OTN 3.0 enabling beyond 100G optical transport

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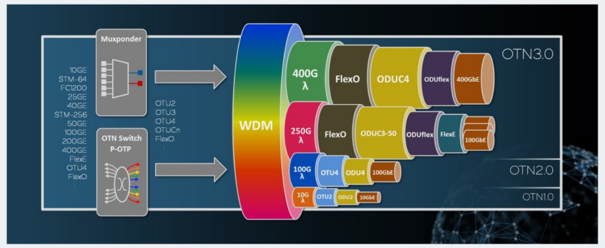
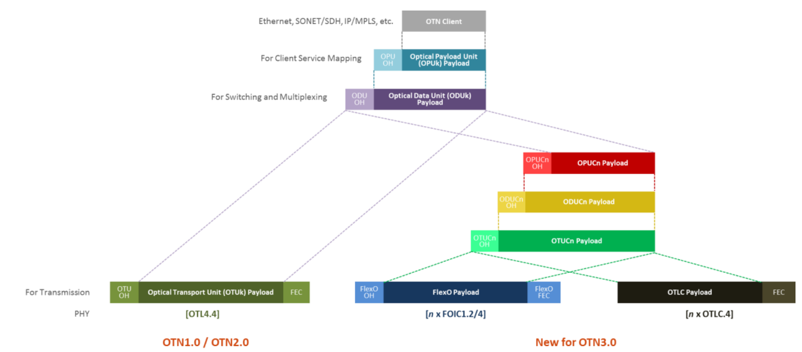
The **Optical Transport Network (OTN)** defined in ITU-T G.709 is the default protocol that underpins today's DWDM packet optical transport networks. Two generations of OTN have already been widely deployed: OTN1.0, which was based on 10G WDM transport; and OTN2.0, which enabled the transition to 100G metro OTN switched networks and is the de facto standard in networks today. OTN has proven to be extremely flexible for accommodating new client signals and line rates. However, the transition to next generation OTN transport has needed to account for greater network densification and flexibility. OTN3.0 responds to this by introducing flexible, "beyond 100G" (B100G) optical transport, coupled with support for new services like 25GE, 50GE, 200GE, 400GE, and Flexible Ethernet. With network traffic destined to undergo another wave of growth, optical transport networks will soon be transitioning to OTN3.0.

OTN Bandwidth Management
unlocks full value of b100g networks



Optical Transport Module (OTM)

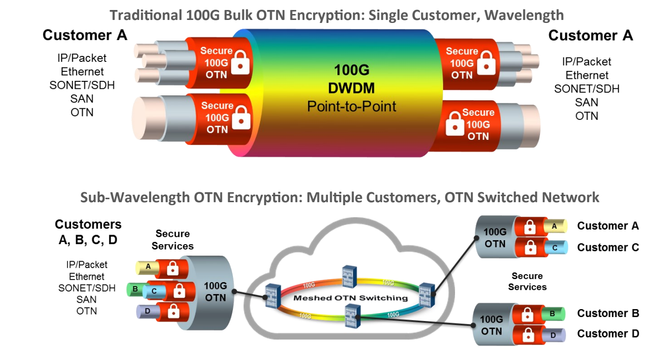


OTN Encryption

OTN encryption encrypts data contained within the existing OTN payload frame (OPUk). Existing reserved bytes within the overhead of the OTN frame carry the authentication tag. The algorithm and authentication modes used vary and are implementation specific; however, AES-256 is a common block cipher with support for both GCM and CTR modes.

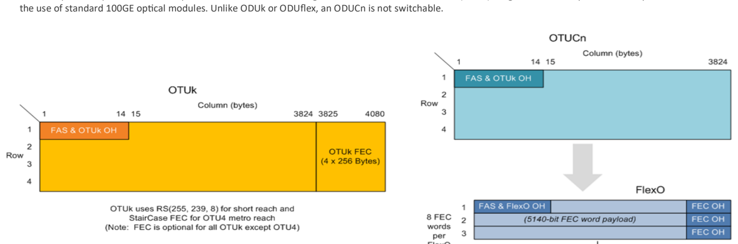
OTN encryption is similar to MACsec in terms of cost, power and complexity to implement while offering low latency at sub-180nsec . As neither the payload nor the frame is padded to facilitate the encryption process, OTN encryption operates at wirespeed and does not come at the expense of wasted bandwidth, unlike IPsec (requiring up to 60% packet size expansion) and MACsec (adds up to 32 bytes/frame).

Microsemi's OTN processors integrate CrypOTN, an AES-256 OTN payload encryption architecture with GMAC authentication solution which is complaint with the FIPS 197 standard. While all OTN encryption solutions perform bulk, High-order (HO), point-to-point network encryption, Microsemi's is the only one in the market that supports both HO and Low-order (LO) – enabling 100G+ metro OTN switching with end-to-end encryption capabilities.



