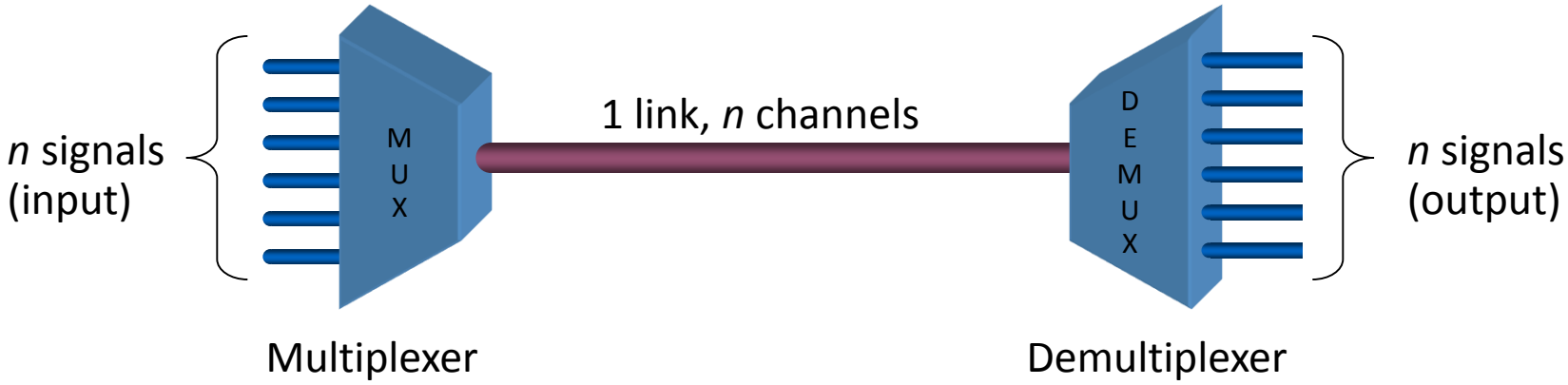
Multiplexing

Sharing Medium

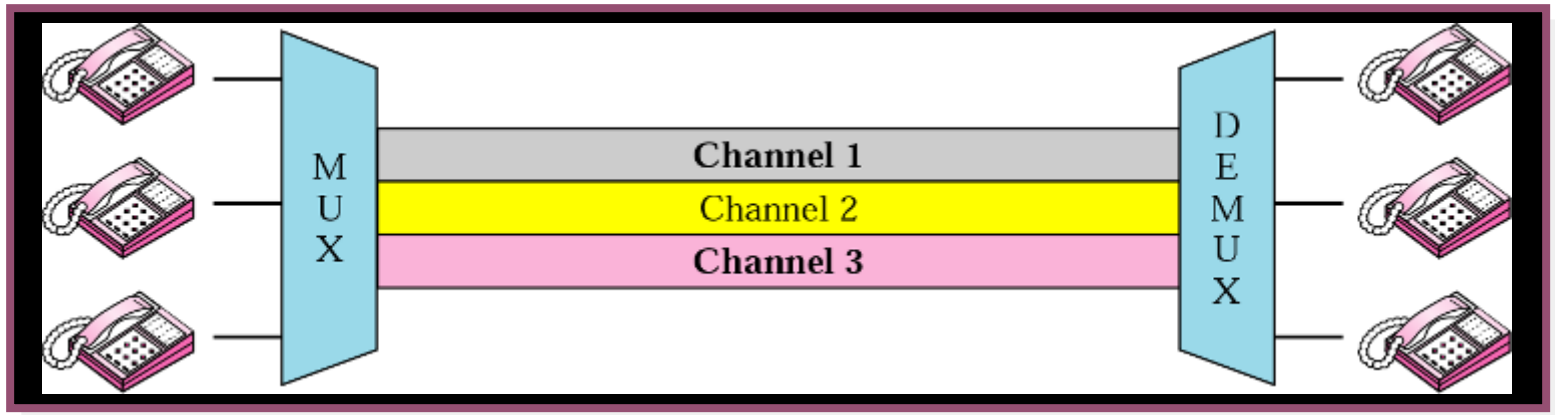
- A link is divided into channels

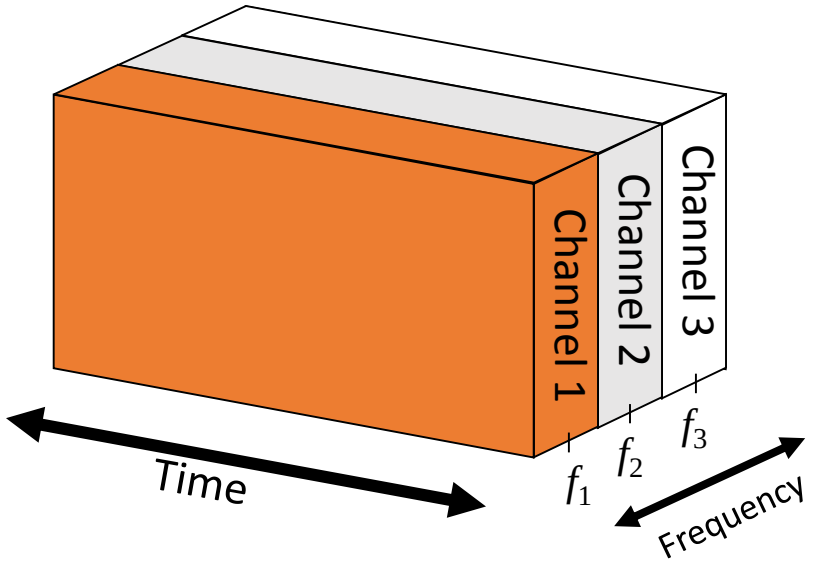


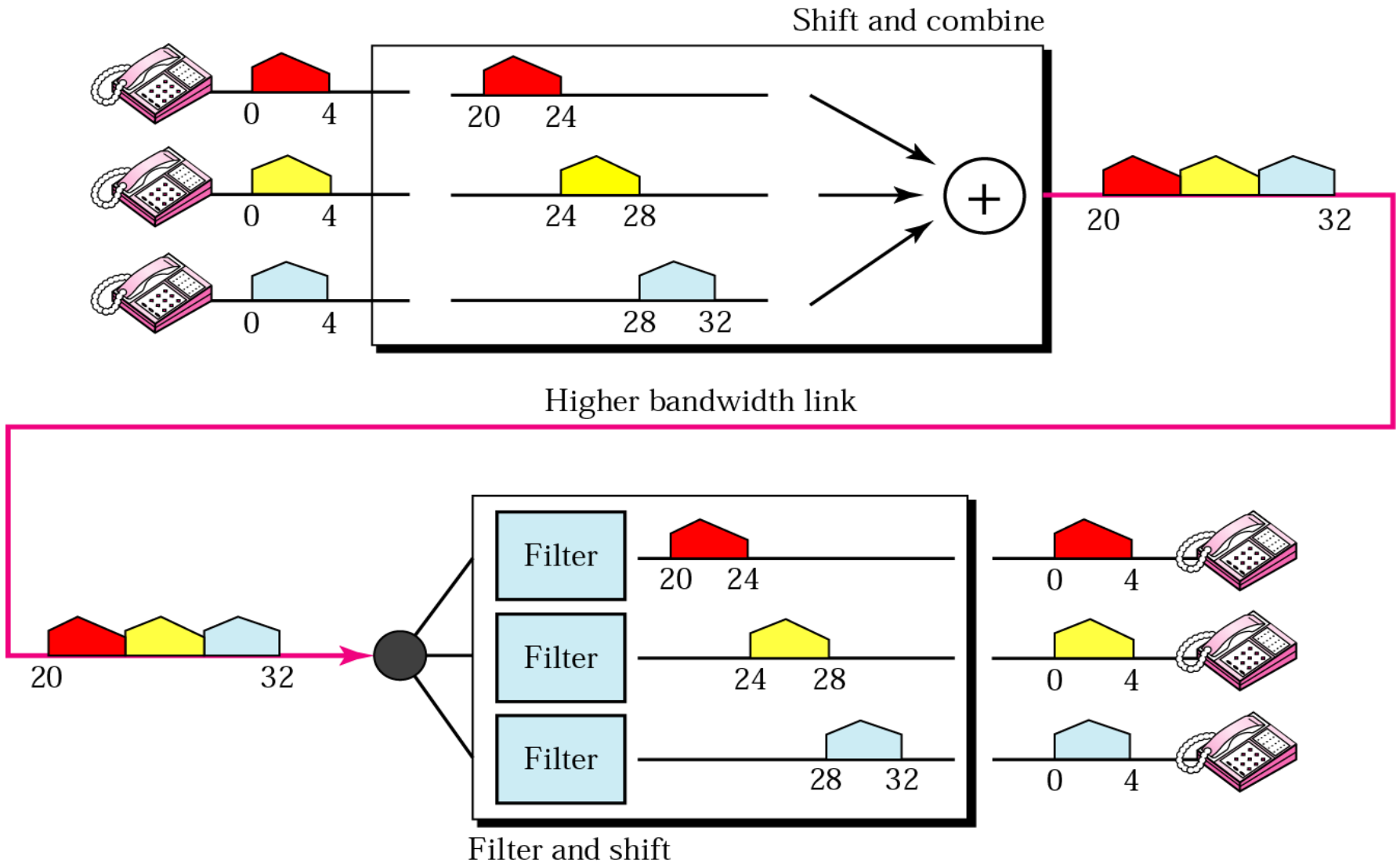
Frequency Division Multiplexing (FDM)

- An analog multiplexing technique to combine signals
- Medium BW > Channel BW
- Each signal is modulated to a different carrier frequency
- E.g., broadcast radio
- Channel allocated even if no data

