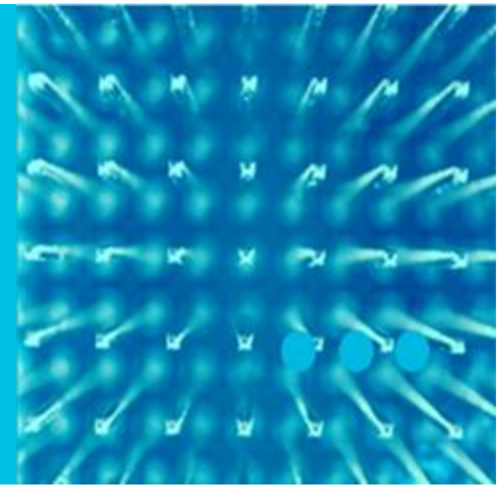
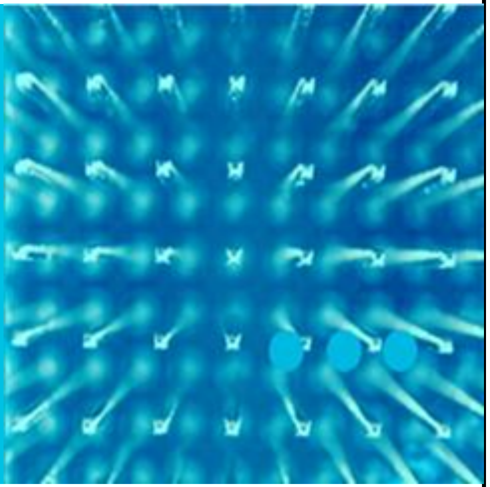
Understanding OTN
Optical Transport Network (G.709)



Agenda

1. Alphabet Soup
2. History Lesson
3. OTN 101
   - Network Application
   - OTN Hierarchy
   - ODUflex
4. Generic Mapping Procedure
5. Next steps in OTN Standardization

