Optical Communication Networks

Access networks

Access networks (1)

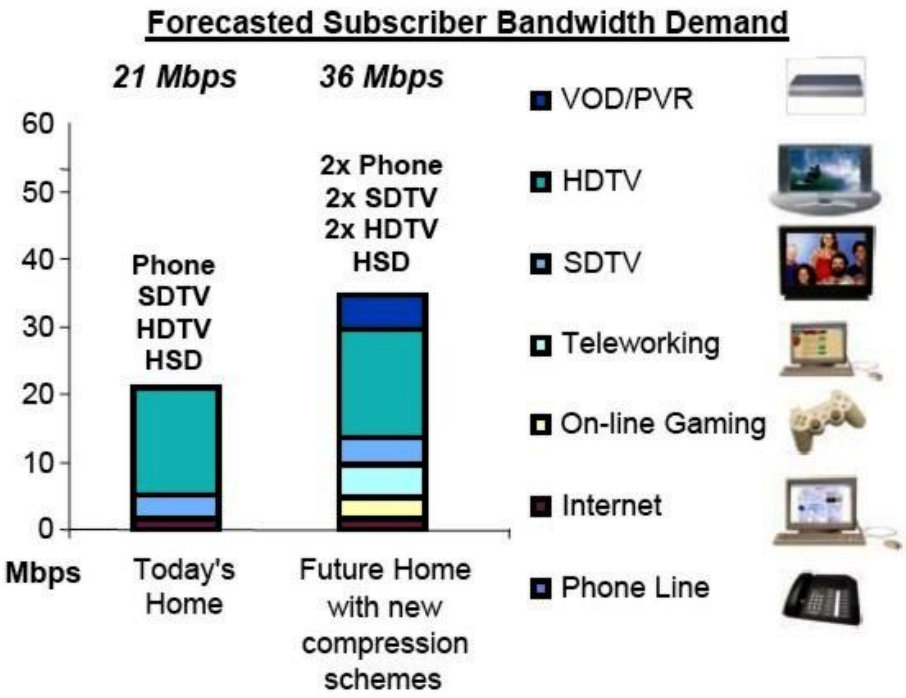
- Access networks
  - Network architecture
  - HFC
  - FTTx

Access networks (2)

- Provide last branch of TLC networks
  - From service provider to homes or offices
  - Ever increasing bandwidth request also at the access level
    - Need to approach fiber to users
    - High performance "business" access networks
      - Sonet/SDH, Ethernet, RPR
      - Business users, renting lines from 1.5 Mbps up to Gbps
    - Individual home access networks
      - Providing of more advanced services
      - Need to overcome limitations of telephone network
      - Main topic of this course chapter
  - In the past only two types of services to homes:
    - POTS on public phone network
    - TV on cable network (USA)

Access networks (3)

- In recent years data services have been added
  - DSL (Digital Subscriber Line) on phone network
  - Cable modem on cable network (USA)
- Request of high capacity access networks
  - Video-on-demand (VOD)
  - High-definition TV (HDTV)
  - Standard TV (SDTV)
  - Remote work
  - Online gaming
  - Internet access
  - Telephone
  - High speed data (HSD)



Access networks (4)

- **Service classification** based on…
  - **Bandwidth request**
    - From a few kHz (telephone) to MHz (video flux) up to hundreds of Mbps (rented lines)
  - **Symmetrical or asymmetrical service**
    - Symmetrical (bidirectional), ex. videoconference
    - Asymmetrical (unidirectional), ex. video broadcast
    - Business services are typically symmetrical…
    - … other services have typically larger downstream than upstream bandwidth
  - **Broadcast or switched service**
    - Broadcast: all users receive the same data
    - Switched: different users receive different data

