CS 55231
Internet Engineering

Kent State University
Dept. of Computer Science

LECT-4B

Digital Trunk Lines

Digital Telephone

- Long before computer communication came into being, telephone companies developed digital communication technology.
- Telephone industries have devised complex long distance digital communication technology.
- Most computer communication rides on the digital communication lines provided by the telephone carriers.
- Key Difference: Synchronous Communication:
  - system designed to move data at a precise rate.

Pulse Code Modulation

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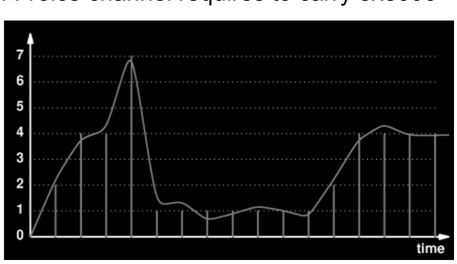
- Human voice is digitized and sent as a digital signal.
- How many times it should be sampled?
  - Human voice has frequencies up to 4KHz.
  - Nyquest’s theorem suggest that for accurate reproduction it must be sampled two times faster at a rate of 8000 times per second or precisely once in every 125 microsecond.
  - Each sample is sampled at 0-255 levels.
  - A voice channel requires to carry 8x8000 =65Kbps data.



What if the network is not synchronous, such as delay at a junction is traffic dependant?

DS Telephone Circuits

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Name	*Bit Rate (Mbs)*	*Voice Circuits*	*Location*
	.06400	1	
T1	1.5440	24	North America
T2	6.3120	96	North America
T3	44.736	672	North America
E1	2.0480	30	Europe
E2	8.4448	120	Europe
E3	34.368	480	Europe

- Telco sales these lines in the form of various trunk lines. The Backbone providers buy them to create Internet. These are sometime called DS levels. DS refers to Digital Signal Level Standard. T defines the multiplexing mechanism.

Digital Circuit & CSU/DSU

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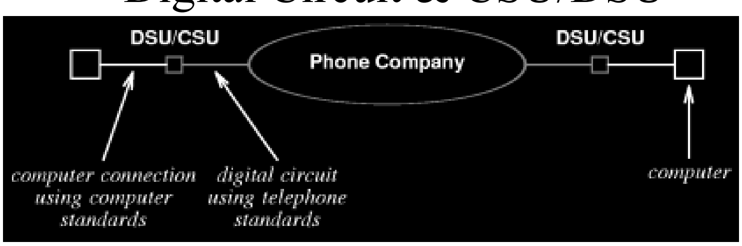
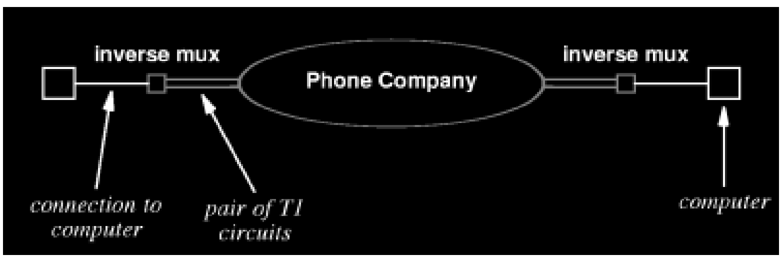


- To send computer data over telephone line, the asynchronous data must be converted into the right synchronous telephone standards.

- Data service Unit/ Channel Service Unit.
  – CSU handles line diagnostics, termination, control current surge, lightening, etc.
  – It prevent too many 1's!
  – DSU handles the computer side. It can use RS-232 (for less than 56K rate) or some other standard.

Capacity Adjustments

- Fractional Capacity
  - available at rates such as 64Kbps, 128Kbps, 9.6Kbps, 4.8Kbps, etc.
  - These are Time Division Multiplexed on T1.
- Intermediate Capacity
  - What if you need 2 T1?
  - Inverse Multiplexer
  - Separate CSU/DSU are required for each line.



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Highest Capacity Fiber Circuits

Optical Name	*SONET Level*	*Payload (kbit/s)*	*Line (kbit/s)*	*Voice Circuits*
OC-1	**STS-1**	**48,960**	**51,840**	**810**
OC-3	**STS-3**	**150,336**	**155,520**	**2430**
OC-12	**STS-12**	**601,344**	**622,080**	**9720**
OC-24	**STS-24**	**1,202,688**	**1,244,160**	**194440**
OC-48	**STS-48**	**2,405,376**	**2,488,320**	**38880**
OC-96	**STS-96**	**4,810,752**	**4,976,640**	
OC-192	**STS-192**	**9,621,504**	**9,953,280**	**Internet2**
OC-768	**STS-768**	**38,486,016**	**39,813,120**	**2007 tested**
OC-1536	**STS-1536**	**76,972,032**	**79,626,120**	
OC-3072	**STS-3072**	**153,944,064**	**159,252,240**	

- Synchronous Transport Protocols (STS) represent trunk circuits.
- OC is a special version of the standards for fibers.

