Optical Access Networks

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Access Networks and Full Service Providers

- The networks feeding the metro (and core) networks by gathering data from the end users (us).
- The two main contenders are CATV companies and phone companies.
- This is due to the two existing network infrastructures:
  - Telephone (POTS) networks (xDSL);
  - Cable TV networks (Cable Modems).
- Since existing cable infrastructures are available, operators try to “milk” their networks to provide data services such as high speed Internet access.
- This requires upgrading those infrastructures, to overcome the 4 kHz limited unidirectional broadcast.
- Services can be switched/broadcast, symmetrical/asymmetrical, unidirectional/bidirectional, and can be provided with different bandwidths.

Services Supported by Access Networks

Service	Type	Downstream Bandwidth	Upstream Bandwidth
Telephony	Switched	4 kHz	4 kHz
ISDN	Switched	144 kbit/s	144 kbit/s
Video Broadcasting	Broadcast	6 MHz or 2 to 6 Mbit/s	0
Interactive Video	Switched	6 Mbit/s	Small
Internet Access	Switched	Some Mbit/s	Small (initially)
Video-Conference	Switched	6 Mbit/s	6 Mbit/s
Enterprise Services	Switched	1.5 Mbit/s to 10 Gbit/s	1.5 Mbit/s to 10 Gbit/s

Downstream: from the service provider to the user.
Upstream: from the user to the service provider.
Full Service: provision of all the services available through access networks.

Criteria for Classification of Services

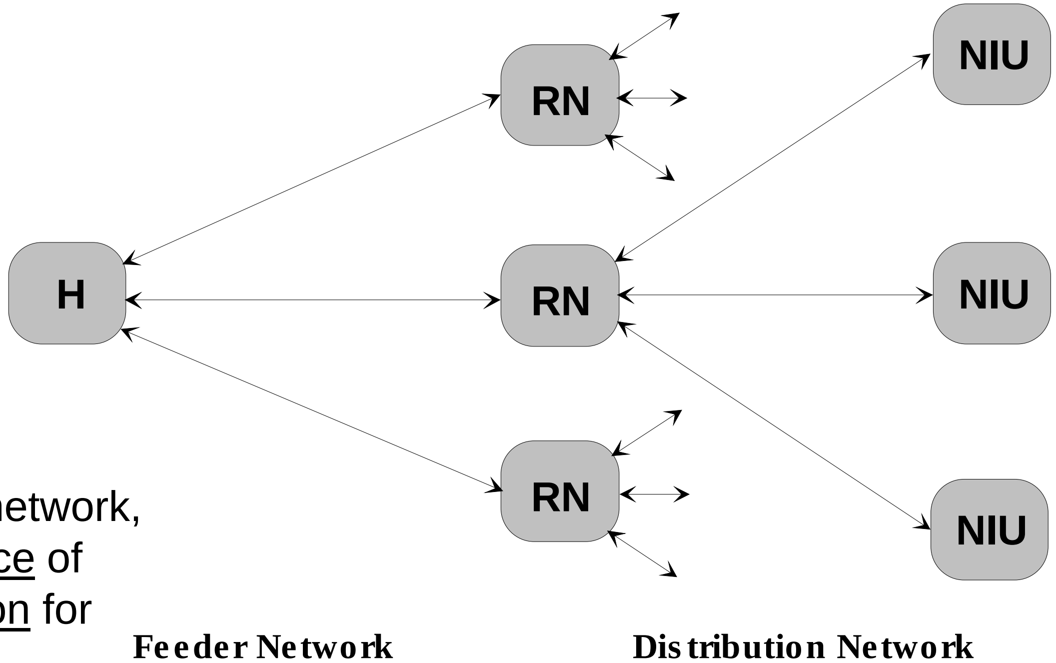
- Bandwidth requirements.
- Symmetrical (bidirectional) or Asymmetrical (unidirectional).
- Broadcast or Switched.

Architectures for Access Networks

H = *Hub*
RN = *Remote Node*
NIU = *Network Interface Unit*

- A NIU may be located in the premises of one subscriber or may serve several subscribers.

- The Hub is usually part of a larger network, but may be considered as the <u>source</u> of data for the NIUs and the <u>destination</u> for data coming from the NIUs.



- Different combinations of services and network topologies are possible: a broadcast service may be supported by a broadcast or switched network, as well as a switched service.

- In a **broadcast network**, a RN broadcasts data it receives from the Hub to all its NIUS.

- In a **switched network**, a RN processes the data coming from the Hub and, eventually, sends different traffic flows to each of its NIUs.

Classification of Access Networks

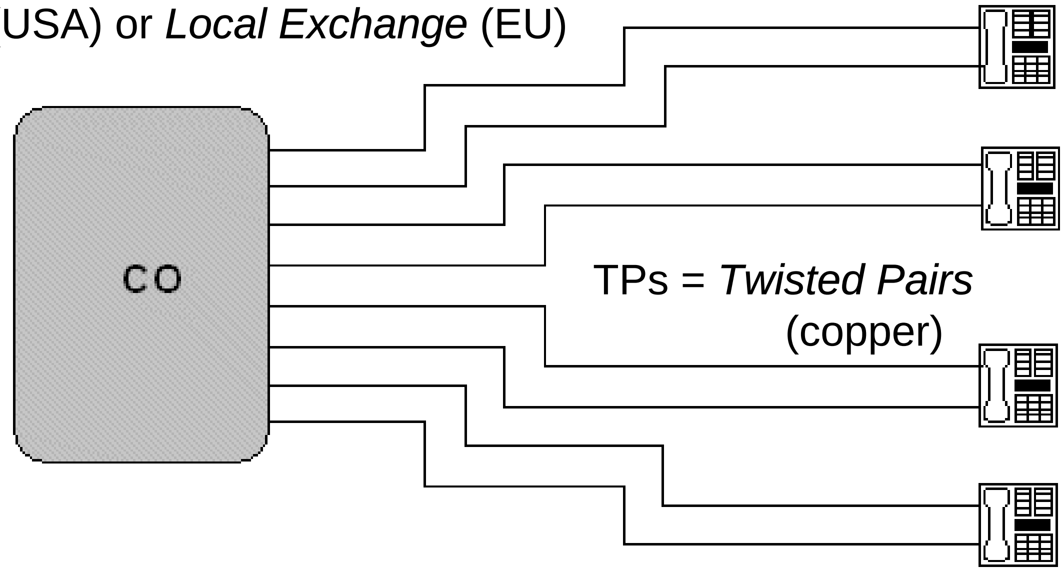
Distribution Network	Feeder Network	
	Shared BW	**Dedicated BW**
Broadcast	CATV (HFC), TPON	WPON
Switched		Telephony, DSL, WRPON

HFC = *Hybrid Fiber Coaxial*; DSL : *Digital Subscriber Loop*; PON : *Passive Optical Network*;
T = *Telephony*; W : *Wavelength*; WR = *Wavelength Routed*; BW = *BandWidth*.

- Broadcast networks may be cheaper than switched ones, are adequate for provision of broadcast services, and have the advantage of identical NIUs for all the subscribers.
- Switched Networks are more appropriate for switched services and provide more security.
- Fault localization is generally easier in switched networks, because intelligence is in the network instead of the NIUs, as in broadcast networks.
- In switched networks the NIUs may be simpler than in broadcast networks.
- A disadvantage of feeder networks with shared bandwidth is the need for each NIU to operate in the total network bandwidth. Besides, with dedicated bandwidth it is possible to provide QoS guaranties to the NIUs.