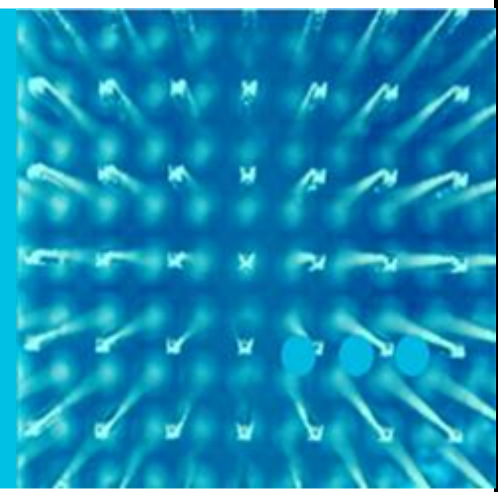
1 Alphabet Soup



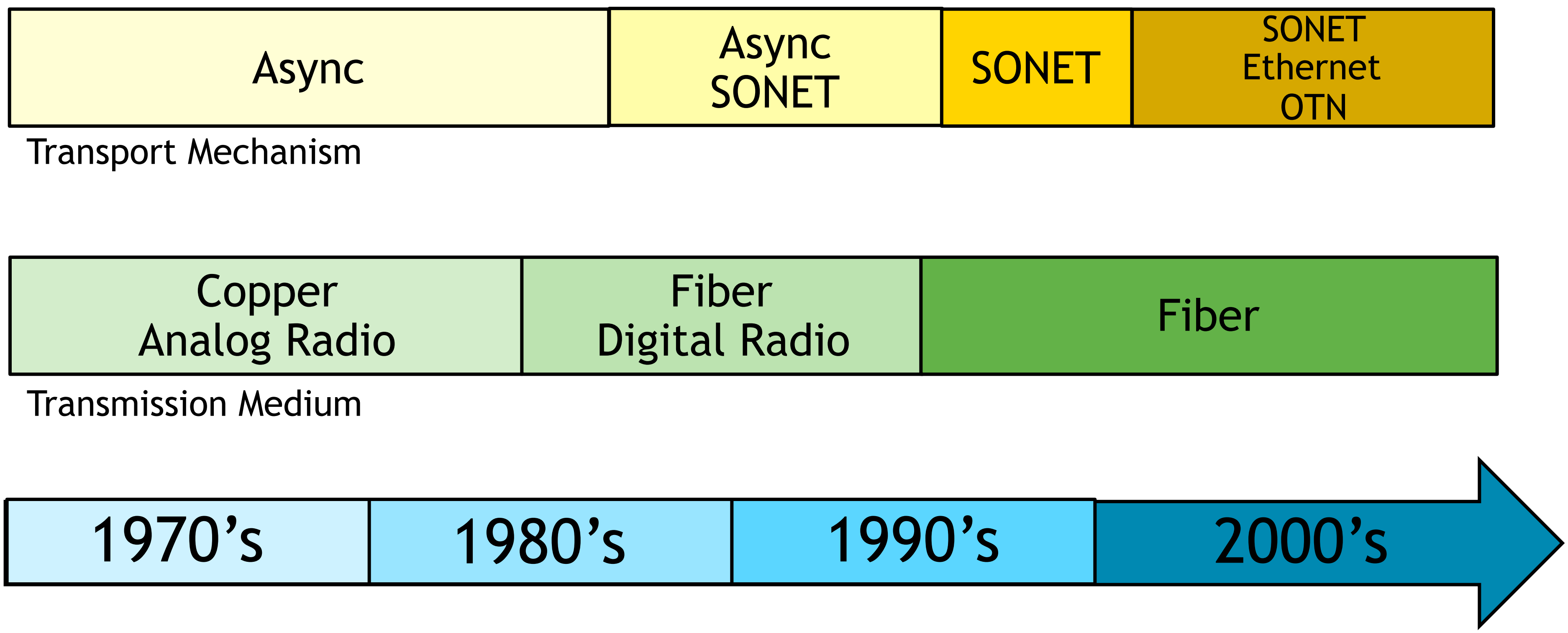
Acronyms

- ITU-T: International Telecommunications Union – Telecommunications Section
- OTN: Optical Transport Network
- OTH: Optical Transport Hierarchy
- ODU: Optical channel Data Unit
- OPU: Optical channel Payload Unit
- OTU: Optical channel Transport Unit
- Och: Optical Channel
- FEC: Forward Error Correction
- LO: Low Order
- HO: High Order
- GMP: Generic Mapping Procedure
- PPM: Parts Per Million
- CBR: Constant Bit Rate
- AMP: Asynchronous Mapping Procedure
- VCAT: Virtual Concatenation
- SONET: Synchronous Optical Network
- SDH: Synchronous Digital Hierarchy
- STS: Synchronous Transport Signal
- STM: Synchronous Transport Module
- GFP: Generic Framing Procedure
- LAN PHY(10GBase-R): LAN Physical interface
- WAN PHY(10GBase-W): WAN Physical interace

2 History Lesson



Telecom History



ITU-T OTN Definition

- Described in the ITU-T Recommendation G.709 (2003), OTN adds operations, administration, maintenance, and provisioning (OAM&P) functionality to optical carriers, specifically in a multi-wavelength system such as dense wavelength division multiplexing (DWDM).
- OTN specifies a digital wrapper, which is a method for encapsulating an existing frame of data, regardless of the native protocol, to create an optical data unit (ODU), similar to that used in SDH/SONET. OTN provides the network management functionality of SDH and SONET, but on a wavelength basis. A digital wrapper, however, is flexible in terms of frame size and allows multiple existing frames of data to be wrapped together into a single entity that can be more efficiently managed through a lesser amount of overhead in a multi-wavelength system.
- The OTN specification includes framing conventions, nonintrusive performance monitoring, error control, rate adaption, multiplexing mechanisms, ring protection, and network restoration mechanisms operating on a wavelength basis.
- A key element of a digital wrapper is a Reed-Solomon forward error correction (FEC) mechanism that improves error performance on noisy links. Digital wrappers have been defined for 2.5-, 10-, 40- and 100Gbps SDH/SONET systems. SDH/SONET operation over an OTN involves additional overhead due to encapsulation in digital wrappers.
- The resulting line rates are defined as optical transport units (OTUs).

What is OTN?

- **OTN is an industry-standard optical transport protocol**
  - ITU G.872 "Architecture for the Optical Transport Network (OTN)" (Oct 2001)
  - Further refined in ITU-T G.709 (Jan 2003, Amendment 3 Oct 2009) and ITU-T G.798 (May 2002, xxxx Jun 2010)

- **OTN is intended to promote network evolution beyond SONET/SDH**
  - Eliminates traditional TDM transport complexity and related costs
  - Removes the gaps/bottlenecks specific to emergent packet and wavelength transport

- **OTN offers tremendous CAPEX/OPEX benefits to carriers**
  - Reducing CAPEX via common transport framework
    - Lowers cost-per-bit via technology simplification and transport commonality
    - Integrates physical and optical layer processing across Network Elements (NEs)
    - Consequently reduces the number of NEs across the network
  - Reducing OPEX through network simplification and integration
    - Less equipment = less Operations, Administration, and Provisioning (OAM&P)
    - Technology offers simplified fault isolation and improved trouble-shooting

How Does OTN Technology Benefit Today's Carriers?

OTN Technology Delivers Value Across Many "Domains"

- **COMMONALITY - via wavelength-based optical transport**
  - Payload equivalency for SONET/SDH, Ethernet, and/or DWDM transport
  - Common network management platform support
  - Permits 'endpoint-only' management by avoiding termination at every midpoint
- **TRANSPARENCY – across the optical domain**
  - Integrates physical and optical layers for seamless networking
  - Promotes integration across disparate networks via common transport framework
- **EFFICIENCY – for overall cost reduction and network monetization**
  - Simplified multiplexing/demultiplexing of sub-rate traffic
  - Reduction in signal overhead requirements relative to payload
- **EVOLUTION – to emerging technologies**
  - Provides simple transition to 40G and 100G transmission speeds
  - Purpose-built for Packet Optical and Wavelength-based transport
  - Integrated, standardized Forward Error Correction (FEC) for extended optical reach
  - Ideal for comprehensive Control-Plane network implementation

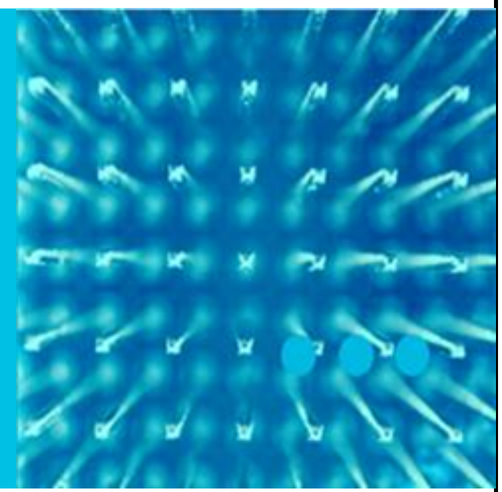
How Does OTN Technology Expand Carrier Applications?

OTN Supports Several Emerging Market Opportunities

- **Optical Wavelength Services**
  - Offers customers full end-to-end transparency
  - Protocol-independent transmission of SONET/SDH, Ethernet, IP, and/or Lambdas
  - Simplifies end-customer network management
  - Ideal for Carrier's carrier applications, wholesale bandwidth services, etc.

