Passive Optical Networks in Particle Physics

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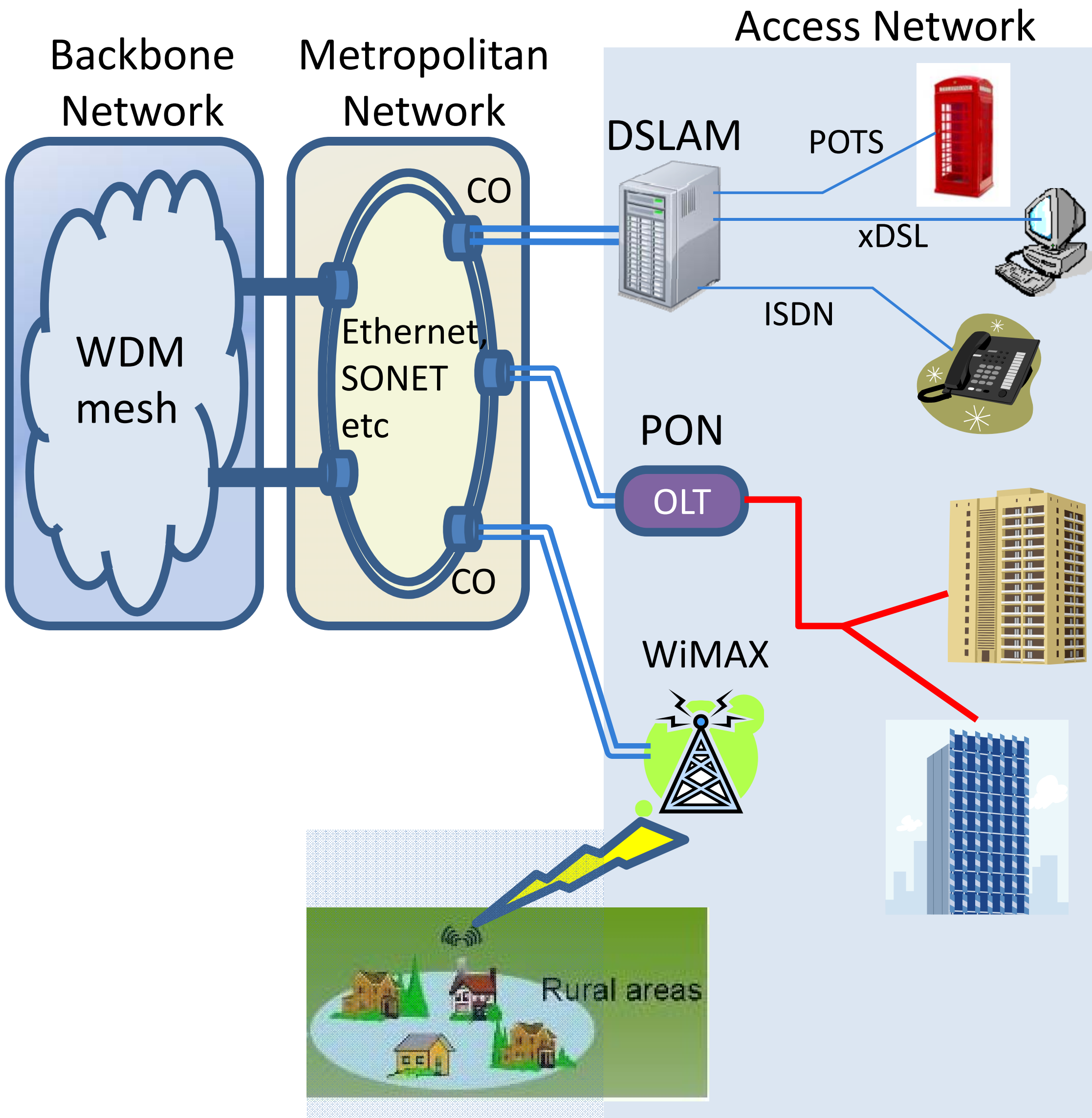
- Definition of TDMA PON systems
- PON systems in TTC systems
- PON Protocols: EPON vs GPON
- Resource Protection in PONs
- Optical Components
- WDM PONs
- Future PON architectures for enhancing fiber bandwidth utilization

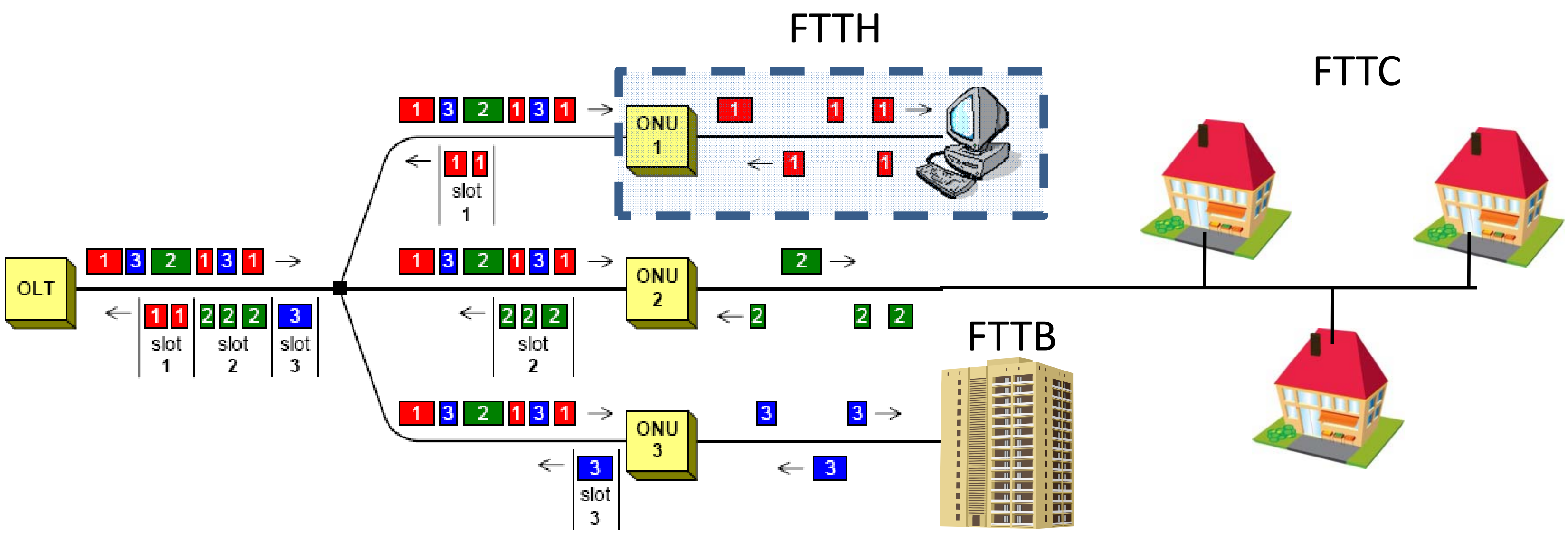
Existing Access Networks

- Access Networks are the last segment connection from COs (central offices) to customers
- They are also called first-last mile networks
- Examples of access networks are:
  - ISDN
  - xDSL
  - WiMAX
  - and most recently PONs…



