>0xFD</td>
<td>Null test signal</td>
</tr>
<tr>
<td>0xFE</td>
<td>PRBS test signal</td>
</tr>
<tr>
<td>0xFF</td>
<td>Not Available (Maintenance AIS signal)</td>
</tr>
</tbody>
</table>
Customer Signal Fail (CSF)

- For support of local management systems, a single-bit OPUk Client Signal Fail (CSF) indicator conveys the signal fail status of the Client Signal mapped into a LO OPUk at the ingress of the OTN.
- OPUk CSF is located in bit 1 of the PSI[2] byte of the Payload Structure Identifier. Bits 2 to 8 of the PSI[2] byte are reserved for future international standardization.
  - OPUk CSF is set to "1" to indicate a Client Signal fail, otherwise it is set to "0".
- Legacy equipment will generate a “0” in the OPUk CSF and will ignore any value in OPUk CSF.

![Diagram of OPU, ODU, and OTU nodes with CSF signal]
OTN Overhead - DM

<table>
<thead>
<tr>
<th>FAS</th>
<th>MFAS</th>
<th>SM</th>
<th>GCC0</th>
<th>Reserved</th>
<th>PS*</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>DM</td>
<td>TDM/ACT</td>
<td>TCM6</td>
<td>TCM5</td>
<td>TCM4</td>
<td>FTFL</td>
</tr>
<tr>
<td>TCM3</td>
<td>TCM2</td>
<td>TCM1</td>
<td>PM</td>
<td>EXP</td>
<td>PS</td>
<td>PS</td>
</tr>
<tr>
<td>GCC1</td>
<td>GCC2</td>
<td>APS/PCC</td>
<td>Reserved</td>
<td>PS*</td>
<td>PSI</td>
<td>PS</td>
</tr>
</tbody>
</table>

* PS: Payload Specific

16 bytes overhead

```
.....1111111111000000000000000000000000.....

...... Delay

.....000000000000000000000001111111111.....
```
ODU Path during Delay Measurement

- Optical line amplifier (OTS termination)
- Optical cross connect/add-drop/terminal mux (OMS termination)
- 3R regeneration (OCh, OTU termination)
- Delay Measurement / Loopback NE
The General Communication Channels (GCC) carry in-band management and signaling information between OTN elements.

**GCC0**
- Two bytes within OTUk overhead.
- GCC0 is terminated at every 3R (Re-shaping, Re-timing, Re-amplification) point and is used to carry GMPLS signaling protocol and/or management information.

**GCC1/2**
- Four bytes (2xTwo bytes) within ODUk overhead.
- Reserved for client end-to-end information.

**GCC bandwidth depends on line rate.**
- In example GCC0 b/w for OTU1 is ~333 Kbps, for OTU2 ~1.3 Mbps.
OTN Overhead – EXP, Reserved, TCM/ACT

- **Experimental**
  - The use of Experimental bytes is not subject to standardization.
  - Addresses instances that require additional ODUk overhead within a sub-network.
  - The Experimental overhead does not need to be forwarded beyond the sub-network.

- **Reserved**
  - Reserved in the overhead for future standardization.
  - Set to all ZEROS at the transmitter and ignored at the receiver.

- **TCM Activation/Deactivation**
  - Its definition is for further study.

* PS: Payload Specific

<table>
<thead>
<tr>
<th></th>
<th>FAS</th>
<th>MFAS</th>
<th>SM</th>
<th>GCC0</th>
<th>Reserved</th>
<th>PS*</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>Reserved</td>
<td>TCM/ACT</td>
<td>TCM6</td>
<td>TCM5</td>
<td>TCM4</td>
<td>FTFL</td>
<td>PS</td>
</tr>
<tr>
<td>TCM3</td>
<td>TCM2</td>
<td>TCM1</td>
<td>PM</td>
<td>EXP</td>
<td>PS</td>
<td>PSI</td>
<td>PS</td>
</tr>
<tr>
<td>GCC1</td>
<td>GCC2</td>
<td>APS/PCC</td>
<td>Reserved</td>
<td></td>
<td>PS*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16 bytes overhead
OTN Basic Rates – OTU1

- OPU1 payload rate = 2.488 Gbps (OC48/STM16)

- Add OPU1 and ODU1 16 bytes overhead:
  - 3808/16 = 238, (3808+16)/16 = 239
  - ODU1 rate: 2.488 x 239/238 ~ 2.499 Gbps

- Add FEC
  - OTU1 rate: ODU1 x 255/239 = 2.488 x 239/238 x 255/239 = 2.488 x 255/238 ~ 2.667 Gbps
OTN Basic Rates – OTU2

• Following the same procedure as for OTU1
  – OPU2 = 9.953 Gbps (OC192/STM64)
  – OTU2 = 9.953 x 255/238 ~ 10.664 Gbps

• But...we want to map 4 x ODU1 into the OPU2 payload
  – 4 x ODU1 = 4 x 2.498 = 9.9951 Gbps

• The rate difference would then be:
  – 9.953 – 9.995 ~ 41.82 Mbps ~ 4182 ppm
  – The Justification scheme cannot compensate for such a difference

• Add fixed stuff

  – (3808-16)/16 = 237, 3808/16 = 238
  – OPU2 = 9.953 x 238/237 ~ 9.9952 Gbps
  – Rate difference: 9.9952 – 9.9951 ~ 177 Kbps = 18 ppm

• OTU2 = 9.953 x 238/237 x 239/238 x 255/239 = 9.953 x 255/237
• OTU2 rate ~ 10.709 Gbps
# OTN Rates

<table>
<thead>
<tr>
<th>k</th>
<th>OPUk [kbps]</th>
<th>ODUk [kbps]</th>
<th>OTUk [kbps]</th>
<th>Tolerance [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1238954.310</td>
<td>1244160.000</td>
<td>-</td>
<td>±20</td>
</tr>
<tr>
<td>1</td>
<td>2488320.000</td>
<td>2498775.126</td>
<td>2666057.143</td>
<td>±20</td>
</tr>
<tr>
<td>2</td>
<td>9995276.962</td>
<td>10037273.924</td>
<td>10709225.316</td>
<td>±20</td>
</tr>
<tr>
<td>2e</td>
<td>10356012.658</td>
<td>10399525.316</td>
<td>-</td>
<td>±100</td>
</tr>
<tr>
<td>3</td>
<td>40150519.322</td>
<td>40319218.983</td>
<td>43018413.559</td>
<td>±20</td>
</tr>
<tr>
<td>4</td>
<td>104355975.330</td>
<td>104794445.815</td>
<td>111809973.568</td>
<td>±20</td>
</tr>
</tbody>
</table>