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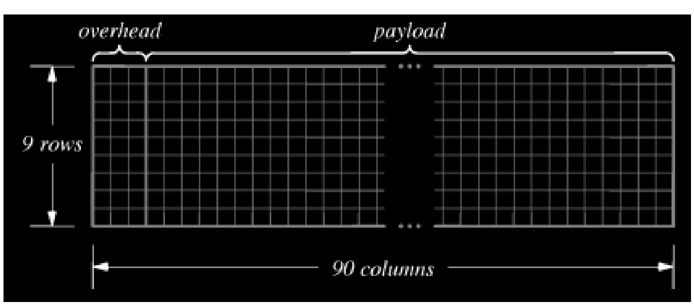
SONET/ SDH

- Before the breakup AT&T all carriers will use their own TDM. After the breakup in 1984 a standard was needed and developed.
- SONET Goals:
  - Carriers to interoperate within USA and with Europe & Japan.
  - Multiplex multiple digital channels T3 and up.
  - Support for operations, administration & maintenance (OAM).
- Synchronous Communication
  - Precisely controlled by highly accurate master clock 1 in 10^9.
  - A frame must leave in 125 ms.

SONET

- Synchronous Optical Network frames carry these data.



- The frame size is circuit dependent.
  - STS-1 (51.84 Mbps) contains 810 (9x90) 8-bit octates,
  - STS-3 holds 2430 8-bit octates.

How the size is determined?

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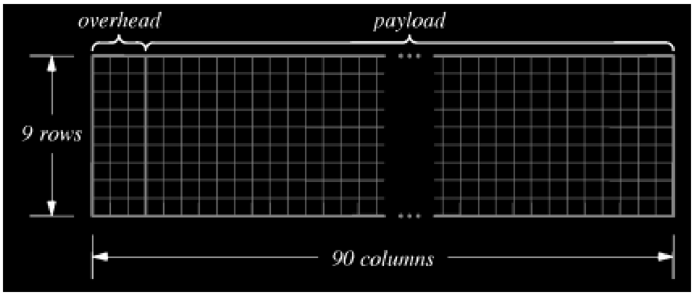
SONET (contd)



- One Frame must be sent in every 125 microsecond.
  - At STS-1 rate, 51.840 Mbps, exactly 6480 bits=810 octates need to be carried in 125 microsecond.
- Synchronous multiplexing
  - multiplexing without introducing delay.
- SONET is used for Point-to-Point data comm. But it can be used in other ways as well, such as in FDDI ring.

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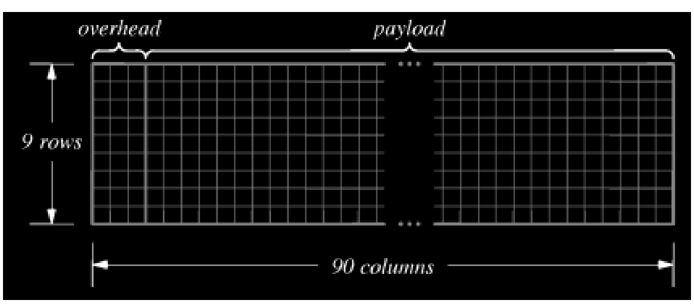
How the size is determined?

SONET (contd)



- The first three columns carry system management info.
- The first three rows contain section overhead.
- The next six contains line overhead.
- Frames are sent data or not. A frame with data is identified with fixed pattern in first two bytes.
- User payload can start anywhere in the frame. A pointer to first byte appears in the first row of line overhead.

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Last Mile

Local Subscribers Lines

- Leased lines provides the ability to send data across long distance. But, before Internet can be ubiquitous the problem of reaching every house hold have to be solved.

- Local Loop;
  - the last mile or a local subscribers carrier line connecting the phone company central office (CO) with the subscriber's place of business.

- Despite the dial-up modems, progress, the need of bandwidth has grown even faster.
- The voice bandwidth and signal-to-noise ratio dictates the ultimate limit of simple modems.

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ISDN

- Integrated Service Digital Line
  - One of the first effort to provide large scale digital service.
  - Uses the same twisted-pair copper wire as telephones, no need to special wiring or equipment.
  - Offers 2B+D channels. B for digitized voice or compressed video.D for control.
  - Bandwidth 64+64+16=144 Kbps + (16 signaling).
  - The two Bs can be combined into one
  - Uses TDM over single pair of wire.
- ISDN is an old technology and faces extinction from improved modems and other technologies.

