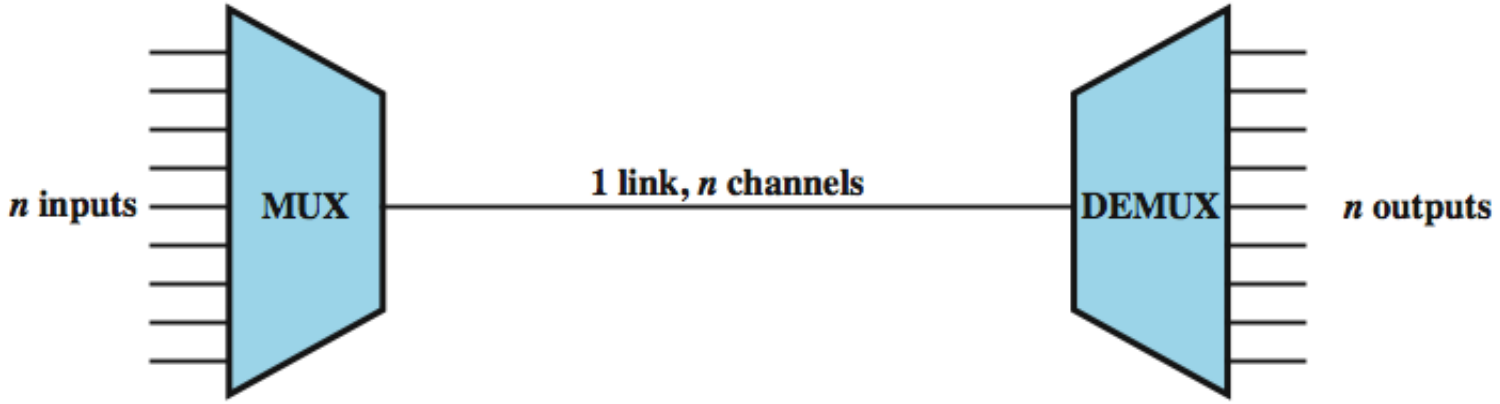
Multiplexing

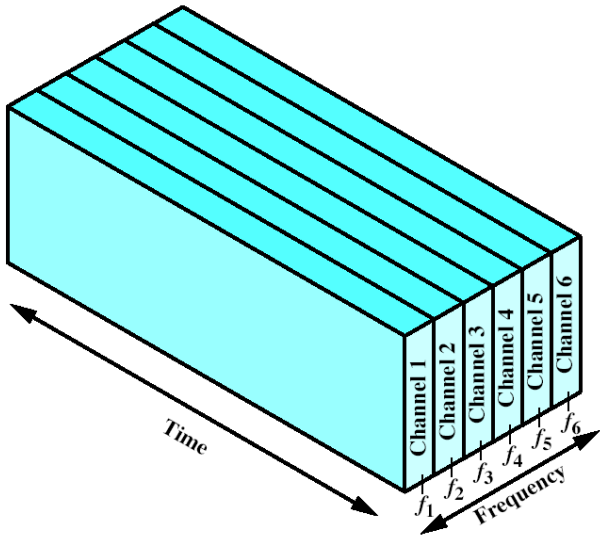
Multiplexing

- To make efficient use of high-speed telecommunications lines, some form of multiplexing is used
- Multiplexing allows several transmission sources to share the same transmission media
- Trunks on long-haul networks are high-capacity fiber, coaxial, or microwave links
- Common forms of multiplexing are Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM), and Statistical TDM (STDM).



