Hot topics in
Optical Transport Networks

OFC2018

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Scope of OTN Standardization

WP3 – Digital Layer Aspects

- Q12/15
  Architecture, SDN Control
  G.872, G.7702
- Q11/15
  Signal Formats
  G.709, G.709.x, G.7041
- Q9/15
  Network Protection & Restoration
  G.873.x
- Q13/15
  Synchronization, Jitter & Wander Performance
  G.8251
- Q14/15
  Management and Control
  G.874, G.874.x

WP2 – Physical Layer Aspects

- Q6/15
  Optical Physical Interfaces
  G.959.1, G.695, G.698.x
- Q7/15
  Optical Components
  G.680, G.66x, G.67x
- Q5/15
  Optical Fibers
  e.g., G.652

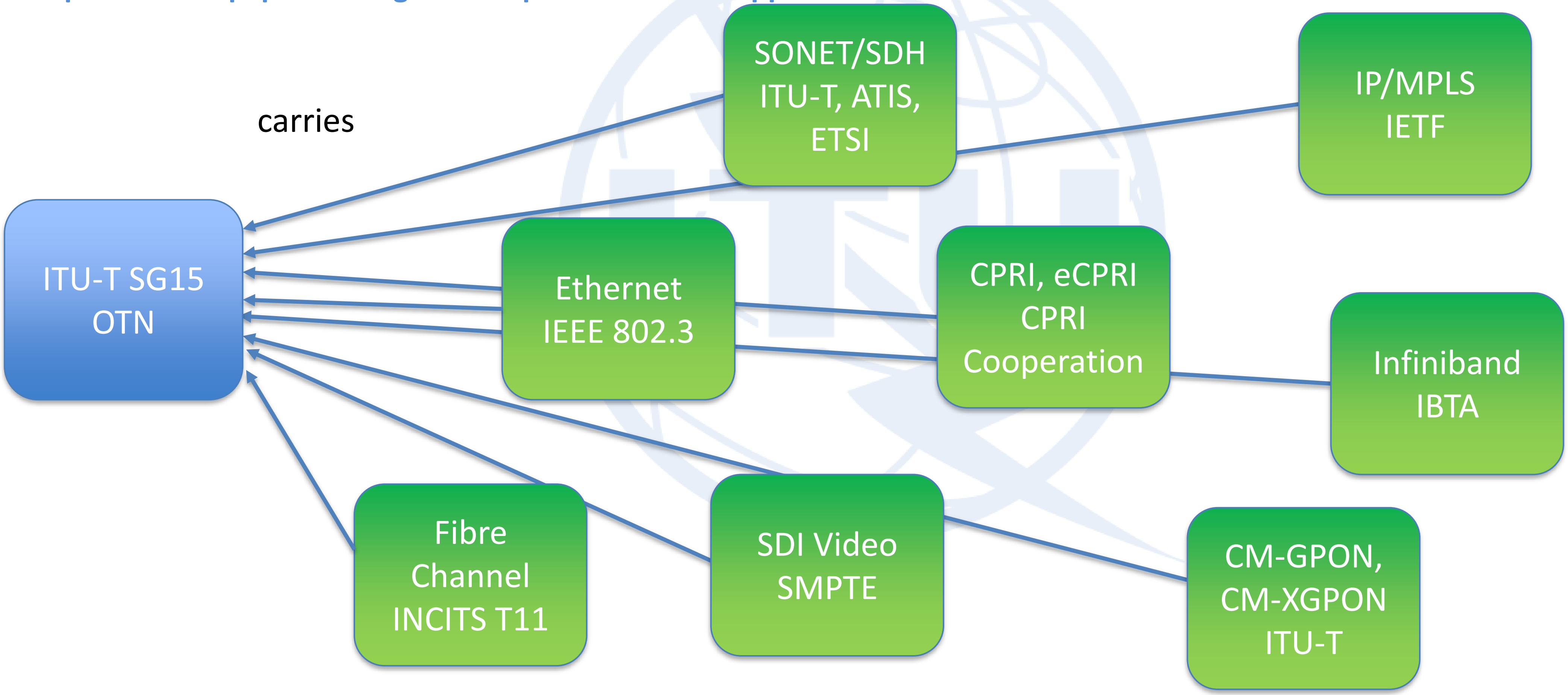
Published Recommendations available for free download at:
https://www.itu.int/ITU-T/recommendations/index.aspx?ser=G

What kinds of OTN interfaces does SG15 Standardize?