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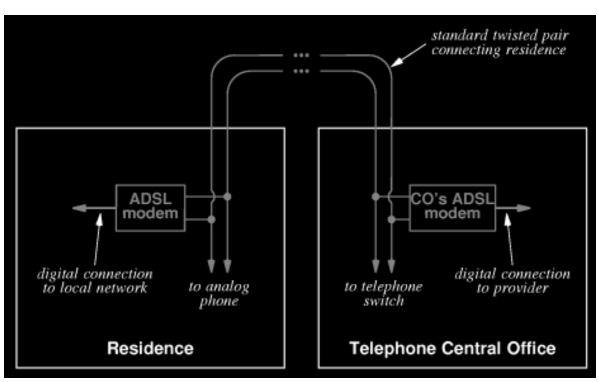
Asymmetric Digital Subscribers Line (ADSL)

- It has more download and smaller upload bandwidth.
  - 6.144 Mbps Down + 576 Kbps Up + 64 Kbps (control Up)
- It keeps the telephone as well.



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How ADSL Works

- Telephone lines are not designed for such high data rate!
- It does everything to evade interference.
  - Combines FDM an Inverse Multiplexing known as Discrete Multi-tone Modulation (DMT).
  - Divides the bandwidth into 286 sub-channels
  - assigns 255 down and 31 upstream.
  - Conceptually a separate modem runs on each of them.
  - Carriers are spaces 4.1325 KHz apart to avoid cross-cha interference.
  - It also does not use frequency from 0-4KHz. To avoid voice.
  - Each modem also tracks the error rate and adjusts the modulation scheme (quantization levels etc) dynamically with the noise in the sub-channels.
  - Does not guarantee a capacity, but is the best effort depending on the cable quality and local interference.
  - Effective rate varies in 32Kbps-6.4mbps DN/32-640 Kbps UP

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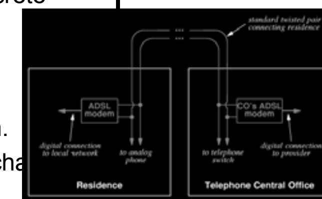

Other xDSLs

- Symmetric DSL (SDSL)
  - inverse ADSL is not easy to find so best choice for server farms.
  - Uses a somewhat different encoding technology.
- High rate DSL(HDSL)
  - 1.544 Mbps both directions.
  - Does it by restricting to shorter distances.
  - Requires two pairs of twisted pairs.
  - A one pair variant is HDSL2.
  - It can survive bridge-tap
  - Fails gracefully, works at half capacity when one wire fails, thus provides reliability to businesses.
- Very High DSL (VDSL)
  - 52 Mbps!
  - Requires special concentrator devices to be inserted in between.
- ADSL G.LITE
  - ITU standard for 1.5 Mbps/ 512Kbps (December 1999)

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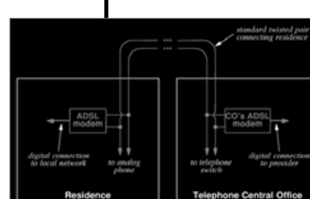

Cable Modem

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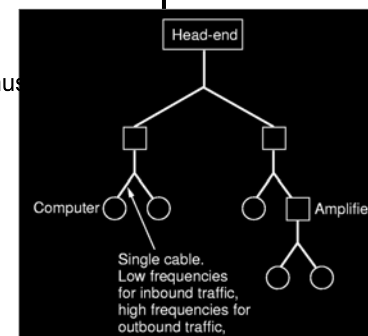
- Cable Modem
  - A coax is better carrier than twisted pair.
  - CATV available at 80% residential units in USA.
  - Currently 1-450 MHz band is in use (can take upto ~1 GHz)
  - Divided into 6MHz television sub-channels.
  - Amplifies signal in the neighborhood.
  - A very good download broadcast media with high unus capacity.
- Limitations:
  - The FDM does not scale.
  - Capacity is divided by customers.
  - Actually unidirectional architecture
    - no upstream channel
    - amplifiers in between are unidirectional too.



Wireless Mesh

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Wireless Mesh

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- **First Generation of Wireless Mesh Networks**
  - One-radio "Ad Hoc" Wireless Mesh. In first-generation mesh products, a single radio provides both service (connection to individual user devices) and backhaul (links across the mesh to the wired or fiber connection), so wireless congestion and contention takes place at every node. Users soon discovered that only one or two radio "hops" were possible between connections to the wired or fiber Ethernet. Support is also very poor for Video and Voice applications because of excessive and varying delay (latency) across the network.

- **Second Generation of Wireless Mesh Networks**
  - Two-radio Wireless Mesh, shared backhaul. To solve these contention and congestion issues, second-generation mesh was developed by placing two radios in each node, combining an 802.11b/g service radio with an 802.11a backhaul radio.While this offered a performance improvement in terms of bandwidth over first-generation mesh, problems remain. With heavy user demand, there is still significant contention and congestion on the backhaul links. This limits the number of radio hops before another costly wired or fiber Ethernet connection is needed.