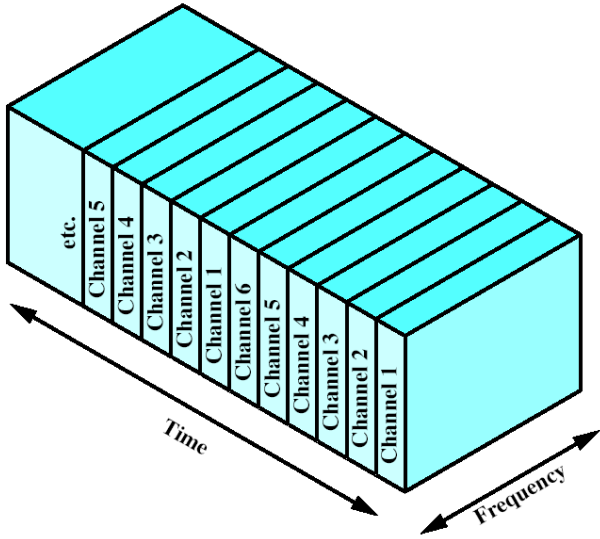
Multiplexing Techniques

- Frequency Division Multiplexing (FDM)
  - Each signal is allocated a different frequency band
  - Usually used with analog signals
  - Modulation equipment is needed to move each signal to the required frequency band (channel)
  - Multiple carriers are used, each is called sub-carrier
  - Multiplexing equipment is needed to combine the modulated signals



(a) Frequency division multiplexing

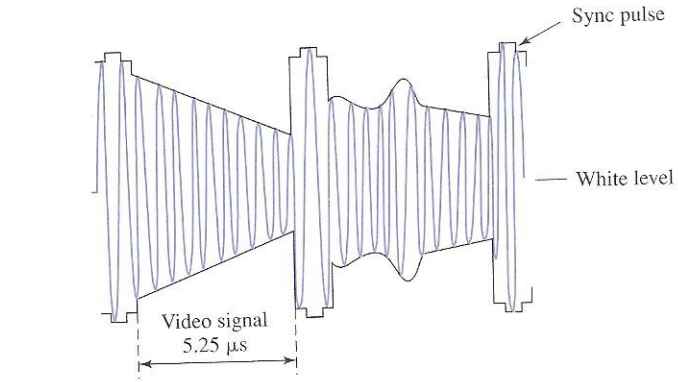
- Dime Division Multiplexing (TDM)
  - Usually used with digital signals or analog signals carrying digital data
  - Data from various sources are carried in repetitive frames
  - Each frame consists of of a set of time slots
  - Each source is assigned one or more time slots per frame



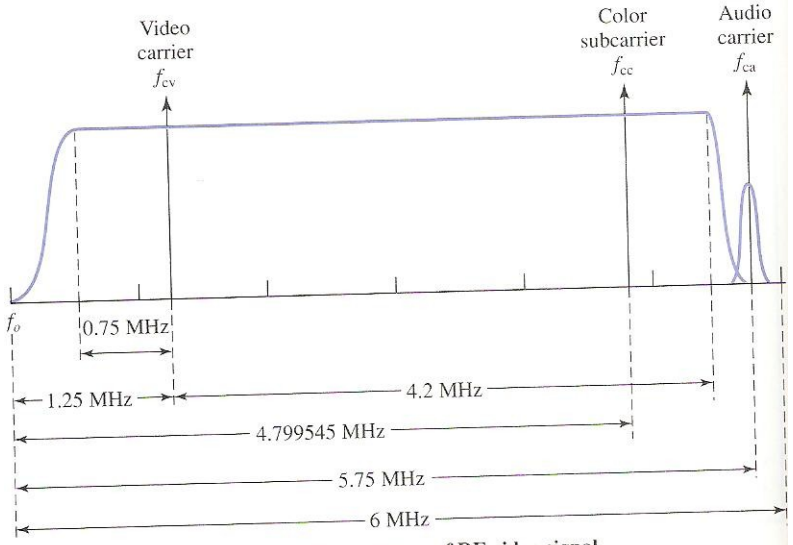
(b) Time division multiplexing

Example of FDM: Broadcast and Cable TV

- Figure 8.3 (a) shows the time domain description of the AM modulated TV signal
- Figure 8.3 (b) shows the frequency domain description of the TV signal
- The bandwidth of the TV signal is 6MHz
- Multiple TV signals can be FDM on a CATV coaxial cable
- Given that the bandwidth of the coaxial cable is up to 500MHz
- The number of TV signals or channels that can be multiplexed is up to 500/6=83 TV signal or channel



