Passive Optical Fibre Access Network

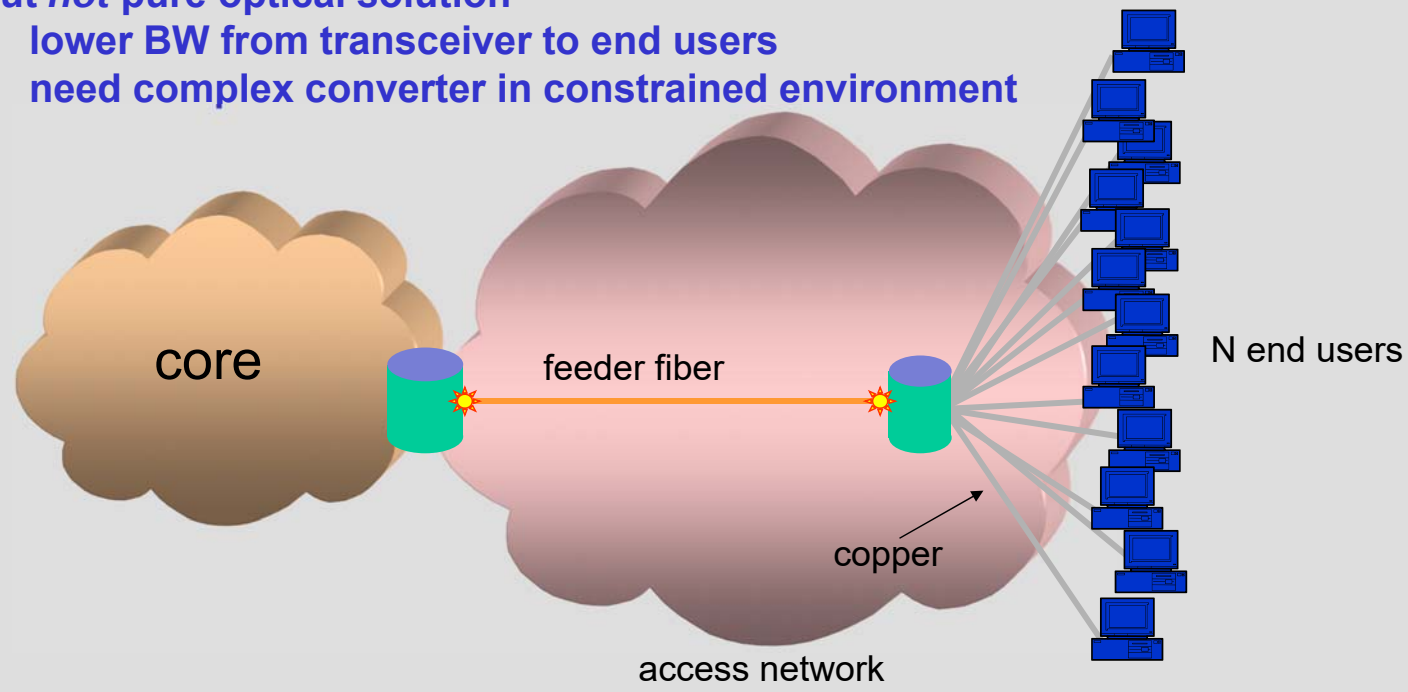
Fiber To The Curb

Hybrid Fiber Coax and VDSL

- switch/transceiver/mini DSLAM located at curb or in basement
- need only 2 optical transceivers

but *not* pure optical solution

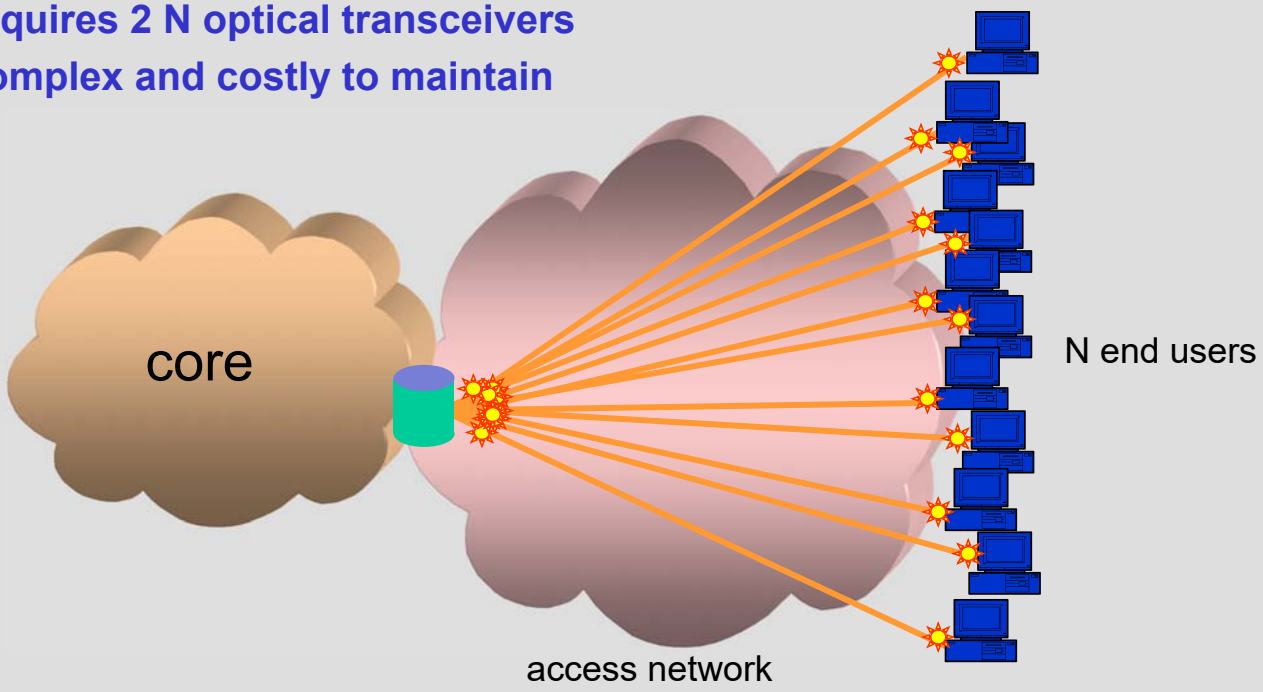
- lower BW from transceiver to end users
- need complex converter in constrained environment



Fiber To The Premises

we *can* implement point-to-multipoint topology purely in optics

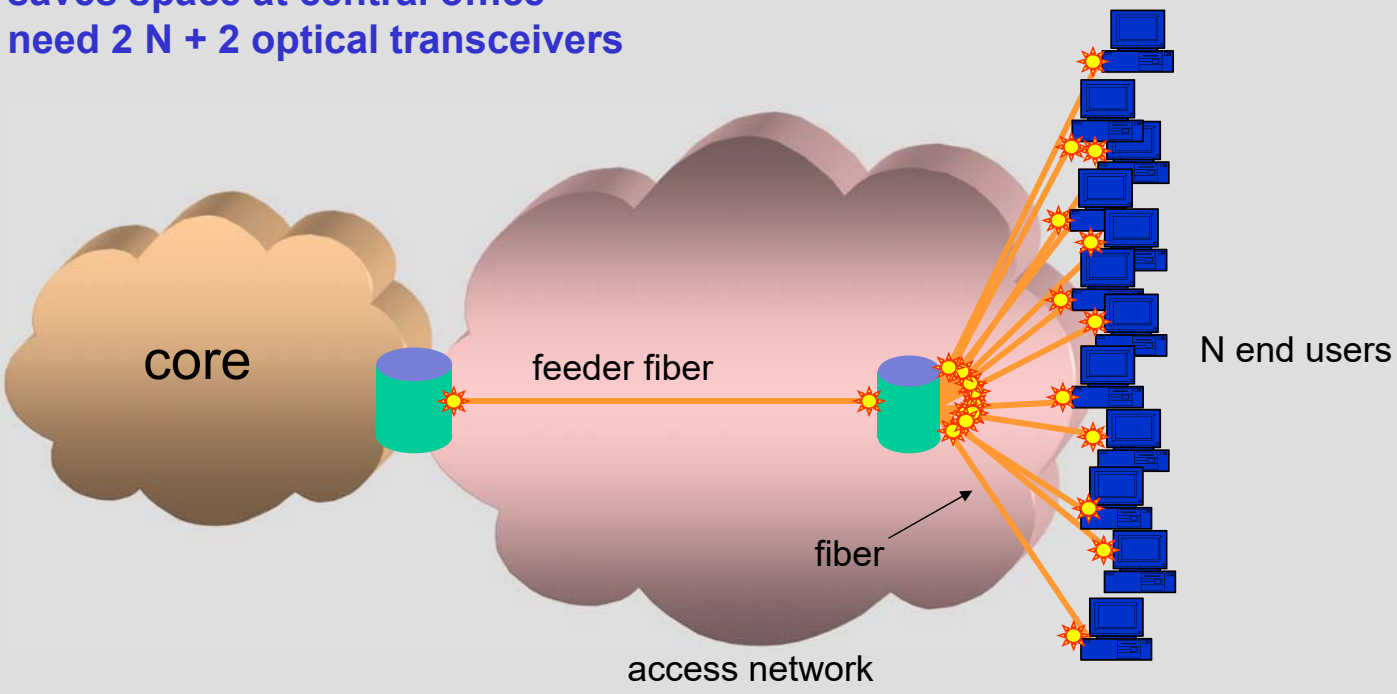
- **but we need a fiber (pair) to each end user**
- **requires 2 N optical transceivers**
- **complex and costly to maintain**



