ECE 271 INTRODUCTION TO TELECOMMUNICATION NETWORKS

COURSE CONTENTS

1. Telecommunications Fundamentals
2. Changes in Telecommunications
3. The New Public Network
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11. Twisted-Pair Copper Cable
12. Coaxial Cable
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14. Satellite
15. Fiber Optics
16. Establishing Communications Channels, Switching and Networking Modes
17. Public Switched Telephone Network (PSTN) Infrastructure
18. Plesiochronous Digital Hierarchy (PDH) Transport Network Infrastructure
19. Synchronous Digital Hierarchy (SDH) Transport Network Infrastructure

REFERENCE BOOKS:

1.   NAME   : Communication Networks-Fundamental Concepts and Key Architectures
       AUTHORS   : Alberto Leon-Garcia, Indra Widjaja
       PUBLISHER : McGraw-Hill
       ISBN   : 0-07-123026-2
       EDITION   : 2003 (International Edition)

2.   NAME   : Essential Guide to Telecommunications
       AUTHORS   : Annabel Z. Dodd
       PUBLISHER : Prentice-Hall, Inc.
       ISBN   : 0-13-064907-4
       EDITION   : 2002 (Third Edition)

3.   NAME   : Communication Systems Engineering
       AUTHORS   : John Proakis, Masoud Salehi
       PUBLISHER : Prentice-Hall, Inc.
       ISBN   : 0-13-061793-8
       EDITION   : 2002 (Second Edition)

4.   NAME   : Optical Fiber Communications
       AUTHOR   : Gerd Keiser
       PUBLISHER : McGraw-Hill
       ISBN   : 0-07-116468-5
       EDITION   : 2000

5.   NAME   : Data Communications and Networking

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        AUTHOR      :  Behrouz A. Forouzan
        PUBLISHER  :  McGraw-Hill
        ISBN        :  0-201-63442-2
        EDITION     :  2001 (Second Edition)

6.      NAME        :  Telecommunications Essentials
        AUTHOR      :  Lillian Goleniewski
        PUBLISHER  :  Addison-Wesley
        ISBN        :  0-201-76032-0
        EDITION     :  2002

7.      NAME        :  Communication Sysytems
        AUTHOR      :  Simon Haykin
        PUBLISHER  :  John Wiley&Sons
        ISBN        :  0-471-17869-1
        EDITION     :  2001 (Fourth Edition)

8.      NAME        :  Modern Digital and Analog Communication Systems
        AUTHOR      :  B. P. Lathi
        PUBLISHER  :  Oxford Univ. Press, Inc
        ISBN        :  0-19-511009-9
        EDITION     :  1998

9.      NAME        :  Next generation intelligent optical networks
        AUTHOR      :  Kartalopoulos, Stamatios
        CODE        :  TK5103.59 K37
        EDITION     :  2008

10.     NAME        :  Data communications and networks
        AUTHOR      :  Miller, Dave
        CODE        :  TK5105 M55
        EDITION     :  2006

11.     NAME        :  Digital communications
        AUTHOR      :  Proakis, John G
        CODE        :  TK5103.7 P76
        EDITION     :  2008

12.     NAME        :  Introduction to digital communications
        AUTHOR      :  Pursley, Michael B.
        CODE        :  TK5103.7 P87
        EDITION     :  2005

13.     NAME        :  Advanced free-space optical communications
        AUTHOR      :  Ross, Monte
        CODE        :  TA1677 A38
        EDITION     :  2004

14.     NAME        :  Advanced free-space optical communications
        AUTHOR      :  Ross, Monte
        CODE        :  TA1677 A38
        EDITION     :  2004

15.     NAME        :  Mobile wireless communications
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AUTHOR      : Schwartz, Mischa
CODE        : TK5103.2 S39
EDITION     : 2005
```

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16.  NAME     : Communication systems: analysis and design
     AUTHOR   : Stern, Harold P.E.
     CODE     : TK5101 S74
     EDITION  : 2004
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17.  NAME     : Electronic communications systems and design
     AUTHOR   : Tomasi, Wayne
     CODE     : TK5101 T66
     EDITION  : 2004
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18.  NAME     : Principles of communication systems simulation
     AUTHOR   : Tranter, William H.
     CODE     : TK5102.5 P75
     EDITION  : 2004
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GRADING: 1 MID TERM EXAM (IN CLASS)   :   %40
            1 FINAL EXAM (IN CLASS)   :   %50
               PERFORMANCE IN CLASS   :   %10
                                TOTAL :   %100

NOTE: Performance in class covers attendance in lectures, performing the homework
       assignments, obeying rules and discipline, good conduct of communication, etc.

       It is essential that students show at least 70 % attendance in lectures.

<u>Telecommunications Fundamentals</u>

<u>Changes in Telecommunications</u>

Human Senses Added in Telecommunications

- Hearing and speaking computers

    – Voice activated services providing free stock quotes, weather information, entertainment information etc.

- Virtual touch known as haptics – Enabling the user to reach in and physically interact with simulated computer content

    – The user feeling the weight of jewelry as if it is in the user's hand

    – The user feeling the fur of an animal

    – Virtual reality job training

    – Computer-aided design

    – Remote handling of hazardous materials

    – "Touch" museums

- Smell applications in computers

    – Using aroma to trigger fear, excitement and other emotions

    – Applications in e-commerce

- Seeing computers (equipped with camera)

    – Capturing and sending images

    – Displaying high-quality entertainment programming

    – Visual streams

- Wearable Computing – Dressed for success

    - Today's portable devices are approaching to wearables

    – Wearable computer with CPU, disc, RAM ..etc in the form of dress, wrist keyboard, headgear suspended in front of the eye, in the size of a stamp, providing full-color screen appearing as 15 inch monitor, shirt pocket video camera

- Intelligent home and office utilities – Becoming more intelligent, getting smaller, more powerfull

- Smart refrigerators, smart washing machines, smart ovens, smart furniture, smart T.V .... etc.

- Machine-to-machine communication

    - Around 15 billion microprocessors in the world as compared to 6 million human beings.

    - Learning devices becoming more intelligent everyday

    - In 2015 it is estimated that 95% of the total communications traffic in the world will be machine-to-machine communication and only 5% will be human-to-human.

Types of traffic in the network

- Voice
- Data
- Image
- Video
- Combination (Multimedia)

Factors effecting the traffic

- Network capacity
- Tolerance for delays in the network (latency)
- Tolerance for the variations in the delay in the network (jitter)
- Tolerance for potential congestion, thus the loss of traffic in the network

Importance of the factors effecting the traffic for each traffic type

	Network capacity (Bandwidth)	Tolerance for delays in the network (latency)	Tolerance for the variations in the delay in the network (jitter)	Tolerance for potential congestion, thus the loss of traffic in the network
Voice	Narrowband	Must be kept minimum	Must be kept minimum	Minimum loss for understandibility
Data	Medium to high. Increases as image and video are included	More tolerant to text based data but much less tolerant for real time applications like video	More tolerant to text based data but much less tolerat for real time applications like video	Up to certain percentage depending on the required performance
Image	Medium to high. Increases for greater resolution	Tolerates certain delay	Tolerates certain delay variation	Up to certain percentage depending on the required performance
Video	Ever-greater bandwidth is required	Extremely sensitive to delay	Extremely sensitive to delay variation	Minimum loss for clear image
Combination (Multimedia)	Ever-greater bandwidth is required	Extremely sensitive to delay	Extremely sensitive to delay variation	Minimum loss for good quality

Demanding Applications

- Streaming media applications like on-line education, telemedicine consultations and practices
- Digital entertainment involving video editing

- Interactive multimedia

- Digital TV

- 3D Gaming

- Virtual Reality Applications (Holographic Presence)

- E-commerce and m-commerce (mobile commerce)

Backbone Bandwidth Requirements for Advanced Applications

- Online virtual reality (e.g. life-size 3D holography; telepresence): 1 - 70 Petabits/sec (Peta=10^{15})

- Machine communications (e.g. smart utility communications, Web-agents, robots): 50 - 200 Petabits/sec

- High volume computing (e.g. 3-D computer aided design, weather forecasting): 50 - 200 Petabits/sec

- Residential applications after 100 Gbps broadband residential access is available: In the order of Exabits/sec (Exa=10^{18})

| (Sub)multiple	Prefix	Symbol	Name (US and Canada)
10^{24}	yotta	Y	Septillion
10^{21}	zetta	Z	Sextillion
10^{18}	exa	E	Quintillion
10^{15}	peta	P	Quadrillion
10^{12}	tera	T	Trillion
10^{9}	giga	G	Billion
10^{6}	mega	M	Million
10^{3}	kilo	k	Thousand
10^{2}	hecto	h	Hundred
10^{1}	deka or deca	da	Ten
10^{-1}	deci	d	Tenth
10^{-2}	centi	c	Hundredth
10^{-3}	milli	m	Thousandth
10^{-6}	micro	μ	Millionth
10^{-9}	nano	n	Billionth
10^{-12}	pico	p	Trillionth
10^{-15}	femto	f	Quadrillionth
10^{-18}	atto	a	Quintillionth
10^{-21}	zepto	z	Sextillionth
10^{-24}	yocto	y	Septillionth

The New Public Network

- End-to-end digitalization

  – Worldwide around 80% of the backbones are digitized

  – Local loop (Last mile between the subscriber and network) is currently around 93% analog. Great deal of effort needed to digitilize local loop. Without broadband access Internet and advanced applications can't grow.

- Currently networks are electronic, in the future end-to-end optical or photonic networking is foreseen

- Intelligent programmable network: From anywhere in the world, any service or feature will be accessible irrespective of the connected network provider or network platform

- Very high bandwidth infrastructure

- Infrastructure offering multichannel service (one physical medium carrying multiple channels of different traffic)

- Low-latency network, i.e. networks with minimum delays. E.g. return time of 500 msec in satellite communications is disturbing. Today's internet has up to 1 – 2 sec delay

- Agnostic network, i.e. should be able to follow multiprotocol. E.g. a box interfacing most used data protocols

- QoS (Quality of Service) guarantees: Meeting bandwidth, latency, loss requirements

- Encryption and security

Basic elements of Telecommunications

Transmission Lines

- Circuit: Physical path between two or more points, terminating on a port (an electrical or an optical interface)

  – Two-Wire Circuits: Has two electrical conductors. E.g. the ones used in analog local loop, i.e between the subscriber and the subscriber's first point of access into the network

  – Physical Four-Wire Circuits: Has two pairs of electrical conductors. E.g. connection between PSTN switches, leased lines, digital circuits

  – Logical Four-Wire Circuits: Has two electrical conductors. Transmit and receive paths are formed by appling two frequencies

- Channel: Defines a logical conversation path. Channel is the frequency band, time slot or code over which a single traffic flows. Number of channels in a transmission line determines the number of simultaneous conversations.

- Line: A connection configured to support call generated by one user

- Trunk: A circuit configured to support call generated by a group of users. Trunk connects two switches.

- Virtual Circuits: Series of logical connections between sending and receiving devices belonging to two hosts in a packet switching network. Connection is composed of a variety of different routes which are defined by table entries inside the switch. Connection is established after sending and receiving devices mutually agree on communication parameters like message size, path to be taken, error acknowledgements, flow control procedures, error control procedures.


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— —    Virtual Circuit
▬▬▬    Trunk
☐      User
◯      Switch with internal routing table
```
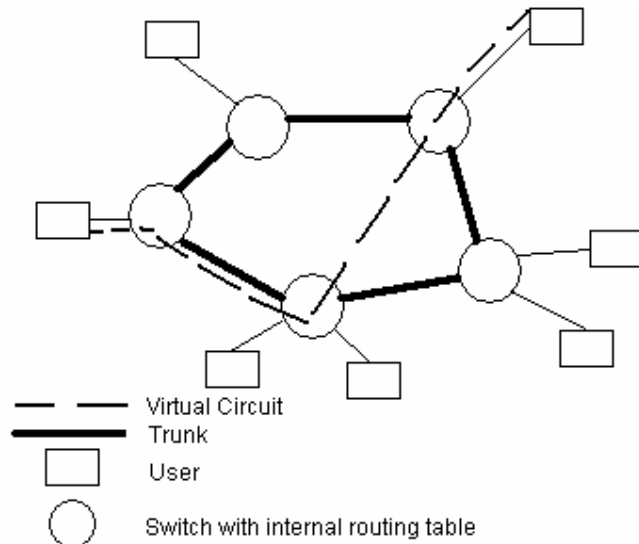
  - PVC (Permanent Virtual Circuit): Virtual circuit available on a permanent basis. Manually configured by the network management system. Similar to leased line.

  - SVC (Switched Virtual Circuits): Virtual circuit set up on demand. Provisioned dynamically by using signalling techniques. Must be reestablished each time data is to be sent and disappears after the data is sent. Similar to dialup connection in PSTN. Applicable when user is outside the physical location of the network (home, hotel etc.).

Network Connection Types

- Switched network connections: Dialup connection using a series of network switches

- Leased line network connections: Same two points are always connected, the transmission between these two always being on the same path.

- Dedicated network connections: Leased line connection where the end user may own the transmission equipments thus being exclusive to that user.

Electromagnetic Spectrum

ELF = Extremely Low Frequency
VF = Voice Frequency
VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency
UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extremely High Frequency

30 Hz	300 Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	1 GHz	2 GHz	3 GHz	4 GHz	8 GHz	12.5 GHz	18 GHz	26.5 GHz	30 GHz	40 GHz	300 GHz	>300 GHz
ELF																			
	VF																		
		VLF																	
			LF																
				MF															
					HF														
						VHF													
							UHF												
								L-Band											
									S-Band										
										SHF									
											C-Band								
												X-Band							
													Ku						
														K					
															Ka				
																EHF			
																	Millimeter		
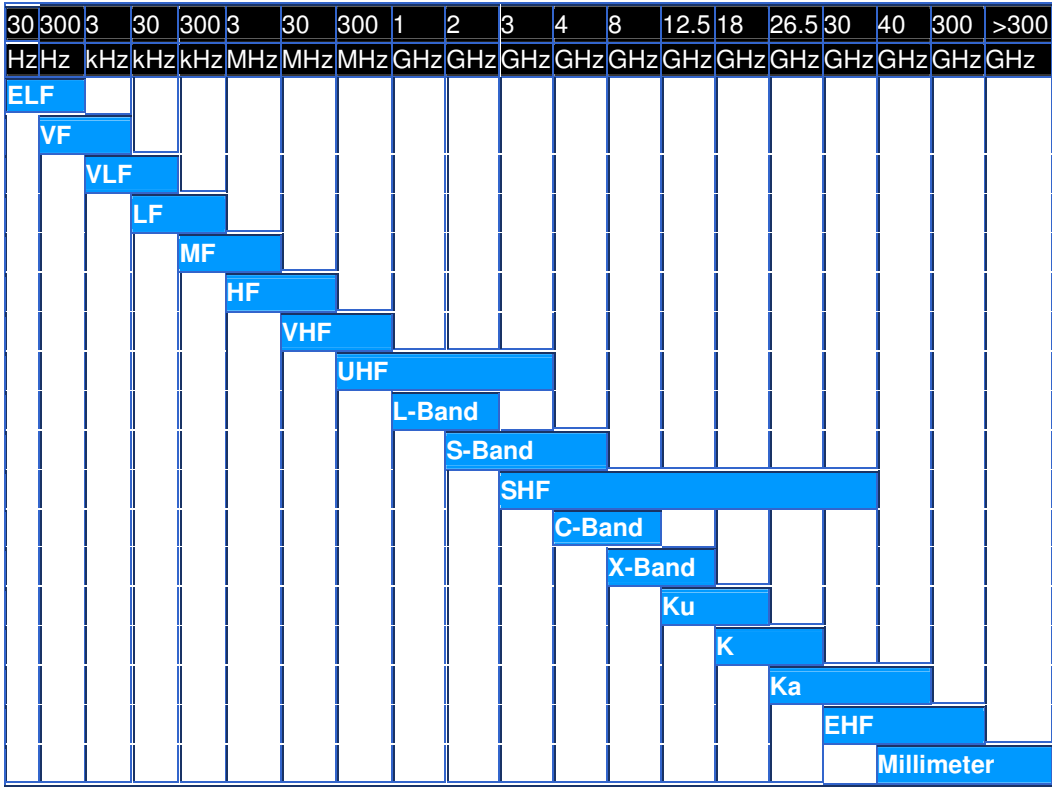
	Wavelength	Frequency
Gamma rays	< 10 pm	>30.0 EHz
X-rays	< 10 nm	>30.0 PHz
Extreme UV	< 200 nm	>1.5 PHz
Near UV	< 380 nm	>789 THz
Visible	< 780 nm	>384 THz
Near IR	< 2.5 um	>120 THz
Mid IR	< 50 um	>6.00 THz
Far IR/submillimetre	< 1 mm	>300 GHz
Microwaves	< 100 mm	>3.0 GHz
Ultrahigh Frequency Radio (TV, Cellular Radio)	<1 m	>300 MHz
Very High Frequency Radio (TV, COAX), FM (88 MHz-108 MHz)	<10 m	>30 MHz
Shortwave Radio, (COAX from 1 MHz)	<180 m	>1.7 MHz
Medium Wave (AM) Radio, (Twisted Pair Up to 1 MHz)	<650 m	>650 kHz
Longwave Radio	<10 km	>30 kHz
Very Low Frequency Radio	>10 km	<30 kHz

- Bandwidth is the range of frequencies that make up the signal. Some (not strict) definitions:

  - Narrowband usualy means up to 64 Kbps (DS-0 channel, i.e Digital Signal Level 0). 64kbps is the basic channel that an uncompressed digital voice can be carried in the network

  - Wideband is n x 64 Kbps

  - Broadband is more than 2 Mbps

Analog and Digital Transmission

- Analog Transmission

  - Analog signal is continuous in amplitude and frequency

  - Natural voice and video signals are analog

  - Human voice is generated within the frequency range of 100 Hz – 10 KHz, i.e a bandwidth of 9.9 KHz.