- Fully Standardized Interfaces and Aspects
  - Mappings of Client Interfaces into Line Interface Frame formats
  - Fully Standardized OTN Client Interfaces – Optical Budgets recently based on IEEE 802.3 with an OTN frame Format
  - Line interfaces where technology is sufficiently mature for multi-vendor interoperability (typically 200-450km over amplified metro ROADM networks (80km under consideration), initially 2.5G and 10G NRZ, under development 100G DP-QPSK)
- Functionally Standardized Interfaces
  - Long/Ultra-Long Haul (1000s of km terrestrial or subsea)
  - The Information flow across an interface, the OAM and how it is processed are standardized so that different vendor systems are managed in the same way, but the precise modulation, FEC, Frame Format is left to individual vendor designs
  - Examples: Flexible Coherent with probabilistic constellation shaping and exotic proprietary FEC
  - Single-vendor subnetworks composed of functionally standardized interfaces are interconnected using shorter reach fully-standardized interfaces

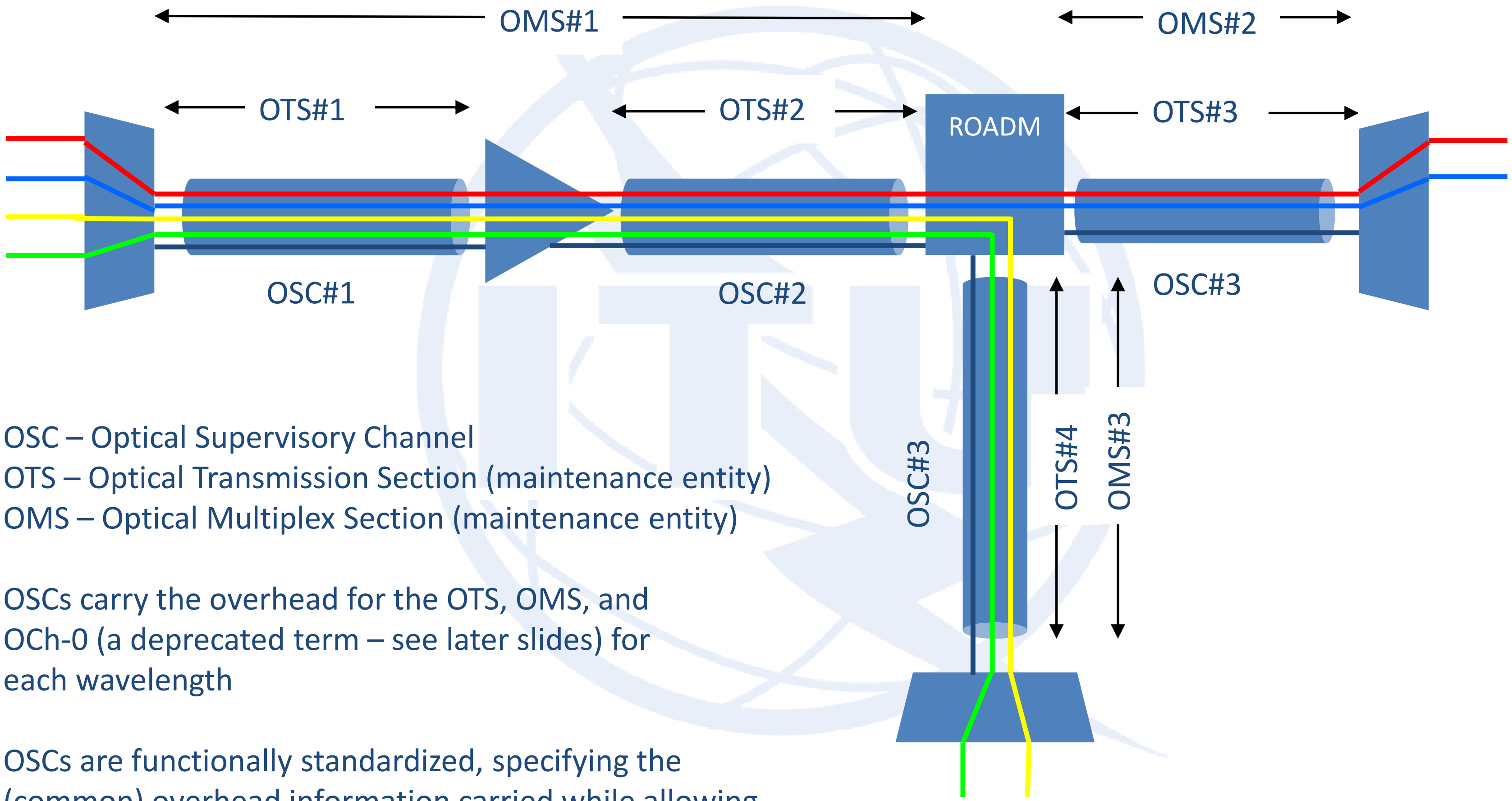
Ecosystem of Services that may be carried as client services over OTN Technology

Note: OTN is a toolbox – not every product implements every possible mapping, and some services are only available in specialized equipment targeted at specific network applications



Optical Media Layer Management

Functionally Standardized Architecture for Management and Fault Isolation in Optical Networks



OSC – Optical Supervisory Channel
OTS – Optical Transmission Section (maintenance entity)
OMS – Optical Multiplex Section (maintenance entity)

OSCs carry the overhead for the OTS, OMS, and OCh-0 (a deprecated term – see later slides) for each wavelength

OSCs are functionally standardized, specifying the (common) overhead information carried while allowing the exact physical format to be vendor specific

Historical OTN Standardization
Evolving from 2.5G-10G-40G-100G (through 2010)