Conceptual View of FDM

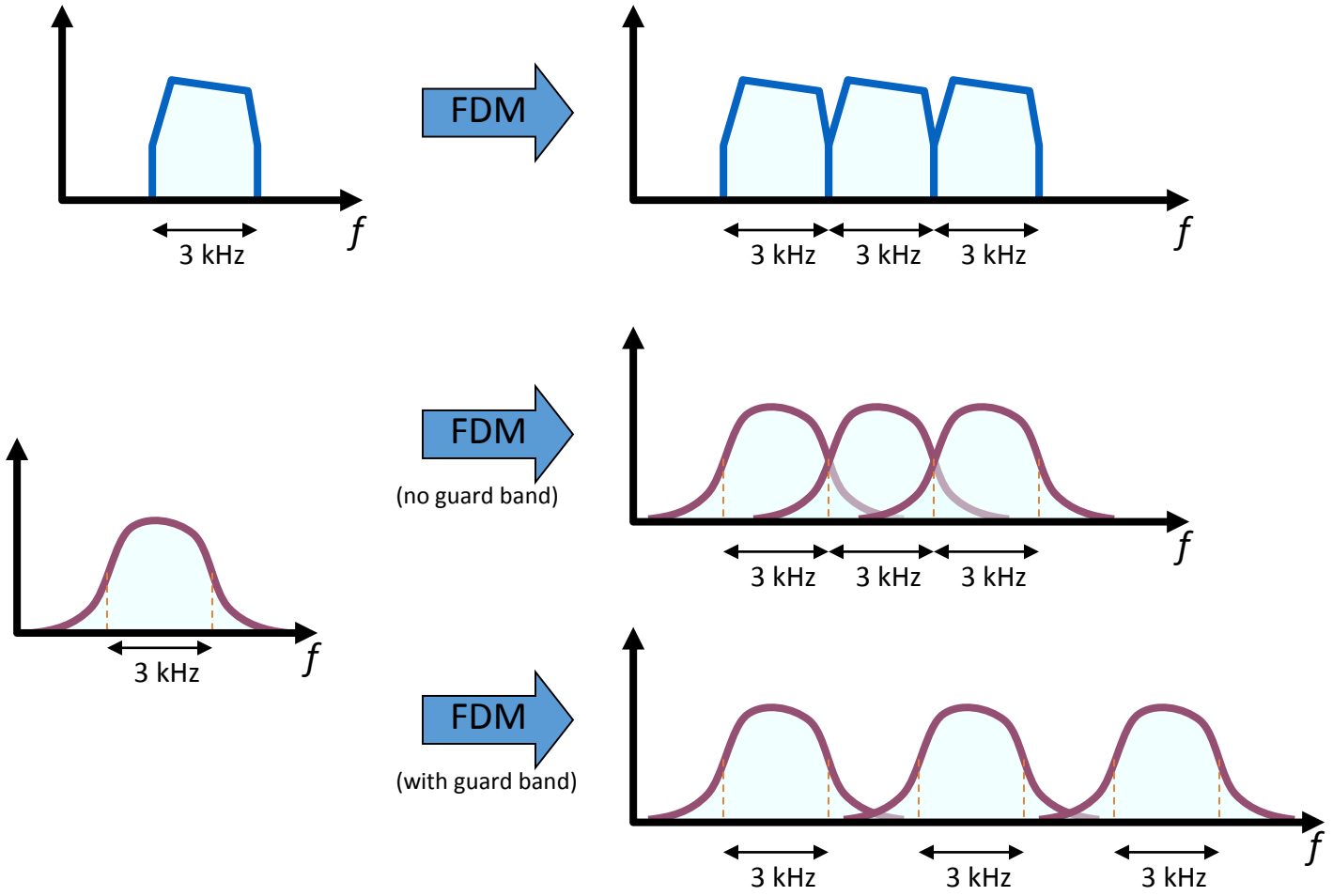





Shift and combine
0
4
20
24
0
4
24
28
0
4
28
32
20
32
Higher bandwidth link
20
32
Filter
Filter
Filter
20
24
24
28
28
32
0
4
0
4
0
4
Filter and shift

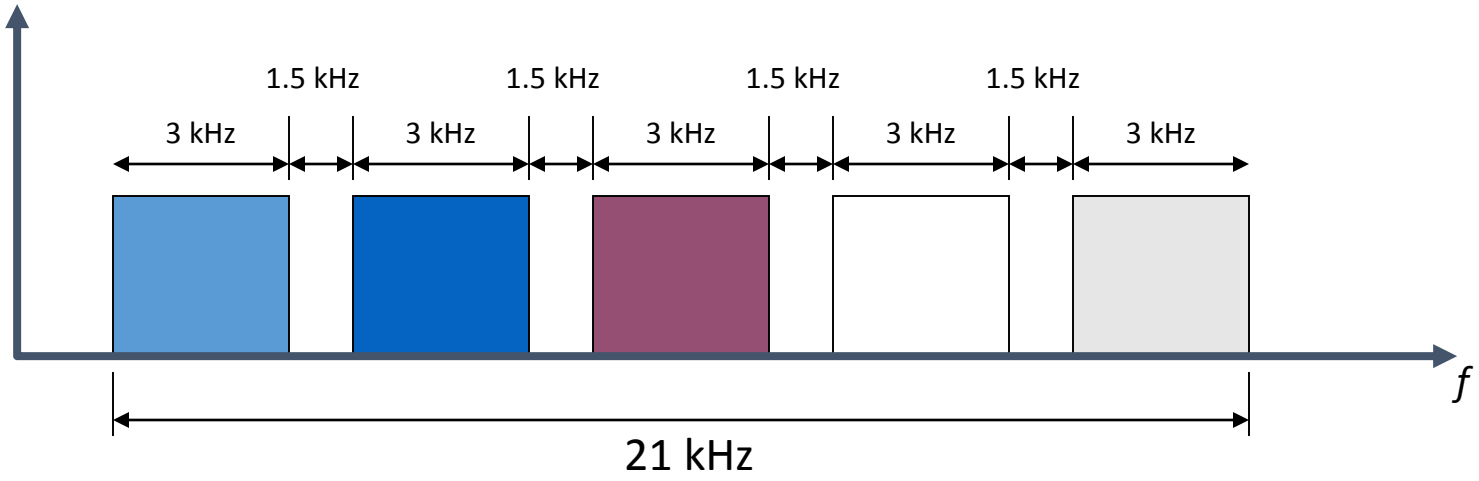
Guard Bands

- Strips of unused bandwidth to prevent signals from overlapping

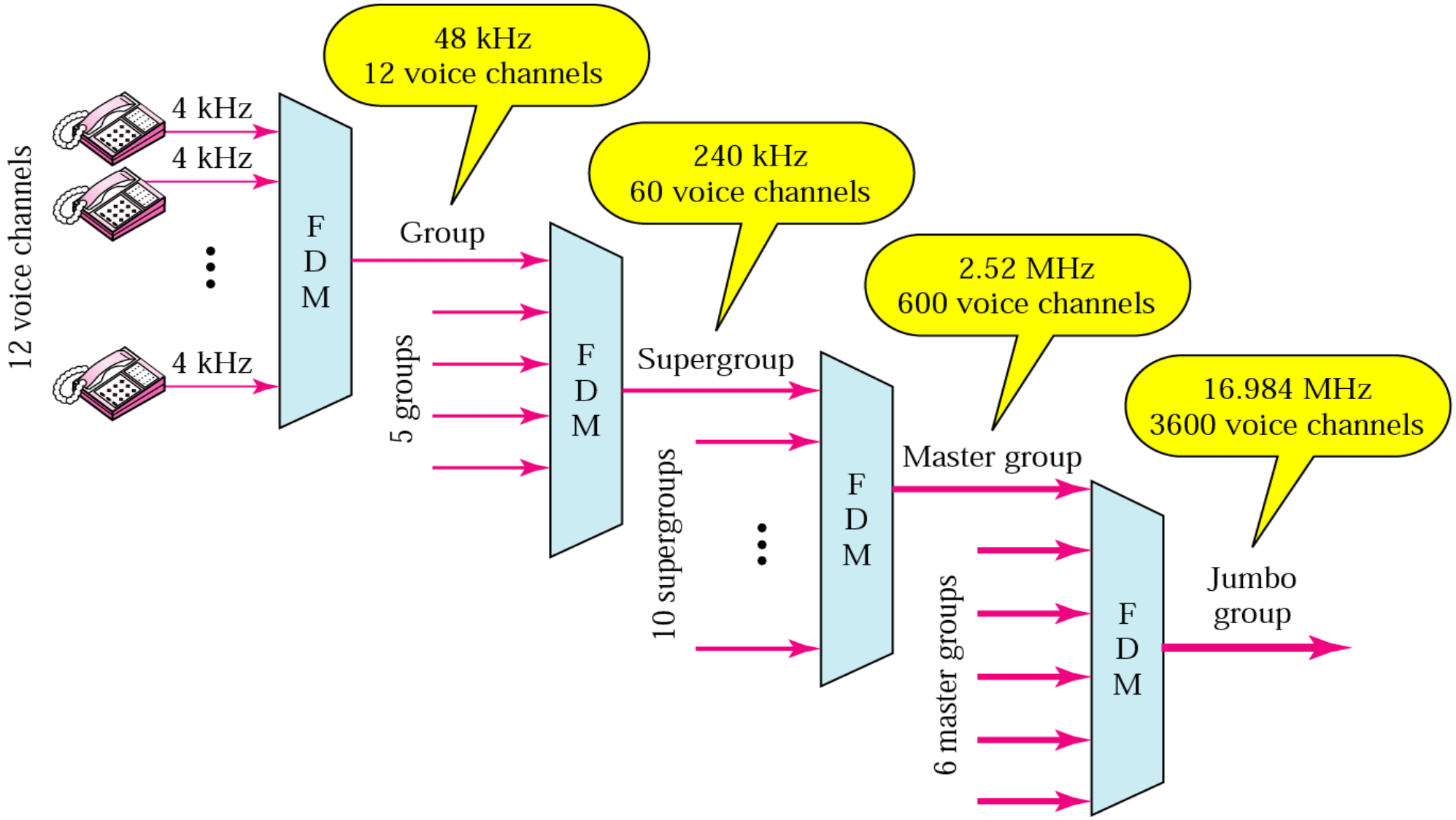


FDM: *Example 1*

Five voice channels, each with 3-kHz bandwidth, are to be multiplexed together.
If there is a need for a guard band of 1.5 kHz, what is the minimum bandwidth of the link?