Evolution to OTUCn and FlexO

The B100G family of interfaces, officially referred to as OTUCn, were defined as an $n \times 100$Gbit/s modular structure. Traditionally, standard OTN rates were defined in discrete increments (OTUk) but this system had largely reached its practical limits. OTUCn was needed because until it was defined, the highest OTUk was OTU4. OTUCn allows for 200G, 400G, 600G or higher rate OTUk's. OTUC operates at 105.258 Gbps and an OTUCn is composed of n x OTUC. A client can span multiple OPUCs, thus allowing for the transport of > 100G traffic flows such as 200GE, 400GE, FlexE, etc. OTUCn signals reuse much from the OTUk structure, but also incorporate aspects influenced by IEEE 802.3 Ethernet, including the introduction of flexible OTN (FlexO) for greater flexibility and scalability. FlexO enables client OTN handoffs (IRDI) at > 100G and also allows the use of standard 100GE optical modules. Unlike ODUk or ODUflex, an ODUCn is not switchable.



OTUk uses RS(255, 239, 8) for short reach and StairCase FEC for OTU4 metro reach (Note: FEC is optional for all OTUk except OTU4)

FlexO uses RS(5440, 5140, 10) for short reach and StairCase FEC for metro reach

FEC increases system margin for a given Bit Error Rate (BER) and optical signal power and detects and corrects errors, thereby increasing the signal-to-noise ratio, enabling longer spans.

ITU G.709 defines an RS(255,239,8) code (i.e., a Reed-Solomon using 8-bit symbols) as the base FEC integrated into OTUk frames. It provides 6 dB of coding gain.

For the OTUCn interface, the FEC is independent from the OTUCn frame so that it can be chosen to be optimized for interface type. G.709.1 defines the Flexible OTN (FlexO) short reach interface based on RS(5440,5140,10) FEC (i.e., an RS code using 10-bit symbols). It also provides 6dB of coding gain, but with less overhead than the RS255,239,8). It is compatible with IEEE 802.3 "KP4" FEC.

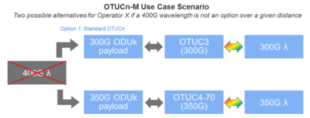
Sub-Rate OTUCn (OTUCn-M)

The distance over which a signal can be transmitted is a function of the signal rate. Power consumption is also a function of the signal clock rate. Consequently, there are applications where it is desirable to transmit a B100G signal at a rate less than the discrete $n \times$ OTUC rate in order to achieve the desired reach for that channel and thereby increasing network utilization and overall network capacity. For such applications, the B100G signal definition includes the option of transmitting a signal that has the full set of OTUCn/ODUCn overhead, but has an OPUCn consisting of only the active Tributary Slots. Specifically, an OTUCn-M signal consists of n copies of the OTUC, ODUC and OPUC overhead, and M of the 5Gbit/s TS. Since the overhead and TS each occupy 16 bytes of a row, and there are 3808/20/16 = 11.9 bytes/TS/row, the minimum OTUCn-M rate can be calculated as follows:

$$\text{OTUCn-M rate} = (\text{OTUCn rate})(\text{OTUCn-M row size}/\text{OTUCn row size})$$
$$= (\text{OTUCn rate})[(16)(n + 11.9M)]/[(16n)(1 + (11.9)(20))]$$
$$\text{OTUCn-M rate} = (\text{OTUCn rate})[(n + 11.9M)]/(239n)$$

As an example, consider a scenario where an operator needs to transmit a signal over a given distance, but cannot support 400G over that distance. Whereas in a standard OTUCn case, that operator is forced to use 300G; with OTUCn-M, it is able to increment that wavelength to 350G, and as such increase its fiber efficiency by 17%. The availability of TS on an OTUCn-M interface are indicated in the OPUCn MSI fields. The specific values of M are a vendor-specific choice. Since OTUCn-M is a single-vendor interconnect application, the specific format of the transmitted signal (e.g., the manner in which the active TS are interleaved into a frame format) are not defined in G.709. Network solutions that enable OTUCn-M include next generation DSPs, working in conjunction with Microsemi's next generation DIGI-G5 OTN processor, capable of right-sizing the optical transmission channel to match the usable capacity of the OTN payload.

