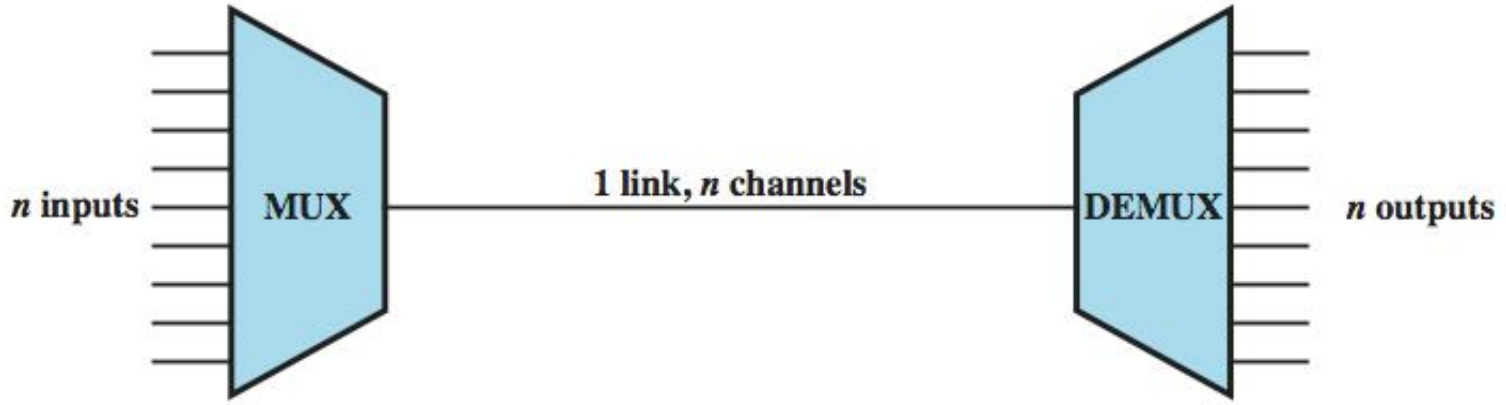
Multiplexing

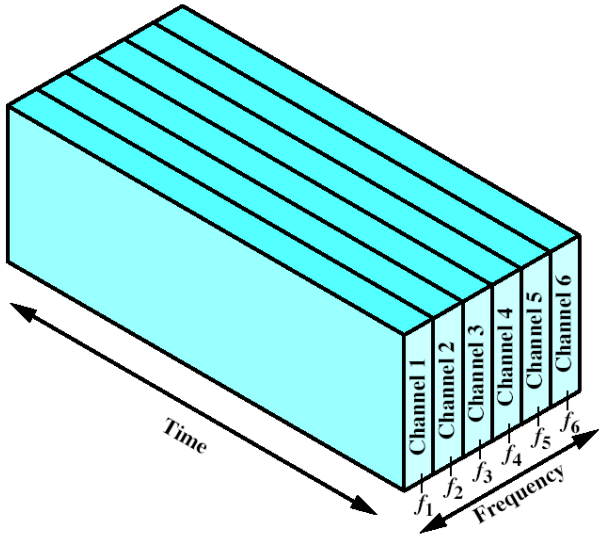
Multiplexing

- 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).



