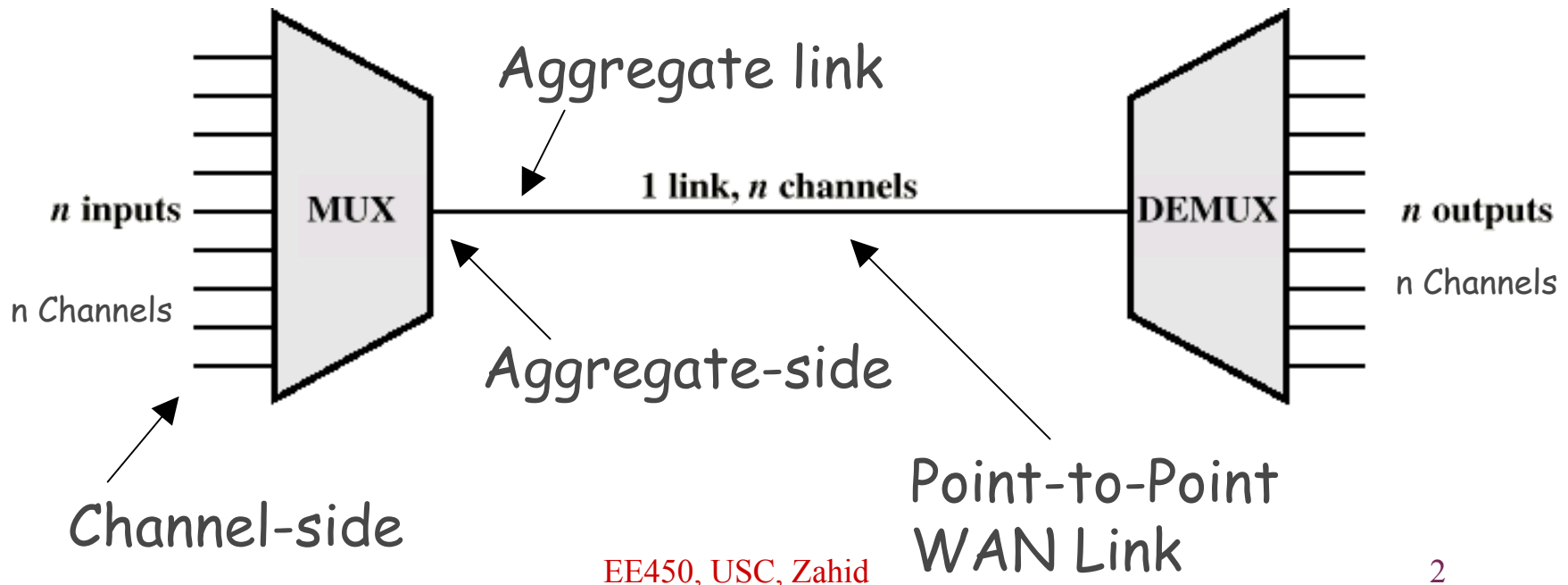# Multiplexing: "Resource Sharing"
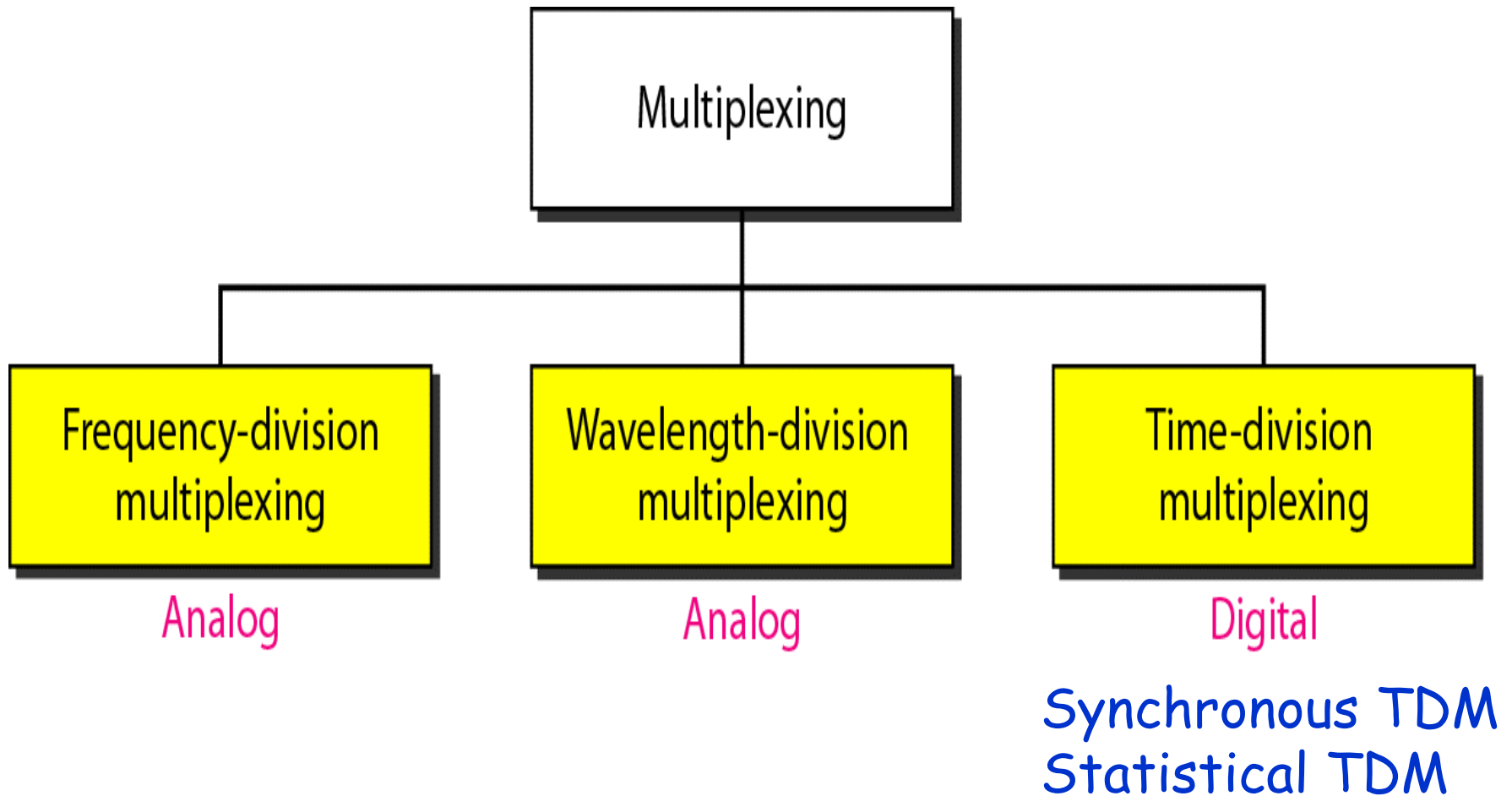
EE450: Introduction to Computer Networks