An obvious solution

deploy intermediate switches

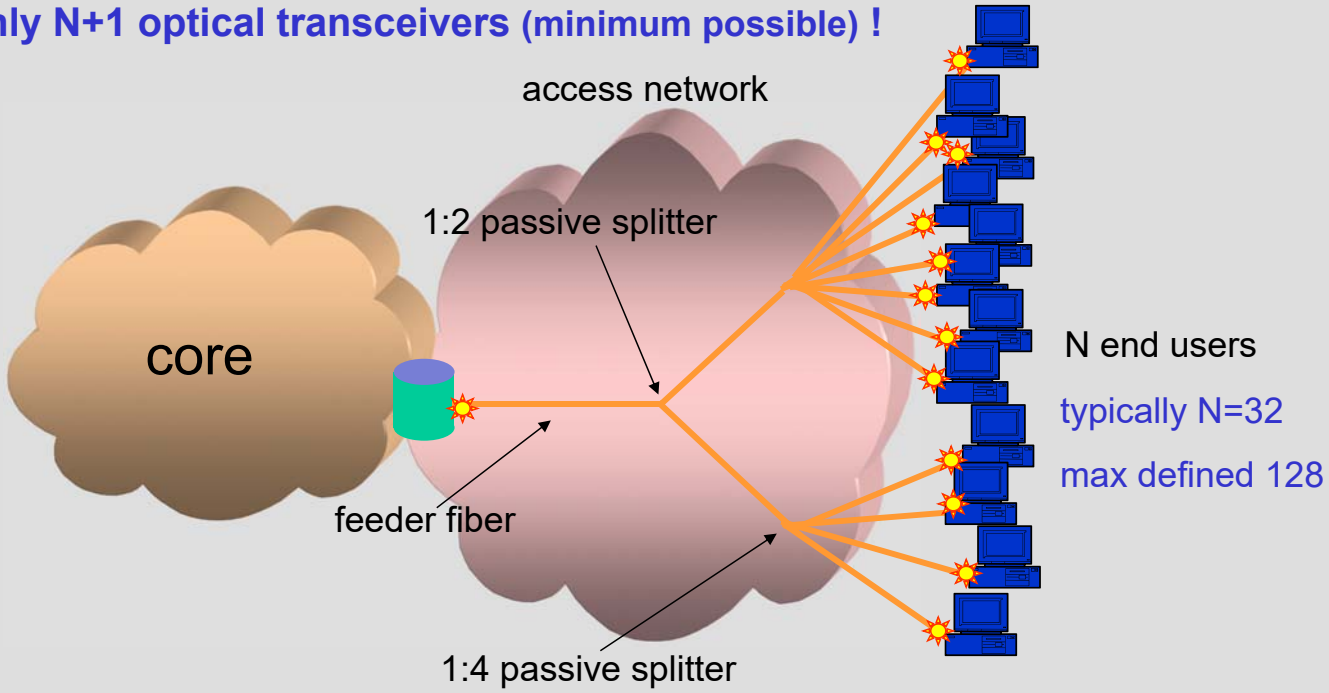
- **(active) switch located at curb or in basement**
- **saves space at central office**
- **need 2 N + 2 optical transceivers**



The PON solution

another alternative - implement point-to-multipoint topology purely in optics

- **avoid costly optic-electronic conversions**
- **use *passive splitters* – no power needed**
- **only N+1 optical transceivers (minimum possible) !**



Point-to-Point vs. PON Fibre Access

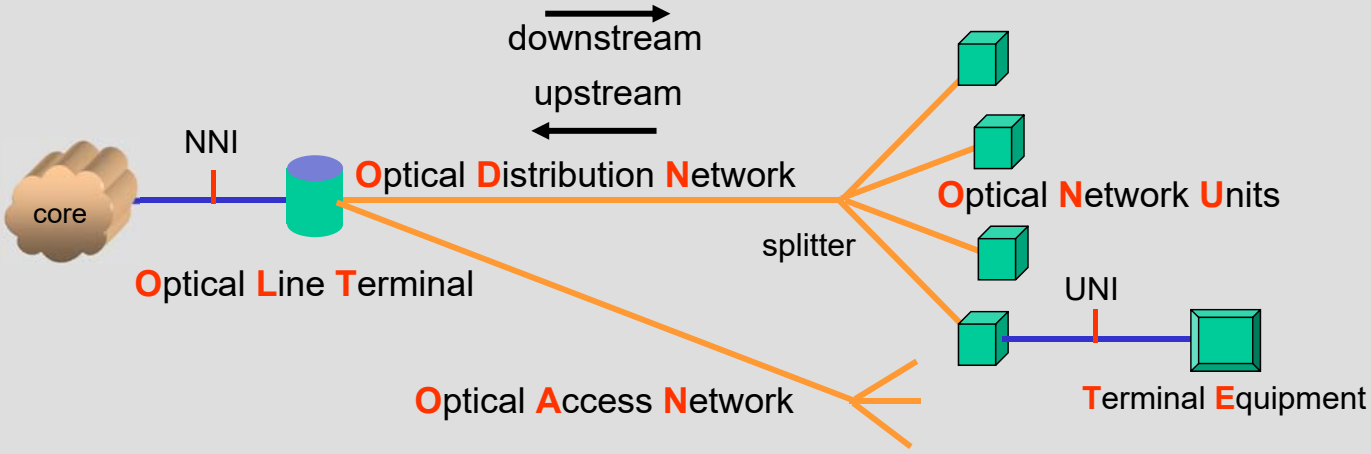
Comparison of Point-to-Point Fiber Access and PONs

Point-to-Point Fiber Access	PON
Point-to-Point Architecture	Point-to-Multipoint Architecture
Active electronic components are required at the end of each fiber and in the outside plant.	Eliminates active electronic components, such as regenerators and amplifiers, from the outside plant and replaces them with less-expensive passive optical couplers that are simpler, easier to maintain, and longer lived than active components
Each subscriber requires a separate fiber port in the CO.	Conserves fiber and port space in the CO by passively coupling traffic from up to 64 optical network units (ONU) onto a single fiber that runs from a neighborhood demarcation point back to the service provider's CO, head end, or POP
Expensive active electronic components are dedicated to each subscriber	Cost of expensive active electronic components and lasers in the optical line terminal (OLT) is shared over many subscribers

Terminology

like every other field, PON technology has its own terminology

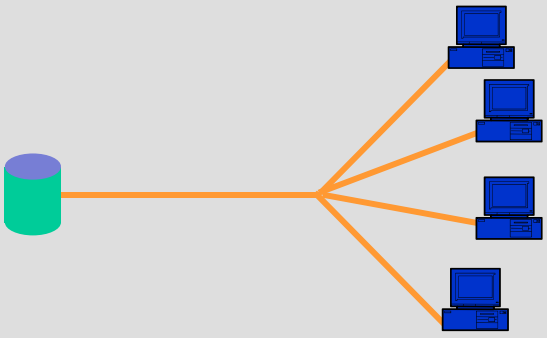
- the CO head-end is called an OLT
- ONUs are the CPE devices (sometimes called ONTs in ITU)
- the entire fiber tree (incl. feeder, splitters, distribution fibers) is an ODN
- all trees emanating from the same OLT form an OAN
- downstream is from OLT to ONU (upstream is the opposite direction)



PON types

many types of PONs have been defined

APON	ATM PON
BPON	Broadband PON
GPON	Gigabit PON
EPON	Ethernet PON
GEPON	Gigabit Ethernet PON
CPON	CDMA PON
WPON	WDM PON