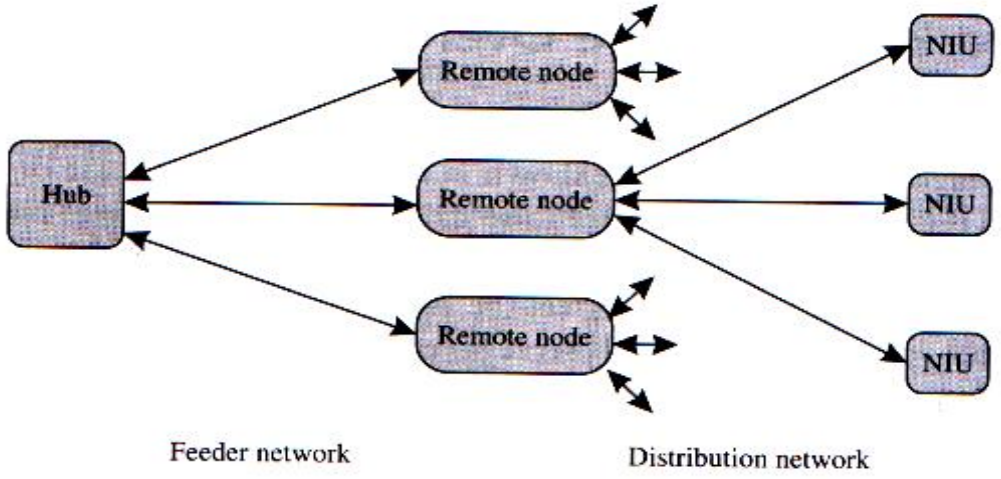
Access networks

- Access networks
  - Network architecture
  - HFC
  - FTTx

Network architecture (1)

- Access network composed by
  - **Hub**
    - CO (*local exchange*) for phone networks
    - *Head end* for cable networks (USA)
    - Each hub provides services to different homes/offices through the NIU, hub belongs to a bigger network
  - **Remote nodes (RN)**
    - Second hierarchic level among hub and NIU
    - Each hub connected to different RN, each RN serves a group of NIU
  - **Network interface units (NIU)**
    - One NIU for each user (or small group)
- **Access network= feeder network + distribution network**

Network architecture (2)



- **Feeder network**: network between hub and RN
- **Distribution network**: network between RN and NIU
- Broadcast vs. switched services
  - All users receive same data or not
- Broadcast vs. switched distribution network
  - Network topology
  - All 4 service-network combinations are possible

Network architecture (3)

- **Broadcast distribution network**
  - RN broadcasts to all NIUs data from the hub
  - Inexpensive networks, use of all equal NIUs
    - Intelligent functions at the NIU level
  - Well suited for delivery of broadcast services
  - Ex. Cable network (USA)
- **Switched distribution network**
  - RN processes data from the hub and sends separate data fluxes to all NIUs
  - In general, use of different NIUs for different users
    - Intelligent functions at network level, NIUs are simple
  - Higher security level
    - Against hackers and network failures
  - Well suited for switched services delivery
  - Ex. telephone network

Network architecture (4)

- Classification based on type of **feeder network** (hub - RN)
  - The network assigns to each NIU its *dedicate bandwidth*
    - Each NIU operates on different frequency
    - Possibility to guarantee QoS to users
    - NIU includes devices operating at the NIU bitrate
  - NIU *share* the total network bandwidth
    - NIU share the bandwidth in the time domain
    - Each NIU may in principle use all the bandwidth
    - Need for a MAC for upstream traffic
    - Very efficient for “bursty” traffic
    - Difficult to guarantee QoS
    - NIU include devices operating at the total line bitrate

Network architecture (5)

- **Broadcast or switched distribution**
- **Feeder with either dedicated or shared bandwidth**
- Telephone network
  - Switched distribution network
  - Feeder network with dedicated bandwidth of 4 kHz
- Cable network(USA)
  - Broadcast distribution network
  - Feeder network with shared bandwidth
- WPON
  - PON WDM network
  - Broadcast distribution network
  - Feeder network with dedicated bandwidth

Distribution Network	Feeder Network	
	Shared	Dedicated
Broadcast Switched	Cable TV (HFC), TPON	WPON Telephony, DSL, WRPON