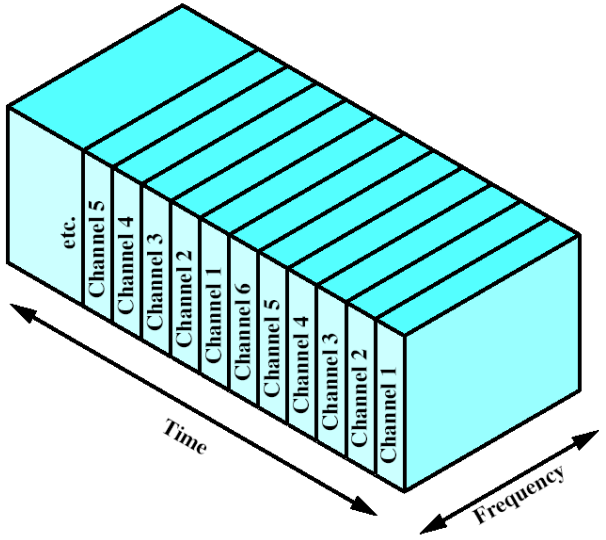
Multiplexing Techniques

- 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

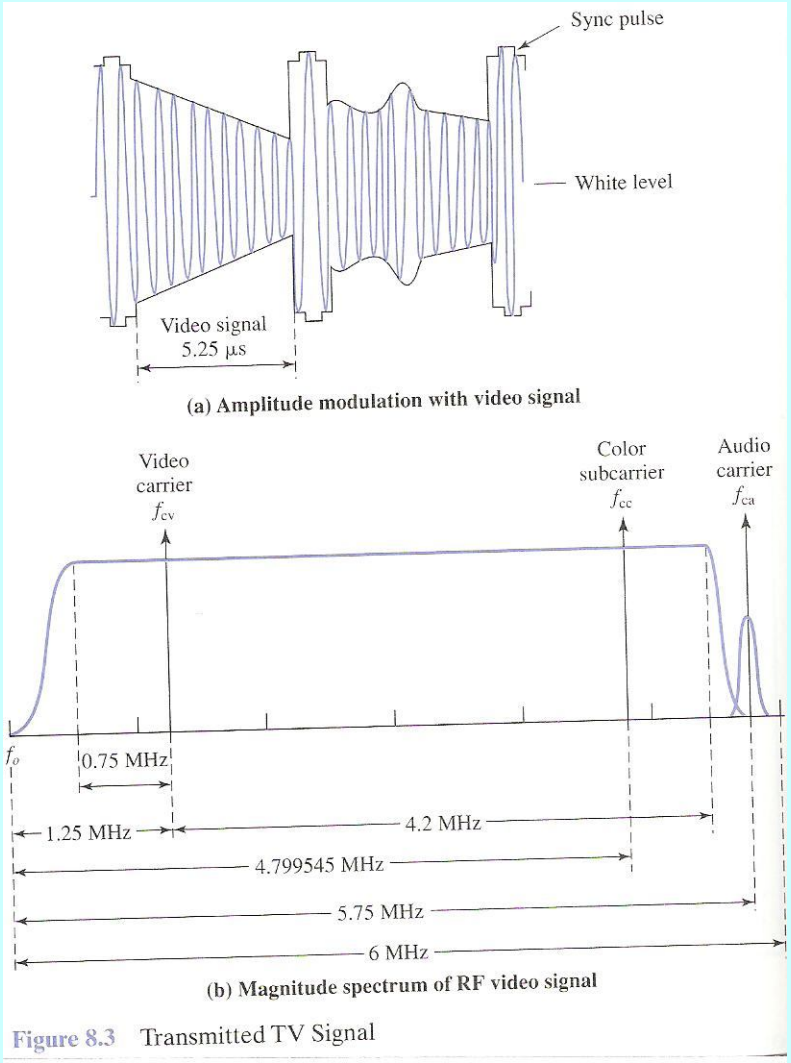
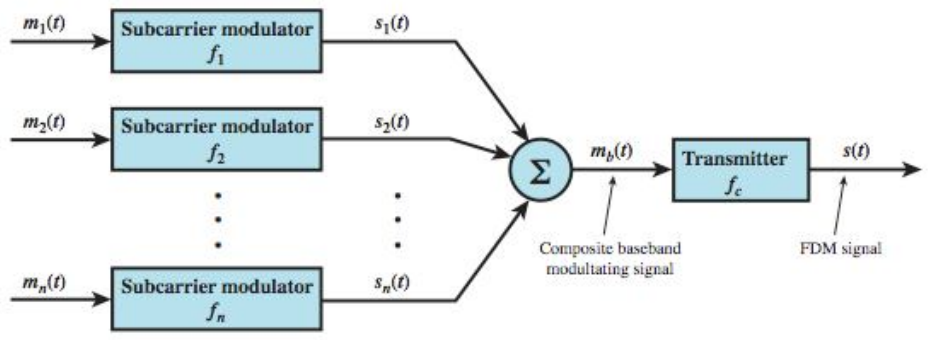
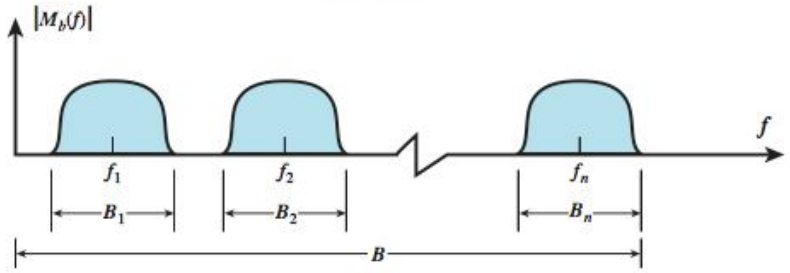


Figure 8.3 Transmitted TV Signal

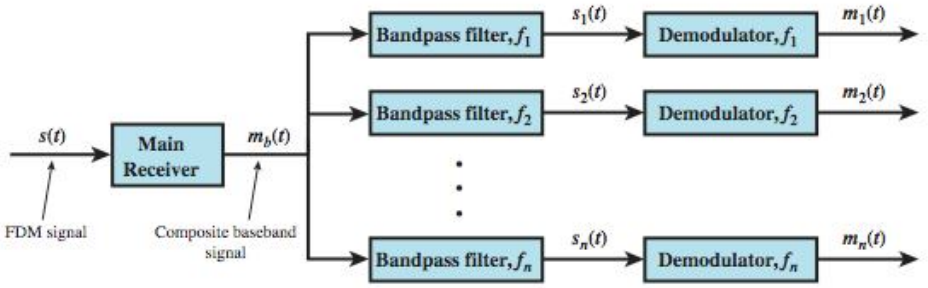
FDM System Overview



(a) Transmitter



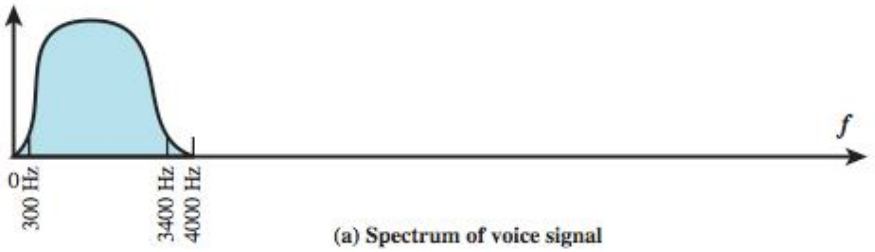
(b) Spectrum of composite baseband modulating signal



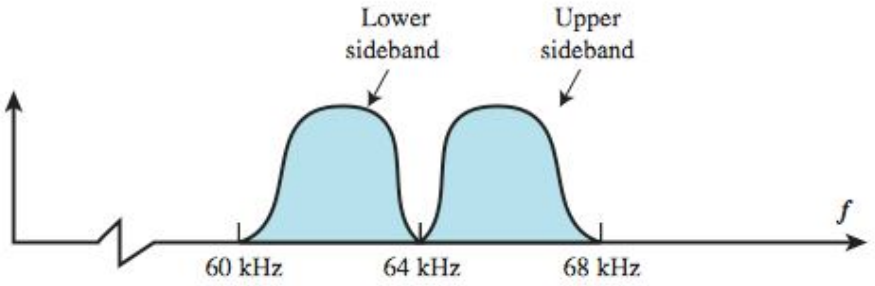
(c) Receiver

FDM example: multiplexing of three voice signals

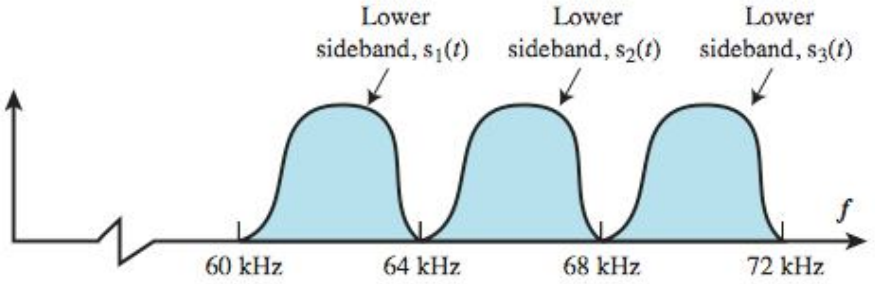
- The bandwidth of a voice signal is generally taken to be 4KHz, with an effective spectrum of 300-3400Hz
- Such a signal is used to AM modulate 64 KHz carrier
- The bandwidth of the modulated signal is 8KHz and consists of the Lower Side Band (LSB) and USB as in (b)
- To make efficient use of bandwidth, 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