Discrete per Lambda Line Interface Rates

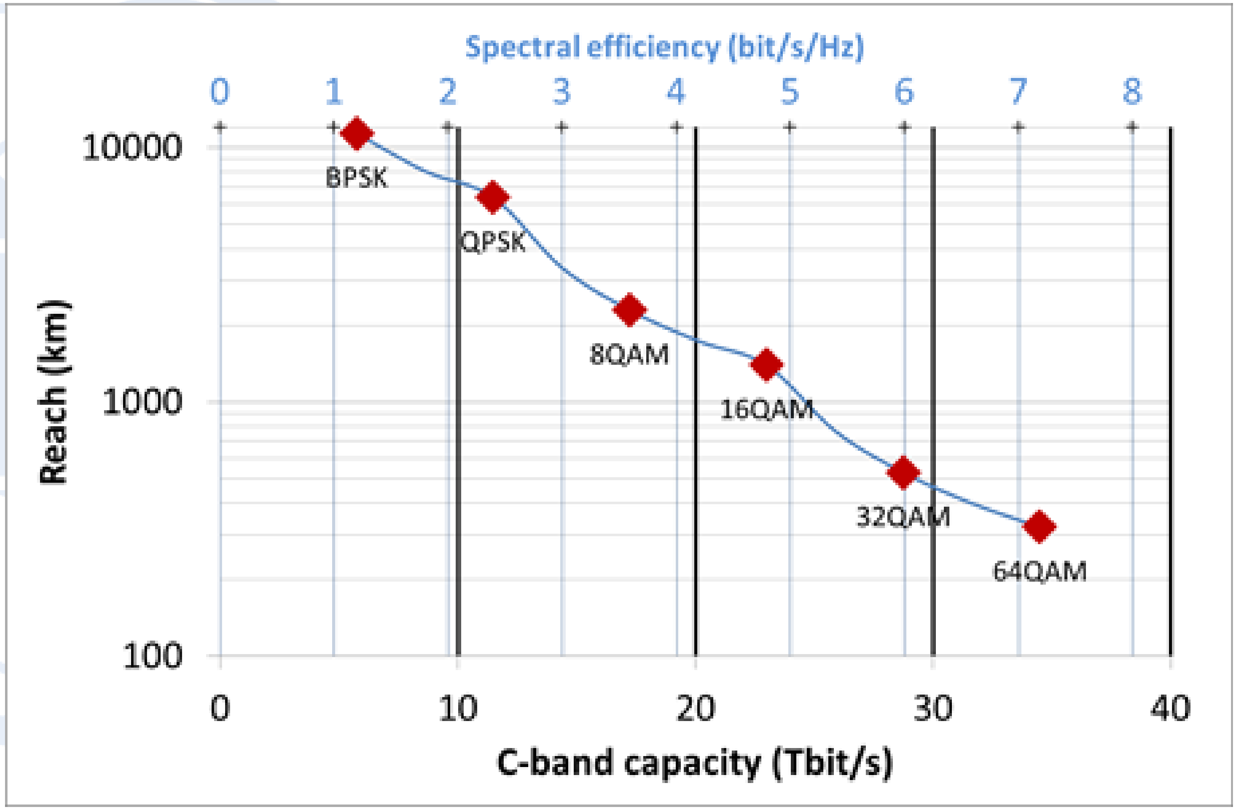
Lambda carrying one client

Lambda carrying multiple "individually wrapped" clients, TDM multiplexed

		HO ODUk			
		ODU1	ODU2	ODU3	ODU4
Direct Client Mapping		BMP, AMP, GMP, or GFP			
Wrapped Clients	ODU0	AMP	GMP	GMP	GMP
	ODU1		AMP	AMP	GMP
	ODU2			AMP	GMP
	ODU2e			GMP	GMP
	ODU3				GMP
	ODUflex		GMP	GMP	GMP