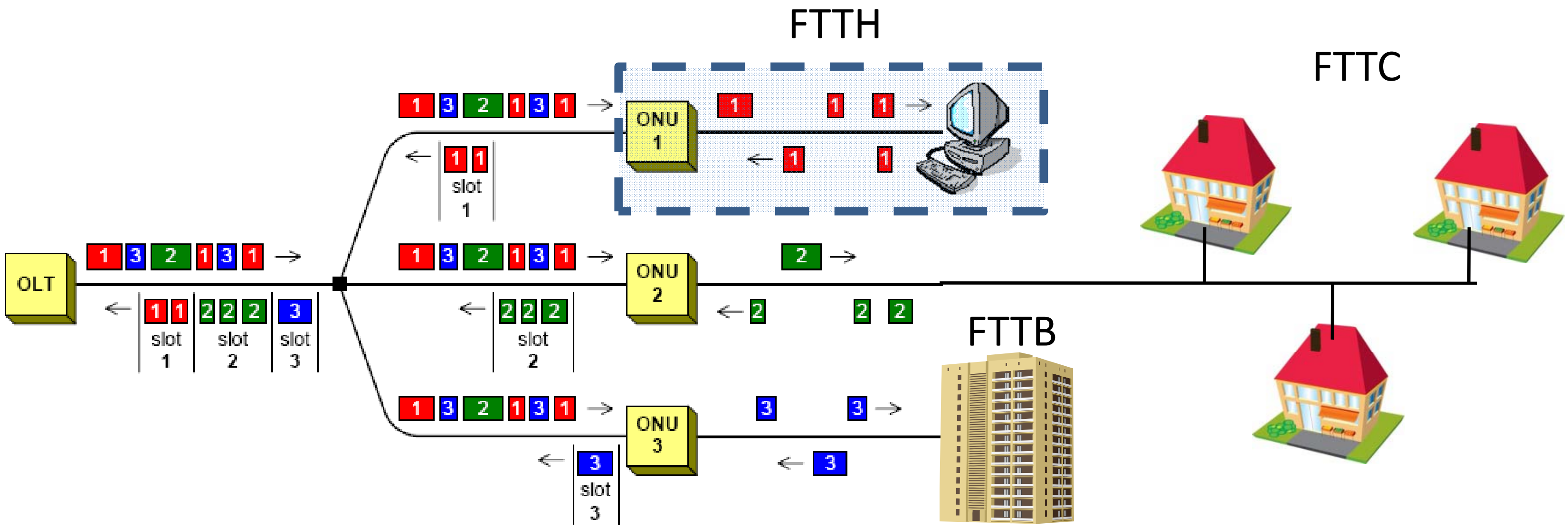
What is a PON?

- PON is a Point-to-MultiPoint (PMP) optical network with no active elements in the signal’s path from the source to the destination
- Data are exchanged between a central node, the Optical Line Terminal (OLT), and a number of end terminals, the Optical Network Units (ONUs)
- According to where ONUs are placed we have different PON versions namely FTTH, FFTC, FFTB etc



General PON Considerations

- In the downstream direction (OLT→ONUs) PON is a broadcast network
- Since there is only one transmitter collisions do not occur downstream
- ONUs are filtering out data not addressed to them
- In the upstream direction (ONUs→OLT) however a number of customers share the same transmission medium
- Some channel arbitration mechanism should exist to avoid collisions and to distribute bandwidth fairly among ONUs
- TDM is the preferred multiplexing scheme in first generation PONs as it is very cost effective. Dynamic Bandwidth Allocation Algorithms are employed for fairness



Where do PONs Fit in Particle Physics Experiments?

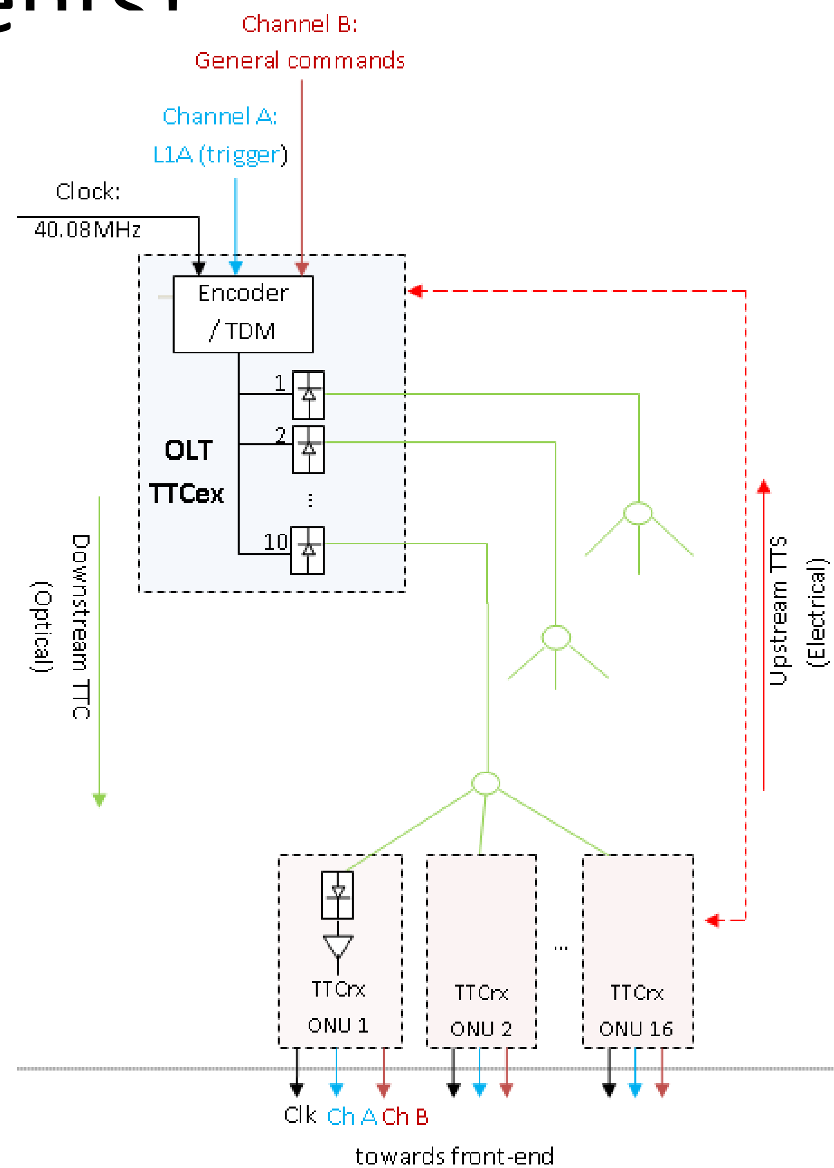
- CMS TTCex Encoder multiplexes L1A (Ch. A) and control data (Ch. B) in time
- A separate electrical link provides TTCex with a “slow control” feedback
- Replacing existing optical network with PONs can bring the following advantages:

a) One TTC system for all experiments (CMS, ATLAS, ALICE etc)

b) One bi-directional link for both downstream and slow control messages

c) No need to come up with communication protocols as advanced PON protocols already exist

d) Safer prediction of components available in the future if we tight research with existing technology



