PIEDMONT SCTE CHAPTER
UNDERSTANDING PON TECHNOLOGIES

November 20th, 2013

AGENDA

1. WHAT IS PON?
2. MULTIPLE WAVELENGTHS (RFOG, 10G PON, EPON/GPON) ON THE SAME FIBER
3. PON TECHNOLOGIES
    1. EPON & 10G EPON,
    2. GPON, XGPON1, NGPON2
    3. Efficiency, Pros, Cons of such technologies
4. DPoE

WHAT IS PON?

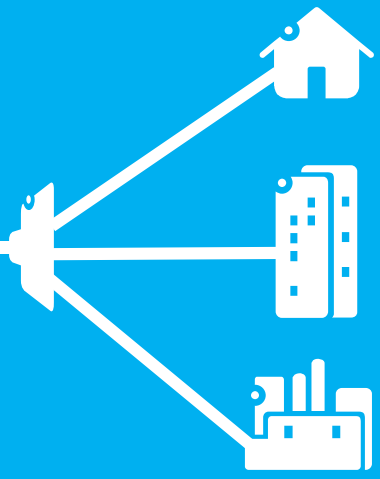
BUILDING HIGH-CAPACITY FIBER NETWORKS

OLT

SPLITTER

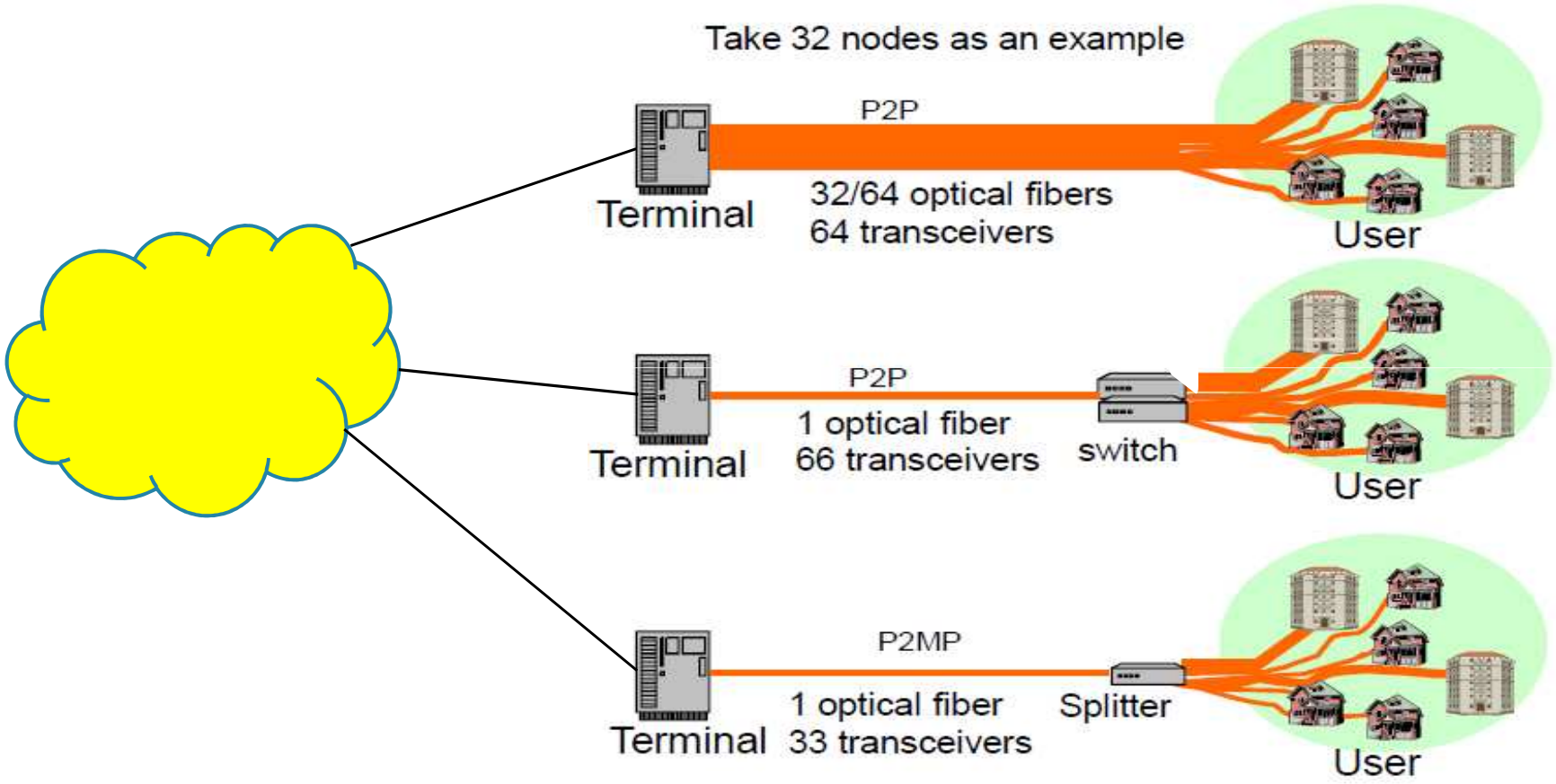
ONT/ONU

- Is a point-to-multipoint, Fiber-to-the-Premises(FTTP) network with unpowered optical splitters
- Typically 16-128 premises on the same fiber.
- It contains 1xPON port, many Optical Network Units which are connected through the Optical Distribution Network (ODN)



- No Active electronic devices between the OLT & ONUs => “Passive Optical Network”

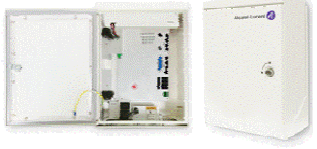
Composition of PON vs P2P Ethernet



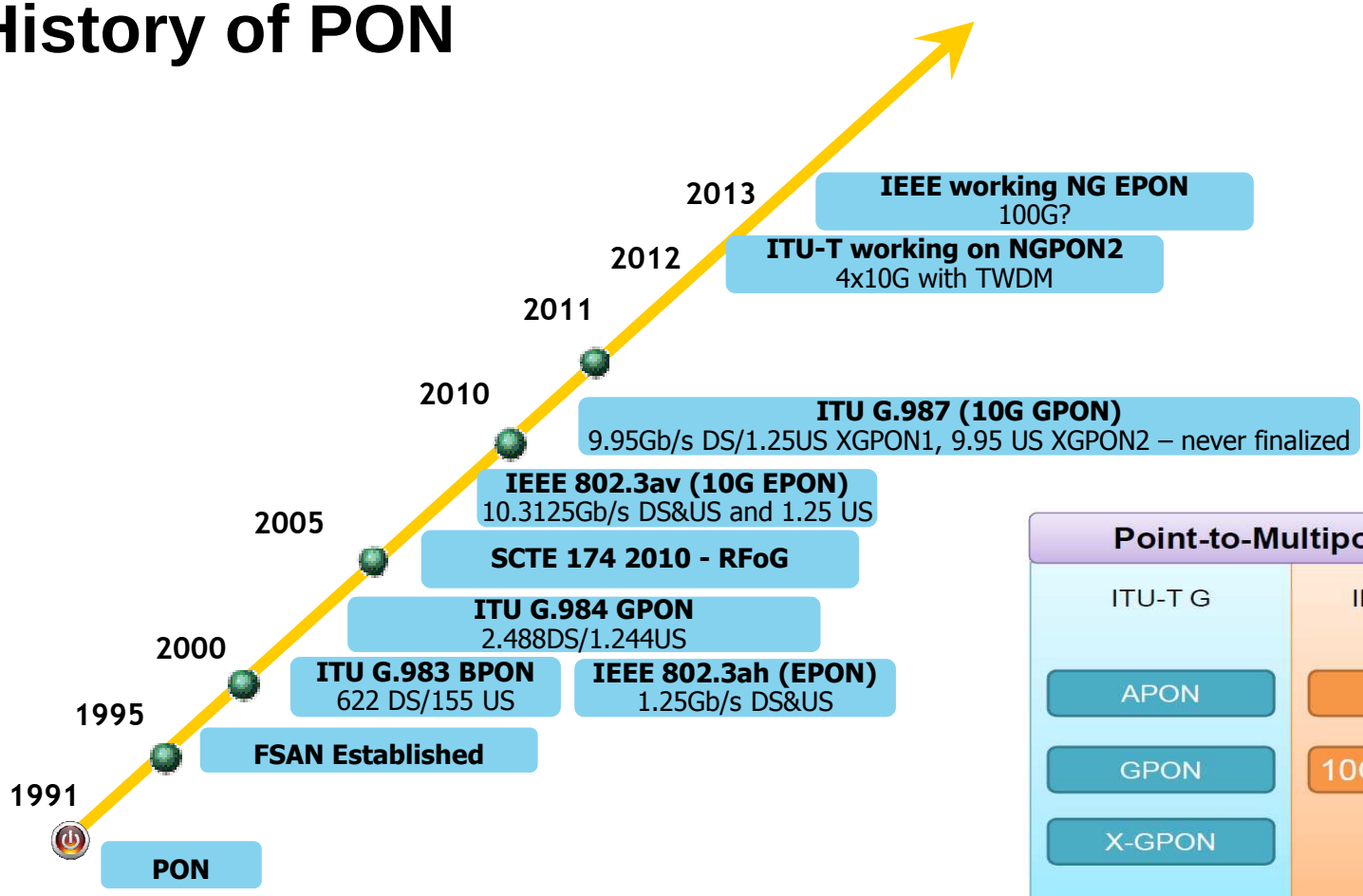
VARIETY OF ONT/ONUS

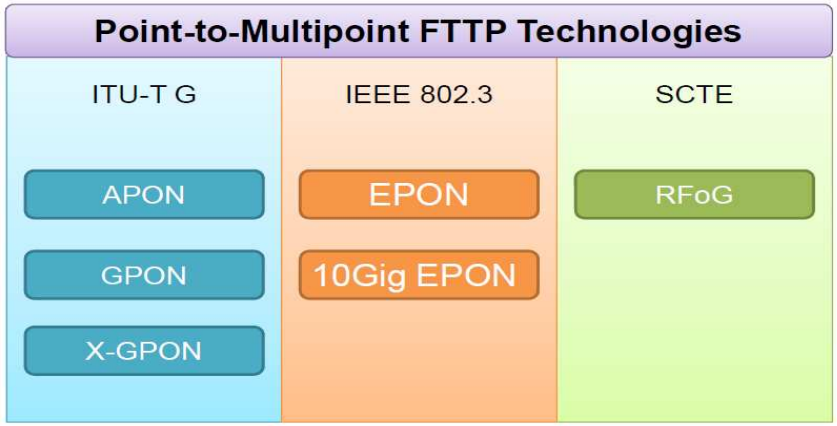
Data only	Voice & Data	Voice/Data/Wireless	Business	Universal Indoor/Outdoor