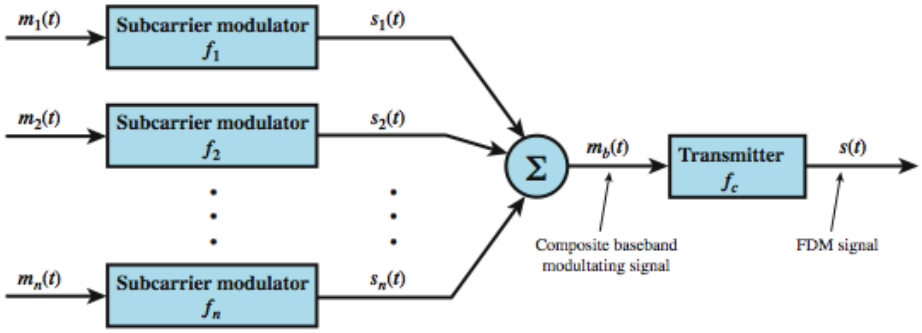
(a) Amplitude modulation with video signal



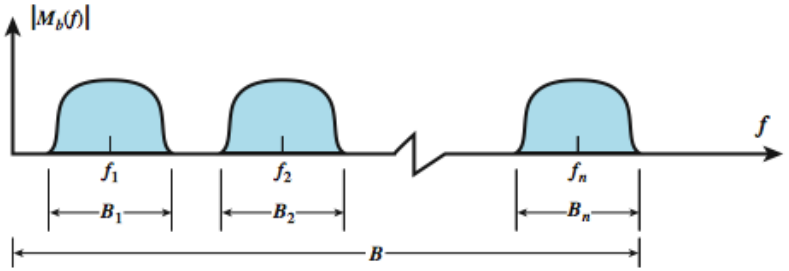
(b) Magnitude spectrum of RF video signal

Figure 8.3 Transmitted TV Signal

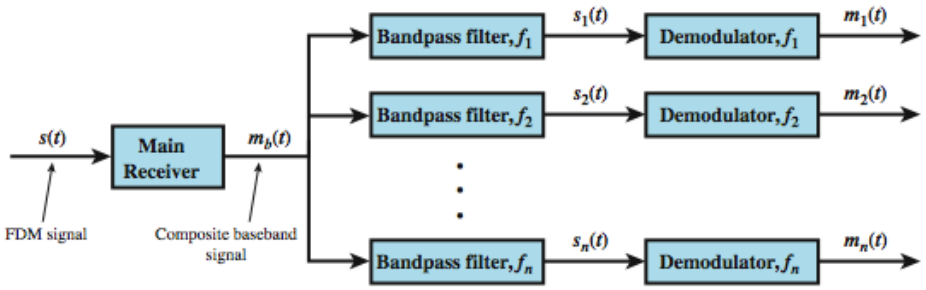
FDM System Overview



(a) Transmitter



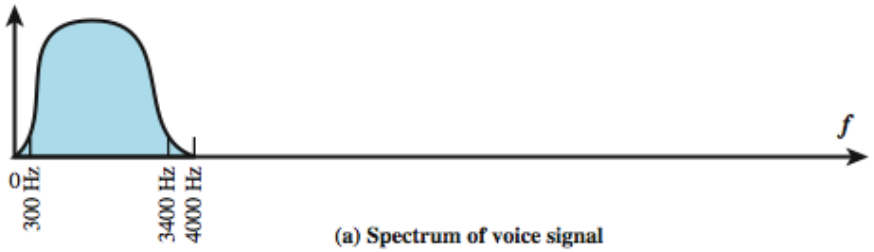
(b) Spectrum of composite baseband modulating signal