## G.709

<table>
<thead>
<tr>
<th>k</th>
<th>OPUk [kbps]</th>
<th>ODUk [kbps]</th>
<th>OTUk [kbps]</th>
<th>Tolerance [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1e</td>
<td>10312500.000</td>
<td>10355829.832</td>
<td>11049107.143</td>
<td>±100</td>
</tr>
<tr>
<td>1f</td>
<td>10518750.000</td>
<td>10562946.429</td>
<td>11270089.286</td>
<td>±100</td>
</tr>
<tr>
<td>2f</td>
<td>10563132.911</td>
<td>10607515.823</td>
<td>11317642.405</td>
<td>±100</td>
</tr>
<tr>
<td>3e1</td>
<td>41599576.271</td>
<td>41774364.407</td>
<td>44570974.576</td>
<td>±20</td>
</tr>
<tr>
<td>3e2</td>
<td>41611131.871</td>
<td>41785968.560</td>
<td>44583355.576</td>
<td>±20</td>
</tr>
</tbody>
</table>

## Non standard

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1e</td>
<td>10312500.000</td>
<td>10355829.832</td>
<td>11049107.143</td>
<td>±100</td>
<td>10GGE</td>
</tr>
<tr>
<td>1f</td>
<td>10518750.000</td>
<td>10562946.429</td>
<td>11270089.286</td>
<td>±100</td>
<td>10GFC</td>
</tr>
<tr>
<td>2f</td>
<td>10563132.911</td>
<td>10607515.823</td>
<td>11317642.405</td>
<td>±100</td>
<td>10GFC</td>
</tr>
<tr>
<td>3e1</td>
<td>41599576.271</td>
<td>41774364.407</td>
<td>44570974.576</td>
<td>±20</td>
<td>4xODU2e AMP</td>
</tr>
<tr>
<td>3e2</td>
<td>41611131.871</td>
<td>41785968.560</td>
<td>44583355.576</td>
<td>±20</td>
<td>4xODU2e GMP</td>
</tr>
</tbody>
</table>
ODUflex for CBR client signals

- An ODUflex (CBR) signal is generated using the timing of its client signal.
- The ODUflex bit rate is $239/238$ times the CBR client bit rate.
- The client signal may have a bit rate tolerance up to $\pm 100$ ppm

<table>
<thead>
<tr>
<th>OPUk [kbps]</th>
<th>ODUk [kbps]</th>
<th>Tolerance [ppm]</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4250000</td>
<td>4267857.143</td>
<td>$\pm 100$</td>
<td>2G FC</td>
</tr>
<tr>
<td>8500000</td>
<td>8535714.286</td>
<td>$\pm 100$</td>
<td>4G FC</td>
</tr>
</tbody>
</table>
ODUflex for GFP-F Mapped Packet Signals

- ODUflex(GFP) signals are generated using a local clock. This clock may be the local HO ODUk (or OTUk) clock, or an equipment internal clock of the signal over which the ODUflex is carried through the equipment.

- Any bit rate is possible for an ODUflex(GFP) signal
  - However it is suggested for maximum efficiency that the ODUflex for GFP will occupy an integer number of time slot payload bytes (in the initial container).

- The ODUflex for GFP-F has a bit rate tolerance of ±20 ppm.
ODU1/ODU2 Multiplexing into ODU3 via ODTUG3 (PT=20)
OTN Multiplexing and Mapping Structures

OTU1

ODU1

ODU0

ODUflex

ODTUG1

ODTU01

ODTU12

ODTU2.1

ODTU2.ts

ODTU2

ODTUG2

ODTU12

ODTU1

Client Signal

Multiplexing

Mapping
Multiplexing and Mapping Structures (cont.)

- **ODU4** to **ODU(H)**
- **ODU4 (L)** to **ODU4 (H)**
- **OPU4 (L)** to **OPU4 (H)**
- **OTU4**
- **ODTUG4** PT=21
  - **ODTU4.1**
  - **ODTU4.2**
  - **ODTU4.8**
  - **ODTU4.31**
  - **ODTU4.ts**
- **ODU0**
- **ODU1**
- **ODU2**
- **ODU2e**
- **ODU3**
- **ODU3flex**

- **ODU3** to **ODU(H)**
- **ODU3 (L)** to **ODU3 (H)**
- **OPU3 (L)** to **OPU3 (H)**
- **OTU3**
- **ODTUG3** PT=21
  - **ODTU13**
  - **ODTU23**
  - **ODTU3.1**
  - **ODTU3.9**
  - **ODTU3.ts**

- **ODU2e** to **ODU(H)**
- **ODU2e (L)** to **ODU2e (H)**
- **OPU2e (L)** to **OPU2e (H)**
- **ODTUG3** PT=20
  - **ODTU13**
  - **ODTU23**
Asynchronous Mapping Procedure - AMP

- Mapping of a CBR2G5, CBR10G or CBR40G signal (with up to ±45 ppm bit-rate tolerance) into an OPUk (k = 1,2,3) may be performed according to the asynchronous mapping procedure.
- The OPUk signal for the asynchronous mapping is created from a locally generated clock which is independent of the client signal.
- The client signal is mapped into the OPUk using a positive/negative/zero justification scheme.
- The maximum bit-rate tolerance between OPUk and the client signal clock, which can be accommodated by the asynchronous mapping scheme, is ±65 ppm.
  - With a bit-rate tolerance of ±20 ppm for the OPUk clock, the client signal's bit-rate tolerance can be ±45 ppm.
**JC, NJO and PJO in AMP**

**JC, NJO and PJO generation by asynchronous mapping process**

<table>
<thead>
<tr>
<th>JC bits</th>
<th>NJO</th>
<th>PJO</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Justification</td>
<td>Data</td>
</tr>
<tr>
<td>01</td>
<td>Data</td>
<td>Data</td>
</tr>
<tr>
<td>10</td>
<td>Not generated</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Justification</td>
<td>Justification</td>
</tr>
</tbody>
</table>

**JC, NJO and PJO interpretation**

<table>
<thead>
<tr>
<th>JC bits</th>
<th>NJO</th>
<th>PJO</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
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<td>10</td>
<td>Justification</td>
<td>Data</td>
</tr>
<tr>
<td>11</td>
<td>Justification</td>
<td>Justification</td>
</tr>
</tbody>
</table>

- Majority vote (two out of three) shall be used to make the justification decision in the demapping process to protect against an error in one of the three JC signals.
- The value contained in NJO and PJO when they are used as justification bytes is all-0s. The receiver is required to ignore the value contained in these bytes whenever they are used as justification bytes.
Mapping a CBR2G5 Signal into OPU1

- Each successive 8 bits of the CBR2G5 signal are mapped into a Data (D) Byte of the OPU1
- Once per OPU1 frame, it is possible to perform a justification action.

