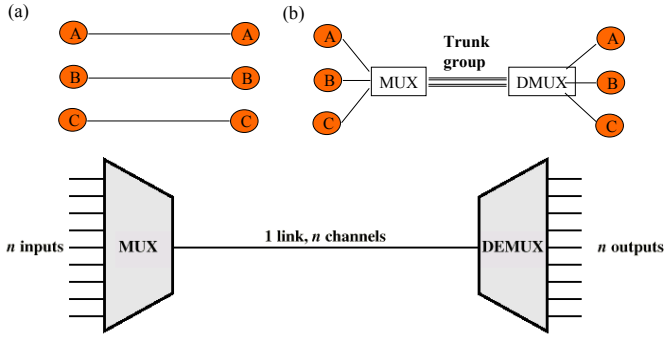
Chapter 8 Multiplexing

- Frequency-Division Multiplexing
- Synchronous Time-Division Multiplexing
- Statistical Time-Division Multiplexing
- Asymmetric Digital Subscriber Line

Multiplexing

The higher the data rate, the more cost-effective the trans. facility

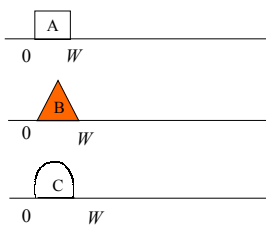


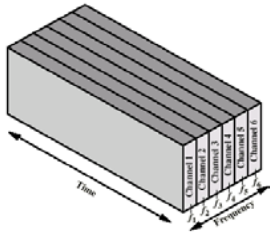
Frequency Division Multiplexing

- A number of signals are carried simultaneously on the same medium.
- Each signal is modulated to a different carrier frequency
- Useful bandwidth of medium should exceed required bandwidth of channels
- Carrier frequencies separated so signals do not overlap (guard bands)
- e.g. FM radio, CATV
- Channel allocated even if no data

Frequency Division Multiplexing

- Individual signals occupy W Hz





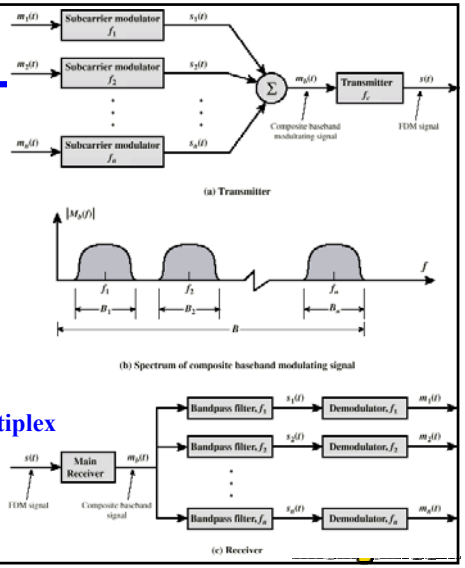
- The transmission channel bandwidth is divided into a number of frequency slots, each of which can accommodate the signal of an individual connection; Multiplexer assigns a frequency slot to each connections and uses **modulation** to place the signal of the connection in the appropriate slot

FDM System

Transmitter:

1st Modulate -> Multiplex

-> 2nd Modulate



Receiver:

1st Demodulate->Demultiplex

->2nd Demodulate

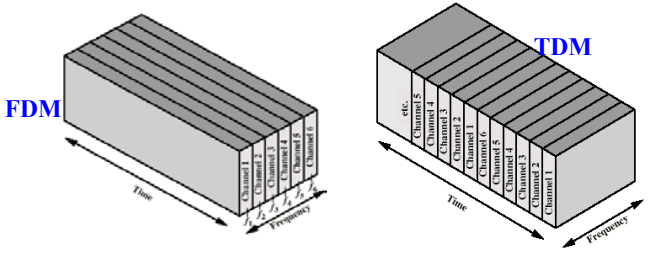
FDM (Con't)

- AT&T analog carrier system used a hierarchy of FDM schemes
  - Group
    - **-12 voice channels (4kHz each) = 48kHz**
    - **-Range 60kHz to 108kHz**
  - Supergroup
    - **- 60 channel**
    - **- FDM of 5 group signals on carriers between 312kHz and 552kHz**
  - Mastergroup
    - **-10 supergroups : 2.52MHZ bandwidth between 564KHz and 3084 kHz**

Synchronous Time Division Multiplexing

- Data rate of medium exceeds data rate of ***digital signals*** to be transmitted
- Multiple ***digital signals*** interleaved in time
- Interleaving can be at: ***bit level; blocks of bytes level; or larger quantities level***
- Time slots **preassigned** to sources and **fixed**
- Time slots allocated even if no data
- *Time slots do not have to be evenly distributed amongst sources -> **TDM can handle source with different data rate.***