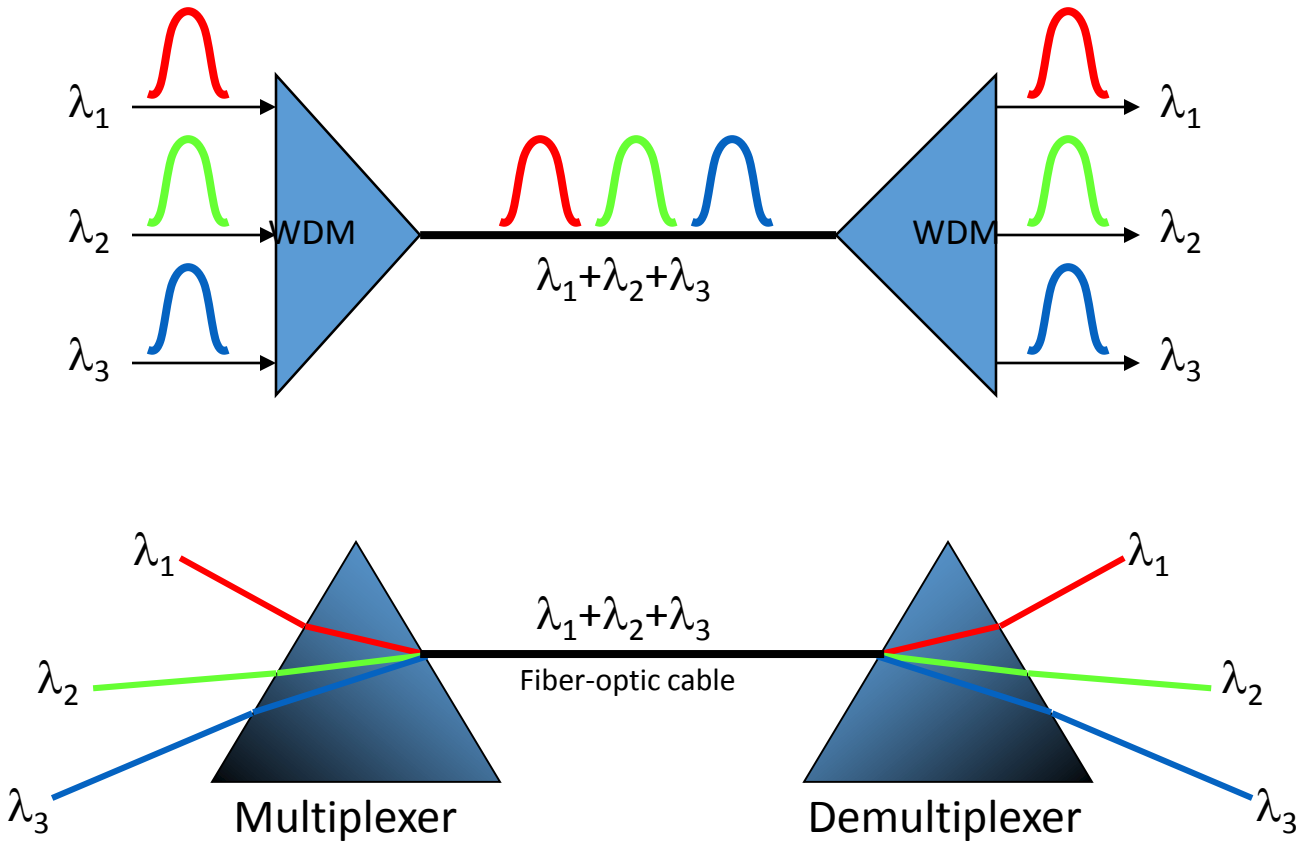


FDM Carrier Standards in Telephone Network



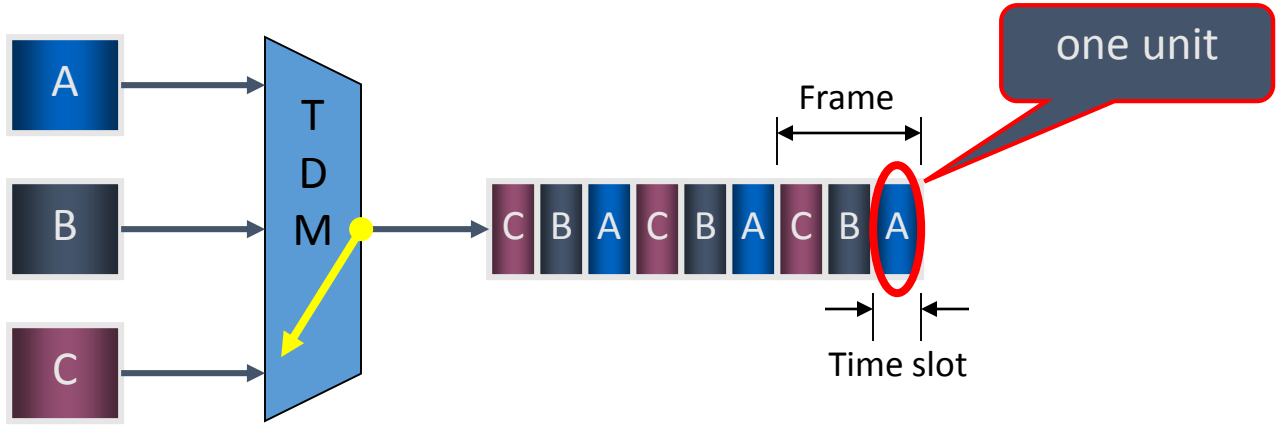
Wavelength Division Multiplexing (WDM)

- WDM is a special case of FDM used for optical signals



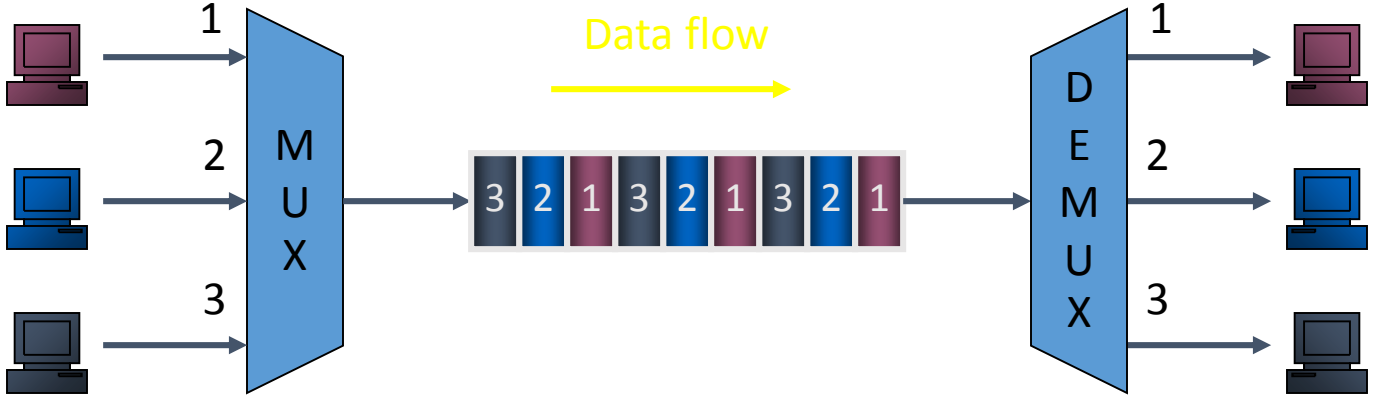
Time Division Multiplexing (TDM)

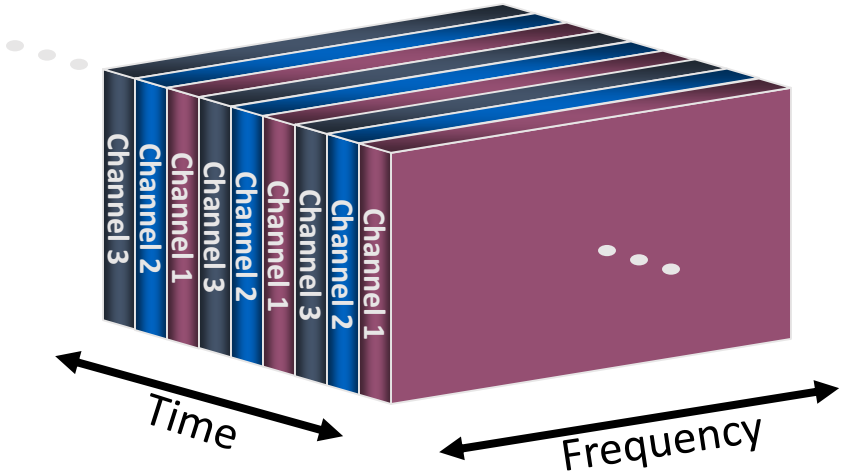
- A Digital multiplexing technique to combine data
- Medium Data Rate > Signal Data Rate
- Multiple digital signals interleaved in time



- Time slots
  - are preassigned to sources and fixed
  - are allocated even if no data
  - do not have to be evenly distributed among sources