<table>
<thead>
<tr>
<th></th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Res</td>
<td>JC</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>Res</td>
<td>JC</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>Res</td>
<td>JC</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>PSI</td>
<td>NJO</td>
<td>PJO</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
</tbody>
</table>

Negative justification

<table>
<thead>
<tr>
<th></th>
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<th>16</th>
<th>17</th>
<th>18</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Res</td>
<td>01</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>Res</td>
<td>01</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>Res</td>
<td>01</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>PSI</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
</tbody>
</table>

Positive justification

<table>
<thead>
<tr>
<th></th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Res</td>
<td>11</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>Res</td>
<td>11</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>Res</td>
<td>11</td>
<td>D</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
<tr>
<td>PSI</td>
<td>Just</td>
<td>Just</td>
<td>D</td>
<td></td>
<td>3805 x D</td>
</tr>
</tbody>
</table>
Bit-Synchronous Mapping Procedure - BMP

- Mapping of a CBR2G5, CBR10G or CBR40G signal (with up to ±20 ppm bit-rate tolerance) into an OPUk (k = 1,2,3) may be performed according to the bit synchronous mapping procedure.
- Mapping of a CBR10G3 signal (with up to ±100 ppm bit-rate tolerance) into an OPUk (k = 2e) is performed using bit synchronous mapping procedure.
- The OPUk clock for the bit synchronous mapping is derived from the client signal.
- During signal fail conditions of the incoming client signal (e.g., in the case of loss of input signal), the OPUk payload signal bit rate shall be within the specified limits and neither a frequency nor frame phase discontinuity shall be introduced.
- The resynchronization on the incoming client signal shall be done without introducing a frequency or frame phase discontinuity.
- The JC interpretation is the same for AMP and BMP

<table>
<thead>
<tr>
<th>JC bits</th>
<th>NJO</th>
<th>PJ0</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Justification</td>
<td>Data</td>
</tr>
<tr>
<td>01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Not generated</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Generic Mapping Procedure (GMP)

- For any given CBR client signal the number of n-bit (e.g. $n = 1/8, 1, 8$) data entities that arrive during one server frame or server multi-frame period is defined by:
  - $C_n = \left( \frac{f_{\text{client}}}{n} \right) \times T_{\text{server}}$

- As only an integer number of n-bit data entities can be transported per server frame or multi-frame, the integer value $C_n(t)$ of $C_n$ has to be used.

- Since it is required that no client information be lost, the rounding process to the integer value has to take care of the truncated part, e.g. a $C_n$ with a value of 10.25 has to be represented by the integer sequence $10, 10, 10, 11$.
  - $C_n(t)= \text{INT} \left( \left( \frac{f_{\text{client}}}{n} \right) \times T_{\text{server}} \right)$
  - $\text{FLOOR} \left( \left( \frac{f_{\text{client}}}{n} \times T_{\text{server}} \right) \right) \leq C_n(t) \leq 1 + \text{FLOOR} \left( \left( \frac{f_{\text{client}}}{n} \times T_{\text{server}} \right) \right)$

- As the client data has to fit into the payload area of the server signal, the maximum value of $C_n$ and as such the maximum client bit rate is limited by the size of the server payload area.
GMP Data Distribution

- $C_n(t)$ client data entities are mapped into the payload area of the server frame or multi-frame using a sigma/delta data/stuff mapping distribution.

- Payload field $j$ ($j = 1 .. P_{server}$) carries:
  - Client data (D) - if $(j \times C_n(t)) \mod P_{server} < C_n(t)$
  - Stuff (S) - if $(j \times C_n(t)) \mod P_{server} \geq C_n(t)$.

- As the same start value and $C_n(t)$ are used at the mapper and demapper the same results are obtained and interworking is achieved.
GMP in OTN

- Asynchronous mappings in OTN have a default 8-bit timing granularity. Such 8-bit timing granularity is supported in GMP by means of a \( C_n \) with \( n=8 \) (\( C_8 \)).
- The jitter/wander requirements for some of the OTN client signals are such that for those signals an 8-bit timing granularity may not be sufficient. For such case, a 1-bit timing granularity is supported in GMP by means of \( C_n \) with \( n=1 \) (\( C_1 \)).
- The insertion of client data into the payload area of the OPUk frame at the mapper is performed in \( M \)-byte (or \( m \)-bit, \( m = 8 \times M \)) data entities, denoted as \( C_m(t) \).
- The remaining \( C_{nD}(t) \) data entities are signaled in the Justification Overhead as additional timing/phase information.
  - Actually \( \Sigma C_{nD}(t) \) (the cumulative value of \( C_{nD}(t) \)) is signaled.
GMP Overhead

- The justification overhead (JOH) for Generic Mapping Procedure consists of two groups of 3 bytes of Justification Control; the general (JC1, JC2, JC3) and the client/LO ODU specific (JC4, JC5, JC6).