Wireless Mesh

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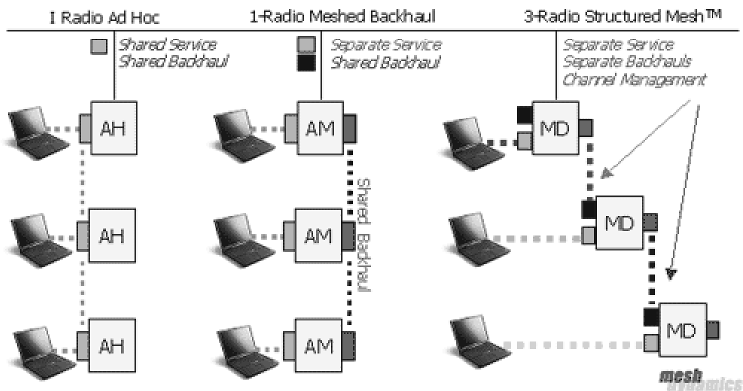
- **Third Generation of Wireless Mesh Networks**
  - Three Radio with Multi-radio Wireless Backhaul. Third-generation mesh networking products add at least two physical radios for the backhaul. One backhaul radio is used to create a link to its upstream (nearer the wired source or "root") node. Another backhaul radio creates a link downstream to the next neighbor node. Unlike second-generation solution, these two radios may make use of different channels.
- **Mobile Ad-Hoc Networking(MANet)**
  - Mobile ad-hoc networking(MANet), and mesh networking are therefore closely related, but mobile ad hoc networks also has to deal with the problems introduced by the mobility of the nodes.
- Mesh networks are self-healing: the network can still operate even when a node breaks down or a connection goes bad. As a result, a very reliable network is formed. This concept is applicable to wireless networks, wired networks, and software interaction.

3G Wireless Mesh



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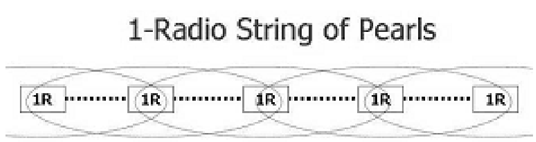
The 1/N vs. the 1/2N Controversy



- A service node receives and then pauses to send. Thus the bandwidth is halved. A client of it thus has ½ bandwidth to forward. On the other hand this client has again ½ of the bandwidth to its own client. Thus is each hop the effective bandwidth halves.

- Thus the performance decreases in order of ($½)^N$

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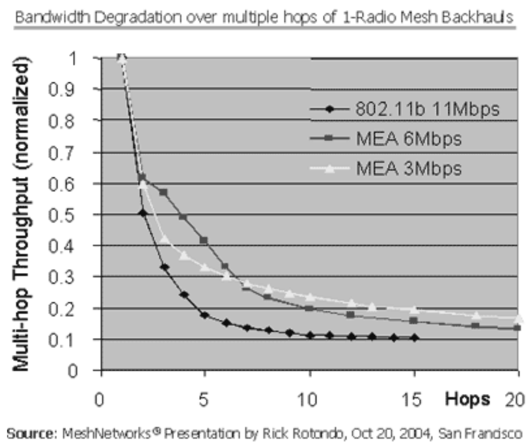
Bandwidth Slide in Mesh



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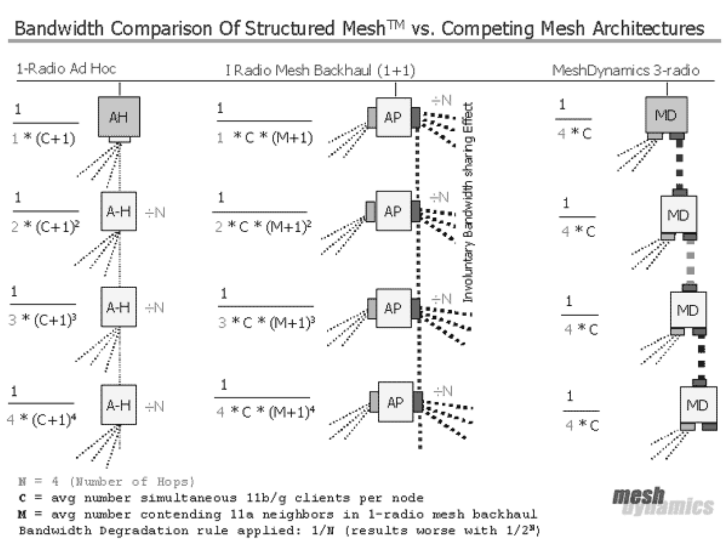
Bandwidth Comparison



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Other Local Loop Technologies

- Municipality Wireless Mesh (Mu-Fi)
  - Wi-Fi 802.11
  - Wi-Max 802.16

- Fiber To The Premises (FTTP)
  - 1GB at home.
- Satellite
- Cellular Technology
  - CDMS2000
  - GSM/4G (100 Mbit/s-1 Gbit/s)