Local Telephone Network

CO = *Central Office* (USA) or *Local Exchange* (EU)



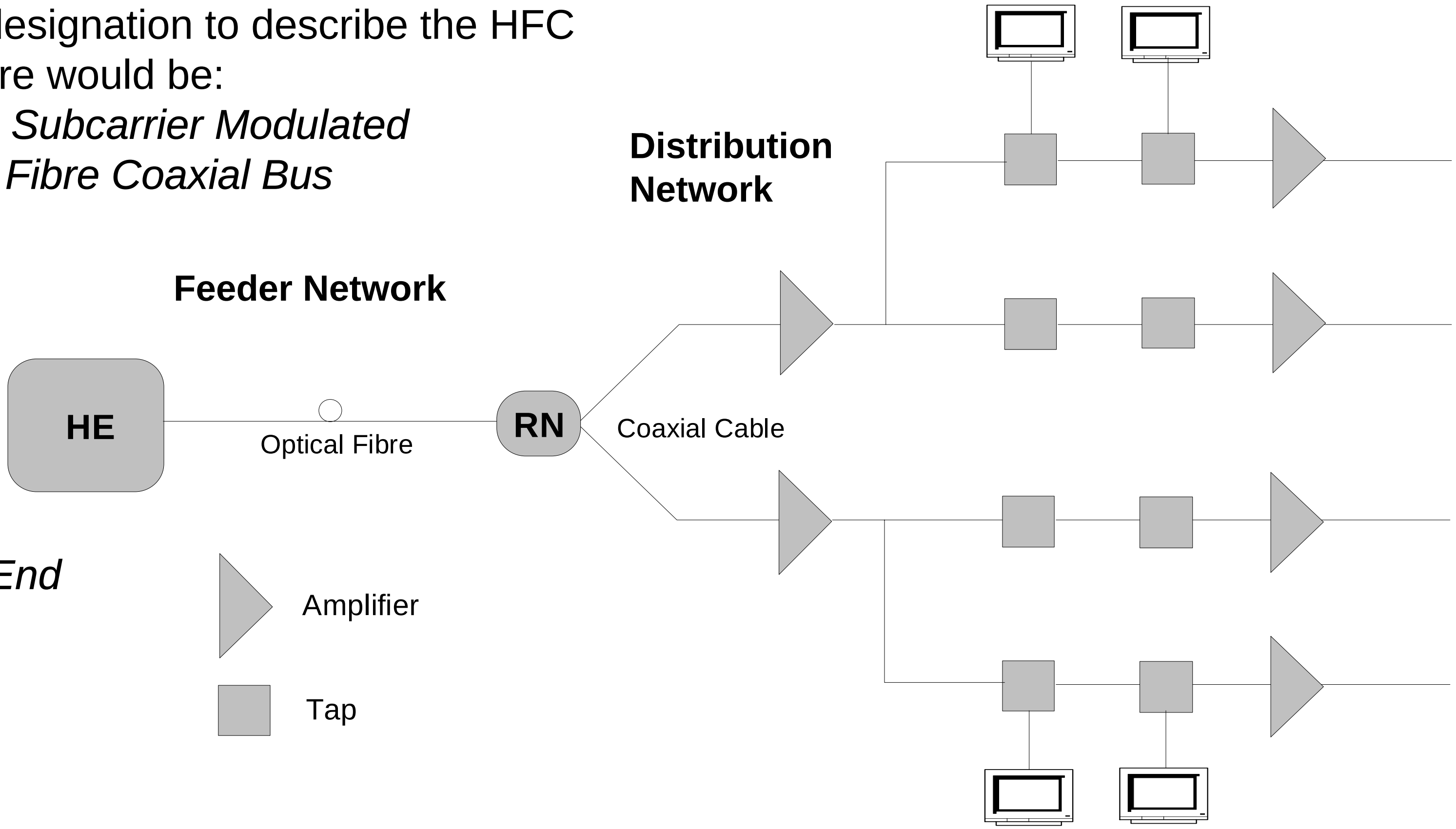
- This is a switched network designed to provide a bandwidth of 4 kHz to each subscriber, although modulation and signal processing techniques available nowadays enable the use of much larger bandwidths.

- The same infrastructure is used by the ISDN (BW of 144 kbit/s) and by DSL technology (a few Mbit/s). With the latter, the possible data rate varies inversely with the distance to the local exchange, and the 4 kHz filters of the original telephone line must be removed.

http://www.dslforum.org/

CATV Network – HFC Architecture

- A better designation to describe the HFC architecture would be:
  SMFCB = *Subcarrier Modulated Fibre Coaxial Bus*



HE = *Head End*

- The feeder network uses the signal of a laser with SCM (*Sub Carrier Multiplexing*).
- The feeder network uses a bandwidth between 50 and 550 MHz. In this band, the coaxial cable can carry about 70 TV signals in AM-VSB.
  A spectral window between 5 and 40 MHz is also available, for return signals.

Alternative (broadband) Access Technologies

Satellite Systems

- Systems for direct broadcasting by satellite (**DBS**) use geostationary satellites to broadcast a few hundred TV channels, and may provide larger bandwidth than cable broadcasting systems, but frequency reuse is limited due the large coverage area (footprint) of each satellite, and it is not easy to provide support for upstream traffic.

Fixed Wireless Access (FWA)

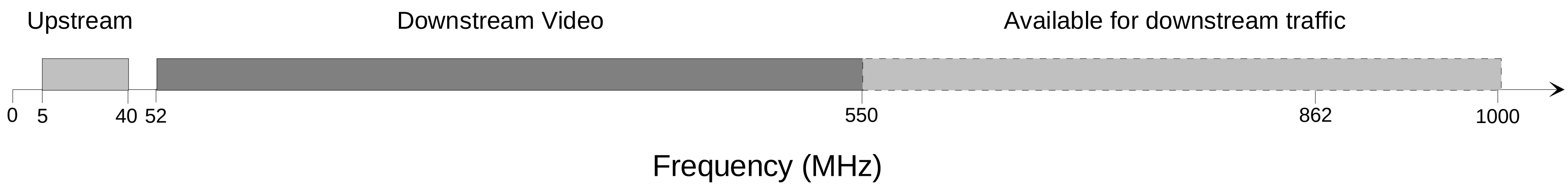
- Although with limited BW and reach, these systems may be deployed quickly and enable new service providers to enter the market without a cable infrastructure.
- The more relevant alternatives are **MMDS** (*Multichannel Multipoint Distribution System*) and **LMDS** (*Local Multipoint Distribution System*). Both are line of sight systems.
  MMDS provides more than 30 TV channels in the bandwidth from 2 to 3 GHz, with a reach of 15 to 55 km, depending on the transmitted power. http://www.wcai.com/mmds.htm
  LMDS operates in the 28 GHz band with a bandwidth of 1.3 GHz, and is more adequate for short reach coverage (3 to 5 km, depending on rain) in dense urban areas.
  http://www.lmdswireless.com/

Free Space Optics (*Optical Wireless*)

- These systems employ lasers, and may provide a transmission capacity from about 100 Mbit/s up to 2.5 Gbit/s, with a reach from hundreds of m to a few km, in line of sight.
  http://www.fsona.com/index.php

Enhanced HFC (EHFC) Architecture

http://www.adventnetworks.com/products/Overview.pdf



Improvements provided by the EHFC Architecture

- The bandwidth may be increased up to 1 GHz. Systems using 862 MHz are already available.
- In each channel, digital modulation techniques with high spectral efficiency may be used, such as 256-QAM (7 (bit/s)/Hz).
- The fibre may penetrate deeper into the network, thereby reducing the number of subscribers served by each RN to about 50 (instead of 500, typical of the HFC architecture).
- Multiple fibres and multiple wavelengths may be used (greater capacity).
- Besides high power lasers combined with booster optical amplifiers in the wavelength of 1.55 μm, signals in the 1.3 μm window may be multiplexed in narrow band mode (*narrowcasting*), for selected groups of users.