MDU portfolio



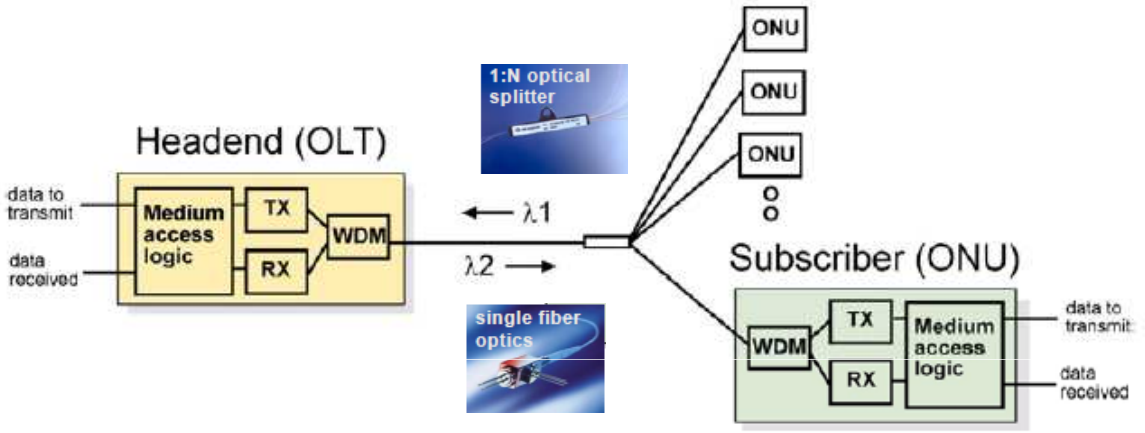
History of PON





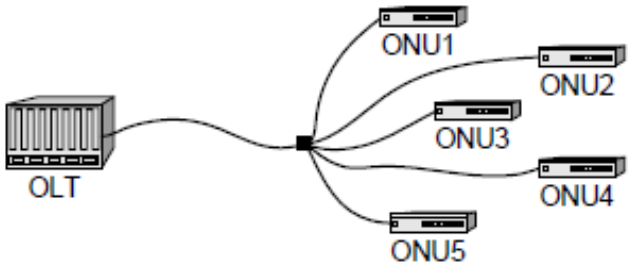
Basic Transmission Mechanism

- PON systems use Wavelength Division Multiplexing (WDM) to achieve transmission of 2 directions (Up and down) in the same fiber)
- If multiple PON technologies (EPON & 10G EPON, or GPON and XGPON or any of those with RFoG) are required to co-exist again WDM technique is used.
- Aside from the WDM technology within the PON itself in the upstream direction Time-Division Multiple Access (TDMA) is also used.
- So in Downstream direction all the packets are broadcasted to all the ONU/ONTs on the PON,
- In Upstream direction, each ONU is given a time-slot that changes dynamically.
- The dynamic allocation of timeslots in upstream provides each ONU to have a certain bandwidth on the line which is controlled by "Dynamic Bandwidth Allocation (DBA)" Engine on the OLT.

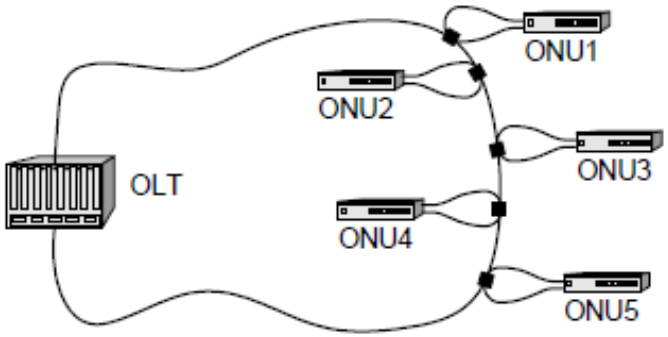


λ_2 =1310nm -1Gbps
=1270nm – 10Gbps
λ_1 =1490nm -1Gbps
=1578nm – 10Gbps

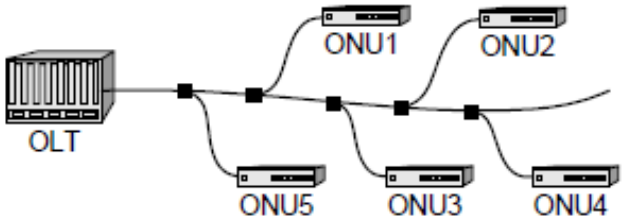
PON Deployment Topologies



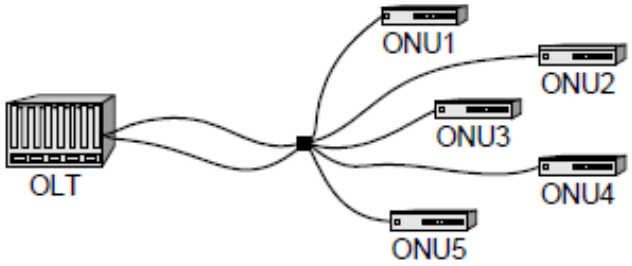
(a) Tree topology (using 1:N splitter)



(c) Ring topology (using 2x2 tap couplers)



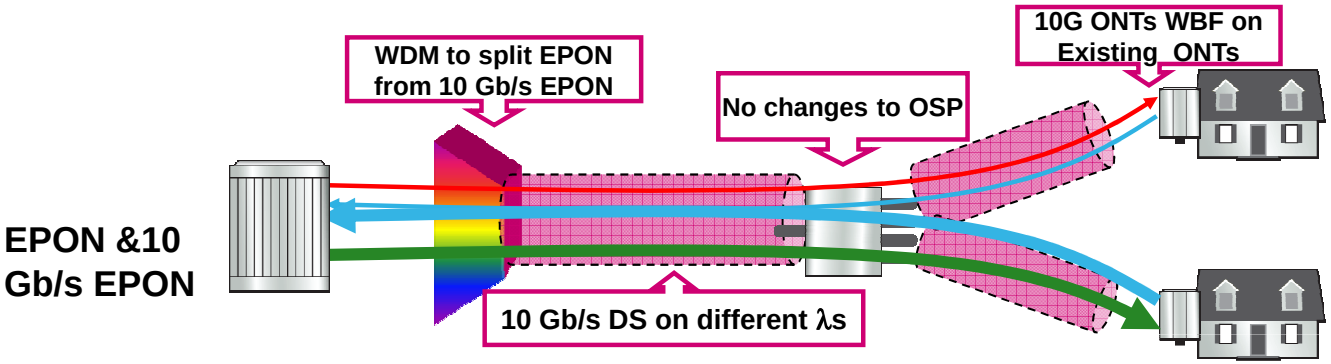
(b) Bus topology (using 1:2 tap couplers)

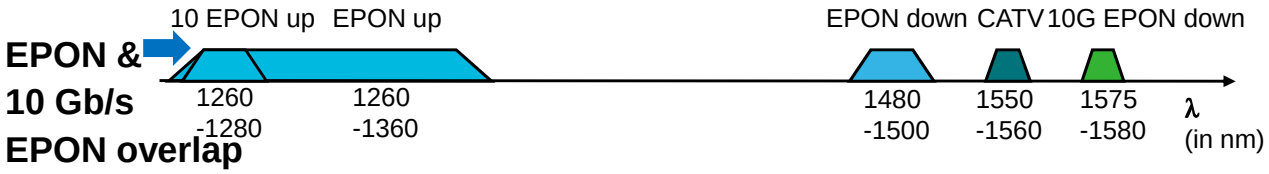


(d) Tree with redundant trunk (using 2:N splitter)