G

CWDM & DWDM

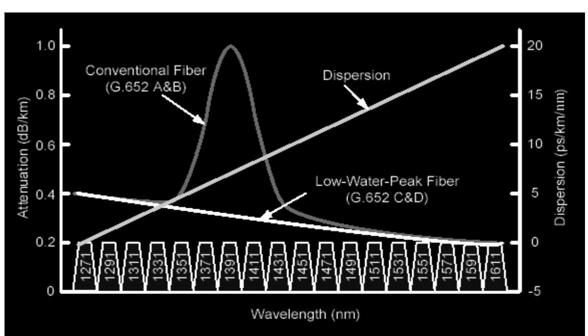

Fig. 2. Wavelength assignment for CWDM [2].

- Wavelength spacing of more than 20 nm is generally called coarse WDM(CWDM). A total of 18 CWDM channels are available on a fiber.

- A newer technology Dense WDM (DWDM) has wavelength spacing that is far lesser than that of CWDM, typically less than 3.2 nm. Today's DWDM systems use 50 GHz or even 25 GHz channel spacing for up to 160 channel operation.

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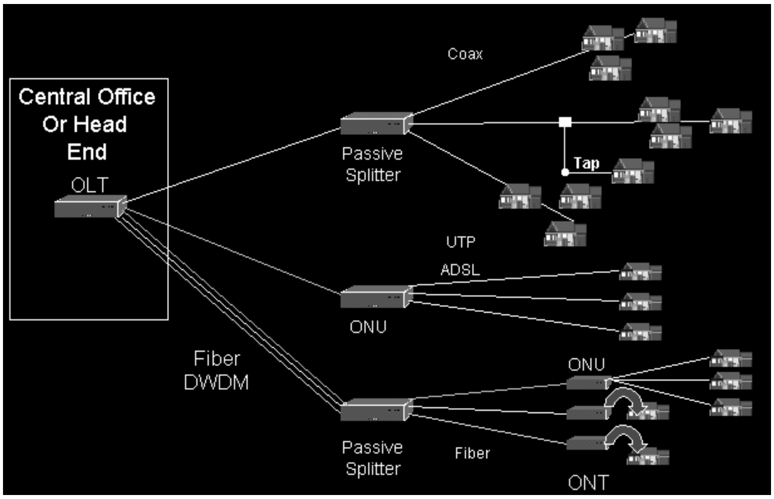
Passive Optical Network (PON)



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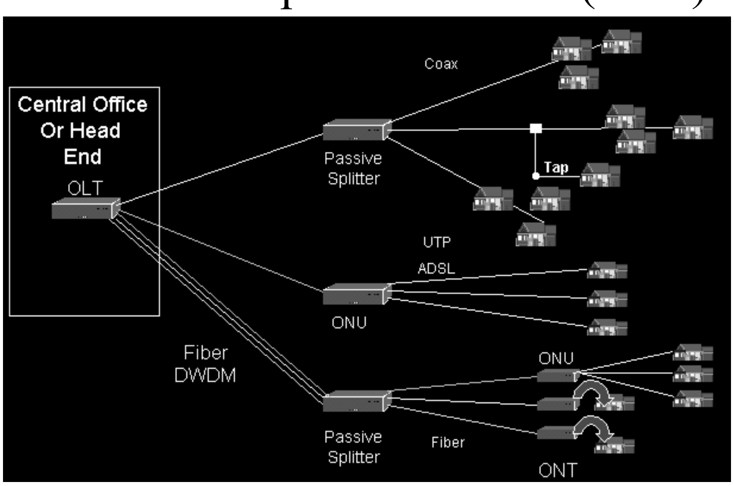
Passive Optical Network (PON)



- PON network elements consist of Optical Line Terminals (OLTs), Optical Network Terminals (ONTs), Optical Network Units (ONUs), and passive splitters. As illustrated in Figure 1 the OLT is located in the carrier's Central Office (CO) in a telco application, or in the CATV provider's headend.

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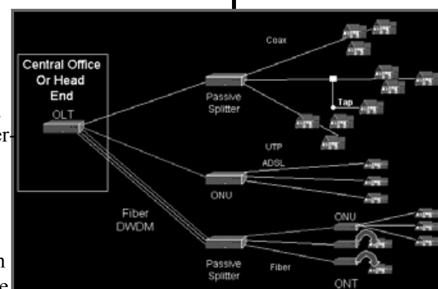
Passive Optical Network (PON)

- Optical Line Terminals:
  - The OLT can either generate optical signals on its own, or pass optical signals (e.g., SONET or DWDM) from a collocated optical crossconnect or other device, broadcasting them downstream through one or more ports.
- Optical Network Terminals:
  - An ONT is used to terminate the circuit inside the premises in an FTTP (Fiber-To-The-Premises) scenario, where it serves to interface the optical fiber to the copper-based inside wire.
- Passive Optical Splitter
  - The passive optical splitter sits in the local loop between the OLT and the ONUs or ONTs. The splitter divides the downstream signal from the OLT at the network edge into multiple, identical signals that are broadcast to the subtending ONUs. .