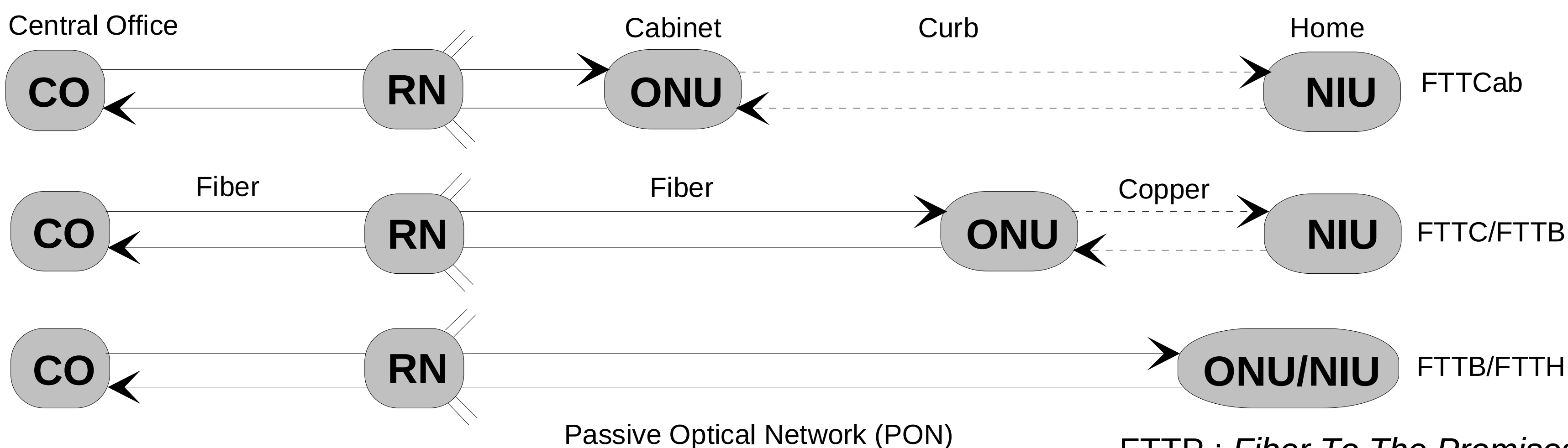
Functions of the NIUs

- Each NIU may serve one or more subscribers, and its functions are: (1) to decompose the signals into telephone and video signals, and (2) send them on twisted and coaxial pairs, respectively, to each subscriber.

Fibre Access Networks: FTTCab, FTTC/B, FTTB/H

- In contrast with the HFC architecture, in fibre access networks (Fiber In The Loop, FITL) data are transmitted in digital format over optical fibre, in the distribution network, until fibre terminating nodes designated by ONUs = *Optical Network Units*

- The designations used to describe this architecture depend on the proximity between the ONUs and the subscribers' premises:
  - **FTTH** (*Fiber To The Home*); ONUs perform the functions of NIUs;
  - **FTTC** (*Fiber To The Curb*) / **FTTB** (*Fiber To The Building*); the ONUs serve a small number of subscribers (8 to 64); typically, the fibre is terminated at less than 100 m from the subscriber, and there is an additional copper distribution network between ONUs and NIUs;
  - **FTTCab** (*Fiber To The Cabinet*); the fibre is terminated in a nearby cabinet, less than 1 km from the subscriber, and a distribution network between ONUs and NIUs is also employed.



FTTP : *Fiber To The Premises*

PON Architectures

PON = *Passive Optical Network* : network between the CO and the ONU.

- The remote node (RN) is a simple passive device, such as an optical star coupler or a static wavelength router, and sometimes may be installed at the central office.

- The designation FTTC is commonly used to describe an architecture in which the signals are broadcast from the CO to the ONUs, and the ONUs share the total bandwidth in TDM. This architecture is also designated by **BMFCB** (*Baseband Modulated Fiber Coaxial Bus*) or **SDV** (*Switched Digital Video*).

- In the context of FTTC architectures, the feeder network is the part of the network between the CO and the RNs, and the distribution network is the part between the RNs and the ONUs.
  Several types of architectures may be realized by employing different types of sources at the CO, combined with different types of RNs.

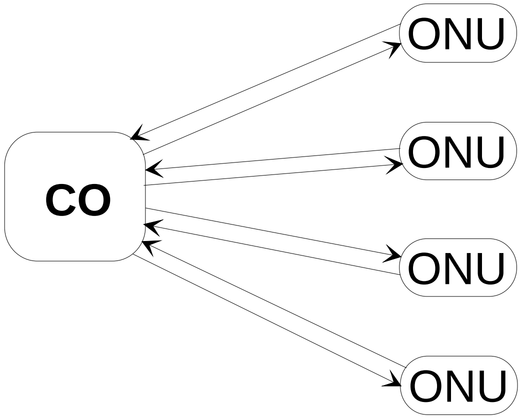
Architecture	Shared Fiber	Power Splitting	Data Rate at the ONU	Node Synchronization	Shared CO
AF (*All Fiber*)	No	None	1	No	No
TPON	Yes	$1/N$	N	Yes	Yes
WPON	Yes	$1/N$	1	Yes	No
WRPON	Yes	None	1	Yes	Yes

N : number of ONUs in the network.

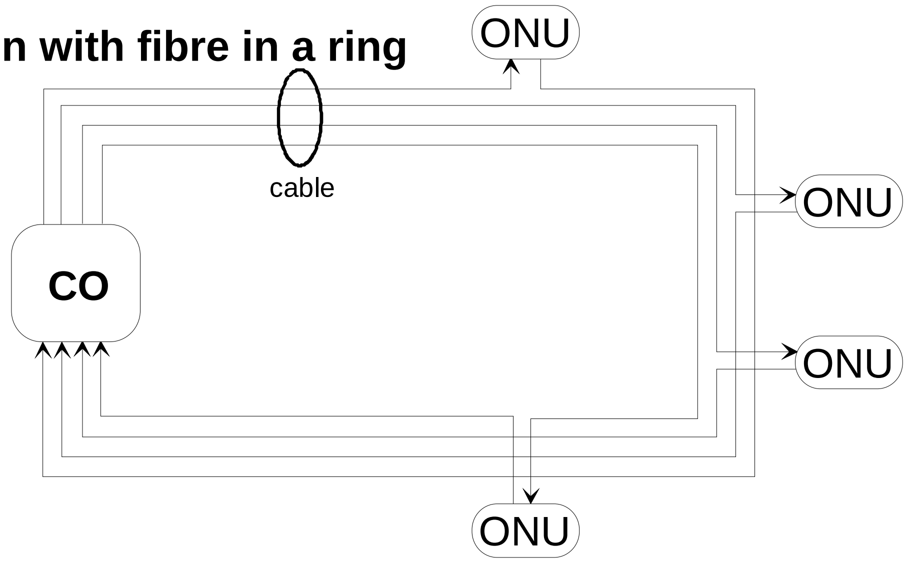
Data Rate: 1 means that ONU operates at the rate of the traffic delivered to it, instead of the aggregate rate N.