in this course we will focus on GPON

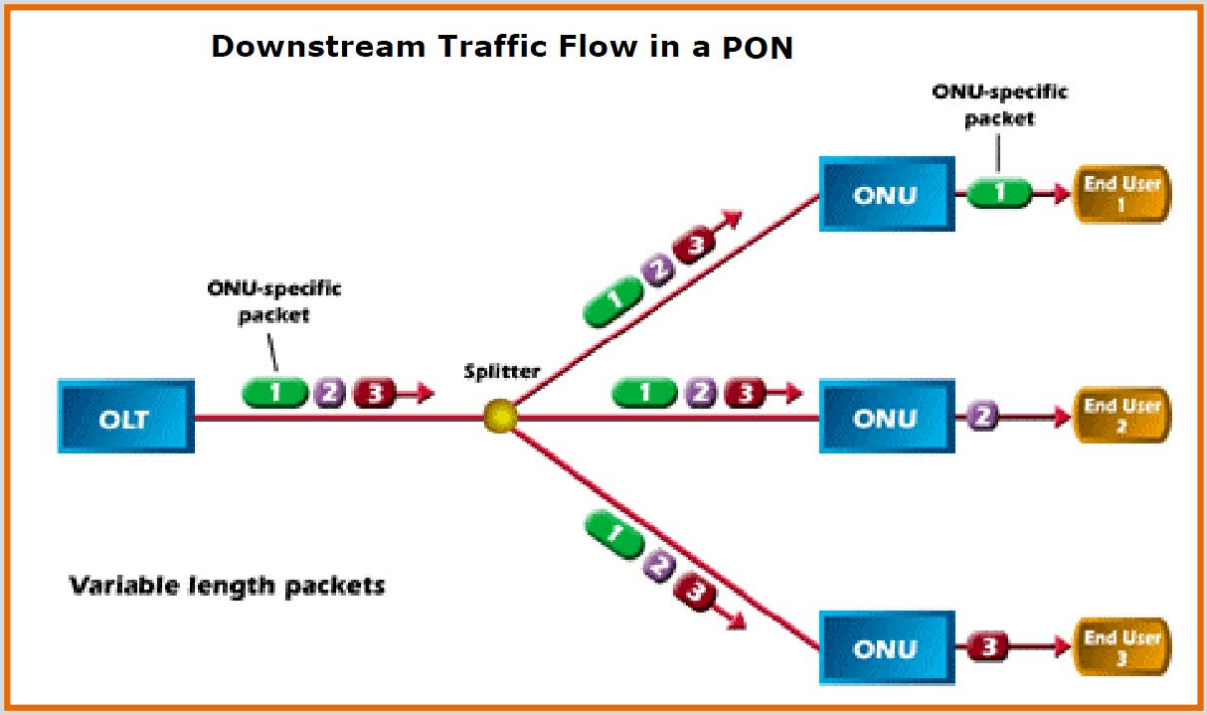
Passive Optical Networks

Principles

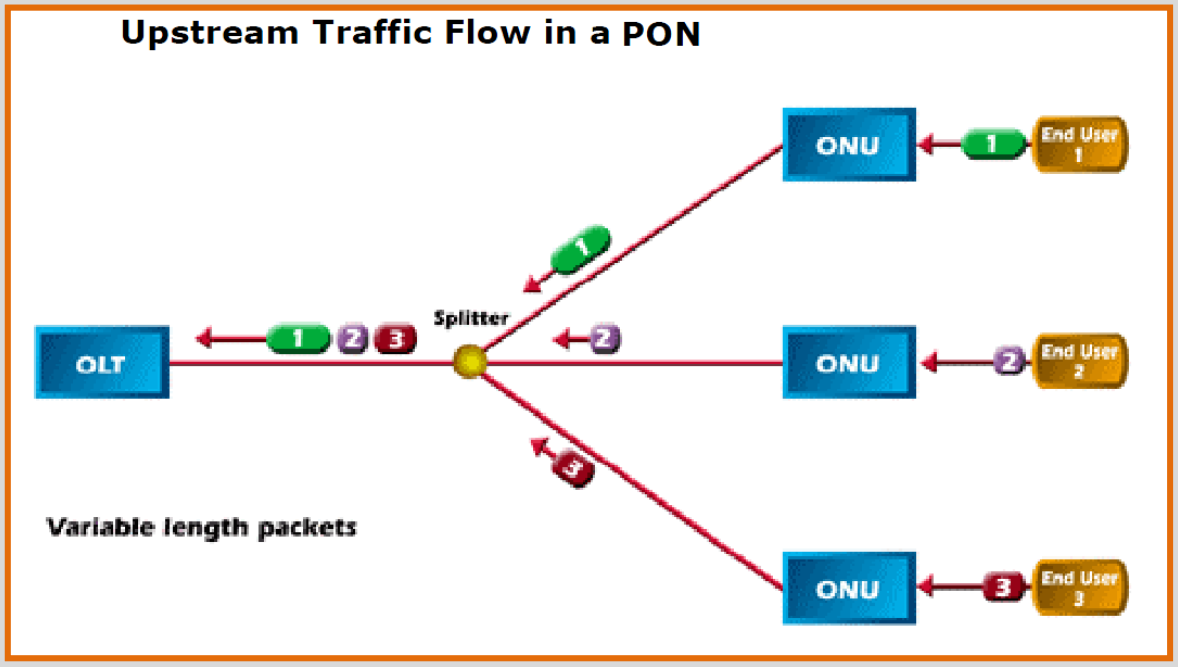
***(almost)* all PON types obey the same basic principles**

- ***OLT and ONU functions***
  - Layer 2 (Ethernet MAC, ATM adapter, etc.)
  - optical transceiver using different λs for transmit and receive
  - optionally: Wavelength Division Multiplexer
- ***Downstream transmission***
  - OLT broadcasts data downstream to all ONUs in ODN using Time Division Multiplexing (TDM)
  - ONU captures data destined for its address, discards all other data
  - encryption needed to ensure privacy
- ***Upstream transmission***
  - ONUs share bandwidth using Time Division Multiple Access (TDMA)
  - OLT allocates BW dynamically according to ONU queue levels
  - ranging is performed to determine ONU-OLT propagation time

Passive Optical Networks



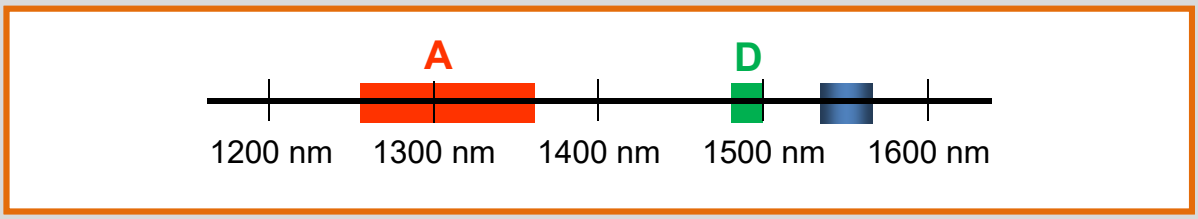
Passive Optical Networks



Rede de Acesso por Fibra Óptica

Transmissão

- ***Comprimentos de onda***
  - Alocação de comprimentos de onda nas 2ª e 3ª janelas
  - 2 ou 3 comprimentos de onda por acesso
  - Possível usar WDM para aumentar a capacidade



- **Ascendente 1260-1360 nm (1310 ± 50)**
- **Descendente 1480-1500 nm (1490 ± 10)**
- **Video (RF analógico) 1550 - 1560 nm**

Rede de Acesso por Fibra Óptica

Transmissão

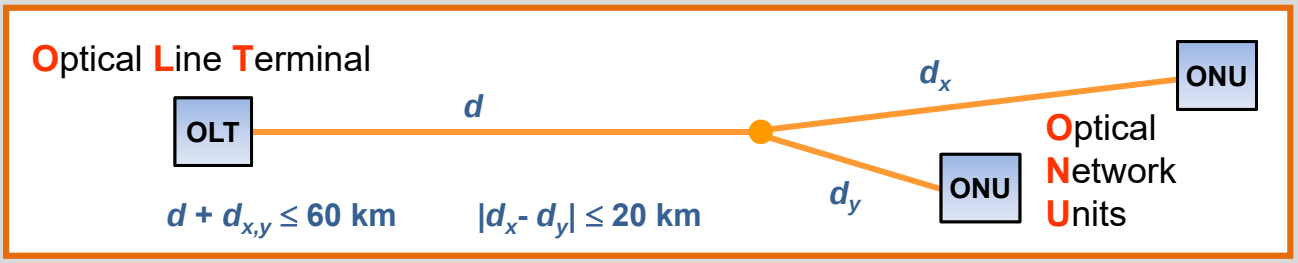
- ***Taxas de transmissão***
  - Taxas de transmissão simétricas ou assimétricas
  - Valores múltiplos de 8 kHz

Direcção de transmissão	Taxas de transmissão nominais
Descendente	1 244,16 Mbit/s
	2 488,32 Mbit/s
Ascendente	155,52 Mbit/s
	622,08 Mbit/s
	1 244,16 Mbit/s
	2 488,32 Mbit/s

Rede de Acesso por Fibra Ótica

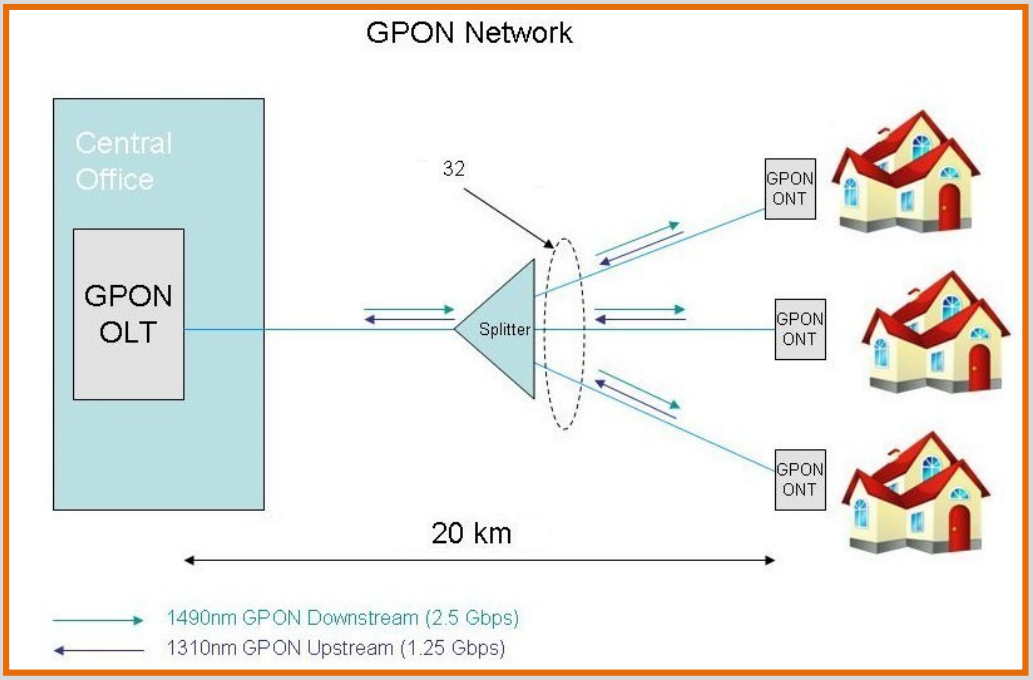
Transmissão

- ***Alcance***
  - Vários modos previstos, correspondentes à utilização de componentes de emissão e receção e tipos de fibra ótica com diferentes características
  - Sistema típico: 20 km
  - Sistema de baixo custo: 10 km
  - Sistema de longa distância: 60 km, com diferença máxima de 20 km entre o ONU mais próximo e o mais distante