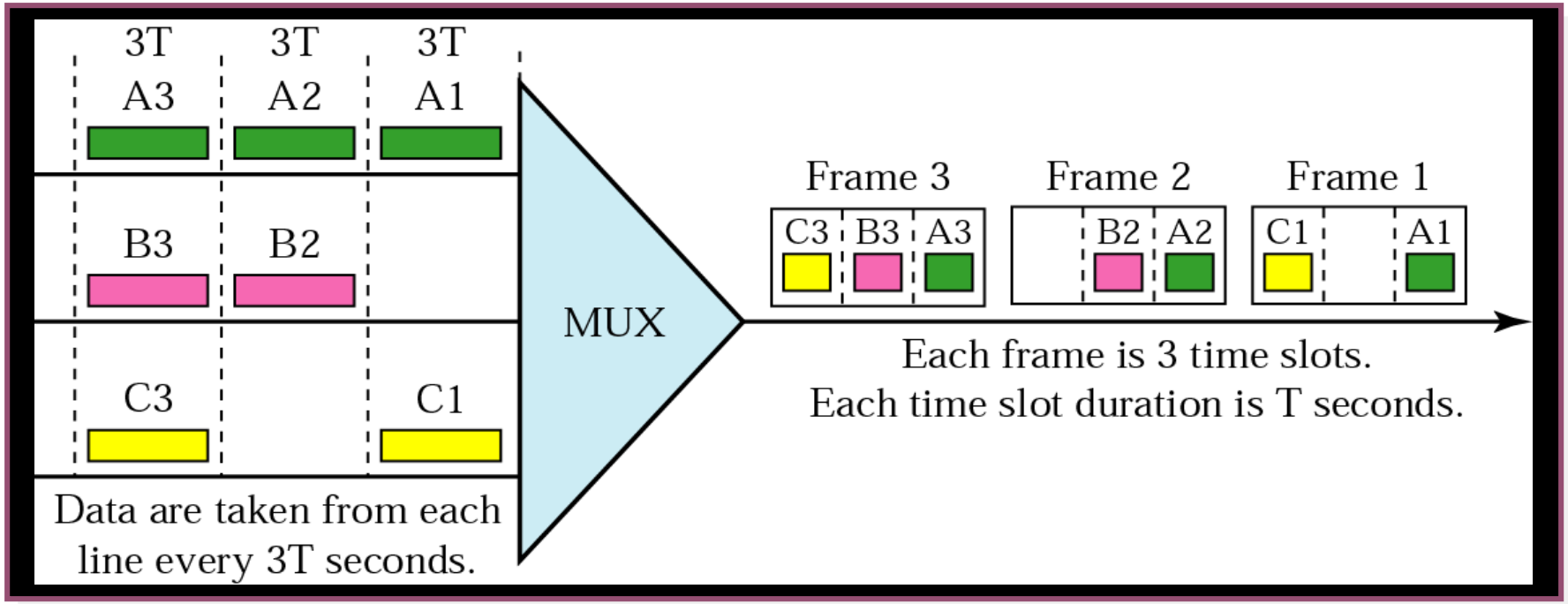
Conceptual View of TDM



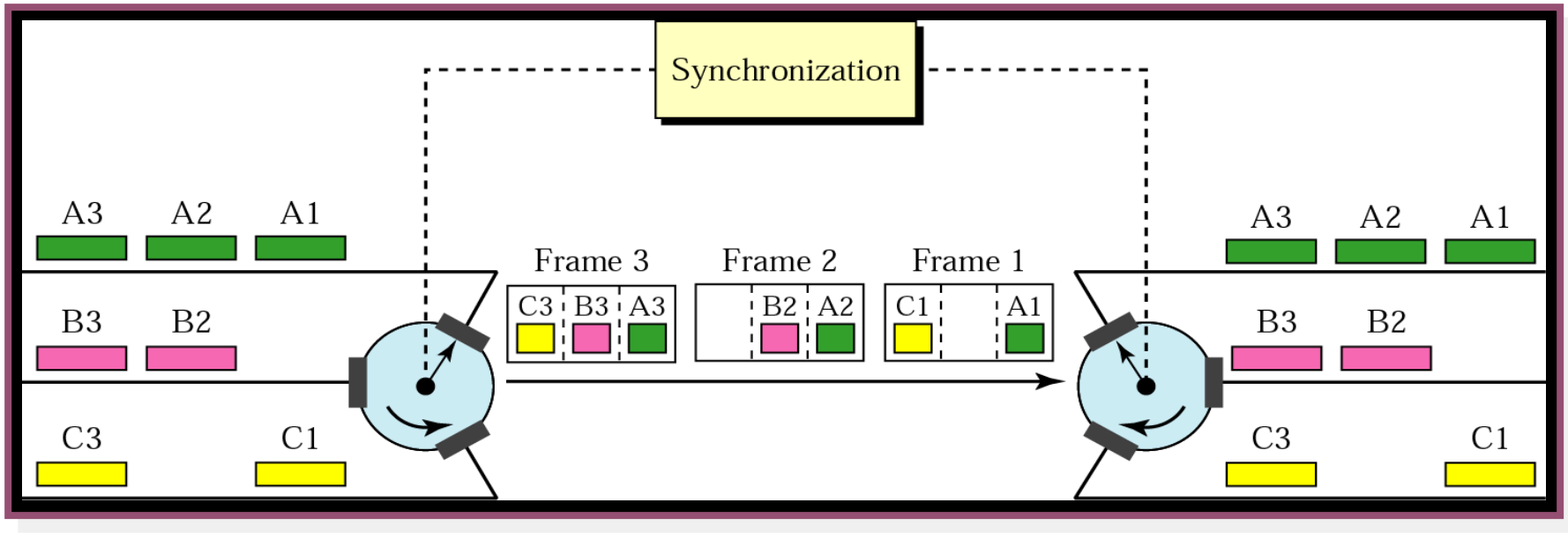


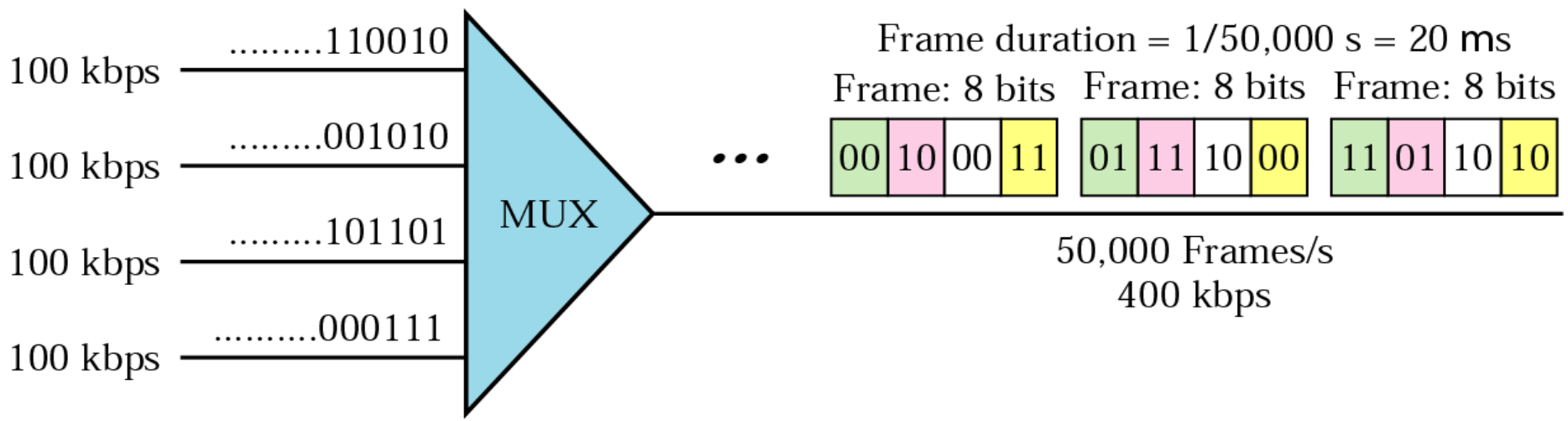
TDM Frames

- A frame consists of one complete cycle of time slots



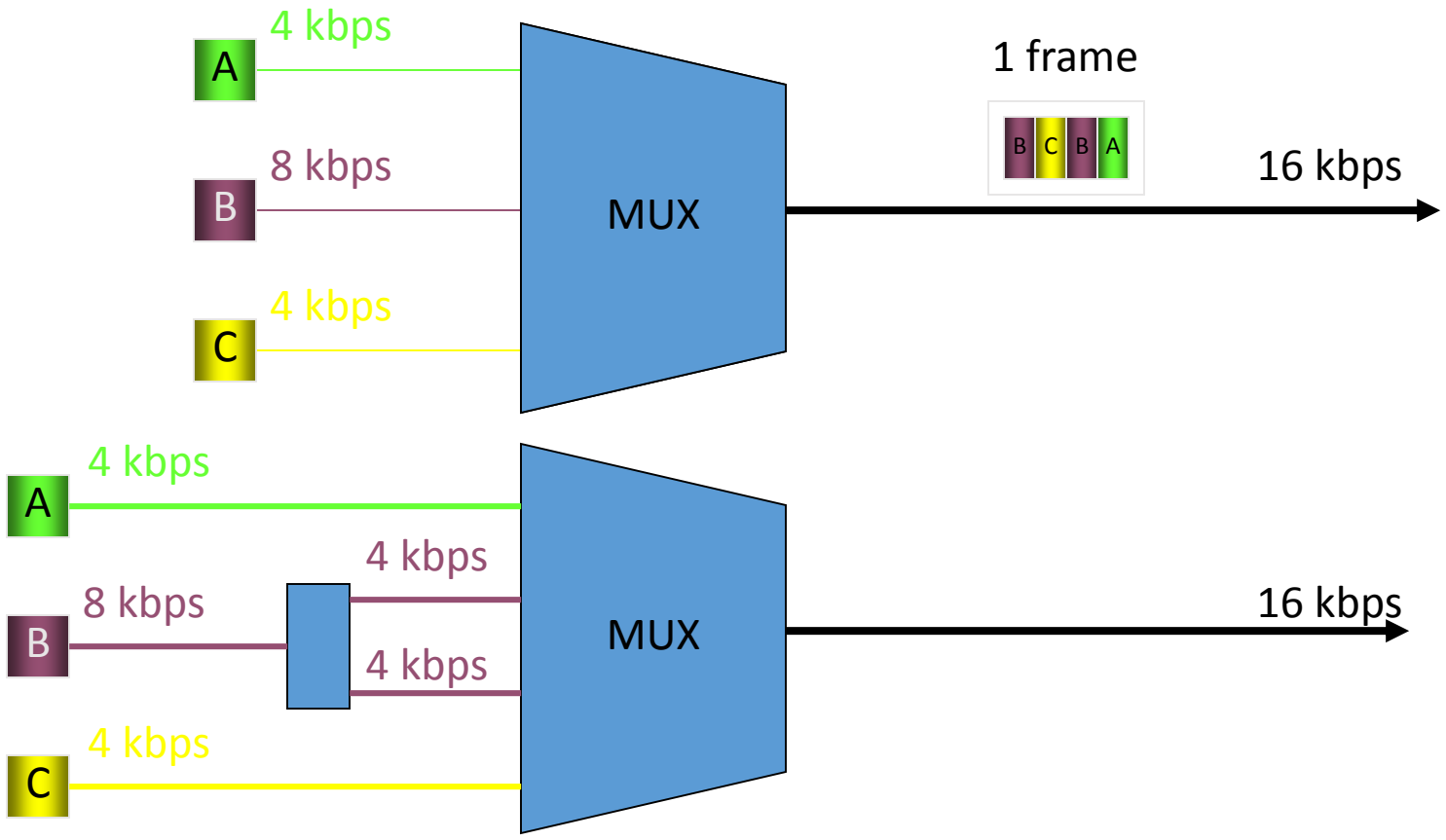
Empty Slot


Synchronization
A3
A2
A1
B3
B2
C3
C1
Frame 3
C3
B3
A3
Frame 2
B2
A2
Frame 1
C1
A1
A3
A2
A1
B3
B2
C3
C1