  - Intelligible speech is in the frequency range of 250 Hz – 3.4 KHz. Total 4 KHz bandwidth is allotted for one analog voice transmission

  - In commercial TV broadcasting, bandwidth of the video signal is limited to 4.2 MHz. Allocated channel bandwidth for commercial TV is 6 MHz

  - Typical analog modulations are Amplitude Modulaion (AM) and Frequency Modulation (FM)

- Analog circuits like analog local loop can support low-speed communications (56 Kbps)

- Noise is accumulative as the signal propagates along the transmission medium. Thus signal reaching the repeater is not only attenuated (repairable by amplifiers) but also degraded (very difficult to repair). Shorter repeater distances needed

- Management of the analog network is poor

- Low security. Tapping or interfering is easier

- High bit error rates (10^{-5})

- Digital Transmission

  - Signal is represented by series of dicrete pulses (0's and 1's)

  - Computer output signals are digital

  - Bir rate determines the bandwidth. (e.g one voice channel carries 64 Kbps)

  - Typical digital modulations are Phase Shift Keying (PSK) and Frequency Shift Keying (FSK)

  - Very high speed data communications especially with fiber optic communications

  - Digital signal is much more easily reproduced as compared to analog signal. Regenerative repeaters does not only amplify the attenuated digital signal but also regenerates the degraded signal. Longer repeater distances can be used

  - Management of digital network is much more creative. Remote and/or central management, traffic statistics, performance measurements, management of different networks are possible through smart devices

  - Through encryption can be high security

  - Low bit error rates. (10^{-7} in twisted pair, 10^{-9} in satellite, 10^{-11} in fiber)

Conversion between analog and digital signals

Some of the existing networks are neither all-analog nor all-digital, but a mixture of analog and digital. At the relevant points of such networks there is need for conversion from analog to digital or vice versa.

- **Modems** (MOdulator/DEModulator)

  - Modems convert digital information to analog by MODulating it on the sending end and DEModulating the analog information into digital information at the receiving end

  - The need to communicate between distant computers led to the use of the existing phone network for data transmission

  - Most phone lines were designed to transmit analog information – voices

- Computers and their devices work in digital form – pulses

- So, in order to use an analog medium, a converter between the two systems is needed

- At the transmitting side, modem accepts serial binary pulses from a device, modulates some property (amplitude, frequency, or phase) of an analog signal in order to send the signal in an analog medium

- At the receiving side, modem performs the opposite process, enabling the analog information to arrive as digital pulses at the computer or device on the other side of connection

- Data rates commonly used today are 56 Kbps

- Transmission involves data compression techniques which increase the rates, error detection and error correction for more reliability

Various Modem Classifications

- Leased, Private or dedicated lines: Usually 4-wire

- Dial up: Point-to-point connections on the PSTN by any combination of manual or automatic dialing or answering

- Two and Four-Wires Lines: A four-wire (4W) line is a pair of two-wire (2W) lines, one for transmitting and one for receiving, in which the signals in the two directions are to be kept totally separate

- Half Duplex: Signals can be passed in either direction, but not in both simultaneously

- Full Duplex: Signals can be passed in either direction in full speed, simultaneously. Full duplex operation on a two-wire line requires the ability to separate a receive signal from the reflection of the transmitted signal. This is accomplished by either FDM (frequency division multiplexing) in which the signals in the two directions occupy different frequency bands and are separated by filtering, or by Echo Canceling (EC)

- Split-speed or asymmetric modems: Provide a low-speed reverse channel

- Simplex: Signals can be passed in one direction only

- In a 2-wire line, full duplex operation can be achieved by splitting the channel into two sub-channels
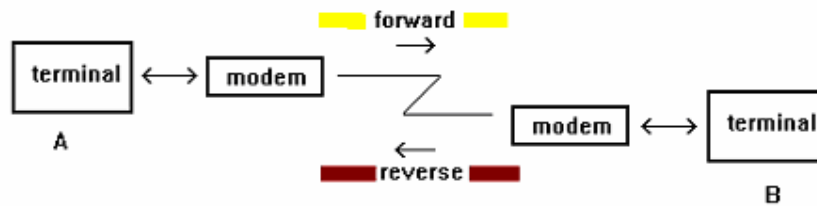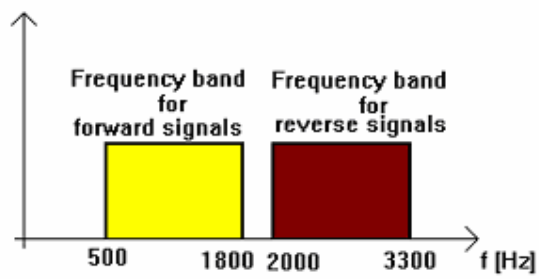
Operating Asynchronous Modem in a 2 Wire Line
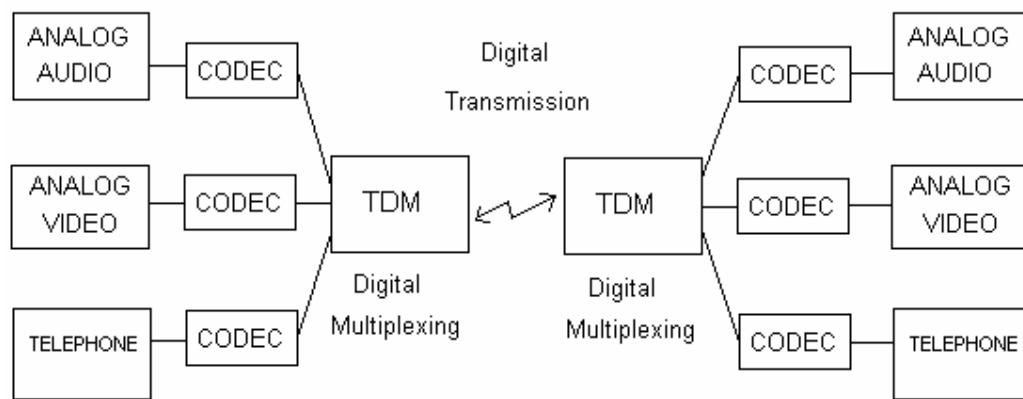
- Amplitude modulation (AM)

.
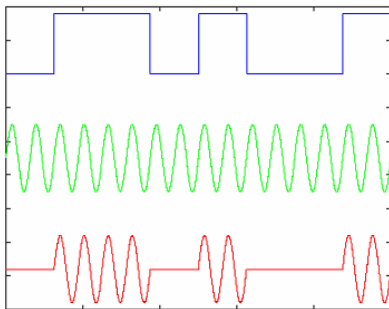
- Frequency modulation (FM)

.
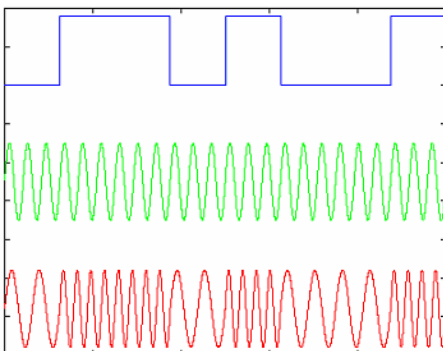
- Phase modulation (PM)
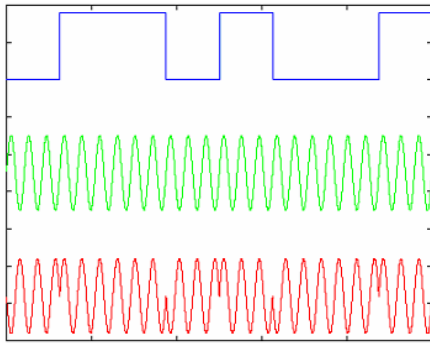
- **Codecs** (COder DECoder)

- Converts analog signals into digital signals

Multiplexing

- How to transfer data between two sites once there is a digital link between them?

- Analog to Digital conversion

  - Human voice is a continues signal in the range 0-4 KHz

  - On the other hand digital communication is based on discrete bits (0 and 1)

  - Thus, there is a need for converting the human voice into a stream of bits and vice versa

  - Analog to digital conversion is done by sampling the sound wave and denoting the level of the wave by a number which is transmitted over the digital link

  - Reverse process is done by creating a wave according to the received numbers

  - According to Nyquist law, the minimum number of such wave samples needed for complete reconstruction of the wave is twice the number of the maximum frequency of that wave

  - For voice signals, this yields: 2 x 4KHz = 8K Samples per second

- The most common method for denoting the level of the wave is called Pulse Code Modulation (**PCM)**

- In PCM, the level is divided into 256 levels (8 bits)

- Thus, if sampling is 8K times a second and each sample is in the range of 0-255, then per voice line 8K x 8 = 64K bits per second is obtained
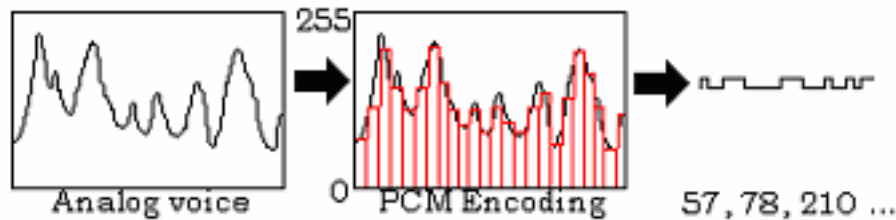
- Multiplexing

  - There are two points to be settled:

    1. To be able to transmit more than just 64Kb/s

    2. The receiving end should know where in the bit stream is the beginning of a new 8 bit number.

  - These two points are settled by multiplexing and the use of synchronization bits

  - In order to transfer much more than a single channel between two sites, installing a separate line for every channel is clearly not a good solution

  - Multiplexing is a way of sending many channels over a single line

  - This is done by using Time Division Multiplexing (**TDM**)

  - There are 32 channels, each with a rate of 64Kbs, that will be transferred to the other end

  - The multiplexer takes from each of the 32 lines a <u>single byte</u> and sends them one after the other

  - Then the multiplexer takes the next byte from every channel, and so on

  - In order for the bytes not to be lost, the multiplexer must be able to send all the 32 x 8 bits from the 32 channels without the second byte of the first channel getting lost

  - This implies that the output rate of the multiplexer should be at least 32 x 64Kbs or 2048 Kbs

  - This method is called Time Division Multiplexing (TDM)

  - In TDM, the multiplexer needs 1/8000 sec (i.e. 1/ (8K samples/sec)) for transferring a single byte of a single channel

15

- Then the multiplexer divides this between the 32 channels by increasing the rate so that each byte of a channel will take 1/(8000 * 32) sec to send

Example

To multiplex 3 channels of 64Kbs each:
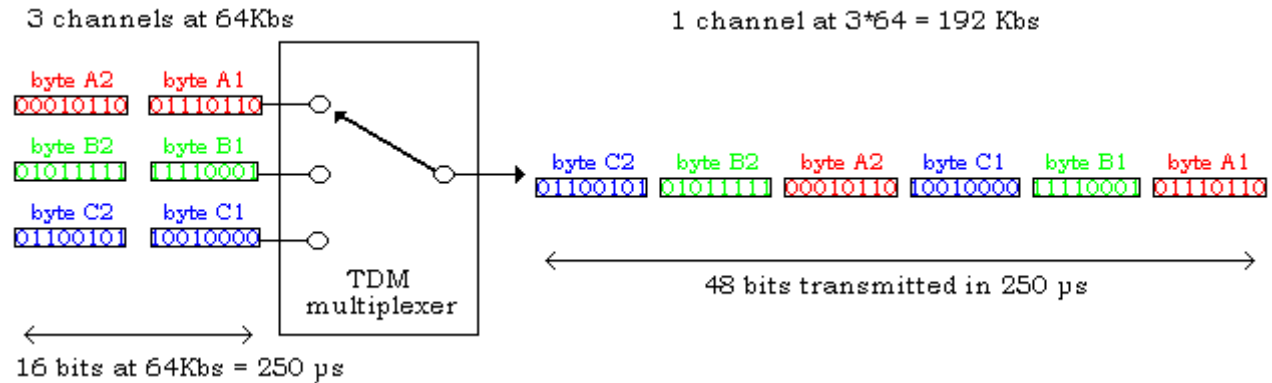
- This method could be further used for increasing the number of channels from 32 channels to 4 x 32 channels and so on

- By each increase in the number of channels, bit rate of the line is increased accordingly

- After sending the 32 channels over a single line, then the question is how will the receiving end (the demultiplexer) know which bit belongs to which channel ?

- Synchronization

  - Special bits in the bit stream are used for synchronization

  - These bits tell the demultiplexer where a new 32 byte group starts so it will know how to divide the following bits between the channels

  - No synchronization is needed for distinguishing between each of the 32 channels

  - If we multiplex several 32 channels together, more synchronization bits are added for distinguishing between the different groups

- Digital data and digital Video

  - For transmitting digital data or digital video, no analog to digital conversion is needed.

  - Instead, the bit stream in directly inserted into the multiplexer

  - Video, which needs a much higher bit rate than 64Kbs is usually inserted directly into the second level multiplexer, thus allowing a bit rate of 1.5-2 Mbs

- Standards

  There are several standarts like

- CEPT/E-Carrier mainly used in Europe and in Turkey

- T-Carrier mainly used in USA and in some far-eastern countries.