AF (*All Fiber*) Architectures

Solution with point-to-point fibre



Solution with fibre in a ring



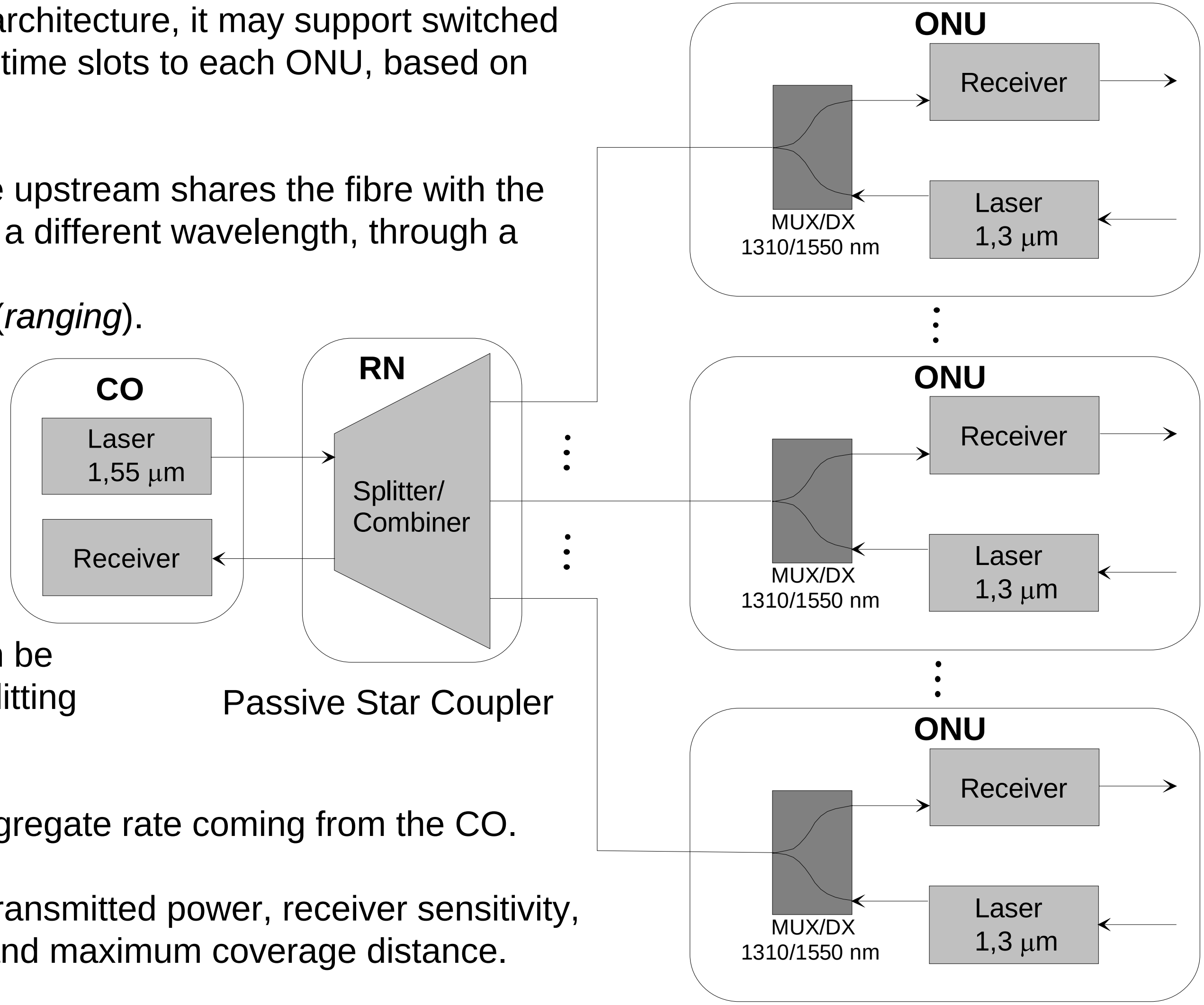
- The simplest PON architecture uses a pair of fibres between the CO and each ONU. Physically, the fibres may be deployed in a ring configuration. Instead of a pair, a single fibre with bidirectional transmission may be used, but the same wavelength cannot be used to simultaneously transmit in both directions, due to reflections at the ends. The solution is to use *Time Division Duplex* (TDD) or different wavelengths, (1.3 and 1.55 μm, for example), which may be called *Wavelength Division Duplex* (WDD)..
- The cost of this solution grows linearly with the number of ONUs, and the operator must deploy and maintain all the fibres.
- Presently, this architecture is used in small scale, mainly to provide high speed services to enterprises (NTT, in Japan, operates a system with data rates between 8 and 32 Mbit/s in each fibre).
- In the SONET/SDH rings, a pair of fibres is shared by multiple ONUs (which are OADMs). These rings are considered as an alternative access solution, but not as members of the PON family.

TPON (*Telephony* PON) Architecture

- In spite of being a broadcast architecture, it may support switched services by assigning specific time slots to each ONU, based on its bandwidth needs.

- In the distribution network, the upstream shares the fibre with the downstream by using TDM, in a different wavelength, through a coupler.
- ONUs must be synchronized (*ranging*).

ONU
Rx: pin FET
Tx: LED or FP laser



Passive Star Coupler

- The number of ONUs that can be supported is limited by the splitting losses at the RN.

- ONUs must operate at the aggregate rate coming from the CO.

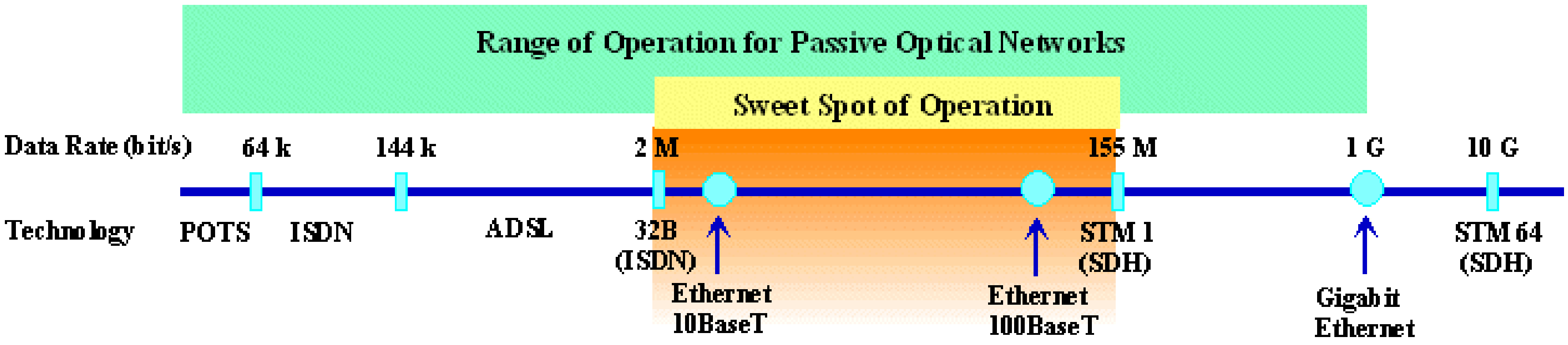
- There is a trade off between transmitted power, receiver sensitivity, data rate, number of ONUs, and maximum coverage distance.

Commercial Opportunity for PONs

- Presently, the higher data rates in the deployed access networks are offered by xDSL technologies and *Cable* MODEMs, and they do not usually reach more than 1.5 Mbit/s.
- Contrasting with this, the bandwidth grows dramatically in the transport network due to the adoption of WDM technology, which is already penetrating into metropolitan networks (MANs).
- Simultaneously, most organizational LANs have been upgraded from 10 do 100 Mbit/s, and it is expectable that they will be upgraded to *gigabit*-Ethernet in the near future.

- The result of these conditions is an ever larger gap between the capacity of metropolitan networks and the needs of residential subscribers and SMEs (Small and Medium Enterprises).

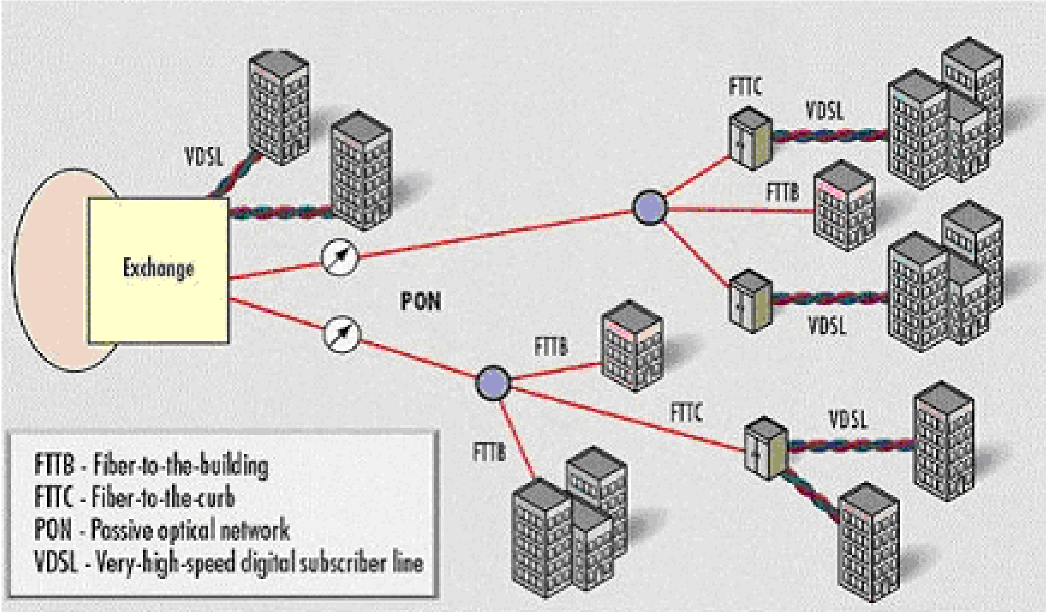
- PONs may fill this gap, satisfying the market needs in the interval of data rates from 1.5 Mbit/s to 155 Mbit/s, not yet supported by economical alternative technologies.