Professor A. Zahid

Multiplexing

- Multiplexing is a resource sharing process allowing information from several information sources to be aggregated onto a single, high-speed link

Aggregate link

1 link, *n* channels

n inputs — MUX — — DEMUX — *n* outputs

n Channels

n Channels

Aggregate-side

Channel-side

Point-to-Point WAN Link

Categories of Multiplexing


```
                    ┌─────────────────────┐
                    │    Multiplexing     │
                    └─────────────────────┘
          ┌──────────────────┼──────────────────┐
┌──────────────────┐ ┌──────────────────┐ ┌──────────────────┐
│ Frequency-division│ │ Wavelength-division│ │  Time-division   │
│    multiplexing   │ │    multiplexing   │ │   multiplexing   │
└──────────────────┘ └──────────────────┘ └──────────────────┘
        Analog              Analog              Digital
```
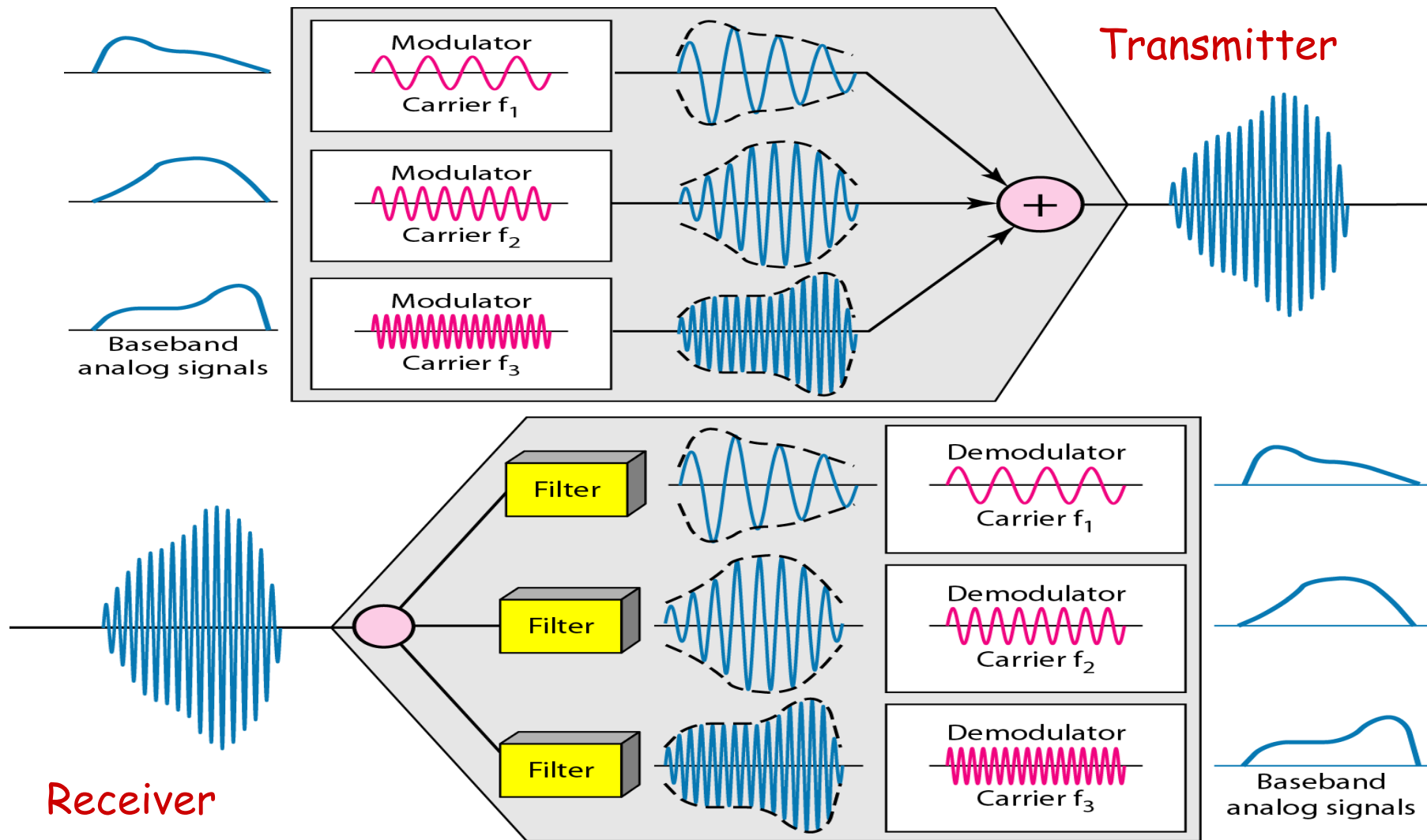
Synchronous TDM
Statistical TDM
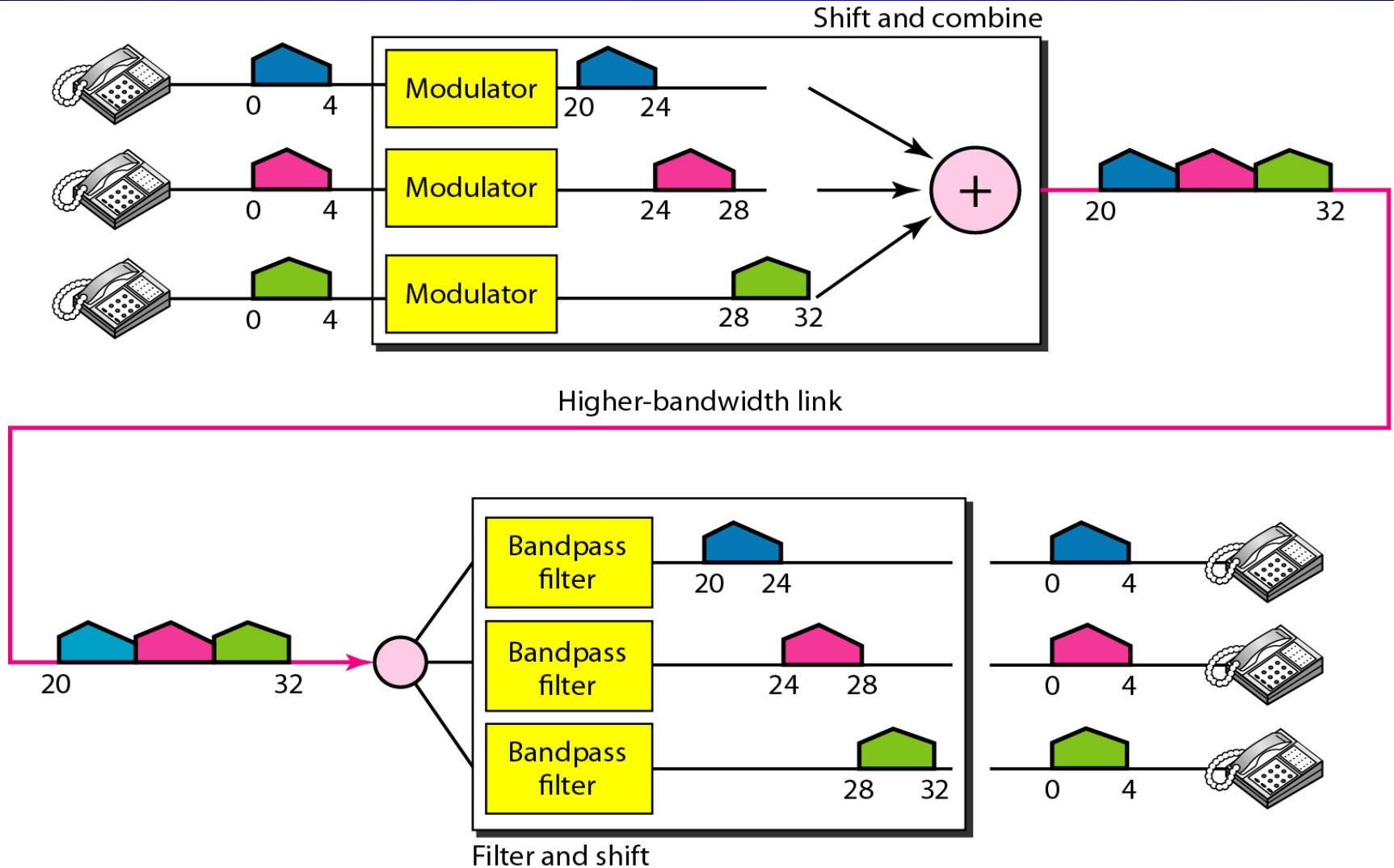
Frequency Division Multiplexing