OTUCn-M Use Case Scenario
Two possible alternatives for Operator X if a 400G wavelength is not an option over a given distance



OTU Bit Rate Capacity

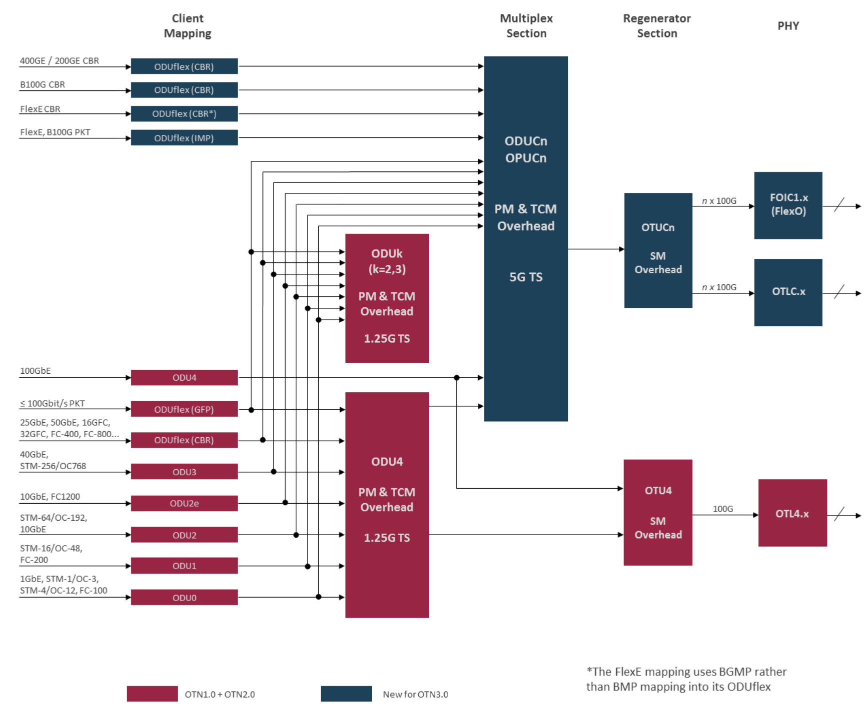
OTU Type	OTU Rate (Gbit/s)	OPU Payload Rate (Gbit/s)	Client Signals	OTU Type	OTU Rate (Gbit/s)	OPU Payload Rate (Gbit/s)	Client Signals
OTU1	2.6661	2.48832	STM-1/OC-3, STM-4-OC-12, STM-16/OC-48, 1GbE, FC-100/200	OTU3	43.018	40.150	40GbE, STM-256/OC-768, IB QDR
OTU2	10.709	9.9953	STM-64/OC-192, FC-400/800, 10GbE WAN, 10GbE LAN (GFP), IB SDR/DDR	OTU4	111.80997	104.35597	100GbE, FlexE
OTU2e	11.095	10.356	10GbE LAN (BMP with fixed stuff), FC-1200	OTUCn*	$n \times 105.258$	$n \times 104.8177$	200GbE, 400GbE