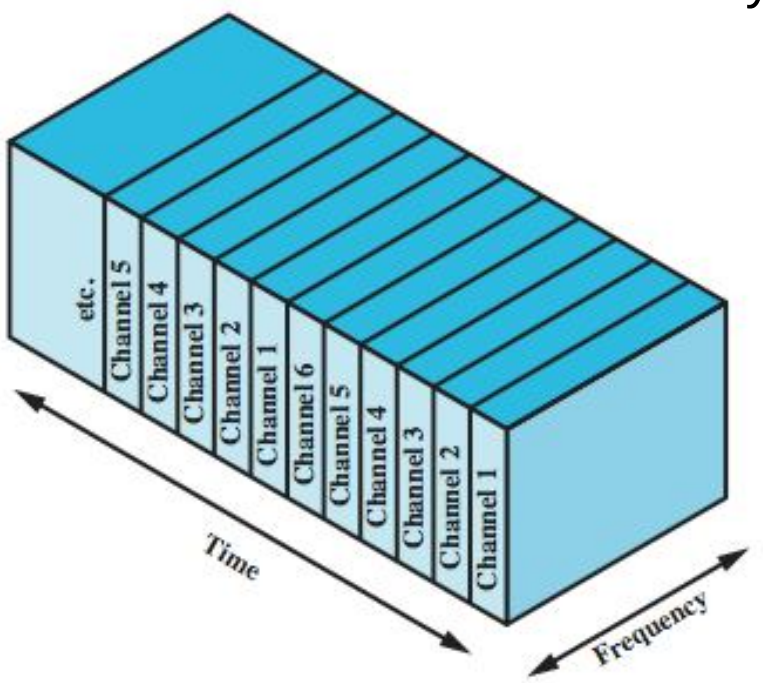
- Long-distance links use an FDM hierarchy
- AT&T (USA) and ITU-T (International) variants
- Group
  - 12 voice channels (4kHz each) = 48kHz
  - in range 60kHz to 108kHz
- Supergroup
  - FDM of 5 group signals supports 60 channels
  - on carriers between 420kHz and 612 kHz
- Mastergroup
  - FDM of 10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

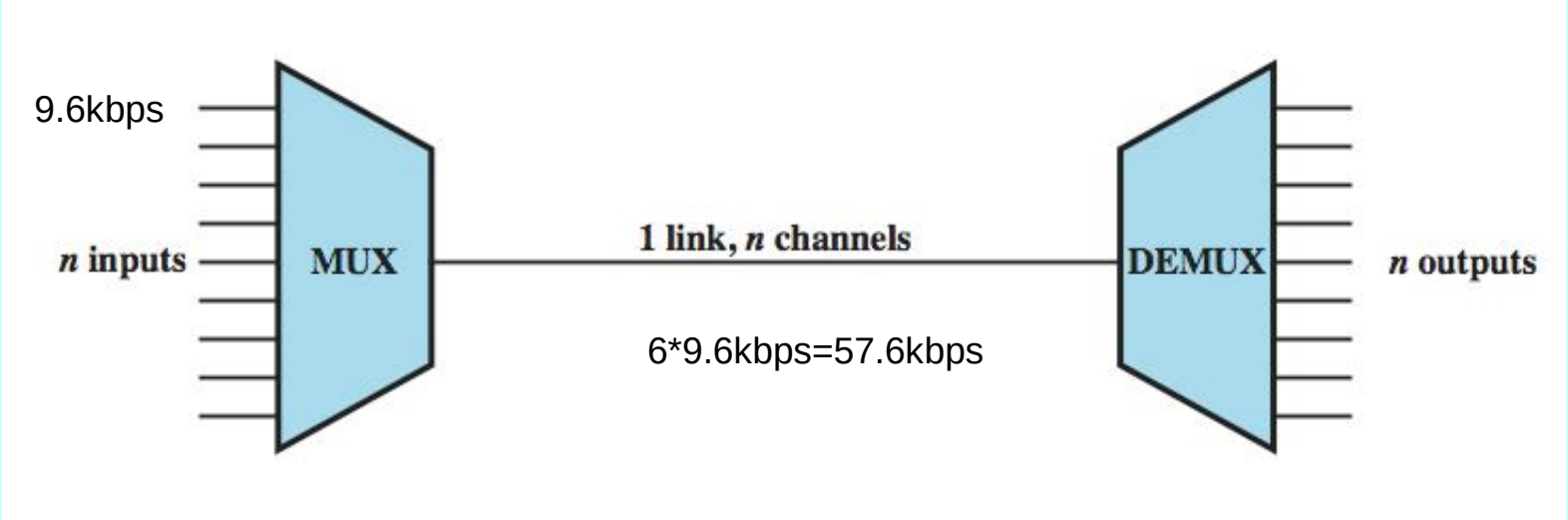
- Synchronous TDM can be used with digital signals or analog signals carrying digital data.
- Data from various sources are carried in repetitive frames.
- Each frame consists of a set of time slots, and each source is assigned one or more time slots per frame
- The effect is to interleave bits of data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