- Useful bandwidth of medium exceeds required bandwidth of channel

- In FDM, each signal is modulated to a different carrier frequency

- Carrier frequencies separated so signals do not overlap (guard bands), example: Broadcast Radio
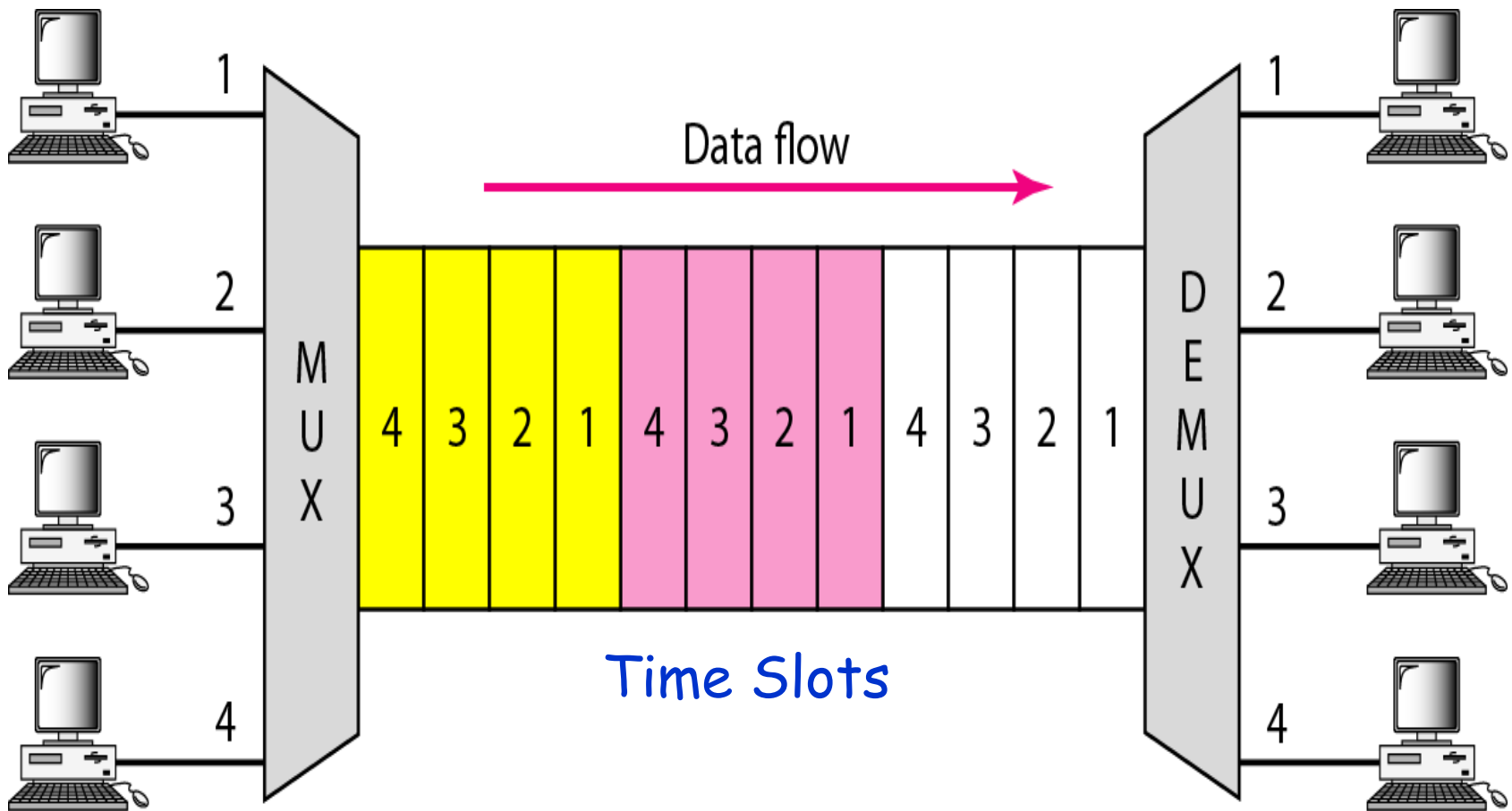
FDM Process