Access networks

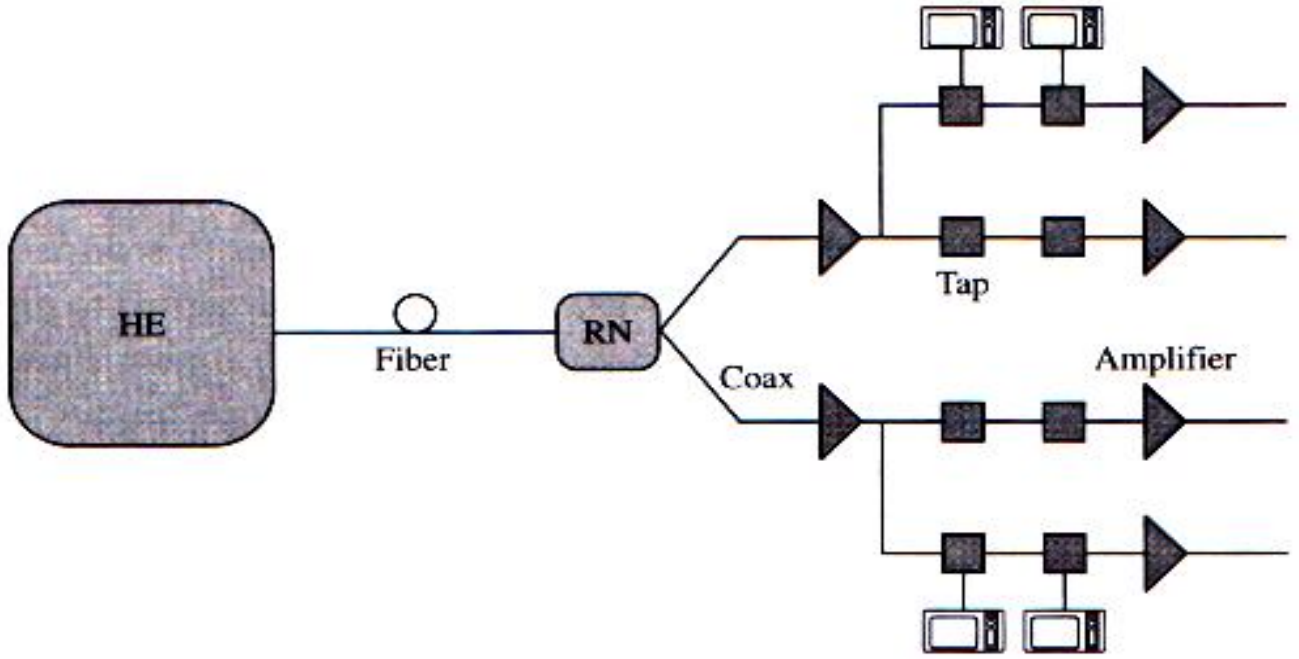
- Access networks
  - Network architecture
  - HFC
  - FTTx

Hybrid Fiber Coax (1)

- **HFC (Hybrid Fiber Coax) network**
- Reaches almost all homes (USA)
- Fiber optic links between head end and RN
- Channels from head end to RN in broadcast with SCM (Subcarrier Modulation) over a single laser
- From RNs coaxial cables to the homes
- Each RN serves from 500 to 2000 users
- Used bandwidth from 50 to 550 MHz, transmission of 78 TV AM-VSB channels spaced by 6 MHz (NTSC)
- Return channel from 5 and 40 MHz
- Operators look for upgrade to video transmission in digital format (Enhanced HFC)
- Broadcast network with shared bandwidth

Hybrid Fiber Coax (2)

- Telephone and cable networks are radically different
  - Phone network provides little band per user, but using complex network switching and management
  - Cable network provides large band per user, but it is broadcast and unidirectional, without switching



Access networks

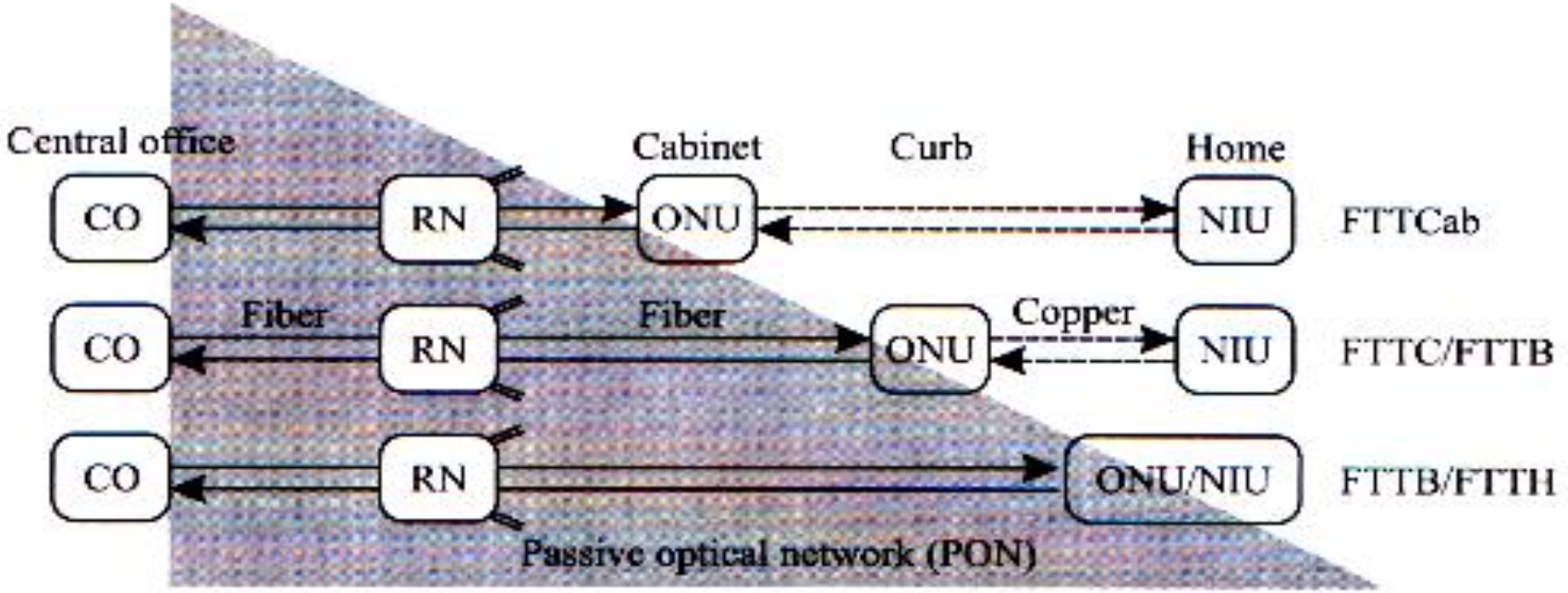
- Reti di accesso
  - Architettura di rete
  - HFC
  - FTTx