- **Differentiated Services**
  - New Service Level Agreement (SLA) options
    - Via OTN Control-Plane mesh
  - New Integrated multi-domain operations
    - E.g. Multi-Region Networking to integrate Physical, Transport, and Data layers under a common network management model for customer control
  - Bandwidth on Demand Services
    - Fast provisioning via end-to-end OTN

3 OTN 101



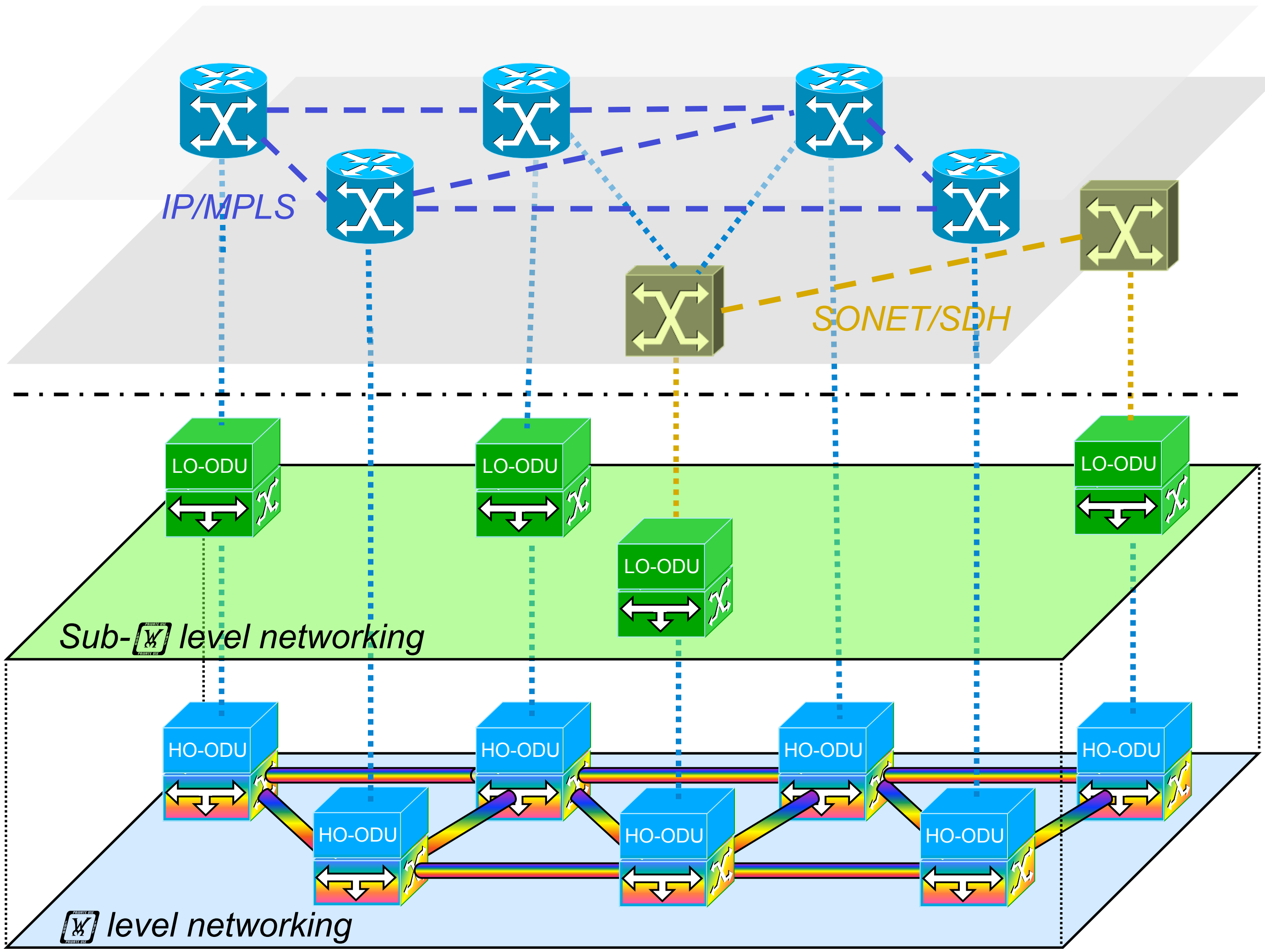
OTN Network Vision

OTN can be implemented as an overlay to an existing network or as a replacement

- **HO-ODU** networking is used when the client throughput does not need further aggregation within a lambda
- **LO-ODU** networking is used when sub-λ multiplexing is needed (no stranded sub-λ)

- **ODU Termination** (G.709 OAM) guarantees a clear boundary between client and server organizations
- **Intermediate Monitoring** can be either optical (proprietary WaveTracker) or electronic (standard G709 TC)

- **Switching** can be accomplished by means of fast electronic technology and/or slower photonic technology