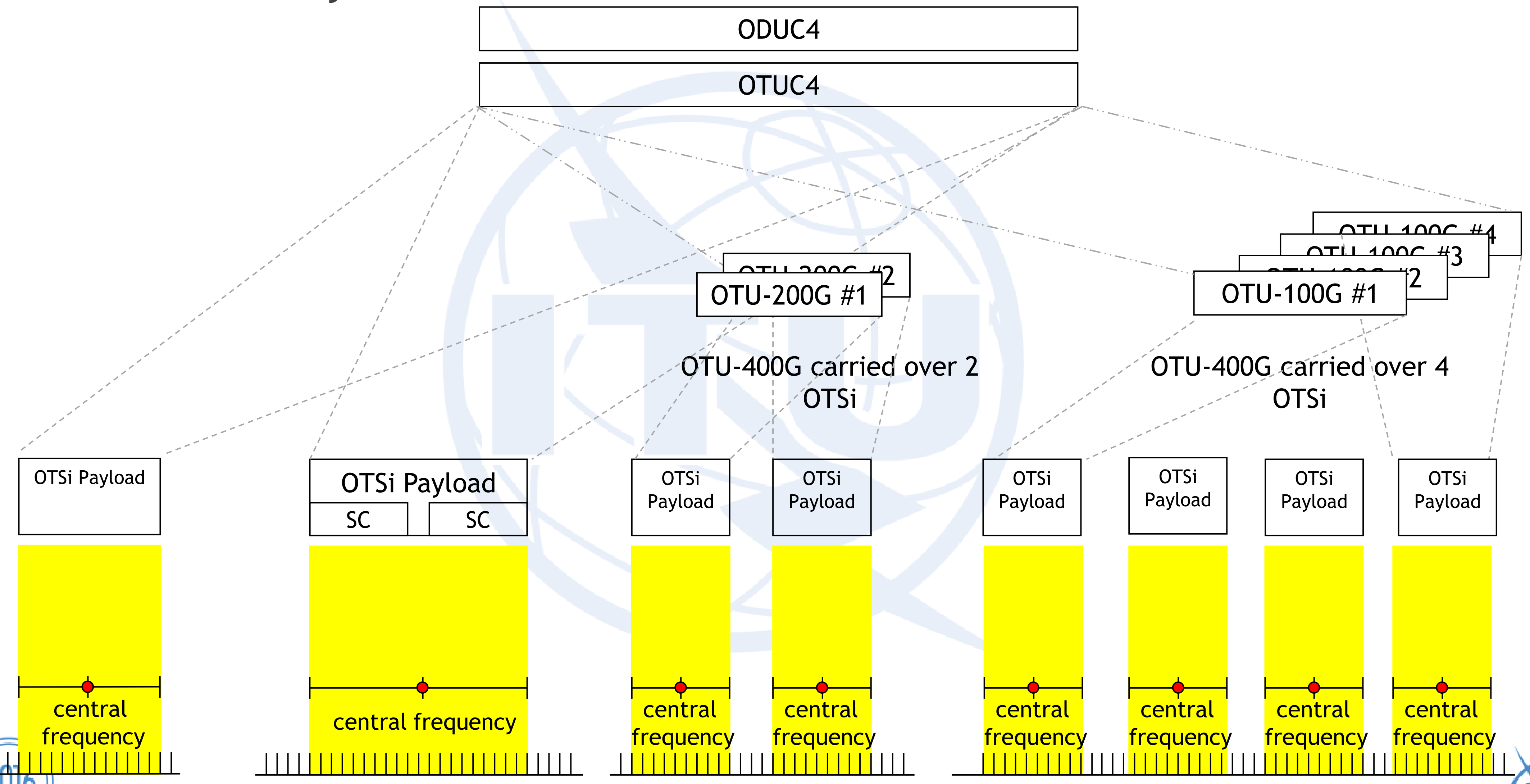
What forces a new evolutionary path beyond 100G?

- Continued emergence of new, higher, discrete client interface rates (e.g., 200GBASE-R and 400GBASE-R from IEEE Std 802.3bs-2017)
- No single “next” coherent line interface rate – how many bits you can carry per lambda depends on how far you need to go
- Numbers of lambdas required to carry a high-rate client may vary depending on distance



Possible 400G Mapping Examples

Differences in spectral efficiency based on reach, number of carriers and whether carriers are adjacent

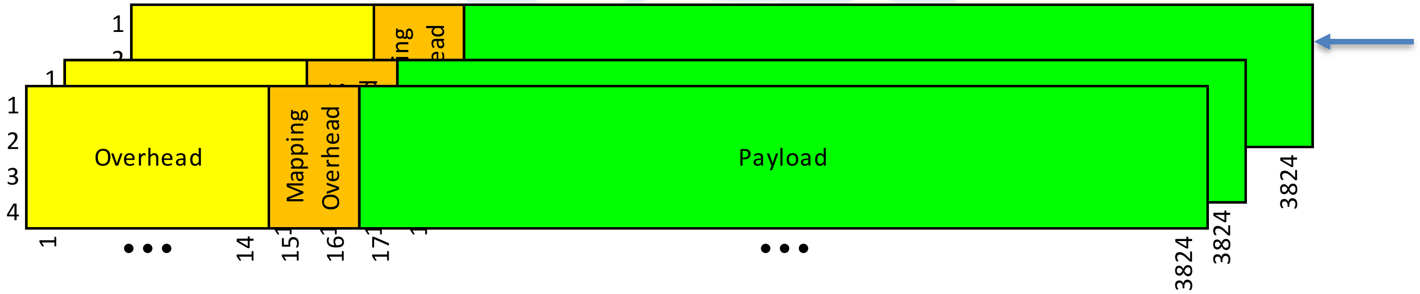


SC: Sub-Carrier, OTSi=Optical Tributary Signal

Beyond 100G Line Interface Format Formulation – OTUCn
n instances of a logically interleaved 100G (C=100) frame format

- Fully Standardized interfaces are all multiple of 100G, and may be inversely multiplexed over 100G, 200G, or 400G optical tributary signals
- Functionally standardized interfaces may have reduced tributary slot capacity on one or more of the 100G "slices". Aggregate size can scale in steps as small as 5G. Manner in which "odd-size" aggregates may be inversely multiplexed over "odd-size" optical tributary signals may be vendor-specific. Full specification of overhead processing and information content allows for common management paradigm to be applied to equipment of multiple vendors

n instances of a logically Interleaved frame structure, frame and multiframe syncronous