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Passive Optical Network (PON)

- Optical Network Unit
  - An ONU is used in an FTTC (Fiber-To-The-Curb) scenario, in which case the fiber stops at the curb, with the balance of the local loop being provisioned over embedded copper -- UTP in conventional telco networks and coax in CATV networks.
  - An ONU also is used in an FTTN (Fiber-To-The-Neighborhood) scenario, in which it is positioned at a centralized location in the neighborhood, with the balance of the local loop being provisioned over embedded coax or UTP..
- Each OLT/ONU is responsible for determining which data are intended for it, and for ignoring all others.
- Upstream signals are supported by a time-division multiple access scheme, with the transmitters in the ONUs operating in burst mode. FSAN supports both symmetric and asymmetric modes.

Simple WDM-PON Architecture

- A simple approach is to use separate wavelength from each OLT to ONU for each upstream and downstream connections.

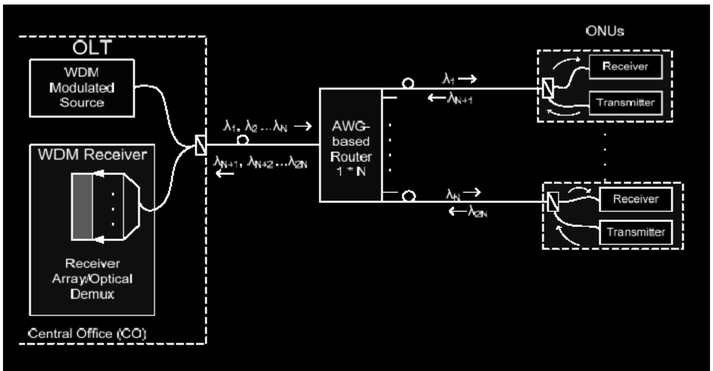

Fig. 1. Simple WDM-PON architecture.

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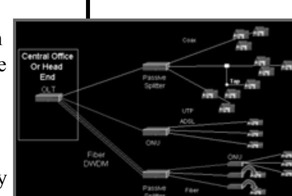
Passive Optical Network (PON)

- Upstream signals are supported by a time-division multiple access scheme, with the transmitters in the ONUs operating in burst mode. FSAN supports both symmetric and asymmetric modes.
- Current FSAN implementations generally are asymmetric, running at speeds of 622 Mbps downstream over a wavelength running between 1480nm (nanometers) and 1580 nm, and 155 Mbps upstream running between 1260nm and 1360nm. Upstream and downstream transmissions can occur over separate fibers, or can share a single fiber through WDM (Wavelength Division Multiplexing).
- As PON is a passive network technology, the network elements do not amplify the signal. Therefore, trunk lengths and signal splits are limited.
- FSAN trunk lengths can be up to 20km, and as many as 32 users and 64 endpoints can be supported per trunk at the current speeds and with the current splitter technologies.



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Composite PON (CPON)

- Separate WDM waves down stream and one TDMA upstream wave upstream.

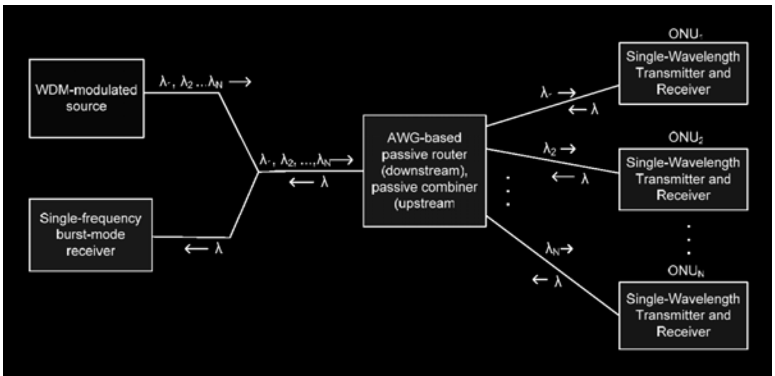

Fig. 8. Architecture of CPON [33–35].

Single Frequency Laser at ONU is expensive

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Local Access Router Network

(LARNET PON)

- Uses inexpensive broad source LED as source at ONUs. The AWG slices it and puts into different optical bands. All customer ONU units can be identical.