- J-Carrier used in Japan

Although all of the above standards start with a single channel rate being 64Kbs, those channels are still incompatible because of the different ways by which the voice was digitized

- CEPT/E1

  - The first hierarchy of E1 is composed of 32 channels totaling 32 x 64Kbs = 2048 Kbs

  - Two of the channels are not used for transmitting data but for frame synchronization and signaling
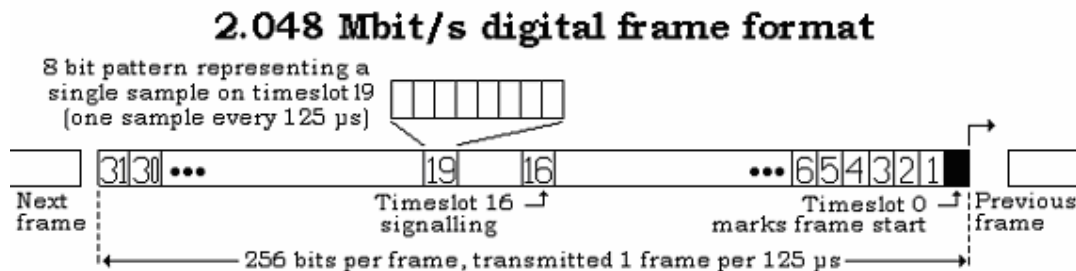
The hierarchies are presented in the following table:

	E-Carrier European (CEPT)	T-Carrier North American	J-Carrier Japanese
Level zero (Channel data rate)	64 kb/s	64 kb/s (DS0)	64 kb/s
First level (E-1, T-1, J-1)	2.048 Mb/s (30 user channels + 2 channels for synchronization and signalling)	1.544 Mb/s (DS1) (24 user channels + 8Kb/s for signalling)	1.544 Mb/s (24 user channels)
(Intermediate level, North American Hierarchy only)	-	3.162 Mb/s (DS1C) (48 Ch.)	-
Second level(E-2, T-2, J-2)	8.448 Mb/s (120 Ch.)	6.312 Mb/s (DS2) (96 Ch.)	6.312 Mb/s (96 Ch.)
Third level(E-3, T-3, J-3)	34.368 Mb/s (480 Ch.)	44.736 Mb/s (DS3) (672 Ch.)	32.064 Mb/s (480 Ch.)
Fourth level(E-4, T-4, J-4)	139.264 Mb/s (1920 Ch.)	274.176 Mb/s (DS4) (4032 Ch.)	97.728 Mb/s (1440 Ch.)
Fifth level(E-5, T-5, J-5)	565.148 Mb/s (7680 Ch.)	400.352 Mb/s (5760 Ch.)	397.200 Mb/s

Below is a photograph representing
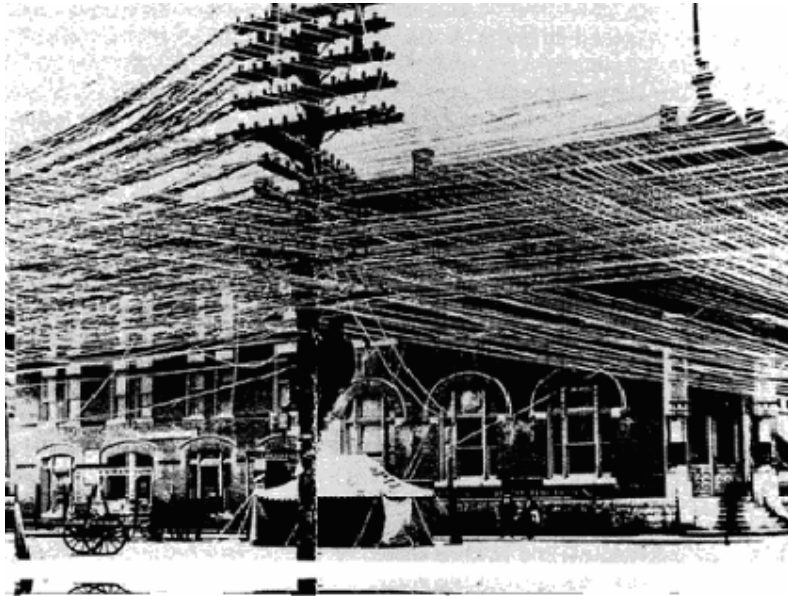
- **Frequency Division Multiplexing**
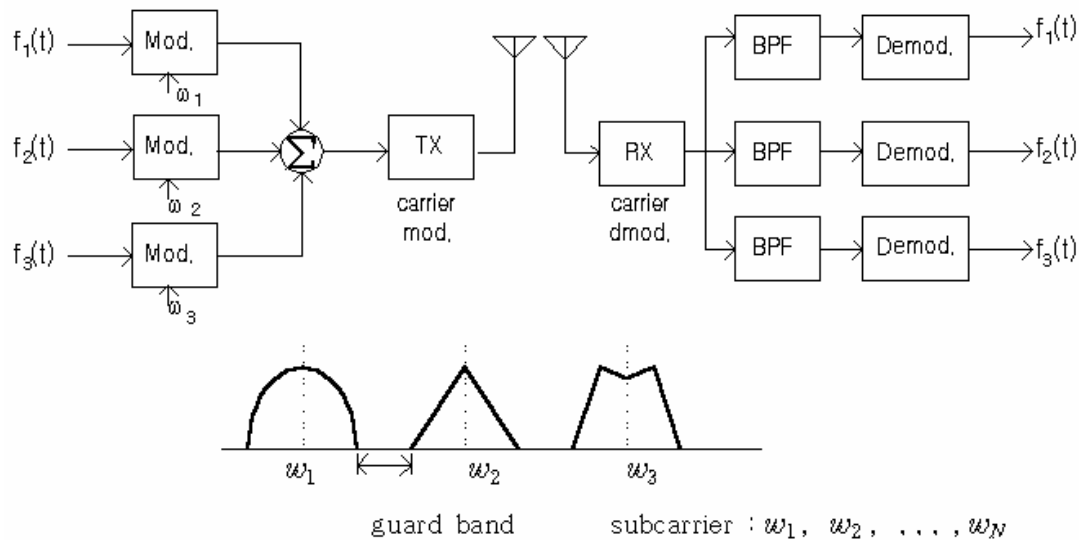
- Statistical Multiplexers

    - TDM is limited because the terminals cannot use each other's time slots

    - Statistical Time Division Multiplexers (STDM) dynamically allocate the time slots among the active terminals

    - In this way, bandwidth is used most efficiently, thus transmission is efficient

    - Is able to carry 2 – 5 times more traffic than TDM

    - Thus one can have more terminals than the available time slots

    - Statistical multiplexers are smarter and have more memory than other muxes

- When all the time slots are busy, excess data goes into buffer

- When buffer is full, additional access data gets lots

- Thus traffic analysis must be made to ensure the performance parameters

- Statistical multiplexers form the basis of packet switching technologies like X.25, IP, Frame Relay and ATM
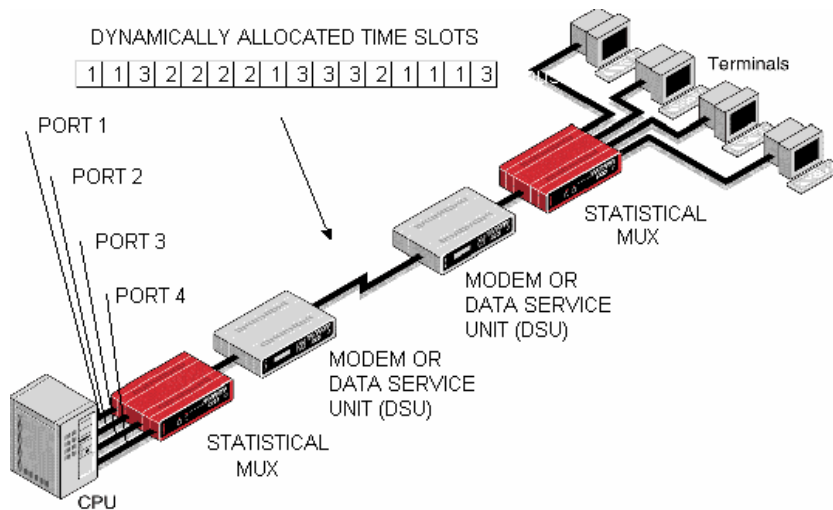

- Intelligent Multiplexers
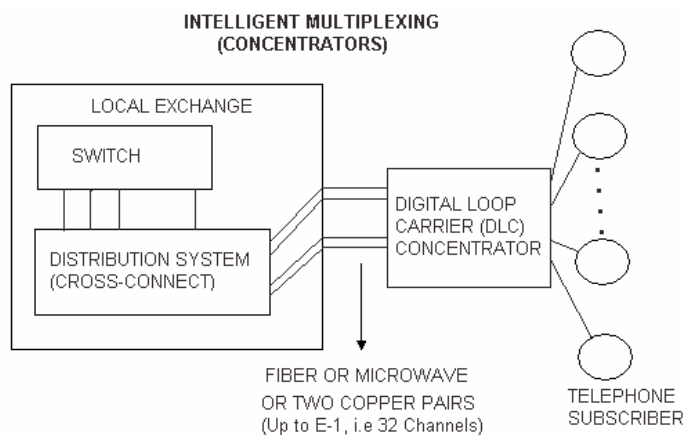
- Intelligent Multiplexers are also known as **Concentrators**

- They concentrate (combine) large numbers of low speed lines to be carried over a high speed line to a further point in the network

- Digital Loop Carrier is an example for remote concentrator or remote terminal

- **Inverse Multiplexers**

- Performs reverse operation as compared to multiplexers

- Thus, instead of combining many low-bit-rate streams to carry on a high bit-rate medium, inverse multiplexer:

    - Divides a high-speed serial data stream from a router or PC or other device into partial data streams of approximately 1.5 Mbps / 2Mbps each

    - Transmits these partial streams across separate T-1 / E-1 lines or N-ISDN or switched 64Kbps

    - Then recombines the partial streams into the exact original stream at the far end

INVERSE MULTIPLEXING
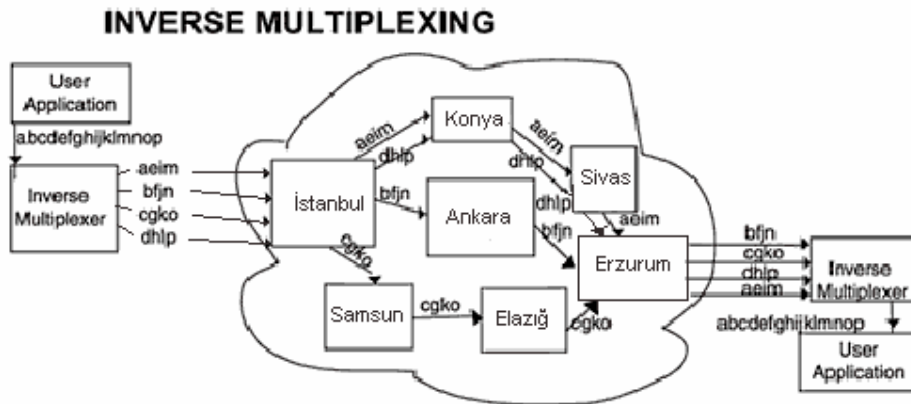
    - Separate channels take diverse paths through the network and arrive at their destination at different times and not in order

    - Inverse mux puts the packets back into proper order and adjusts the delays

    - Via inverse multiplexing, high bandwidth applications which are not very frequently utilized (like videoconferencing once in a month) can be achieved without the need to pay a separate link for this use only

- **Inverse Multiplexing for ATM (IMA)**

    - IMA allows a high-bandwidth stream of ATM cells over multiple T-1 or E-1 (2.048Mbps) circuits

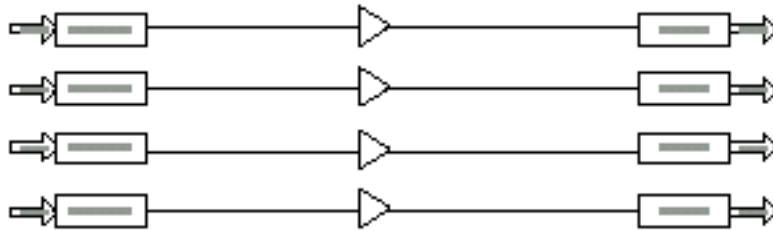- **Wavelength Division Multiplexing/Dense WDM (WDM/DWDM)**
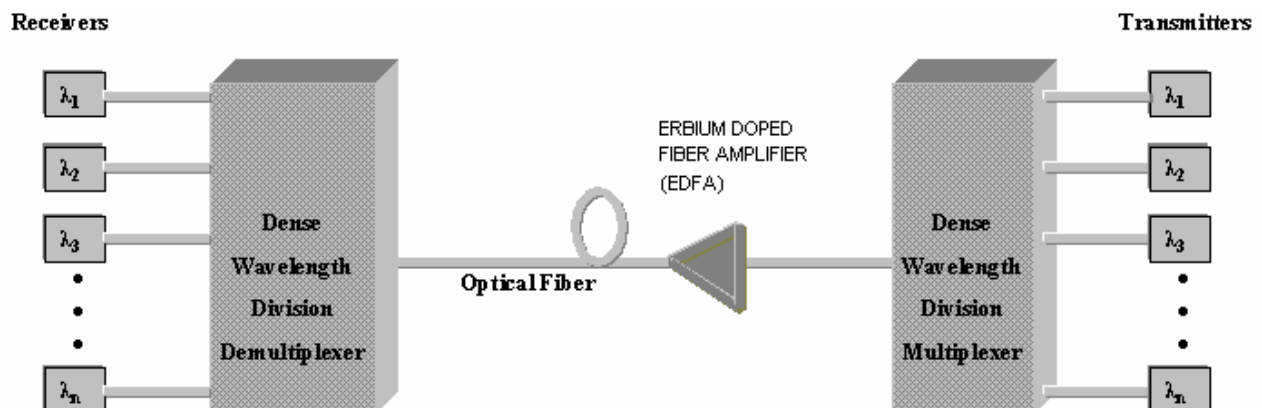
- Data from different sources are put together on an optical fiber, with each signal carried at the same time on its own separate light wavelength

- Using Wavelength Division Multiplexing (WDM) or Dense Wavelength Division Multiplexing (DWDM) more than 16 , realized up to 160 (and theoretically 15,000 channels pronounced) separate wavelengths or channels of data can be multiplexed into a lightstream transmitted on a single optical fiber

- Each channel carries a time division multiplexed (TDM) signal. In a system with each channel carrying 2.5 Gbps (30,720 telephone channels)

- Up to 160 x 2.5 Gbit/s (total of 4,915,000 telephone channels) is realizable by the same optical fiber

- If 15,000 channels can be realized, total of 460,800,000 telephone channels

- In dense WDM, wavelengths are closely spaced, commonly at intervals as small as 0.4 or 0.8 nm in the main telecommunications band near 1550 nm

- The International Telecommunications Union (ITU) has specified a grid of standard frequencies separated by increments of 100 GHz (approximately 0.8 nm), referenced to a frequency of 193.1 THz (corresponding to a wavelength of 1552.52 nm)

- These wavelengths are in the "conventional" or C band of the erbium-doped fiber amplifier (EDFA) at 1530 to 1570 nm

- Other bands of interest are the "long" or L band (approximately 1570 to 1610 nm) and the "short" or S band (approximately 1490 to 1530 nm)

- The importance of DWDM is for exploiting the enormous capacity of optical fiber to carry information

How a DWDM System Works

- Most DWDM systems support standard SONET/SDH short-reach optical interfaces to which any SONET/SDH compliant "client" device can attach

- Clients may be SONET/SDH terminals or add/drop multiplexers (ADMs), ATM switches, or IP routers

- Within the DWDM system a device called a transponder converts the SONET/SDH compliant optical signal from the client back to an electrical signal

- This electrical signal is then used to drive a WDM laser

- WDM laser is a very precise laser operating around the 1550-nm wavelength range

- Each transponder within the system converts its client's signal to a slightly different wavelength

- The wavelengths from all of the transponders in the system are then optically multiplexed onto a single fiber

- In the receive direction of the DWDM system, the reverse process takes place

- Individual wavelengths are filtered from the multiplexed fiber and fed to individual transponders, which convert the signal to electrical and drive a standard SONET/SDH interface to the client
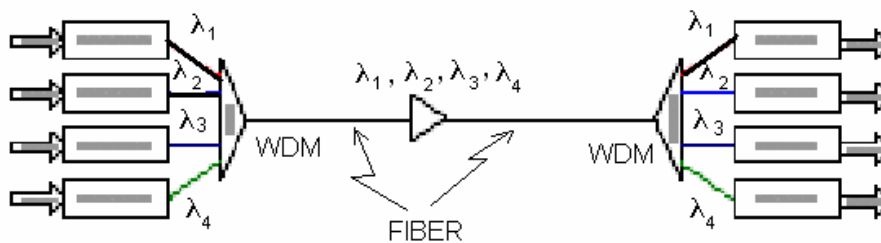
Technologies Competitive to DWDM