100 kbps
.....110010
100 kbps
.....001010
100 kbps
.....101101
100 kbps
.....000111
MUX
Frame duration = 1/50,000 s = 20 ms
Frame: 8 bits
Frame: 8 bits
Frame: 8 bits
00 10 00 11
01 11 10 00
11 01 10 10
50,000 Frames/s
400 kbps

TDM of Different Data Rates

- Data rate from one source may be faster than the others
- More than one time slot can be assigned to certain sources



Note: assume 1 unit = 1 bit

TDM Link Control

- no headers and trailers
- data link control protocols not needed
- flow control
  - data rate of multiplexed line is fixed
  - if one channel receiver can not receive data, the others must carry on
  - corresponding source must be quenched
- error control
  - errors detected & handled on individual channel

Data Link Control on TDM

(a) Configuration

Input$_1$ ••••••••••• F_1 f_1 f_1 d_1 d_1 d_1 C_1 A_1 F_1 f_1 f_1 d_1 d_1 d_1 C_1 A_1 F_1

Input$_2$ ••• F_2 f_2 f_2 d_2 d_2 d_2 d_2 C_2 A_2 F_2 f_2 f_2 d_2 d_2 d_2 d_2 C_2 A_2 F_2

(b) Input data streams

••• f_2 F_1 d_2 f_1 d_2 f_1 d_2 d_1 d_2 d_1 C_2 d_1 A_2 C_1 F_2 A_1 f_2 F_1 f_2 f_1 d_2 f_1 d_2 d_1 d_2 d_1 d_2 d_1 C_2 C_1 A_2 A_1 F_2 F_1

(c) Multiplexed data stream

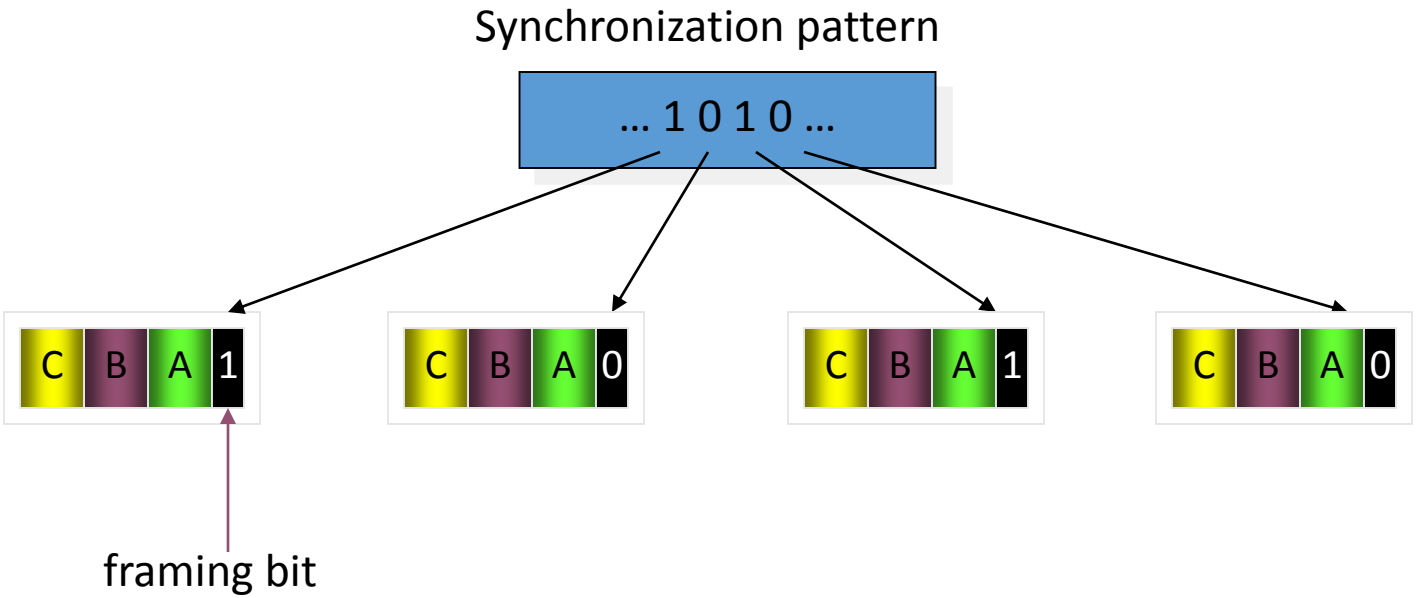
Legend: F = flag field; d = one octet of data field
A = address field; f = one octet of FCS field
C = control field

Framing

- no flag or SYNC chars bracketing TDM frames
- must still provide synchronizing mechanism between src and dest clocks
- added digit framing
  - one control bit added to each TDM frame
  - identifiable bit pattern used on control channel
  - eg. alternating 01010101…unlikely on a data channel
- frame search mode
  - compare incoming bit patterns on each channel with known sync pattern

Synchronization

- Multiplexer and demultiplexer must be synchronized
- Framing bits are used to provide synchronization



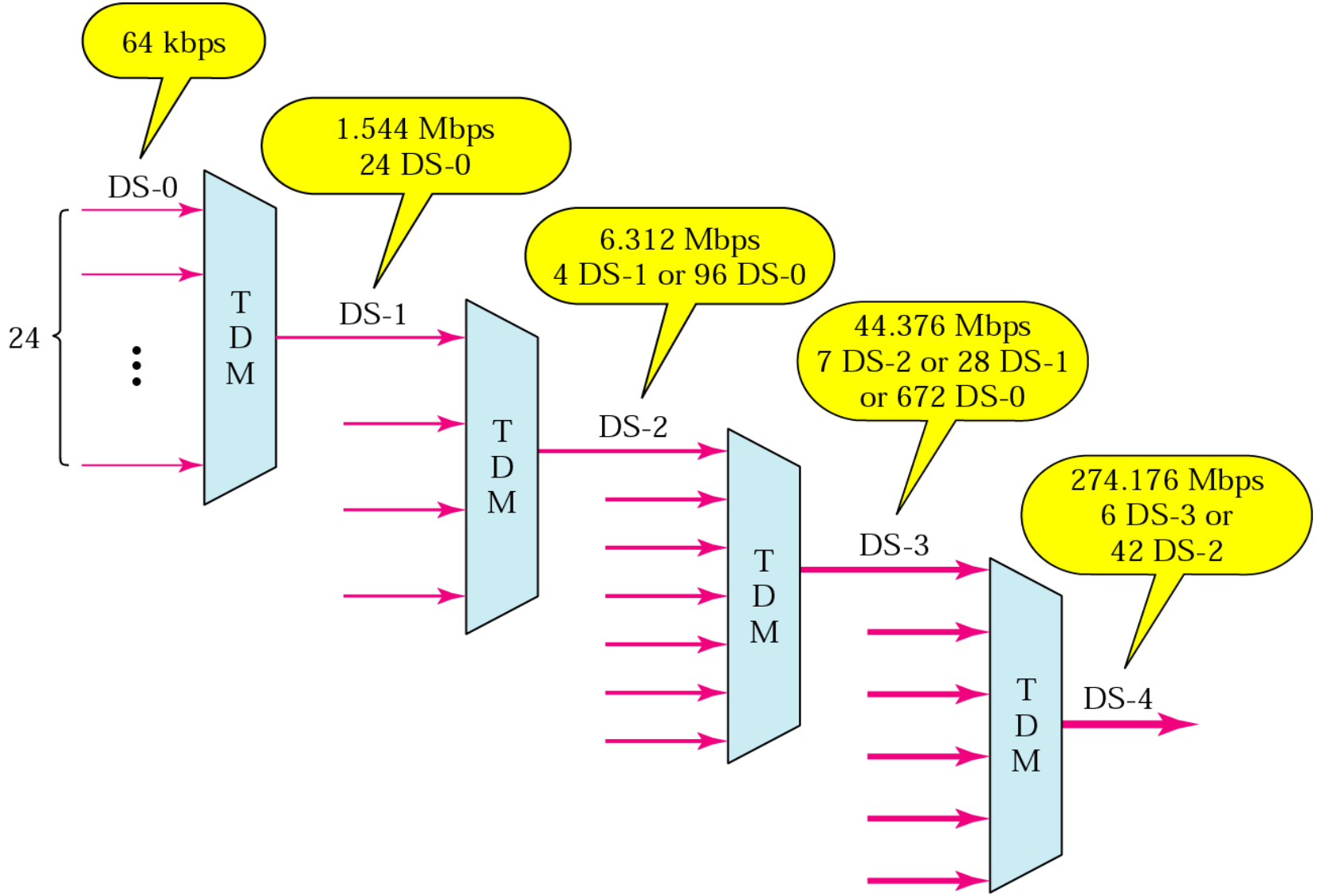
Pulse Stuffing

- have problem of synchronizing data sources
- also issue of data rates from different sources not related by simple rational number
- Pulse Stuffing a common solution
  - 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