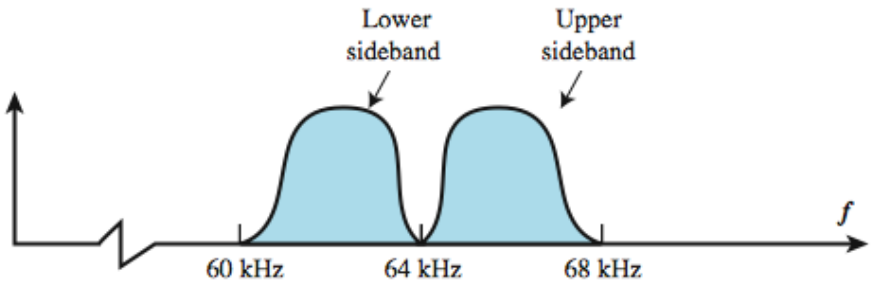
(c) Receiver

FDM example: multiplexing of three voice signals

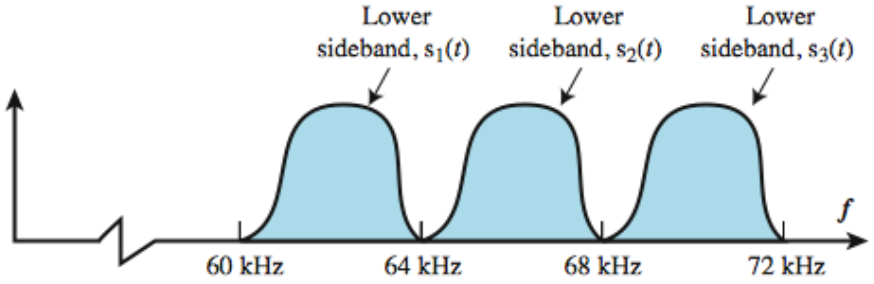
- The bandwidth of a voice signal is generally taken to be 4KHz, with an effective spectrum of 300-3400Hz
- Such a signal is used to AM modulate 64 KHz carrier
- The bandwidth of the modulated signal is 8KHz and consists of the Lower Side Band (LSB) and USB as in (b)
- To make efficient use of bandwidth, transmit only the LSB
- If three voice signals are used to modulate carriers at 64, 68 and 72 KHz, and only the LSB is taken, the resulting spectrum will be as shown in (c)



(a) Spectrum of voice signal



(b) Spectrum of voice signal modulated on 64 kHz frequency



(c) Spectrum of composite signal using subcarriers at 64 kHz, 68 kHz, and 72 kHz

North America and International FDM Carrier Standard

Number of Voice Channels	Bandwidth	Spectrum	AT&T	ITU-T
12	48 kHz	60–108 kHz	Group	Group
60	240 kHz	312–552 kHz	Supergroup	Supergroup
300	1.232 MHz	812–2044 kHz		Mastergroup
600	2.52 MHz	564–3084 kHz	Mastergroup	
900	3.872 MHz	8.516–12.388 MHz		Supermaster group
$N \times 600$			Mastergroup multiplex	
3,600	16.984 MHz	0.564–17.548 MHz	Jumbogroup	
10,800	57.442 MHz	3.124–60.566 MHz	Jumbogroup multiplex	

Analog Carrier Systems

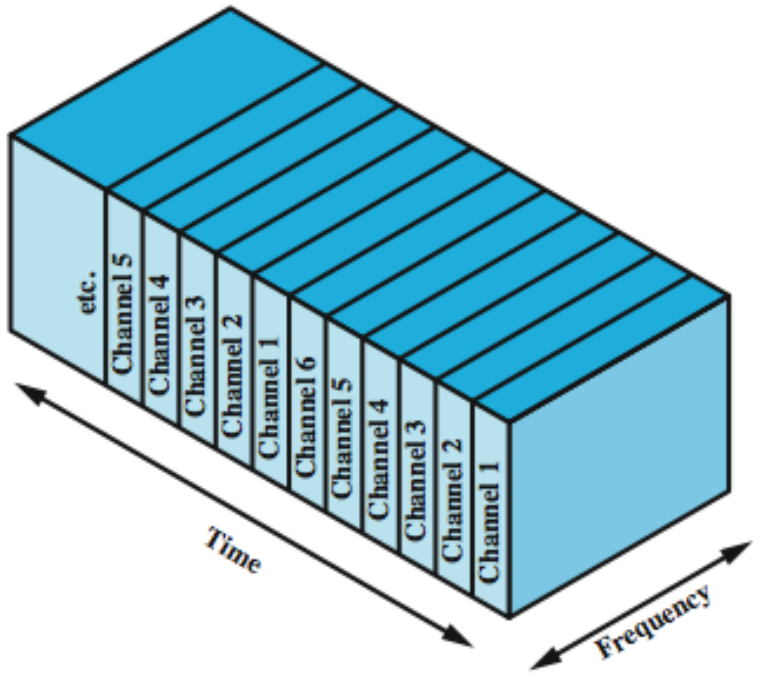
- Long-distance links use an FDM hierarchy
- AT&T (USA) and ITU-T (International) variants
- Group
  - 12 voice channels (4kHz each) = 48kHz
  - in range 60kHz to 108kHz
- Supergroup
  - FDM of 5 group signals supports 60 channels
  - on carriers between 420kHz and 612 kHz
- Mastergroup
  - FDM of 10 supergroups supports 600 channels
- So original signal can be modulated many times