Fiber-to-the-Home (1)

- **FTTx (Fiber to the x)**
  - Strategy: bring the fiber as close as possible to final user
  - Data digitally transmitted on optical fiber from hub to the nodes called **ONUs** (Optical Network Units)
  - Depending on distance between ONU and user we may have
    - **FTTH (Fiber-to-the-Home)**
      - Fiber arrives to homes, ONU have NIU functionalities
    - **FTTC/FTTB (Fiber-to-the-Curb/Building)**
      - Each ONU serves a few tens of homes or buildings
      - Fiber arrives at about 100 m distance from users
      - Copper distribution section between ONU and NIU
    - **FTTN (Fiber-to-the-Node)**
      - Fiber terminates in a note at about 1 km from users

Fiber-to-the-Home (2)

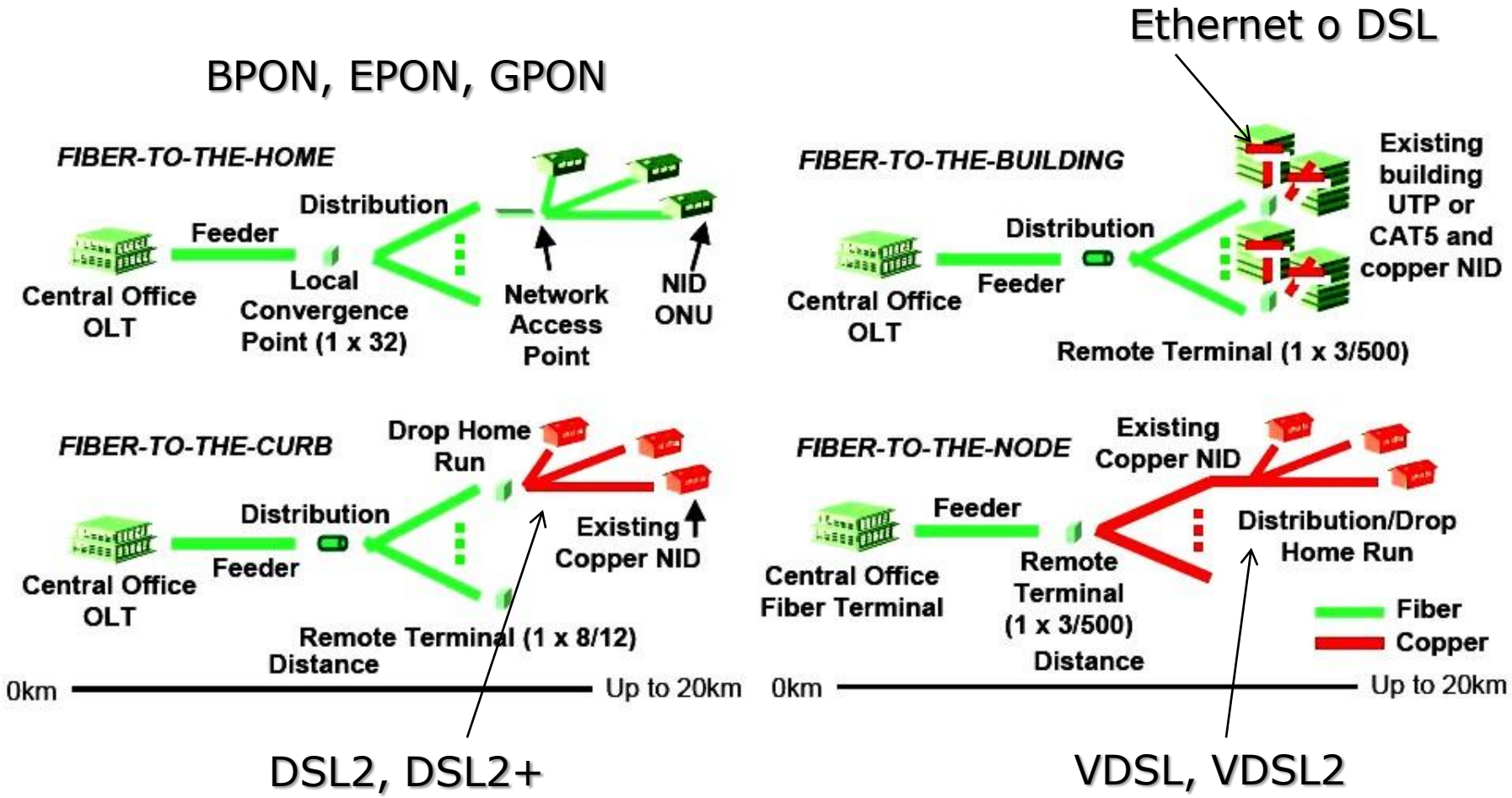
- Connection CO – RN with fiber
- Connection RN – ONU with fiber, ONU terminates the fiber link
- Connection ONU – NIU with copper