Example: FDM of Voice Signals

Shift and combine

Higher-bandwidth link

Filter and shift

Time Division Multiplexing (TDM)

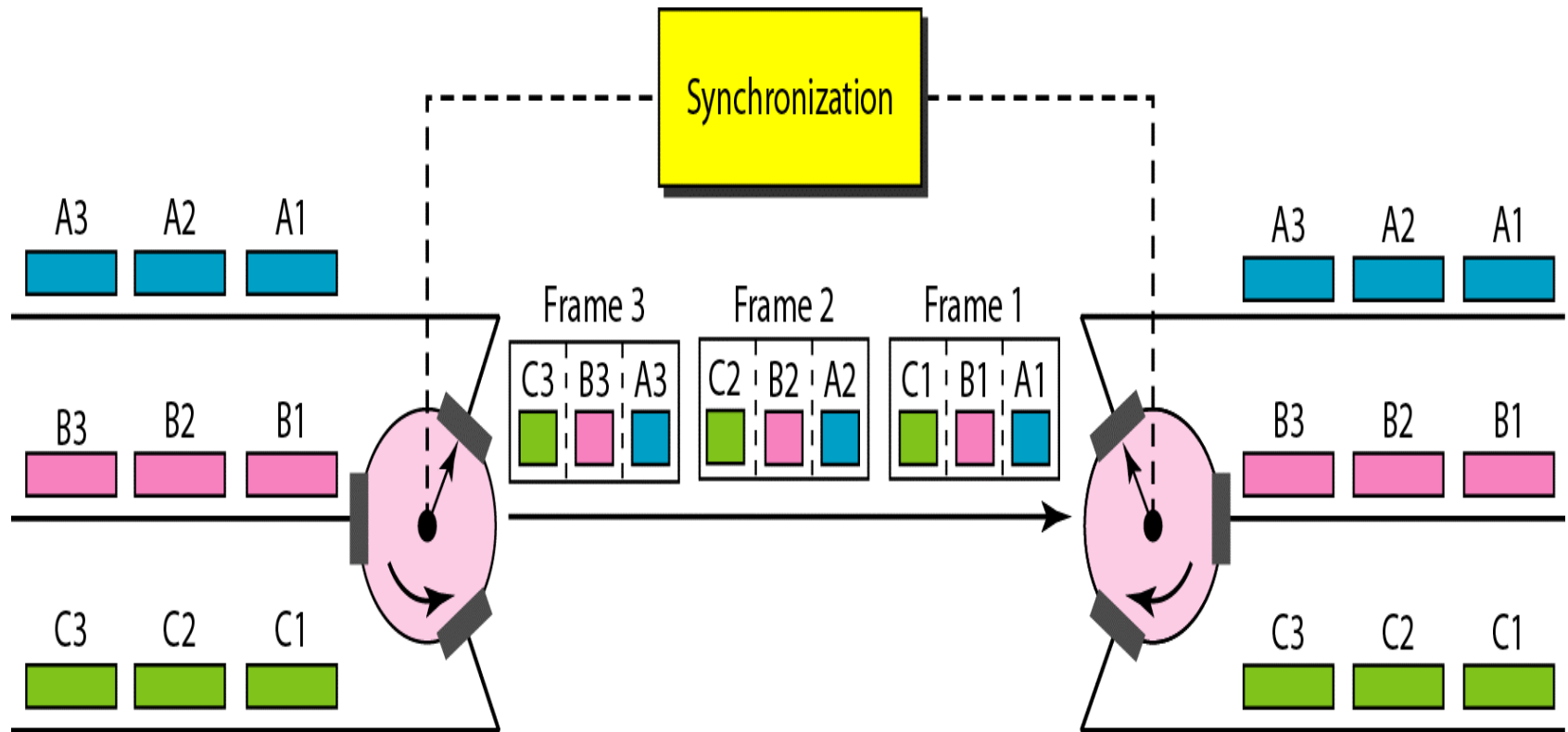Time Slots

Synchronous TDM

- Data rate of medium exceeds data rate of digital signal to be transmitted

- Multiple digital signals interleaved in time

- May be at bit level or block of bits

- Time slots pre-assigned to sources and fixed