PON – Typical Architecture

- A PON is formed by and Optical Line Terminal (OLT), located at the CO, and a set of ONUs located at or in the neighbourwood of subscribers' premises.
- Between these active elements an ODN (Optical Distribution Network) is deployed, employing optical fibres and passive components (splitters/combiners and couplers).

- Presently, the ODN may operate at 155 Mbit/s, 622 Mbit/s, 1.25 Gbit/s, or 2.5 Gbit/s, by using one of the available standards APON/BPON/EPON/GPON.



http://www.ponforum.org/

- Downstream traffic is broadcast by the OLT to all ONUs. Each of these processes the traffic which is destined to it, through an address contained in the header of the PDU (*Protocol Data Unit*).

- Upstream traffic uses TDMA, under control of the OLT located at the CO, which assigns time slots to each ONU for synchronized transmission of its data bursts.

- The bandwidth assigned to each user may be static or dynamically variable, for support of voice, data and video applications.

FSAN (*Full Service Access Network*) Standard

- This standard was developed by an alliance of service providers and equipment builders, and specifies a **TPON** architecture based on ATM (**APON**) with a downstream bandwidth of up to 622 Mbit/s and an upstream bandwidth of up to 155 Mbit/s.
- Maximum coverage distance is 20 km, with a total fibre attenuation between 10 and 30 dB.
- Practical values of the link power budget allow power splitting by 16 or 32 at the RN.
- For example, an APON operating at 622 Mbit/s with a 32-way splitter may provide a data rate of 20 Mbit/s to each subscriber.
- An APON may operate over a single fibre, by using different wavelengths in the upstream (1.3 μm) and downstream (1.55 μm), or over a pair of fibres, by employing only 1.3 μm transmitters.

http://www.fsanweb.org/

FSAN
Full Service
Access Network

BPON (*Broadband* PON) and GPON (*Gigabit-capable* PON)

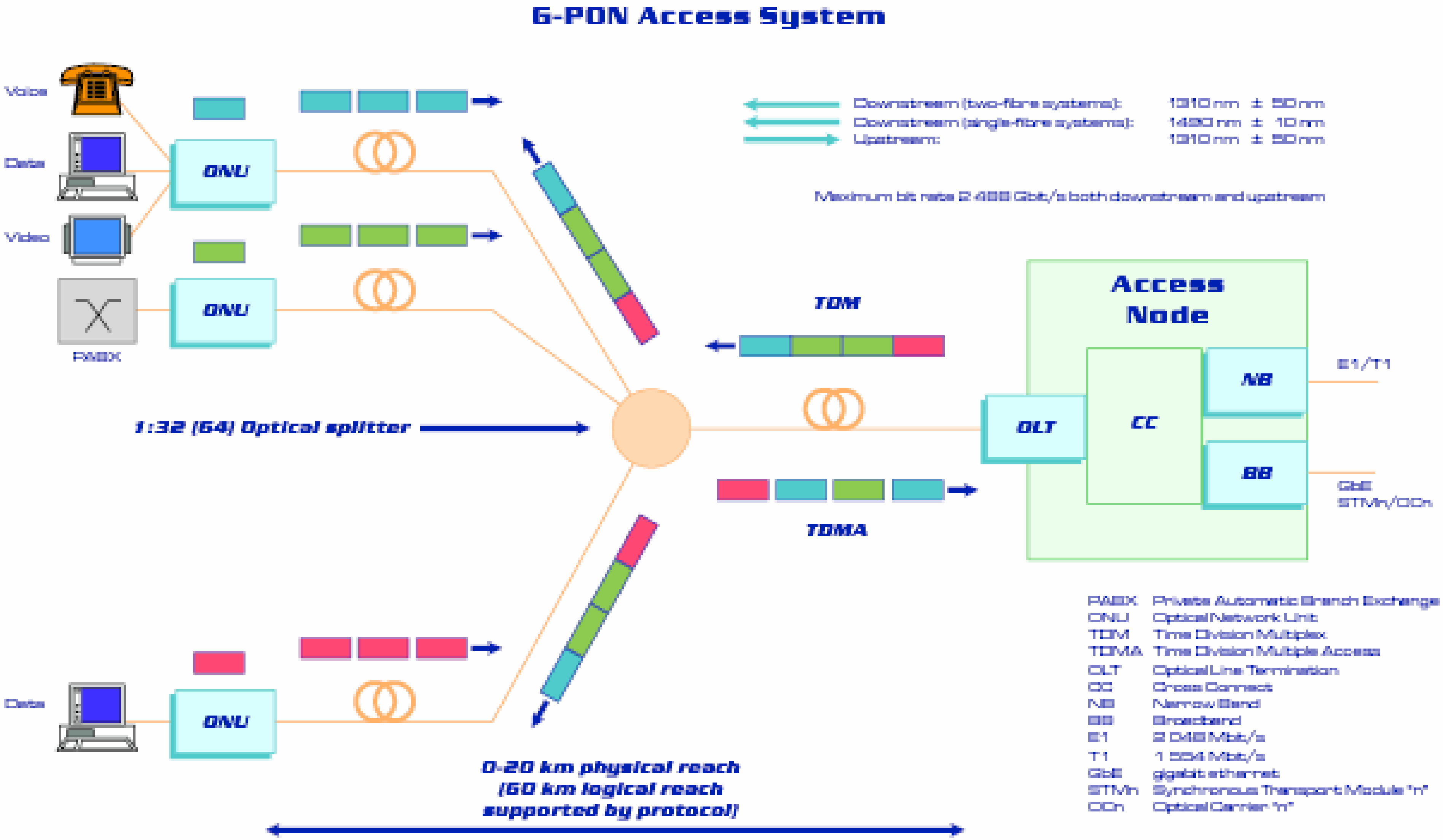
- APONs (ATM-based PONs) were developed during the second half of the 1990 decade, through the FSAN (*Full Service Access Network*) initiative, which resulted from the industrial alliance promoted by BT in 1995 with the objective of developing standards to extend high speed services (such as data over IP, video and Ethernet 10/100) over fibre to residential customers and SMEs.
- The APON standard was primarily focused in applications for SMEs, and its initial version did not include provision of video services over the PON.

- The APON format developed by the FSAN alliance was used as the basis for an international standard released by ITU-TS (Rec. **G.893**), designated by **BPON** (*Broadband* PON).
  This standard supports more broadband services, including high-speed Ethernet and video distribution.

- In 2001, the FSAN group initiated the development of the standard **GPON** (Gigabit-capable PON, Rec. G.984, ITU-T, 2003), for full service support, including voice (TDM, over SONET/SDH), *Ethernet* (10/100 BaseT), ATM, leased lines, wireless extension, etc., by using a convergence protocol layer designated GFP (*Generic Framing Procedure*).

- The main characteristics of the GPON standard are:
  - Physical reach of at least 20 km, with support for logical reach up to 60 km;
  - Support of several data rate options, using the same protocol, including a symmetrical link at 622 Mbit/s or 1.25 Gbit/s, or 2.5 Gbit/s downstream with 1.25 Gbit/s upstream.
  - Management of end-to-end services with good capabilities of OAM&P (*Operation, Administration, Maintenance and Provisioning*).
  - Security of downstream traffic at protocol level, due to the multicast nature of the PON.

GPON (*Gigabit-capable* PON) - Architecture



EPON (*Ethernet* PON)

- When it was developed, the APON standard was not the more appropriate solution for local access in large scale, because it did not include the capability to transport video.