PON Protocols: EPON vs GPON

– Standardized PON protocols
– Physical Layer Comparison
– Bandwidth allocation

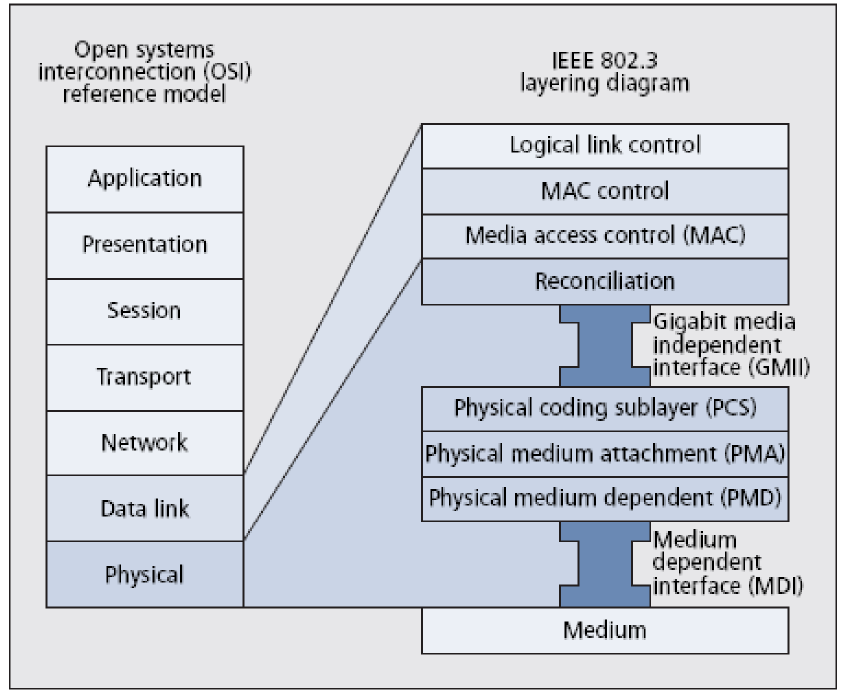
TDMA PON Protocols

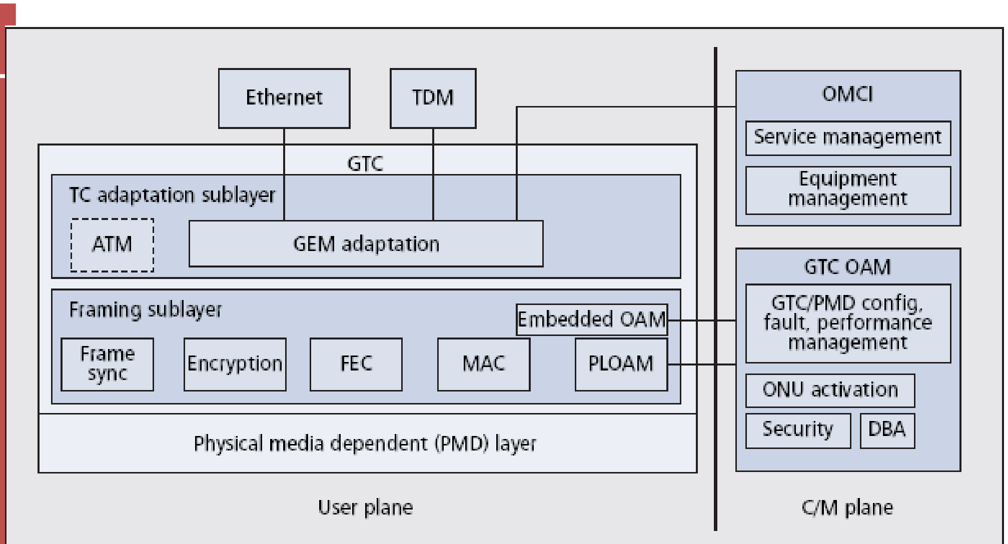
- Broadband-PON (BPON) established by ITU. Work started in 1995, ITU G.983
- Supports ATM frames
- Ethernet PON (E-PON) established by IEEE. Work started in 2001, IEEE 802.3ah
- Supports Ethernet frames
- Giga-bit PON (GPON) established by ITU. Work started in 2001, ITU G.984
- Supports mixed ATM and Ethernet frames through generic framing procedure (ITU G.7041)
- BPON has not found wide acceptance
- In the following we will focus on GPON and EPON

Standard	EPON	BPON	GPON
Framing	Ethernet	ATM	GEM
Max. BW	1 Gb/s	622 Mb/s	2.48 Gb/s
Splitting ratio	16	32	64
Avg. BW / user	60 Mb/s	20 Mb/s	40 Mb/s
Max. Reach	20 km	20 km	20 km

PONs in OSI Architecture

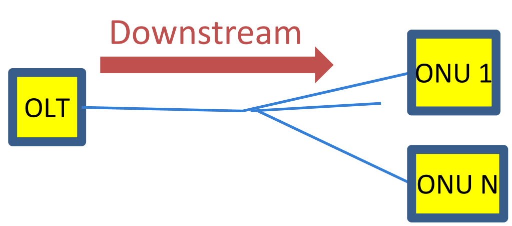
- PONs reside in the last two layers in the OSI architecture namely
- Data link layer which is responsible for the access to the medium and for error correction
- Physical layer which is responsible for transmitting and receiving the information
- In GPON terminology the two layers are called: G-Transmission Convergence (GTC) and Physical Media Dependent (PMD)
- EPON modifies MAC layer to allow for bridging data back to the same port