- Time slots allocated even if source is idle

- Time slots do not have to be evenly distributed amongst sources
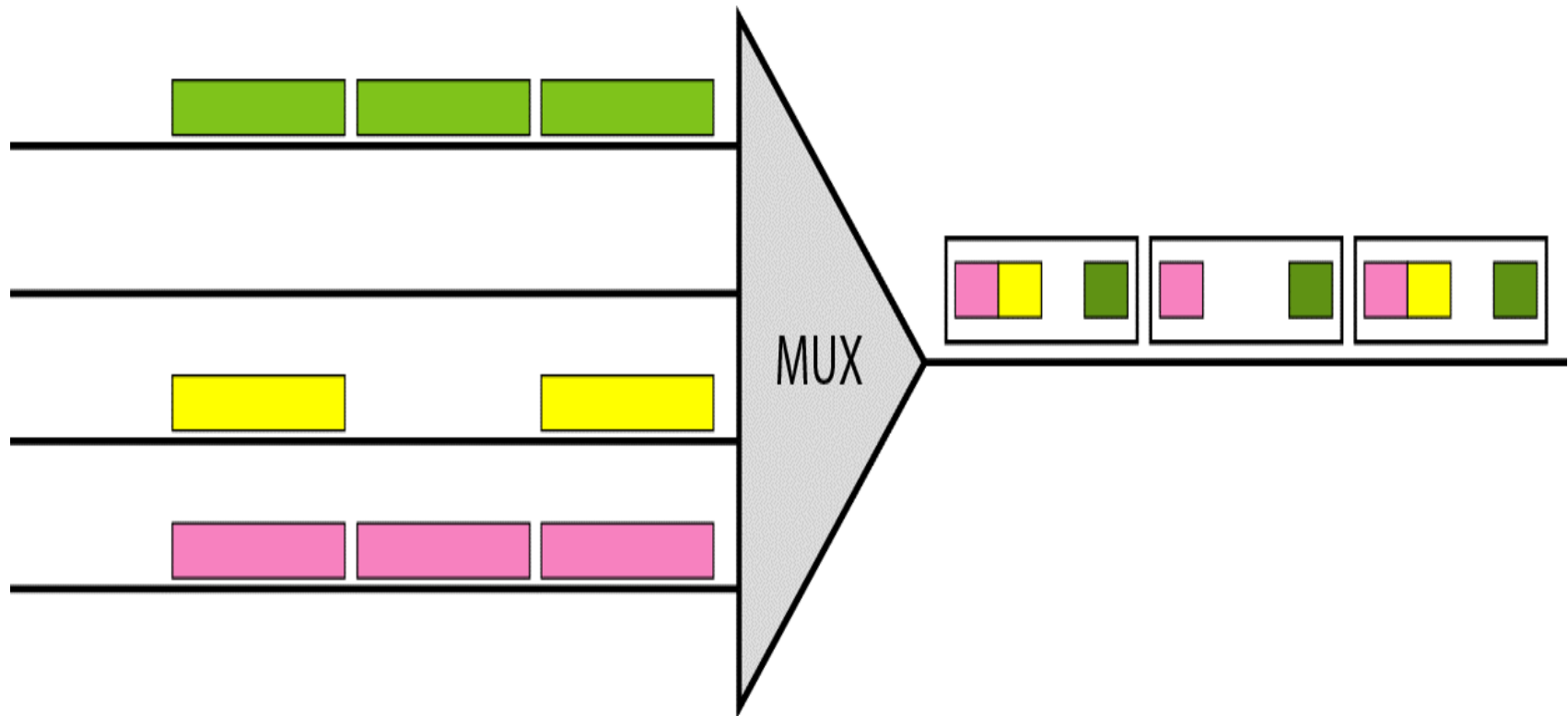
Synchronous TDM (Cont.)
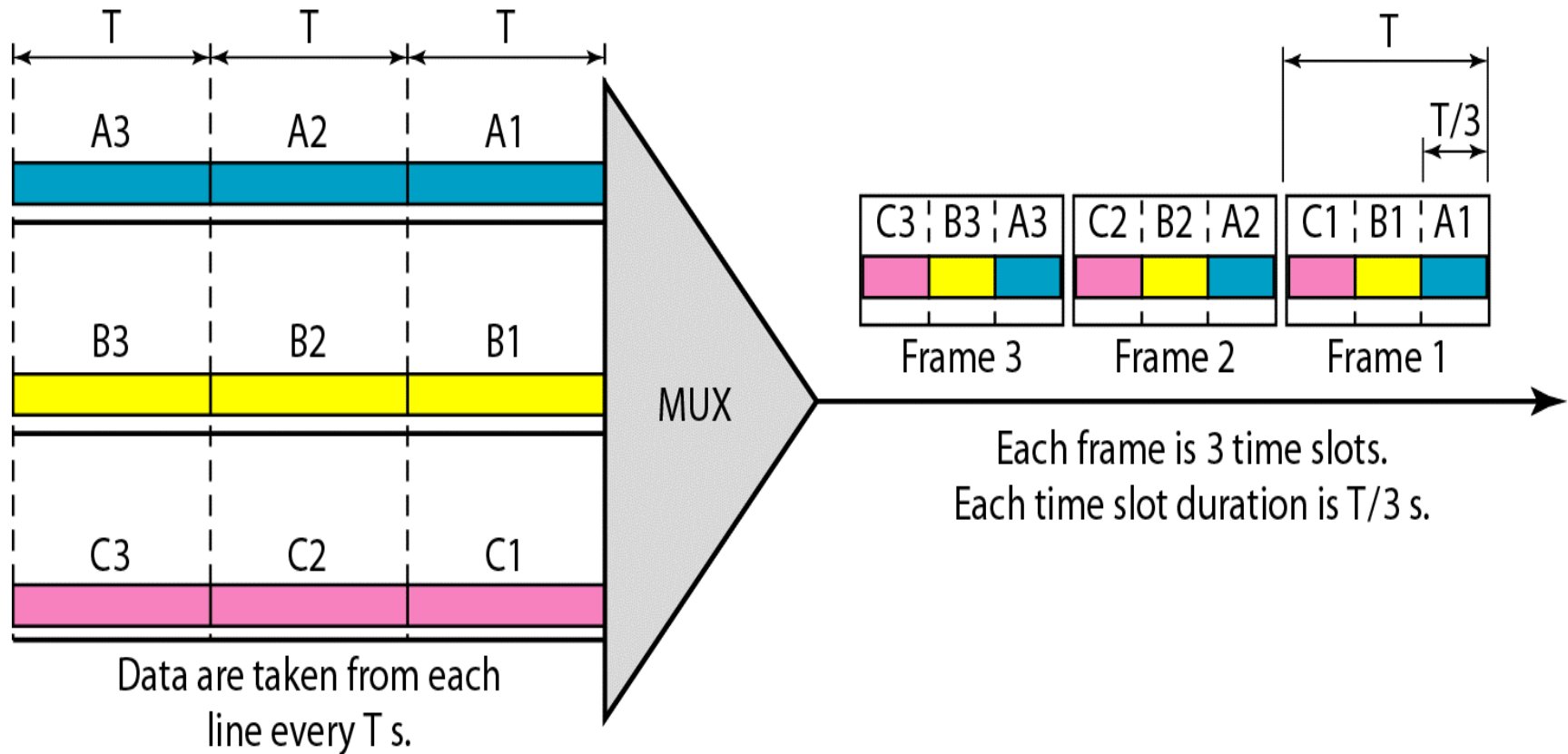
In synchronous TDM, the data rate of the link is n times faster, and the unit duration is n times shorter.
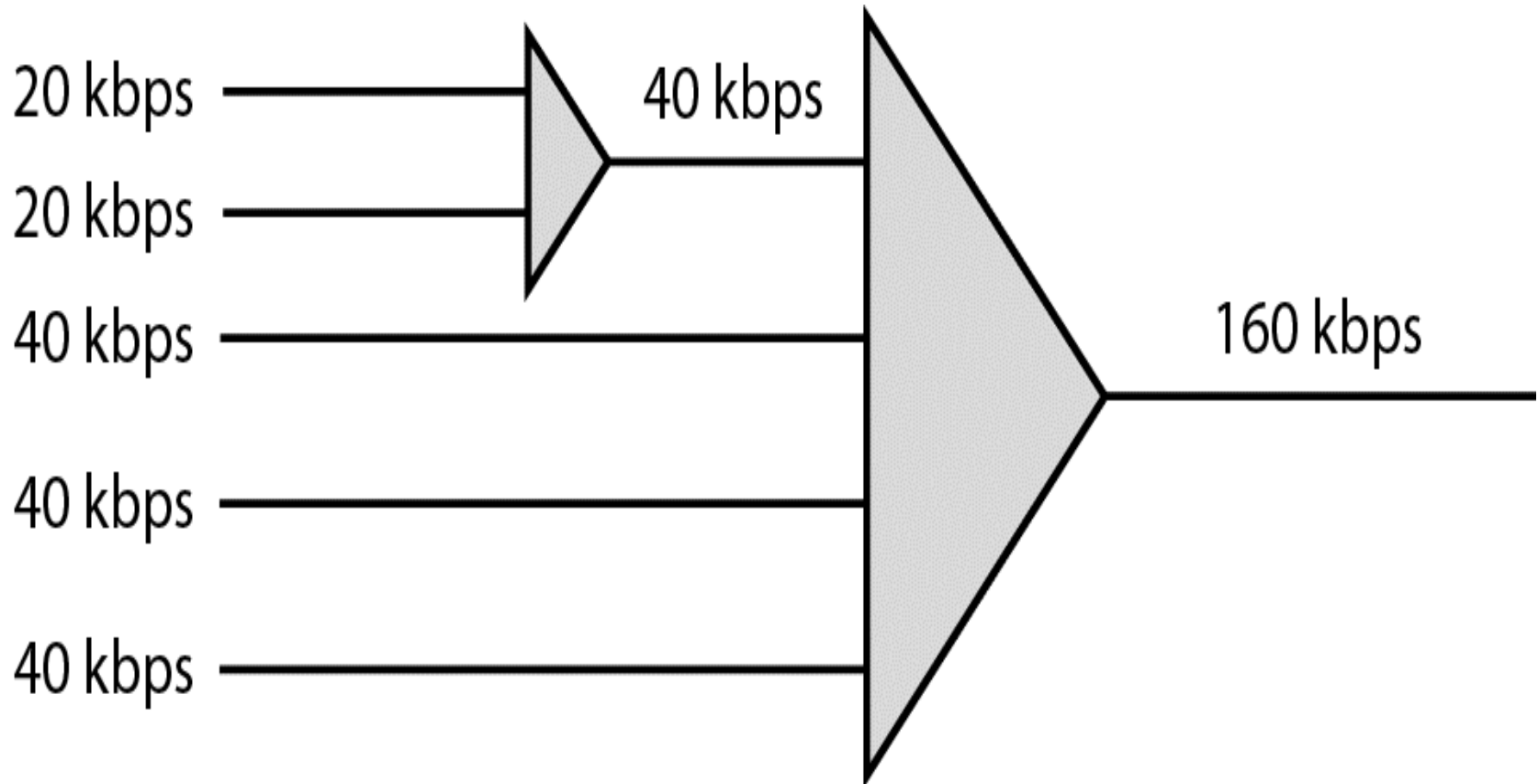
Synchronous TDM (Cont.)