*OTUCn is by design a non-switchable protocol

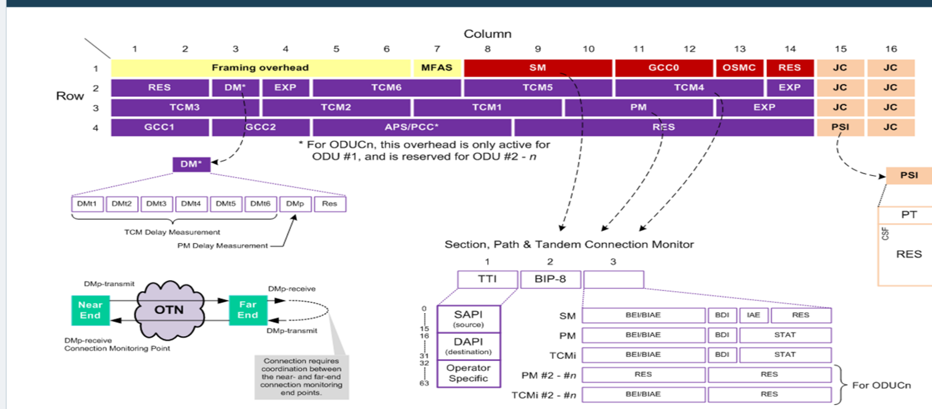
Acronyms

3R	Retiming, reshaping, & regeneration	FAS	Frame Alignment Signal	ITU	International Telecommunications Union	OPUCn	n×100Gbit/s Optical Channel Payload Unit	RS	Reed-Solomon (FEC)
B100G	Beyond 100Gb/s OTN	FC	Fibre Channel	JC	Justification Control	OSC	Optical Supervisory Channel	SAPI	Source Access Point Identifier
BEI	Backward Error Indication	FEC	Forward Error Correction	LAN	Local Area Network	OSMC	OTN Synchronization Message Channel	SAN	Storage Area Network
BER	Bit Error Rate	FlexE	Flexible Ethernet (from OIF)	LO	Low order encryption	OTM	Optical Transport Module	SDH	Synchronous Digital Hierarchy
BIAE	Backward Incoming Alignment Error	FlexO	Flexible OTN (G.709.1)	MFAS	Multi Frame Alignment Signal	OTS	Optical Transmission Section	SONET	Synchronous Optical Network
BIP-8	8-bit Bit-Interleaved Parity	GCC	General Communication Channel	MPLS	Multi-Protocol Label Switching	OTSiG	Optical Tributary Signal Group	SM	Section Monitor
BMP	Bit-synchronous Mapping Procedure	GFP	Generic Framing Procedure	OAM	Operations, admin & maintenance	OTU	Optical Channel Transport Unit	STAT	Status
CBR	Constant Bit Rate	G.HAO	Hitless Adjustment of ODUflex	OC	Optical Carrier	OTUC	100Gbit/s element (slice) of an OTUCn	STM	Synchronous Transport Module
CM	Connection Monitor	GMP	Generic Mapping Procedure	OCh	Optical channel with full functionality	PKT	Packet Signal	TCM	Tandem Connection Monitoring
CSF	Client Signal Fail	HO	High order encryption	ODU	Optical Channel Data Unit	PMON	Performance Monitoring	TS	Tributary Slots
DAPI	Destination Access Point Identifier	IB	Infiniband	OH	Overhead	PT	Payload Type	TTI	Trail Trace Identifier
DM	Delay Measurement	IMP	Idle Mapping Procedure	OMS	Optical Multiplex Section	RES	Reserved	UNI	User-Network Interface
EXP	Experimental	IP	Internet Protocol	OPUC	100Gbit/s element (slice) of an OPUCn	ROADM	Reconfigurable Optical Add/Drop Multiplexer	WAN	Wide Area Network

OTN Client Mapping & Multiplex Hierarchy



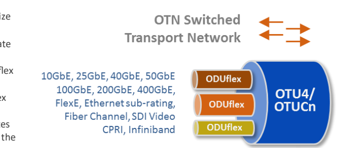
OTN B100G Overhead Structures



Maximize Network Efficiency with OTN

OTN offers optimal network utilization with the ability to right-size the bandwidth of all services carried over the network

- Clients are mapped into an OPUk or OPUflex by the appropriate mapping protocol such as BMP, GMP, GFP, or IMP
- Overhead is added to the OPUk or OPUflex to create an ODUflex
- The ODUflex can vary by increments of:
  - 1.25G, which are used for efficient mapping into ODUflex with payload rates ≤100G
  - 5G, which are used for mapping clients with payload rates >100G into an ODUflex in order to simplify multiplexing the resulting ODUflex into ODUCn
- Providers can limit the bandwidth of each client entering their network per the SLA to the desired amount with 1.25G/5G granularity

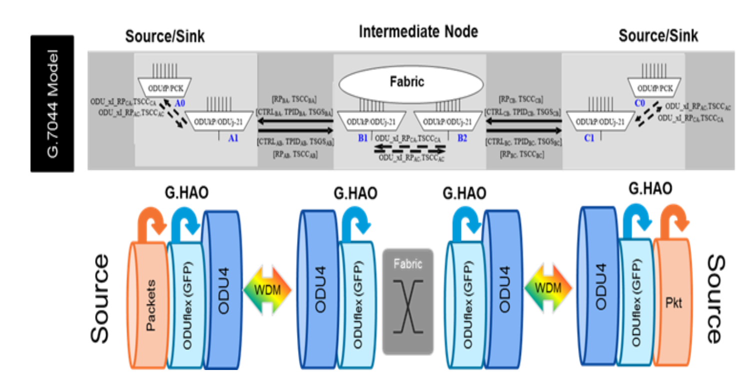


ODUflex containers can transport a wide variety of multi-rate clients

OTN3.0 WHITE PAPER

the evolution of itu-t g.709 optical transport networks (otn) beyond 100gbit/s

Optical Bandwidth-on-Demand (BoD) with G.HAO



Hitless Adjustment of ODUflex (G.HAO), specified by the ITU-T G.7044 standard, is a resizing mechanism that allows for on-demand scaling of ODUflex client data rate without affecting the integrity of existing traffic across an end-to-end connection path in an OTN transport network. Source nodes are the demarcation point for the G.HAO service – these nodes GFP-F map/de-map packet traffic to and from ODUflex containers and initiate the bandwidth increase/decrease for the end-to-end connection. Intermediate nodes track changes in the ODUflex rate at any point downstream in the connection path.

With G.HAO, Service Providers can offer a targeted on-demand, 'pay-as-you-grow' service that delivers the same quality of service, regardless of bandwidth required. Microsemi's DIGI Family of OTN Processors are the industry's only G.HAO solution, with three generations of carrier-qualified software/firmware.

MICROSEMI'S
OTN PROCESSOR FAMILY

The DIGI-G5 is Microsemi's 5th Gen OTN Processor. Built for the Cloud and 5G data transport era, the DIGI-G5 is the industry's first 16nm single-chip 600G Flexible Ethernet (FlexE) and Packet-Optimized OTN Processor.