CO-EXSITENCE ON THE SAME FIBER

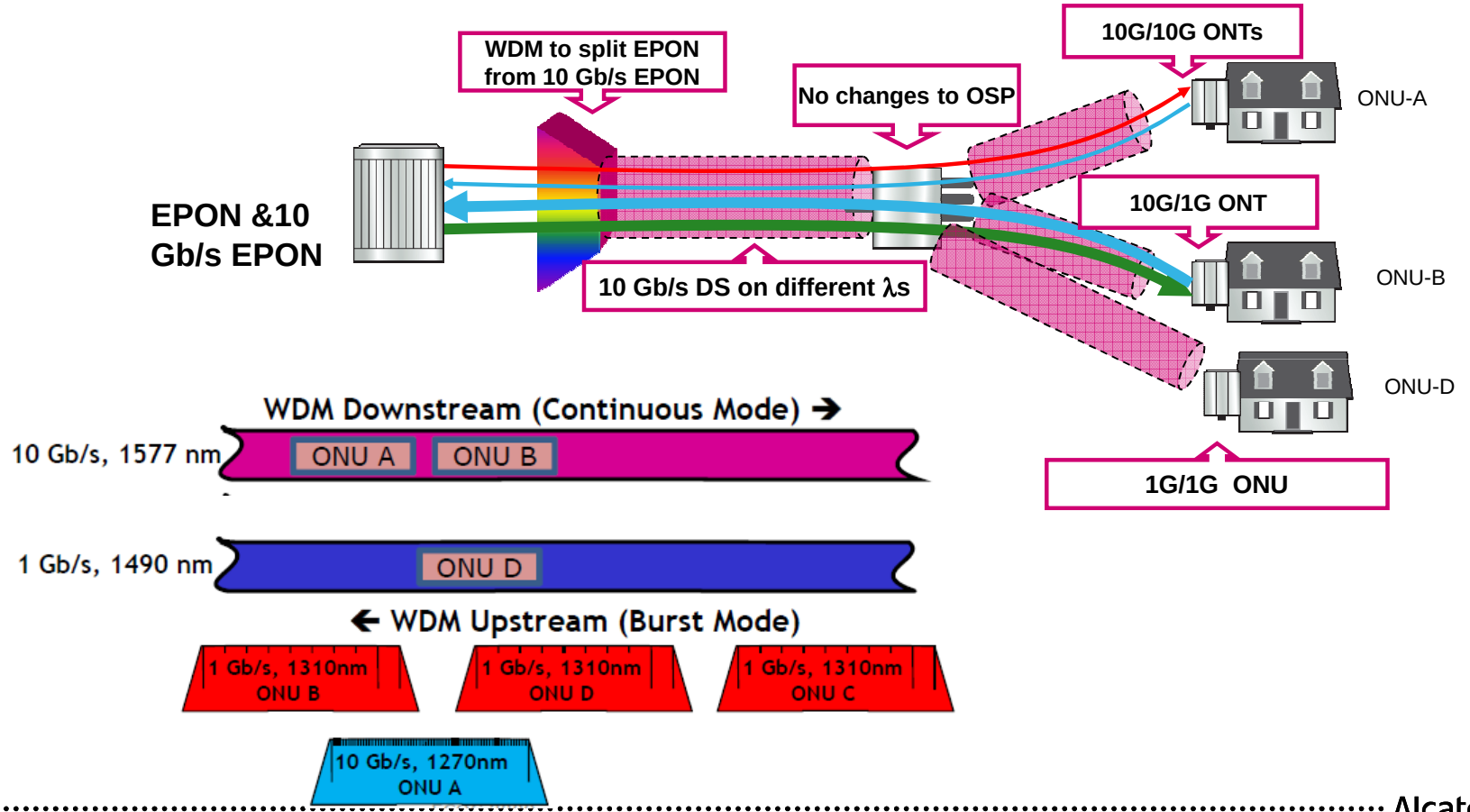
Co-existence and Evolution





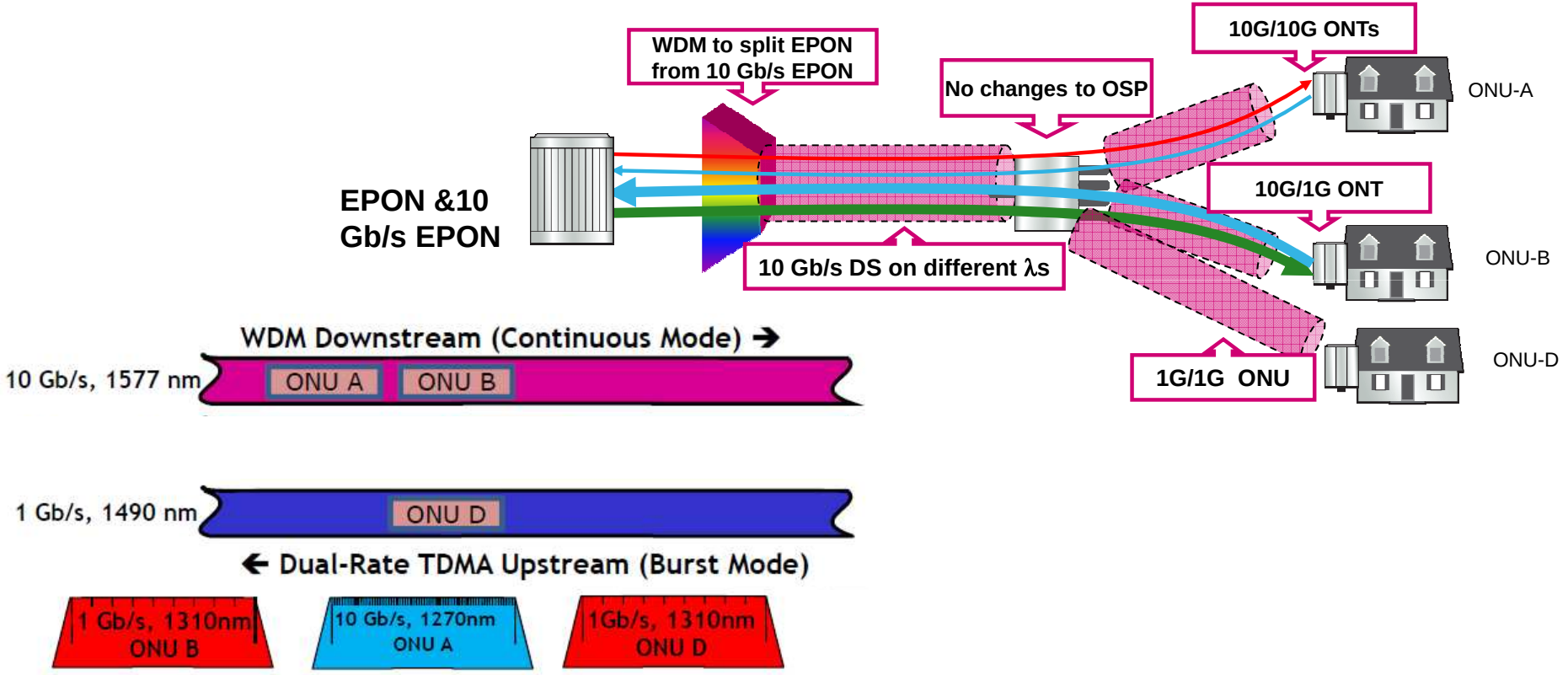
- Coexistence with WB EPON can relegate the 10G US to near 1G performance
- Ideally it is better to separate but for economic reasons 1G US with 10G DS may may prove to be widely deployed

1G/10G ONUs on the same PON in WDMA Mode



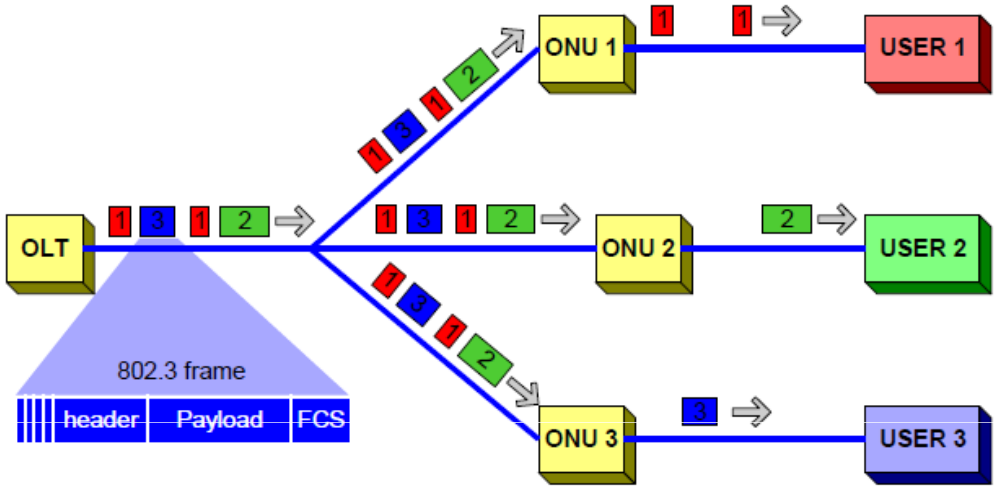
1G/10G ONUs on the same PON in TDMA Mode

Every 100Mb/s on 1G US consumes 1G capacity on a 10G US pipe



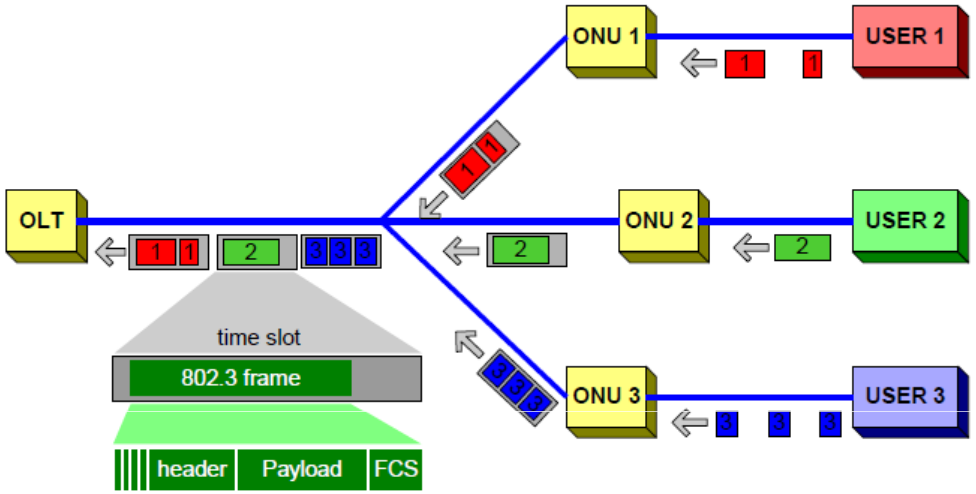
PON TECHNOLOGY DETAILS

PON DOWNSTREAM IS BROADCAST



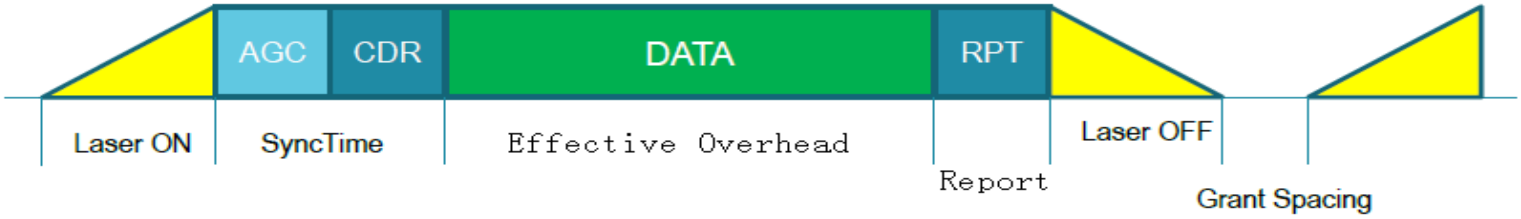
- Each Flow is given a unique identifier.
  - The unique identifier is called LLID (Logical Link identifier) in EPON & 10G EPON, and is called GEM (GPON Encapsulation Method) in GPON or XGEM in XGPON.
  - The unique identifier of LLID was initially used 1 per ONU but lately it is multiple per ONU (1.. 32).
- The LLID/GEM is part of the packet on the PON (prepended to the packet)
- So there is a logical pipe/channel for each flow where all the ONT/ONUs are monitoring all the incoming traffic but only picking up the ones destined for themselves (LLIDs = mine, so pick it up)
- There is also Broadcast LLID/GEMs where all the ONUs are picking up the traffic from these broadcast