Empty Time Slots

Empty TS can't be used by other
Sources ⇒ Waste of Bandwidth
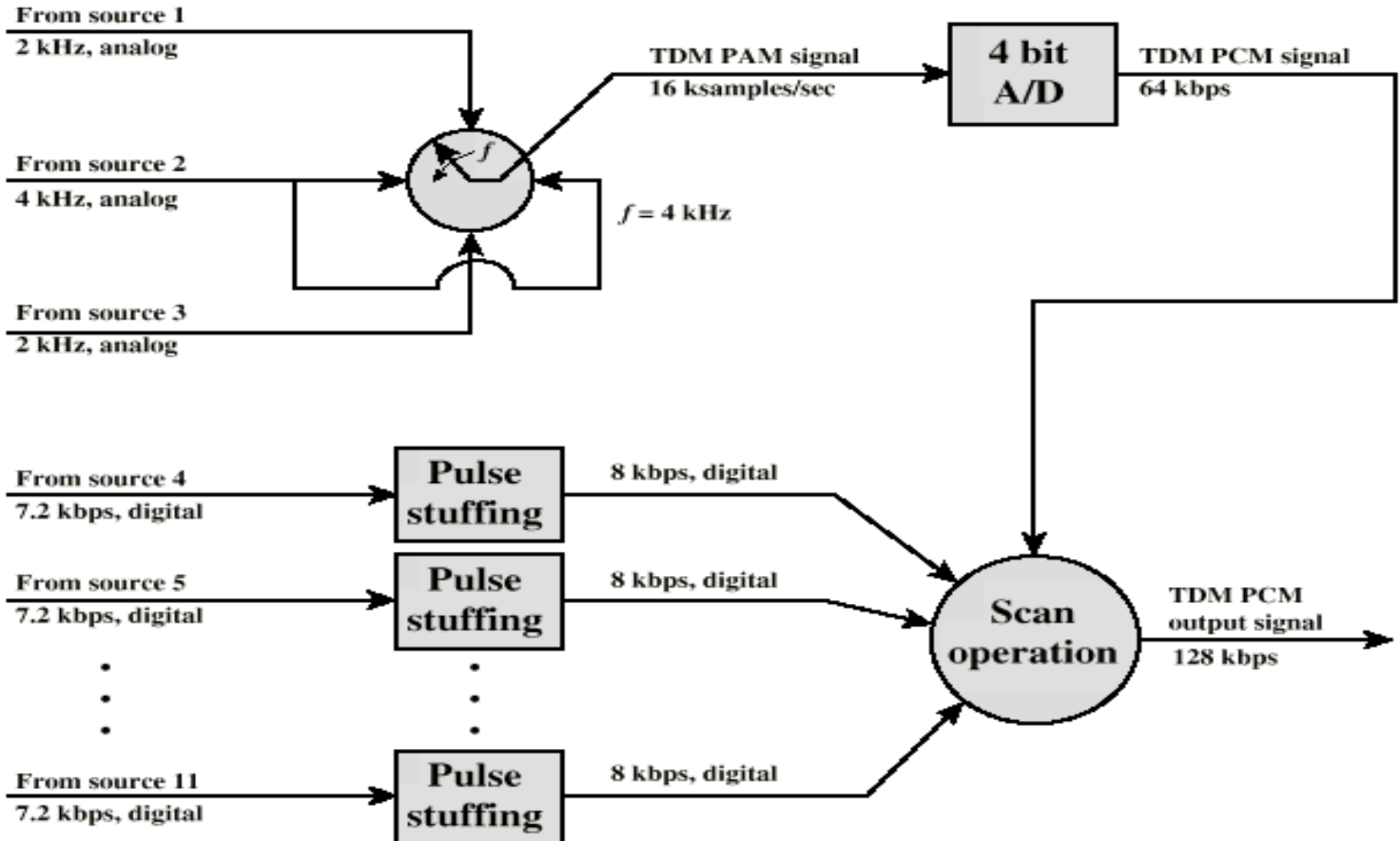
Multilevel Multiplexing

20 kbps
20 kbps
40 kbps
40 kbps
40 kbps
40 kbps
160 kbps

Multiple-Slot Multiplexing

50 kbps → 25 kbps, 25 kbps

25 kbps

25 kbps

25 kbps

125 kbps

The input with a 50-kHz data rate has two slots in each frame.