- On the other hand, evolution of LANs to *gigabit Ethernet* and 10-*gigabit Ethernet* is a strong motivation to eliminate the need of conversion between IP and ATM protocols, in the interconnection of LANs to WANs (Wide Area Networks).

- In November 2000, a group of manufacturers of Ethernet equipment initiated the development of an Ethernet PON (**EPON**) standard under an agreement with the IEEE, with the creation of the the **EFM** (*Ethernet in the First Mile*) study group in 2001.

- Although the EPON concept provides larger bandwidth, lower costs, and wider service capabilities than the APON standard, the network architecture is similar and the EPON standard complies to many specifications included in recommendations G.983/4 of ITU-T.

http://www.alloptic.com/products/whitepapers/031601.htm

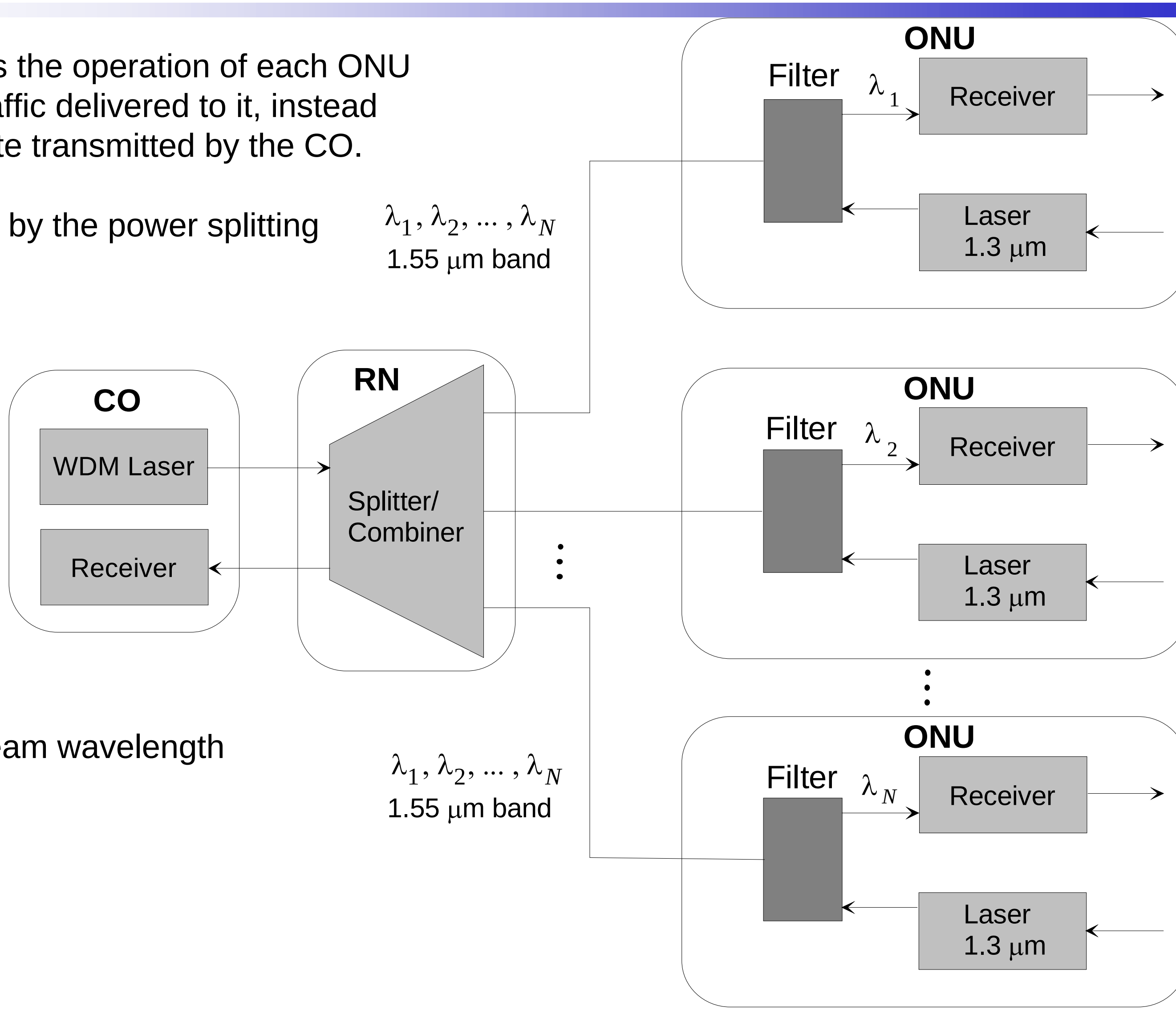
- The IEEE standard for Ethernet in the first mile is 802.3ah.

WPON (WDM PON) Architecture

- This architecture enables the operation of each ONU at the data rate of the traffic delivered to it, instead of the aggregate data rate transmitted by the CO.

- However, it is still limited by the power splitting at the star coupler (RN).

Tx at the CO:
Array of Lasers
or Tuneable Laser

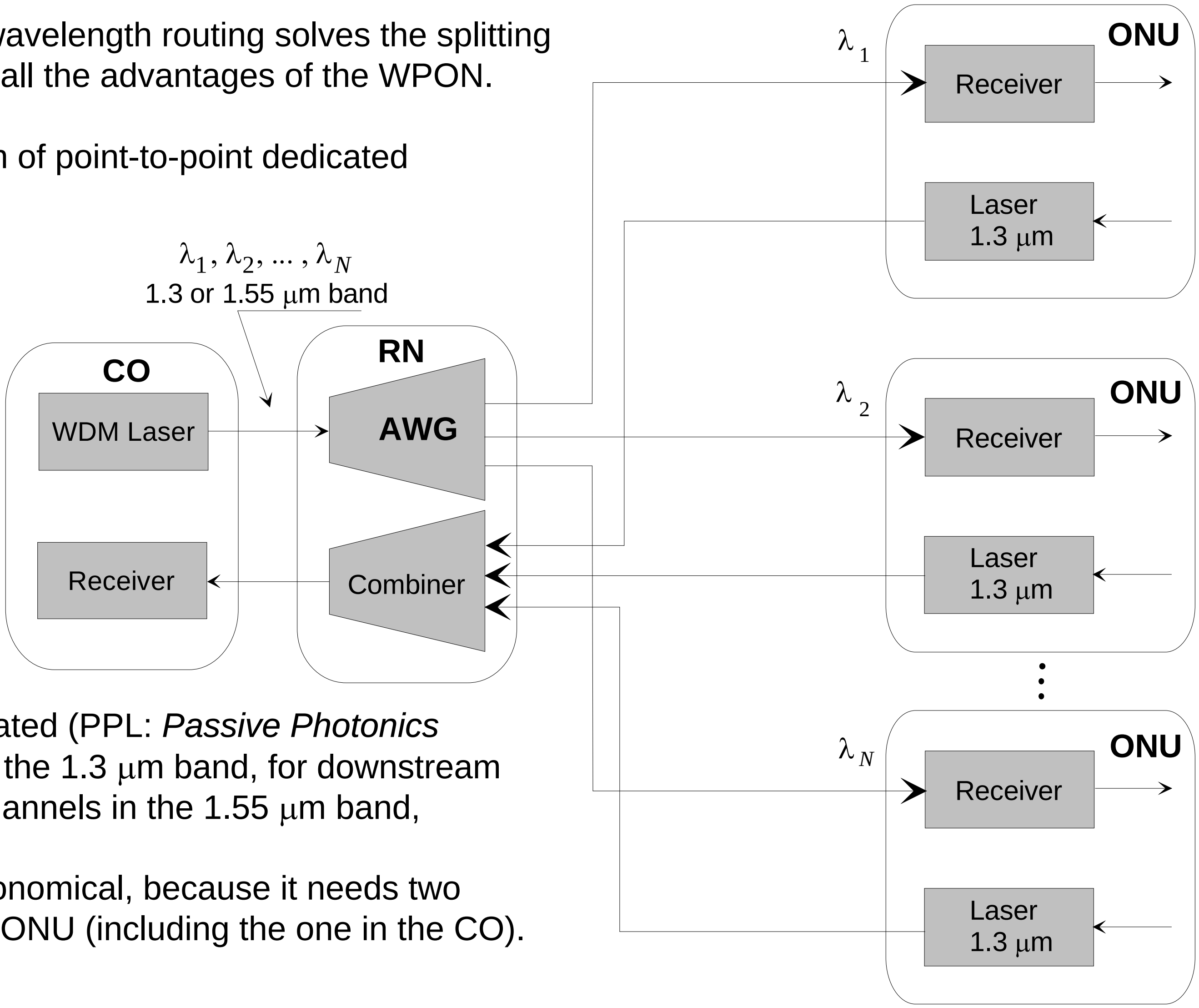


- ONUs share the upstream wavelength of 1.3 μm, with TDM.

