Hot Topics in Optical Transport Networks

OFC2019

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Scope of OTN Standardization

WP3 – Digital Layer Aspects

Q12/15
Architecture, SDN Control
G.872, G.7702
Control plane restoration

Q11/15
Signal Formats
G.709, G.709.x, G.7041, Circuit Protection Switching

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

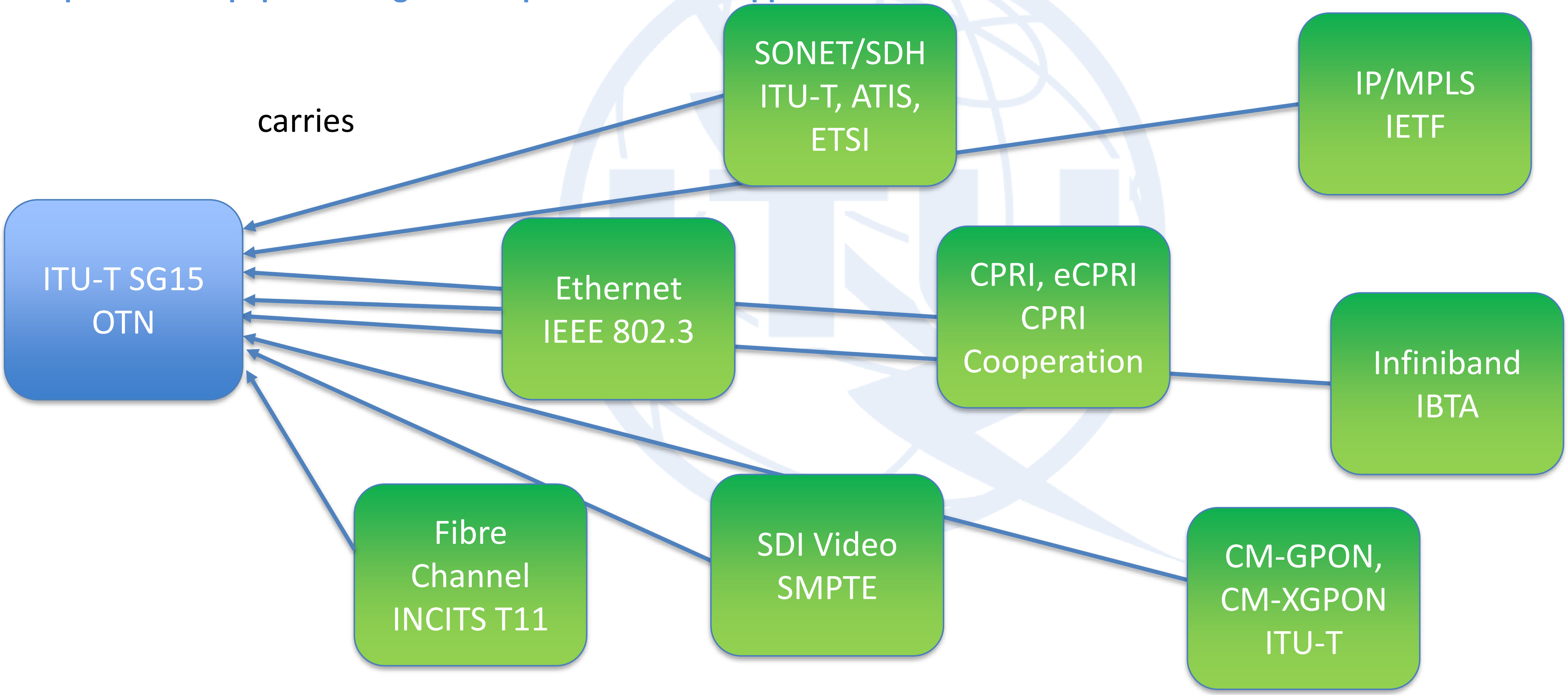
Published Recommendations available for free download at:
https://www.itu.int/ITU-T/recommendations/index.aspx?ser=G