Example

From source 1
2 kHz, analog

From source 2
4 kHz, analog

From source 3
2 kHz, analog

TDM PAM signal
16 ksamples/sec

$f = 4$ kHz

4 bit A/D

TDM PCM signal
64 kbps

From source 4
7.2 kbps, digital

Pulse stuffing

8 kbps, digital

From source 5
7.2 kbps, digital

Pulse stuffing

8 kbps, digital

From source 11
7.2 kbps, digital

Pulse stuffing

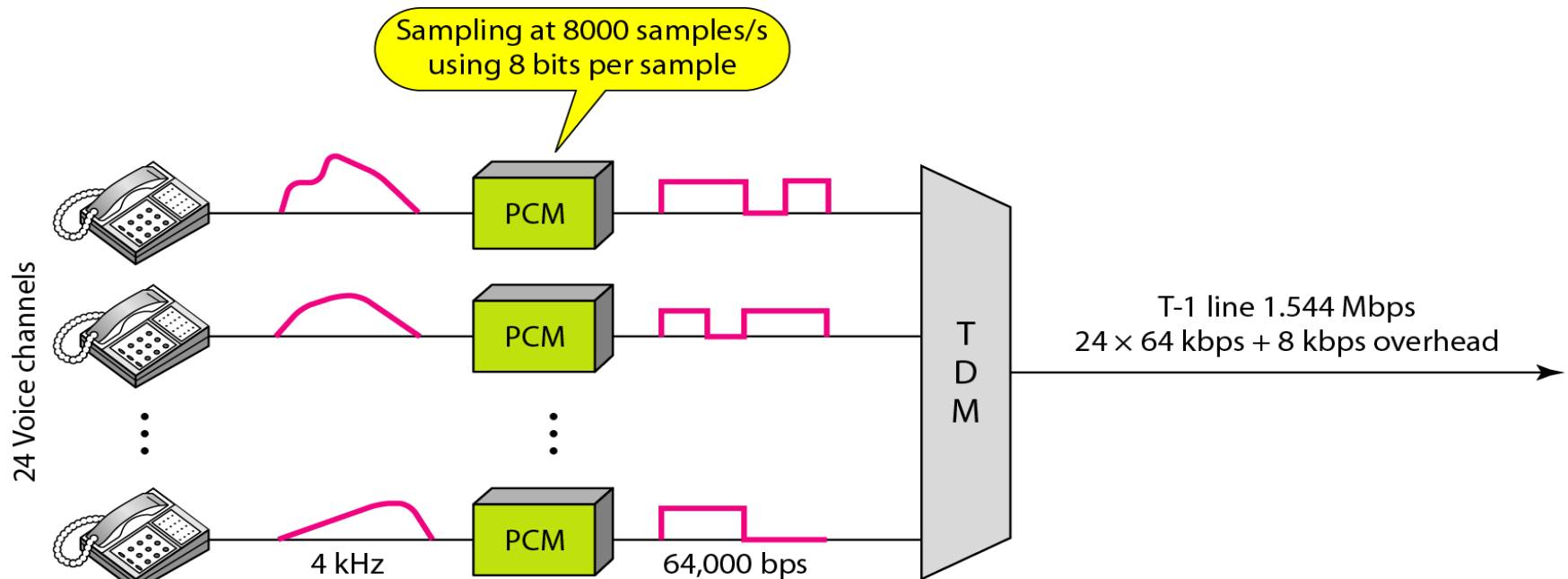8 kbps, digital
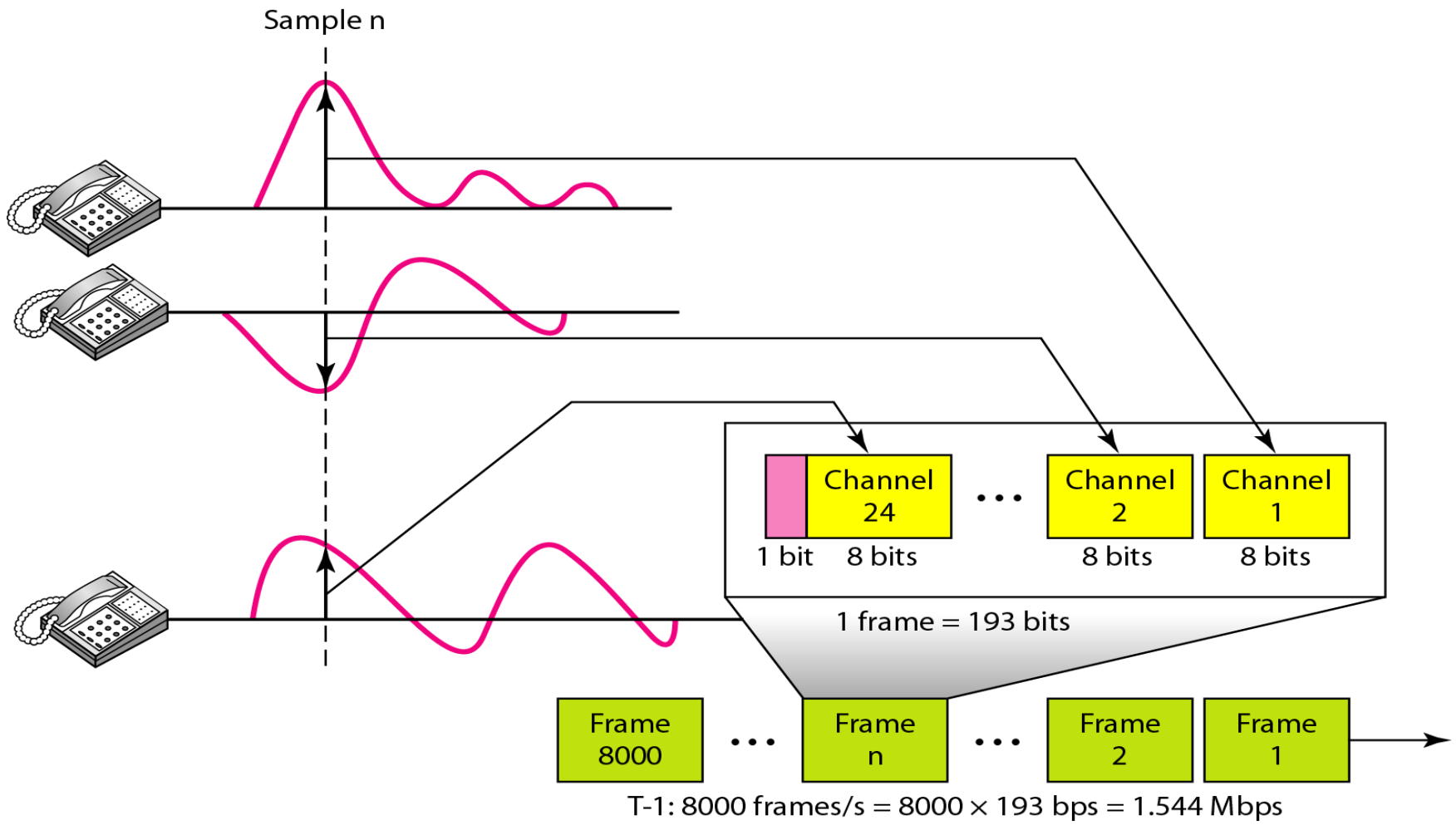
Scan operation