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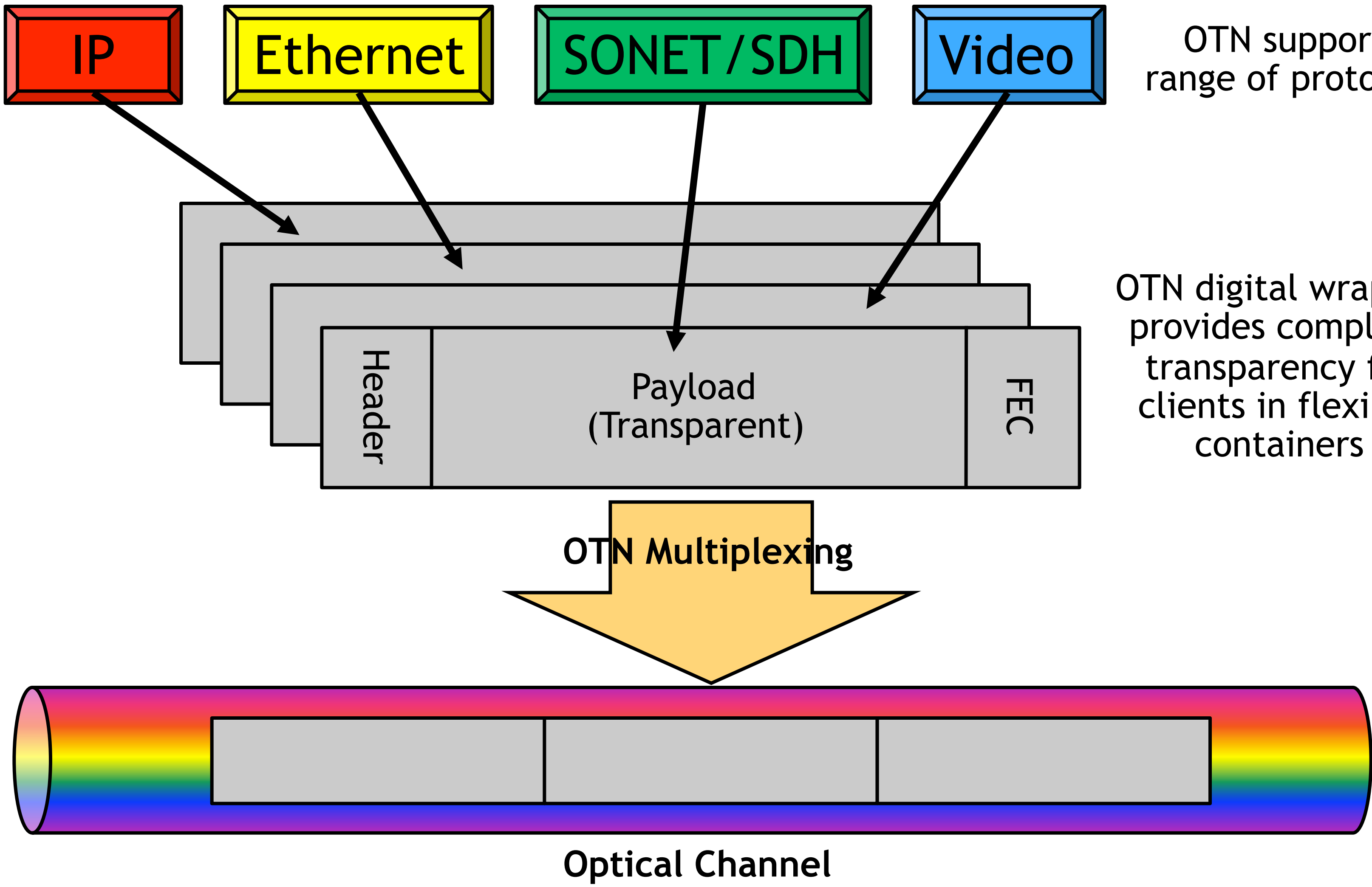
OTN Supports Variety of Protocols



OTN supports range of protocols

OTN digital wrapper provides complete transparency for clients in flexible containers