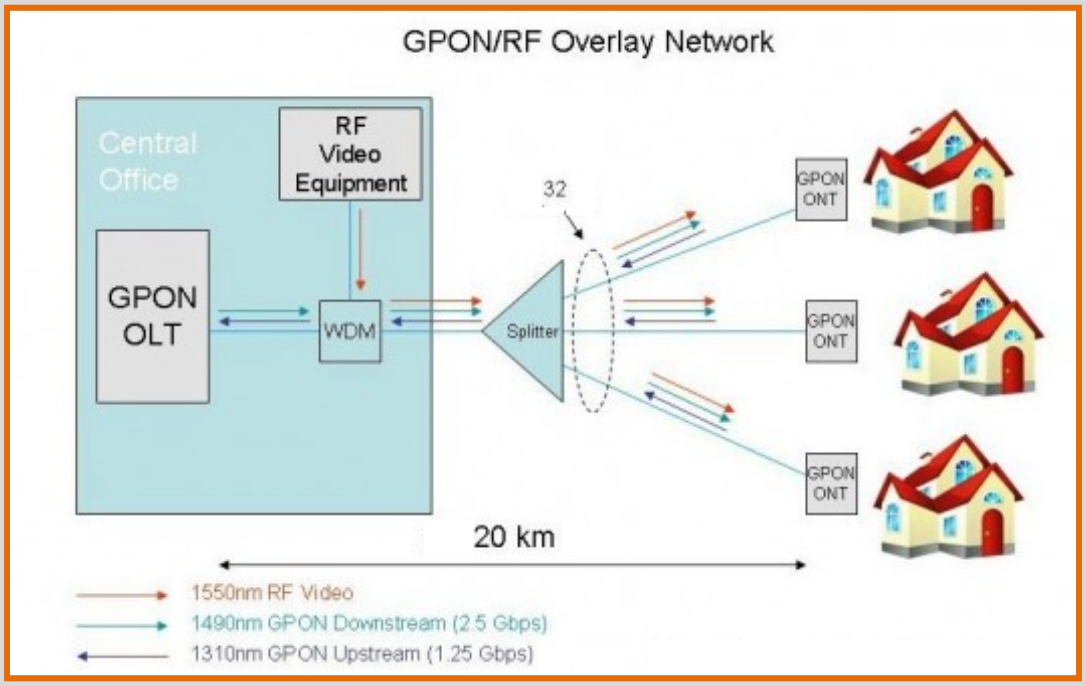
Alcance do sistema de longa distância

Rede de Acesso por Fibra Ótica



Exemplo de configuração de uma GPON com dois comprimentos de onda – sistema típico

Rede de Acesso por Fibra Ótica



Exemplo de configuração de uma GPON com três comprimentos de onda – sistema típico

Rede de Acesso por Fibra Ótica

Transmissão

- ***Outras características da camada física***

  – Codificação de linha
  - NRZ: "1" lógico – nível alto; "0" lógico – nível baixo
  - codificação de blocos 64B-66B

  – Taxa de erros objetivo de 1 x 10^{-10}: para o caso extremo de atenuação no trajeto ótico e de condições de dispersão

  – FEC: possibilidade de suporte após negociação entre OLT e ONU

  – Controlo dinâmico da potência da ligação ascendente: o OLT controla o nível de potência de transmissão dos ONU para uniformizar a potência recebida no OLT

Rede de Acesso por Fibra Ótica

Transmissão

- ***Outras características da camada física***

  – Controlo de emissão do laser do ONU
  - desligado eletricamente enquanto não transmite
  - requer um tempo de ativação relativamente longo até atingir o ponto de funcionamento
  - ONU ao OLT reporta tempos de ativação/desativação
  - OLT define duração do preambulo

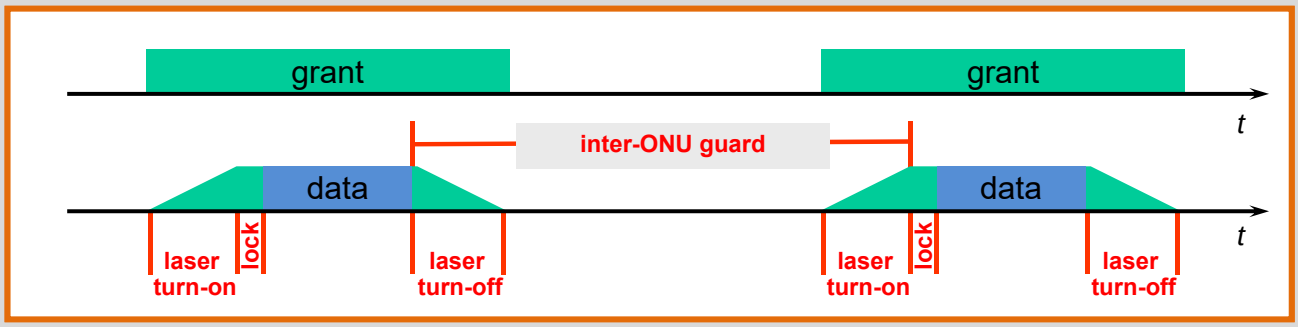


Diagrama de temporização da ligação ascendente

Rede de Acesso por Fibra Ótica

Transmissão

- ***Balanço de potência***
  - P_e : potência de transmissão ótica
  - P_r : potência mínima (sensibilidade) no recetor
  - BP : balanço de potência

$$BP = P_e - P_r$$

  - O balanço de potência disponível é repartido pelas perdas nos componentes passivos e pela atenuação da ligação
  - O excedente é a margem (de segurança)

$$BP = \alpha L + \sum Perdas\_Componentes + Margem$$

(a : atenuação específica da fibra)

Rede de Acesso por Fibra Ótica

Transmissão

- ***Balanço de potência***
  - Perdas de inserção de divisores – a maior parcela diz respeito à funcionalidade básica de divisão de potência
  - Há uma perda adicional de 1 a 1,5 dB

Factor de divisão	Perda ideal (dB)	Perda típica (dB)
1:4	6,0	7,0
1:8	9,0	10,0
1:16	12,0	13,5
1:32	15,0	16,5

Rede de Acesso por Fibra Ótica

Transmissão

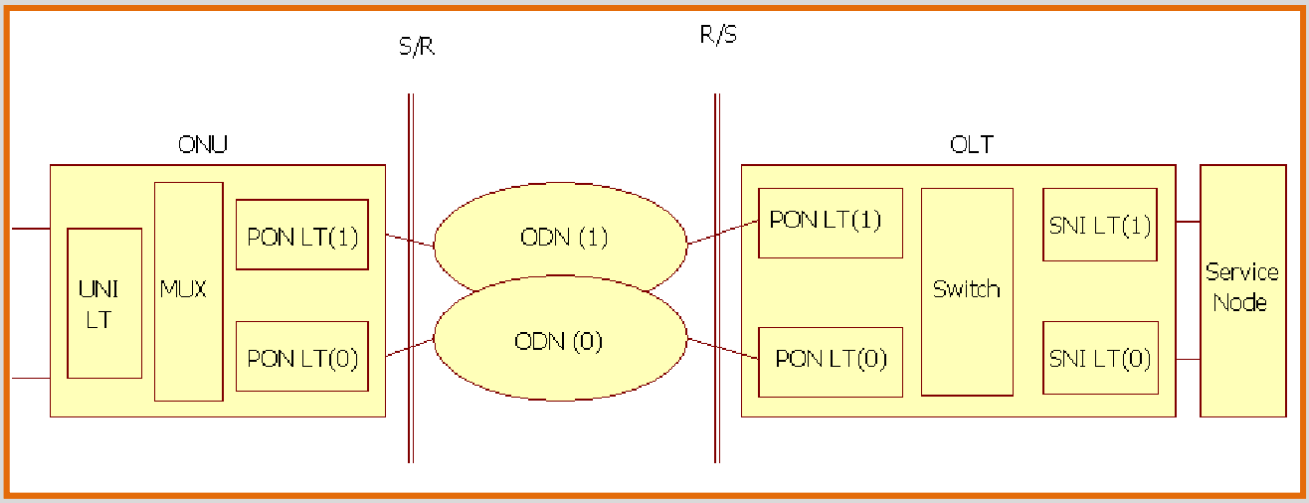
- ***Balanço de potência***
  - Exemplo
    - Fibra ótica monomodo a 1310 nm e divisor 1:32
    - Atenuação específica: $\alpha = 0{,}35$ dB/km
    - Perda de inserção do divisor: $P_d = 16{,}5$ dB
    - Perdas em conectores: $P_c = 2$ dB
    - Potência de transmissão ótica: $P_e = 0$ dBm
    - Potência mínima (sensibilidade) no recetor : $P_r = -26$ dBm
    - Alcance máximo: $L_{max} = 21$ km

$$L_{max} = \frac{BP - \sum Perdas\_Componentes}{\alpha}$$

Rede de Acesso por Fibra Ótica

Transmissão

- ***Proteções***
  - Duplicação de equipamentos ativos, dos divisores ou da fibra
  - A proteção é assegurada por comutação automática ou forçada