Wavelength Division Multiplexing (WDM)

- WDM: multiple beams of light at different frequencies or wavelengths are transmitted on the same fiber optic cable
- This is a form of Frequency Division Multiplexing (FDM)
- Commercial systems with 160 channels (frequencies, wavelengths or beams) of 10 Gbps each; 160*10Gbps=1.6Tbps
- Alcatel laboratory demo of 256 channels of 39.8 Gbps each; 39.8*256=10.1Tbps
- architecture similar to other FDM systems
  - multiplexer multiplexes laser sources for transmission over single fiber
  - Optical amplifiers amplify all wavelengths
  - Demux separates channels at the destination
- Most WDM systems operates in the 1550 nm range
- Also have Dense Wavelength Division Multiplexing (DWDM) where channel spacing is less than 200GHz

Synchronous Time Division Multiplexing

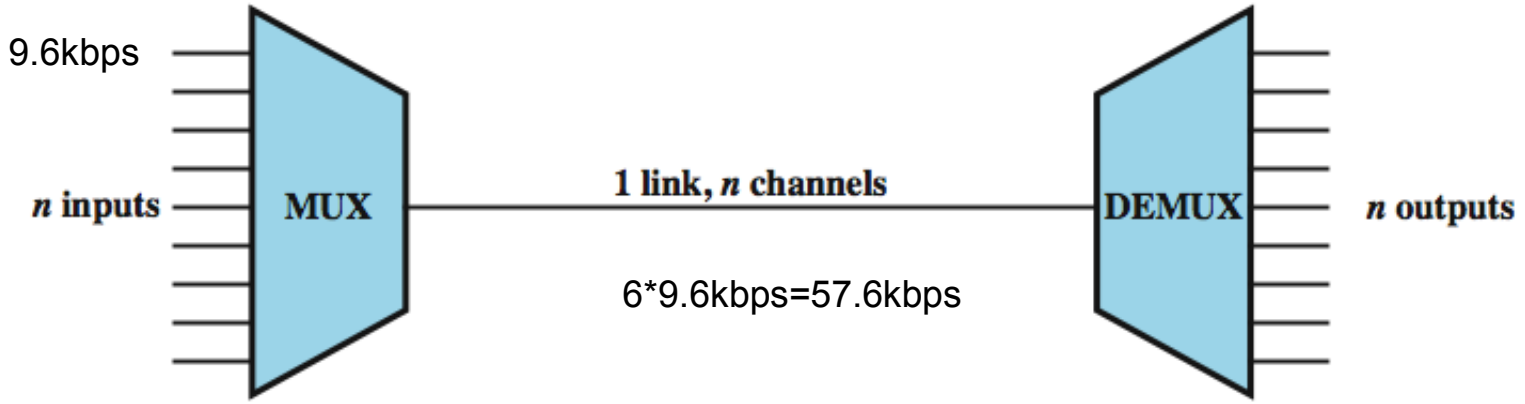
- Synchronous TDM can be used with digital signals or analog signals carrying digital data.
- Data from various sources are carried in repetitive frames.
- Each frame consists of a set of time slots, and each source is assigned one or more time slots per frame
- The effect is to interleave bits of data from the various sources
- The interleaving can be at the bit level or in blocks of bytes or larger