<table>
<thead>
<tr>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>3824</th>
</tr>
</thead>
<tbody>
<tr>
<td>JC4</td>
<td>JC1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JC5</td>
<td>JC2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JC6</td>
<td>JC3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSI</td>
<td>RES</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **JC1:**
  - C1 C2 C3 C4 C5 C6 C7 C8

- **JC2:**
  - C9 C10 C11 C12 C13 C14 II DI

- **JC3:**
  - CRC-8

- **JC4:**
  - RES RES RES C1 C2 C3 C4 C5

- **JC5:**
  - RES RES RES C6 C7 C8 C9 C10

- **JC6:**
  - RES RES RES CRC-5

14 bit Cm (m=8xM)
Decrement Indication
Increment Indication
Client specific 10 bit ∑CₙD

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GBE Transcoding

- GBE rate (125000 Kbps) > OPU0 rate (1239 Kbps)
- The GBE signal (8B/10B coded, nominal bit rate of 125000 Kbps and a bit rate tolerance up to ±100ppm) has to be synchronously mapped into a 75-octet GFP-T frame stream with a bit rate of 15/16 x 1250000 Kbps ±100ppm (approximately 1171875 Kbps ±100ppm).
- This process is referred to as “timing transparent transcoding (TTT)”.
- The 15/16 x 1250000 Kbps ±100 ppm signal is then mapped into an OPU0 by means of the generic mapping procedure.
Adapting 8B/10B Signals via 64B/65B Block Codes

<table>
<thead>
<tr>
<th>Input client character</th>
<th>Flag bit</th>
<th>64-bit (8-Octet) field</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data</td>
<td>0</td>
<td>D1 D2 D3 D4 D5 D6 D7 D8</td>
</tr>
<tr>
<td>7 data, 1 control</td>
<td>1</td>
<td>0 aaa C1 D1 D2 D3 D4 D5 D6 D7</td>
</tr>
<tr>
<td>6 data, 2 control</td>
<td>1</td>
<td>1 aaa C1 0 bbb C2 D1 D2 D3 D4 D5 D6</td>
</tr>
<tr>
<td>5 data, 3 control</td>
<td>1</td>
<td>1 aaa C1 1 bbb C2 0 ccc C3 D1 D2 D3 D4 D5</td>
</tr>
<tr>
<td>4 data, 4 control</td>
<td>1</td>
<td>1 aaa C1 1 bbb C2 1 ccc C3 0 ddd C4 D1 D2 D3 D4</td>
</tr>
<tr>
<td>3 data, 5 control</td>
<td>1</td>
<td>1 aaa C1 1 bbb C2 1 ccc C3 1 ddd C4 0 eee C5 D1 D2 D3</td>
</tr>
<tr>
<td>2 data, 6 control</td>
<td>1</td>
<td>1 aaa C1 1 bbb C2 1 ccc C3 1 ddd C4 1 eee C5 0 fff C6 D1 D2</td>
</tr>
<tr>
<td>1 data, 7 control</td>
<td>1</td>
<td>1 aaa C1 1 bbb C2 1 ccc C3 1 ddd C4 1 eee C5 1 fff C6 0 ggg C7 D1</td>
</tr>
<tr>
<td>8 control</td>
<td>1</td>
<td>1 aaa C1 1 bbb C2 1 ccc C3 1 ddd C4 1 eee C5 1 fff C6 1 ggg C7 0 hhh C8</td>
</tr>
</tbody>
</table>

- Leading bit in a control octet (LCC) = 1 if there are more control octets and = 0 if this payload octet contains the last control octet in that block
- aaa = 3-bit representation of the 1st control code's original position (1st Control Code Locator)
- bbb = 3-bit representation of the 2nd control code's original position (2nd Control Code Locator)
- ccc = 3-bit representation of the 3rd control code's original position (3rd Control Code Locator)
- ddd = 3-bit representation of the 4th control code's original position (4th Control Code Locator)
- eee = 3-bit representation of the 5th control code's original position (5th Control Code Locator)
- fff = 3-bit representation of the 6th control code's original position (6th Control Code Locator)
- ggg = 3-bit representation of the 7th control code's original position (7th Control Code Locator)
- hhh = 3-bit representation of the 8th control code's original position (8th Control Code Locator)
- Ci = 4-bit representation of the ith control code (Control Code Indicator)
- Di = 8-bit representation of the ith data value in order of transmission

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Proprietary and Confidential 53
Adapting 64B/65B Block Codes into GFP

Octet 1, 1

Octet 1,2

Octet 1,3

where: Octet j, k is the kth octet of the jth 64B/65B code in the superblock
Lj is the leading (Flag) bit jth 64B/65B code in the superblock
CRC-i is the ith error control bit where CRC-1 is the MSB of the CRC
Mapping GFP-T into OPU0

• Since the OPU0 payload less the stuff bytes rate is equal to the GFP-T rate there is no need for:
  – GFP-T special 65B_PAD
  – GFP-T Idle frames

• $14405 \leq C_8 \leq 14410$
Mapping Sub-1.238 Gbps CBR Signals into OPU0

- 1GFC rate (1062500 Kbps) < OPU0 rate (1238954 Kbps), no transcoding is required

<table>
<thead>
<tr>
<th>Client Signal</th>
<th>Nominal rate [Kbps]</th>
<th>Tolerance [ppm]</th>
<th>Floor $C_8$</th>
<th>Ceiling $C_8$</th>
<th>$\Sigma C_{10}$ range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1GFC</td>
<td>1062500</td>
<td>±100</td>
<td>13601</td>
<td>13605</td>
<td>NA</td>
</tr>
<tr>
<td>STM-1</td>
<td>155520</td>
<td>±20</td>
<td>1911</td>
<td>1913</td>
<td>0 to +7</td>
</tr>
<tr>
<td>STM-4</td>
<td>622080</td>
<td>±20</td>
<td>7647</td>
<td>7649</td>
<td>0 to +7</td>
</tr>
</tbody>
</table>
IPGs are deleted as the Ethernet MAC frame is extracted from the client bit-stream. The extracted (decoded) Ethernet MAC frame is then forwarded to the GFP source adaptation process for subsequent encapsulation into a GFP frame.

IPGs are restored after the Ethernet MAC frame is extracted from the GFP frame by the GFP termination element.
Since the /S/ control character is always present at the beginning of the preamble it is mapped as a fixed value of 0x55 when it is inserted into the GFP-F frame.