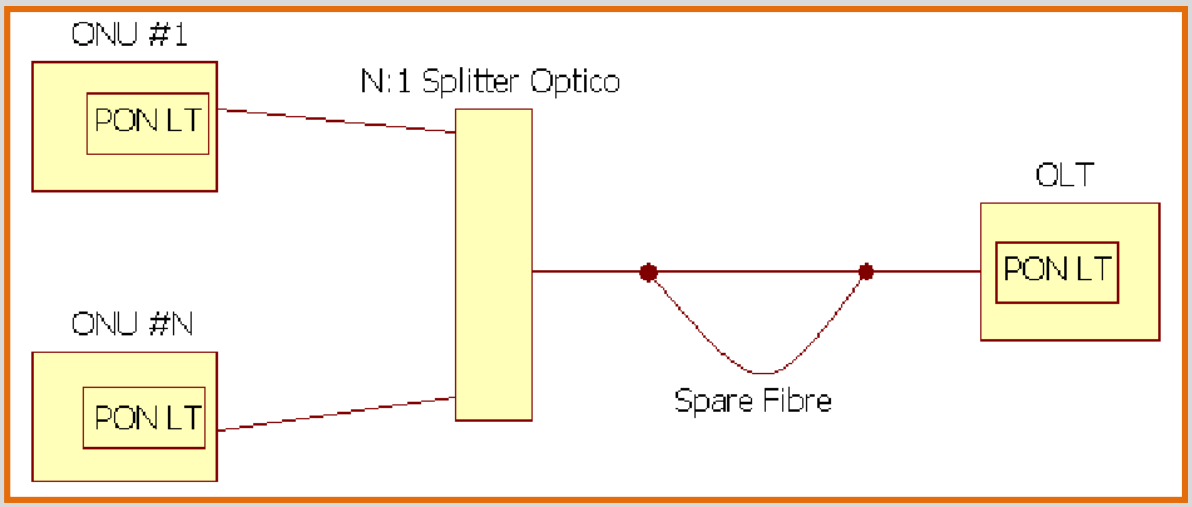
Modelo genérico do sistema de proteção

Rede de Acesso por Fibra Ótica

Transmissão

- ***Proteções***

Tipo A: duplica apenas a fibra ótica - neste caso, o ONU e OLT são singulares

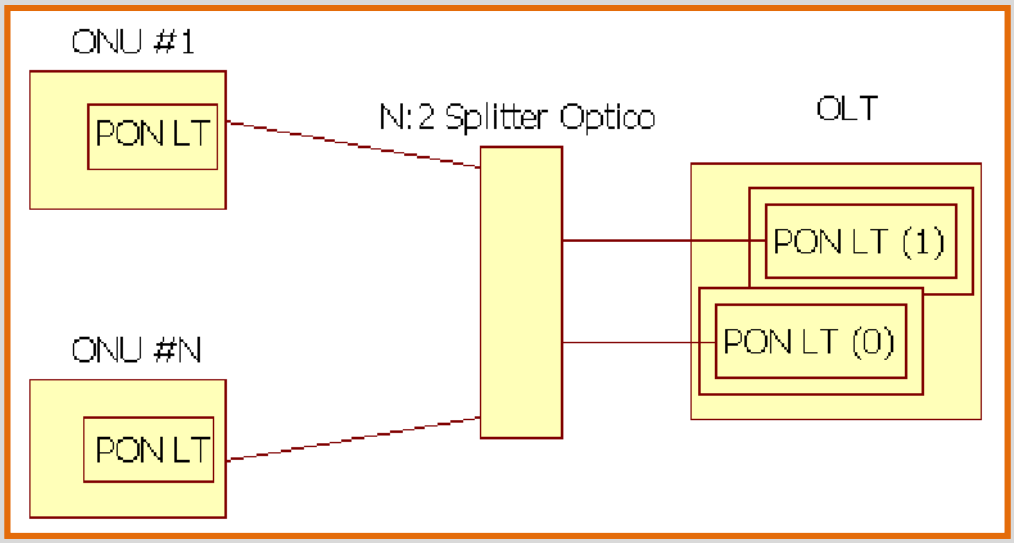


Rede de Acesso por Fibra Ótica

Transmissão

- ***Proteções***

Tipo B: duplica o OLT e a fibra ótica entre os OLTs e o *splitter* ótico - o *splitter* terá duas entradas/saídas no lado do OLT

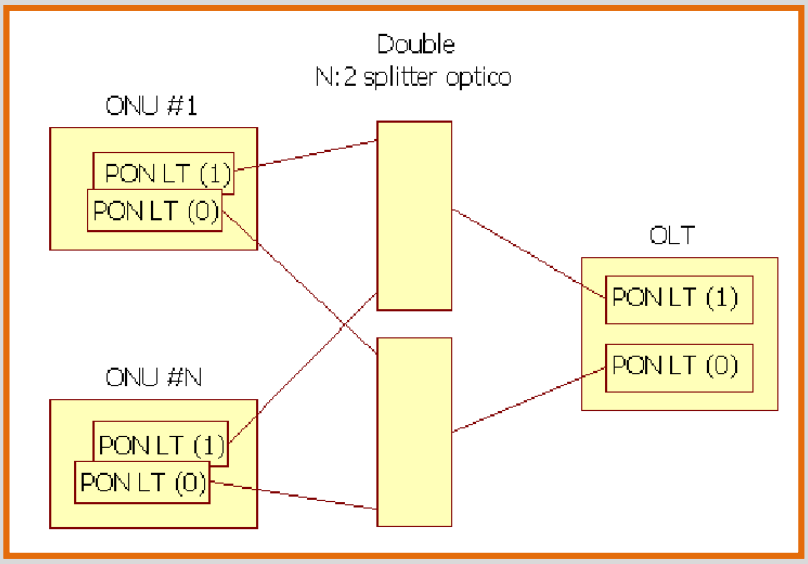


Rede de Acesso por Fibra Ótica

Transmissão

- ***Proteções***

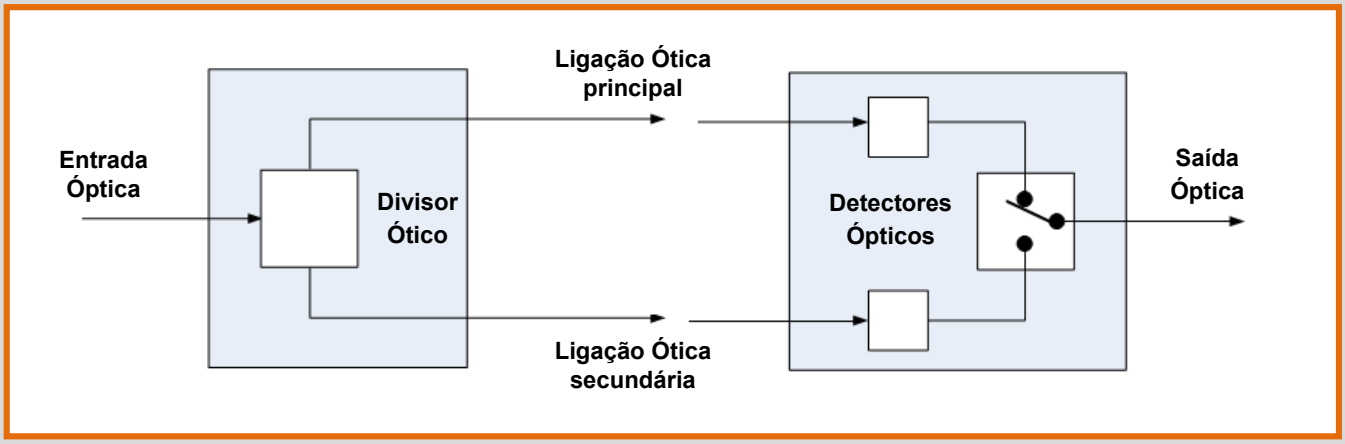
Tipo C: duplica não só do lado do OLT, mas também do lado do ONU



Rede de Acesso por Fibra Ótica

Transmissão

- ***Proteções***



Implementação prática da proteção de fibra

Passive Optical Networks

User Plane Operation

- ***Downstream traffic***

  – traffic multiplexing functionality is centralized and connection oriented

  – OLT multiplexes the GEM (GPON Encapsulation Method) frames onto the transmission medium using GEM Port-ID as logical connection identifier

  – each ONU filters the downstream GEM frames based on their GEM Port-ID and processes only the GEM frames that belong to that ONU

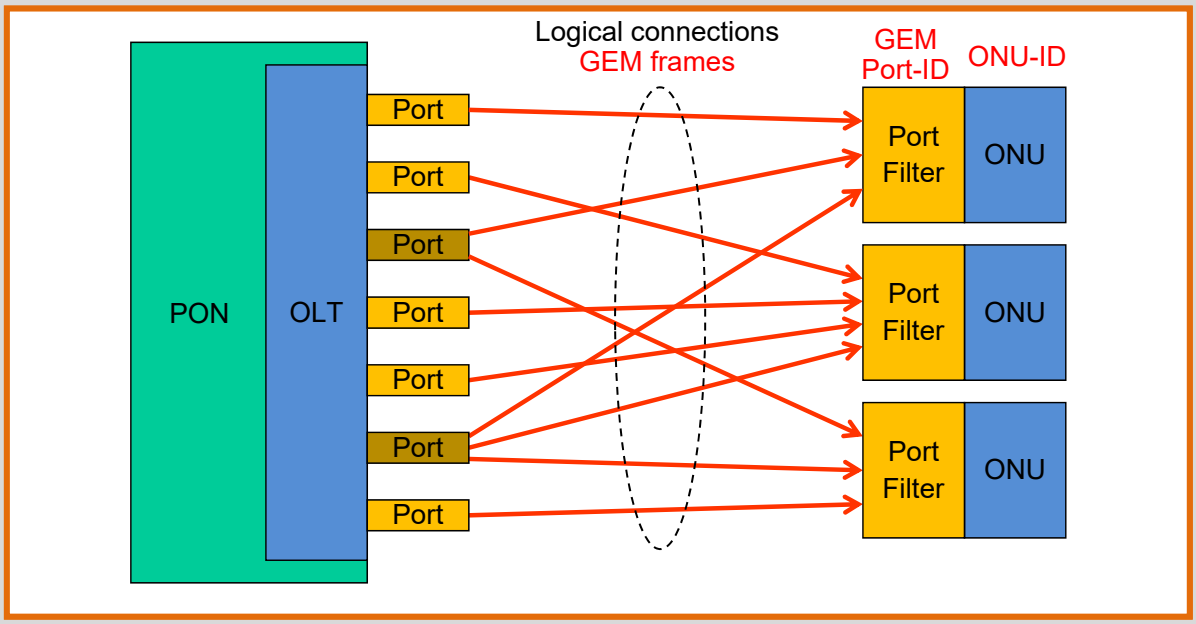
  – each GEM Port-ID may be assigned to multiple ONU, in order to support multicast logical channels