Fiber-to-the-Home (3)

- Typically the network between CO and ONU is a PON (Passive Optical Network)
- RN is typically a simple star coupler
  - Often directly placed in the CO
- Term FTTx indicates different architectures…
- However the classical version involves signal broadcast from CO to the ONUs
  - Total band shared among ONU using TDM
- Feeder network: between the CO and the RNs
- Distribution network: between the RNs and the ONUs
- We focus on the optical side of the access network
  - Must be simple, esasy to install and manage
  - Preference for passive vs active networks

Fiber-to-the-Home (4)



Passive Optical Networks (1)

- **PON (Passive Optical Networks)**
  - Optical networks without switching and control functions
  - Only need power supply at their extremes
  - Large cost reduction
- **ONU**
  - Simple structure in terms of low cost and flexibility
    - No laser or complex optical components
    - No cooling or temperature control device
  - Intelligent functions at the CO level
    - Managed space, expensive components shared among all users

Passive Optical Networks (2)

- PON structure
  - RN composed by star coupler or static wavelength router
    - This has all of the previously seen advantages
  - Fiber infrastructure is transparent to bitrate and modulation format
    - Ease of upgrade without changes to the network
  - Different PON types in table
    - We are going to examinate them next (typically N = 16 – 32)

Architecture	Fiber Sharing	Power Splitting	ONU Bit Rate	Node Sync	CO Sharing
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

Standard per FTTH

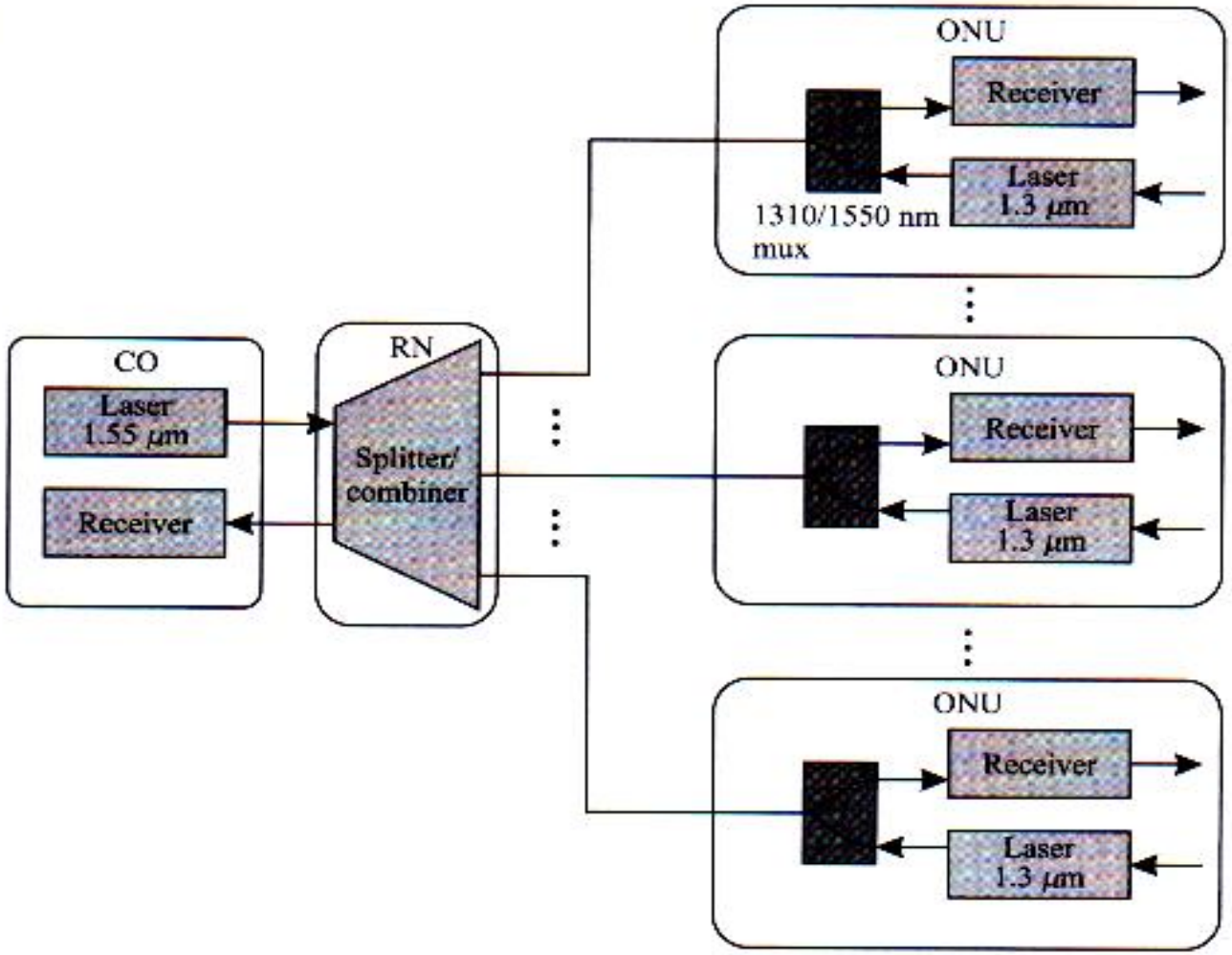
- PTP (point-to-point) networks
  - IEEE 803.2ah (extension of Ethernet)
- PON networks
  - FSAN (Full Service Access Network)
    - **BPON**: 20 – 30 Mbps per user, TDM
    - **EPON**: 30 – 40 Mbps per user
    - **GPON**: up to 100 Mbps per user