The SFD character is included to avoid ambiguity regarding the beginning of the client data frame.
Ordered Set Encapsulation

- The first octet of the ordered set has the four most significant bits set to all zero and the four least significant bits equal to the O Code.
  - This way both Sequence Ordered Sets (O Code = 0000) and Signal Ordered Sets (O Code = 1111) can be transferred.
- Since Ordered sets are transported there is no need for GFP CMF RDI/FDI or OPU2 CSF

<table>
<thead>
<tr>
<th>UPI</th>
<th>GFP frame payload area</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x14</td>
<td>Frame mapped 64B/66B encoded Ethernet, including the Ethernet frame preamble</td>
</tr>
<tr>
<td>0x15</td>
<td>Frame mapped 64B/66B encoded Ethernet Ordered Set information</td>
</tr>
</tbody>
</table>
Mapping a 10GFC Signal into OPU2e

- The nominal line rate for 10GFC is 10518750 Kbps ±100ppm, and must therefore be compressed to a suitable rate to fit into an OPU2e.
  - 10GFC rate is 2% higher than 10GBE rate

- The adaptation process performs a 50/51 rate compression, so the resulting GFP stream has a signal bit rate of 50/51 x 10518750 Kbps ±100 ppm (i.e. 10312500 Kbps ±100ppm).
### 513B Block Code

<table>
<thead>
<tr>
<th>Input client character</th>
<th>Flag bit</th>
<th>512-bit (64-Octet) field</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data</td>
<td>0</td>
<td>D1 D2 D3 D4 D5 D6 D7 D8</td>
</tr>
<tr>
<td>7 data, 1 control</td>
<td>1</td>
<td>0 AAA aaaa C1 D1 D2 D3 D4 D5 D6 D7</td>
</tr>
<tr>
<td>6 data, 2 control</td>
<td>1</td>
<td>1 AAA aaaa C1 0 BBB bbbb C2 D1 D2 D3 D4 D5 D6</td>
</tr>
<tr>
<td>5 data, 3 control</td>
<td>1</td>
<td>1 AAA aaaa C1 1 BBB bbbb C2 0 CCC cccc C3 D1 D2 D3 D4 D5</td>
</tr>
<tr>
<td>4 data, 4 control</td>
<td>1</td>
<td>1 AAA aaaa C1 1 BBB bbbb C2 1 CCC cccc C3 0 DDD dddd C4 D1 D2 D3 D4</td>
</tr>
<tr>
<td>3 data, 5 control</td>
<td>1</td>
<td>1 AAA aaaa C1 1 BBB bbbb C2 1 CCC cccc C3 1 DDD dddd C4 0 EEE eeee C5 D1 D2 D3</td>
</tr>
<tr>
<td>2 data, 6 control</td>
<td>1</td>
<td>1 AAA aaaa C1 1 BBB bbbb C2 1 CCC cccc C3 1 DDD dddd C4 1 EEE eeee C5 0 FFF ffff C6 D1 D2</td>
</tr>
<tr>
<td>1 data, 7 control</td>
<td>1</td>
<td>1 AAA aaaa C1 1 BBB bbbb C2 1 CCC cccc C3 1 DDD dddd C4 1 EEE eeee C5 1 FFF ffff C6 0 GGG gggg C7 D1</td>
</tr>
<tr>
<td>8 control</td>
<td>1</td>
<td>1 AAA aaaa C1 1 BBB bbbb C2 1 CCC cccc C3 1 DDD dddd C4 1 EEE eeee C5 1 FFF ffff C6 1 GGG gggg C7 0 HHH hhhh C8</td>
</tr>
</tbody>
</table>

Leading bit in a control octet (FC) = 1 if there are more control blocks and = 0 if this payload contains the last control block in that 513B block.

**AAA** = 3-bit representation of the 1<sup>st</sup> control block code’s original position (1<sup>st</sup> control locator: POS).

**BBB** = 3-bit representation of the 2<sup>nd</sup> control block code’s original position (2<sup>nd</sup> control locator: POS).

**HHH** = 3-bit representation of the 8<sup>th</sup> control block code’s original position (8<sup>th</sup> control locator: POS).

**aaaa** = 4-bit representation of the 1<sup>st</sup> control code’s type (1<sup>st</sup> Control Block Type: CB TYPE).

**bbbb** = 4-bit representation of the 2<sup>nd</sup> control code’s type (2<sup>nd</sup> Control Block Type: CB TYPE).

... **hhhh** = 4-bit representation of the 8<sup>th</sup> control code’s type (8<sup>th</sup> Control Block Type: CB TYPE).

**Ci** = 56-bit representation of the ith control code characters.

**Di** = 64-bit representation of the ith data value in order of transmission.
**513B Block Code Format**

- The 3-bit POS field is used to encode the position in which this control block was received in the sequence of eight 66B blocks.

- Will be set to a 0 if this is the final 66B control in this 513B block, or to a 1 if one or more 66B control blocks follow this one.
GFP Frame Format for 10GFC

Payload Frame Check Sequence (pFCS)

1. Payload Length Indicator (PLI) MSB
2. Payload Length Indicator (PLI) LSB
3. Core HEC (cHEC) MSB
4. Core HEC (cHEC) LSB
5. PTI PFI EXI=0000
6. User Payload Identifier (UPI)=0x15
7. Type HEC (tHEC) MSB
8. Type HEC (tHEC) LSB

Reserved

Super block data

Superblock flags

CRC-24

Superblock #2

Superblock #3

Superblock #4

Superblock #5

Superblock #6

Superblock #7

Payload Frame Check Sequence (pFCS)

F C POS CB Type

Block #0 (512 bit)
Block #1 (512 bit)
Block #2 (512 bit)
Block #3 (512 bit)
Block #4 (512 bit)
Block #5 (512 bit)
Block #6 (512 bit)
Block #7 (512 bit)

Protects flags, POS and CB type

Payload size: 512x17 = 8704 bytes
GFP-T Frame size: 516x17 + 8 + 16 + 4 = 8800 bytes

Payload size: 512x17 = 8704 bytes
64B/66B blocks: 8704/8 = 1088 blocks
Sync bytes: 1088/4 = 272 bytes
64B/66B total: 8704+272 = 8976 bytes

8976/8800 = 51/50

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Mapping a Supra-2.488 Gbps CBR Signal into OPUflex

- Mapping of a supra-2.488 CBR Gbps client signal (with up to ±100 ppm bit-rate tolerance) into an OPUflex is performed by BMP.
- The BMP processes exercised in mapping CBR client signals into OPUflex do not generate any justification control signals.