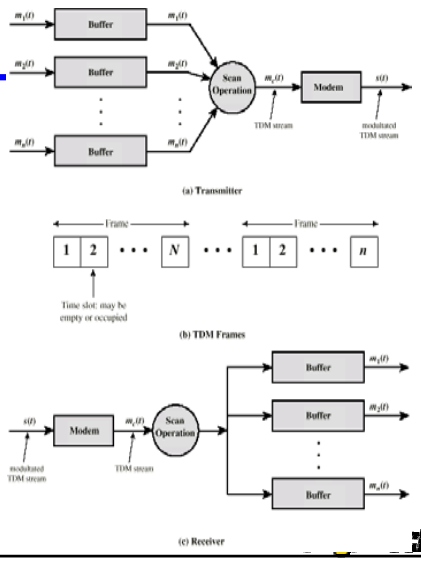
Time Division Multiplexing



- **With FDM, each channel continuously gets a fraction of the bandwidth.**
- **With TDM, each channel gets all of the bandwidth periodically during brief intervals of time.**

TDM System

Transmitter:
Buffer->Multiplex ->Modulate



Receiver:
Demodulate-> Demultiplex -> Buffer

Synchronous TDM Link Control

- No headers and tailers for the TDM frame needed
- Data link control protocols are not needed for the overall TDM link, why?
  - Flow control
    - Data rate of multiplexed line is fixed
    - If one channel receiver can not receive data, the others must carry on. This leaves empty slots
    - Data link control protocol can be used on a per-channel basis
  - Error control
    - Errors are detected and handled by individual channel systems

Framing

- No flag or SYNC characters bracketing TDM frames
- Must provide frame synchronization mechanism
- Added digit framing
  - One control bit added to each TDM frame
    - Looks like another channel - "**control channel**"
  - Identifiable bit pattern used on control channel: **e.g. alternating 01010101…unlikely on a data channel**
  - To synchronize, a receiver compares incoming bits of one frame position to the expected sync pattern

Pulse Stuffing

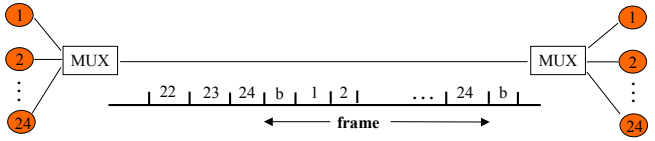
- Problem - Synchronizing ***various*** data sources
- Clocks in different sources drifting
- Data rates from different sources not related by simple rational number
- Solution - Pulse Stuffing
  - Outgoing data rate (excluding framing bits) higher than sum of incoming rates
  - Stuff extra dummy *bits or pulses* into each incoming signal until it matches ***local clock***
  - Stuffed pulses inserted at fixed locations in the multiplexer frame format, and identified/removed at demultiplexer

Digital Carrier Systems: T-1 Carrier

- Digital Hierarchy of TDM
- USA/Canada/Japan use this TDM structure of various capacities
- ITU-T use a similar (but different) system
- US system based on DS-1 format
- Multiplexes 24 channels
- Each frame has 8 bits per channel plus one framing bit
- 193 bits per frame

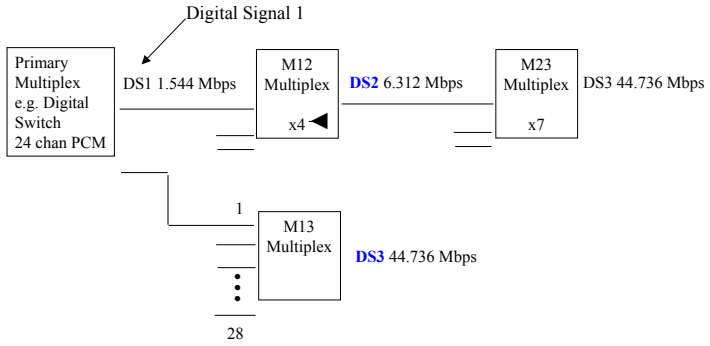
T-1 Carrier System

- A digital Telephone speech signal is obtained by sampling a speech waveform **8000** times/sec and by representing each sample with **8** bits.
- T-1 system uses a transmission frame that consists of **24** slots of **8** bits each. Each slot carries one PCM sample for a single connection.
- DS1: **(1+24x8) bits/frame x 8000 frames/sec =1.544** Mbps



T-1 Carrier System (Con't)

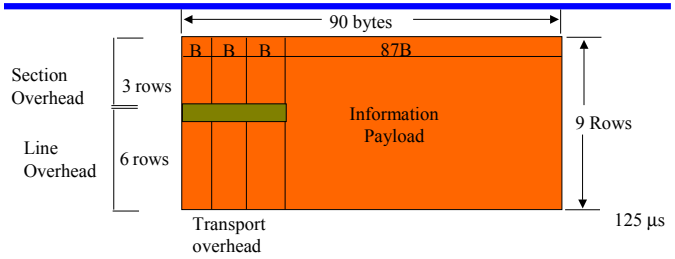
Higher-level multiplexing achievable by interleaving bits from DS-1 inputs -> **DS2** (6.312 Mbps), **DS3** (44.736Mbps)