	BPON	EPON	GPON
Standard	ITU-T G.983	IEEE803.2ah	ITU-T G.984
Bandwidth	Downstream up to 622Mbps Upstream 155Mbps	Up to symmetric 1.25Gbps	Downstream up to 2.5Gbps Upstream up to 2.5 Gbps
Downstream λ (nm)	1490 and 1550	1550	1490 and 1550
Upstream λ (nm)	1310	1310	1310
Transmission	ATM	Ethernet	ATM, Ethernet, TDM

TPON (1)

- **TPON (PON for Telephony)**
  - Broadcast of downstream traffic from CO to all ONUs through a passive star coupler
  - Delivery of switched services also possible by TDM
    - Different time slots for each ONU
  - Upstream is shared, for example using TDM
    - Or other multi-access protocol
  - TDM approach
    - ONU must by synchronized to common clock
    - *Ranging* process
      - Each ONU measures delay from CO
      - Clock adjustement and their synchronization with respect to CO
      - CO assigns necessary time slots to each ONU

TPON (2)


ONU
Receiver
Laser
1.3 μm
1310/1550 nm
mux
CO
Laser
1.55 μm
Receiver
RN
Splitter/
combiner
ONU
Receiver
Laser
1.3 μm
ONU
Receiver
Laser
1.3 μm

TPON (3)

- Expensive equipment at CO shared among the ONUs
- Use of standard low cost optical components
  - CO transmitter: LED or Fabry Perot laser
  - ONU transmitter: LED or Fabry Perot laser
  - ONU receiver: pinFET
    - Inexpensive, does not require cooling
- Number of supported ONUs limited by power splitting at star coupler
- ONU with electronics working at aggregate bitrate
- Trade-off between transmitted power, receiver sensitivity, bitrate, distance, number of ONUs
- **TPON less expensive with respect to Sonet/SDH, RPR and Ethernet for medium bitrat services**