Passive Optical Networks

User Plane Operation

- ***Downstream traffic***

GEM (GPON Encapsulation Method)



Downstream multiplexing (darker GEM ports indicates multicast)

Passive Optical Networks

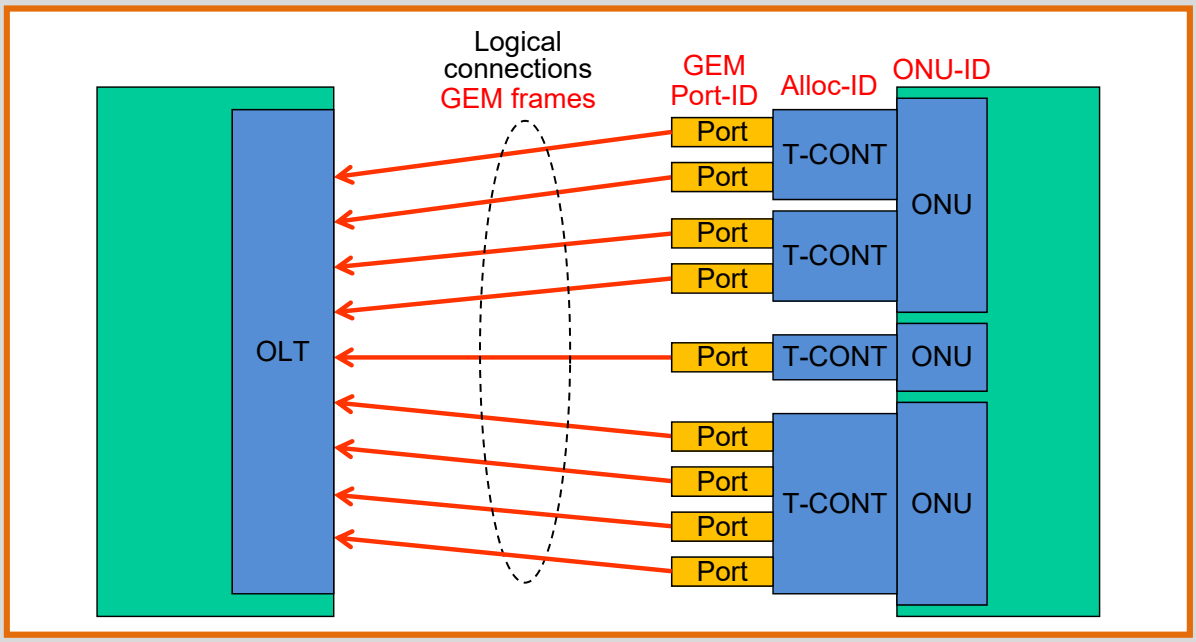
User Plane Operation

- ***Upstream traffic***
  - traffic multiplexing functionality is distributed and connection oriented
  - each ONU may support one (default) or multiple T-CONT (Transmission CONtainers) – each T-CONT represents an upstream traffic-bearing entity
  - OLT grants upstream transmission opportunities (bandwidth allocations) to each T-CONT – allocations are identified by their Alloc-ID (Allocation ID)
  - each T-CONT may support one or multiple logical connections – GEM frames are multiplexed onto T-CONT using GEM Port-ID as logical connection identifier
- ***Identifier assignments***
  - ONU-ID: identifies the ONU; assigned by OLT during ONU's activation
  - Alloc-ID: identifies an upstream traffic-bearing entity
    - default Alloc-ID: numerically equal to ONU-ID
    - additional Alloc-ID: assigned by OLT via OAM messages
  - GEM Port-ID: logical connection identifier; assigned by OLT via OAM messages

Passive Optical Networks

User Plane Operation

- ***Upstream traffic***

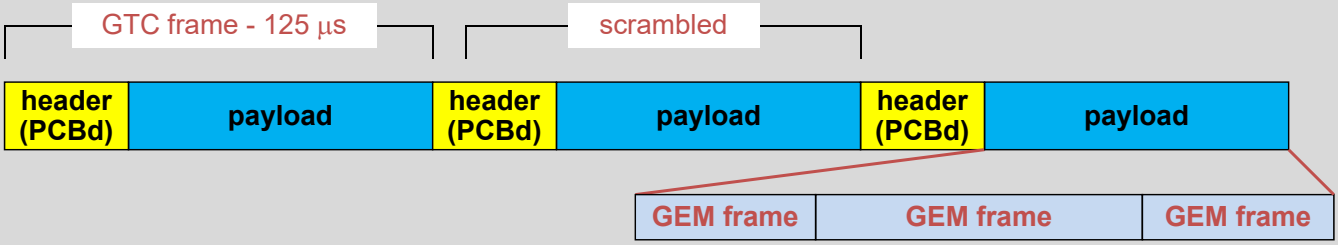


Upstream multiplexing

Passive Optical Networks

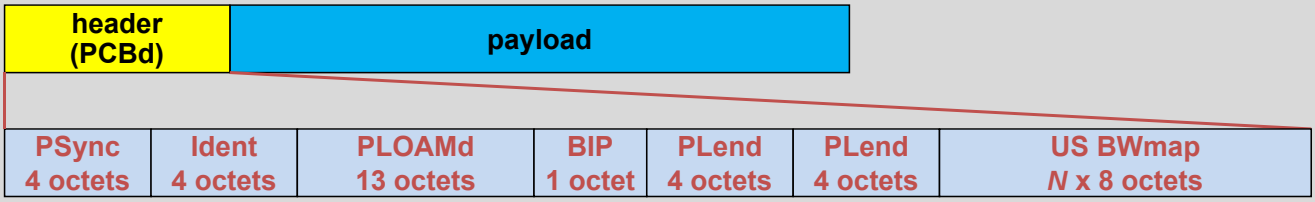
Frame formats – GPON Transmission Convergence

- ***Downstream traffic***
  - GTC (GPON Transmission Convergence) frames are always 125 μs long
    - 19 440 octets / frame for 1 244.16 Mbit/s
    - 38 880 octets / frame for 2 488.32 Mbit/s
  - GTC frame consists of a header (Physical Control Block downstream) + payload
  - header is prefixed by a physical synchronization pattern
  - payload carries GEM (GPON Encapsulation Method) frames with user data
  - transmitted data is scrambled (but not physical synchronization pattern)



Downstream GTC frame format

Passive Optical Networks



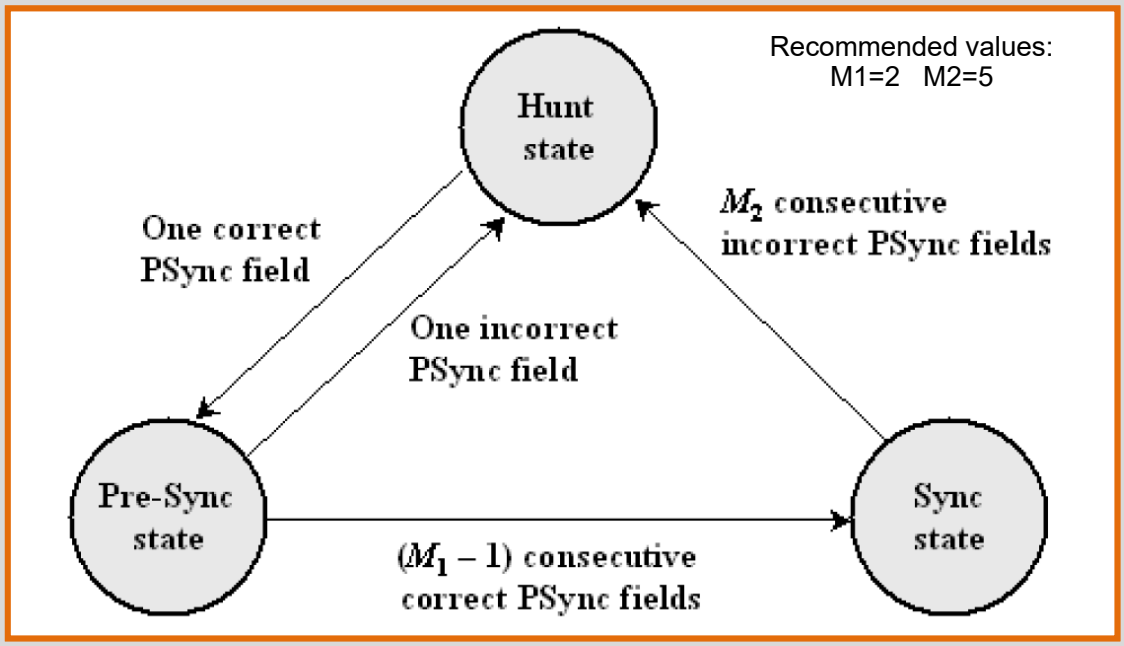
PSync – Physical synchronization
- 32-bit frame alignment pattern that begins every PCBd
- the ONU logic can use this pattern to find the beginning of the frame