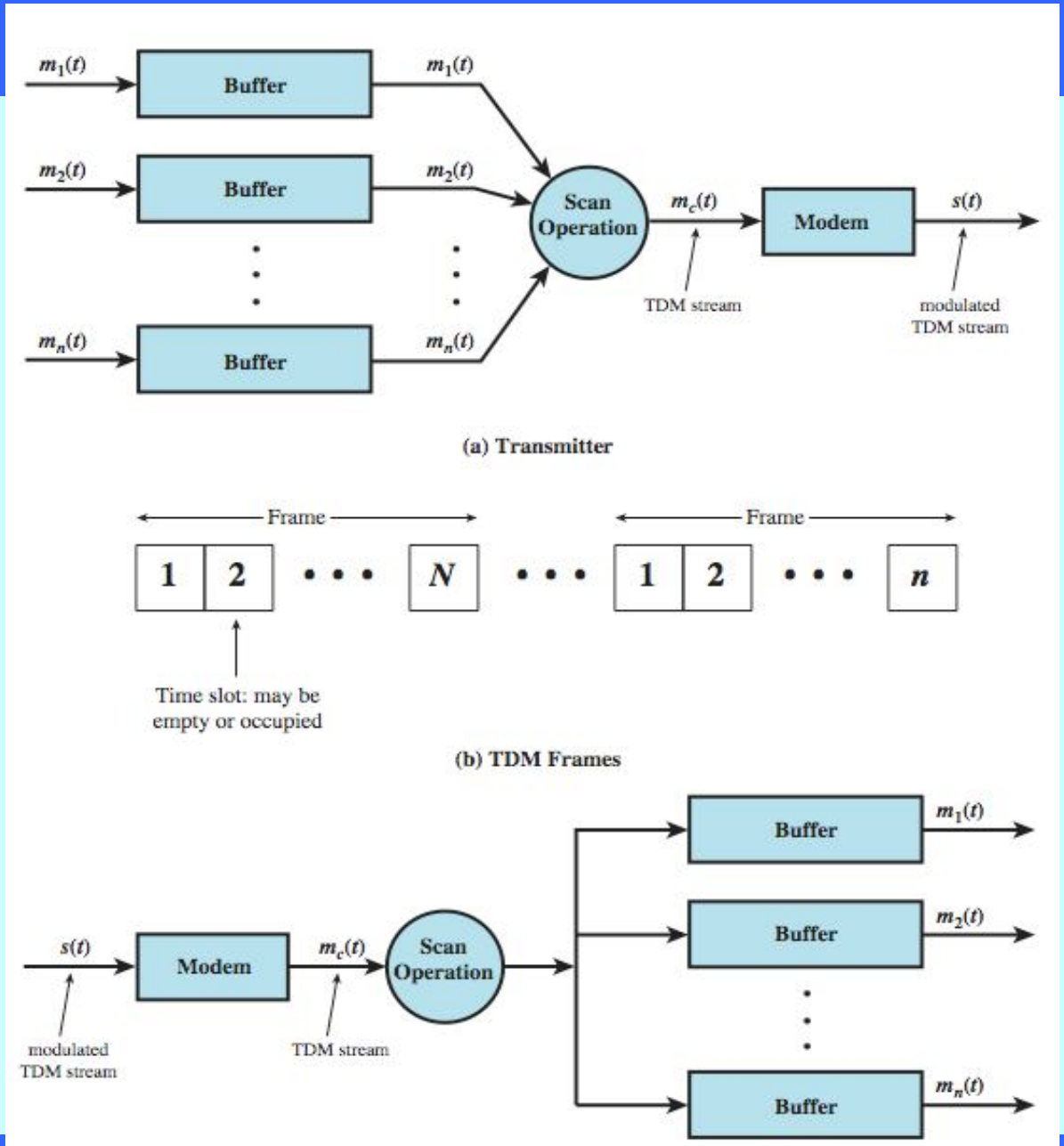
- For example, a multiplexer has six inputs n=6 with 9.6 kbps. A single line with a capacity of at least 57.6 kbps could accommodate all six sources.