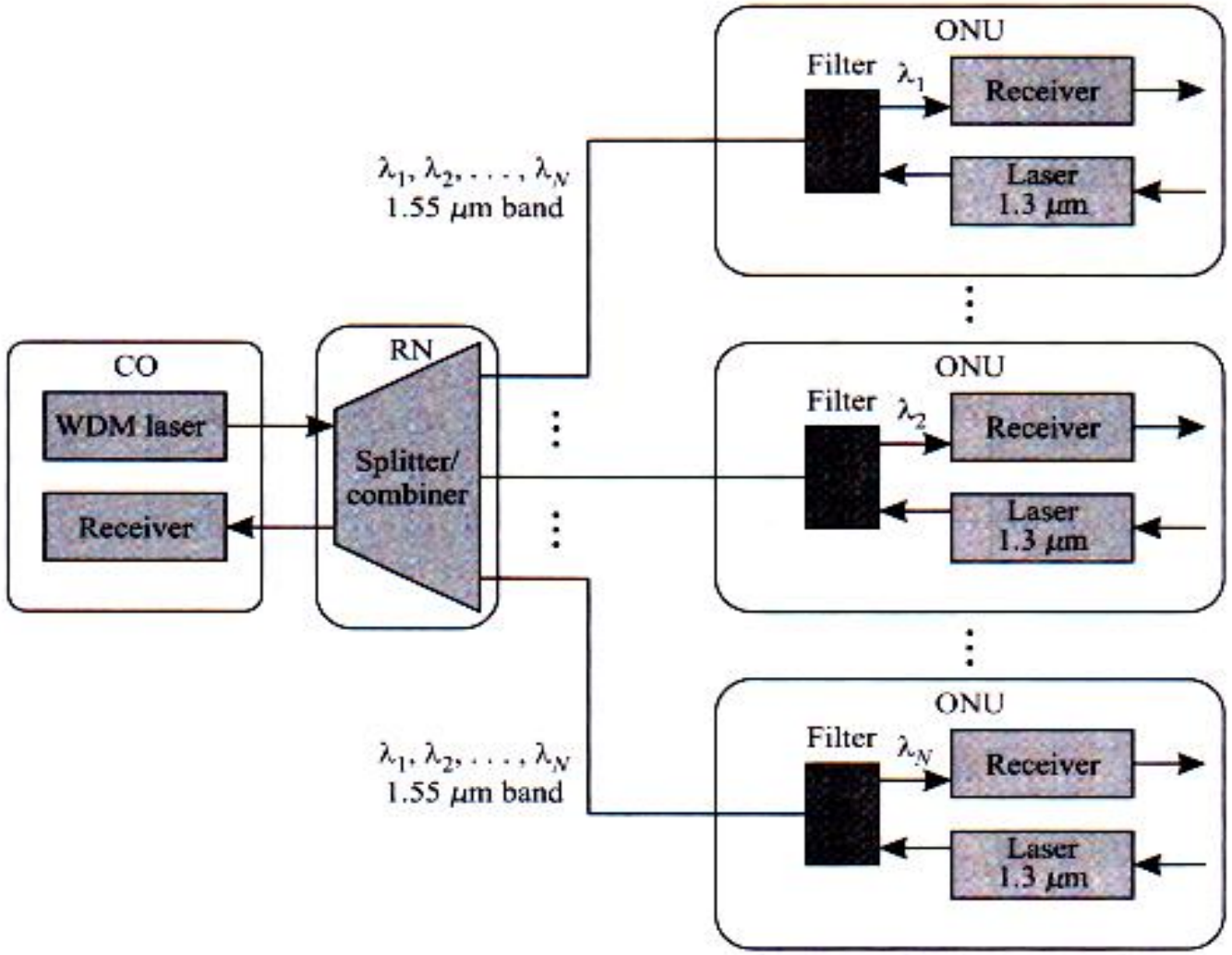
TPON (4)

- **Flexible bandwidth delivery**
  - TPON: by varying time slot distribution
  - Sonet/SDH: latest device generation improves dynamic bandwidth management
- **Failures**
  - TPON: user failure does not affect others
    - Fieber breaks not easy to manage
  - Sonet/SDH: failure makes the ring useless
    - However there are fast protection mechanisms
- **Adding new users**
  - TPON: very simple process
  - Sonet/SDH: complex and lengthy process

WPON (1)

- **WPON (WDM PON)**
  - Evolution of standard TPON in order to increase capacity and flexibility
  - Substitution of single transmitter at CO with
    - Array of WDM lasers or…
    - Single tunable laser
  - CO broadcasts all wavelengths to all ONUs
  - Each ONU selects its wavelength with a filter
    - Every ONU provided with electronics at its own bitrate and not at the aggregate bitrate
  - Upstream channel shared in TDM at 1310 nm
  - Remains the limitation due to the star coupler