Ident – Identifier
- Superframe counter (larger frame structures)
- Indication if FEC is being used in the downstream

PLOAMd – Physical Layer OAM downstream
- Operations, Administration and Maintenance downstream messages

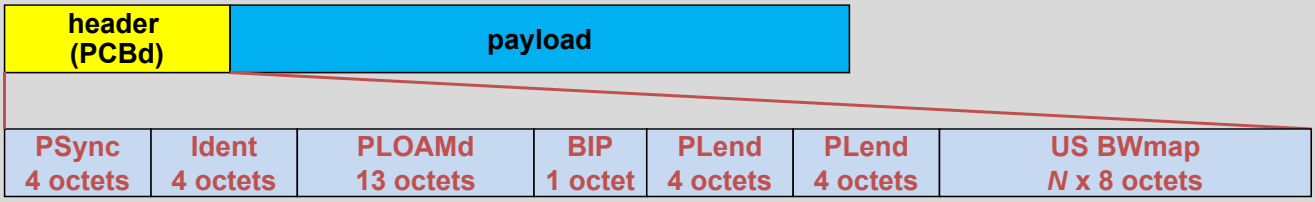
BIP – Bit-Interleaved Parity
- bit-interleaved parity of all bytes transmitted since the last BIP
- measures the number of errors on the link

Passive Optical Networks



GTC downstream ONU synchronization state machine

Passive Optical Networks



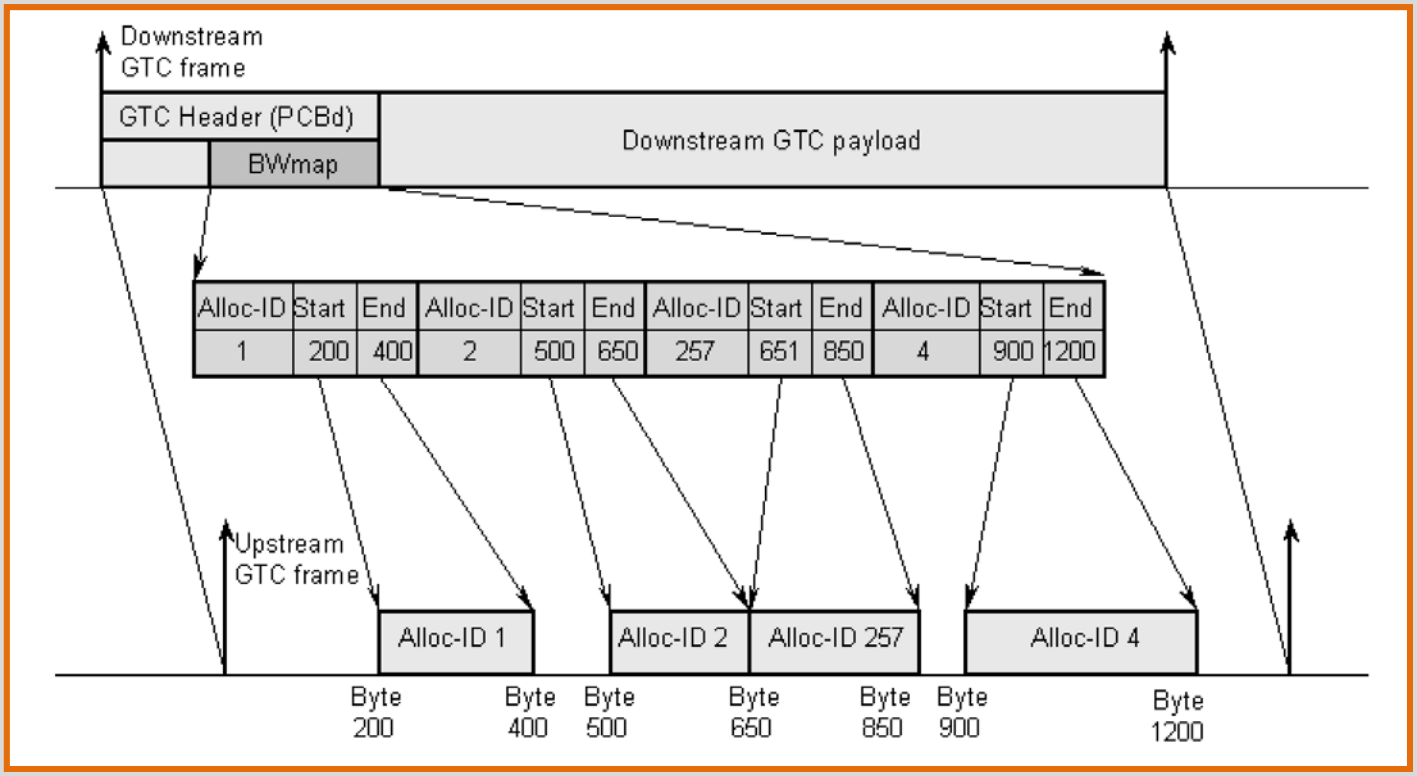
PLend – Payload Length downstream

- length of the Bandwidth map (number *N* of upstream traffic-bearing entities – T-CONT)
- CRC over this field with error detecting and correcting capabilities
- PLend is transmitted twice for robustness

US BWmap – Upstream Bandwidth map

- a Dynamic Bandwidth Allocation scheme is used based on monitoring traffic status (buffers) reported by ONUs
- OLT grants BW to US flow – defines start and end byte position of ONU transmission in the upstream frame
- flags in the BWmap indicate requests for the ONU to send a OAM report, send a sequence for power level adjustment, send a dynamic bandwidth report or use FEC
- CRC protects BWmap data

Passive Optical Networks

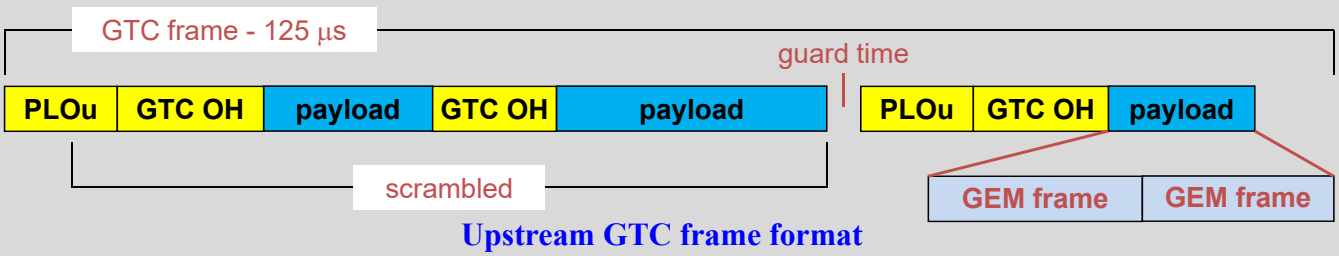


GTC media access control concept (flags and CRC in BWmap field are omitted)

Passive Optical Networks

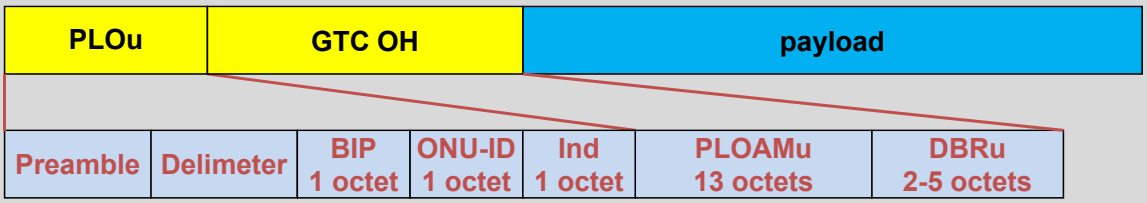
Frame formats – GPON Transmission Convergence

- ***Upstream traffic***
  - GTC (GPON Transmission Convergence) frames are also125 μs long
  - GTC frames are shared amongst ONU and transmitted as bursts
    - each burst consists of a Physical Layer Overhead upstream + GTC OH + payload (one or multiple T-CONT)
    - each burst is prefixed by a Preamble and a Delimiter for synchronization
    - contiguous bursts are separated by a guard time
    - transmitted data is scrambled (but not preamble+delimiter)



Upstream GTC frame format

Passive Optical Networks



Preamble + Delimeter
- enable OLT to acquire power and phase and to obtain frame alignment (respectively)
- lengths set by OLT in PLOAMd

BIP – Bit-Interleaved Parity
- bit-interleaved parity of all bytes transmitted since the last BIP

ONU-ID – ONU Identifier
- contains the unique ONU-ID of the ONU

Ind – Indication
- real time ONU status reports to the OLT

PLOAMu – Physical Layer OAM upstream
- Operations, Administration and Maintenance upstream messages (requested by OLT)

DBRu – Dynamic Bandwidth Report upstream
- traffic status of the T-CONT in question (requested by OLT)

Passive Optical Networks

Frame formats – GPON Transmission Convergence

- ***GEM frames***

Consultar a recomendação da UIT

ITU-T G984.3 (03/2008)
Secção 8.3 Mapping of GEM frames into GTC payload

Rede de Acesso por Fibra Óptica

Recomendações IUT-T – Gigabit-Capable Passive Optical Networks

G.984.1 – Gigabit-capable Passive Optical Networks (G-PON): General characteristics
Provides examples of services, User Network Interfaces (UNI) and Service Node Interfaces (SNI) that are required by network operators. In addition, it shows the principal deployment configuration. Wherever possible, this Recommendation maintains characteristics from the ITU-T G.982 and G.983.x series Recommendations in order to promote backward compatibility with existing Optical Distribution Networks (ODN) that comply with these Recommendations.