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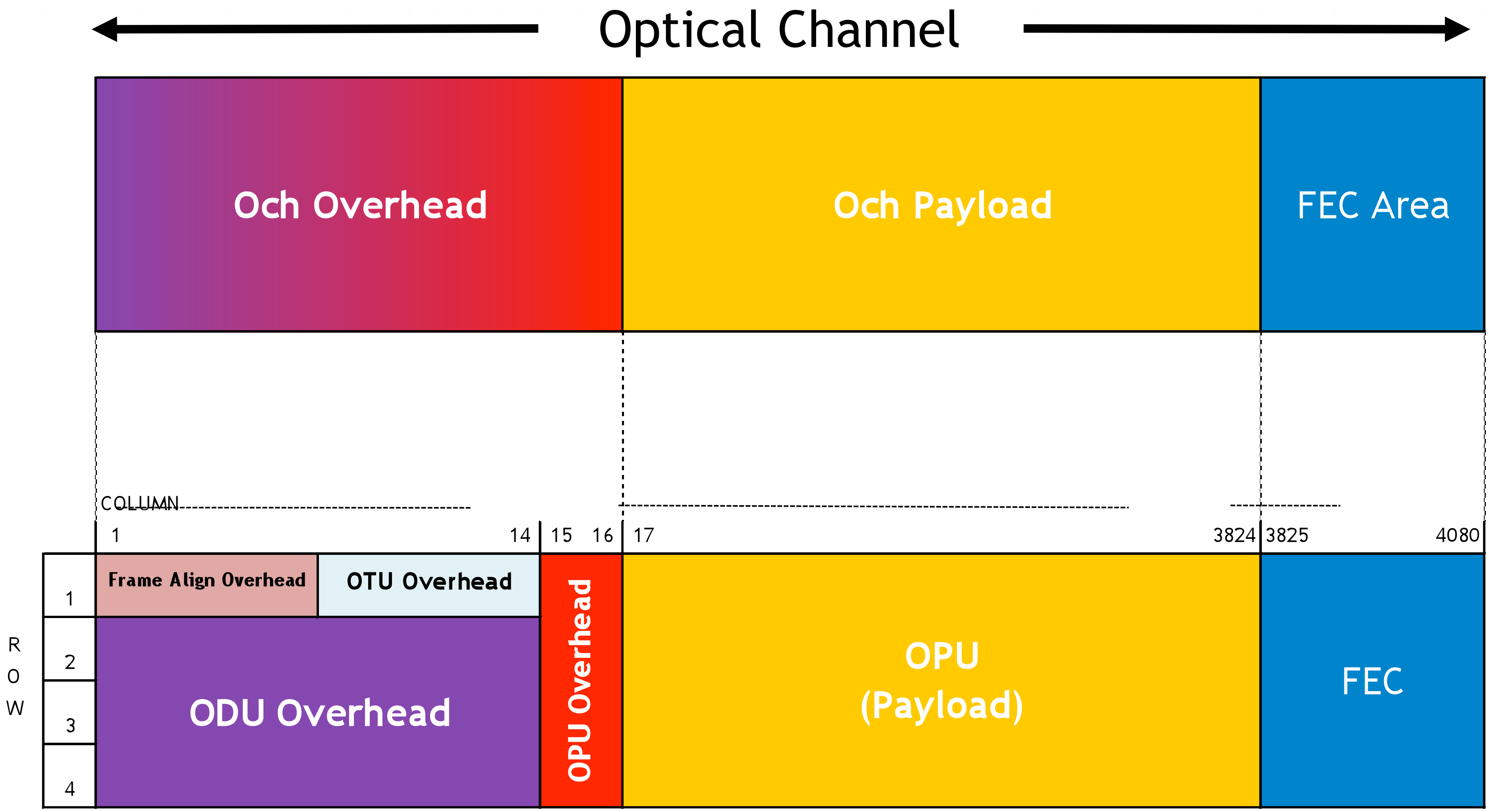
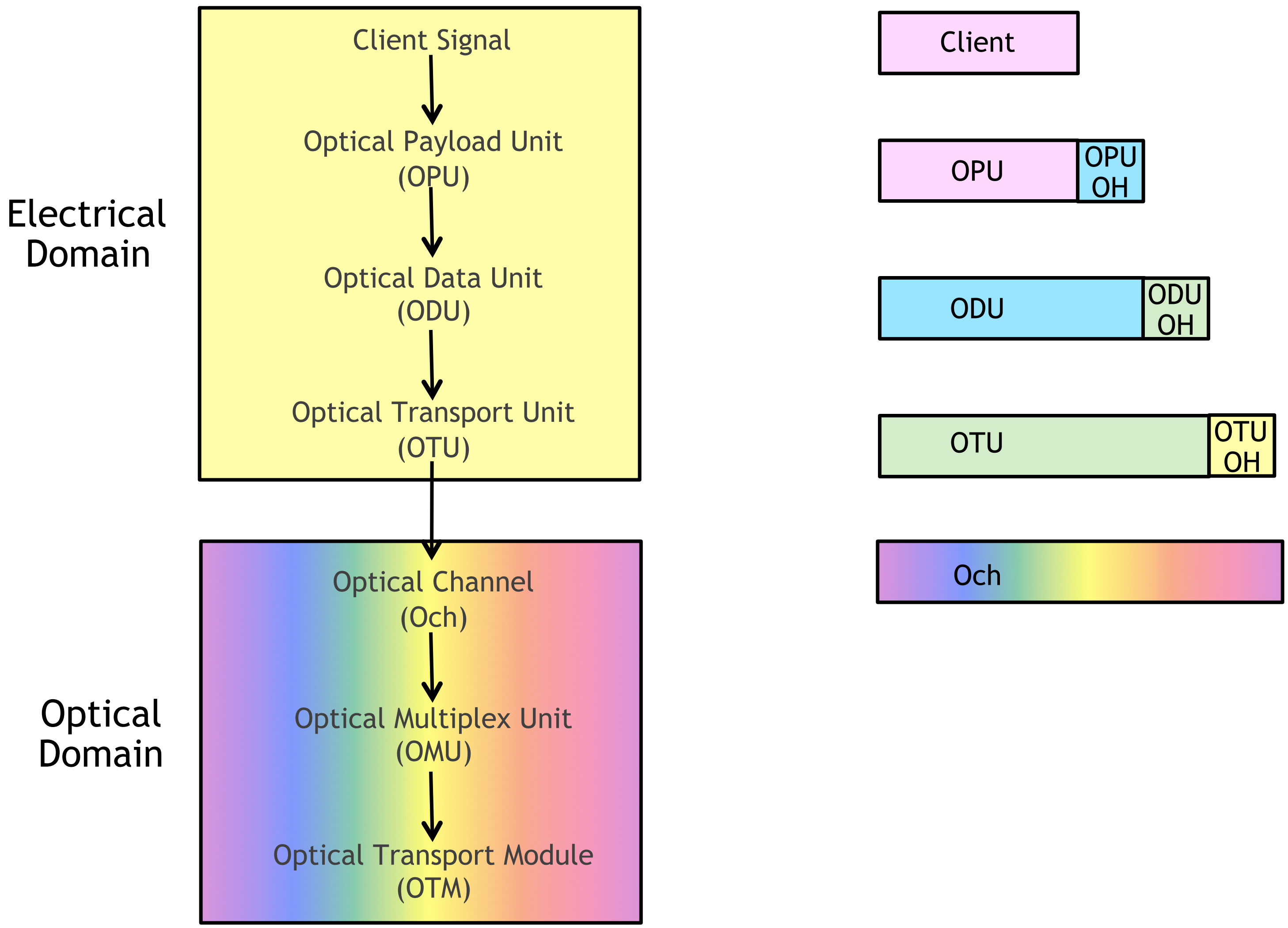
Makeup of an Optical Channel



Building an OTN Container



OTN Rates

OTU	ODU	Marketing Rate	True Signal (OTU)	True Payload (OPU)
	0	1.25G	NA	1.238G/s
1	1	2.5G	2.666G/s	2.488G/s
2	2	10G	10.709G/s	9.953G/s
3	3	40G	43.018G/s	39.813G/s
4	4	100G	111.809G/s	104.794G/s

ODUflex is also defined by G.709. Similar to Virtual Concatenation, but avoids differential delay problem and is managed as a single entity

OTN Standardization Status

- Major revision to ITU-T Rec. G.709 reached consent in October 2009, including new features from Amendment 3 and subsequent agreements
- Highlights encompassed in October revision
  - New LO ODU0 rate and format
  - New ODU4 rate and format (HO or LO)
  - New LO ODU2e rate and format, originally in G.sup43:
  - 40/100GBASE-R, handling of parallel 66B interfaces
  - Transcoding for 40GBASE-R into OPU3 and FC-1200 into OPU2e
  - OTU3/OTU4 striping over parallel lanes allow use of Ethernet modules for IrDI
  - New delay measurement capability added