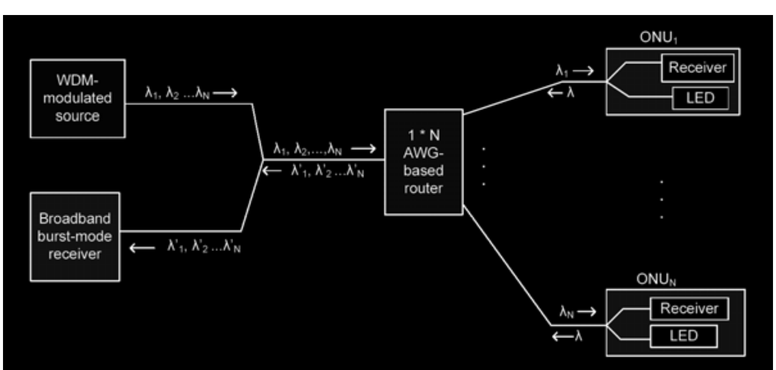

Fig. 9. Architecture of LARNET [36].

Spectral slicing at AWG has high loss. Distance from OLT to ANU is limited.

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Remote Interrogation of terminal Network (RITENET)

- Instead of a LED a cheap modulator (refractor) is used to modulate a signal initiated by the AWG router. Thus, the device is very cheap and the distance limitation is not there. Time sharing in upstream and downstream. Bandwidth is symmetric.

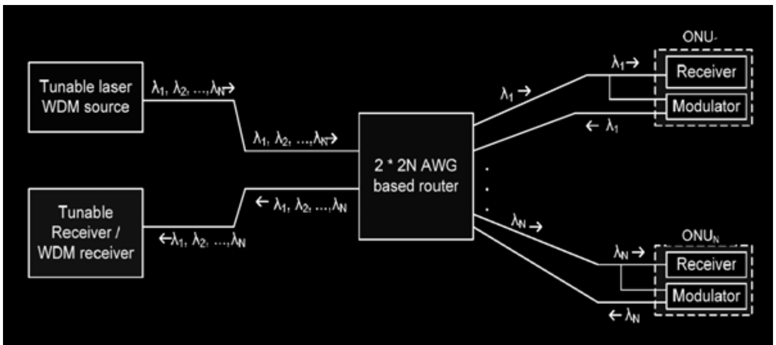

Fig. 10. Architecture of RITENET [37].

Still expensive at sender end. Double fiber at customer end.

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Multistage AWG

- Needs more ONUs and more users per ONU. Multistage AWG addresses the problem.

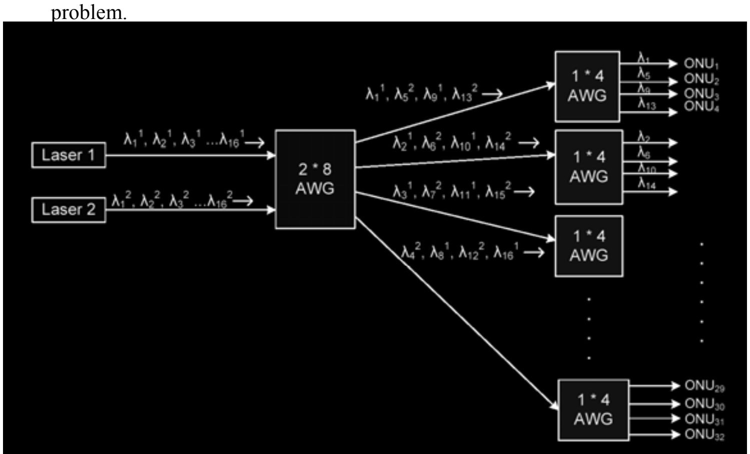

Fig. 11. Multistage AWG-based architecture [39].

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DWDM Super PON

- PONs also have distance limitations such as EPON is 20km and the maximum number of nodes supported is 32. Super-PON (SPON) covers a range of 100 km, and with optical amplifies splitting ratio of 2000. Each direction uses separate DWDM channels.

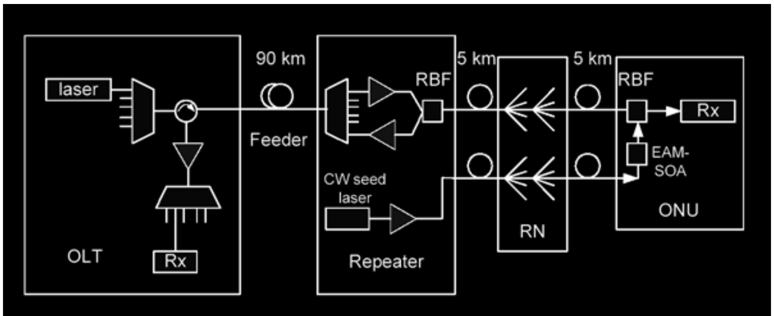

Fig. 12. DWDM super-PON (SPON) architecture using colorless ONUs [42].

Optical amplifiers are not passive.