Bandwidth allocation granularity is twenty 5G "tributary slots" per 100G slice

Aggregate bit-rate = n × 239/226 × 99 532 800 kbit/s

OTN Beyond 100G Functional Model

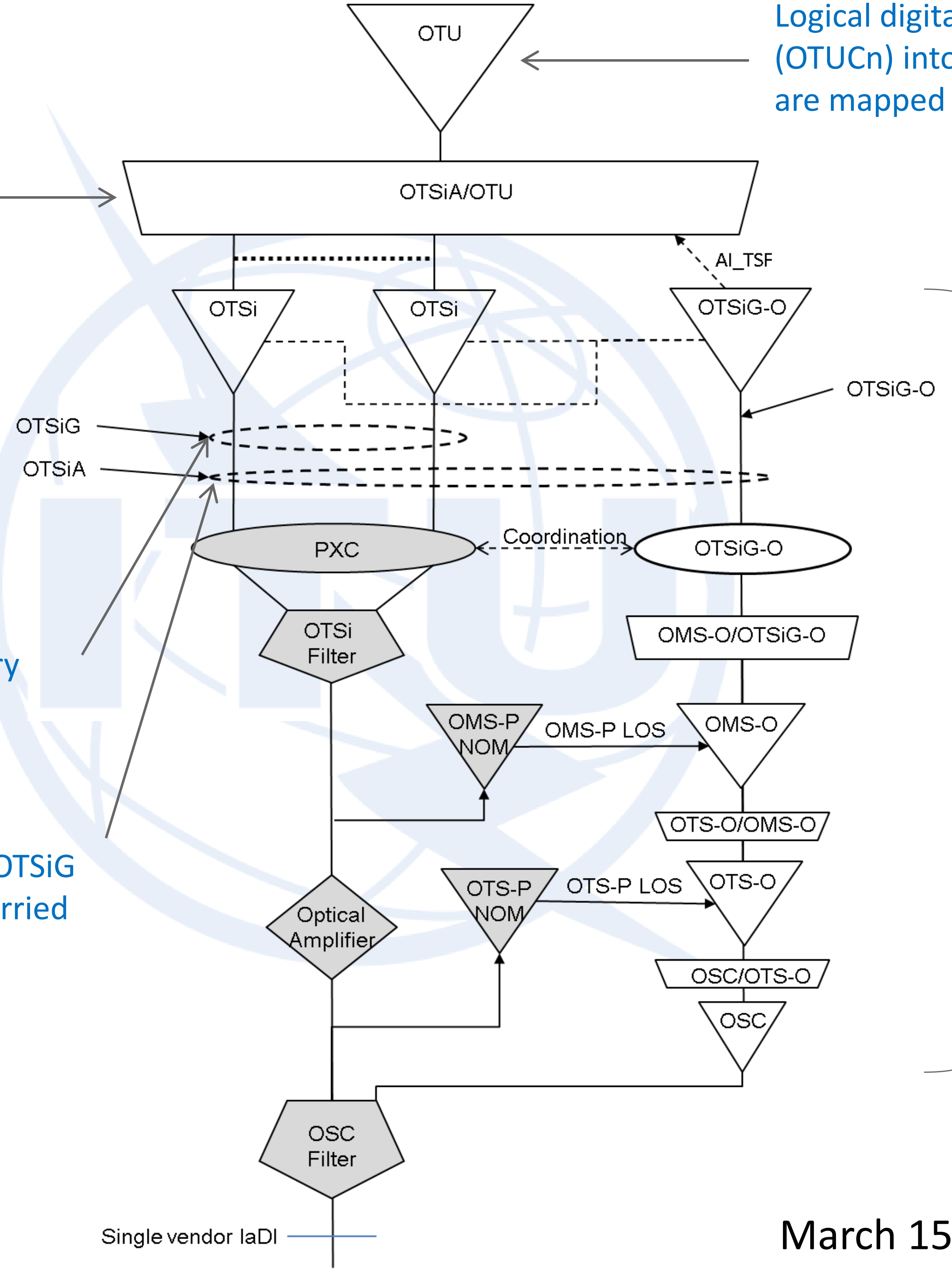
General-purpose framework for carrying a digital container on multiple lambdas

Logical digital container (OTUCn) into which clients are mapped

Digital container is mapped over one or more optical tributary signals (OTSi). FEC is part of the adaptation to the physical layer. For line side, the adaptation is vendor specific (e.g., might disinterleave OTUCn frame and apply FEC per OTSi, or might stripe a single SD-FEC frame over all the OTSi

OTSiG is the group of optical tributary signals carrying the OTUCn

OTSiA is the assembly including the OTSiG plus the non-associated overhead carried In the optical supervisory channel



Non-associated overhead carried in the optical supervisory channel (OSC). Single instance of overhead for the group of optical tributary signals carrying the OTUCn. Analogous to OCh-O used for up to 100G OTN