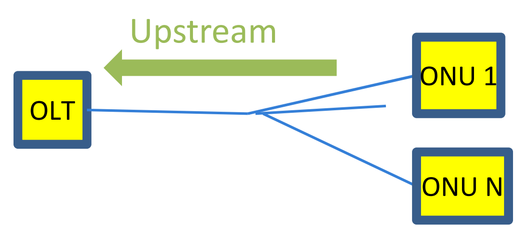




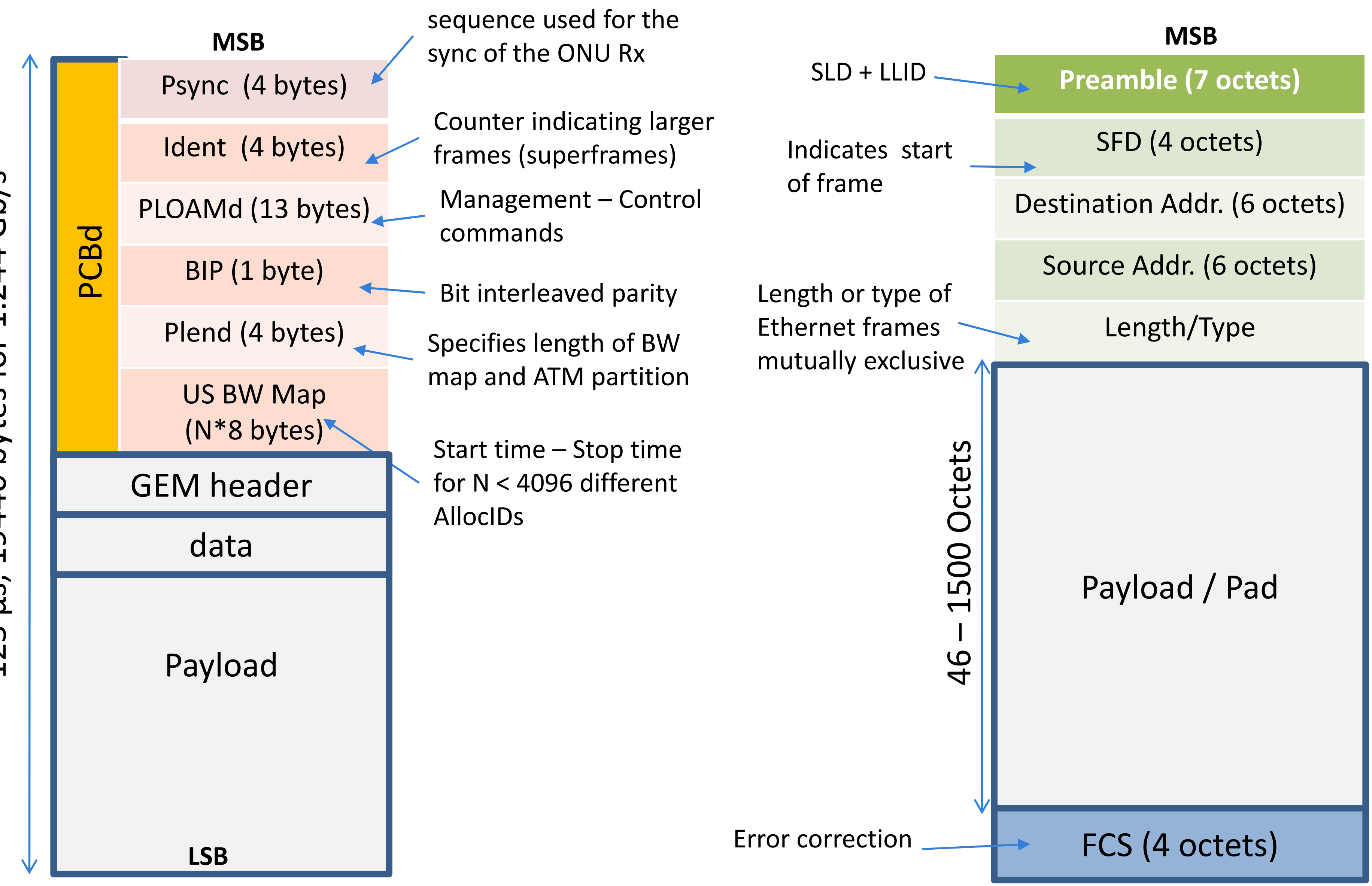
EPON vs GPON Physical Layer

	UNIT	Downstream (GPON)	Downstream (EPON)	Upstream (GPON)	Upstream (EPON)
Bit-rate	Gb/s	1.244/2.48	1	1.244/2.48	1
Wavelength (SF)	nm	1480-1500	1480-1500	1260-1360	1260-1360
Mean Tx Power Min	dBm	-4 A/+1 B/ +5 C	-7	-3 A/ -2 B/ +2 C	-4
Mean Tx Power MAX	dBm	+1 A/ +6 B/ +9 C	2	+2 A/ +3 B/ +7 C	-1
Splitting Ratio		<64	<32	—	—
Max reach	Km	20	20	—	—
Line coding	-	NRZ	NRZ	NRZ	NRZ
Rx Sensitivity	dBm	-25 A/ -25 B/ -26 C	-27	-24 A/ -28 B/ -29 C	-24
Tx On-Off (1 Gbps)	ns	—	—	13	512
Clock recovery /AGC (1 Gbps)	ns	—	—	36	<400





GPON and EPON Frames Downstream

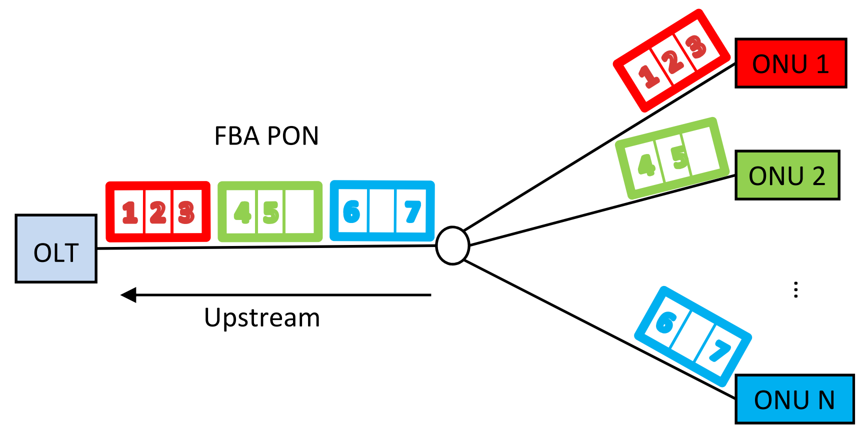


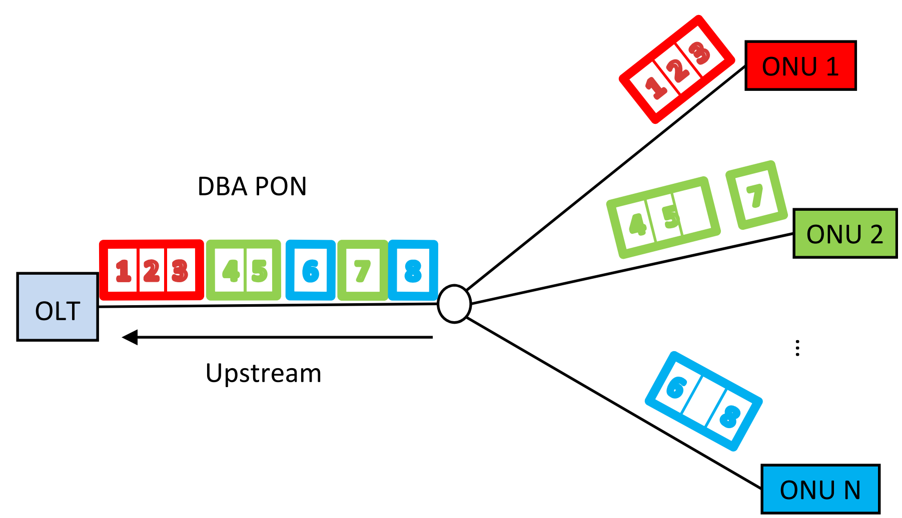
Bandwidth Allocation Schemes

- BW allocation schemes are not part of protocols
- However, both EPONs and GPONs provide with the necessary tools for any allocation algorithm to be implemented
- Two main bw allocation schemes:

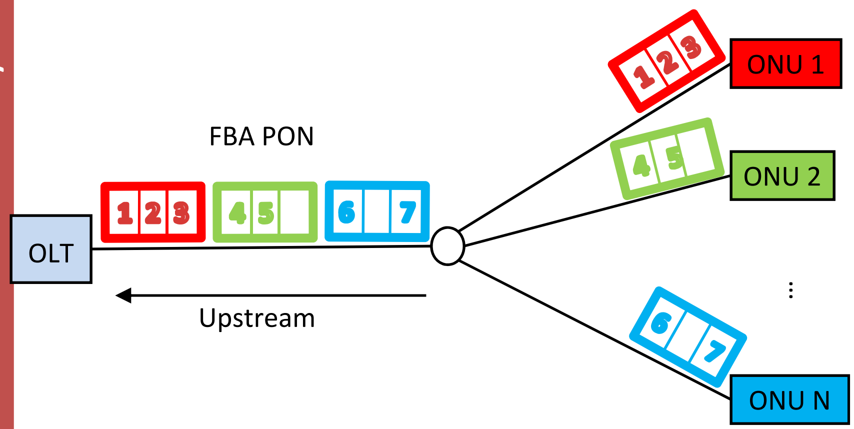
A. Fixed/Static Bandwidth Allocation (FBA)

B. Dynamic Bandwidth Allocation (DBA)



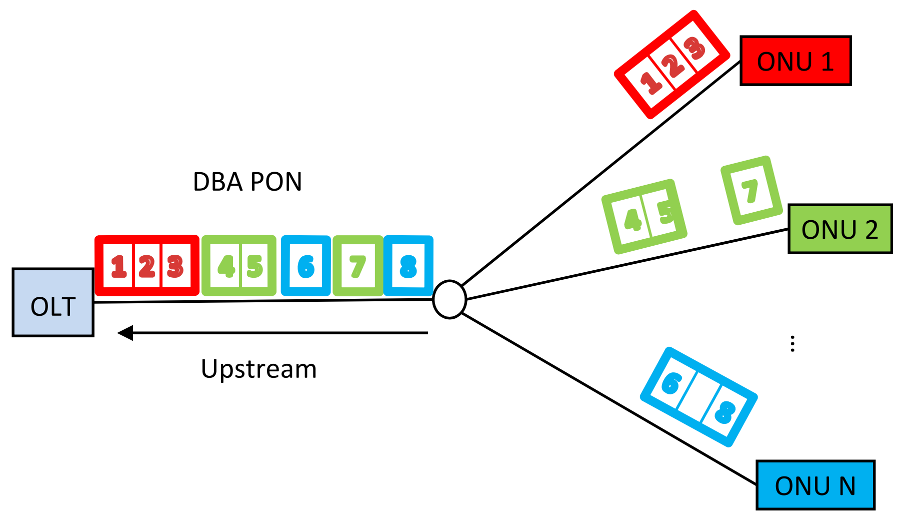


FBA – DBA Comparison



- FBA algorithm is easy to implement
- However, unused bw is wasted
- FBA is not frequently encountered

- DBA can result in high bw utilization efficiency
- It can also run efficiently different classes of service
- However, efficiency is traded with higher complexity at the scheduler



DBA Algorithms

- Requirements for DBA:

a) **Fairness**: Allocates the bw between users fairly

b) **Low delay**: Minimize latency (<1.5 ms for voice channels)

c) **High efficiency**: Can increase the efficiency of the bw (throughput) and increase peak rate

- Fair Queuing Scheduling
- Interleaved Polling with Adaptive Cycle Time (IPACT)

i. Fixed Service
ii. Limited Service
iii. Constant Credit Service
iv. Linear Credit Service
v. Elastic Service

- Deficit Round-Robin Scheduling
- DBA using Multiple Queue Report Set
- etc ..