WRPON Architecture

- The introduction of static wavelength routing solves the splitting loss problem, maintaining all the advantages of the WPON.
- Besides, it allows provision of point-to-point dedicated services.

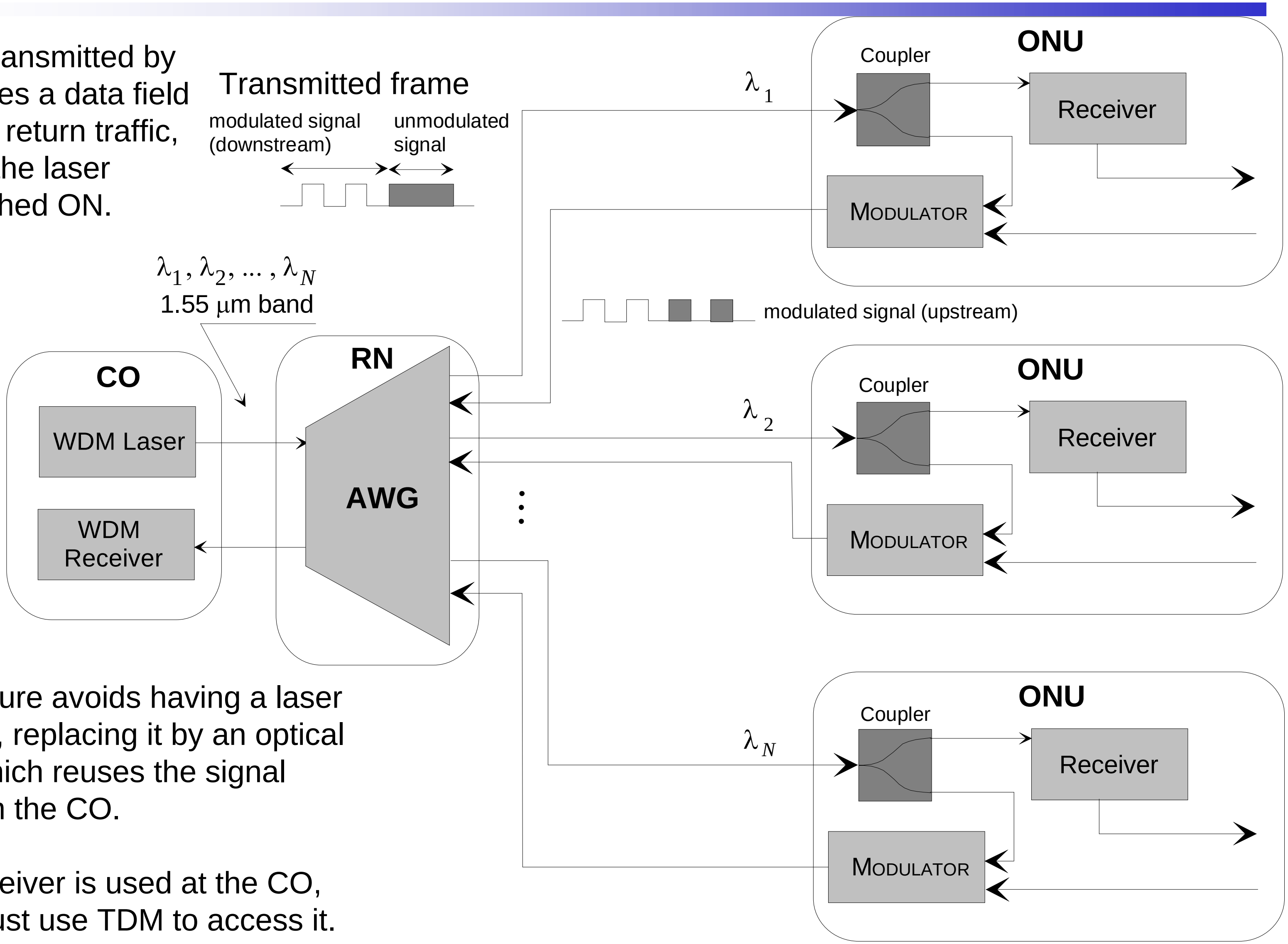
The **AWG** (*Arrayed Waveguide Grating*) operates as a static wavelength router.



- The first system demonstrated (PPL: *Passive Photonics Loop*) used 16 channels in the 1.3 µm band, for downstream traffic, and 16 additional channels in the 1.55 µm band, for upstream transmission.
- This architecture is not economical, because it needs two expensive lasers for each ONU (including the one in the CO).

RITENET WRPON Architecture

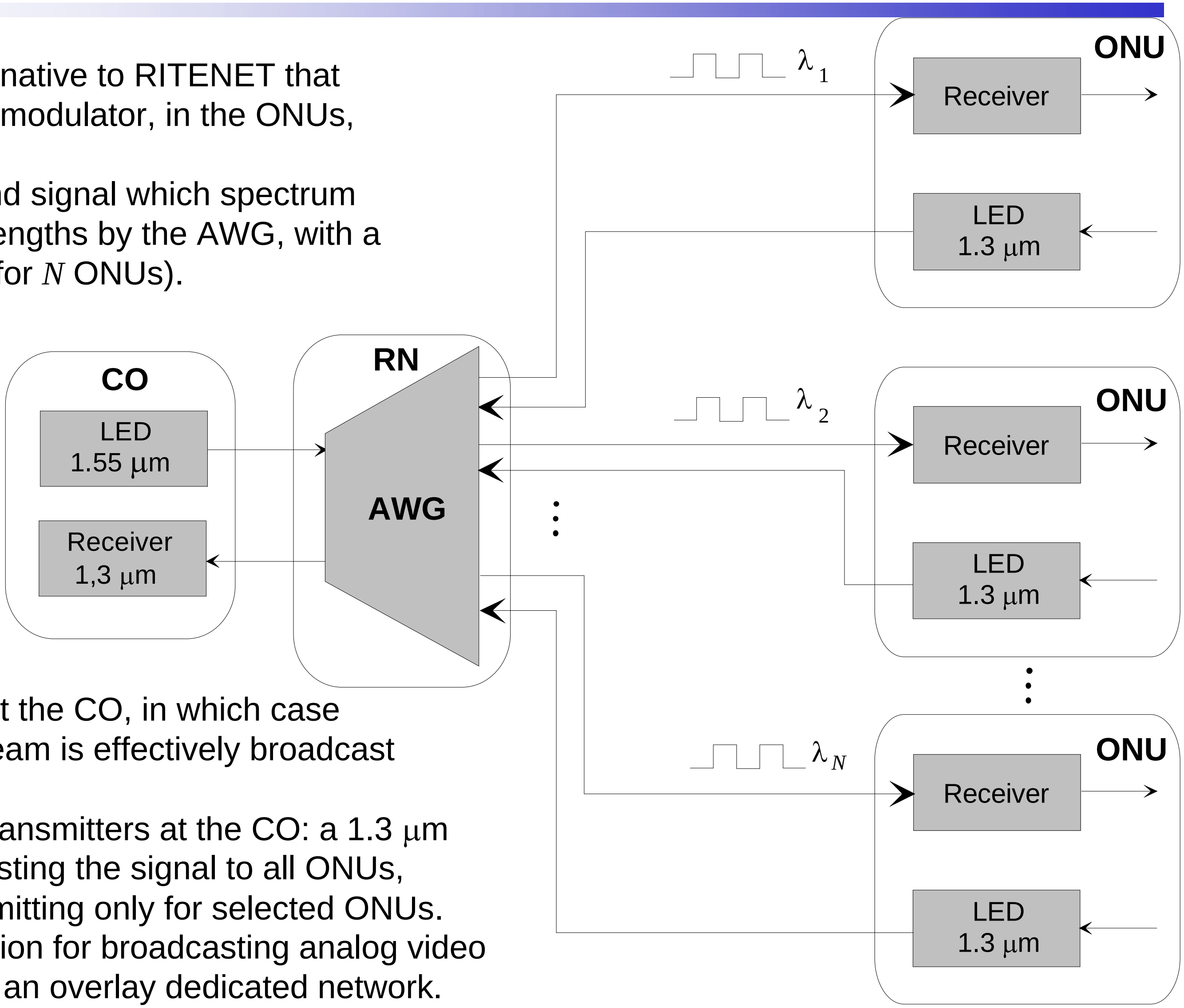
- Each frame transmitted by the CO includes a data field and a field for return traffic, during which the laser remains switched ON.