SONET/SDH: An example of TDM

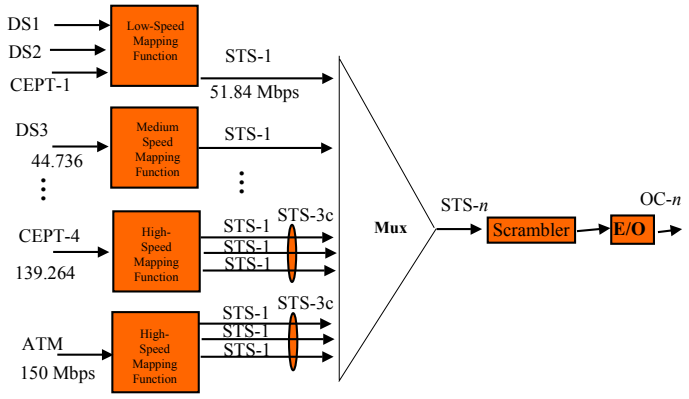
- Synchronous Optical Network by BellCore (ANSI)
- Synchronous Digital Hierarchy (ITU-T)
- Signal Hierarchy
  - **SONET**: Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1): ***51.84Mbps***
  - Can carry DS-3 or a group of lower rate signals (DS1 DS1C DS2) plus ITU-T rates (e.g. 2.048Mbps)
  - **SDH**: lowest rate is 155.52Mbps (STM-1)
  - SONET uses a frame structure with the same 8khz repetition rate as traditional TDM system
  - Multiple STS-1 combined into STS-N signal

SONET STS-1 Frame Format



- ***Section overhead*** is used to provide framing, error monitoring, and other section-related management functions.
- ***Line overhead*** is used to provide synchronization and multiplexing for the path layer, as well as protection-switching capacity
- The first two bytes of the line overhead are used as a ***pointer*** that indicates the byte within the information payload where the SPE begins

SONET Multiplexing



SONET STS-1 Overhead Octets

Section Overhead	Framing A1	Framing A2	STS-ID C1
	BIP-8 B1	Orderwire E1	User F1
	DataCom D1	DataCom D2	DataCom D3
Line Overhead	Pointer H1	Pointer H2	Pointer Action H3
	BIP-8 B2	APS K1	APS K2
	DataCom D4	DataCom D5	DataCom D6
	DataCom D7	DataCom D8	DataCom D9
	DataCom D10	DataCom D11	DataCom D12
	Growth Z1	Growth Z2	Orderwire E2

(a) Transport Overhead

Trace J1
BIP-8 B3
Signal Label C2
Path Status G1
User F2
Multiframe H4
Growth Z3
Growth Z4
Growth Z5

(b) Path Overhead

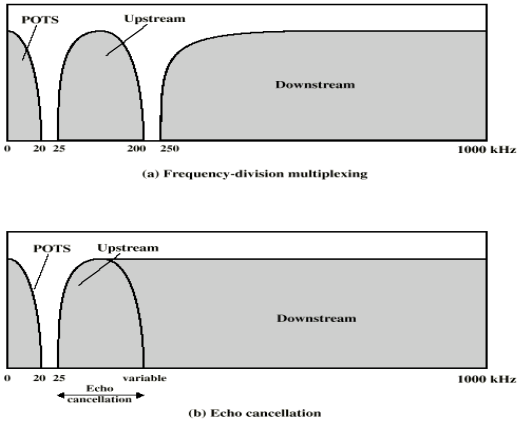
Statistical TDM

- **In Synchronous TDM many slots are wasted**
- **Statistical TDM allocates time slots dynamically based on demand** -> Sequence of data packets from multiple users does not have fixed pattern as FDM & TDM
- **Data rate on output line lower than aggregate rates of input lines** -> higher facility utilization; however, the need for "address" and "data length" causes big overhead
- **May cause problems during peak periods**
  - Buffer inputs
  - Keep buffer size limited to reduce delay
- **Statistical TDM is the base for Packet Switching**. While FDM and Synchronous TDM belong to Circuit Switching

Asymmetrical Digital Subscriber Line

- **Explore the potential capacity of the installed twisted pair (0-1MHz)**
- **Asymmetric Digital Subscriber Line**
  - Greater capacity downstream than upstream
- **Supported by Frequency division multiplexing**
  - Lowest 25kHz for voice: plain old telephone service (POTS)
  - The region above 25kHz is used for data transmission
    - Upstream: 64kbps to 640kbps
    - Downstream: 1.536Mbps to 6.144Mbps

ADSL Channel Configuration



Discrete Multitone (DMT)

- ITU-T G.992.1 standard for ADSL uses DMT
- DMT divides available bandwidth into # of subchannels
- 4kHz for each subchannels
- The binary bits are distributed among the subchannel, each of which use QAM (using two copies of the carrier frequency, one shifted by $90^{0)}$
- More bits feed to subchannels with high SNR, less bits to subchannels with poor SNR
- Current ADSL: 256 downstream subchannels (1.5 to 9Mbps).

xDSL

- High data rate DSL (HDSL): deliver T1 data (1.544Mbps) over two twisted pair lines -> replace T1 lines – 1.544 or 2.048 Mbps
- Single line DSL (SDSL): echo cancellation used
- Very high data rate DSL: 13 to 52 Mbps downstream