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 (80km point to point, or 200-450km over amplified metro ROADM networks, initially 2.5G and 10G NRZ, recently completed 100G DP-DQPSK. Under development: 200G, 400G
- 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

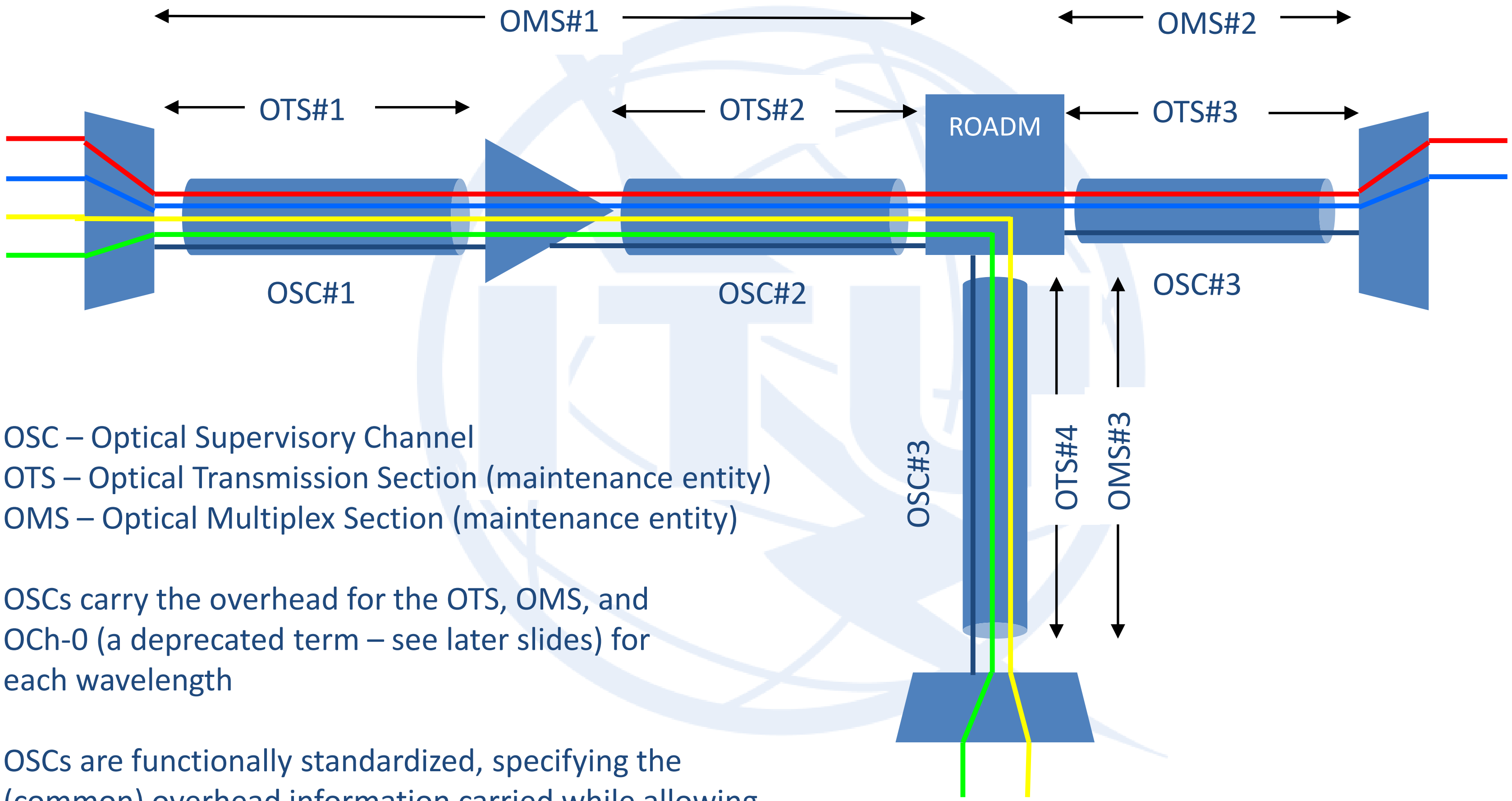
Ecosystem of Services that may be carried as client services over OTN Technology