Space Division Multiplexing: four fibers, four 2.5Gbps lasers

Time Division Multiplexing: one fiber, one 10Gbps laser Mux

Wavelength Division Multiplexing: one fiber, four 2.5Gbps lasers

- Drawbacks of the TDM approach:

  - TDM requires a service-affecting, "all-at-once" upgrade to the new higher rate so network interfaces must be replaced by units with four times their capacity, whether or not all the capacity is immediately required whereas DWDM is non-service affecting, incremental capacity upgrades in 2.5Gbps increments from 2.5Gbps to 10 Gbps as demand increases

  - TDM constrains the capacity of the fiber to the speed of the available electronics. The highest transmission rate in commercially available electronics is 10Gbps, while the capacity of the fiber is orders of magnitude higher. Electronic components capable of operating at this speed are costly to construct, operate and maintain. With DWDM, electrical components operate at 2.5Gbps while the multiplexing is done in the optical domain

Transmission Media

  - It is the physical medium between the transmitter and receiver

  - Transmission media make use of some form of electromagnetic energy, in the form of electricity, radio or light

- Types of transmission media are:

    • Twisted pair

    • Coaxial Cable

    • Microwave (Radio-Link)

    • Satellite

    • Optical Fiber

Twisted Pair Copper Cable

• Unshielded Twisted Pair (UTP)

    - Oldest and the most common transmission system

    - It comprises two thin copper wires, usually solid core, which are separately insulated and twisted around each other

    - Various categories (Cat 1 for voice only, Cat 2, ...,Cat 5 used in LAN applications operating over 100 MHz handling 100 Mbps over a range of 100 meters, ...Cat 6 expected to support 1 Gbps but only over short distances, Cat 7 expected to operate over 600 MHz)

    - in UTP, as the conductor cross section increases, attenuation decreases. Attenuation is higher at higher frequencies

    - Billions of miles of UTP installed, most especially in the local loop which is the circuit that connects the customer premises to the CO (Central Office) switch at the edge of the PSTN (Public Switched Telephone Network)

    - UTP was originally installed for analog voice communications (4 KHz), but supports digital transmission as well (64 Kbps and higher bandwidth signals if properly deployed and conditioned

    - Can support Digital Subscriber Line (DSL) and T-1/E-1

    - UTP is also used in the LAN (Local Area Network) to connect terminals to hubs, switches and routers

    - Inexpensive and easy to install and reconfigure

    - Highly susceptible to EMI (Electromagnetic Interference), which is the source of crosstalk and other types of noise and signal distortion

• STP (Shielded Twisted Pair) and ScTP (Screened Twisted Pair)

    - STP has a metal foil, or shield, that surrounds each pair in a cable, sometimes with another shield surrounding all the pairs in a multi-pair cable

    - ScTP uses metal screen instead

- Used to avoid crosstalk and EMI (Electromagnetic Interference)

- Shields and screens block interference by absorbing it and conducting it to ground. İ.e. the foils and screens have to be spliced and there should be sound ground connection

- STP and ScTP are a lot more expensive, and a lot more difficult to install

- Developing high-speed LAN cabling standards for Cat 6 and Cat 7 are examples of this high-performance copper approach

Digital Subscriber Line (DSL) Technologies

- Digital applications of twisted pair in the local loop cover Narrowband ISDN and xDSL (HDSL, ADSL, IDSL, SDSL, RADSL, VDSL)

- Symetrical services provide the same rates both upstream and downstream

- Asymmetrical services have higher bit rate in downstream and lower bit rate upstream

- Some application parameters for DSL Technologies are tabulated below:

| Abbreviation	Full Name	Downstream Rate (Rate from the Host to the Subscriber	Upstream Rate (Rate from the Subscriber to the Host)	Maximum Loop Length (i.e Subscriber Distance from the Digital Loop Carrier or from the Local Exchange)
N-ISDN, BRI	Narrowband Integrated Services Digital Network, Basic Rate Interface (Symetrical)	2B + D Channels (i.e.2 x 64+16 =144 Kbps) B (Bearer Channels for Telephone or Data), D (Delta Channel for signalling + low speed packet-switched data)	2B + D Channels (i.e.2 x 64+16 =144 Kbps)	5.5 km over single twisted pair
N-ISDN, PRI	Narrowband Integrated Services Digital Network, Primary Rate Interface (Symetrical)	30B + D Channels in Europian Standard (i.e.30 x 64+64 =2 Mbps)	30B + D Channels in Europian Standard (i.e.30 x 64+64 =2 Mbps)	3.5 km over two twisted pairs
HDSL	High-Bit-Rate Digital Subscriber Line (Symmetrical)	Up to 2 Mbps	Up to 2 Mbps	3.5 km
ADSL	Asymmetrical Digital Subscriber Line	Up to 6 - 8 Mbps	Up to 640 -840 Kbps	3.5 km
IDSL	ISDN DSL	128 Kbps (ISDN without voice service)	128 Kbps (ISDN without voice service)	5.5 km over single twisted pair
SDSL	Symmetrical Digital Subscriber Line	Up to 2.3 Mbps in multiples of 64 Kbps	Up to 2.3 Mbps in multiples of 64 Kbps	5.5 km over single twisted pair
RADSL	Rate Adaptive Digital Subscriber Line (Asymetrical)	Dynamically adapted data rate from 600 Kbps to 7 Mbps	Dynamically adapted data rate from 128 Kbps to 1 Mbps	5.5 km over single twisted pair
VDSL	Very-High-Bit-Rate Digital Subscriber Line	Up to 13 Mbps with 1.5 km Up to 52 Mbps with 300 m	Up to 1.5 - 2.3 Mbps	Over two twisted pairs 1.5 km for 13 Mbps 300 m for 52 Mbps

Coaxial Cable

- Formed by single thick solid core copper conductor surrounded by an insulator separating the center conductor from the outer shield of metal foil.

- That insulating material serves to separate the center conductor, over which the data is transmitted, from the shield

- Surrounding all of that often is a layer of metal mesh for protection, and then a cable sheath

- Thick center conductor supports high frequency signal

- Supports high frequency (1 GHz)

- Immune to Electromagnetic Interference (EMI) However,.

- CATV systems traditionally uses coax to support signals as high as 500-750 MHz over considerable distances

- CATV signal is subdivided into frequency channels of 6 MHz for downstream TV transmission

- Interactive CATV systems also have channels of various widths for two-way data and even voice transmission

- Tradiditionally used in Ethernet and other LAN technologies, however today being replaced by data grade UTP

- Also used in Hybrid Fiber Coax (HFC) applications which uses fiber in the backbone and in the access network. From the access point (in the neighbourhood) to home, coax is used. HFC can support services like telephony, broadcast video and interactive services.

Microwave (Radio Link)

- Free-space systems

- Operates in the UHF (Ultra-High Frequency) up to the EHF (Extremely High Frequency) bands, which covers the range between 300 MHz and 300 GHz, current practice being mainly from 1 GHz up to 45 GHz

- Generally, point-to-point links

- Transmitter focuses (to overcome the spread) the radio beams over relatively long distances (around 50 km)

- Microwave signals being high frequency signals are severely impacted by atmospheric constituents like rain, fog, smog and haze between the transmit and receive antenna

- Line-of-sight is critical and dense physical objects like trees and mountains should be avoided

- Distance between the transmitting and receiving antenna towers (hop) decreases as the carrier frequency is increased. Hopping distance is around 70 km for up to 6 GHZ and around 8 km for 18GHz, 23 GHz, 45 GHz.

Microwave System Design
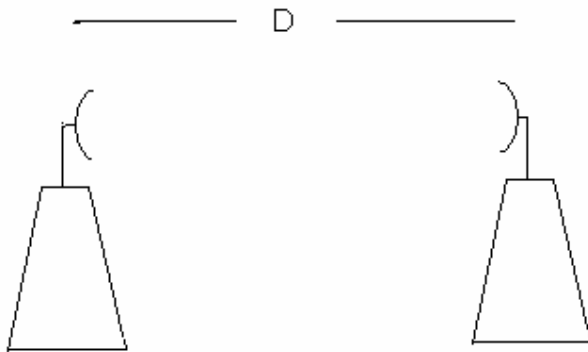
- Free Space Loss (FSL) in decibels (dB) is given by:

  FSL = 96.6 + 20 log D + 20 log F

  where F = frequency in GHz

  D = distance in miles

  e.g.   **LINK-1:** 1-mile link at 5.825 GHz has a FSL of approximately

     FSL = 96.6 + 20log(1) + 20log(5.825) = 111.9 dB

     LINK-2: 1-mile link at 2.437 GHz has a FSL of approximately

     FSL = 96.6 + 20log(1) + 20log(2.437) = 104.3 dB

- Receiver Sensitivity Threshold

  The Receiver Sensitivity Threshold (R_x) defines the minimum signal strength required in order for a radio to successfully receive a signal

  A radio cannot receive or interpret a signal that is weaker than the receiver sensitivity threshold

  E.g. for LINK-1, Receiver Sensitivity Threshold is -77 dBm.

     for LINK-2, Receiver Sensitivity Threshold is -81 dBm

     where dBm is 10 log (received power/1 mwatt)

- Received Signal Level

  Received Signal Level (RSL) is the expected strength of a signal when it reaches the receiver. Receive Signal Level is defined as:

  P_o - L_ct_x + G_at_x - L_cr_x + G_at_x - FSL = RSL

where P_o is the output power of the transmitter (in dBm)

L_ct_x is the cable loss between the transmitter and its antenna (in dB)

G_at_x is the gain of the transmitter's antenna (in dBi)

where dBi dB isotropic

L_cr_x is the cable loss between the receiver and its antenna (in dB)

G_at_x is the gain of the receiver's antenna (in dBi)

FSL is free space loss (in dB)

Example

Consider the 1-mile **LINK-1** in the above example where Free Space Loss (FSL) is 111.9 dB. Output power 1 dBm. For both transmitting and receiving antennas the gain is 26 dBi.

The RSL at the receiver is

1 dBm + 26 dBi + 26 dBi – 111.9 dB = -58.9 dBm

Example:

Consider the 1-mile **LINK-2** in the above example where Free Space Loss (FSL) is 104.3 dB dB. Output power +12 dBm. For both transmitting and receiving antennas the gain is 12 dBi. Both at the transmitter and at the receiver there is cabling with a loss of 1.5 dB.

The RSL at the receiver is

12 dBm - 1.5 dB + 12 dBi - 1.5 dB + 12 dBi - 104.3 dB = -71.3 dBm

Remark

RSL does not account for antenna alignment errors or path fading phenomena, such as multipath reflections, signal distortions, variable atmospheric conditions, and obstructions in the path.

- Link Feasibility Formula

To determine if a link is feasible, compare the calculated Receive Signal Level with the Receiver Sensitivity Threshold.

The link is theoretically feasible if $RSL \geq R_x$

If the Receive Signal Level ≥ Receiver Sensitivity Threshold, then the link may be feasible since the signal should be strong enough to be successfully interpreted by the receiver

In the above **LINK-1** Example, link is feasible since –58.9 dBm is greater than –77 dBm

In the above **LINK-2** Example, the link is feasible since -71.3 dBm is greater than -81 dBm.

- Fade Margin and Link Availability

Path fading weakens the radio signals

Fading occurs more frequently in flat, humid environments than in rough, dry places

Fade Margin = Unfaded Receive Signal Level - Receiver Sensitivity Threshold

Link must have sufficient Fade Margin to protect against path fading

Fade Margin is the link's insurance against unexpected system outages

Fade Margin is directly related to Link Availability, which is the percentage of time that the link is functional

The percentage of time that the link is available increases as the Fade Margin increases

A link will experience fewer system outages with a greater Fade Margin

In the above **LINK-1** Example, Fade Margin is –58.9 – (-77) = 18.1 dB

In the above **LINK-2** Example, Fade Margin is –71.3 – (-81) = 9.7 dB

Multichannel Multipoint Distribution Services (MMDS)

RECEIVER AT HOME
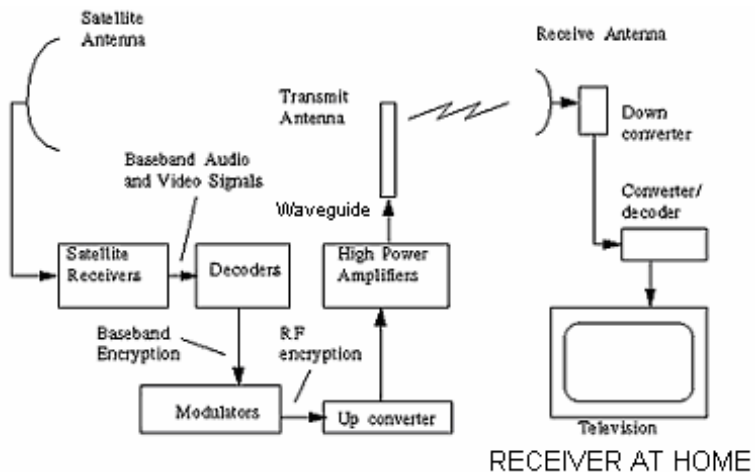
MMDS is also known as cableless Cable-TV systems

TV Signals from satellite or other sources are received and retransmitted by microwave

Material to be delivered over MMDS are satellite, terrestrial and cable delivered programs, local baseband services.

MMDS channels are transmitted from an omni-directional antenna (or doughnut pattern) which yields radiation equal in all directions in a chosen plane

Range is around 50 km

Only 200 MHz of spectrum (between 2.5 GHz and 2.7 GHz) is allocated for MMDS use

This means for TV signals with 6 MHz bandwidth, there are only 33 TV channels in MMDS

Local Multipoint Distribution Services (LMDS)
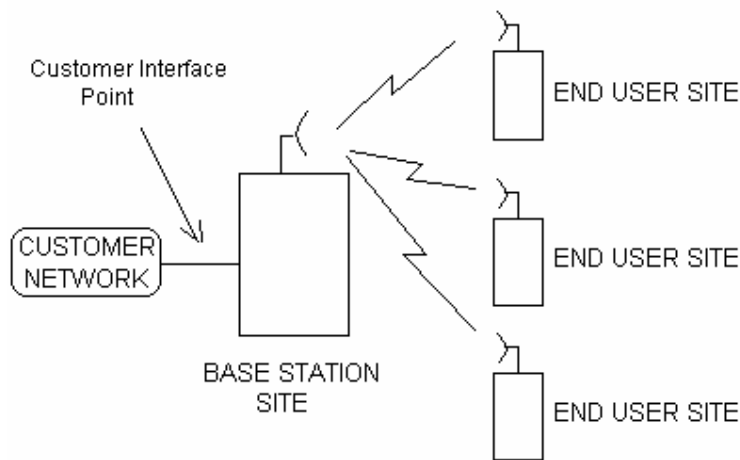
Deploying a fixed link for broadband network access to customers' premises is difficult and expensive

LMDS provides wireless broadband

LMDS consists of a radio transmitter which sends signals on a combination of channels to numerous receivers such as homes and businesses (i.e it is a point to multipoint system)

LMDS operates in various frequency bands, from 24GHz to 38GHz

Compared to MMDS which operates at lower frequencies (2.5 GHz) LMDS can have broader bandwidth but coverage is limited (around 5 km) and components are more expensive

Network coverage is increased by connecting the existing carrier network to a Base Transceiver Station (BTS) through a Customer Interface Point

This connection is extended, using high frequency radio transmission, to an antenna located at the customer's premises

i.e. LMDS provides wireless broadband connection between the carrier's network and its customers

LMDS applications

- LMDS provides digital two-way voice, high speed Internet access and data and video services

- LMDS offers the service providers and ISPs last mile connectivity between their fixed networks and customer sites