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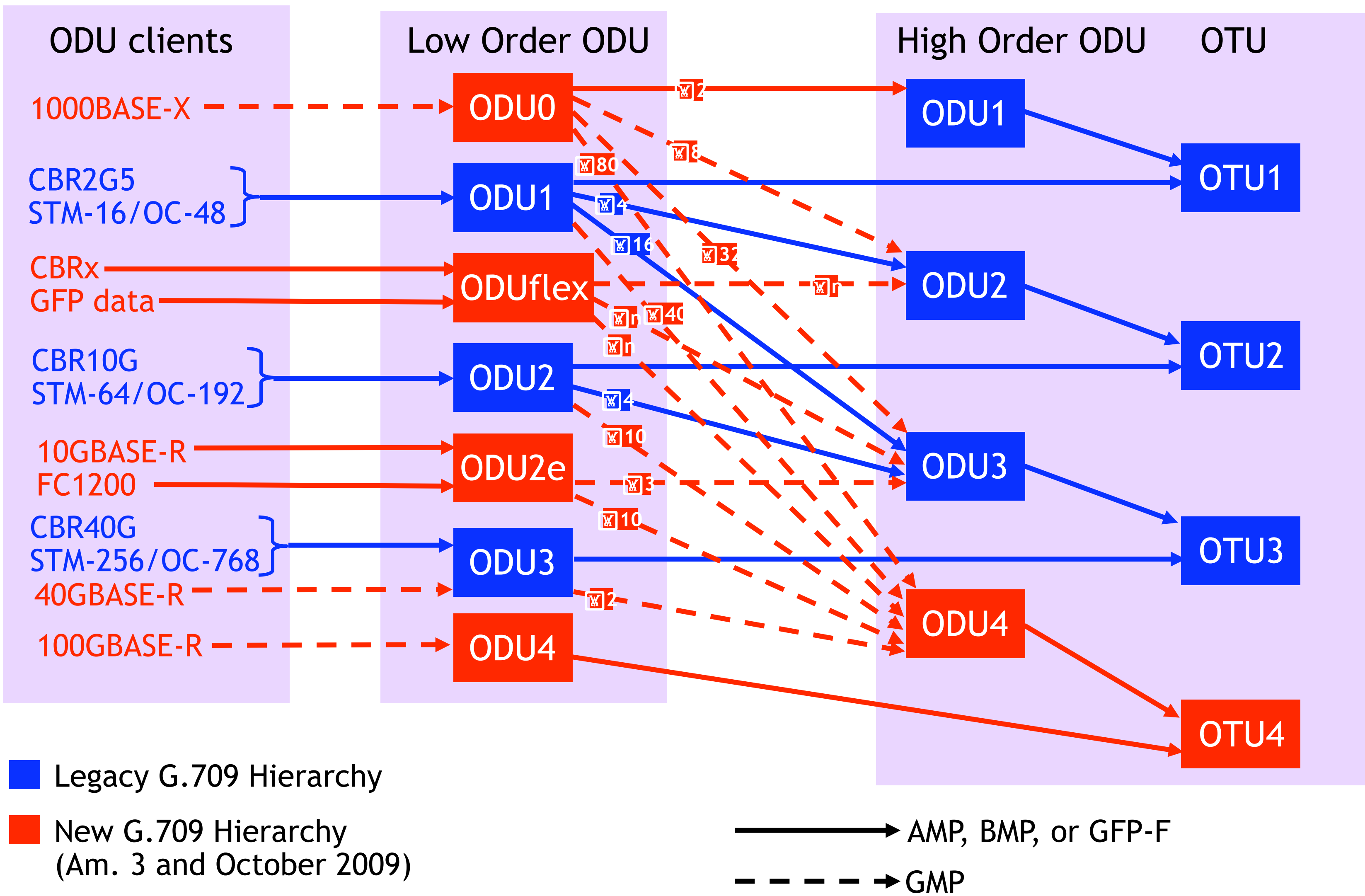
OTN Hierarchy



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ODU0 Definition

- Smallest contained defined in G.709 (OTN Standard)
  - 1.25G container size (specifically 1.244160 Gbit/s±20ppm)
  - Established in October 2009 for transport of 1000BASE-X (Gigabit Ethernet)
- Sized to fit existing OTN hierarchy
  - ×2 into ODU1
  - ×8 into ODU2
  - ×32 into ODU3
  - ×80 into ODU4
- ODU0 can carry:
  - 1000Base-X (1GbE)
  - STM-1
  - STM-4
  - FC-100
- No OTU0 physical layer
  - Only a lower order wrapper for 1000BASE-X mapped into standardized physical layers OTU1 and above

ODU1 Definition

- Original tier of the hierarchy to transport 2.5G signals
  - ODU1 = 2.498775Gbit/s
  - OTU1 = 2.666057Gbit/s
  - Can be used as a higher order ODU to carry lower order ODU0s
- Divided into 2×1.25G tributary slots:
  - ODU0 maps into 1 tributary slot
- OPU1 can carry:
  - STS-48
  - STM-16
  - FC-200

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ODU2 Definition

- Original tier of the hierarchy to transport 10G signals
  - ODU2 = 10.037273Gbit/s
  - OTU2 = 10.709224Gbit/s
  - Can be used as a higher order ODU to carry lower order ODUs
- Divided into 4×2.5G or 8×1.25G tributary slots:
  - ODU0 maps into 1 tributary slot
  - ODU1 maps into 1 2.5G or 2 1.25G tributary slot(s)
  - ODUflex maps into 1-8 1.25G tributary slots
- OPU2 can carry:
  - STS-192
  - STM-64

ODU2e Definition

- New Low Order (LO) tier of the hierarchy (Oct 2009) to transport “proprietary” 10G signals
  - Serves as a logical wrapper for 10GBASE-R when carried over a standardized physical layer of OTU3 or OTU4
  - Part of compromise made to enable standards progress - most commonly deployed “proprietary” transparent mapping of 10GBASE-R
  - Over-clocked physical OTU2e signal remains in G.sup43