- This architecture avoids having a laser in each ONU, replacing it by an optical modulator which reuses the signal received from the CO.
- If a single receiver is used at the CO, the ONUs must use TDM to access it.

LARNET WRPON Architecture

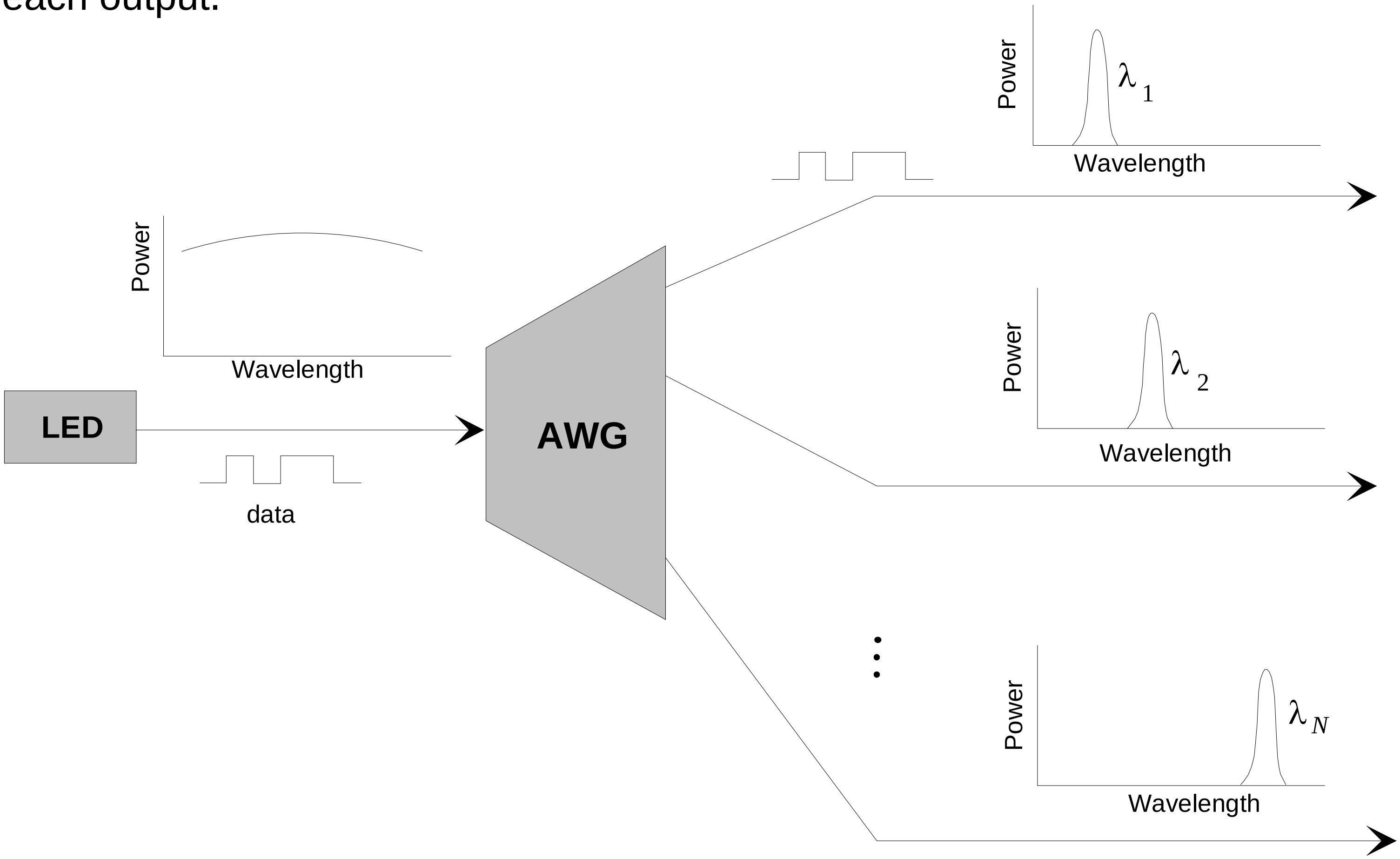
- This is an economical alternative to RITENET that uses a LED instead of the modulator, in the ONUs, for upstream transmission.
- The LED emits a broadband signal which spectrum is split into different wavelengths by the AWG, with a loss factor of at least $1/N$ (for N ONUs).



- A LED may also be used at the CO, in which case the signal emitted downstream is effectively broadcast to all ONUs.
- It is possible to have two transmitters at the CO: a 1.3 µm LED, for example, broadcasting the signal to all ONUs, and a 1.55 µm laser, transmitting only for selected ONUs. This is an economical solution for broadcasting analog video signals without the need of an overlay dedicated network.

Spectral Slicing

- The broadband signal emitted by the LED is sent through the AWG.
- Only the fraction of the spectrum corresponding to the channel pass band of the AWG comes out of each output.



Scenario for PON Evolution

***Grow As You Go* Strategy**

- An operator may follow a progressive upgrading sequence, from a simple TPON architecture towards one of the more complex WRPON architectures.
- This evolution may be realized with minimum disruption of existing services and without waste of installed equipment. The terminal equipment may be upgraded when new services and/or additional capacity are required, without any change in the deployed fibre network (*grow as you go*).

Possible Evolution Scenario for a PON

- The operator installs a simple **broadcast PON**, which is a <u>star network with bandwidth shared</u> by the ONUs.
- If it becomes necessary to support more ONUs, the operator may upgrade the network to a **WPON**, which is a <u>broadcast network with dedicated bandwidth</u> provided to each ONU. The transmitters at the CO must be replaced by WDM transmitters, maintaining the same ONUs.
- If greater capacity per ONU becomes necessary, the operator may upgrade the network to a **WRPON**, which is a <u>switched network with dedicated bandwidth</u> to each ONU.
- The WRPON may also support broadcast services efficiently, by employing the *spectral slicing* technique.

Future Developments

Capacity Increase (in both GPON and EPON)

- Through combinations of TDM with WDM and, eventually, CDMA; cheaper components are required (probably Coarse WDM with polymer based AWGs and VCSEL arrays).
- Through increase of data rate, with faster lasers and more sensitive burst-mode receivers (with broadband SAGM APDs).

QoS in EPON

- None of the currently existing EPON network access protocols is capable of supporting variable burst and delay sensitive multimedia streams and, in view of the increasing share of multimedia in the overall IP traffic, this inability represents a serious drawback and lack of future proof characteristics.
- There is a need for introducing future-proof QoS policies along with increased security measures to counteract any possible network intrusion and data theft.

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  - Denis J. G. Mestdagh, "Fundamentals of Multiaccess Optical Fiber Networks", *Artech House*, 1995. (Part II)
- Periodicals
  You may start with the *IEEE Communications Magazine*
  (the February 2005 issue includes two papers on EPON access protocols).

END

Thank You for your patience and attention.

Please send your queries and comments to:
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