PON UPSTREAM IS TIME DIVISION MULTIPLE ACCESS

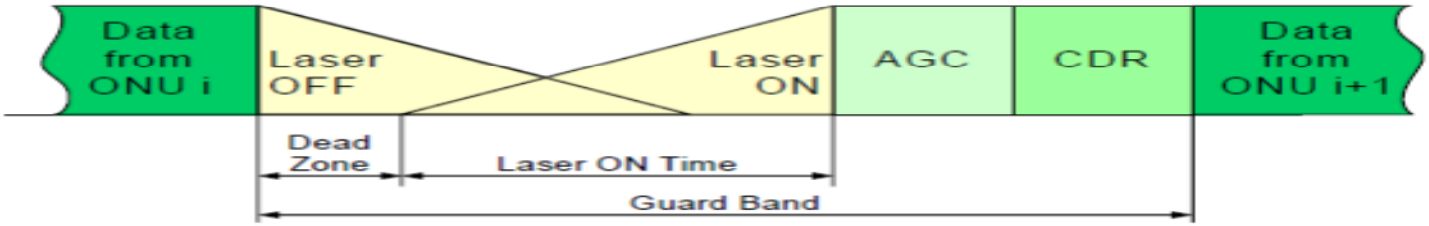


- Each Flow is given a unique timeslot to send traffic upstream by the OLT ahead of the time,
- Each assigned timeslot contains compensations for time delays and optic
- The OLT assigns the timeslot for the related traffic sometimes independent of the amount of the traffic in the ONU queues, thus some traffic may be left over. Also in GPON case, the traffic is segmented.
- Then the ONU/ONT sends the related LLID/GEM traffic in the reserved/assigned timeslot.
- The collision is not possible and guaranteed by the OLT.
- The mechanism that calculates the BW usage, checks the demands and assigns the timeslots is called Dynamic Bandwidth Allocation (DBA) Engine

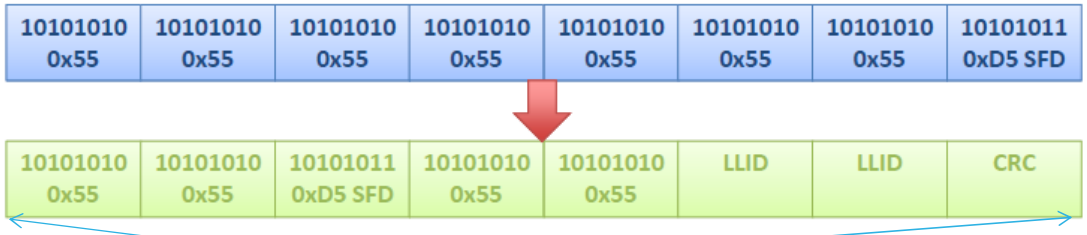
PON UPSTREAM GENERAL CHARACTERISTICS



- For EPON:
  - Laser ON = Laser OFF which are roughly 512nSecs,
  - AGC (Automatic Gain Control) and CDR (Clock & Data Recovery) easily combined takes another 512nS.
  - Grant Spacing (aka Dead Zone) is ~512nSecs
- For GPON:
  - Guard Band = ~ 100Bytes, roughly 643nsecs
- Even in US, the raw data rate for GPON .



EPON -1-: EPON FRAMES VERSUS ETHERNET

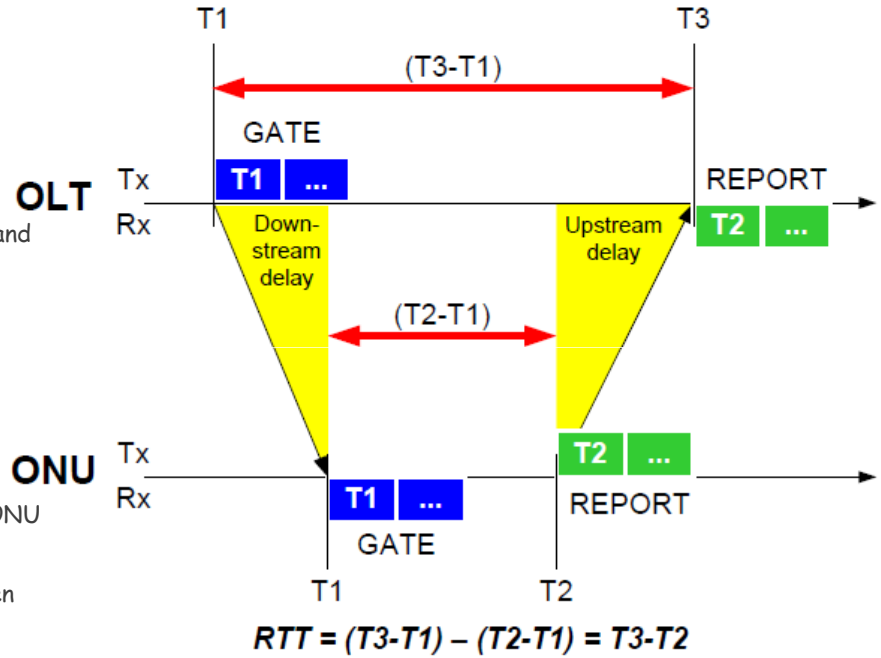


Preamble	Start of Frame Delimiter	MAC destination	MAC source	802.1Q tag (optional)	Length	Payload	Frame Check Sequence (32-bit CRC)	Interframe gap
7 octets of 01010101 (0x55)	1 octet of 11010101 (0xD5)	6 octets	6 octets	(4 octets)	2 octets	42–1500 octets	4 octets	12 octets
		64–1522 octets						
		72–1530 octets						
		84–1542 octets						

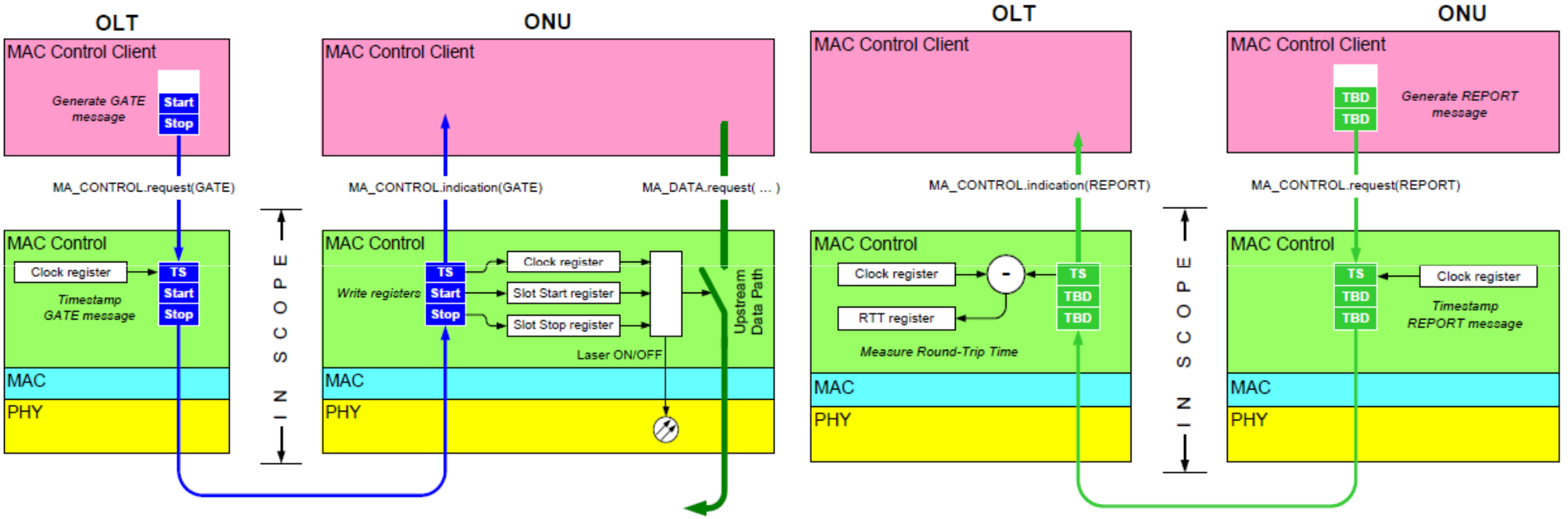
- EPON packets differ only in the Preamble & SFD section from a regular Ethernet packet.
- The preamble of 7-octets of 0x55 is reduced to 4-Octets just that 2 before SFD and 2 after. Thus SFD is moved to 3rd octet.
- The gained 3 octets are used as 16-bit LLID and a CRC (protects from SFD -3rd octet- through LLID -7th octet).
- LLID is such that (mode, logical_link_id[15]) => it has 32K Unicast values and 32K Multicast values):
  - Mode (Upper most bit) =0 , The traffic is UNICAST and can be either direction
  - Mode (Uppermost bit) =1, The traffic is Multicast/Broadcast and is only in DS.