Summary GPON vs EPON

- GPON is a synchronous protocol while EPON is asynchronous (non-restrictive condition)
- GPON timing mandates are stricter than EPONs
- However, GPON employs power levelling and distance equalization
- GPON management packets are transmitted as part of the header in GEM frames
- EPON uses a separate GATE-REPORT frame approach. In that sense EPON is an offline protocol.
- Both protocols favour centralized architectures where processing is accomplished at OLT
- Both protocols encourage dynamic bandwidth allocation.

PON Resource Protection

- Preplanned Protection
- WDM Protection
- Ring architectures

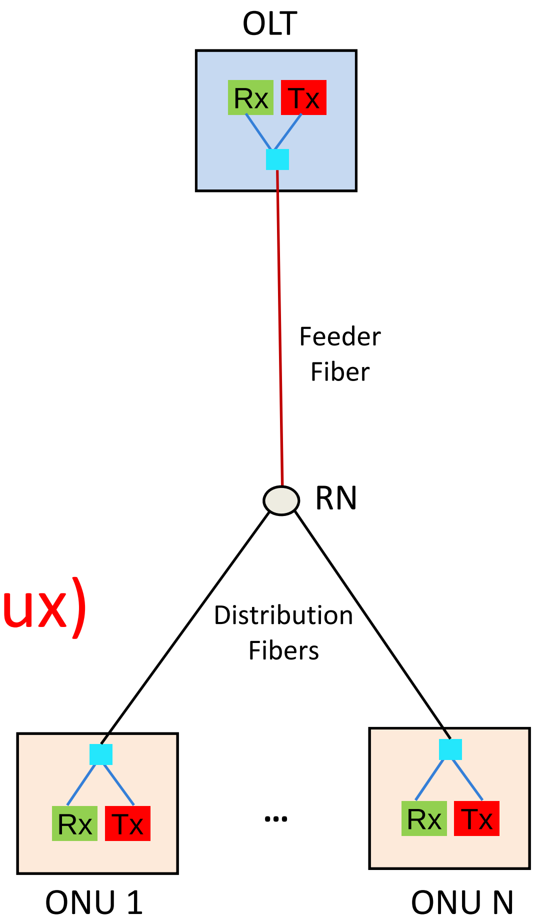
PON Protection

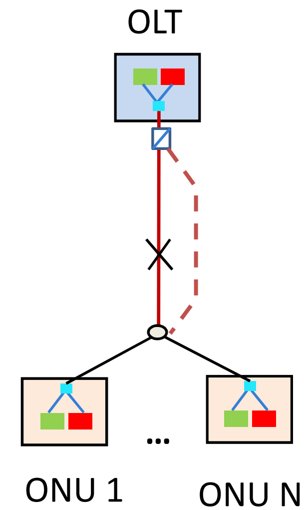
- Resources that require protection:

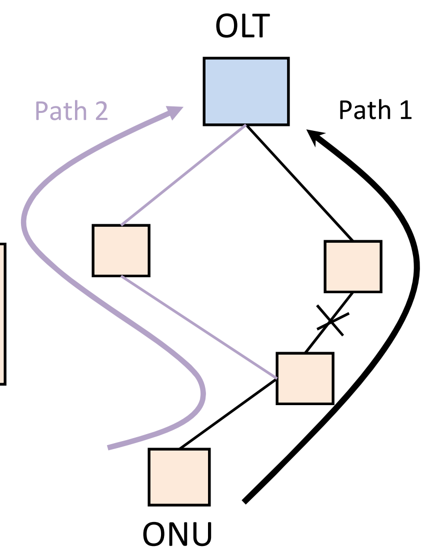
1) Feeder fiber
2) Distribution Fiber
3) OLT Transceiver
4) ONU Transceiver
5) RN (Splitter / WDM Demux)

- Protection Schemes

a) Preplanned Protection
b) Dynamic Restoration







Protection Schemes

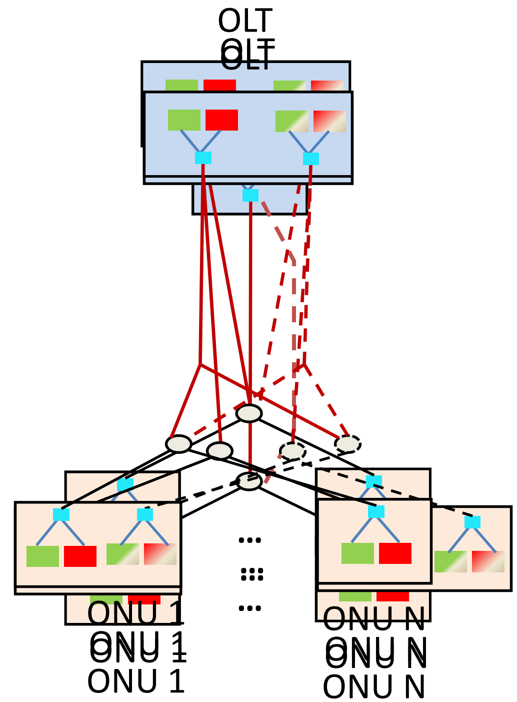
- ITU-T G.983.1 GPON Protocol specifies four protection architectures for PONs