- LMDS connects LANs, intranets and PBXs of companies with distributed offices

- LMDS can provide 10 Mbps or faster connections which is attractive to customers who are using E1/T1 leased line connections between their LANs or to their ISP

- LMDS uses up to 622Mbps by allocating a large spectrum (100-112MHz) to a single subscriber or usually 10 Mbps for each subscriber in order to maximise the number of subscribers

LMDS link separation

Two ways of separating the uplink connection (from the subscriber to the base station) from the downlink connection (from the base station to the subscriber)
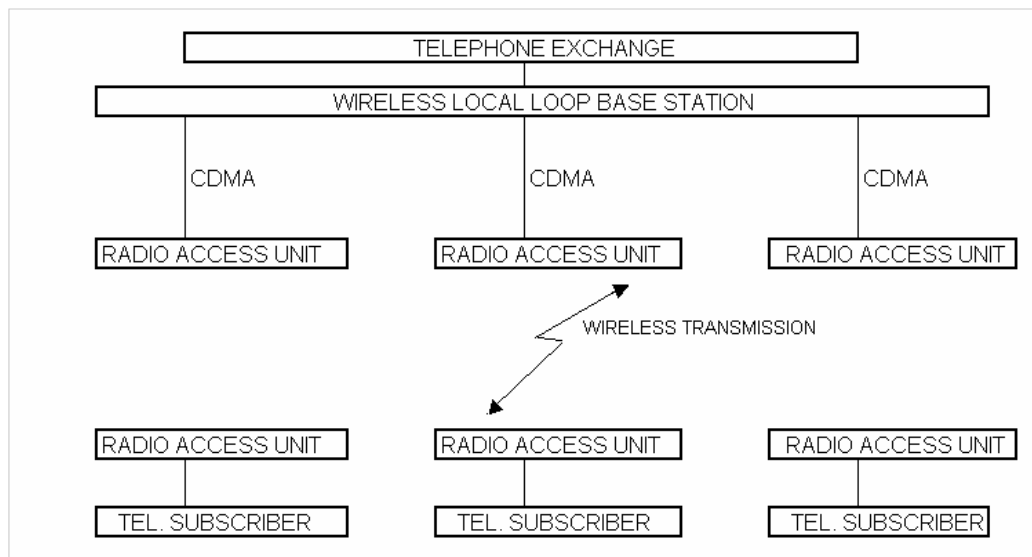
In Time Division Duplexing (TDD), the subscriber and the base station take turns talking to each other. At any time, both parties will use the entire spectrum allocated for that link

In Frequency Division Duplexing (FDD), the uplink and the downlink use different frequency bands separated by a large guard band (e.g. a separation of 1008MHz for the 24.5-26.5GHz band) to avoid interference

Since one base station needs to communicate with several sets of Consumer Premises Equipment (CPE), there is need to partition

- The uplink or the downlink frequency band (for the FDD case) among all the subscribers served by the base station

- The uplink or the downlink transmission duration (for the TDD case) among all the subscribers served by the base station

- In Frequency Division Multiple Access (FDMA), each CPE is allocated a small slice of the spectrum allocated to the uplink or downlink, and transmits simultaneously along with the other CPEs, i.e. different user transmissions are separated in frequency

- Time Division Multiple Access (TDMA) approach separates the transmissions to the various CPEs in time such that at any instance the base station communicates with only one CPE, i.e. different user transmissions are separated in time

Wireless Local Loop (WLL)

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                    ┌──────────────────────────────────┐
                    │       TELEPHONE EXCHANGE         │
                    └──────────────────────────────────┘
        ┌───────────────────────────────────────────────────────┐
        │         WIRELESS LOCAL LOOP BASE STATION              │
        └───────────────────────────────────────────────────────┘
         │ CDMA              │ CDMA              │ CDMA
 ┌───────────────┐   ┌───────────────┐   ┌───────────────┐
 │RADIO ACCESS UNIT│ │RADIO ACCESS UNIT│ │RADIO ACCESS UNIT│
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                          WIRELESS TRANSMISSION

 ┌───────────────┐   ┌───────────────┐   ┌───────────────┐
 │RADIO ACCESS UNIT│ │RADIO ACCESS UNIT│ │RADIO ACCESS UNIT│
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 ┌───────────────┐   ┌───────────────┐   ┌───────────────┐
 │ TEL. SUBSCRIBER │ │ TEL. SUBSCRIBER │ │ TEL. SUBSCRIBER │
 └───────────────┘   └───────────────┘   └───────────────┘
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- Wireless Local Loop (WLL) system makes Public Switching Telephone Service possible in a wireless environment

- WLL can be based on CDMA and is connected directly to the telephone exchange

- Operates in wide range of frequency bands

- Covers an area of diameter bigger than 15 km

- Supports up to 56 kb/s modems or digital data rates of 64 kb/s or 128 kb/s

- Provides wireless Internet access

Wireless Local Area Networks (WLAN)

WLAN:

- Operates at 900 MHz or in the microwave range (2400 –2483.5 MHz, 5150-5250 MHz, 5470- 5725 MHz)

- Data rates of 22Mbps , 54 Mbps

- Is an alternative to the traditional LANs based on twisted pair, coaxial cable, and optical fiber

- Is used for the same applications as wired or optical LAN

- Is more flexible because moving a wireless node is easier

- Is the best fit for portable computers

- Can be used in combination with cabled LANs

WLANs use three types of transmission techniques:

1. Spread Spectrum Technology

Currently the most widely used transmission technique for WLANs

In spread-spectrum more than essential bandwidth is used to achieve reliability and security

If a receiver is not tuned to the right frequency, a spread-spectrum signal looks like background noise

Two types of spread spectrum radio: frequency hopping and direct sequence

Direct-Sequence Spread Spectrum Technology (DS-SS)

Most wireless spread-spectrum LANs use DS-SS

Direct-sequence spread-spectrum (DS-SS) generates a redundant bit pattern for each bit to be transmitted

This bit pattern is called a code

Each bit in this code is called a chip

Receiver should know the transmitter's spreading code to decipher data

This spreading code is what allows multiple direct sequence transmitters to operate in the same area without interference

Once the receiver has all of the data signal, it uses a correlator to remove the chips and bring the signal to its original length

To an unintended receiver, DS-SS appears as low-power wideband noise and is rejected (ignored) by most narrowband receivers
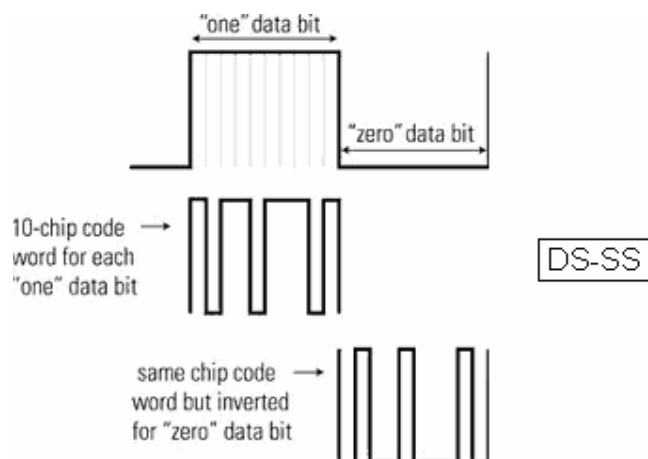
Frequency-Hopping Spread Spectrum (FH-SS)

FH-SS uses a narrowband carrier that changes frequency in a code pattern known to both transmitter and receiver

A receiver, hopping between frequencies in synchronization with the transmitter, receives the message

The message can only be fully received if the series of frequencies are known

Since only the intended receiver knows the transmitter's hopping sequence, only that receiver can receive all the data

To an unintended receiver, FH-SS appears to be short-duration impulse noise.
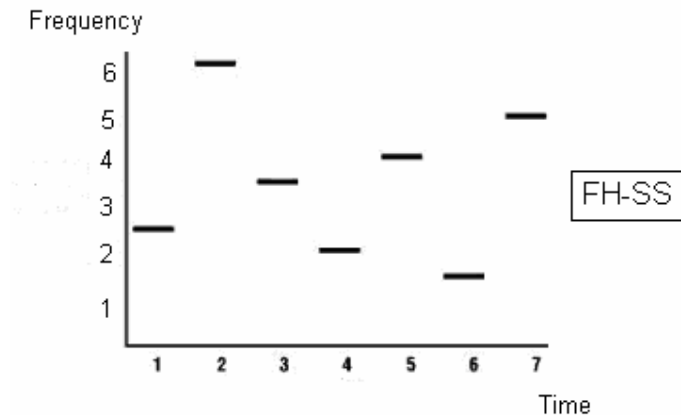
Infrared WLAN (IR WLAN)

-   Line-of-sight (LOS) or diffuse (or reflective) systems

-   LOS are limited in range (a few meters)

-   Diffuse IR WLAN does not require line-of-sight but their use is limited within a single room

-   IR WLAN is high bandwidth

-   Major disadvantage is that they can easily be obstructed

Comparison of WLAN Systems

Wireless LAN Transmission Techniques			
*	Spread Spectrum	Narrowband	Infrared
Frequency	902 - 928 MHz 2.4 -2.4385 GHz 5.725 - 5.825 GHz	18.825 - 19.205 GHz	3×10^{14} Hz
Maximum Coverage	30 - 250 meters	15 – 40 meters	10 m - 15 km
Line of sight	No	No	Yes/No
Transmit power	< 1 W	25 mW	1 – 800 mW
Maximum Rate	22 – 54 Mbps	22 – 54 Mbps	1.5 - 622 Mbps

BlueTooth

- Allows users to make wireless connections between various communication devices such as mobile phones, desktop and notebook computers

- Uses radio transmission

- Point-to-multipoint (7-8) voice and data transmission

- Uses spread spectrum, frequency hopping techniques (full-duplex signal at up to 1600 hops/sec). Signal hops among 70-80 frequencies at 1 MHz intervals and gives a high degree of interference immunity.

- Short range applications (10 cms - 10 metres)

- Operates in the 2.4GHz band

- Gross data rate is 1 Mbps, actual data rates are 432 Kbps in full duplex (Time Division Duplex), 721/56 Kbps for asymmetrictransmission and also 384 Kbps.

Satellite

- Microwave but not terrestrial

- In some cases satellites can operate in the same frequency range as terrestrial systems

- GEO (Geosynchronous Earth-Orbiting) satellites are positioned directly above the equator at altitudes of 35,786.1 km. GEOs maintain their positions relative to the Earth's surface. Orbital travel is in east-west direction.

- GEOs are used for communication and weather forecast

- LEO (Low Earth-Orbiting) satellites have altitudes of 320 - 800 - 1500 kilometres and mainly used in Remote Sensing applications.

- LEOs have polar orbits (north-south direction, descending from north-south, ascending from south-north)**,** with orbital speed of LEO satellites are 27,359 kilometres per hour. They can circle Earth in about 90 minutes.

- MEOs (Middle Earth-Orbiting) are at at altitudes of 10.000 - 15.000 km.

- LEOs and MEOs do not maintain their relative positions.

- Satellites can transmit to, and receive from, a large area (foot print or coverage), thus advantageous in point-to-multipoint and broadcast applications.

- Thousands of satellites exist in space among which around 500 of them are communication based satellites (mainly GEOs)

- Similar to microwave systems, their performance varies with the weather condition.

- Propagation delay is quite important in satellite communications. 0.25 second delay from the transmitter to the receiver on earth, i.e 0.5 sec delay between the times when one communication point says 'Hello' and hears the response 'Hello' from the other

communication point. For voice, videophone and some data applications (like games) this amount of delay is disturbing.

- Transponder in the satellite includes:

    • The receiving antenna to pick-up signals from the ground station

    • Broadband receiver

    • Input multiplexer and a frequency converter which is used to reroute the received signals through a high powered amplifier for downlink

- Telecommunication satellites receive signals from a ground station and send them down to another ground station located at a very long distance from the first (Relay action)

- In the case of a long distance phone call or data transmission, communication can be two-way

- In the case of television broadcasts, the ground station's uplink is then downlinked over a wide region

- Another application is in remote sensing where the satellite (equipped with cameras or various optical sensors). In this case the satellite only downlinks data which is sensed from Earth's surface Atmosphere.

Ground Station

- In the uplink or transmitting station, terrestrial data in the form of baseband signals is sent to the orbiting satellite by passing through:

    • Baseband processor
    • Up converter (frequency conversion)
    • High powered amplifier
    • Parabolic dish antenna

- In the downlink, or receiving station, operation is reversed as compared to uplink.

Applications of Satellite Communications

- Long distance telephone network among countries: International satellite consortium (Intelsat)

- Television Broadcasting (Analog and digital):

    • Direct free reception by home dishes (Free or scrambled channels)

    • Terrestrial distribution after the satellite reception at the ground station

- Automotive Navigation: Inmarsat applications as Global Positioning System GPS, Vehicle Tracking in a Fleet, Land Navigation as Maps in Cars, Maritime applications

- VSAT (Very Small Aperture Terminal) Networks

VSATs   VSATs

HUB STATION
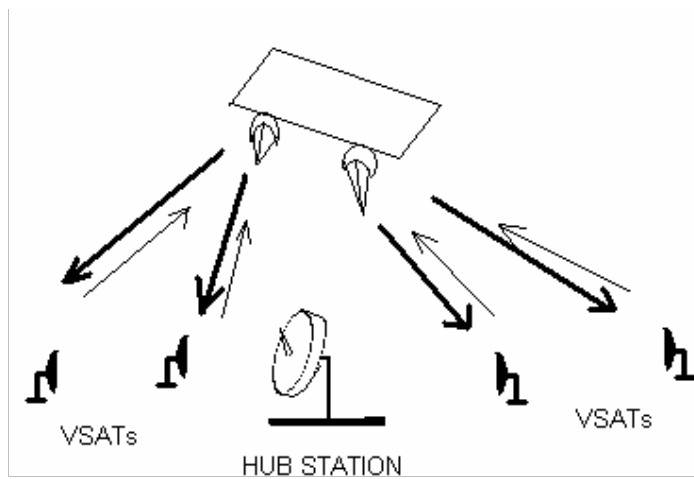
- Receive/transmit home/office small antenna aperture terminals connecting to a central hub via satellite

- Antenna dishe diameter around 0.6 - 3.8 meter

- Operates in the Ku-band (around 14 GHz uplink, 11 GHz downlink) and C-band (around 6 GHz uplink, 4 GHz downlink) frequencies

- Ku-band requires smaller antenna diameter than C-band

- Can have Bi-Directional Operation (uplink and downlink) or Receive-Only Operation (downlink)

- Multipoint network providing two-way data, voice and multi-media transmission

- Can provide internet downloads at up to 2 Mbps

- Star-network that connects one or more main sites to various remote sites

- Uses TDMS (Time Division Multiple Access) as the means to send data to each remote site

- A chart is given below for various satellite applications

	L-Band (390 - 1550 MHz)	800 MHz range	2 GHz range	C-Band (Uplink around 6 GHz, Downlink around 4 GHz)	Ku-Band (Uplink around 14 GHz, Downlink around 11 GHz)	Ka-Band (Uplink around 30 GHz, Downlink around 20 GHz)
GEO (Geosynchronous Earth-Orbiting) satellites above the equator at altitudes of 35,786.1 km altitude	VSAT			Commercial TV Broadcast, Digital Radio, VSAT	Up to 155 Mbps global area data communications, Most of the Current Commercial Analog/Digital TV Broadcast, Digital Radio, VSAT	Up to 155 Mbps data, Multimedia, Military Applications, High speed internet access, tele-education, tele-medicine, ATM based services including wide area networks and local area network interconnection, video-telephony, cheap videoconferencing, television services to aircraft, local television, rural telephony, satellite newsgathering, alternative to VSAT networks, remote monitoring
MEO (Middle Earth-Orbiting) satellites at altitudes of 10.000 - 15.000 km			Voice (Cellular)	Mobile	Up to 155 Mbps regional area data communications, Analog/Digital TV Broadcast, Digital Radio	
LEO (Low Earth-Orbiting) satellites have altitudes of 320 - 800 - 1500 kilometres		Little LEOs (Below 1 GHz) 2.4 - 300 Kbps. Messaging, paging, vehicle location	Big LEOs (Above 1 GHz) 2.4 - 9.6 Kbps. Voice (Cellular)	Mobile		Broadband LEOs 16 - 155 Mbps Data, Multimedia

Optical Fiber

According to Snell's Law:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

θ_1 and θ_2 are angle of incidences. The angle of incidence is measured with respect to the normal at the refractive boundary. n_2 is the refractive index of the less optically dense medium, and n_1 is the refractive index of the more optically dense medium.