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WDM-PON Comparisons

Table 1. Comparison of Various WDM-PON Architectures

		CPON [33]	LARNET [36]	RITENET [37]	Multi-Stage [39]	Super-PON [42]	Success-DWA [43]
Main Objective of architecture		AWG based basic system	Reduce ONU Cost	Reduce ONU Cost	Scalable PON Wide-area service	Long-distance Wide-area service	Scalable PON Throughput increment
Sharing of Fiber		Up/down shared or separate	Up/down shared	Up/down separate	Dependent on upstream option	Up/down shared	Up/down shared
Sharing of Wave-length	down	1 λ/ONU	1 λ/ONU	Up/down shared (TDMA, dynamic allocation)	Dependent on upstream option	Share (TDMA)	- Shared among ONUs - Up/down shared (TDMA, dynamic allocation)
	up	Shared (TDMA)	Shared (TDMA, CSMA/CD)			Share (TDMA)	
Scalability		Poor	Poor	Poor	Good	Good	Excellent
Cost of user terminal (ONU)		Poor (DFB LD)	Good (LED)	Good	Dependent on upstream option	Poor	Poor
Cost of deployment		Good	Good	Poor	Very poor	Good	Poor
Distance (OLT-ONU)		Average	Poor	Very poor	Average	Excellent (~100 Km)	Average

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Ethernet in the First Mile (EFM)

- Ethernet in the First Mile (EFM), also known as IEEE 802.3ah, is a collection of protocols specified in IEEE 802.3, defining the Ethernet in the Access networks, i.e. First/Last Mile.

- EFM allows continuous standard Ethernet network across the globe, as well as to last mile eliminating non-native transport such as Ethernet over ATM from the Access Networks.

- EFM is not a new Ethernet. It defines how Ethernet can be transmitted over new media types:
  - Voice-grade copper.
  - Long wavelength single fiber (as well as long wavelength dual-strand fiber)
  - Point-To-Multipoint (P2MP) fiber. Ethernet over Passive Optical Networks (EPON).

- EFM also addresses other issues, required for mass deployment of Ethernet services, such as Operations, Administration & Management (OAM) and compatibility with existing technologies (e.g. spectral compatibility for copper).

Ethernet Physical Layer (PHY) Standards

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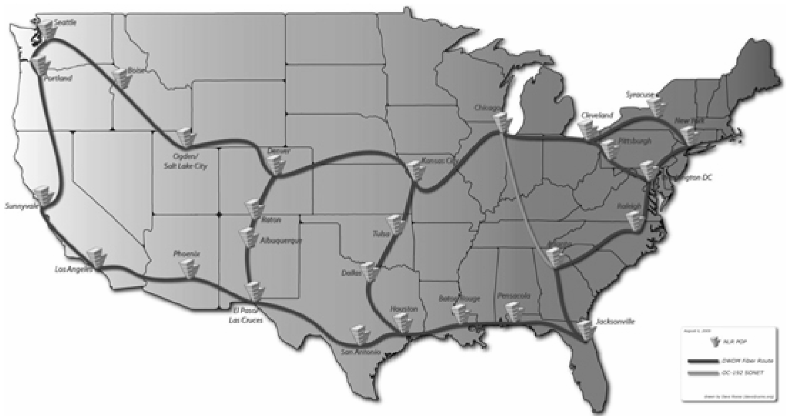
- The EFM defines the following new Ethernet physical layer (PHY) interfaces:
- EFMC - EFM Copper
  - **2BASE-TL** -- Full-duplex long reach Point-to-Point link over voice-grade copper wiring., delivers a minimum of 2 Mbit/s over distances of up to 2700 m (9 kft), over a single copper pair.
  - **10PASS-TS** -- Full-duplex short reach Point-to-Point link over voice-grade copper wiring. 10PASS-TS PHY can deliver a minimum of 10 Mbit/s over distances of up to 750m (2460 ft), over a single copper pair.

- EFMF - EFM Fiber
  - **100BASE-LX10** -- point-to-point 100 Mbit/s Ethernet links over a pair of single-mode fibers up to at least 10 km.
  - **100BASE-BX10** -- point-to-point 100 Mbit/s Ethernet links over an individual single-mode fiber up to at least 10 km.
  - **1000BASE-LX10** -- point-to-point 1000 Mbit/s Ethernet links over a pair of single-mode fibers up to at least 10 km.
  - **1000BASE-BX10** -- point-to-point 1000 Mbit/s Ethernet links over an individual single-mode fiber up to at least 10 km.

- EFM PON - EFM Passive Optical Network
  - **1000BASE-PX10** -- P2MP 1000 Mbit/s Ethernet links over PONs up to at least 10 km.
  - **1000BASE-PX20** -- P2MP 1000 Mbit/s Ethernet links over PONs up to at least 20 km.

Newest Trunk Technology



LambdaRail (2006-2007): A a high-speed national computer network in the United States that runs over fiber-optic lines, and is the first transcontinental Ethernet network.

INTERNET ENGINEERING

LECT-4b, S-43

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Next Topic:
WAN