a) Simple feeder fiber architecture

b) Feeder+OLT transceiver

c) Feeder+Distribution+OLT+ONU Transceivers

d) Hybrid protection



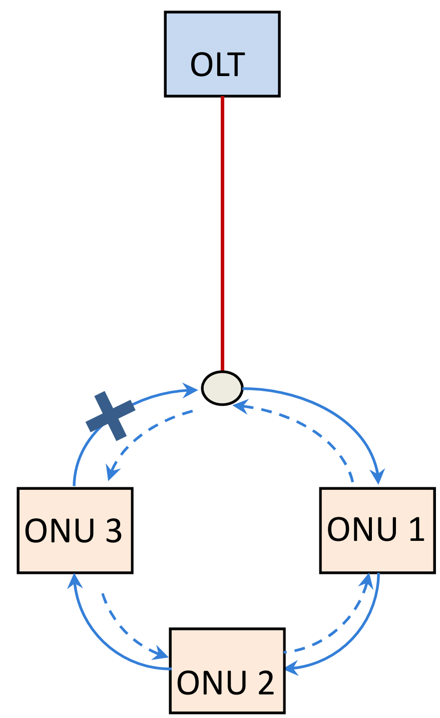
Ring Architectures

- Similar to SONET self-healing rings

a. Two fiber unidirectional

b. Two fiber bi-directional

c. Four fiber bi-directional

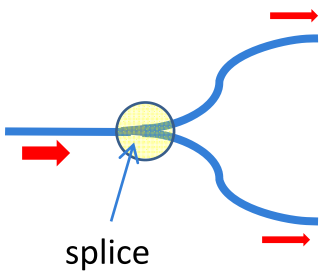


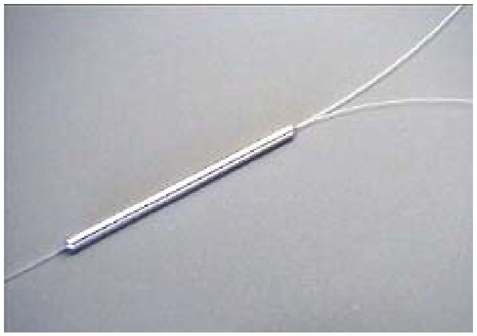
Optical Components

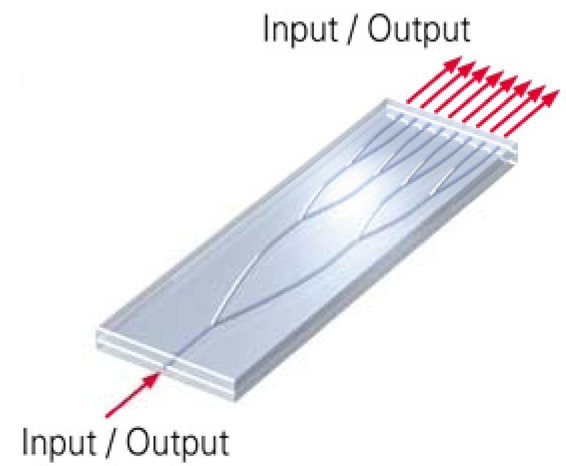
- Optical splitter
- Coarse WDM MUX/DEMUX
- Arrayed Waveguide Grating (AWG)

Optical Components: Splitter

- Two types of splitters are found
1) Traditional bi-conic fused silica splitter
2) Photonic Lightwave Circuit (PLC) splitter
- PLC has the advantage of smaller footprint
- Better alignment with in/out coupled fibers
- Uniform splitting ratio
- Better scalability
- Temperature stability

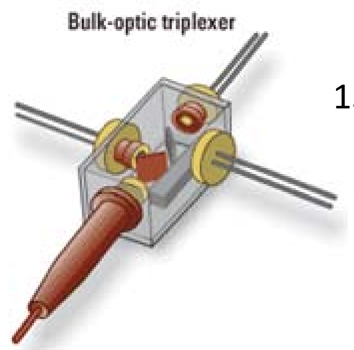


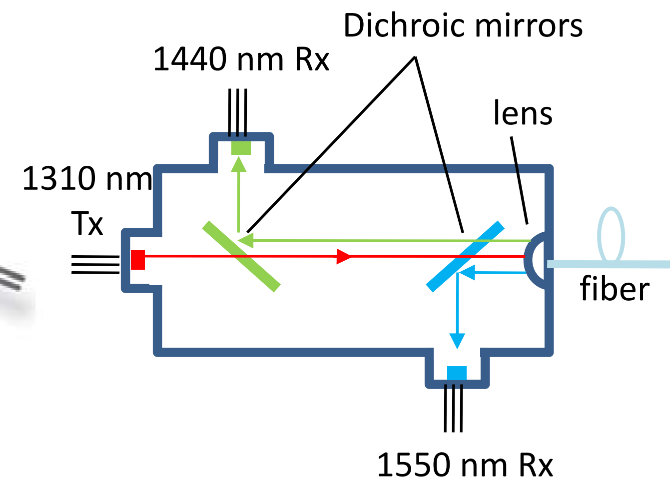


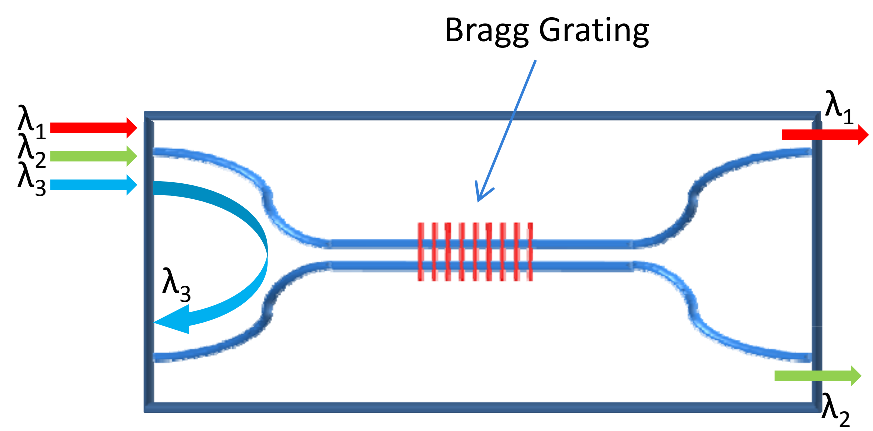


Coarse WDM Multiplexer

- Bulk Optics Assembly packaging
  - Thin film filters
  - Transceivers
  - Fibers and lenses
- Bragg Gratings on PLC
  - Cheaper due to less assembling steps

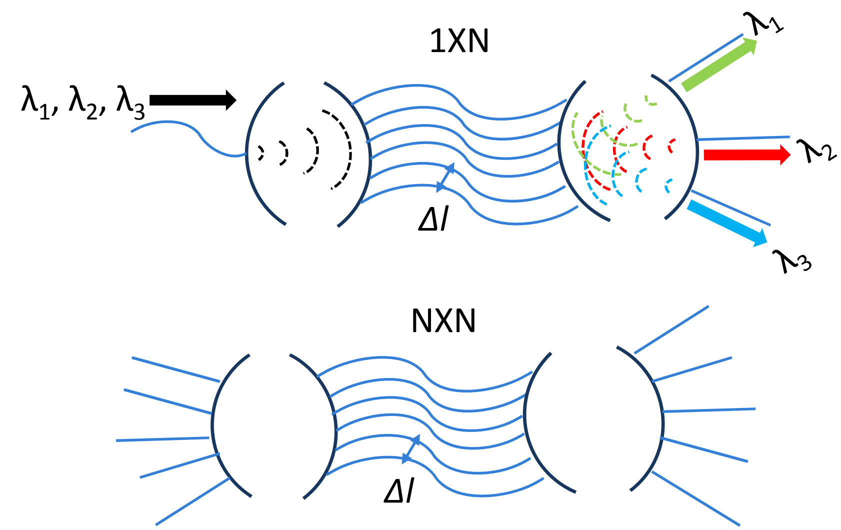


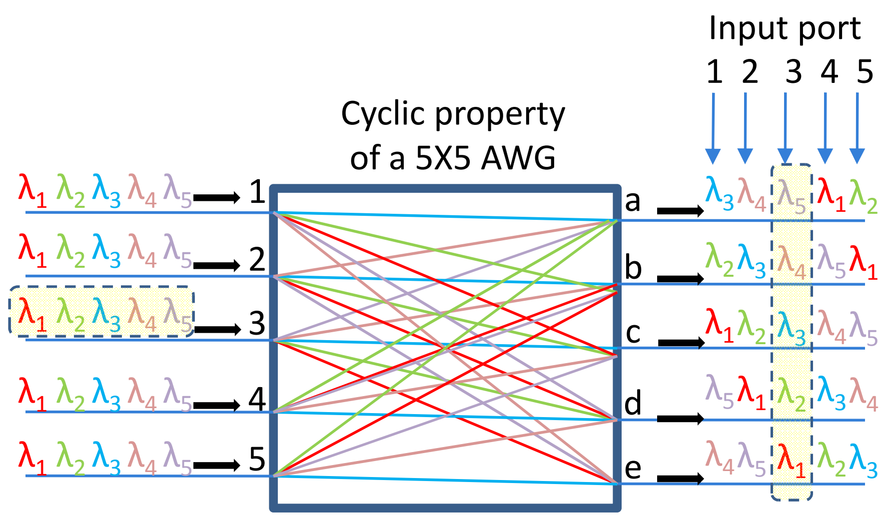




Arrayed Waveguide Grating

- AWGs are compact WDM DEMUX/MUX
- They are the dominant candidate in WDM PONs because
  - They can DEMUX a large number of λ
  - They achieve relatively low cross-talk
  - Athermal versions of the device exist
  - Cyclic property of AWGs can be used in X-switch architectures
  - They can be used in efficient PON protection schemes