OTN Client Interfaces based on Ethernet Optics

Ethernet Spec (optical and logic)	ITU-T Optical	ITU-T Frame Format
100GBASE-LR4	G.959.1 4I1-9D1F	G.709 OTL4.4 or G.709.1 FOIC1.4
100GBASE-ER4	G.959.1 4L1-9C1F	
CWDM4 MSA	G.695 C4S1-9D1F	
4WDM 40km “ER4-lite”	G.959.1 4L1-9D1F	
200GBASE-FR4	G.695 C4S1-4D1F	G.709.1 FOIC2.4
200GBASE-LR4	G.959.1 4I1-4D1F	
400GBASE-FR8	G.959.1 8R1-4D1F	G.709.1 FOIC4.8
400GBASE-LR8	G.959.1 8I1-4D1F	

ITU-T has used the completed optical specification from IEEE 802.3 as a basis for how to use the same pluggable modules for OTN client interfaces rather than developing competing or differing optical specifications for similar link types.

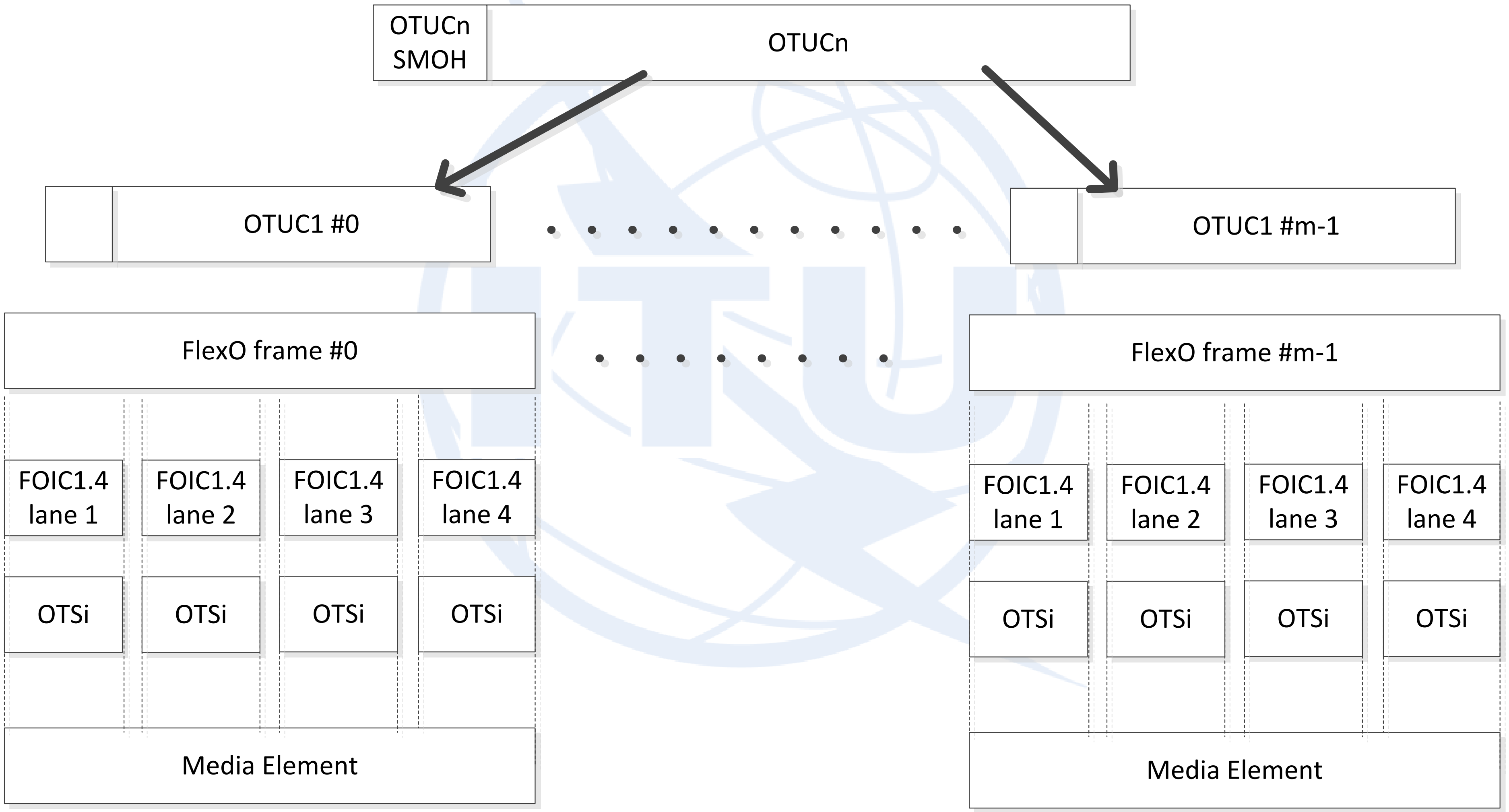
G.709.1 FlexO “Short Reach” Interface

First Edition – Approved January 2017

- Edition 1 was a successor to the “OTL4.4” format used to carry an OTU4 client interface.
- OTL4.4 carries an OTU4 over a pluggable 100GbE module using RS(255,239) FEC, 8.4218% over-clocked as compared to usage for Ethernet at 103.125 Gb/s ±100ppm.
- Borrows concepts of FlexE to create a client interface for an OTUCn over n bonded 100GbE modules using RS(544,514) FEC. Almost exactly the same bit-rate used for FOIC1.4 as for OTL4.4 (491384/462961 × 544/514 × 99.5328 Gb/s ±20ppm instead of
  255/227 × 99.5328 Gb/s ±20ppm, about 3ppm lower and not enough to affect module reuse)