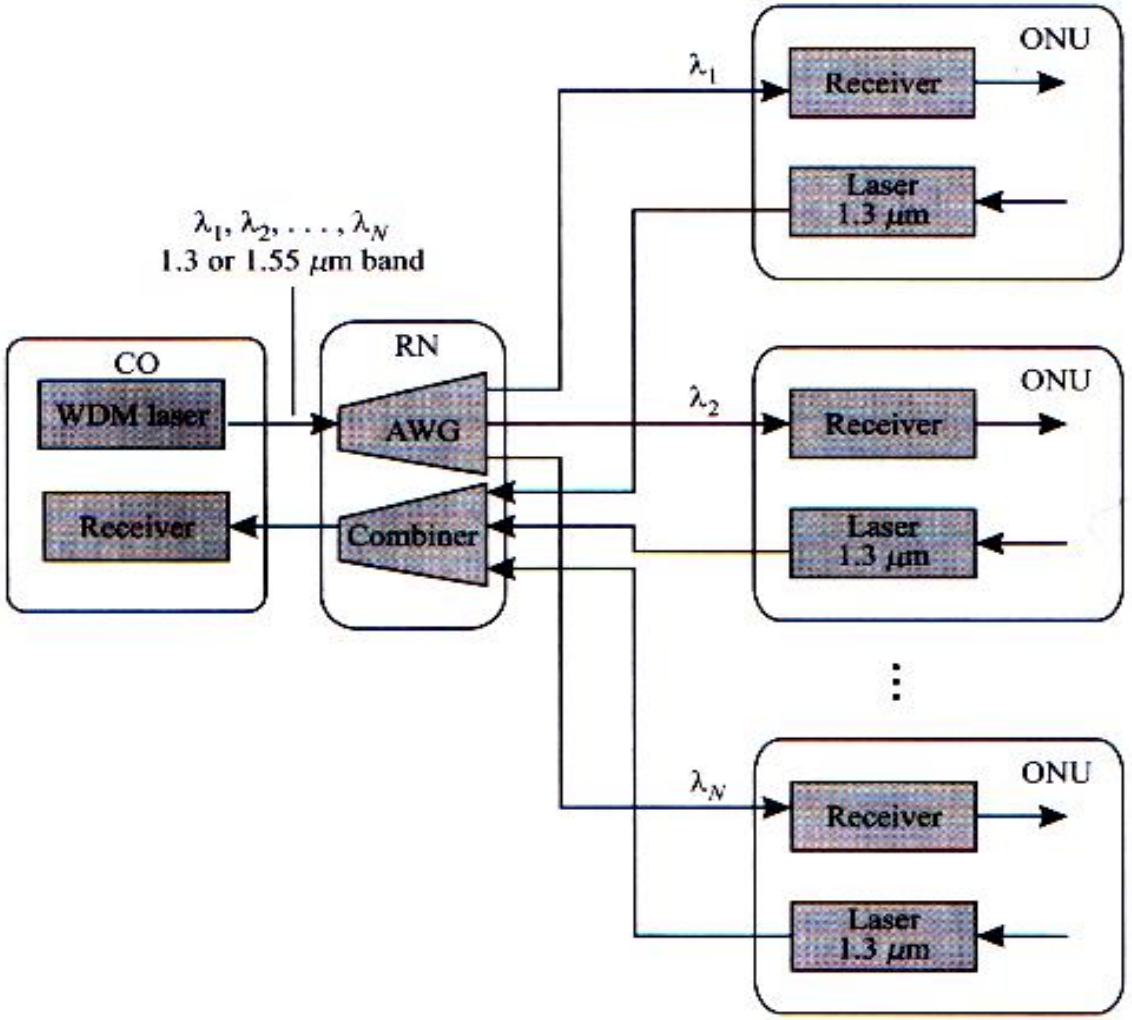
WPON (2)


ONU
Filter
λ_1
Receiver
Laser
1.3 μm
$\lambda_1, \lambda_2, \ldots, \lambda_N$
1.55 μm band
CO
WDM laser
Receiver
RN
Splitter/
combiner
ONU
Filter
λ_2
Receiver
Laser
1.3 μm
ONU
Filter
λ_N
Receiver
Laser
1.3 μm
$\lambda_1, \lambda_2, \ldots, \lambda_N$
1.55 μm band

WRPON (1)

- **WRPON (Wavelength-Routing PON)**
  - Wavelength-routing distribution network
  - Keeps advantages of WPON network but solves splitting problem at star coupler
  - Possibility to provide point-to-point services to ONU
  - RN with wavelength router to manage downstream traffic
    - Typically one uses an AWG
  - Different WRPON versions
    - Different devices in CO and ONU
    - Different management of upstream traffic
  - Ex. PPL (Photonics Loop)
    - Downstream: 16 channels at 1310 nm
    - Upstream: 16 channels at 1550 nm
    - Costly: two expensive lasers for each user

WRPON (2)


$\lambda_1, \lambda_2, \ldots, \lambda_N$
1.3 or 1.55 μm band
CO
WDM laser
Receiver
RN
AWG
Combiner
λ_1
λ_2
λ_N
ONU
Receiver
Laser
1.3 μm
ONU
Receiver
Laser
1.3 μm
ONU
Receiver
Laser
1.3 μm