- 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



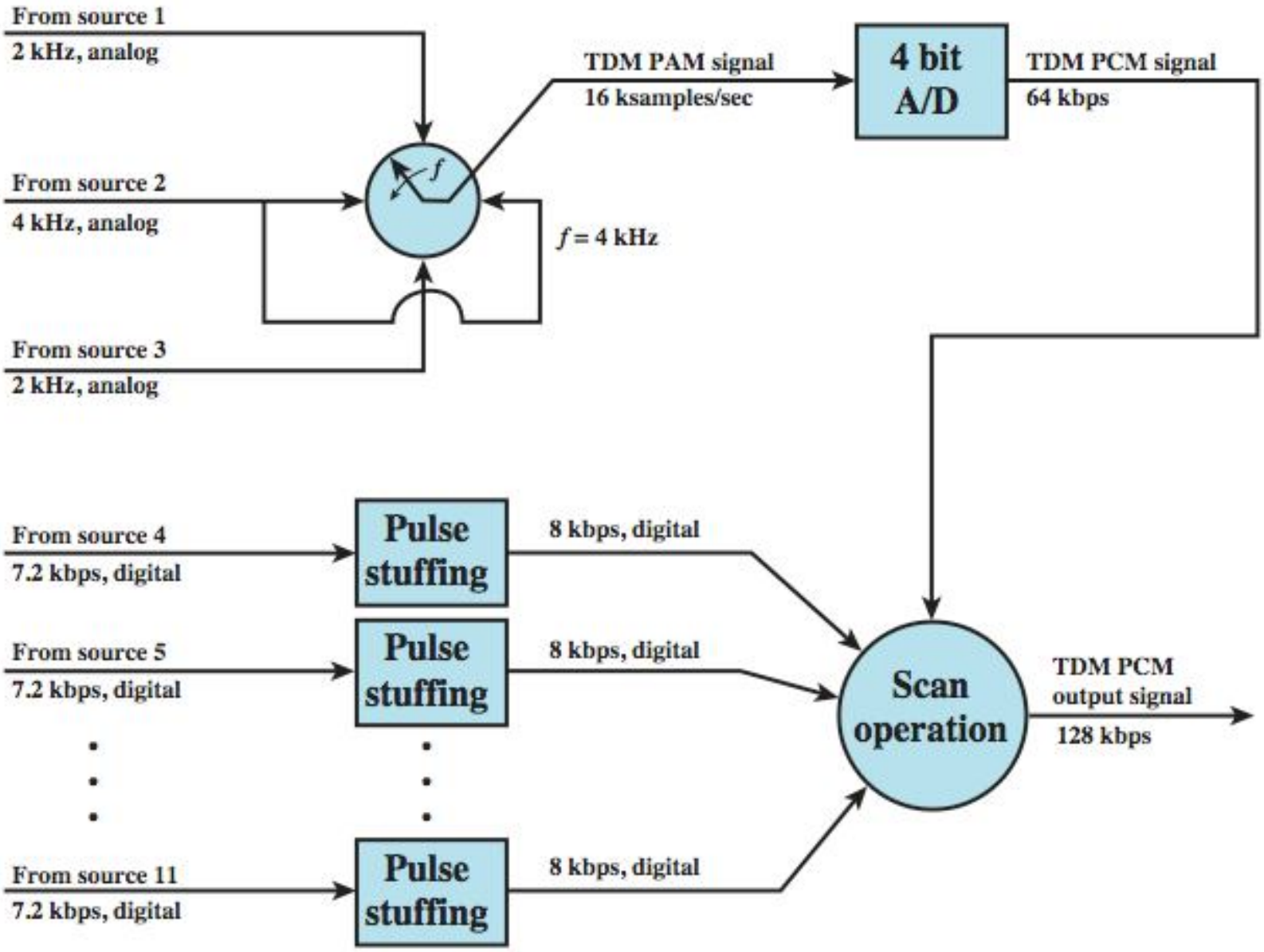
Framing

- 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

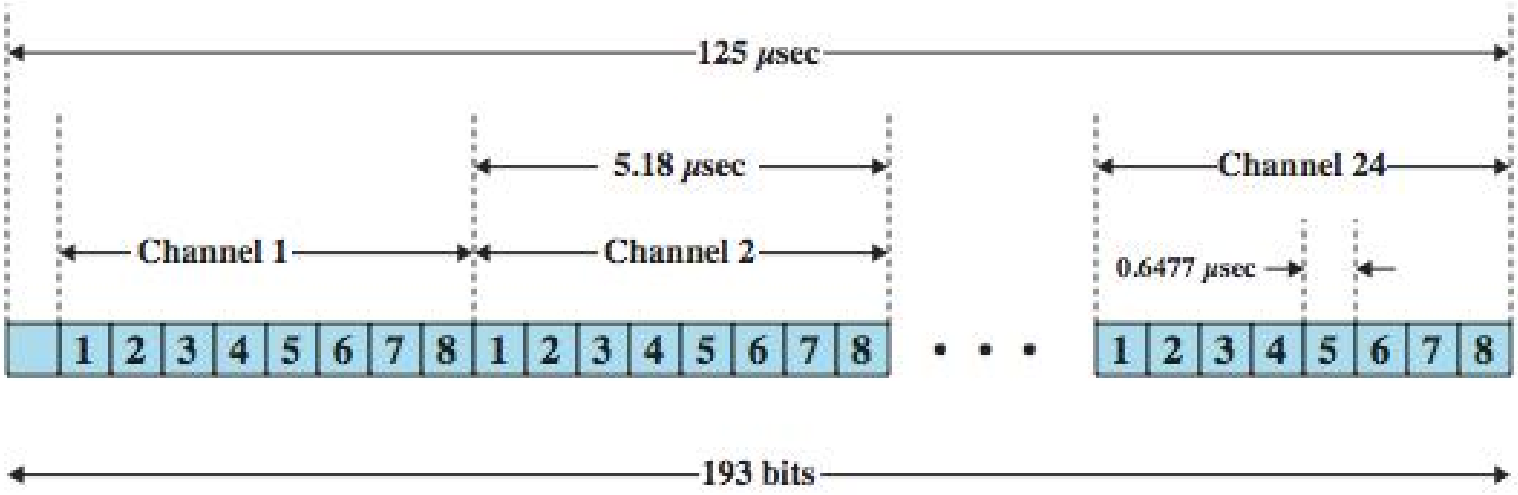
TDM Example


From source 1
2 kHz, analog
From source 2
4 kHz, analog
From source 3
2 kHz, analog
f
f = 4 kHz
TDM PAM signal
16 ksamples/sec
4 bit
A/D
TDM PCM signal
64 kbps
From source 4
7.2 kbps, digital
From source 5
7.2 kbps, digital
From source 11
7.2 kbps, digital
Pulse
stuffing
Pulse
stuffing
Pulse
stuffing
8 kbps, digital
8 kbps, digital
8 kbps, digital
Scan
operation
TDM PCM
output signal
128 kbps

Digital Carrier Systems/Standards

- Long-distance links use TDM hierarchy
- AT&T (USA) and ITU-T (International) variants
- US system based on DS-1 format
- Can carry mixed voice and data signals
- DS-1 multiplexes 24 channels into one frame
- Each frame contains 8 bits per channel plus a framing bit: 24*8+1=193 bits
- Each voice channel contains one word of digitized data (PCM, 8000 samples per sec)
- A total data rate of 8000*193=1.544Mbps
- Can interleave DS-1 channels for higher rates
  - DS-2 is four DS-1 at 4*1.544Mbps=6.312Mbps

DS-1 Transmission Format



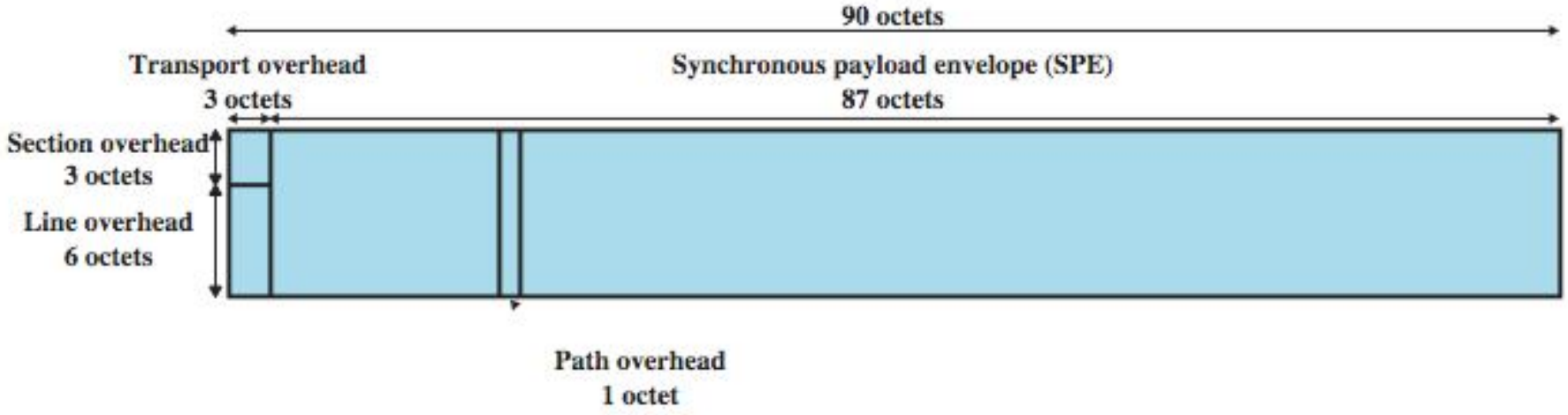
Notes:

1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
   - 8-bit PCM used on five of six frames.
   - 7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
   - Channel 24 is used for signaling only in some schemes.
   - Bits 1-7 used for 56 kbps service
   - Bits 2-7 used for 9.6, 4.8, and 2.4 kbps service.