<table>
<thead>
<tr>
<th>Client Signal</th>
<th>Nominal bit rate [Kbps]</th>
<th>Tolerance [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4G FC</td>
<td>4250000</td>
<td>±100</td>
</tr>
<tr>
<td>8G FC</td>
<td>8500000</td>
<td>±100</td>
</tr>
</tbody>
</table>

OPUflex payload 4 x 3808 bytes
## CBR Client into LO OPU Mappings

<table>
<thead>
<tr>
<th></th>
<th>OPU0</th>
<th>OPU1</th>
<th>OPU2</th>
<th>OPU2e</th>
<th>OPU3</th>
<th>OPU4</th>
<th>OPUflex</th>
</tr>
</thead>
<tbody>
<tr>
<td>STM-1</td>
<td>GMP with C&lt;sub&gt;1&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>STM-4</td>
<td>GMP with C&lt;sub&gt;1&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>STM-16</td>
<td>-</td>
<td>AMP, BMP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>STM-64</td>
<td>-</td>
<td>-</td>
<td>AMP, BMP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>STM-256</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>AMP, BMP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GBE</td>
<td>TTT+GMP no C&lt;sub&gt;n&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10GBE</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>BMP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1G FC</td>
<td>GMP no C&lt;sub&gt;n&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2G FC</td>
<td>-</td>
<td>GMP with C&lt;sub&gt;6&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4G FC</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>BMP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8G FC</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>BMP</td>
<td>-</td>
</tr>
<tr>
<td>10G FC</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>TTT+BMP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CPRI Option 1</td>
<td>GMP no C&lt;sub&gt;n&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CPRI Option 2</td>
<td>GMP no C&lt;sub&gt;n&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CPRI Option 3</td>
<td>-</td>
<td>GMP with C&lt;sub&gt;6&lt;/sub&gt;D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CPRI Option 4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>BMP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CPRI Option 5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>BMP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CPRI Option 6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>BMP</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

CPRI: Common Public Radio Interface
Mapping of Test Signals into OPUk

- **Mapping of a NULL client into OPUk**

  All Zeros pattern

- **Mapping of PRBS test signal into OPUk**
  - A 2147483647-bit PRBS test sequence ($2^{31}-1$) can be mapped into the OPUk.
  - Groups of 8 successive bits of the PRBS signal are mapped into 8 data bits.

PRBS pattern
IEEE 40GBASE-R, 100GBASE-R Interfaces

- IEEE 40GBASE-R and 100GBASE-R interfaces being specified by the IEEE P802.3ba task force will be parallel interfaces intended for short-reach (up to 40km) interconnections.
  - In the future they may be serial interfaces.

- 40GBASE-R signals comprise 4 PCS lanes and 100GBASE-R signals comprise 20 PCS lanes.
  - PCS lanes can be bit-multiplexed to match physical lanes.

- PCS lanes are 64B/66B encoded data with a PCS Lane Alignment Marker inserted every 16384 66-bit blocks.
  - The Lane Alignment Marker is a special format 66B codeword.
Client Frame Recovery

- Dis-interleaving is required when the number of PCS and physical lanes does not match.
  - Recover 64B/66B block lock per the state diagram in IEEE 802.3ba
  - Recover Lane Alignment marker framing on each PCS lane per IEEE 802.3ba.
  - Reorder and deskew the PCS lanes into a serialized stream of 66B blocks.

---

**Serialized stream of 66B blocks**

<table>
<thead>
<tr>
<th>Lane Number</th>
<th>Synch Header</th>
<th>Encoding {M_0, M_1, M_2, BIP_3, M_4, M_5, M_6, BIP_7}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>0x90, 0x76, 0x47, BIP_3, 0x6f, 0x89, 0xb8, BIP_7</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>0xf0, 0xc4, 0xe6, BIP_3, 0x0f, 0x3b, 0x19, BIP_7</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>0xc5, 0x65, 0x9b, BIP_3, 0x3a, 0x9a, 0x64, BIP_7</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>0xa2, 0x79, 0x3d, BIP_3, 0x5d, 0x86, 0xc2, BIP_7</td>
</tr>
</tbody>
</table>

The fourth octet following the sync header is a BIP-8 calculated over the data from one alignment marker to the next. The eighth octet is the complement of this BIP-8 value to maintain DC balance. Note that these BIP-8 values are not manipulated by the mapping or demapping procedure, but simply skipped in the process of recognizing lane alignment markers and copied intact as they are used for monitoring the error ratio of the Ethernet link between Ethernet PCS sublayers.
Mapping 40GBASE-R into OPU3

- OPU3 payload rate ~ $40 \times 150 = 519.322$ Kbps
- 40GBASE-R rate = $40 \text{ Gbps} \times \frac{66}{64} \times \frac{16384}{16383} = 41252\ 517.853$ Kbps
- To reduce the 40GBASE-R rate PCS lane alignment markers are encoded together with 66B control blocks into the uppermost rows of the 513B code blocks.
  - Similar to the one described for 10GFC

At the decoder, a PCS lane alignment marker will be generated in the position indicated by the POS field among any 66B all-data blocks contained in this 513B block.
- The sync header of "10" is generated followed by the received $M_0$, $M_1$ and $M_2$ bytes, the egress BIP$_3$ byte, the bytes $M_4$, $M_5$ and $M_6$ which are the bit-wise inverted $M_0$, $M_1$ and $M_2$ bytes received at the decoder, and the egress BIP$_7$ byte which is the bit-wise inverted egress BIP$_3$ byte.
1027B Block Code

• We need a method to locate the start of 513B blocks for parallel 40GBASE-R signals transcoded and mapped into OPU3 without GFP framing.
• A mechanism is needed to protect the flag bit, whose corruption could cause data to be interpreted as control and vice-versa.