EPON-2-: HOW TO MAKE POINT-TO-MULTIPOINT (P2MP) WORK LIKE REGULAR ETHERNET?

- LLIDs are unique and assigned to the ONU during registration.
- In DS:
  - Just change the Preamble with LLID as described on OLT
  - ONU only picks up its own LLID(s) and broadcasts.
- In US: Multi-Point Control Protocol (MPCP) allows a control mechanism between OLT and ONU.
  - OLT compensates the distance differences between the ONUs,
  - OLT allows only 1 ONU to send data in US at a time,
  - So OLT polls the ONUs periodically.
- System uses "GATE" (from OLT to ONU) and "REPORT" (ONU to OLT) Messages,
- First the Round Trip Time is important as it gives an idea about the location of the ONU (delay wise).
- Moreover using the information from the packet time-stamps, the difference between the time for ONU and OLT can be corrected.

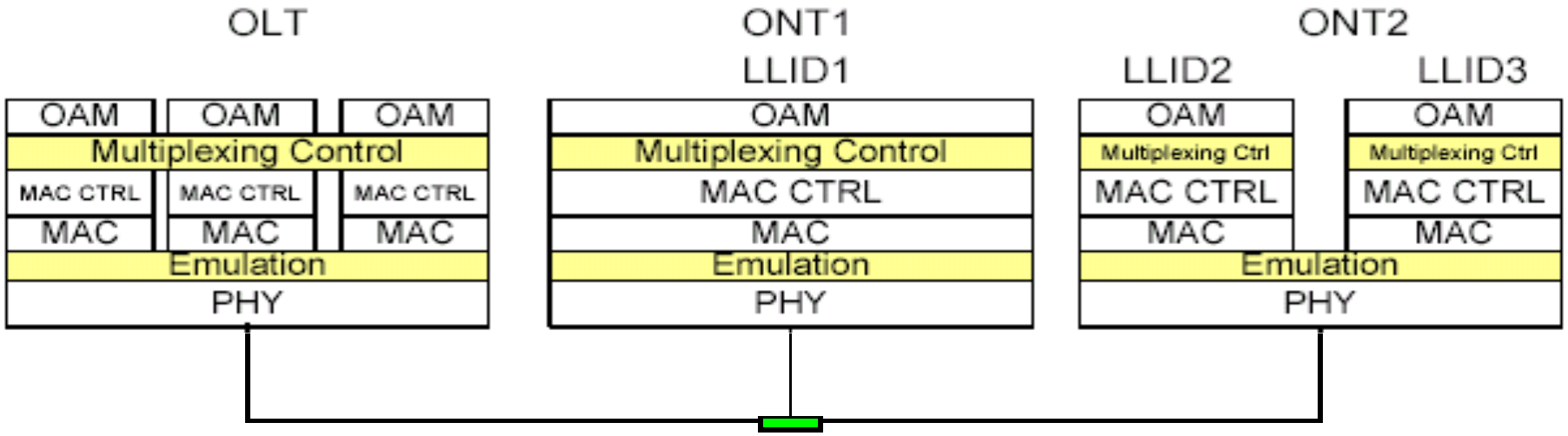


EPON-3-: GATE AND REPORT MESSAGE TIMING



- Time-stamping at the PHY level is critical and is achieved by standard

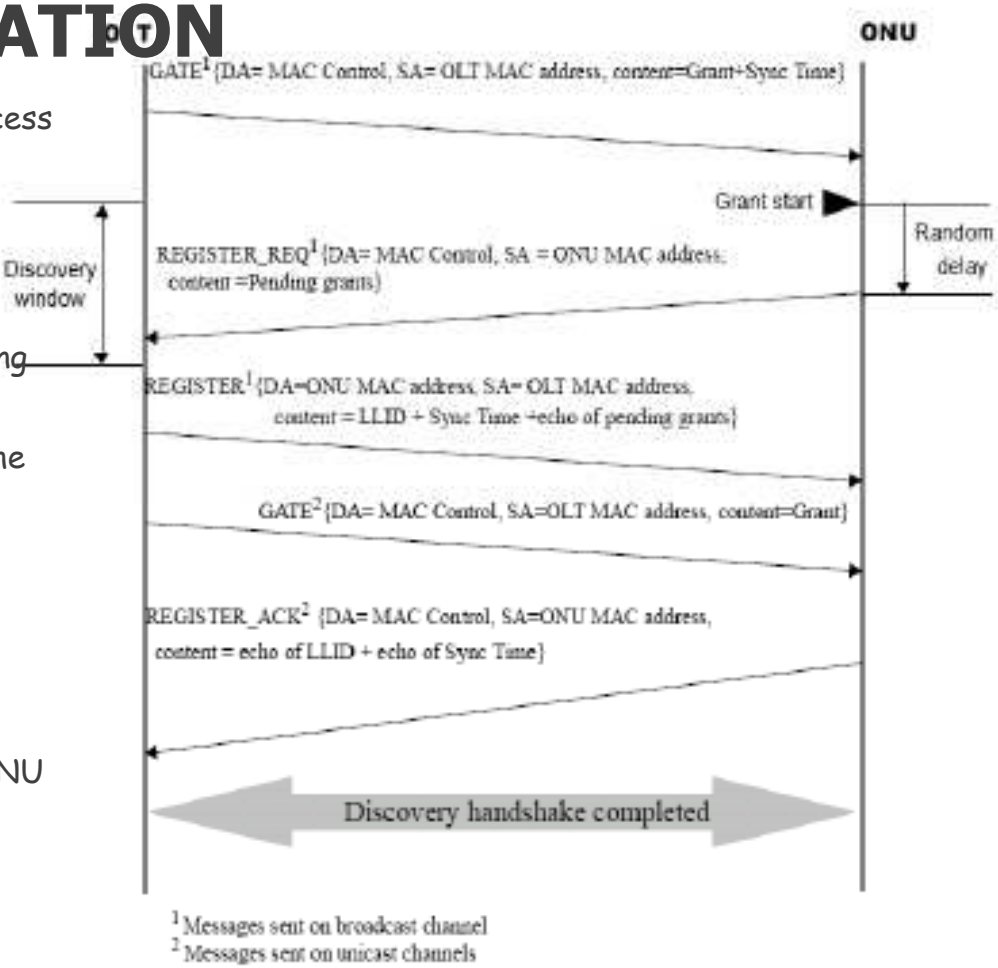
EPON-5-: SINGLE LLID OR MULTI-LLID?



- Single LLID :
  - Single MAC stack at the ONU PON port,
  - Bridge/L2 switch at the ONU
- Multiple LLID
  - The goal of having multiple LLIDs per ONU is to make multi-subscriber ONU behave as multiple single-subscriber ONUs

EPON-4-: ONU INITIALIZATION

- ONU tries to register with OLT upon initialization . The process is called "Discovery", and is controlled by OLT.
- 1. OLT sends periodical "Discovery" Frames to open up discovery windows. "Discovery Gate" messages are sent in a broadcast mode,
- 2. Upon power-up, the ONU is in the "Discovery state" waiting for "Discovery Gate".
- 3. If the received frame is a "Discovery Gate" and LLID is the default then the ONU responds after a random delay with a "Register_Request" message.
- 4. The OLT upon receiving the request message, knows the RTT, MAC Address of the ONU and assigns an LLID to the ONU and sends a Register Gate Message (again in Broadcast mode) towards the ONUs.
- 5. OLT sends a GATE message to allow a time-slot for the ONU to respond back (unicast this time).
- 6. The ONU that is being registered acknowledges the Registration with "Register_ACK" message.
- So the ONU is now registered and working.



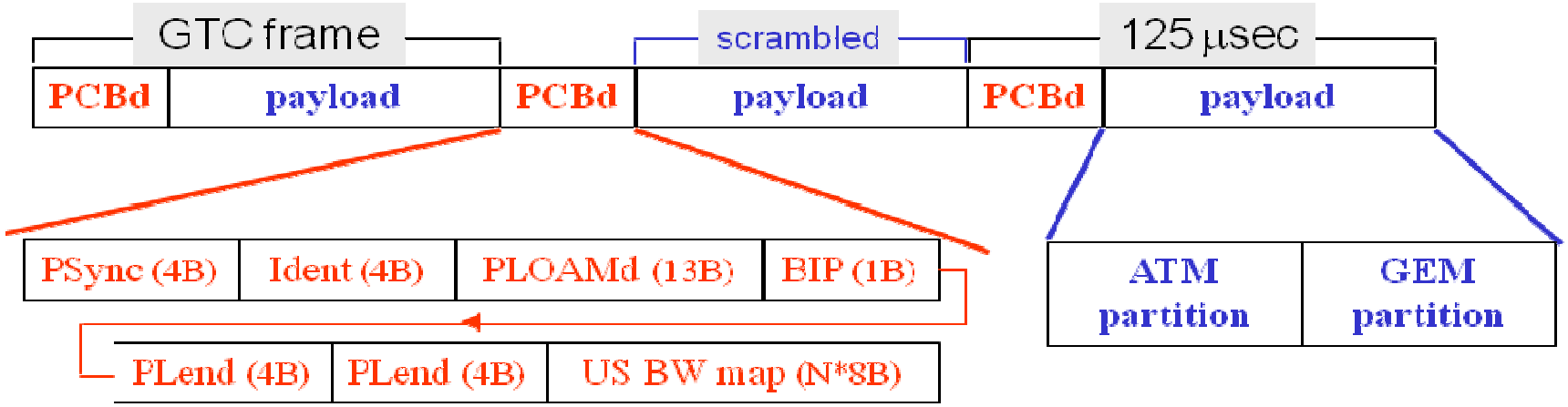
EPON-6-: OPTICAL TERMINOLOGY IN EPON

- | | DS | US |
- 1G EPON: 1480-1500nm 1290-1330nm
- 10G EPON: 1575-1580nm 1260-1280nm