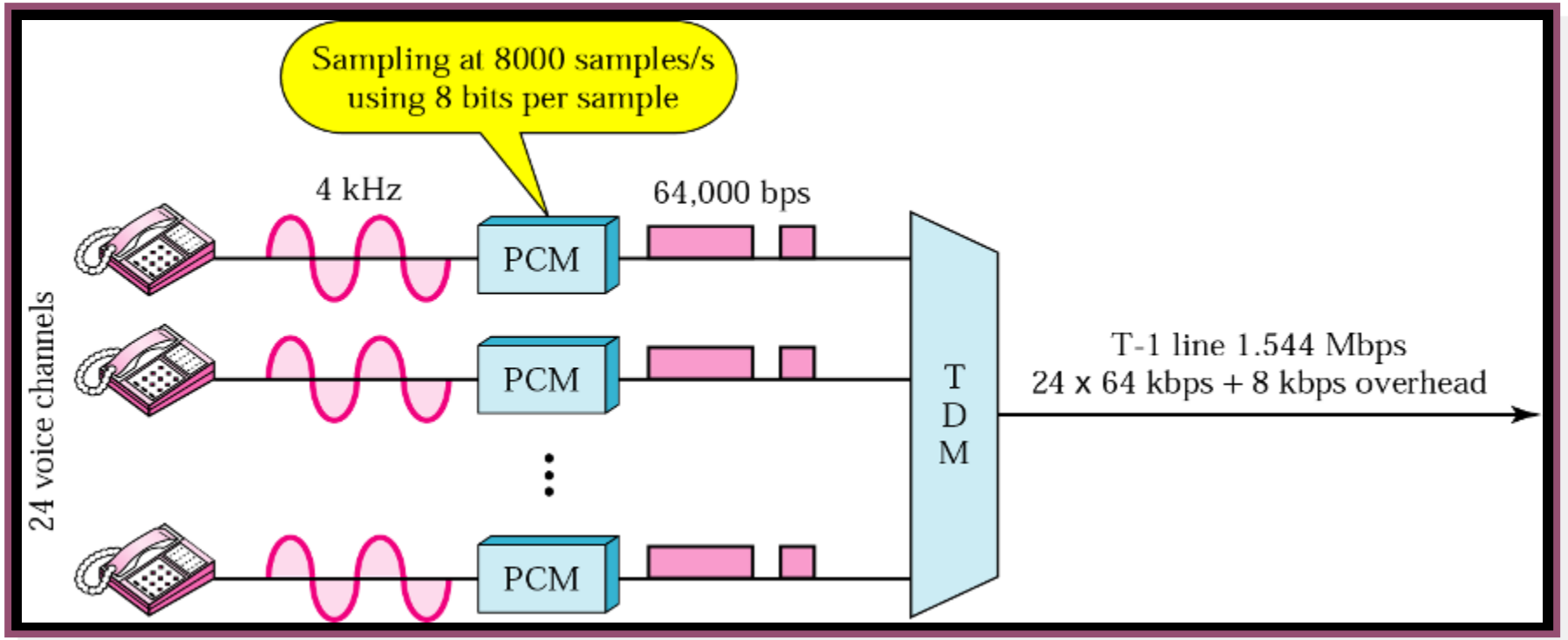
Digital Carrier Systems

- long-distance links use an TDM hierarchy
- AT&T (USA) and ITU-T (International) variants
- US system based on DS-1 format
- can carry mixed voice and data signals
- 24 channels used for total data rate 1.544Mbps
- each voice channel contains one word of digitized data (PCM, 8000 samples per sec)
- same format for 56kbps digital data
- can interleave DS-1 channels for higher rates
  - DS-2 is four DS-1 at 6.312Mbps

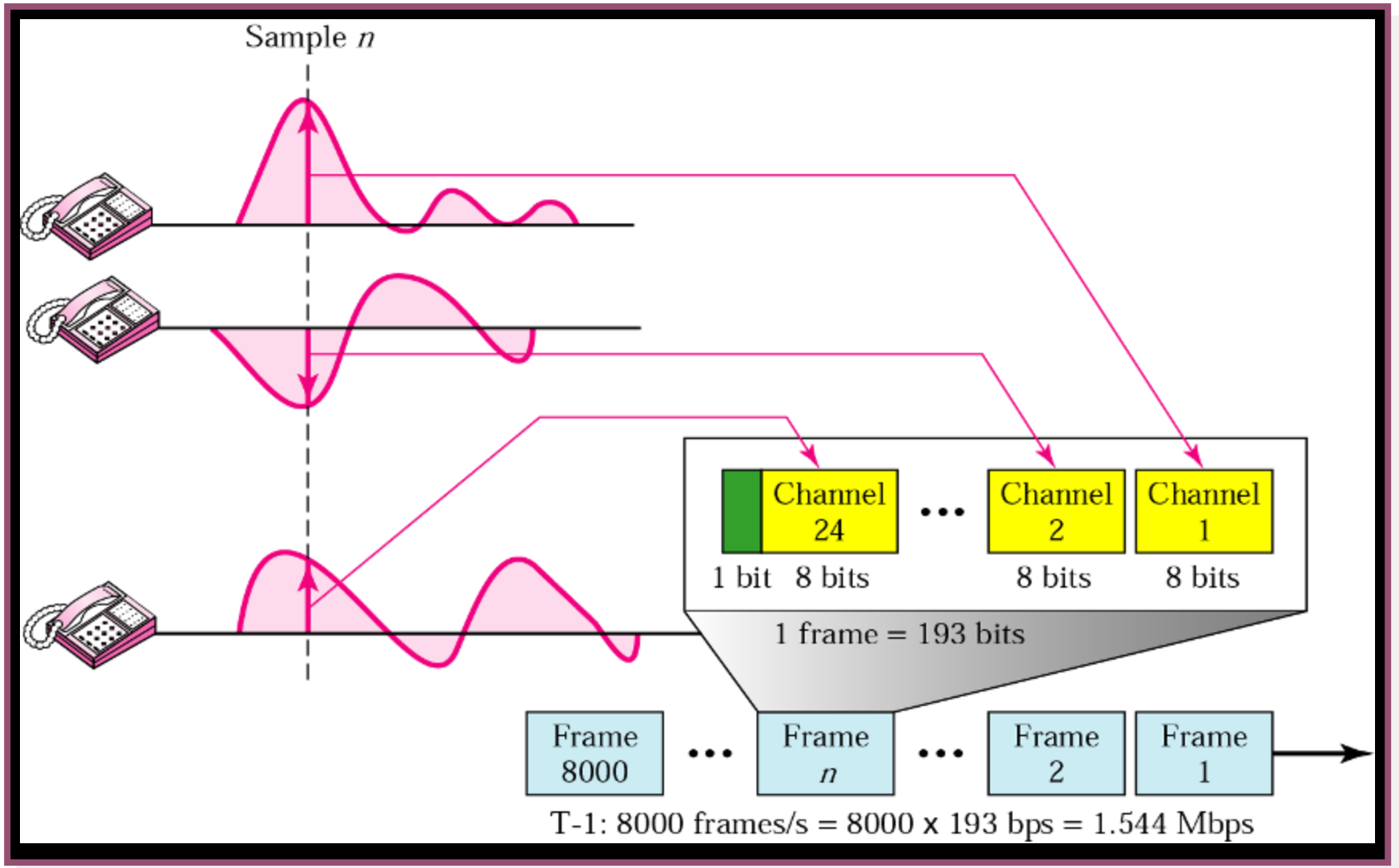
Digital Signal (DS) Hierarchy



T Lines and Analog Signals



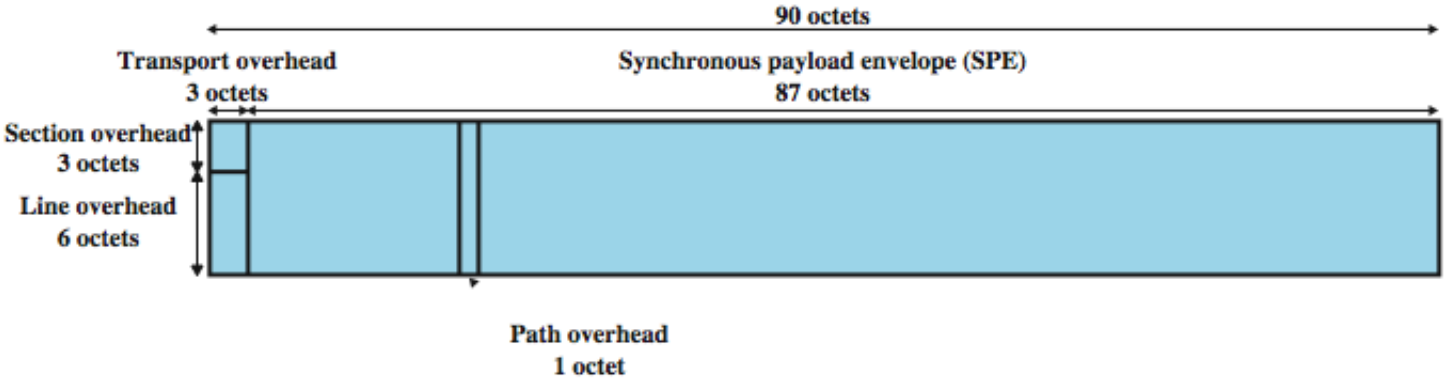
T-1 Frame Structure



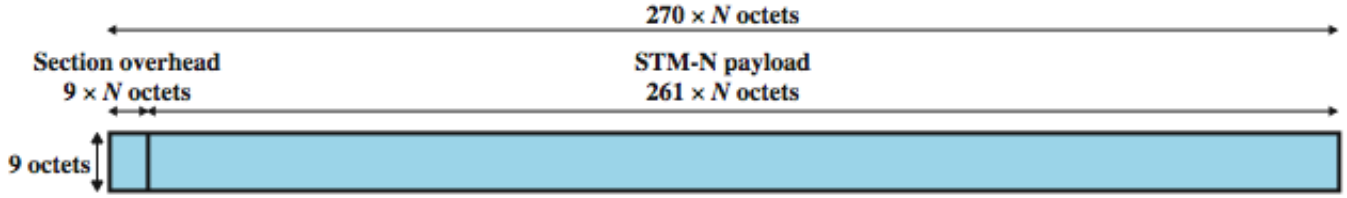
SONET/SDH

- Synchronous Optical Network (ANSI)
- Synchronous Digital Hierarchy (ITU-T)
- have hierarchy of signal rates
  - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) is 51.84Mbps
  - carries one DS-3 or multiple (DS1 DS1C DS2) plus ITU-T rates (eg. 2.048Mbps)
  - multiple STS-1 combine into STS-N signal
- Each frame of 810 bytes sent every 125 microsec.
- 9 rows of 90 octets
  - 27 octets reserved for overhead