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

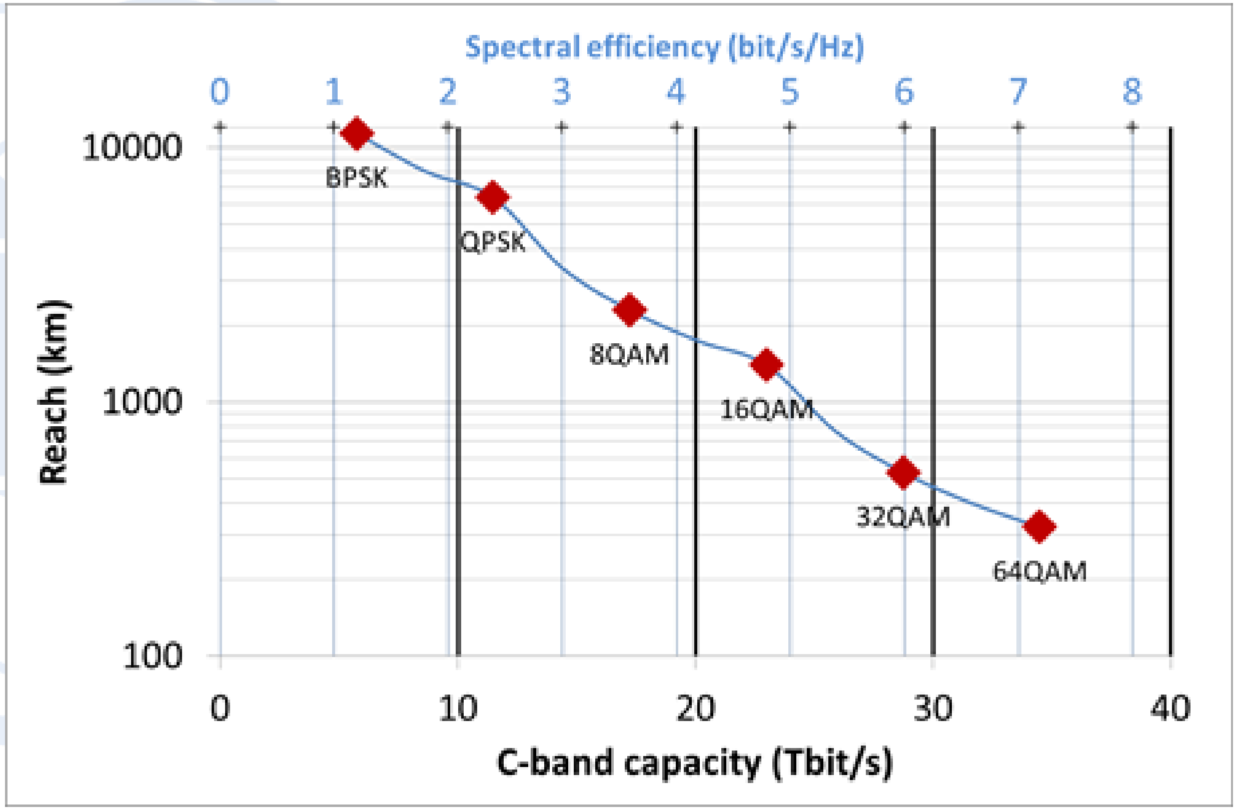
Lambda carrying one client