- Example for PX20:
  - | | TX Side | RX Side |
  - OLT Side: +2 to +7 dBm -6 to -27 dBm
  - ONU Side: +1 to +4 dBm -3 to -24 dBm
- Example for PR30:
  - | | TX Side | RX Side |
  - OLT Side: +2 to +5 dBm -6 to -28 dBm
  - ONU Side: +4 to +9 dBm -10 to -28.5 dBm

1G/1G EPON	10G/1G EPON	10G/10G EPON	Optical Budget
PX10	PRX10	PR10	+20dB
PX20	PRX20	PR20	+24dB
PX20+	-	-	+27dB
PX30	PRX30	PR30	+29dB
PX40	PRX40	PR40	+33dB

GPON-1-: GPON FRAMES

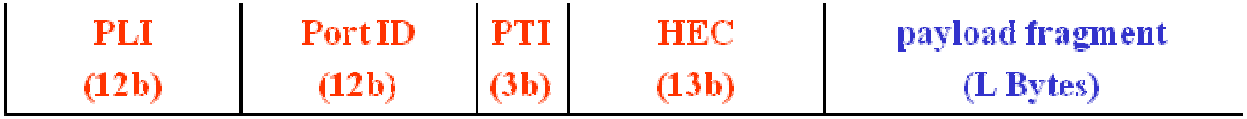


- GPON & XGPON & NGPON2 runs on GTC Frames that are created every 125uSecs (DS & US)
- For DS: Each frame has 38,840 bytes (x8000 x8) -> 2.48832Gb/s and similarly XGPON1 = 155,520 bytes-> 9.95328Gb/s
- For US: Each frame has 19,440 bytes (x8000 x8)-> 1.24416Gb/s and similarly XGPON1 = 38,840 bytes -> 2.48832Gb/s
- Physical Control Block downstream is the header for DS and varies 38 to 518 bytes.
- For DS, the packet has 5bytes GEM header instead of 8bytes Preamble+SFD and 12 bytes IFG.

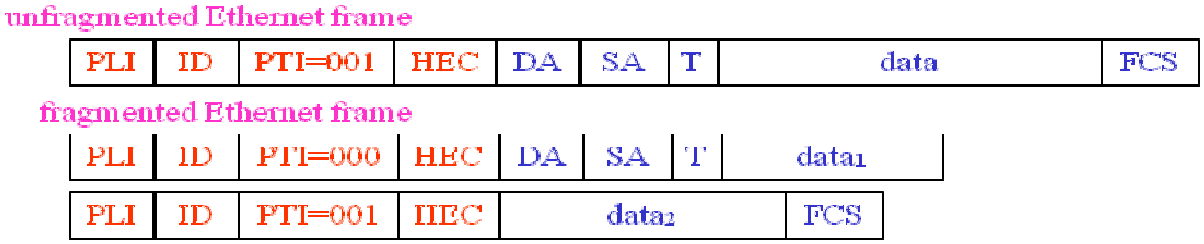
GPON-2- : GPON BASICS

- GPON can carry 2 different encapsulation:
  - ATM cells (with Alen header that is 12bits)
  - GPON Encapsulation Method (GEM) where the header is 5 bytes per packet.

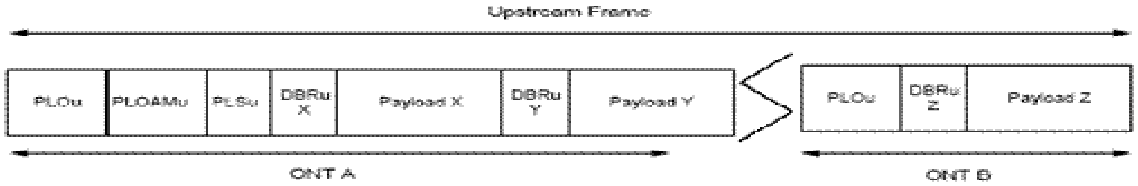
- Generally GEM method is used.



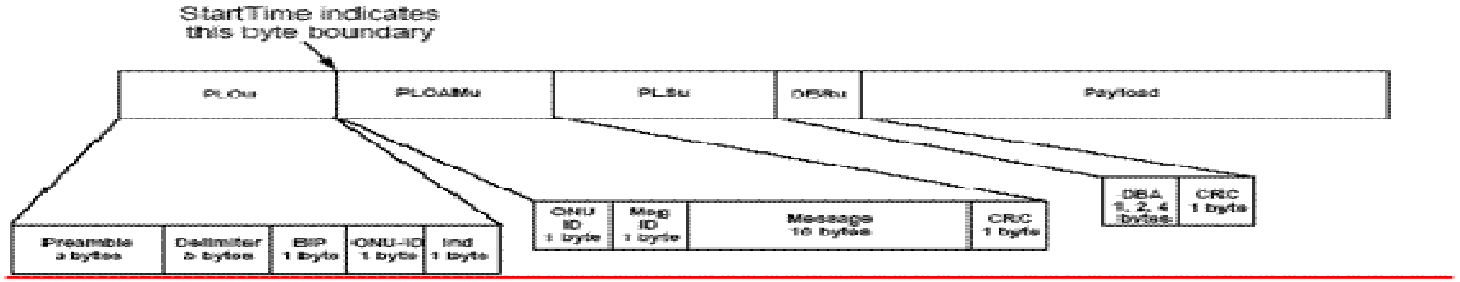
- PLI: Payload Length Indicator (in bytes),
- PortID: GEM#
- PTI: Payload Type Indicator
- HEC: Header Checksum
- GPON allows fragmentation in US & DS so the full BW can be used.



GPON-3-: UPSTREAM



- US frame contains multiple US sub-frames (one per each ONU) since multiple ONUs are served within a frame.



- In US, there is a concept of T-CONT (Transmission Container) where multiple GEMs are combined and the BW is allocated per T-CONT by DBA.
- T-Cont is an abstraction layer to provide aggregated service flow.

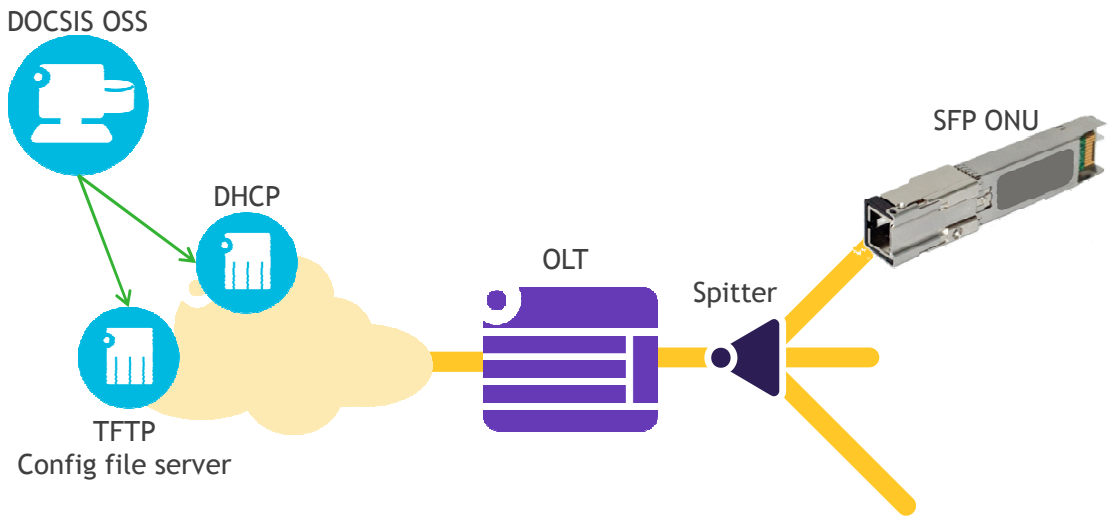
GPON-4-: EFFICENCY OF LINE PER DATA BITS

Packet Size (Bytes)	% Efficiency of Data Bits to line Bit/Baud Rate		
	Ethernet & EPON%		GPON %
	Data/Baud	Data/Data	
64	60.95	76.19	92.68
128	69.19	86.48	96.17
364	75.83	94.79	98.57
1518	78.96	98.70	99.59
2000	79.20	99.00	99.68

- Bits/sec versus data bit/sec.
- EPON is actually 1.25Gbaud/s to carry 1Gb/s Ethernet like the GE lines.
- Data efficiency varies which are dependent on encoding related losses (i.e. 8B/10B encoding), packet headers and gaps.
- Over that protocol related inefficiencies (i.e. EPON 's GATE messages),
- Upstream is a more complicated story which is heavily dependent on the number of ONT/ONUs on the line.