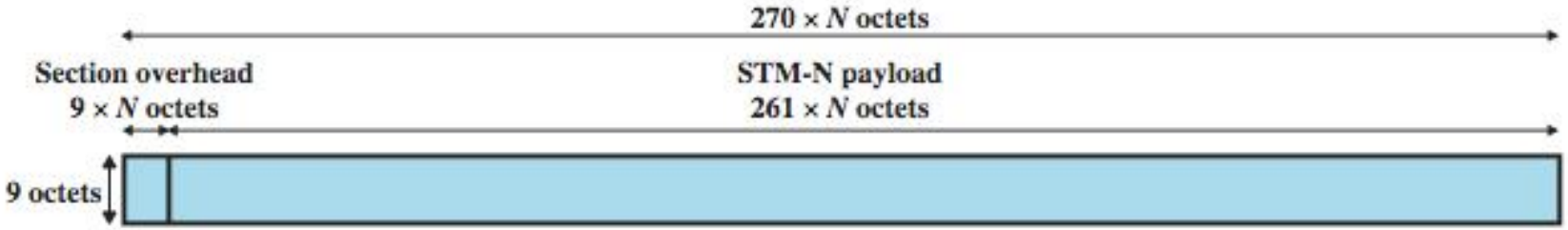
SONET / SDH

- Synchronous Optical Network (SONET) standardized by American National Standards Institute (ANSI)
- Synchronous Digital Hierarchy (SDH) standardized by the ITU-T (international)
- Have hierarchy of signal rates
  - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) is 51.84Mbps
  - multiple STS-1 combine into STS-N signal
  - STS-3 data rate =3* 51.84Mbps=155.52Mbps
  - ITU-T lowest rate is 155.52Mbps (STM-1)

SONET Frame Format



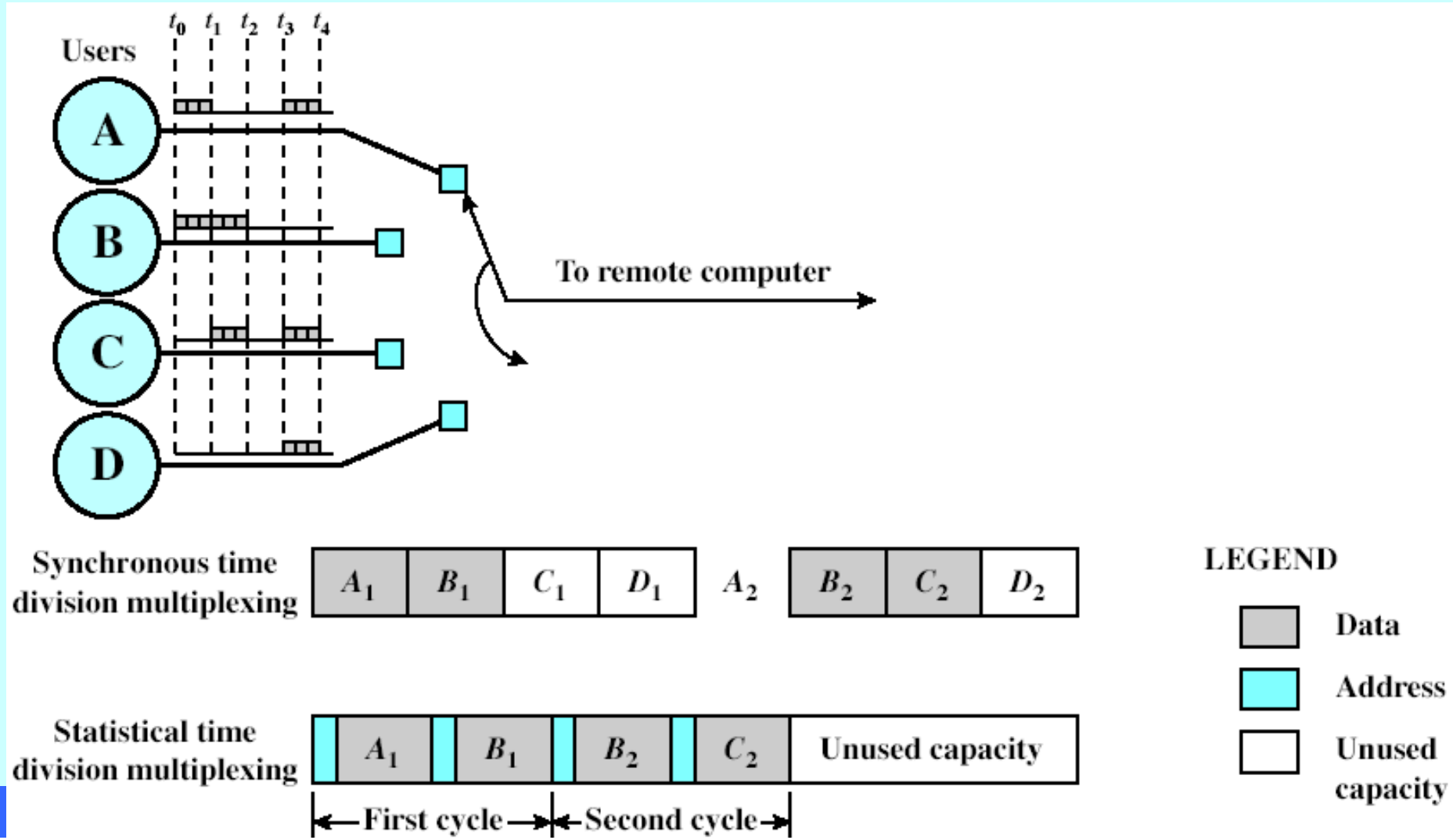
(a) STS-1 frame format



(b) STM-N frame format

Statistical TDM

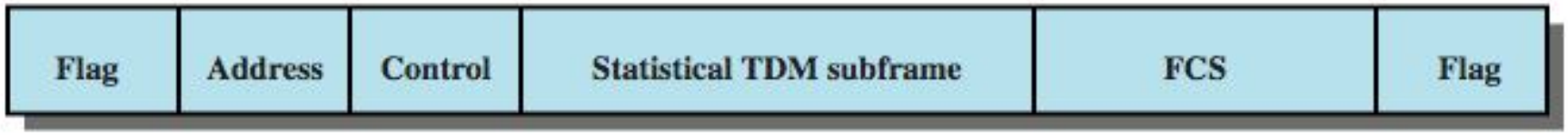
- In synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically, on demand