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

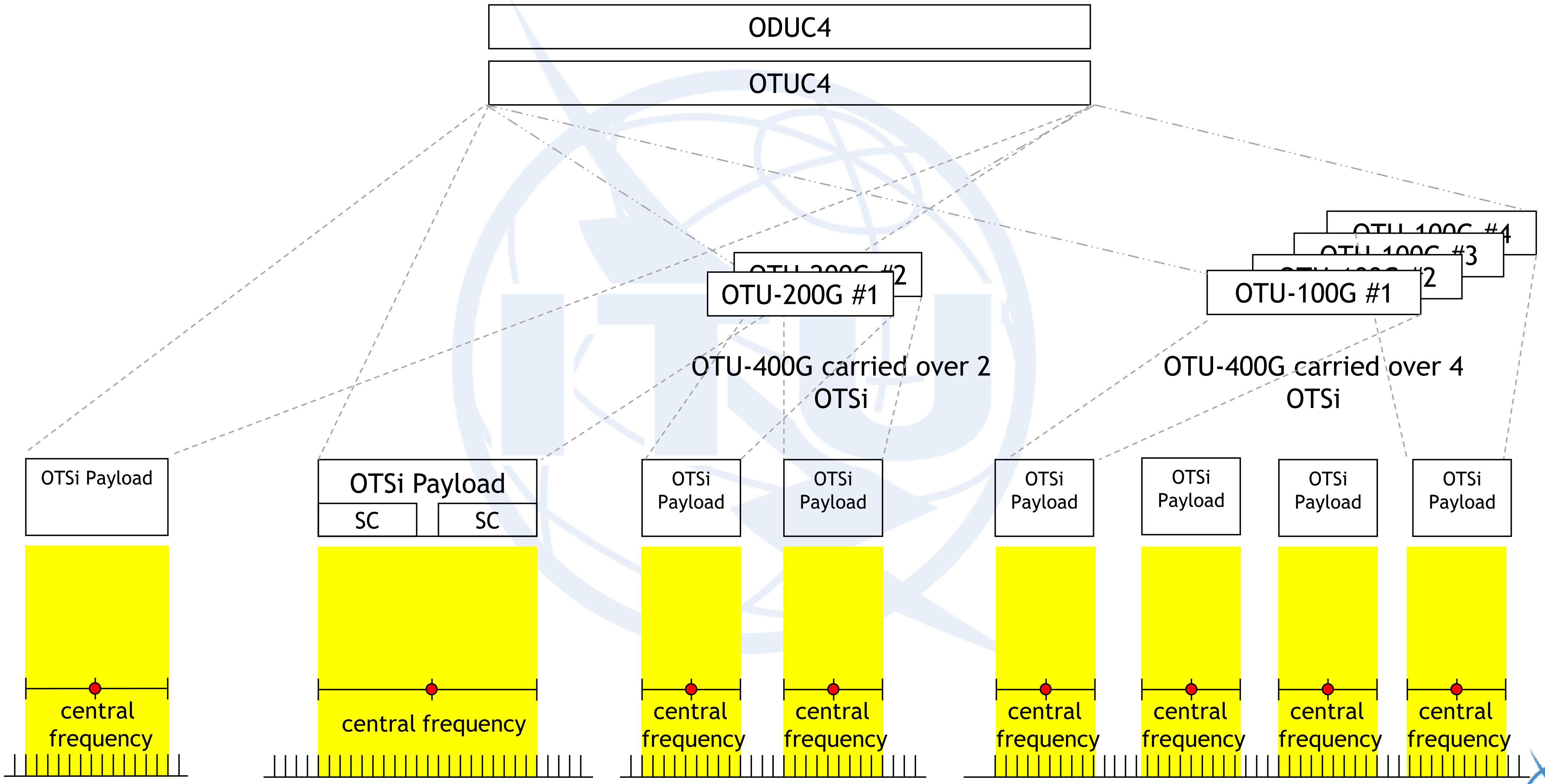
What forces a new evolutionary path beyond 100G?