*The **critical angle** is the angle of incidence above which total internal reflection occurs. The critical angle θ_c is given by:

$$n_1 \sin \theta_1 = n_2 \sin (\pi/2) = n_2$$

i.e., $n_1 \sin \theta_c = n_2$

$$\theta_c = \arcsin (n_2/n_1)$$

If the incident ray is precisely at the critical angle, the refracted ray is tangent to the boundary at the point of incidence.

If for example, visible light were traveling through glass (with an index of refraction of 1.50) into air (with an index of refraction of 1.00). The calculation would give the critical angle for light from acrylic into air, which is

$$\theta_c = \arcsin (1/1.5) = 41.8^0$$

Light incident on the border with an angle less than 41.8° would be partially transmitted, while light incident on the border at larger angles with respect to normal would be totally internally reflected.

- Any optical communications system can be studied in three main parts:

  1. Transmitter which converts information to light
  2. Medium (i.e. fiber optic cable or atmosphere) which transmits the light signal
  3. Receiver which converts the light signal into an electrical signal.

- Light Source is either a semiconductor Light Emitting Diode (LED) or a semiconductor Laser Diode

- LED or Laser Diode receives a modulated electrical signal and converts it into a light signal

- Light signal is coupled into the fiber optic cable

- Light sources emit light at wavelengths of 850, 1300 or 1550 nanometers

LED's

- Common and relatively inexpensive

- Usually low power, thus used in multimode applications for short distances

- Are used in low rate transmission because dispersion is high due to wide spectral widths (36 – 40 nanometers)

Laser diodes

- Usually more expensive than LED's

- Can be high power, thus used in singlemode fibers for long haul communication links

- Are used in very high bit rate transmission (10 Gbps *160 in DWDM) because dispersion is very low due to narrow spectral widths (less than 1 nanometer)

Fiber Optic

- Fiber consists of an inner core, outer cladding and a protective buffer coating
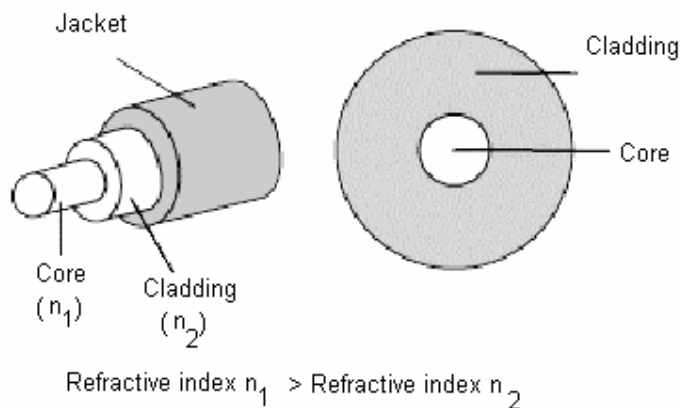
- Core is the glass (SiO_2) area through which light travels and the information is carried

- Surrounding the core is the cladding which is also of glass but with a lower refractive index than the core

- The lower refractive index causes the light to be totally reflected in the core, thus staying in the core until the receiver

- To protect the fiber core and the cladding, several layers of plastic coatings (250 microns - 900 microns) are applied to preserve strength

- Fibers are classified as singlemode or multimode

Singlemode Fiber

- Core (9 micron diameter) is very small compared with cladding(125 micron diameter)

Singlemode Fiber
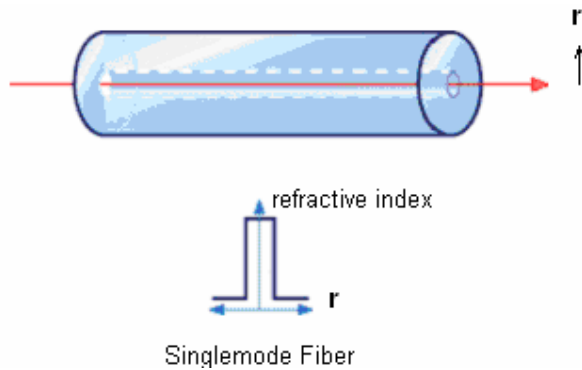
- Because of small core, light in the core travels in a straight line (i.e single mode)

- Has very high bandwidth

- Wavelength of 1310 nanometer is best for dispersion (pulse broadening)

- Wwavelegth of 1550 nanometer is best for attenuation

- For singlemode transmission, repeater distance required in practice is around 50 –100 km. In some systems 1Gbps is announced for repeaterless links of 20.000 km

Multimode Fiber

- Has a much larger core (50/125, 62.5/125 and 100/140 micron)

- Used in LAN applications

- Since the core diameter is large, light travels in multiple paths, or as multimode

- Rates are relatively small, however can be up to 200 Mbs for distances less than 100 meters

- Manufactured as step index or graded index

- Step index has a slight step difference in-between the refractive index of the cladding as compared with the core. Each individual mode (or ray of light) takes a different path. When the signal reaches its destination, different light waves arrive at the receiver at different times


Step index Multimode Fiber
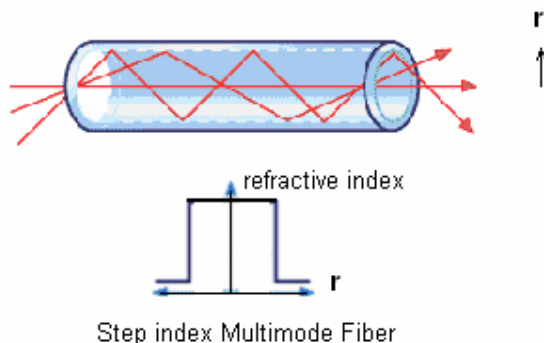
- To compensate for this problem, a graded index fiber is developed. Many layers of glass, each with a lower refractive index are applied to make the fiber core. Faster light rays
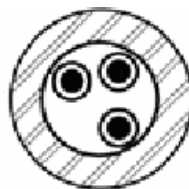
traveling in the outer layers travel longer path than the slower light rays travelling in the inner layers. In this way, all light waves arrive at the receiver at the same time.
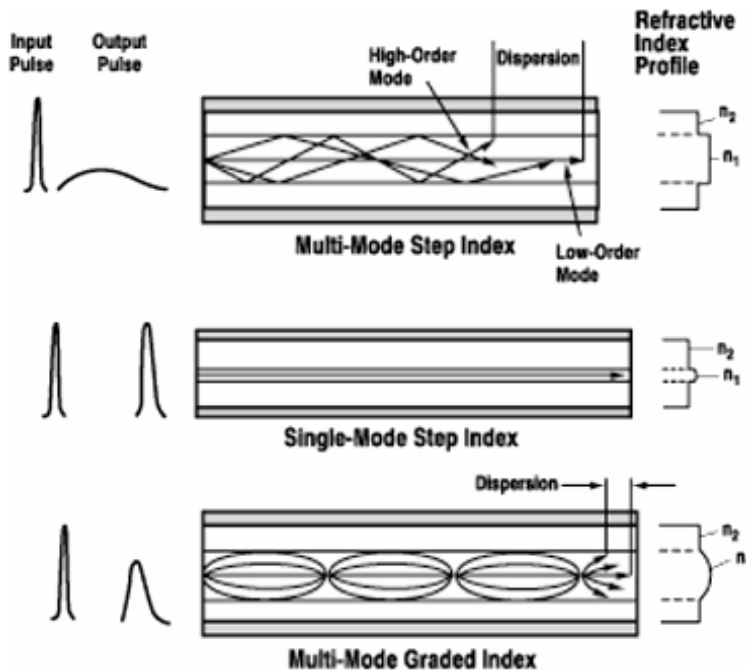
- Some cable types are shown below:
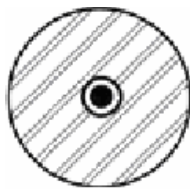
TIGHT TUBE BUFFER CABLE

LOOSE TUBE BUFFER CABLE

Receivers

- At the receiver, a semiconductor photo-diode converts the incoming light signal back into a modulated electrical signal which is then demodulated electrically

- Receiver wavelength must be the same as the transmitter

- System perfromance is measured in Bit Error Rate (BER) for digital systems or Signal to Noise Ratio (SNR) for analog systems

- Sensitivity of the detector is the minimum power that must be received on an incoming signal.

- Saturation defines the maximum received power that can be accepted. If too much power is received, the result is a distortion of the signal, causing poor performance

Free Space Optics (FSO)

- FSO is a wireless optical transmission in the atmosphere

- Current RF bandwidth is limited to 622 Mbps.and does not provide economical solution for service providers looking to extend to optical networks

- In USA, only 5 percent of the buildings are connected to fiber-optic infrastructure (backbone) but 75 percent are within one mile of fiber

- As bandwidth demands increase and businesses require high-speed LANs, FSO becomes one of the most attractive solutions

- Two infrared wavelengths, around 1550 nm (194 THz) and around 800 nm (375 THz)

- Each FSO unit uses mainly high power laser sources (sometimes LED) and a lens that transmits light through the atmosphere to another lens receiving the information

- Receiving lens connects to a high-sensitivity receiver via optical fiber

- Optical pulse modulation

- Line-of-sight (LOS)

- Broadband (100 Mbps, 155 Mbps, 622 Mbps and up to 2.5 Gigabit capacities

- Even DWDM is also tried

- 1.5 –2 km

- Full duplex (bi-directional) communication

- Some disturbances facing FSO:

  • Fog: Major effect to FSO. Rain and snow have little effect. Fog is vapor composed of water droplets, which are only a few hundred microns in diameter modifying light characteristics or completely stopping light through absorption, scattering and reflection. Solution is to shorten the FSO link distances and to add network redundancies

  • Absorption: (Molecular and Aerosol Absorption). Light is converted into heat. Occurs mainly due to water molecules present in the atmosphere. Solution is to use of appropriate power, based on atmospheric conditions, and use of spatial diversity (multiple beams within an FSO unit)

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- Scattering: Occurs when the light beam collides with the scatterer of size d. In scattering, unlike absorption, there is no loss of energy, only a directional redistribution of energy occurs that may have significant reduction in beam intensity for longer distances.

    - For d < λ (wavelength), Rayleigh scattering (i.e molecular scattering). Rayleigh scattering is inversely proportional to λ^4.
    - For d is comparable with λ, Mie scattering (i.e aerosol scattering). More directive
    - For d >> λ, Non-selective scattering

- Physical obstructions: Flying birds can temporarily (for a short time) block a single beam and transmissions are easily and automatically resumed. Solution is to use multi-beam systems (spatial diversity)

- Building sway/seismic activity: Movement of buildings can disturb receiver and transmitter alignment. Solution is to use divergent beam or make tracking

- Scintillation: Heated air rising from the earth or man-made devices such as heating ducts creates temperature variations among different air parsels known as turbulence. This can cause fluctuations in signal amplitude which leads to "image dancing" at the FSO receiver end. Remedy is to use multi-beam system

    - Beam Wander
    - Beam Spreading

- Safety: Human exposure to laser beams and high voltages within the laser systems and their power supplies

Table of Comparison between various transmission media is shown below:

Medium Type	Frequency of Operation	Maximum Bit Rate	Performance as Bit Error Rate (BER)	Distance Between Repeaters	Security	Cost
Twisted Pair	1MHz-100MHz-1GHz	2Mbps-100Mbps-1Gbps	10^{-5}	2 km - 100 m	Poor	Low-Moderate
Coaxial	1 GHz	565 Mbps	10^{-7} - 10^{-9}	2-3 km	Good	Moderate
Microwave	300 MHz - 40 GHz	622 Mbps	10^{-9}	30-70 km	Poor	Moderate
Satellite	390 MHz - 30 GHz	155 Mbps	10^{-9}	800-1500-36000 km	Poor	Moderate-High
Fiber	750 -194 THz	2.5 -10 Gbps -150 Tbps	10^{-11} - 10^{-13}	50 -100 - 6000 km	Good	Moderate-High

Establishing Communications Channels, Switching and Networking Modes

- In order the message to travel across a network a transmission path should be established.

- Network provider should provide the connection:

    - When the connection is requested by the customer

    - Where the connection is requested by the customer

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- Where is fulfilled by the:

    - Path calculation to estabish the proper physical or logical connection to the requested final destination,

    - Forwarding to guide the traffic across the backbone

- Networking techniques:

    1. Networking modes

        a. Connection oriented

        b. Connectionless

    2. Switching modes

        a. Circuit switching

        b. Packet switching

Networking Modes

Connection oriented Networking

- Connection set up is done before information transfer occurs, i.e first the connections from the information source up to the final destination point are made, then the information flow starts

- Provides service guarantees

- Convenient in time-sensitive applications such as voice and video transmission

- Efficiently use network bandwidth by switching transmissions to appropriate connections as the connections are set up

- There can be certain delay at the beginning while the connection is being built up, However, after the path is determined there is no delay at intermediate nodes.

- Can operate in both circuit switching and packet switching modes

- Examples of connection oriented circuit switched networks are PSTN, SDH/SONET, DWDM

- Examples of connection oriented packet switched networks are X.25, Frame Relay and ATM networks

- Can be operated in:

    - Provisioned mode: Connections are made ahead of time (before the request from the customer) based on expected traffic. E.g. leased lines in circuit switching or PVCs (Permanent Virtual Circuits) in packet switching

- Switched mode: Connections are made on demand and released after the communication ends E.g. dial up in circuit switching or SVCs (Switched Virtual Circuits) in packet switching

Connectionless Networking

- No connection set-up is made before data is transmitted, i.e no preconceived path

- Each individual fragment of the overall traffic stream (i.e data packet) is individually adressed and individually routed to its destination based on information contained in the header of the individual data packet

- Delay in the overall transit time is increased because each packet has to be individually routed at each intermediate node

- Not very convenient for time sensitive applications like on-line voice, video transmission because path is not guaranteed

- Difficult to calculate the potential delays or latencies beforehand

- Only some packet switched networks are connectionless

- Example of connectionless network is the public internet consisting of more than 150,000 separate subnetworks and around 10,000 ISPs (Internet Service Providers

Switching Modes

- A <u>network node</u> is any point in the network at which communication lines interface. E.g. local exchange, PBX, modem, host computer, ...etc)

- <u>Switching</u> is the process of physically moving bits through a network node, from an input port to an output port

- Switches connect two or more transmission lines

- Switch, when a number is dialed, looks up a routing table and picks the available and the cost effective trunk from which the call is forwarded

- <u>Routing</u> is the process of moving information from a source to destination across an inter-network. Routing:

  - Determines the optimal path
  - Transports the information across networks

- Routing algorithms use a set of information (metrics) to find the best path to destination

- Metrics used by routing algorithms can be path length, destination, next-hop information, reliability, delay, bandwidth, load, communication cost

- Some routing protocols are RIP (Routing Information Protocol), OSPF (Open Shortest Path First), IS-IS (Intermediate System to Intermediate System)

- Two types of routers:

- Static routers can only look up its own routing table, cannot communicate with thus does not know the routing tables of its upstream neighbors

- Dynamic routers can communicate with its upstream neighbors. If a change occurs to its routing table it can forward that change to the upstream routers so that they can also adjust their routing tables. Dynamic routers, depending on the protocol can also see the routing tables of its neighbors or the entire network, thus can adress the dynamic traffic patterns in a better way.