Statistical TDM

- Multiplexer scans input lines and collects data until frame full
- Line data rate lower than input lines rates
- Overhead per slot for statistical TDM because each slot carries an address as well as data
- May have problems during peak periods
  - must buffer inputs

Statistical TDM Frame Format



(a) Overall frame

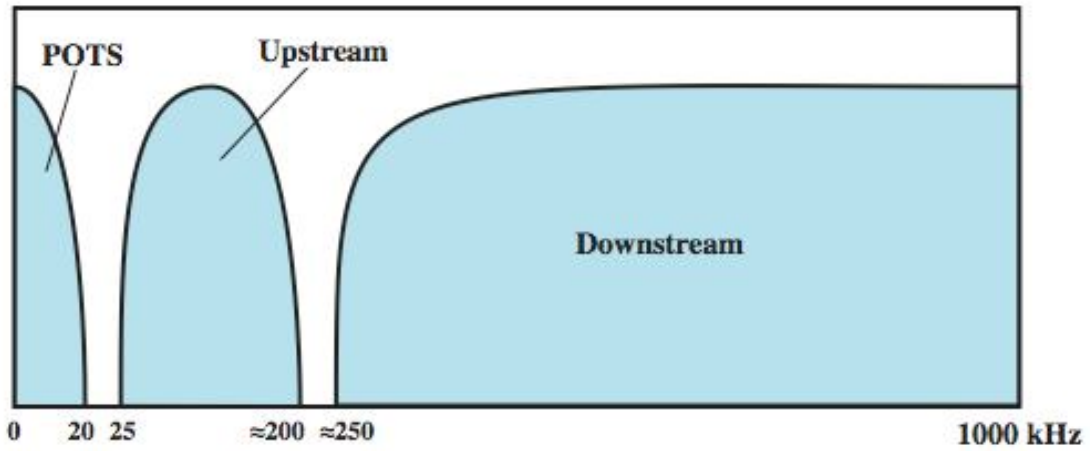
(b) Subframe with one source per frame

(c) Subframe with multiple sources per frame

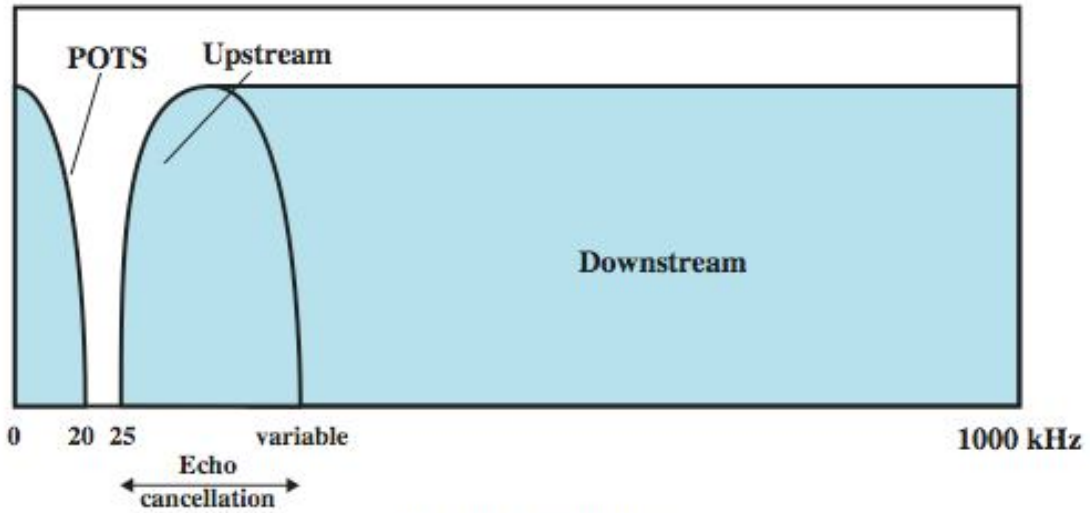
Asymmetric Digital Subscriber Lines (ADSL)

- Link between subscriber and network
- Uses currently installed twisted pair cable
- Is Asymmetric - bigger downstream than upstream
- Uses Frequency division multiplexing
  - reserve lowest 25kHz for voice POTS (Plain Old Telephone Service
  - uses FDM or echo cancellation to support downstream and upstream data transmission
- Has a range of up to 5.5km