- Can map ×10 into OPU4 (which is sized to carry 100GBASE-R)

- Can map as ODUflex in 9×1.25G OPU3 tributary slots (up to 3×ODU2e per OPU3)

- OPU2e can carry:
  - 10GBase-R
  - Transcoded FC-1200

ODU3 Definition

- Original tier of the hierarchy to transport 40G signals
  - ODU3 = 40.319218Gbit/s
  - OTU3 = 43.018410Gbit/s
  - Can be used as a higher order ODU to carry lower order ODUs

- Divided into 16×2.5G or 32×1.25G tributary slots:
  - ODU0 maps into 1 tributary slot
  - ODU1 maps into 1 2.5G or 2 1.25G tributary slot(s)
  - ODU2 maps into 4 2.5G or 8 1.25G tributary slot(s)
  - ODU2e maps into 9 1.25G tributary slots
  - ODUflex maps into 1-32 1.25G tributary slots

- OPU3 can carry:
  - STS-768
  - STM-256
  - Transcoded 40GBase-R

ODU4 Definition

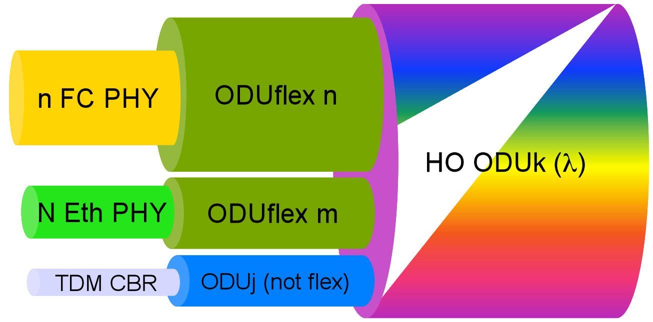
- New tier of the hierarchy (Oct-09)
  - ODU4 = 104.794445Gbit/s
  - OTU4 = 111.809973Gbit/s
  - Can be used as a higher order ODU to carry lower order ODUs

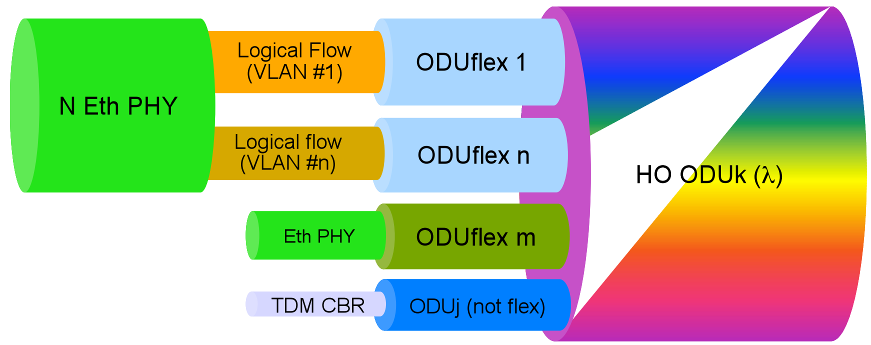
- Divided into 80×1.25G tributary slots:
  - ODU0 maps into 1 tributary slot
  - ODU1 maps into 2 tributary slots
  - ODU2 or ODU2e maps into 8 tributary slots
  - ODU3 maps into 32 tributary slots
  - ODUflex maps into 1-80 tributary slots

- OPU4 can carry:
  - 100GBase-R

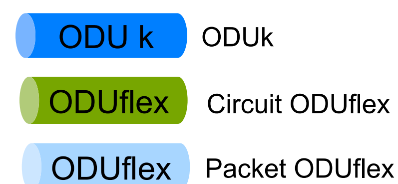
ODUflex Overview

- New to hierarchy (Oct-09)
- Two flavors of ODUflex standardization
  - Circuit ODUflex
    - Supports any possible client bit rate as a service in circuit transport networks
    - CBR clients use a bit-sync mapping into ODUflex (239/238xthe client rate)
  - Packet ODUflex
    - Creates variable size packet trunks (containing GFP-F mapped packet data) for transporting packet flows using L1 switching of a LO ODU
    - In principle, can be of any size, but in a practical implementation it will be chosen to be multiples of the lowest tributary slot size in the network





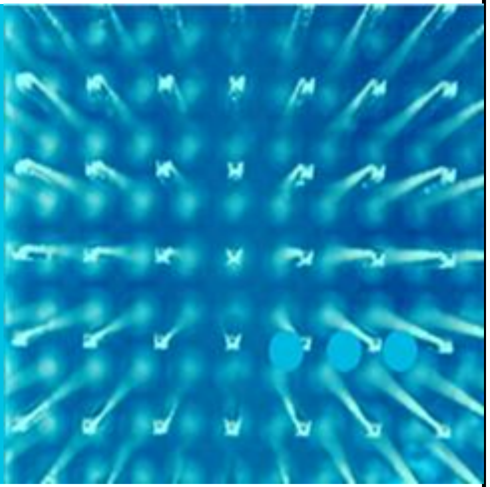
- Similar to VCAT, but avoids differential delay problem by constraining the entire ODUflex to be carried over the same higher order ODUk, and provides one manageable transport entity per service (while also limiting the application to ODUflex that fits within one higher order ODUk)



ODUflex Resizing

- Not yet defined in G.709; draft revision under discussion
  - Mixed operator views
  - Component vendor hesitation due to fear of delay
  - Some vendor opposition (Ciena/Nortel)
- While earlier agreement that hitless resizing should not be precluded, significant time pressure for establishing equipment/component “hooks” to enable resizing capability
  - Unlike VCAT/LCAS, impacts all equipment along path
  - Allay component vendor concerns re-investment payoff (LCAS was a significant development investment for almost no return)
  - Build understanding of benefits from an operator perspective (recognizing differing operator philosophies)
- A coalition of system vendors and device manufacturers has made significant progress in specifying a technical solution that will be brought into standards after it is complete