Circuit Switching

- Forms the basis of the classical telephone networks

- In the circuit switching:

  - When requested by the end user (for example when the user dials up the phone), a circuit is formed between the calling and the called party

  - A fixed share of the network resources for that connection are reserved for this specific communication during the full duration of conversation. İ.e no other call can use those resources until the communication ends. This means that the capacity provisioned on that specific path can only be used by this call, no one else can share or use the capacity available on that path

  - When the conversation is over, connection is released, i.e the circuit is disconnected.
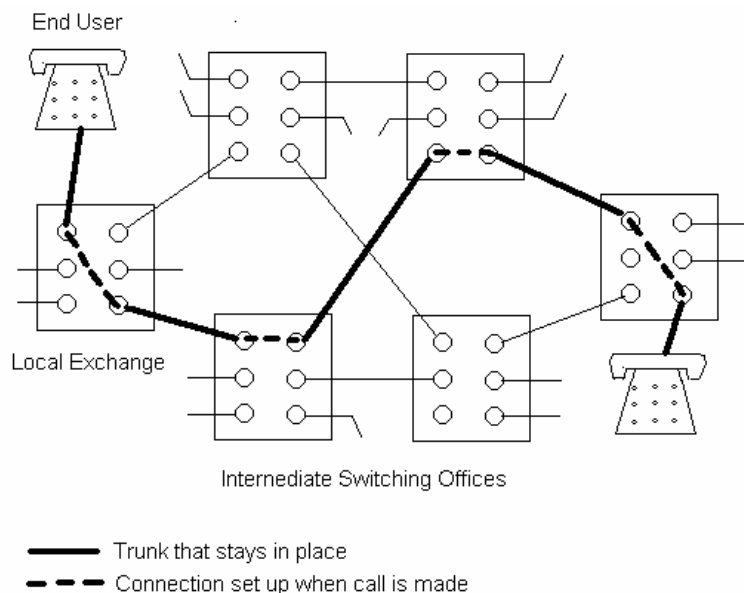
- Circuit switching:

  - Yields low latency (minimal delay) because the routing calculation of the path is made only once at the beginning of the call before the call is set up. After the set up is complete and the traffic starts to flow there are no more routing calculations to find the next hop.

- Bandwidth reserved for the circuit is not optimally utilized. In a real-time voice communication half of the time nothing is transmitted because of the breathing, pauses, etc during speech.

- Optimized for real-time voice traffic, thus guarantees Quality of Service (QoS). İ.e guarantees certain mximum delay, rate, tariff ..etc during the connection.

Packet Switching

- A packet (or frame, block, cell or datagram)

  - Is a container carrying control and data bits.

  - Control and data bits can each be in various sizes, i.e. can contain different number of bits

  - Control bits (start, header, destination address, data sequence number, stop, ...etc) are used by the network nodes to route the packet under certain protocol (available bandwidth, existing noise, need for retransmission, latency considerations, ... etc).

- Packets are stored-and-forwarded by packet switches up to the destination

- In packet switching, packets from many different sources are statistically multiplexed and sent to their destinations over virtual circuits

- Packet switches examine packet header and check destination against a routing table

- Same transmission lines are shared by multiple connections, i.e. packet switches or routers should do many more routing calculations

- Packets can be queued up at some nodes based on the availability of the virtual circuits

- Queuing causes latencies (delays)

- Queues are realized through buffer storage

- If buffers are also full due to congestion, then packets (i.e information) can be lost

- In certain protocols (such as TCP) retransmission can be requested to replace the lost packets or packets received with unacceptable error performance

- In packet switching jitter occurs. Jitter means different delays among different two-switch transmissions. İ.e. Delay could be 30 msec between Switch 1 and 2 whereas 100 msec between Switch 2 and 3.

- Not strong QoS guarantees in connectionless packet switching

  5. Public Switched Telephone Network (PSTN)
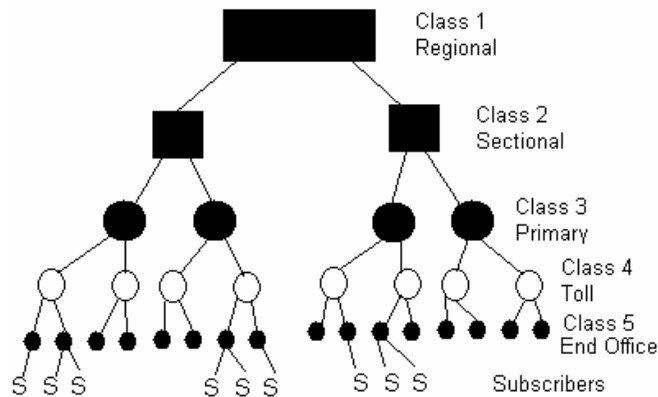
5.1. PSTN Infrastructure
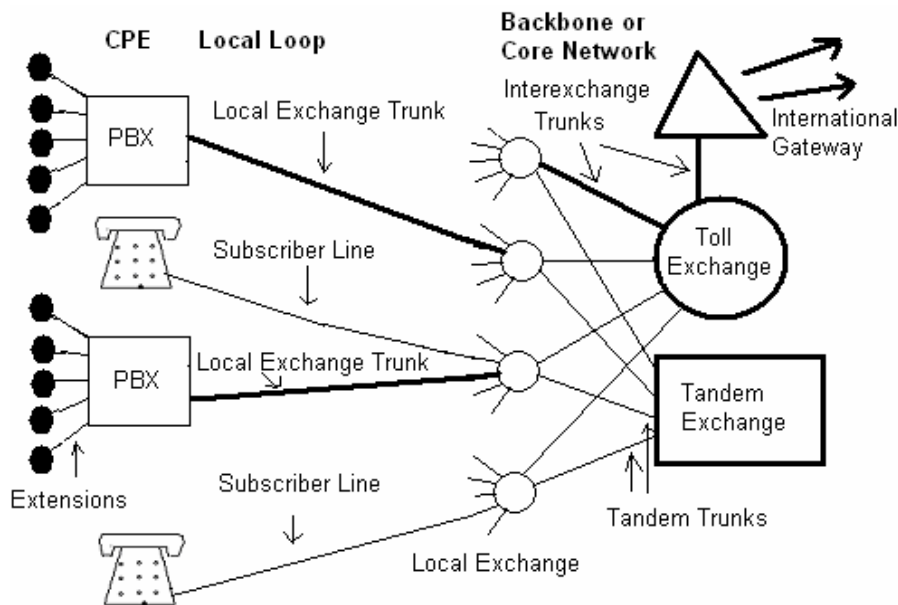
- PSTN has number of transmission links and nodes

- CPE (Consumer Premises Equipment) Nodes are equipments located at the customer site. E.g. single line telephones, key telephone systems, PBX

- Switching Nodes interconnect transmission at various locations and route traffic through the network via a numbering plan which are routing instructions to complete a call through PSTN. Include:

  - Local Exchanges (Class 5) providing local switching and telephone features for subscriber's choice. First 3 digits of the subscriber number represent the local exchange, remaining 4 digits represent the line numberwhich is a physical circuit connected from the local exchange to the subscriber.

  - Tandem/Junction Exchanges routing calls between local exchanges within the city. Not directly connected to subscribers.

  - Toll/Transit/Trunk Exchanges (Class 4) routing calls to or from other cities, providing national long distance switching and network features. There are one or several (in large cities) in a city.

- International Gateway routing calls between countries. Protocol conversion takes place in Gateways.

- **Transmission Nodes** provide communication paths for carrying traffic and network control information between the nodes in the network. Include transmission media such as twisted pair, microwave, coax, staellite, fiber and transmission equipments such as amplifiers, repeaters, line terminal equipments, multiplexers, digital cross-connects, digital loop carriers.

- **Service Nodes** handle signaling. Through signaling, control information is transmitted to

  - Set up, hold, charge and release the connections

  - Control network operations and control billing

  Examples of Service Nodes are R1 Signalling, R2 Signalling, Signalling System No.7 (SS7)

- PSTN is traditionally designed for continuous real-time voice

- Traffic handling of the circuit switches in PSTN infrastructure are designed for short call durations (average around 3 minutes per call). Thus in case of long internet use (around an hour average) by many users, getting dial tone by others could become difficult

- Capacities of channels in PSTN are narrowband based on 64 Kbps channels

- PSTN network has highly developed billing systems and network management

## 5.2. Transport Network Infrastructure, PDH, SDH/SONET

PDH (Plesiochronous Digital Hierarchy)

- PSTN backbone is based on PDH (Plesiochronous Digital Hierarchy) including E-carrier, T-carrier, J-carrier

CEPT Signal Level	Bit Rate	No. of E-0 Channels (Excluding Signalling Channels)	No. of E-0 Channels (Including Signalling Channels	No. of E-1 Lines	No. of E-2 Lines	No. of E-3 Lines
CEPT-0 (E-0)	64 Kb/s	1	-	-	-	-
CEPT-1 (E-1)	2.048 Mb/s	30	32	1	-	-
CEPT-2 (E-2))	8.448 Mb/s	120	128	4	1	-
CEPT-3 (E-3)	34.368 Mb/s	480	512	16	4	1
CEPT-4 (E-4)	139.264 Mb/s	1920	2048	64	16	4
CEPT-5 (E-5))	565.148 Mb/s	7680	8192	256	64	16

- In PDH, each network element (i.e. each exchange, multiplexer, cross-connect, repeater, ..etc) gets its clocking pulse from different clocking sources. These clocks are then synchronized. (Plesiochronous means close to clock)

E-1 Framing
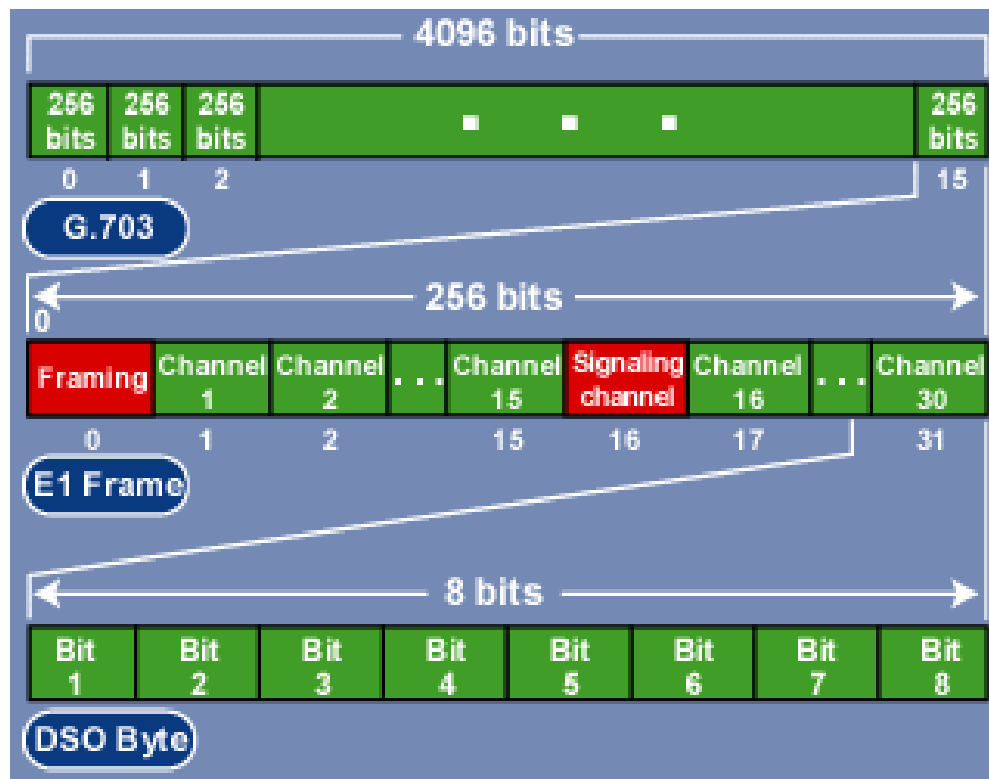
- The standard extended framing structure of an E1 is defined by the ITU as G.703

- 8 bits make a one DS-0 channel.

- 30 DS-0 (Digital signal-0 level, i.e. 64 Kbps) channels plus one framing channel and one signaling channel make up a single E-1 frame, also known as a CEPT-1

- 16 E-1 frames make a single G.703 frame.

- In PDH, in order to access a single 2 Mbit\s line in a 140 Mbit\s system, the 140 Mbit\s channel must be completely demultiplexed to its 64 constituent 2 Mbit\s lines via 34 and 8 Mbit\s.

- Once the required 2 Mbit\s line has been identified and extracted, the channels must then be multiplexed back up to 140 Mbit\s.

- This problem with the "drop and insert" of channels does not make for very flexible connection patterns or rapid provisioning of services.

- Also the "multiplexer mountains" required are very expensive

- Drop-Insert mechanism in PDH is shown below:
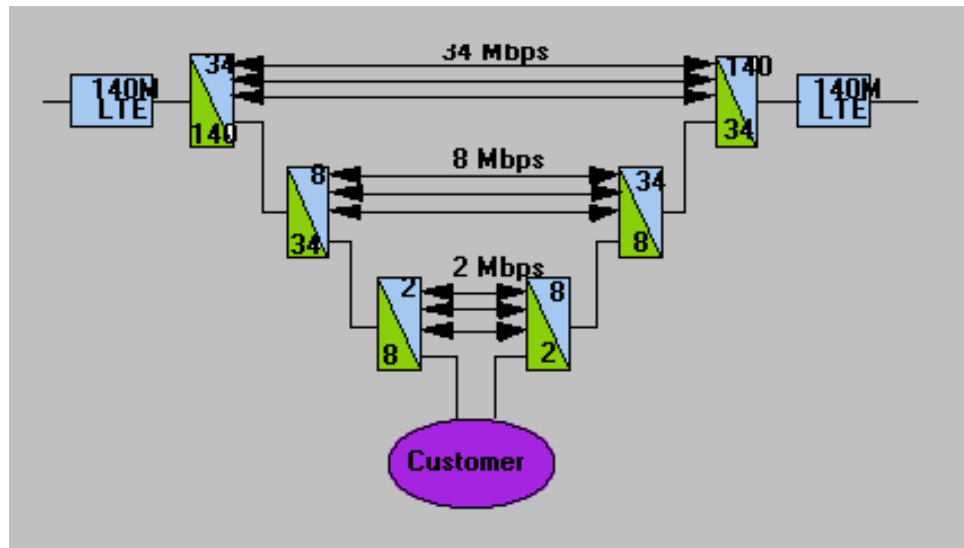
SDH/SONET (Synchronous Digital Hierarchy / Synchronous Optical Network)

- SDH and SONET refer to a group of fiber-optic transmission rates that can transport digital signals with different capacities.

- SDH has provided transmission networks with a vendor-independent and sophisticated signal structure that has a rich feature set.

- As digital networks increased in complexity in the early 1980s, demand from network operators and their customers grew for features based on high-order multiplexing through a hierarchy of increasing bit rates up to 140 Mbps or 565 Mbps

- PDH has high costs of transmission bandwidth

- SDH brings economical use of bandwidth, better performance monitoring and greater network flexibilityswitched broadband services.

- SDH brings the following advantages to network providers:

  1. High transmission rates: Up to 10 Gbit/s. SDH is therefore the most suitable technology for backbones, i.e. super highways in telecommunications networks.

  2. Simplified Add / Drop function: Compared with the older PDH system, it is much easier in SDH to extract and insert low-bit rate channels from or into the high-speed bit streams. It is not necessary to demultiplex and then remultiplex the plesiochronous structure.