SONET Frame Format



(a) STS-1 frame format



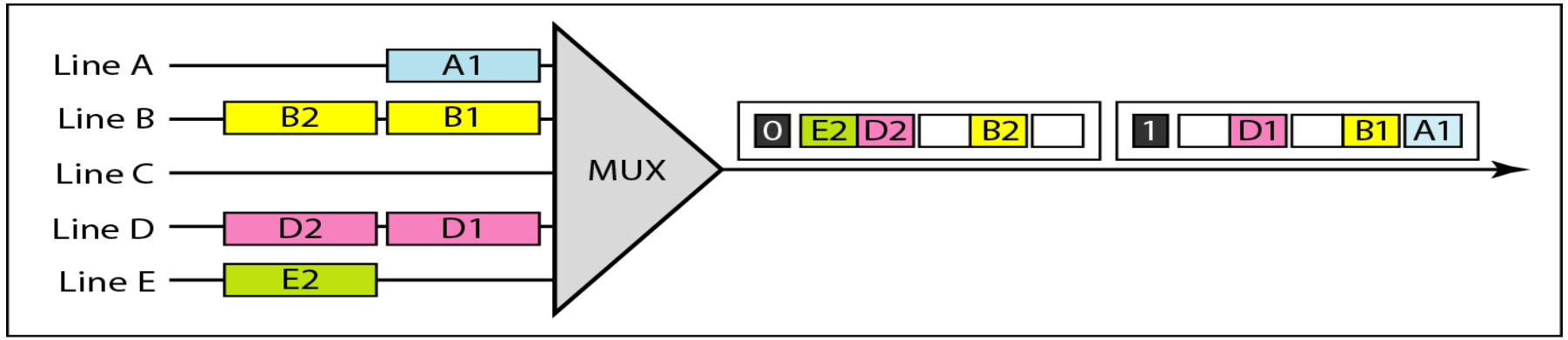
(b) STM-N frame format

Section: Between regenerators; Line: Between Mux and Demux; Path: Between SONET terminals

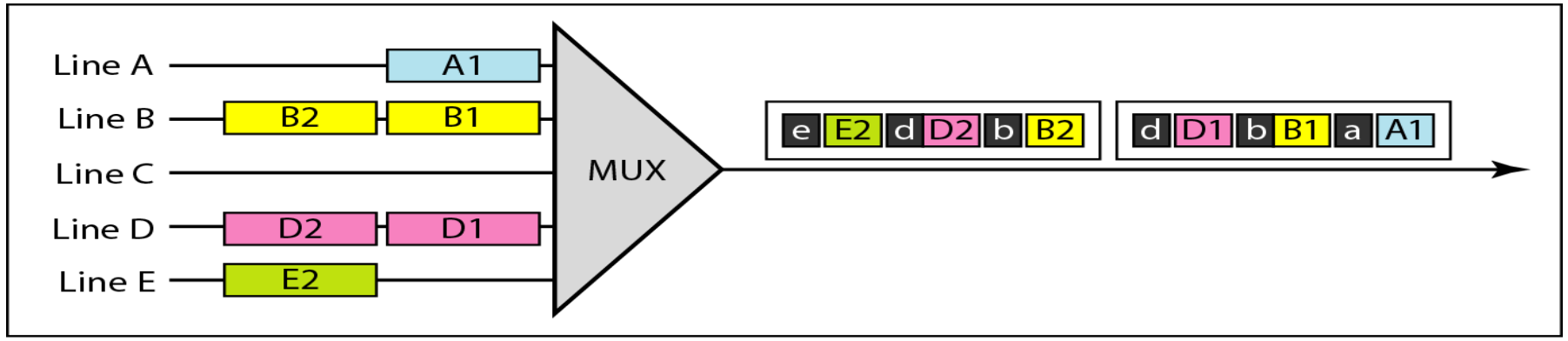
Statistical TDM

- synch TDM many slots are wasted
- statistical TDM allocates time slots dynamically based on demand
- multiplexer scans input lines and collects data until frame full
- multiplexed line data rate lower than aggregate input line rates
- can support more users than sync TDM
- may have problems during peak periods
  - must buffer inputs