- 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
- Further rate variability with techniques like probabilistic shaping



Possible 400G Mapping Examples

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

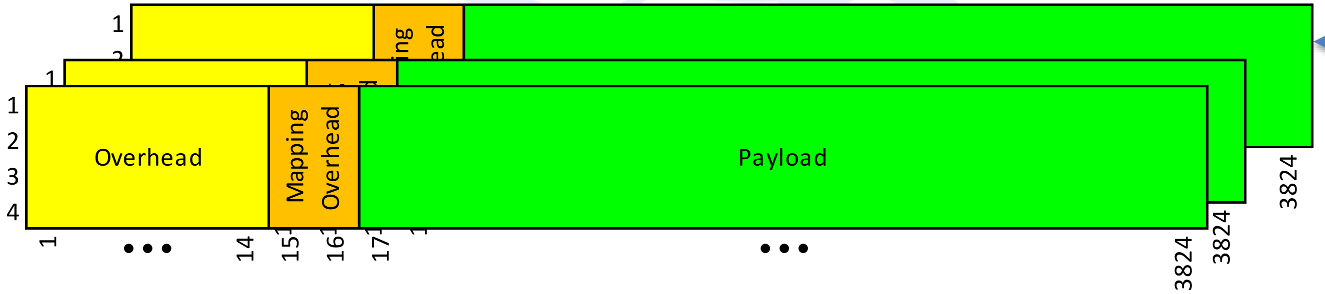


SC: Sub-Carrier, OTSi=Optical Tributary Signal

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

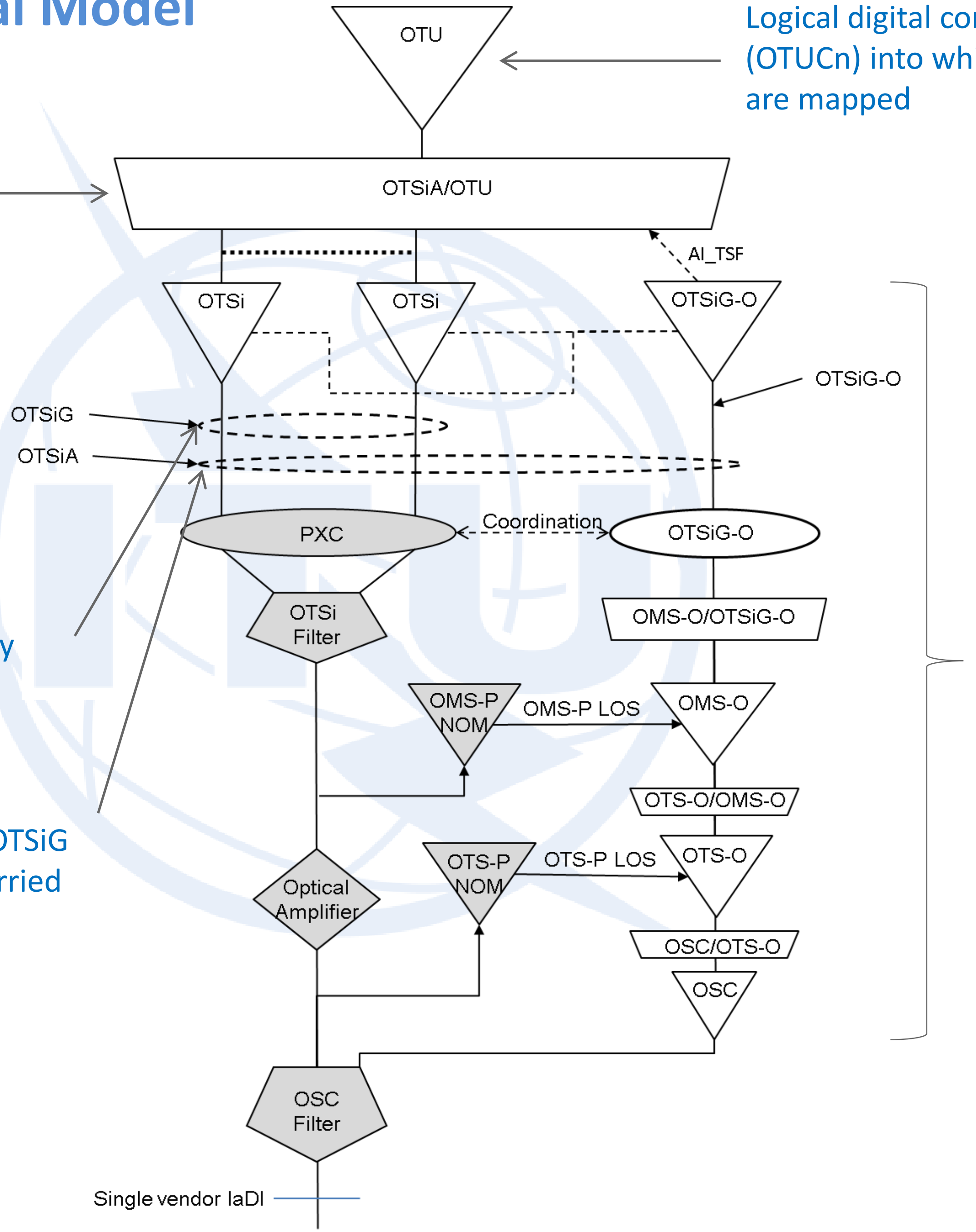
OTN Beyond 100G Functional Model

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