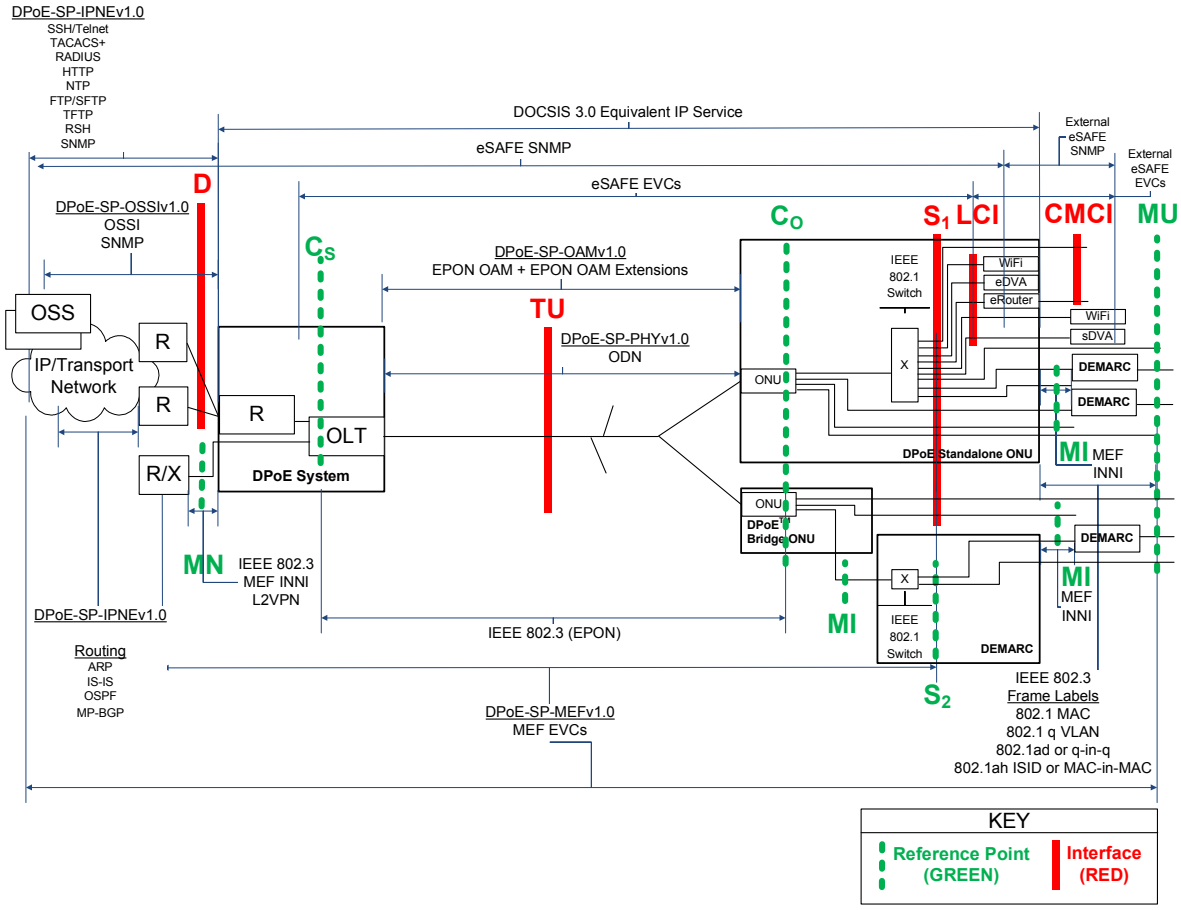
DPoE

What is DPoE?
DOCSIS PROVISIONING OF EPON



1. Service order entered at DOCSIS OSS
2. Config file created and loaded on TFTP server
3. ONU connected to fiber
4. OLT Discovers the ONU
5. Virtual Cable Modem (vCM) created on DPoE System(OLT)
6. vCM launches DHCP request
7. DHCP server responds with offer, TFTP address and config file name
8. vCM retrieves config file from TFTP server
9. Per the config file received, the vCM on the OLT configures
    1. LT PON MAC chipset,
    2. ONU through OAM messaging
10. System integrates vCM provisioning with provisioning of Ethernet switch on LT board
11. ONU is active and running customer configuration received by the config file.
12. vCM behaves like a CM hiding all the PON & ONU details.

DPOE ARCHITECTURE DEFINITION



Interface	Description
D	DOCSIS IP NNI
MN	NNI for MEF svcs (L2 VPN svcs)
Cs	DS classifier ingress
Co	US classifier ingress
TU	PON interface
S1	SA ONU General IF
S2	IF on DEMARC
MI	MEF INNI (form of S1)
LCI	Local CPE IF (form of S1)
CMCI	Docsis CM CPE IF (form of S1)
MU	MEF UNI (form of S1)

PROVISIONING IS ONLY PART OF DPOE!

- DPoE v 1.0 Specifications:

•DPoE-SP-ARCHv1.0-I01-110225	Architecture Description
•DPoE-SP-IPNEv1.0-I06-130808	IP Network Element requirements
•DPoE-SP-MULPIv1.0-I06-130808	MAC and Upper Layer Protocol Reqs
•DPoE-SP-OSSIv1.0-I05-130808	Operation and Support System Intf. Reqs
•DPoE-SP-OAMv1.0-I05-130328	OAM Extensions Specifications
•DPoE-SP-DEMARCv1.0-I02-130614	DEMARC Device Specification
•DPoE-SP-MEFv1.0-I03-120830	Metro Ethernet Forum Specification
•DPoE-SP-PHYv1.0-I03-130328	Physical Layer Specification
•DPoE-SP-SECv1.0-I04-130808	Security and Certificate Specifications

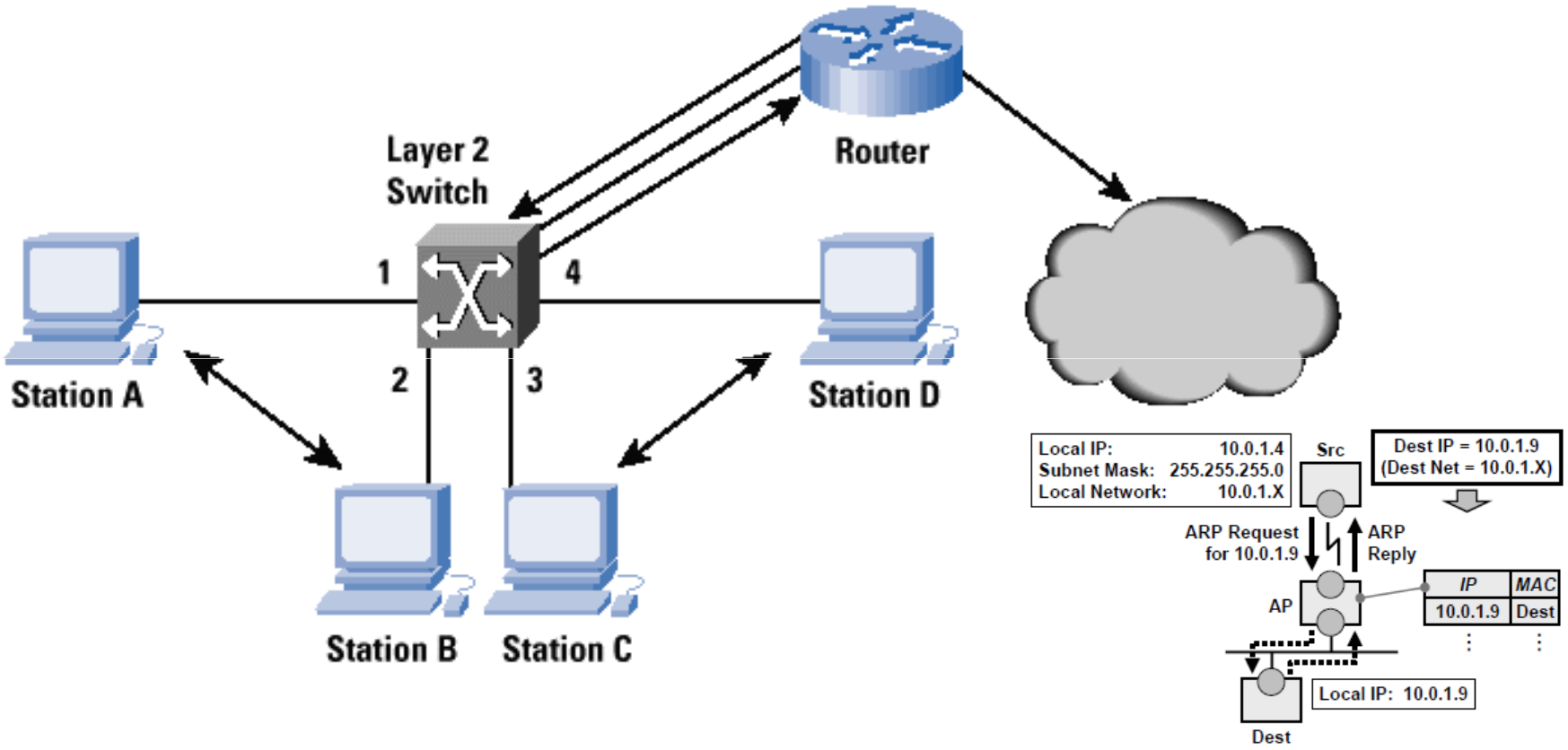
- Similar specs exist for v2.0

DPOE V1.0 VS V2.0 – WHAT'S DIFFERENCE?