Synchronous vs Statistical TDM



a. Synchronous TDM

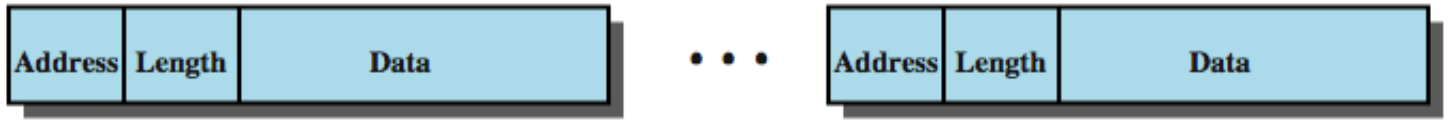


b. Statistical TDM

Statistical TDM Frame Format

(a) Overall frame

(b) Subframe with one source per frame

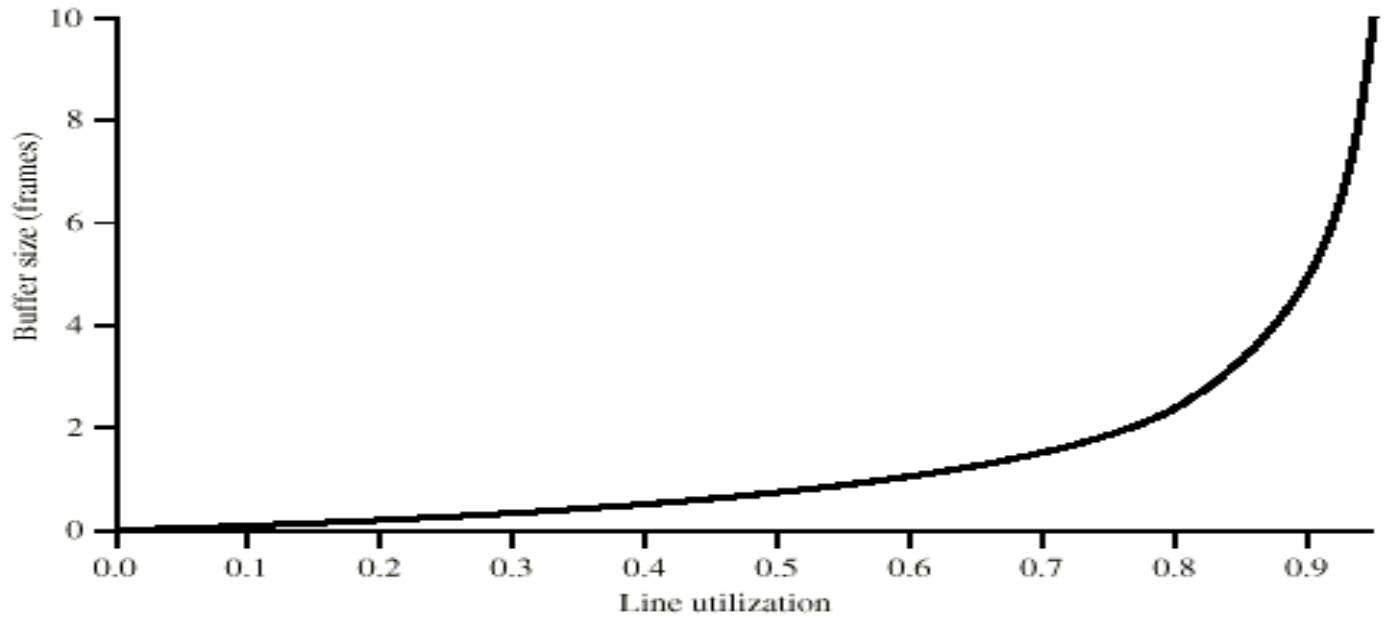


(c) Subframe with multiple sources per frame

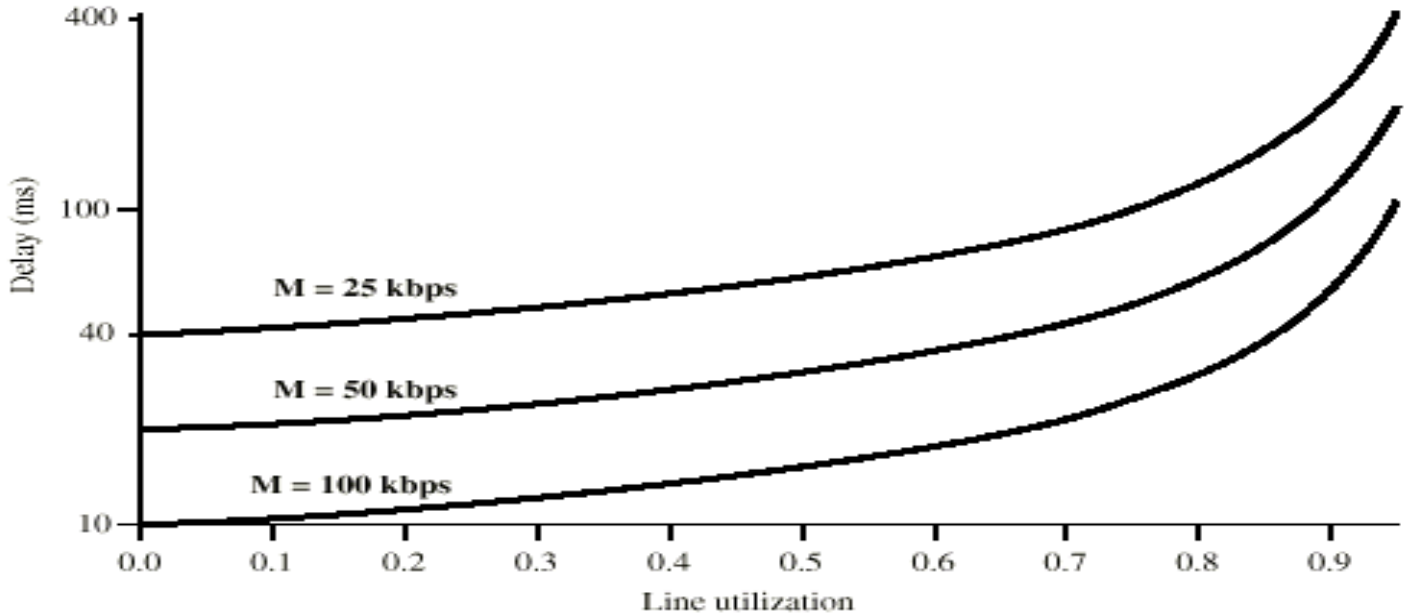
Performance

- Output data rate less than aggregate input rates
- May cause problems during peak periods
  - Buffer inputs
  - Keep buffer size to minimum to reduce delay
  - Queueing delay is random and makes end-to-end delay unpredictable
  - Packet losses occur when buffer is full

Buffer Size and Delay



(a) Mean buffer size versus utilization

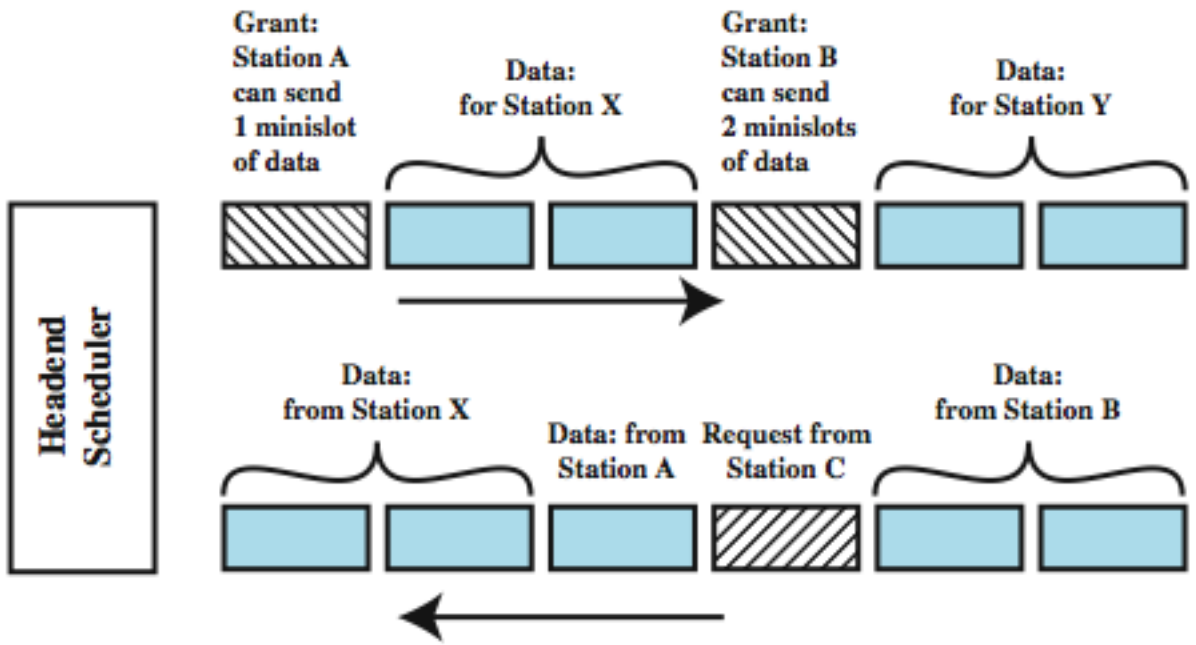


(a) Mean delay versus utilization

Cable Modems

- dedicate two cable TV channels to data transfer
- each channel shared by number of subscribers, using statistical TDM
- Downstream
  - cable scheduler delivers data in small packets
  - active subscribers share downstream capacity
  - also allocates upstream time slots to subscribers
- Upstream
  - user requests timeslots on shared upstream channel
  - Headend scheduler notifies subscriber of slots to use

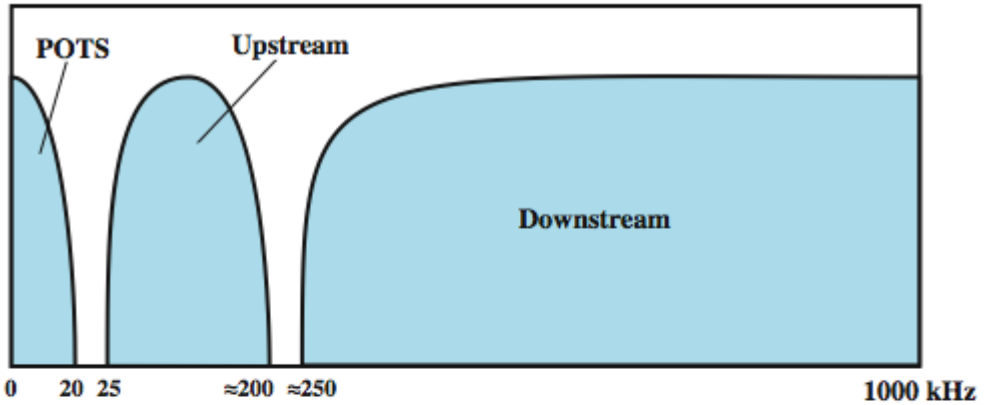
Cable Modem Scheme



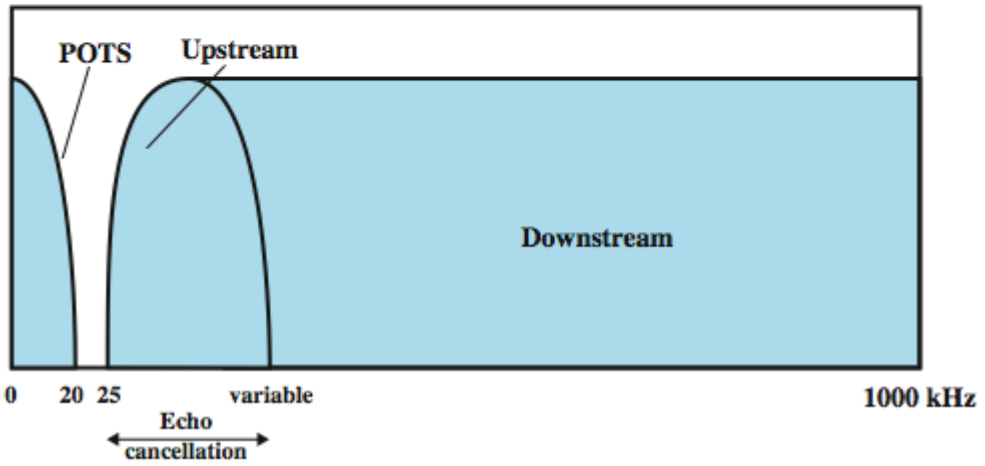
Asymmetrical Digital Subscriber Line (ADSL)

- link between subscriber and network
- uses currently installed twisted pair cable
- is asymmetric - bigger downstream than up
- uses frequency division multiplexing
  - reserve lowest 25kHz for voice (POTS)
  - uses echo cancellation or FDM to give two bands
- has a range of up to 5.5km

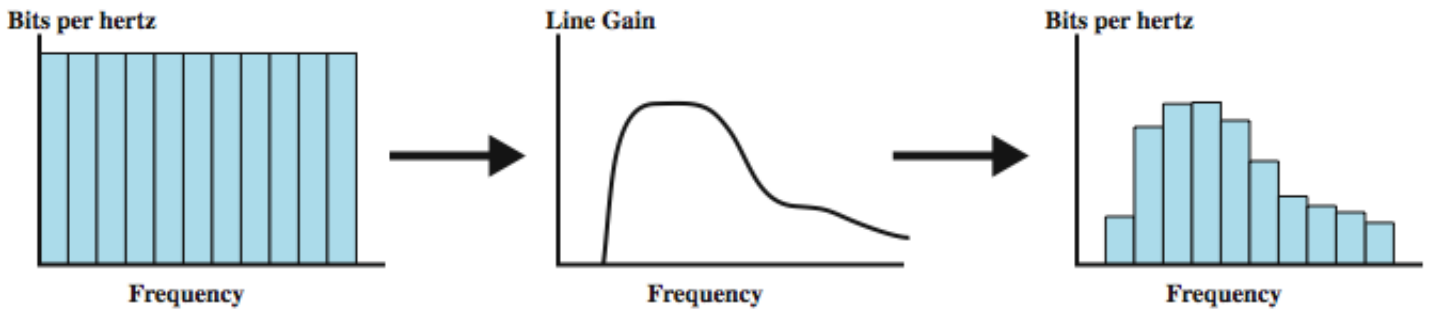
ADSL Channel Configuration



(a) Frequency-division multiplexing



(b) Echo cancellation

Discrete Multitone (DMT)

- multiple carrier signals at different frequencies
- divide into 4kHz subchannels
- test and use subchannels with better SNR
- 256 downstream subchannels at 4kHz (60kbps)
  - in theory 15.36Mbps, in practice 1.5-9Mbps