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



Logical digital container (OTUCn) into which clients are mapped

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	

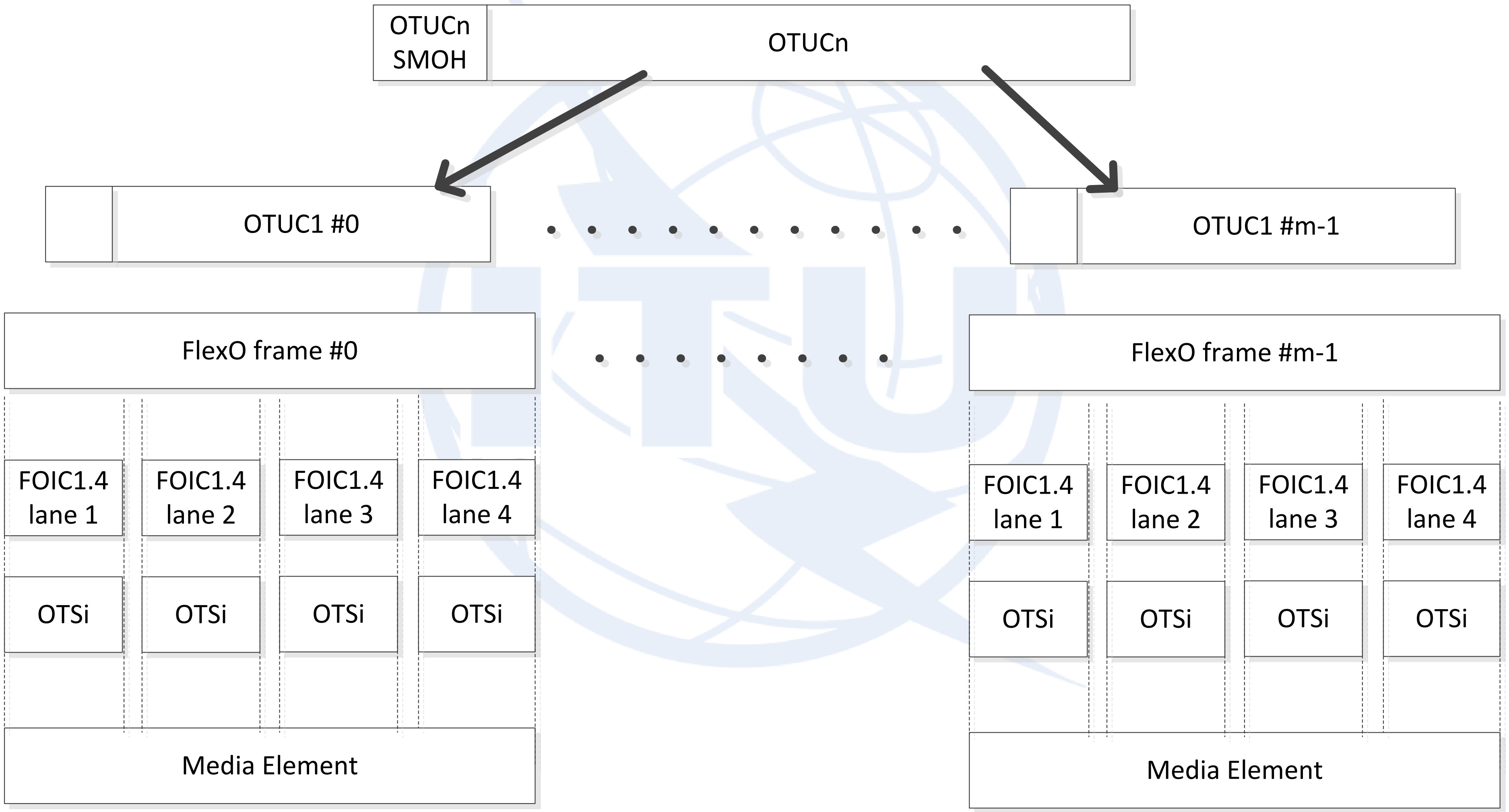
ITU-T has used the completed optical specification from IEEE 802.3 as a basis for how to use the same pluggable modules for OTN client interfaces rather than developing competing or differing optical specifications for similar link types.