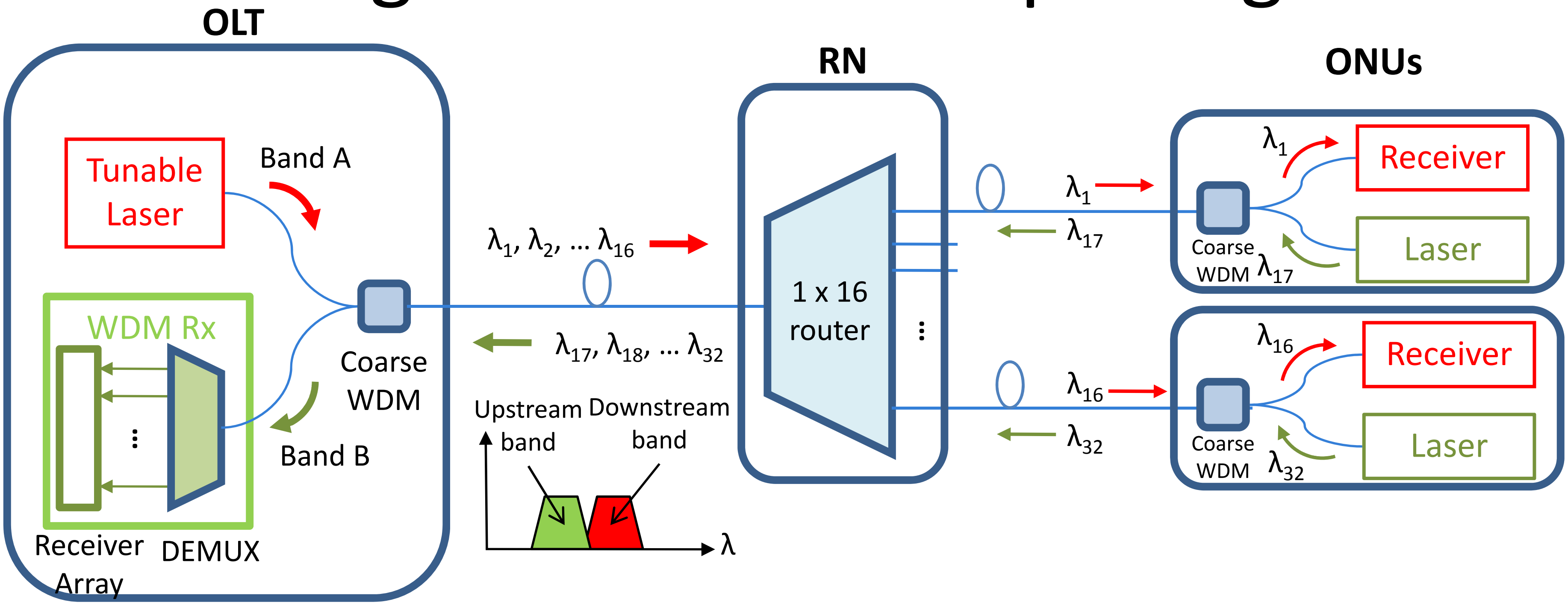




Future PON

- WDM PONs
- Colourless ONUs based on (Reflective Semiconductor Optical Amplifier) RSOAs
- Colourless ONUs with injection locked lasers
- Analogue modulation and OCDMA techniques

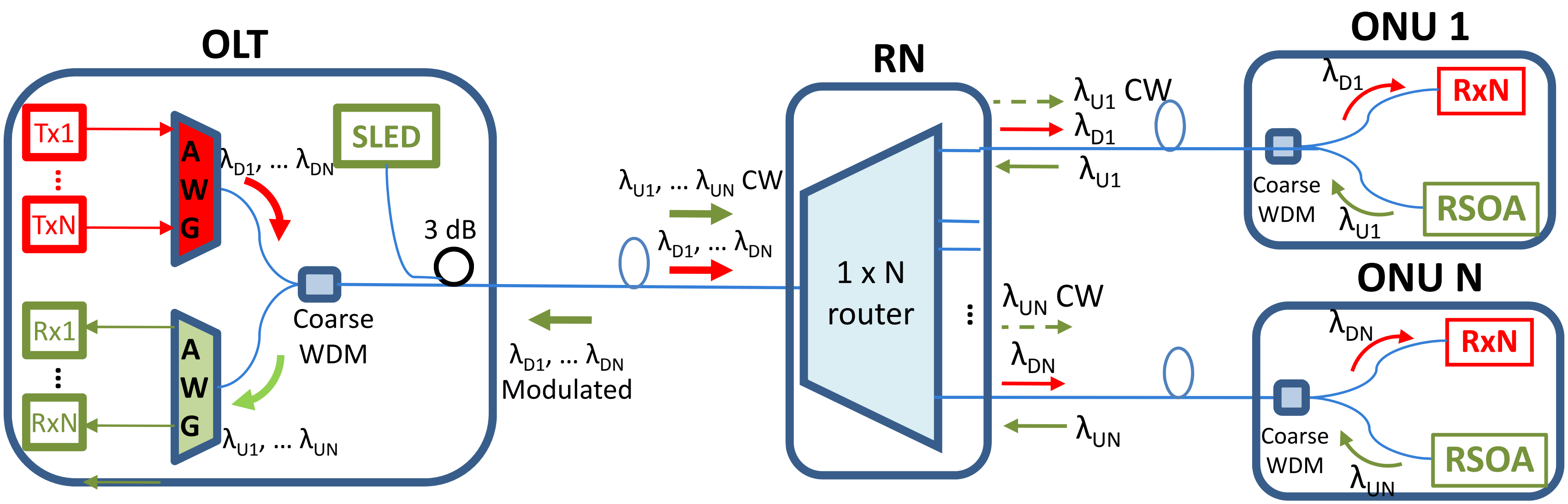
Wavelength Division Multiplexing PON



- In a WDM PON scenario each channel (or channel group) is assigned one wavelength upstream and one downstream for communication with OLT
- Benefits are higher bandwidth per channel, loss is independent from splitting ratio, less complicated scheduling algorithm at OLT, easy expansion, better delivery of services
- Main disadvantage is the need for expensive WDM components such as AWGs, filters, tunable lasers / laser arrays / laser per ONU, broadband receivers etc. Also migration from TDMA PONs to WDM PONs is not straightforward
- "Colorless" WDM PONs are developed to tackle cost issues

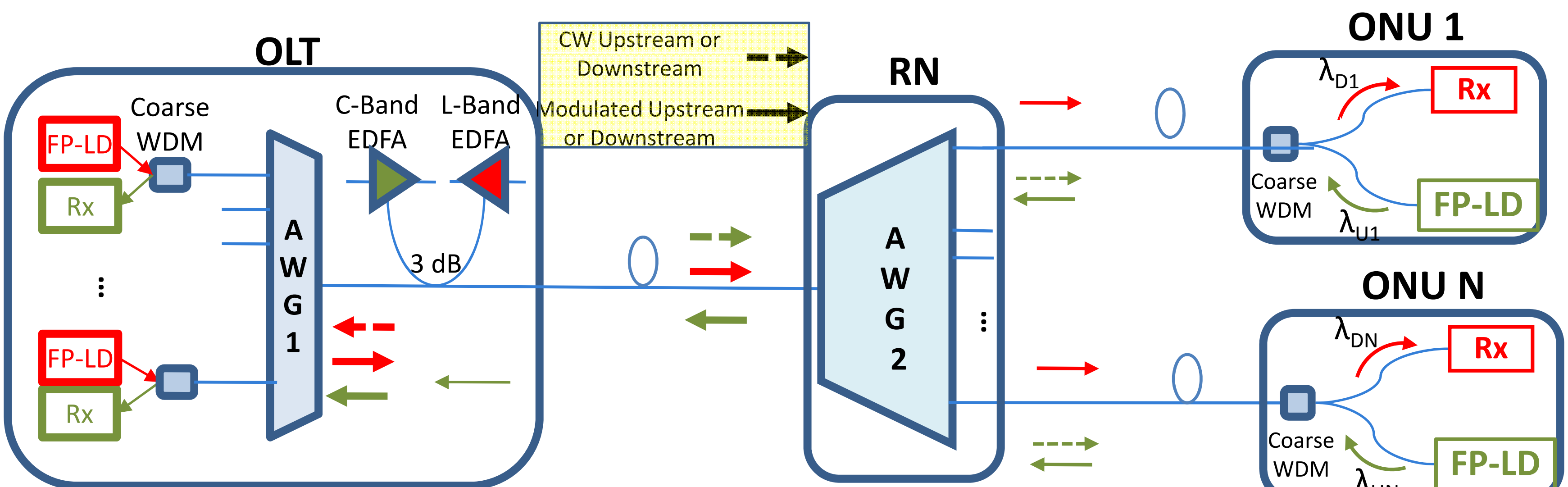
Colorless ONUs based on RSOAs

Externally-Seeded RSOA (Reflective Semiconductor Optical Amplifier) based ONUs at 1.25 Gb/s