ADSL Channel Configuration



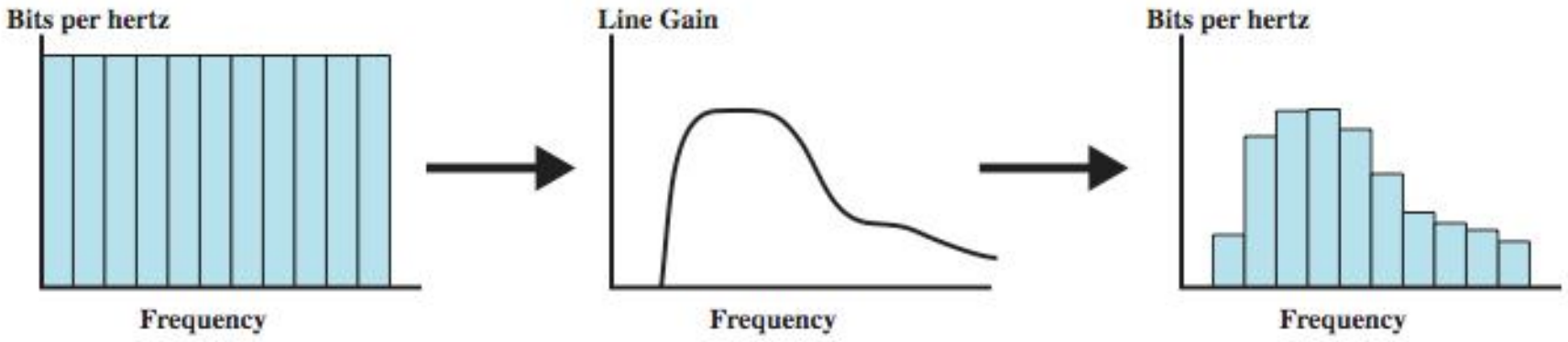
(a) Frequency-division multiplexing



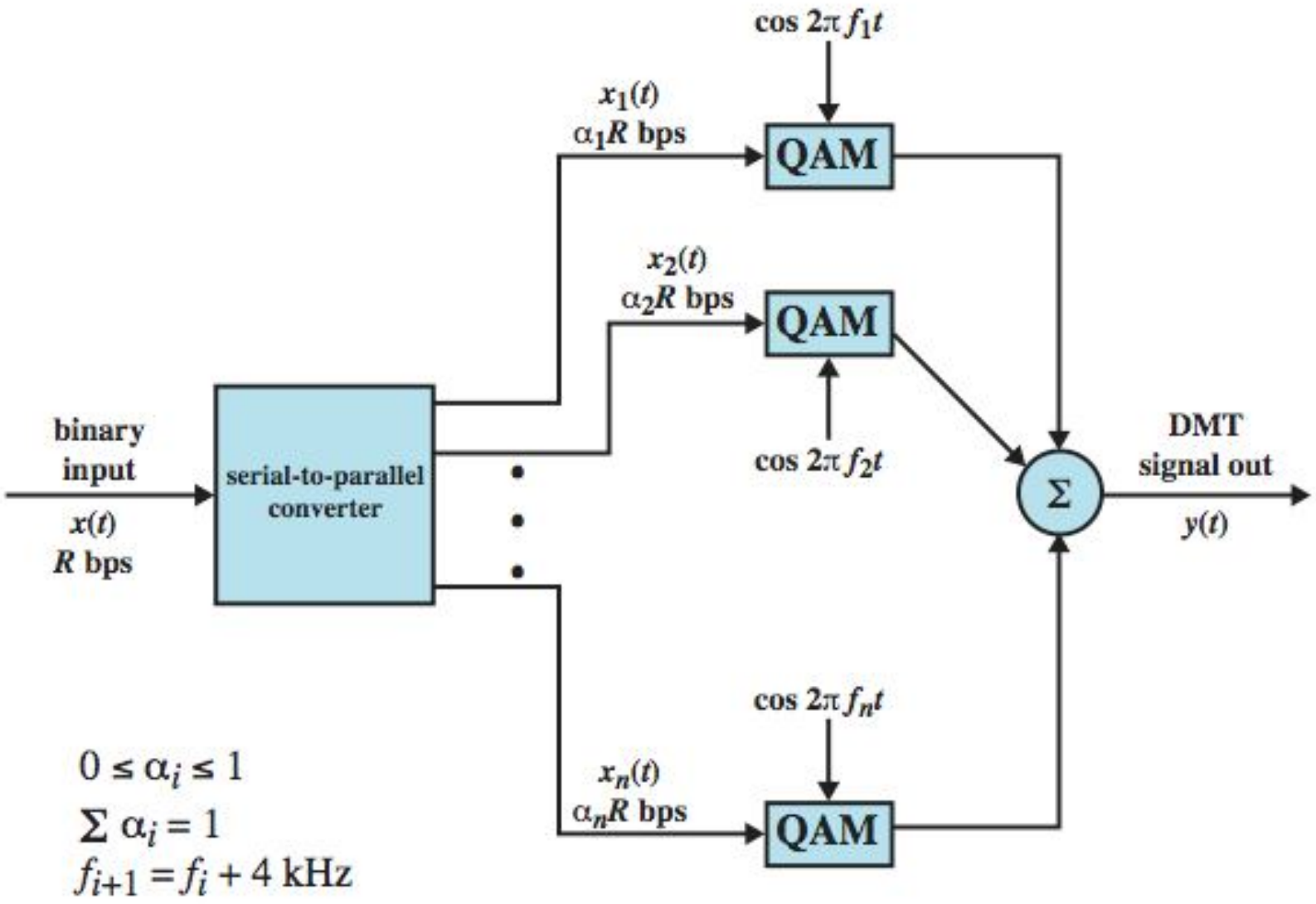
(b) Echo cancellation

Discrete Multi-Tone (DMT)

- DMT Modulation used in ADSL
- Multiple carrier signals at different frequencies
- Divide into 4kHz sub-channels
- Test and use subchannels with better SNR
- Present ADSL/DMT designs employ 256 downstream subchannels at 4kHz (60kbps)
  - in theory 15.36Mbps, in practice 1.5-9Mbps



Discrete Multi-Tone (DMT) Transmitter



xDSL

- High data rate DSL (HDSL)
  - 2B1Q coding on dual twisted pairs(upstream & downstream)
  - up to 2Mbps over 3.7km
- Single line DSL (SDSL)
  - 2B1Q coding on single twisted pair (residential)
  - echo cancelling to separate upstream and downstream
  - up to 2Mbps over 3.7km
- Very high data rate DSL (VDSL)
  - DMT/QAM for very high data rates
  - separate bands for separate services
    - POTS: 0-4KHz
    - ISND: 4-80KHz
    - Upstream: 300-700KHz
    - Downstream: >1MHz

Comparison of xDSL Alternatives

	ADSL	HDSL	SDSL	VDSL
Data rate	1.5 to 9 Mbps downstream 16 to 640 kbps upstream	1.544 or 2.048 Mbps	1.544 or 2.048 Mbps	13 to 52 Mbps downstream 1.5 to 2.3 Mbps upstream
Mode	Asymmetric	Symmetric	Symmetric	Asymmetric
Copper pairs	1	2	1	1
Range (24-gauge UTP)	3.7 to 5.5 km	3.7 km	3.0 km	1.4 km
Signaling	Analog	Digital	Digital	Analog
Line code	CAP/DMT	2B1Q	2B1Q	DMT
Frequency	1 to 5 MHz	196 kHz	196 kHz	≥ 10 MHz
Bits/cycle	Varies	4	4	Varies