  3. Future-proof platform for new services: Can serve ranging from POTS, ISDN, mobile radio, data communications (LAN, WAN, etc.), video on demand, digital video broadcasting via ATM

- Driving forces behind the future telecommunications are:

  - Ever growing demand for more bandwidth (such as STM-64, i.e 10 Gbps)

- Better quality of service and reliability
- Lower costs

SDH in terms of layer model:
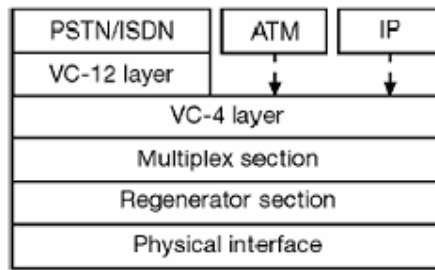
SDH LAYER MODEL
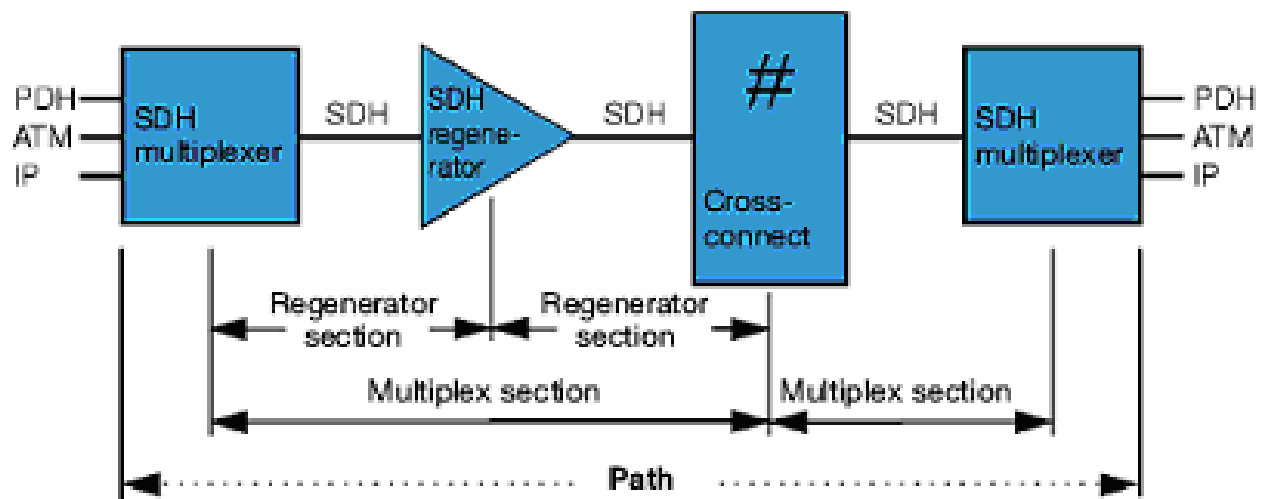

Path section designations

- SDH networks are subdivided into various layers

- The lowest layer is the physical layer, which represents the transmission medium. This is usually fiber or radio-link or satellite link

- Regenerator section is the path between regenerators

- Part of the overhead (RSOH, Regenerator Section Overhead) is available for the signaling required within Regenerator layer

- Remainder of the overhead (MSOH, Multiplex Section Overhead) is used for the needs of the multiplex section.

- Multiplex section is the part of the SDH link between multiplexers

- The carriers (VC, virtual containers) are available as payload at the two ends of Multiplex section

- Two VC layers represent a part of the mapping process

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- Mapping is the procedure whereby the tributary signals, such as PDH and ATM signals are packed into the SDH transport modules

- VC-4 mapping is used for 140 Mbit/s or ATM signals and VC-12 mapping is used for 2 Mbit/s signals

- Uppermost layer represents applications of the SDH transport network.

Components of a synchronous network
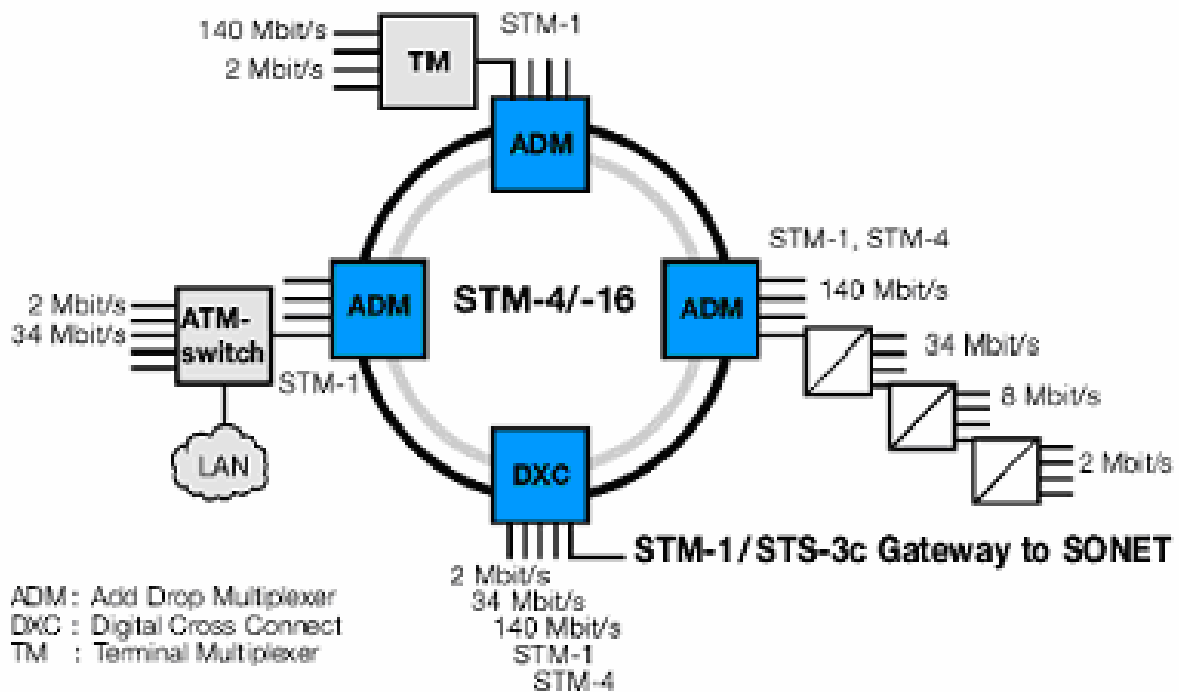
- Above Figure is a schematic diagram of a SDH ring structure with various tributaries

- Mixture of different applications is typical of the data transported by SDH

- Synchronous networks must be able to transmit plesiochronous signals and at the same time be capable of handling future services such as ATM

- Current SDH networks are basically made up of four different types of network elements in the topology (i.e. ring or mesh structure)

  1. Regenerators regenerate the clock and amplitude relationships of the incoming data signals that have been attenuated and distorted by dispersion. Regenerators derive their clock signals from the incoming data stream. Messages are received by extracting various 64 kbit/s channels (e.g. service channels E1) in the RSOH (regenerator section overhead). Messages can also be output using these channels.
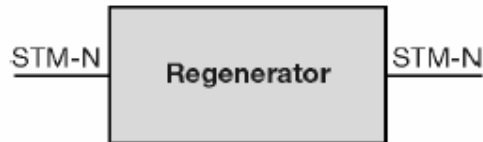
2. Terminal multiplexers are used to combine plesiochronous and synchronous input signals into higher bit rate STM-N signals.
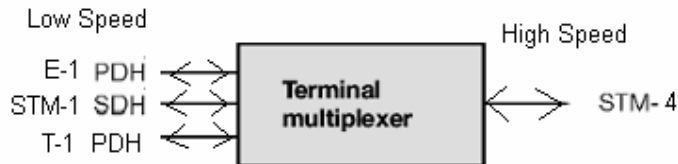
3. Add/drop multiplexers (ADM): Plesiochronous and lower bit rate synchronous signals can be extracted from or inserted into high speed SDH bit streams by means of ADMs. This feature makes it possible to set up ring structures, which have the advantage that automatic back-up path switching is possible using elements in the ring in the event of a fault.
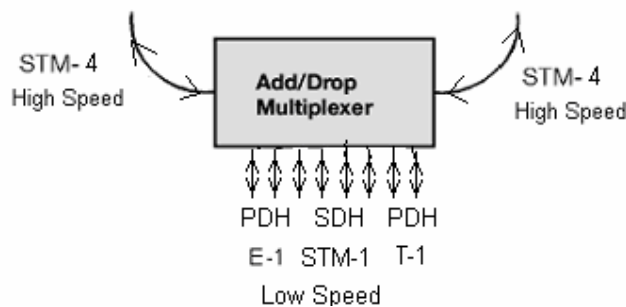
4. Digital crossconnects (DXC or DCS) direct and manage traffic from a multiplicity of sources at different speeds world-wide, continuously.

DXC allows:

- Mapping of PDH tributary signals into virtual containers

- Switching of various containers up to and including VC-4.

e.g. DCS converts between T1 and E1 data and signaling, it cross connects:

- Several fractional E-1 channels to single E-1

- Several fractional T-1 channels to single T-1

- DS-0s, "n" x 64Kbps consecutive data channels and fractional E-1 channels to full E-1 channels

- A 63 E-1 DS-0, using either input streams from the three 21-E1 or the input stream from the single STM-1

- Multiplex to combine 63 E-1 from the low speed inputs into a single STM-1/OC-3 stream. Similarly, 84 T-1 combined into an STM-1/OC-3 stream.

- As many as four OC-192 (10 Gbps) streams or 16 OC-48 (2.5 Gbps) streams,
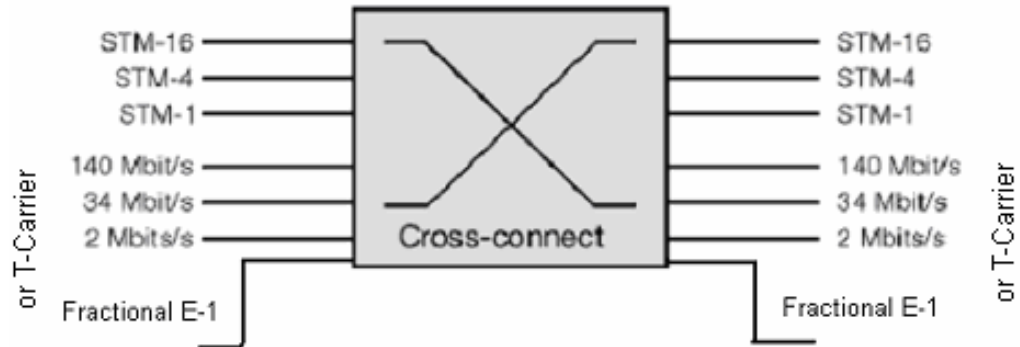
The STM-1 frame format

- The frame with a bit rate of 155.52 Mbit/s is defined as the first level of Synchronous Transport Module (STM-1)
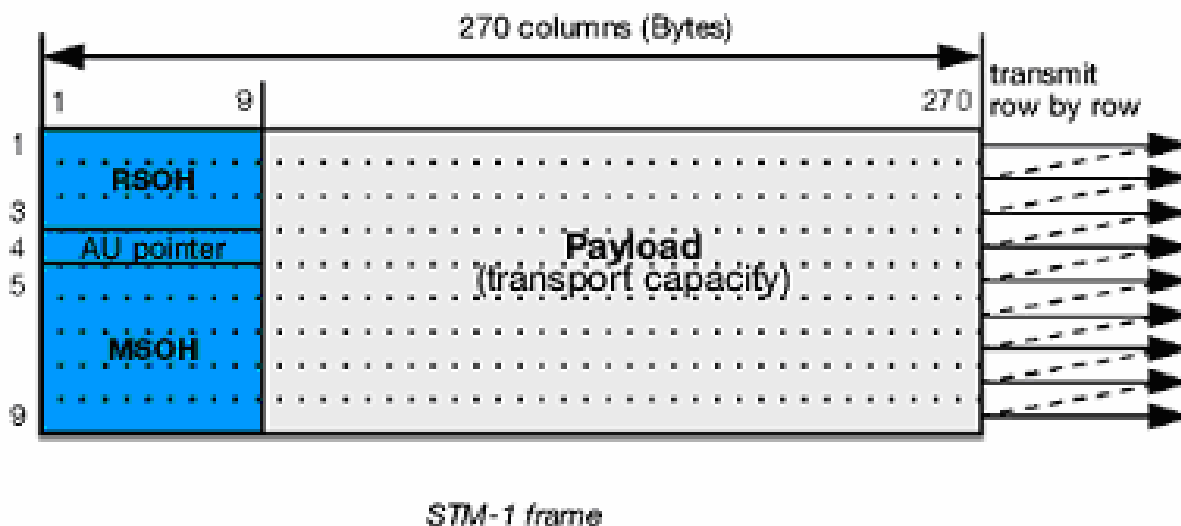
STM-1 frame

- STM-1 frame is made up from a byte matrix of 9 rows and 270 columns

- STM-1 frame carries 9 rows X 270 columns = 2430 bytes (one byte is 8 bits)

- One STM-1 frame is transmitted every 0.000125 seconds (1/8000th of a second)

- Thus rate of STM-1 is (2430 bytes x 8 bits / byte) = 19440 bits in 0.000125 seconds. İ.e 19440 bits x (1/0.000125 sec) = 155.52 Mbps

- Transmission is row by row, starting with the byte in the upper left corner and ending with the byte in the lower right corner, i.e in line order just like the order of reading text in a book.

- First 9 bytes in each of the 9 rows (=81 bytes) are called the **Transport Overhead** (except row 4); Regenerator Section Overhead (RSOH) and Multiplex Section Overhead (MSOH).

- Section overhead allows control information to be passed between adjacent synchronous network elements.

- Columns 10 through 12 are reserved for **Path Overhead (POH)**.

- Remaining columns (13 through 270) comprise the **Synchronous Payload Envelope (SPE)** for an actual data rate of 148.608 Mbps (258 columns x 9 rows x 8 bits/byte x 8000 frames/sec = 148.608 Mbps).

- There is no restriction on STM payloads. Some of the payloads are:

  - PDH frames

  - Broadband ISDN ATM cells

  - Narrowband ISDN data

  - LAN packets
  .

- Each byte in the payload represents a 64 kbit/s channel (like in TDM)

- STM-1 frame is capable of transporting PDH tributary signals of 2, 34, 140 Mbit/s.

Overhead byte	Function
A1, A2	Frame alignment
B1, B2	Quality monitoring, parity bytes
D1...D3	Q_{ECC} network management
D4...D12	Q_{ECC} network management
E1, E2	Voice connection
F1	Maintenance
J0 (C1)	Trace identifier
K1, K2	Automatic protection switching (APS) control
S1	Clock quality indicator
M1	Transmission error acknowledgment

OVERHEAD BYTES AND THEIR FUNCTIONS

- Individual payloads are loaded into the SDH frame by placing them in **Virtual Containers (VCs)** within the frame.

- Any **Virtual Container** consists of the payload information placed within it plus a one column field called **Path Overhead (POH).** İ.e. path overhead (POH) plus a container forms a virtual container

- The POH stays with the container contents from the point where the VC is entered into the STM frame to the point where the payload is extracted and delivered to the end user.

- POH enables the SDH system to identify a VC (indicating the type of container) as it passes through various stages and also to monitor quality.

- As the term virtual container suggests, the bytes of the VC are not loaded contigously into an STM frame but are distributed throughout the frame.

- In this manner, payload area is used efficiently, i.e. individual VCs can be written into and read out of the payload area in a periodic manner

- A virtual container may also start in one frame and finish in the next frame.

- POH format and size depends on the container type. Two different POH types:

- SDH is used everywhere except in the USA, Canada and Japan.

- SONET is the American equivalent of SDH. SONET base bit rate is 51.84 Mbit/s and is designated STS-1 (synchronous transport signal).

- If this bit rate is transmitted over an optical cable system, the signal is designated OC-1 (optical container).

- Levels in SDH/SONET hierarchy are:

SONET signals		Bit rates	Equivalent SDH signal
STS-1	OC-1	51.84 Mbit/s	STM-0
STS-3	OC-3	155.52 Mbit/s	STM-1
STS-9*	OC-9*	466.56 Mbit/s	
STS-12	OC-12	622.08 Mbit/s	STM-4
STS-18*	OC-18*	933.12 Mbit/s	
STS-36*	OC-36*	1244.16 Mbit/s	
STS-48*	OC-48	2488.32 Mbit/s	STM-16
STS-192*	OC-192	9953.28 Mbit/s	STM-64

(* These hierarchy levels are not normally used and are mentioned only for the sake of completeness)