G.709.1 FlexO "Short Reach" Interface

- 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 - continued

- Edition 2 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)

Forward Error Correction for point-to-point or metro ROADM network 100 Gb/s DP-DQPSK

- For both 80km point-to-point WDM application codes (wide spectral excursion) and 200-450km amplified metro ROADM network application codes, “Staircase” FEC is standardized
- Royalty free license available
- 6.7% overhead hard-decision FEC (same overhead as GFEC)
- Blockwise recursively encoded 512×510 staircase code, sandwiched between a 30592+2048 bit-wide optimized error decorrelator interleaver and error decorrelator de-interleaver
- Staircase block overs 2 OTU4 or OTUC frames (2×4080×4×8=512×510)
- G.709.2 specifies an OTU4 frame using Staircase FEC over a single G.698.2 100G DP-DQPSK application code wavelength
- G.709.3 (FlexO “long reach”) specifies how to carry OTUCn over n instances of a G.698.2 100G DP-QPSK application code wavelength. Fully specified dis-interleave of OTUCn into OTUC and addition of Staircase code
- G.709.2 frame format with Staircase FEC selected by IEEE P802.3ct Task Force for 100GBASE-ZR interface

Forward Error Correction for point-to-point or metro ROADM network 400 Gb/s DP-16QAM

- For point-to-point (80km) applications, selected CFEC:
  - Same hard decision Staircase outer code as for 100G DP-DQPSK
  - Soft-decision inner Hamming (128,119) code
  - 14.8% FEC overhead
  - 10.8dB NCG for 16QAM using <0.5W decoder
  - Same FEC as selected by OIF for 400ZR and by the IEEE P802.3ct Task Force for 400GBASE-ZR
  - G.709.3 extended to specify FlexO over 200G and 400G application codes under development in Q6 (OTUCn inversely multiplexed over n/2 200G wavelengths or n/4 400G wavelengths)
  - Expected to be appropriate for 80km point-to-point WDM 200G and 400G applications
  - Depending on modulation format, may also be appropriate for 200G metro ROADM network 200-450km applications
  - Royalty free license available

Under discussion – FEC for 400G metro ROADM network 200-450km applications

- Still expected to use DP-16QAM modulation at around 60Gbaud
- Require FEC NCG of 11.4-11.6dB (more than CFEC), achievable with a 1.3-1.5W decoder
- Three proposals under consideration. Detailed evaluation underway. Proponents expected to provide executable reference encoders and decoders to allow for multiple parties to judge whether the performance claims can be met:
  - "CFEC+" – same encoder ("bits on the wire") as CFEC with an enhanced iterative decoder
  - OFEC
  - TPC

ITU