4 Generic Mapping Procedure



Generic Mapping Procedure (GMP)

Drivers

- Historically, G.709 had three multiplexing routes (ODU1→ODU2, ODU1 →ODU3, ODU2 →ODU3)
  - All options could be described explicitly with small numbers of complete fixed stuff columns
  - Two multiplexing routes are "clean" with a single justification opportunity per multiframe
  - One multiplexing route is "messy" with justification opportunity location and spacing varying based on the particular tributary slots (TS) chosen

- Revised G.709 adds over 100 new multiplexing routes (ODUflex into 1-80 TS of OPU4, 1-32 TS of OPU3, 1-8 TS of OPU2, ODU0 →ODU2,3,4, ODU2e →OPU3, ODU1,2,2e,3 →OPU4)
  - If a traditional justification approach is employed, almost all of the new multiplexing routes would be "messy" with number and location of justification opportunities varying according to the particular TSs assigned
  - Location of even "fixed" stuff would have to be determined algorithmically, because there are too many combinations to draw them all explicitly.
  - Offers possibility to support hitless resizing of packet ODUflex (precluded by traditional justification approach)

Generic Mapping Procedure (GMP)

Basic Concepts

- Single mechanism used to accommodate the nominal bit-rate difference between the client and server, and the clock variations that may occur between client and server
  - i.e., no distinction between “fixed” and “variable” stuff locations
- The server frame (or multi-frame) is divided into a certain number of GMP “words”, where each word may contain either data or stuff.
  - Words containing data are distributed as evenly as possible (quantized to word size) across server frame using sigma/delta distribution algorithm
  - Correct operation depends only on mapper and demapper knowing the number of data words which are filled into each frame (or multi-frame)
- Larger GMP word sizes are used for higher bit-rate clients to avoid the need for large barrel shifters in the implementation.
- If necessary to meet the timing requirements of the client, additional timing information may be transmitted from the mapper to the demapper
  - Enables the demapper to know how many client bytes (or bits) are to be emitted by the demapper during each server frame period
    - Note that the GMP word size for some mappings may be as large as 80 bytes, which could otherwise produce significant mapping jitter

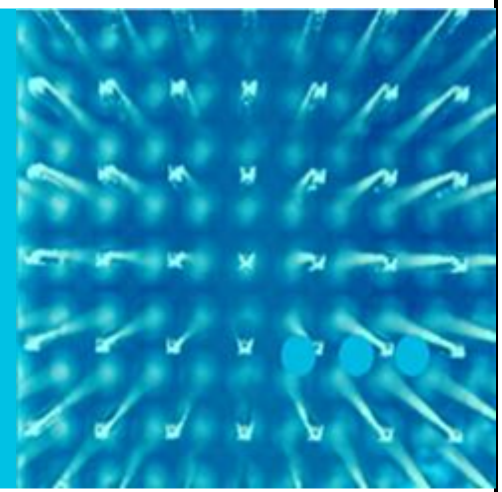
Generic Mapping Procedure (GMP)

Applications

- Client mappings into LO OPUk:
  - CBR clients less than OPU0 bit-rate into OPU0
  - CBR clients greater than OPU0 but less than OPU1 bit-rate into OPU1
  - CBR clients close to bit-rate of OPU2, OPU3, or OPU4 into the respective container
  - Note that CBR clients that are greater than OPU1 bit-rate but not a convenient fit for OPU2, OPU3, or OPU4 are mapped via ODUflex

- Tributary mappings into HO OPUk:
  - LO ODU0 into HO OPU2, OPU3
  - LO ODUflex into HO OPU2, OPU3
  - LO ODU2e into HO OPU3
  - Any LO ODUk (k=0, 1, 2, 2e, 3, flex) into HO OPU4

5 Next Steps in Standardization



Emerging Hot Topics for OTN Standardization

- Architecture & Equipment types, multi-level multiplexing (G.872, G.798.1)
  - A key issue for AT&T is introduce ODU0 and ODUflex into legacy network with new functionality at the edge without the need to upgrade all NEs along a path. Requires support of the following multi-stage multiplexing routes:
    - ODU0→ODU1→ODU2
    - ODU0→ODU1→ODU3
    - ODU0→ODU2→ODU3
    - ODUflex→ODU2→ODU3

- ODU3e2 as generic HO ODUk and/or LO ODUk
  - Advocated by Huawei, Chinese operators, Deutsche Telekom, opposed by many others. Little danger (and some merit) to use as HO ODUk, but risk that possible use as LO ODUk may cause a second, non-interoperable transparent mapping of 40GBASE-R to be introduced

Emerging Hot Topics for OTN Standardization

- ODUflex hitless resizing
  - Urgent to bring back into standards quickly once offline work is completed with collaborators (initially Huawei, Tellabs, Vitesse)

- OTN Protection
  - Linear Protection
    - G.873.1 outdated – revision to align with new base documents underway
    - SNC/I compound group protection is proposed for ODU
  - ODUk-SPRing (HO and LO ODUk shared protection ring)
  - Proposed by Huawei. Needs to be evaluated internally for future position
  - Draft G.873.2 prepared during 2002-2004, but never completed or put for consent
  - Decided at Sept / Oct 2009 SG15 Q9 meeting to progress G.873.2 via correspondence. The previous draft document will need to be modified from OCH SPRING to ODUk shared protection ring
  - If standardized, would require support on 1830 and 1870 systems

OTN Standardization

Non-controversial work items

- Elevate 40GBASE-R/100GBASE-R mappings into OTU3/OTU4 to standard when IEEE P802.3ba is approved (expected June 2010)
- Complete the Equipment model (revision of G.798) corresponding to the recently revised G.709
- Complete the Equipment management model (revision of G.874) corresponding to recently revised G.709 and parallel revision of G.798
- Revise the OTN jitter specification G.8251 to cover new client and tributary mappings introduced by the revision of G.709

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