G.984.2 – Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification
Specifies the physical layer requirements and specifications for the Physical Media Dependent (PMD) layer.
This Recommendation covers systems with nominal line rates of 2488.320 Mbit/s in the downstream direction and 1244.160 Mbit/s and 2488.320 Mbit/s in the upstream direction.
Both symmetrical and asymmetrical (upstream/downstream) Gigabit-capable Passive Optical Network (G-PON) systems are described.

G.984.3 – Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification
Specifies the frame format, media access control method, ranging method, OAM functionality and security in G-PON networks.

G.984.4 – Gigabit-capable Passive Optical Networks (G-PON): ONT management and control interface specification
Specifies the managed entities of a protocol-independent Management Information Base (MIB) that models the exchange of information between the Optical Line Termination (OLT) and the Optical Network Termination (ONT). In addition, it covers the ONT management and control channel, protocol and detailed messages.

G.984.5 – Enhancement band for gigabit-capable optical access networks
Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength-division multiplexing (WDM) in future Passive Optical Networks (PON) for maximizing the value of Optical Distribution Networks (ODNs).

G.984.6 – Gigabit-capable Passive Optical Networks (G-PON): Reach extension
Outlines the architecture and interface parameters for G-PON systems with extended reach using a physical layer reach extension device, including regenerators or optical amplifiers. The maximum physical reach is up to 60 km, with loss budgets in excess of 27.5 dB being achievable in both spans. This new capability will allow operators to provide optical access service to areas that were previously out of reach, and also explore new network designs for greater central office consolidation.

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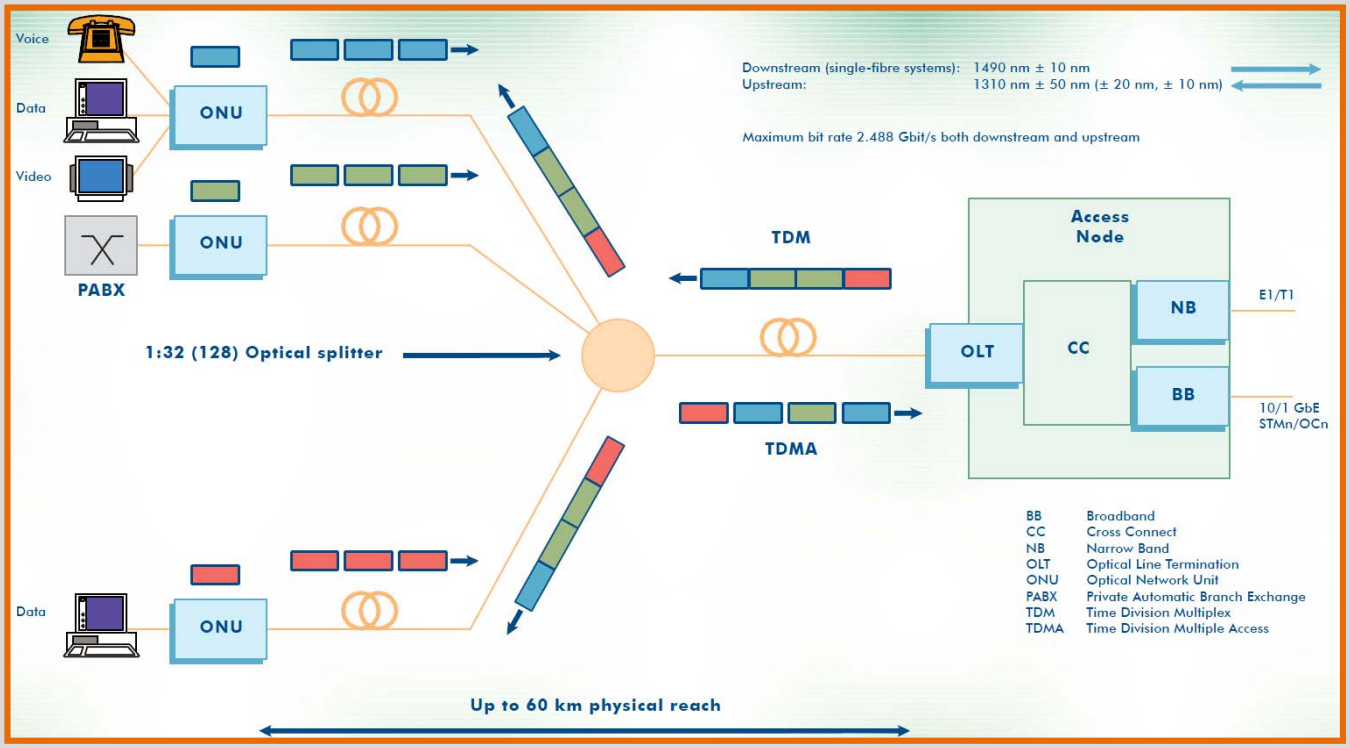

Arquitectura de um sistema de acesso G-PON

Sistemas de Telecomunicações *PON*

Rede de Acesso por Fibra Óptica

Recomendações IUT-T – Ten-Gigabit-Capable Passive Optical Networks

G.987 — 10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms

Establishes common terms and acronyms used in the G.987 series, as well as delineates various optical access topologies.

G.987.1 — 10-Gigabit-capable passive optical network (XG-PON) systems: General requirements

Lists system-level requirements for XG-PON systems. Most significantly, the XG-PON system can coexist with a G-PON system on the same ODN. Provides examples of the wide variety of SNIs, UNIs and system configurations possible.

G.987.2 — 10-Gigabit-capable passive optical network (XG-PON) systems: Physical media dependent (PMD) layer specification

Defines the physical layer interface specifications for the system operating at the nominal data rates of 10 Gbit/s downstream, 2.5 Gbit/s upstream.

G.987.3 — 10-Gigabit-capable passive optical network (XG-PON) systems: Transmission convergence specification

Defines the frame format, forward error correction, media access control method, ranging and activation scheme, physical layer OAM and security features for the XG-PON system.

G.988 — ONU management and control interface specification (OMCI)

Defines the managed entities of a protocol independent MIB for ONU FCAPS management, suitable for PON and point-to-point systems, including XG-PON, G-PON and Gigabit Ethernet. Defines the management control channel, protocol and messages.

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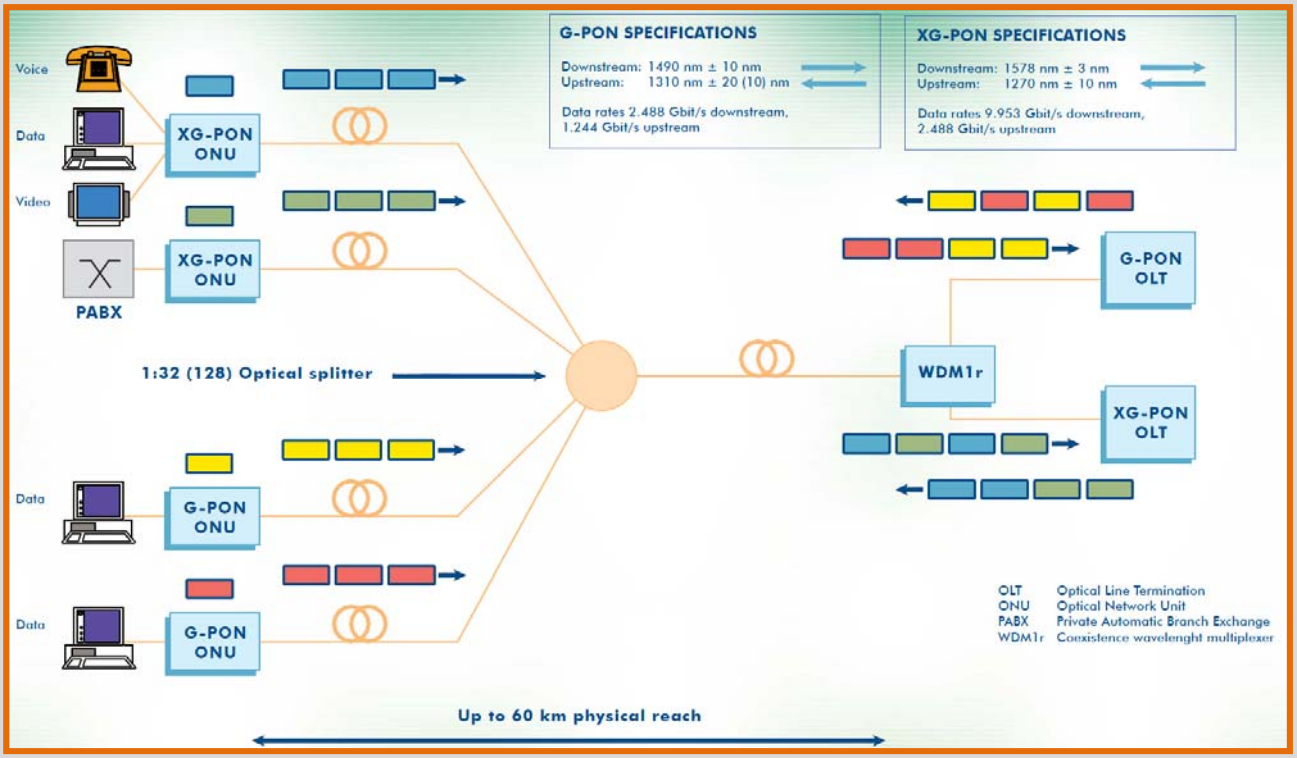

Arquitectura de um sistema de acesso XG-PON

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