**Diagram:**

- **Flag Parity bit**
- **Scramble**

<table>
<thead>
<tr>
<th>1</th>
<th>0</th>
<th>0</th>
<th>Data</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>Data</td>
<td>Control</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>Control</td>
<td>Data</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Control</td>
<td>Control</td>
</tr>
</tbody>
</table>
Mapping 100GBASE-R into OPU4

- **40GBASE-R rate after transcoding:**
  - $40 \text{ Gbps} \times \frac{66}{64} \times \frac{16384}{16383} \times \frac{513}{528} \times \frac{1027}{1026} = 40 \, 119 \, 636.208 \text{ Kbps}$
  - OPU3 payload rate ~ $40 \, 150 \, 519.322 \text{ Kbps}$
  - 40GBASE-R can be mapped into the OPU3 payload after transcoding

- **100GBASE-R rate:**
  - $100\text{ Gbps} \times \frac{66}{64} \times \frac{16384}{16383} = 103 \, 131 \, 294.635 \text{ Kbps}$
  - OPU4 payload rate ~ $104 \, 355 \, 975.330 \text{ Kbps}$

- Since the OPU4 is large enough for the serialized 66B block stream for 100GBASE-R client signals, the recovered client frames are adapted directly.
OTN Multiplexing

• The ODUj into HO OPUk multiplexing is performed in two steps:
  – Asynchronous mapping of ODUj into Optical channel Data Tributary Unit (ODTU) using either AMP or GMP
  – Byte-synchronous mapping of ODTU into one or more HO OPUk Tributary Slots.

• OPUk Tributary Slot definition
  – The OPUk is divided in a number of Tributary Slots (TS) and these Tributary Slots are interleaved within the OPUk.
    • A Tributary Slot includes a part of the OPUk OH area and a part of the OPUk payload area.
  – The bytes of the ODUj frame are mapped into the ODTU payload area and the ODTU bytes are mapped into the OPUk Tributary Slot or Slots.
  – The bytes of the ODTU Justification Overhead are mapped into the OPUk OH area.

• There are two types of Tributary Slots:
  – Tributary Slot with a bandwidth of approximately 2.5 Gbps; an OPUk is divided in n Tributary Slots, numbered 1 to n
  – Tributary Slot with a bandwidth of approximately 1.25 Gbps; an OPUk is divided in 2n Tributary Slots, numbered 1 to 2n.
<table>
<thead>
<tr>
<th>MFAS bits 78</th>
<th>1</th>
<th>11</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row</td>
<td>1</td>
<td>11</td>
<td>Column</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>00</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>01</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>01</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>00</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
<tr>
<td>00</td>
<td></td>
<td></td>
<td>OPU2 Payload (4 x 3808 bytes)</td>
</tr>
</tbody>
</table>
## OPU2 Tributary Slot Allocation – 1.25Gbps TS

<table>
<thead>
<tr>
<th>MFAS bits 678</th>
<th>Row</th>
<th>Column</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Column 1 to 8**
  - OPU2 Payload (4 x 3808 bytes)

The table above illustrates the slot allocation for OPU2 tributary slots across columns 1 to 8, each containing 4 x 3808 bytes of payload.
OPU4 Tributary Slots

- An OPU4 comprises 80x1.25G TS (numbered 1 to 80), located in columns 17 to 3816, and 8 columns of Fixed Stuff in columns 3817 to 3824
- A new OPU Multi Frame Identifier (OMFI) overhead byte has been defined

<table>
<thead>
<tr>
<th>JC4</th>
<th>JC1</th>
<th>JC5</th>
<th>JC2</th>
<th>JC6</th>
<th>JC3</th>
<th>PSI</th>
<th>OMFI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OMFI Overhead byte

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Fixed to 0

OMFI sequence

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## OPU4 1.25G Tributary Slot Allocation

<table>
<thead>
<tr>
<th>OMFI bits 2345678</th>
<th>Multi Frame Row</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000000</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>0000001</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OMFI bits 2345678</th>
<th>Multi Frame Row</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001110</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>314</td>
</tr>
<tr>
<td></td>
<td>315</td>
</tr>
<tr>
<td></td>
<td>316</td>
</tr>
<tr>
<td>1001111</td>
<td>317</td>
</tr>
<tr>
<td></td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>319</td>
</tr>
<tr>
<td></td>
<td>320</td>
</tr>
</tbody>
</table>

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**ODTU Definition**

- The Optical channel Data Tributary Unit (ODTU) carries a justified ODU signal.
- There are two types of ODTUs:
  - ODTU_{jk} in which an ODU_j signal is mapped via AMP
  - ODTU_{k.ts} signal is mapped via GMP

<table>
<thead>
<tr>
<th>ODUj into OPUk mapping types</th>
<th>2.5 T5s</th>
<th>1.25 T5s</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPU2</td>
<td>OPU3</td>
<td>OPU1</td>
</tr>
<tr>
<td>ODU0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ODU1</td>
<td>AMP (PT20)</td>
<td>AMP (PT20)</td>
</tr>
<tr>
<td>ODU2</td>
<td>-</td>
<td>AMP (PT20)</td>
</tr>
<tr>
<td>ODU2e</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ODU3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ODUflex</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Mapping ODUj into ODTUjk

- The mapping of ODUj signals (with up to ±20 ppm bit-rate tolerance) into the ODTUjk signal is performed as an asynchronous mapping.
- The maximum bit-rate tolerance between OPUk and the ODUj signal clock, which can be accommodated by this mapping scheme, is:
  - -130 to +65 ppm (ODU0 into OPU1)
  - -113 to +83 ppm (ODU1 into OPU2)
  - -96 to +101 ppm (ODU1 into OPU3)
  - -95 to +101 ppm (ODU2 into OPU3)
- The ODUj signal is extended with Frame Alignment Overhead and an all-0s pattern in the OTUj Overhead field

<table>
<thead>
<tr>
<th>FA overhead</th>
<th>All zeros</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODUj overhead area</td>
<td>OPUj area 4x3810 bytes</td>
</tr>
</tbody>
</table>
**ODUj Adaptation to ODUk Clock**

- The extended ODUj signal is adapted to the locally generated ODUk clock by means of an asynchronous mapping with $-1/0/+1/+2$ justification scheme.
- An extended ODUj byte is mapped into an ODTUjk byte.

<table>
<thead>
<tr>
<th>JC 78</th>
<th>NJO</th>
<th>PJ01</th>
<th>PJ02</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>justification</td>
<td>data</td>
<td>data</td>
<td>No justification (0)</td>
</tr>
<tr>
<td>01</td>
<td>data</td>
<td>data</td>
<td>data</td>
<td>Negative justification (-1)</td>
</tr>
<tr>
<td>10</td>
<td>justification</td>
<td>justification</td>
<td>justification</td>
<td>Double positive justification (+2)</td>
</tr>
<tr>
<td>11</td>
<td>justification</td>
<td>justification</td>
<td>data</td>
<td>Positive justification (+1)</td>
</tr>
</tbody>
</table>

*Note that this code is not used for the case of ODU0 into OPU1*
Mapping of ODUj into ODTUk.ts

- The mapping of ODUj (j = 0, 1, 2, 2e, 3, flex) signals (with up to ±100 ppm bit-rate tolerance) into the ODTUk.ts (k = 2,3,4; ts = M) signal is performed by means of GMP.