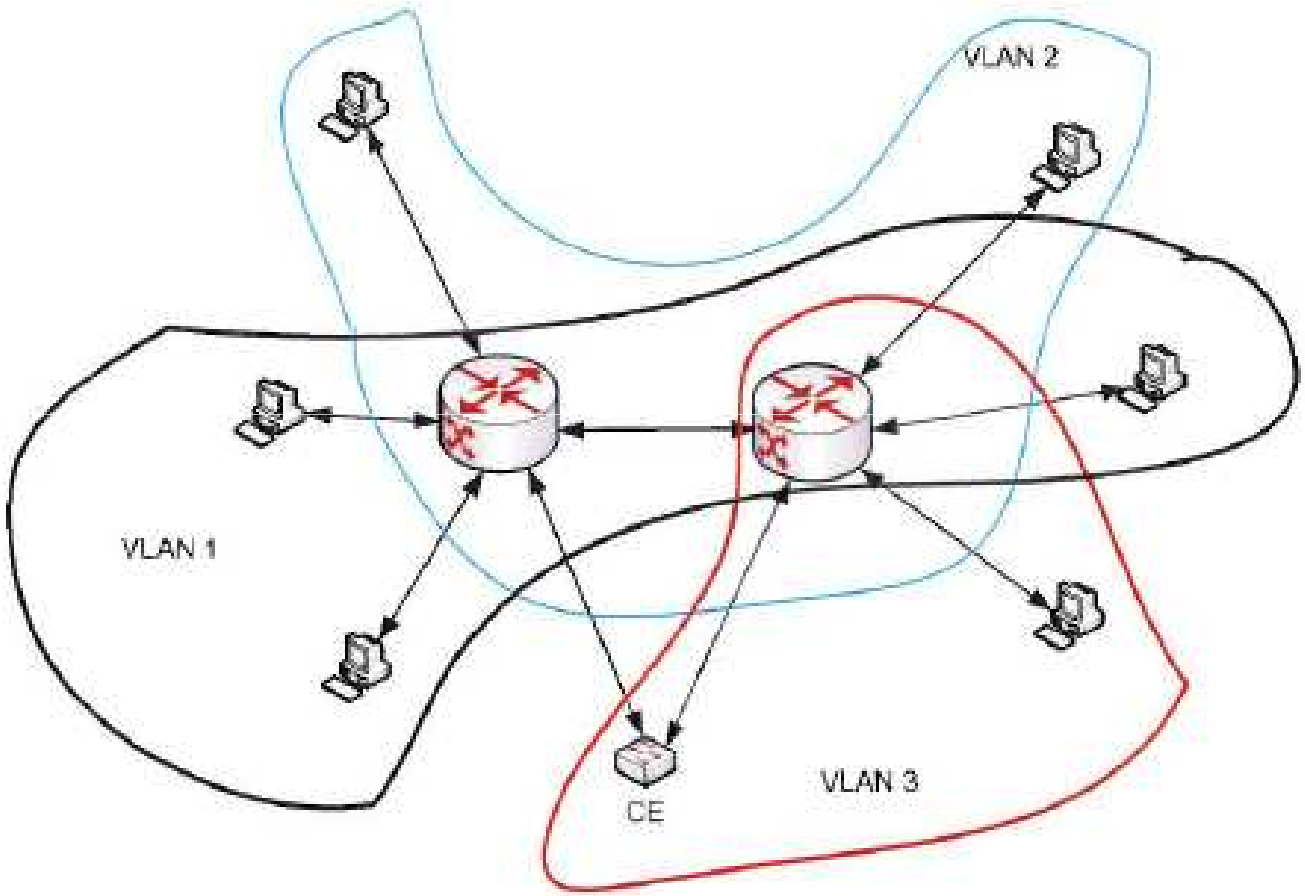
- V1.0: Supports simple services that covers most of the deployment:
  - E-LINE: (all L2 services)
    - EPL (Ethernet Private Line): Transport what comes into the ONU - layer 2
    - EVPL (Ethernet Virtual Private Line): Encapsulate with a VLAN or selectively pick VLANs that are coming to the ONU:
  - IPHSD (Internet – High Speed Data): Allows traffic from a user to exit the OLT on a layer 3 interface
- V2.0: Builds on top of DPoE_1.0 and adds:
  - E-TREE, E-LAN, Voice Services using more MPLS and L3 services.
  - It allows automated end-to-end commercial services.

BACKUP SLIDES

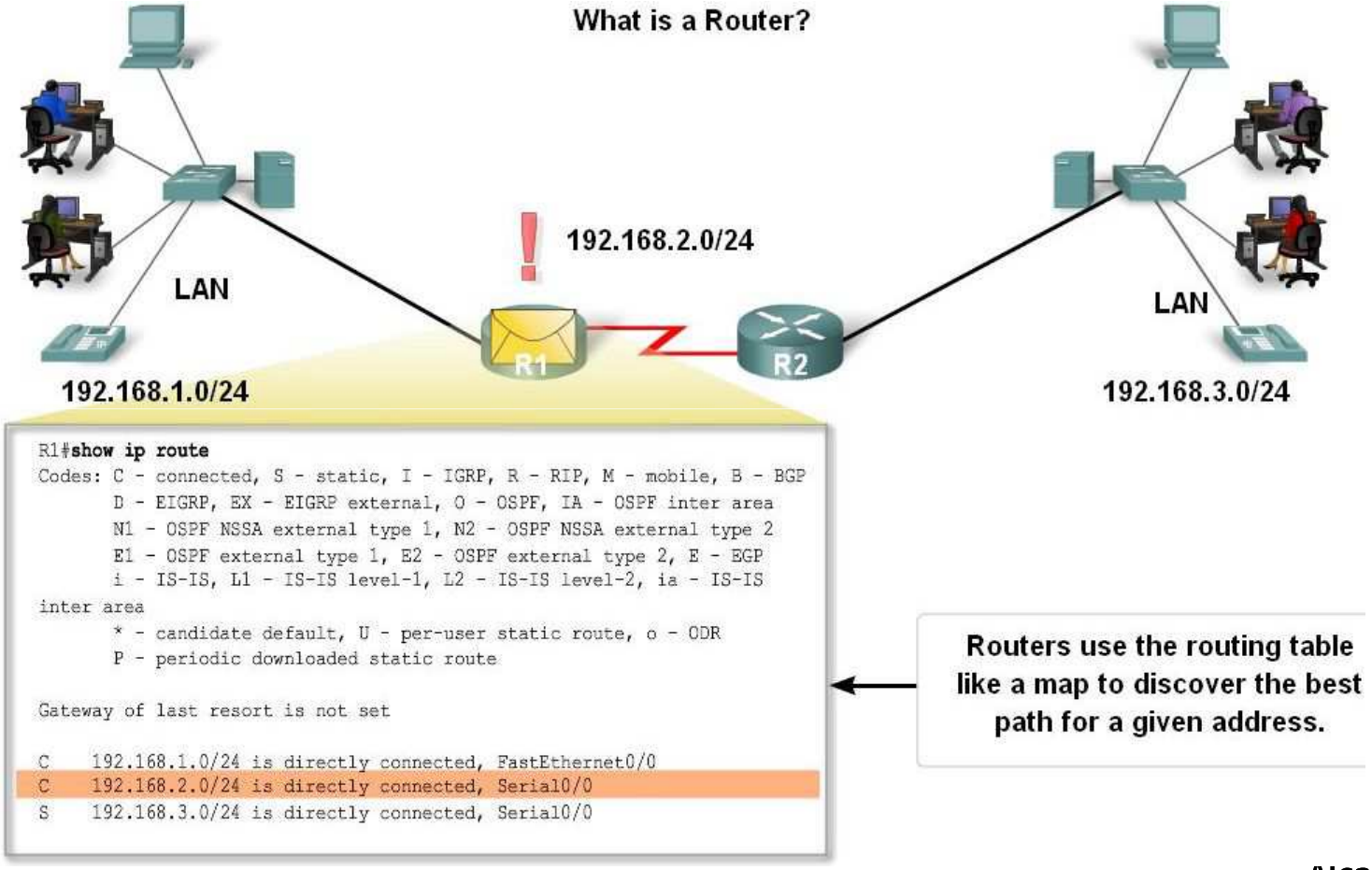
Basic L2 Switching



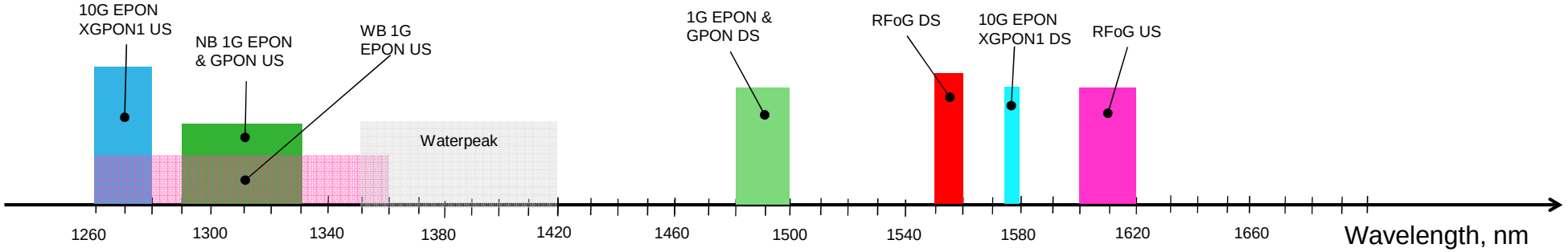
L2 Switching with VLANs



What about L3?



Multiple Wavelengths On The Same Fiber (WDM)



	US	DS
▪ GPON and Narrowband EPON:	1310nm ±20nm -> 1290nm to 1330nm	1490nm ±10nm -> 1480nm to 1500nm
▪ Wideband EPON:	1310nm ±50nm -> 1260nm to 1360nm (*)	1490nm ±10nm -> 1480nm to 1500nm
▪ XGPON & 10G EPON:	1270nm ±10nm -> 1260nm to 1280nm (*)	1577.5nm ±2.5nm-> 1575nm to 1580nm
▪ RFoG:	1610nm ±10nm -> 1600nm to 1620nm	1555nm ±5nm -> 1550nm to 1560nm

- Wideband EPON uses Fabry-Pérot Lasers which have wideband spectrum in TX. However, narrowband EPON uses DFB (Distributed Feedback) lasers which have narrowband TX spectrum.
- (*), the wideband EPON US collides with 10G EPON (or XGPON1) US so co-existence becomes an issue.
- In theory,
  - GPON or NB EPON can co-exist with 10G EPON or XGPON1 and RFoG,
  - WB EPON can co-exist RFoG and 10G EPON in TDMA mode.

Examples of 1G & 10G mixed in a single PON

- Assume the average packet size of 400Bytes for these sample calculations. Also assume each ONU is given equal time-slots and the ONUs are polled at regular intervals (3.93msec) and given acknowledgement for that entire period.

	Configuration		
Case	# 10G/1G ONUs	# 10G/10G ONUs	Effective Data Rate
- 1	1	0	998.787 Mb/s
- 2	32	0	961.177 Mb/s
- 3	0	1	9,989.407Mb/s
- 4	0	32	9,661.012 Mb/s
- 5	31	1	1,233.046 Mb/s
- 6	16	16	5,311.094 Mb/s
- 7	1	31	9,389.142Mb/s

GPON-5-: UPSTREAM DATA EFFICENCY IN GPON

# of ONTs per US Frame	Effiective GPON US Payload (Mb/s) for ONU		Corresponding Effective Data Rate on Ethernet Line for Packet Size (Mb/s)			
	All ONUs	Per ONU	64B	364B	1518B	2000B
1	1240.768	1240.768	1150.86	1223.95	1236.68	1237.66
10	1210.240	121.024	1122.54	1193.84	1206.26	1207.22
32	1135.616	35.488	1053.32	1120.23	1131.88	1132.78
64	1027.072	16.048	952.65	1223.95	1023.69	1024.50

AT THE SPEED OF IDEAS