- Logical OTUCn-M client interface can be created by bonding n 100GbE Ethernet modules (each carrying FOIC1.4) and marking 20×n-M of the 5G tributary slots as “unavailable” in the MSI. Mapping of overhead and available TS to the (non-multiple of 100G) line side interface is vendor specific

FlexO Interface distributed over “n” 100G Ethernet Interfaces

Note that this uses only newer modules with 4x25G electrical interfaces as the structure couldn’t traverse a 10:4 gearbox



G.709.1 FlexO "Short Reach" Interface

Second Edition, Consented February 2018

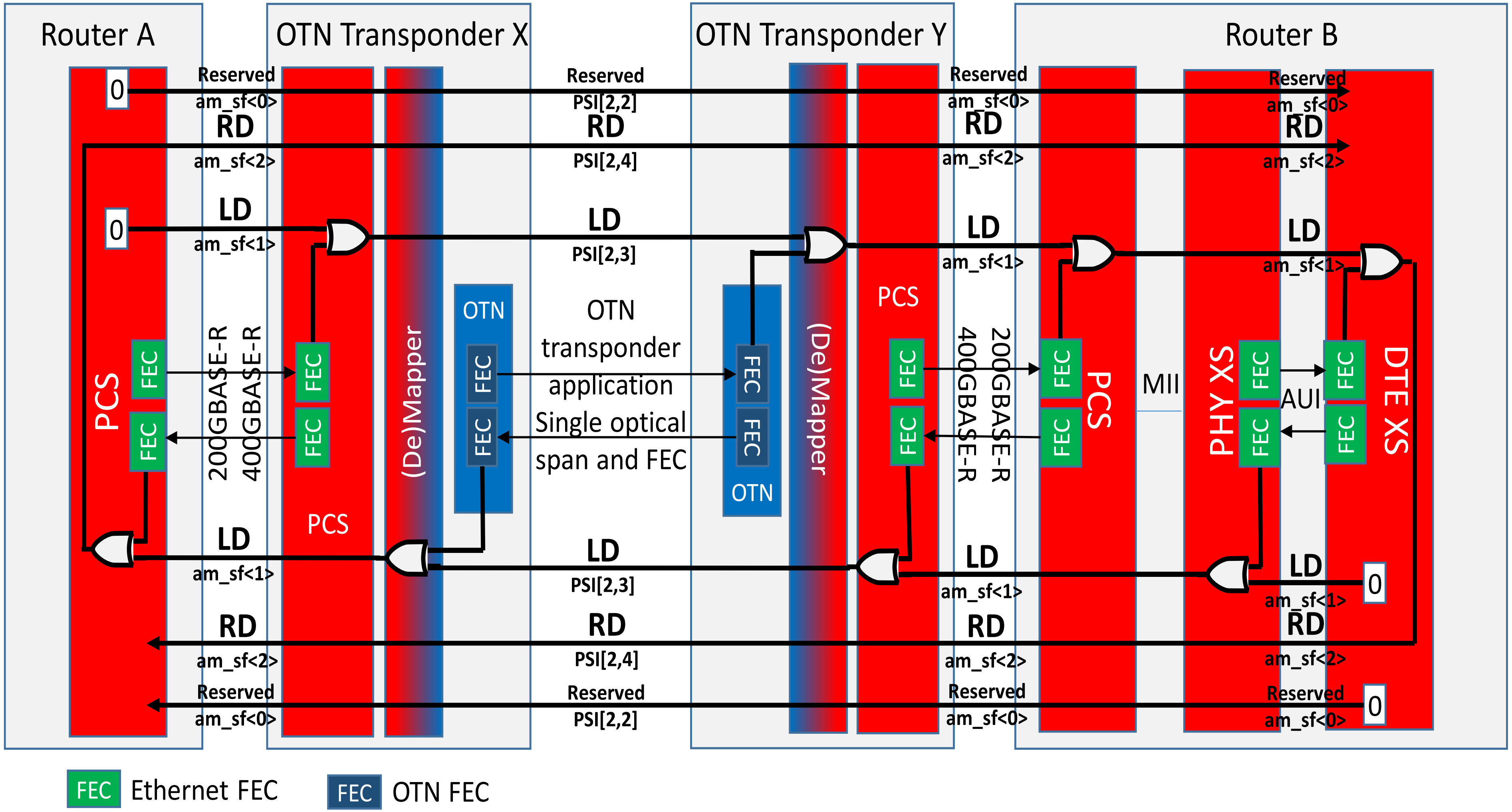
- Adds support of FlexO groups to carry OTUCn over bonded 200GBASE-R or 400GBASE-R pluggable modules
- Interleaving of two or four 100G FlexO "instances" over each 200G or 400G Ethernet PHY.
- The PHYs use the same RS(544,514) interleaved FEC structure as 200GbE and 400GbE and the same alignment markers.
- Some 100G FlexO "instances" may be unequipped, e.g., you could carry an OTUC3 over a 400G Ethernet module with one unequipped FlexO instance. Unequipped instances are at the end of a 200G or 400G PHY.
- OTN Rates of Operation for 200G and 400G Modules (~5.2324% higher than Ethernet rates of operation):
  - 200G: FOIC2.4 is 2 × 30592/27233 × 99.5328 Gb/s ±20ppm (1/4 of this per 50G lane)
  - 400G: FOIC4.8 is 4× 30592/27233 × 99.5328 Gb/s ±20ppm (1/8 of this per 50G lane)