- The OPUk and therefore the ODTUk.ts (k = 2,3,4) signals are created from a locally generated clock which is independent of the ODUj client signal.

- The ODUj signal is extended with Frame Alignment Overhead and an all-0s pattern in the OTUj Overhead field.

- The value of M is the number of Tributary Slots occupied by the ODUj; ODTUk.ts = ODTUk.M.

- A group of ‘M’ successive extended ODUj bytes is mapped into a group of ‘M’ successive ODTUk.M bytes.
Mapping ODUj into ODTU2.M

- Groups of $M$ successive bytes of the extended ODUj ($j = 0$, flex) signal are mapped into a group of $M$ successive bytes of the ODTU2.M payload area under control of the GMP data/stuff control mechanism.
- Each group of $M$ bytes in the ODTU2.M payload area may either carry $M$ ODU bytes, or carry $M$ stuff bytes. The value of the stuff bytes is set to all-0’s.
  - The single instance of ODTUk.ts Overhead is located in the OPUk TSOH of the last OPUk tributary slot allocated to the ODTUk.ts.

<table>
<thead>
<tr>
<th>ODTU2.M Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ODTU2.M Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Example Table:**

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>476</td>
<td>476</td>
</tr>
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<td>477</td>
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<tr>
<td>1429</td>
<td>1429</td>
<td>1430</td>
<td>1430</td>
<td>1904</td>
<td>1904</td>
</tr>
</tbody>
</table>

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Alarms Terminology

• Anomaly:
  – The smallest discrepancy which can be observed between the actual and desired characteristics of an item.
  – The occurrence of a single anomaly does not constitute an interruption in the ability to perform a required function.
  – Anomalies are used as the input for the Performance Monitoring (PM) process and for the detection of defects

• Defect:
  – The density of anomalies has reached a level where the ability to perform a required function has been interrupted.
  – Defects are used as input for PM, the control of consequent actions, and the determination of fault cause.

• Fault Cause
  – A single disturbance or fault may lead to the detection of multiple defects.
  – A fault cause is the result of a correlation process which is intended to identify the defect that is representative of the disturbance or fault that is causing the problem.

• Failure:
  – The fault cause persisted long enough to consider the ability of an item to perform a required function to be terminated.
  – The item may be considered as failed; a fault has now been detected.
A fault may cause multiple defect detectors to be activated. To determine, from the activated defects, which fault is present, the activated defects are correlated to obtain the fault cause.

The fault cause persistency function provides a persistency check on the fault causes that are reported by management.
Optical Signal Maintenance Interaction

**Upstream**
- OTS
- dBDI-O
- BDI-O
- dLOS-O
- dTIM
- dPMI
- dLOS-P
- BDI-P
- dBDI-P

No OMS signal

**OMS**
- OMS FDI-O
- OMS FDI-P
- OMS PMI

**OCh**
- OCh FDI-O
- OCh FDI-P
- OCh OCI
- OCh switching equipment

**OTU**
- Optical Amplifier
- OCh switching equipment

**Downstream**
- Optical Amplifier
- OTU AIS

3R Function

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Performance Monitoring

• Acute fault conditions will be detected by alarm surveillance methods. Very low rate, or intermittent, error conditions in multiple equipment units may interact resulting in poor service quality and may not be detected by alarm surveillance.

• Performance Monitoring is designed to measure the overall quality, using monitored parameters in order to detect such degradation.
  – It may also be designed to detect characteristic patterns of impairment before signal quality has dropped below an acceptable level.

• Performance Monitoring Functions are responsible for the summation of 1-second event counts during 15-minute and 24-hour intervals.
  – The 15-minute intervals are aligned with the quarter of an hour, i.e. 00:00, 15:00, 30:00 and 45:00.
  – The 24-hour interval starts by default at midnight (00:00:00).

• Within performance monitoring, the concepts of "near-end" and "far-end" are used to refer to performance monitoring information associated with the two directions of transport of a bidirectional trail.

• For a bidirectional trail from A to Z:
  – At node A, the near-end information represents the performance of the unidirectional trail from Z to A, while the far-end information represents the performance of the unidirectional trail from A to Z.
ODUk ES and SES

From BIP:
- nN_B
- SSF
- dAIS
- dOCI
- dLCK
- dTIM

From BEI:
- nF_B
- 1 Sec PM
- dBDI

Σ INH CLR → ΣnN_B → D Q → pN_EBC

>1?
Near end ES

Σ INH CLR → ΣnF_B → D Q → pF_EBC

>1?
Near end SES

Higher than SES threshold
Far end ES

Higher than SES threshold
Far end SES

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Other Performance Monitoring Parameters

• **FEC corrected errors (FECcorrErr)**
  – The number of bits corrected by the FEC are counted over one second and reported at the end of the second.
  – During TSF, dAIS, dLOF and dLOM, no corrected bits are counted
  – Usually provided as two counters: Corrected Ones, Corrected Zeros
    • May help in “fine tuning” 1/0 decision threshold
  – A FEC uncorrected errors may also be provided (not required by the standard)

• **Pointer Justification Events (PJE)**
  – In order to locate the source that causes the generation of jitter and wander, e.g., due to a wrongly selected timing reference source, it is required to measure these error conditions.
  – An alternative approach to direct measurement, is to measure the positive and negative pointer justification events (PJE). These events may be an indication of a wrongly applied timing source.
  – The PJE are summed over 24-hour intervals. The analysis of these reports may be an aid to locate the error source.
Timing of ODUflex for CBR Client Signals

- An ODUflex(CBR) signal is generated using the timing of its client signal.
- The ODUflex bit rate is $\frac{239}{238}$ times the CBR client bit rate.
- The client signal may have a bit rate tolerance up to $\pm 100$ ppm.
Timing of ODUflex for GFP-F Mapped Client Signals

- ODUflex for GFP signals are generated using a local clock.
- Any bit rate is possible for these ODUflex signals.
Thank You