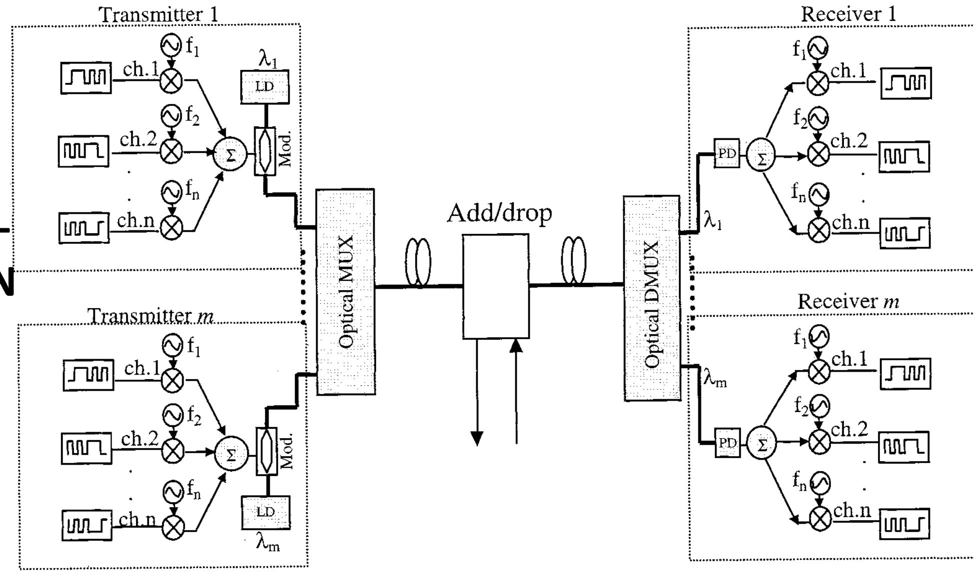
Optically Injection Locked ONUs

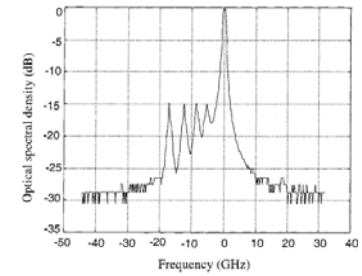
Externally-Seeded Injection Locked FP-LDs.
1.5 Gb/s over 30Km

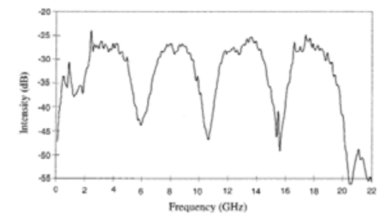


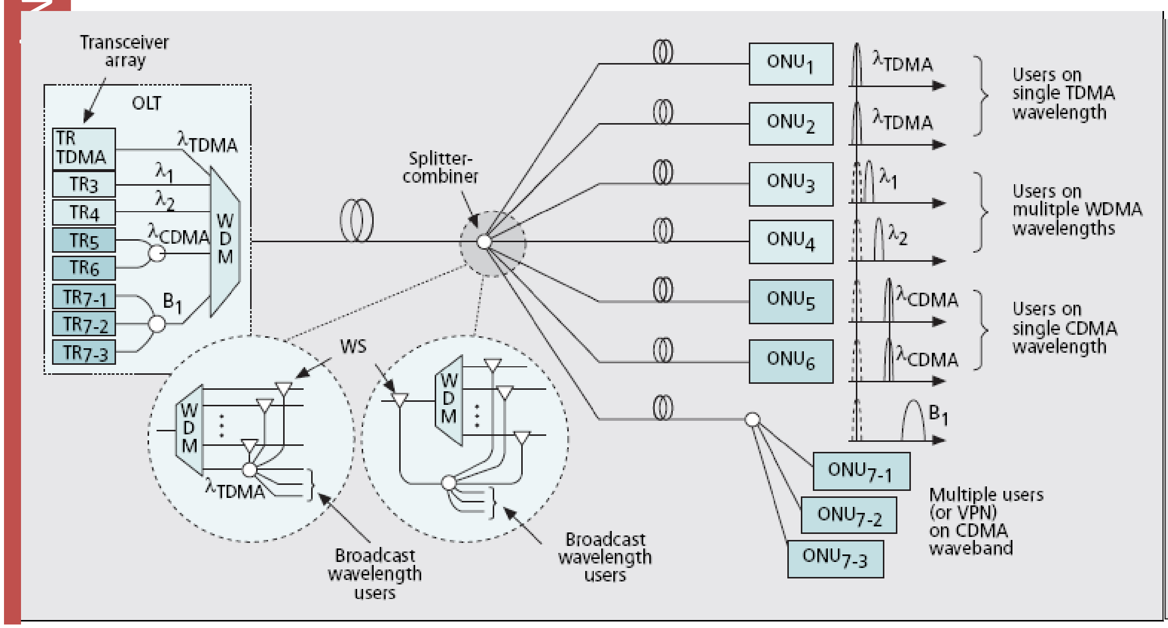
SCM and OCDMA over PONs

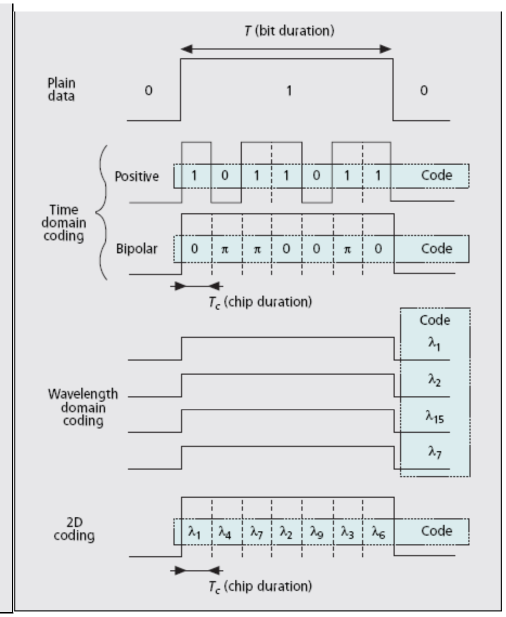
Hybrid WDM-SCM (sub-carrier modulation) PON











Migration scenario with OCDMA (Optical Code Division Multiplexing Access)

General Conclusions

- Passive Optical Networks are evaluated for use in TTC systems
- Both standardized EPON and GPON are capable of delivering TTC signals
- However, EPON is more flexible because:

a) It does not require to run on a synchronous mode (although it can) as GPON does with the 8kHz clock to keep devices synchronized

b) The amount of control message overhead in EPON is variable and can be minimized in contrast to GPON where it is constant

- More work on practical aspects of the protocols is required in order for a final decision to be made …