G.709 Amd. 2 – 200GbE and 400GbE mappings into OPUflex

Consented February 2018

- 200GBASE-R and 400GBASE-R signals have FEC corrected and FEC parity removed by the mapper. The mapper may count FEC corrected errors and compare against a threshold per IEEE Std 802.3bs-2017 clause 119.3 to set the FEC_degraded_SER variable.
- The payload data is trans-decoded from 257B to 66B format and AMs are removed. Rate compensation (RC) blocks are inserted to maintain the client clock after AM removal (not necessarily in the same place)
- The Client Degrade Indication overhead (equivalent to the Status bits in the 200G and 400G AMs) is carried in bits 2-4 of the PSI[2] byte of the OPUflex overhead
- Uses G.709 Clause 17.13 mapping of 66B encoded signal with 2-bit alignment of 66B codewords
- Replacement signal is LF with RC blocks so it works with the demapper
- If a pre-FEC degrade condition can be detected according to the OTN FEC for a single optical span, the OTN can participate in the Ethernet pre-FEC degrade signaling as if it were an extender sublayer according to 802.3

OTN Participation in IEEE 802.3bs “Pre-FEC degrade” signaling based on defined OTN mapper



Interoperable Metro Line-side Interfaces

- New 100G DP-DQPSK Application Codes (G.698.2) under development
  - More detail in companion presentation by Fabio Pittala
  - Appropriate for 200-450km distances, for 3-4 OADMs, not precluding 6-7 OADMs
    - Originally envisioned application for carrying OTU4 using stronger (~9dB) hard decision FEC – G.709.2
    - With advent of FlexO for the client side, it becomes attractive to carry OTUCn over n instances of this application code (n single-channel interfaces into an OTN line system) – G.709.3
  - Agreed to specify a 2nd 100G application code, appropriate for 80 km distances, single span, no OADMs, not precluding 120 km and 1 or 2 OADMs
    - Area to investigate – could this link be closed with a lower-latency FEC (e.g., RS(544, 514) rather than a higher-latency 9dB gain FEC?
  - Future 200G and 400G interfaces and applications
    - Exclusively "FlexO" approaches for OTN over these interfaces

G.709.2 – Strong HD FEC for OTU4

Consented February 2018

- Staircase FEC in the same FEC area of the frame as RS(255,239)
- Same bit-rate of 255/227 × 99.5328 Gb/s ±20ppm
- Usable for applications requiring more net coding gain than RS(255,239). Expected to be adequate for the G.698.2 200-450km DP-QPSK 100G application code
- Striping to a 4-lane interface is described. This is how the bits will be mapped onto the phase and polarization of the DP-QPSK symbols by G.698.2.
- The common specification for the standardized Staircase FEC code is in this document – it will be referred to from other places (G.798.3 and OIF 400ZR)
- (RF license available)

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G.709.3 – Flexible OTN long-reach interface

Consented February 2018

- Specifies striping for OTUCn over n 100G OTSi, where each OTSi is a line-side application that can be closed with Staircase FEC
- Similar Frame Format and Alignment Markers as FOIC1.4 for use over 100G Modules
- Uses Staircase FEC on each 100G FOIC1.4
- Nominal bit-rate per 100G is 524366/462961 × 99.5328 Gb/s ±20ppm. This is ~0.8268% higher bit-rate than OTU4-LR described in G.709.2.
- Striping to a 4-lane interface per 100G is described. This is how the bits will be mapped onto the phase and polarization of the DP-QPSK symbols by G.698.2.

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Emerging Hot Topic – 5G Mobile Transport

- Recently Completed GSTR-TN5G - *Transport network support of IMT-2020/5G*, covering SG15's current understanding of the transport network requirements for support of 5G mobile fronthaul, mid-haul, and backhaul networks in both standalone and non-standalone configurations
- Wide range of network operator views about the technologies and approaches they prefer to employ
- Work item to specify how current OTN capabilities can be used to meet the needs of 5G mobile fronthaul, mid-haul and backhaul networks
- Work item to identify the appropriate aspects of frame formats to provide hard isolation between aggregated digital clients, e.g., to support the requirements for network slicing in 5G mobile transport networks