(b) Time division multiplexing

Synchronous Time Division Multiplexing

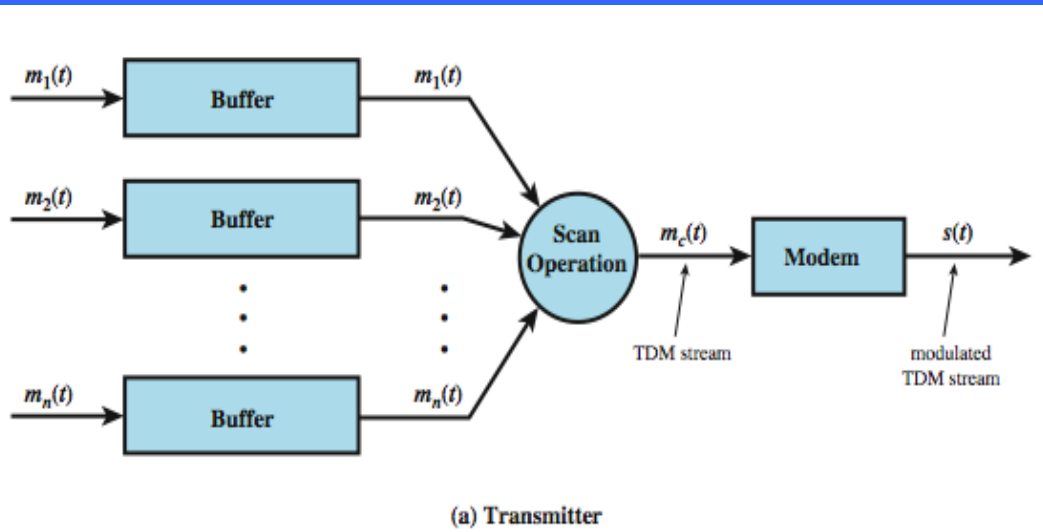
- For example, a multiplexer has six inputs n=6 with 9.6 kbps. A single line with a capacity of at least 57.6 kbps could accommodate all six sources.



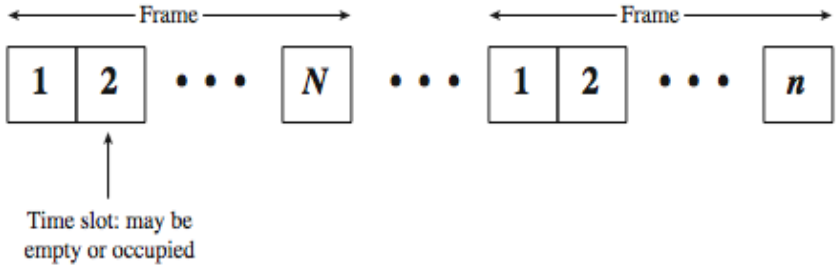
- Synchronous TDM is called synchronous as the time slots are pre-assigned to sources and fixed
- The time slots for each source are transmitted whether or not the source has data to send.

Synchronous TDM System

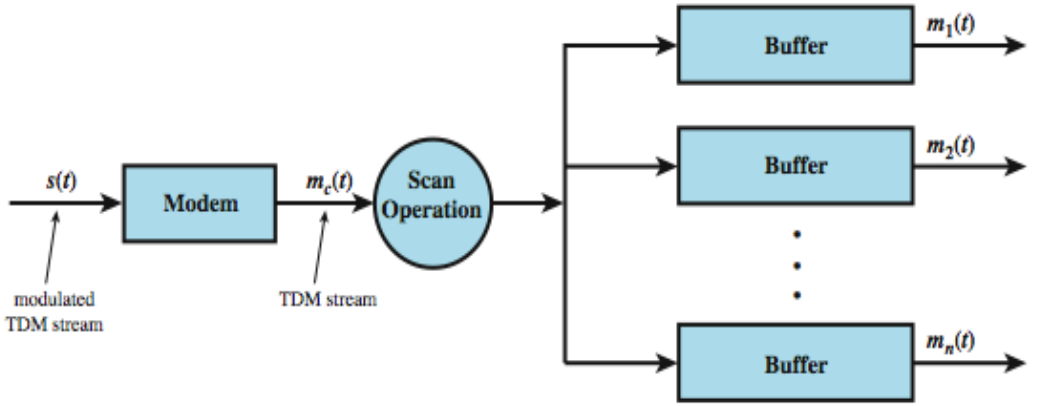
TDM System Overview



(a) Transmitter



(b) TDM Frames



(c) Receiver

Framing

- Need to provide synchronizing mechanism between source and destination
- Added-digit framing
  - one control bit added to each TDM frame
  - identifiable bit pattern, from frame to frame, is used as “control channel”
  - e.g. alternating 01010101…unlikely on a data channel

Pulse (bit) Stuffing

- Have problem of synchronizing data sources
- With clocks in different sources drifting
- Also issue of data rates from different sources not related by simple rational number
- Pulse Stuffing a common solution
  - have 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 frame and removed at demultiplexer