TDM PCM
output signal
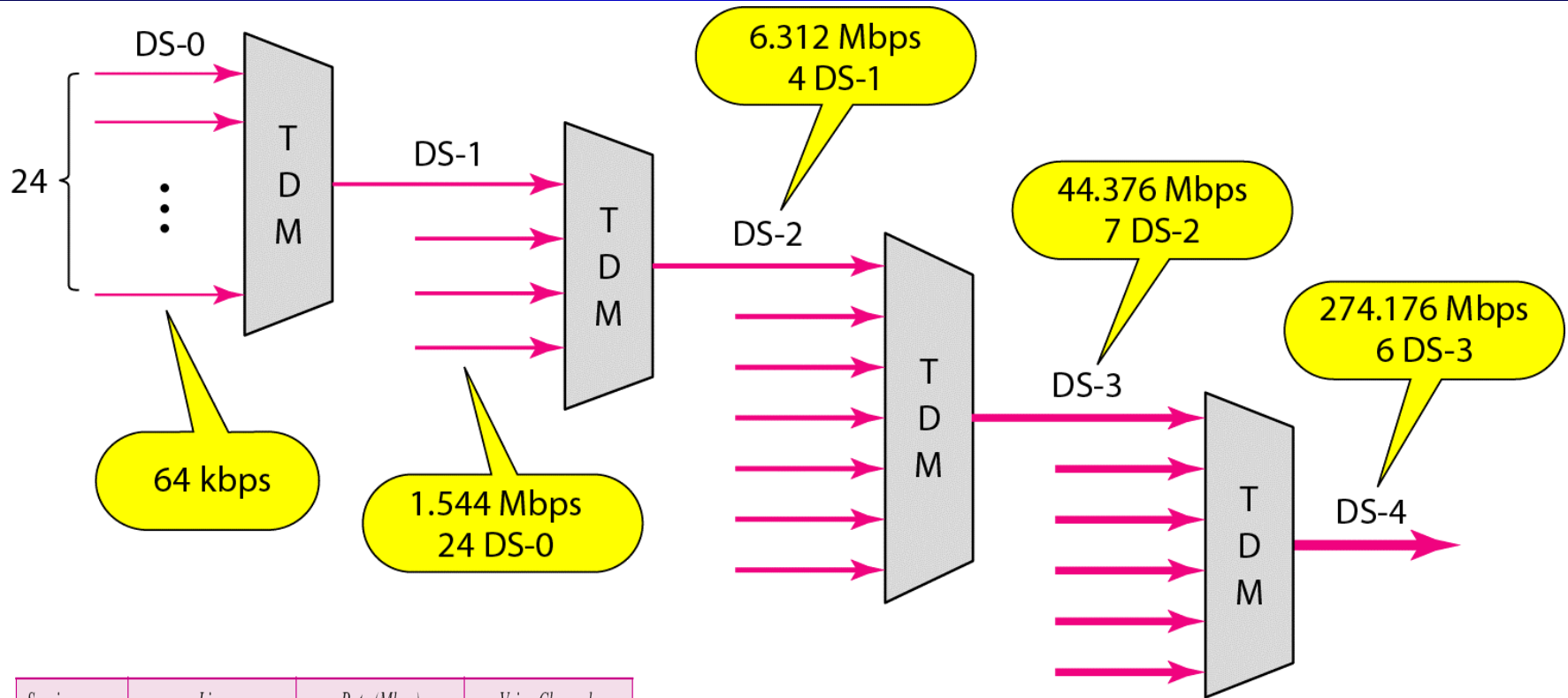128 kbps

Digital Carrier Hierarchy (US)

- US system based on DS-1 format

- Multiplexes 24 channels

- Each frame has 8 bits per channel plus one framing bit
  $\Rightarrow$ 193 bits/frame. Frame Duration is 125μseconds

Sampling at 8000 samples/s using 8 bits per sample

24 Voice channels

PCM

PCM

PCM

4 kHz

64,000 bps

T
D
M

T-1 line 1.544 Mbps
24×64 kbps + 8 kbps overhead

T1 illustrated

Sample n

Channel 24 | ... | Channel 2 | Channel 1

1 bit   8 bits   8 bits   8 bits

1 frame = 193 bits

Frame 8000 | ... | Frame n | ... | Frame 2 | Frame 1

T-1: 8000 frames/s = 8000 × 193 bps = 1.544 Mbps

Digital Hierarchy (US)

DS-0

24

TDM

DS-1

TDM

DS-2

TDM

DS-3

TDM

DS-4

6.312 Mbps
4 DS-1

44.376 Mbps
7 DS-2

274.176 Mbps
6 DS-3

64 kbps

1.544 Mbps
24 DS-0

Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

| Line	Rate (Mbps)	Voice Channels
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

Statistical (Asynchronous) TDM

- In Synchronous TDM many slots are wasted

- Statistical TDM allocates time slots dynamically, i.e. based on demand

- Every Slot has to start with a header identifying the device (address)

- Multiplexer scans input lines and collects data until frame full

- Data rate on line lower than aggregate rates of input lines

Synchronous vs. Statistical
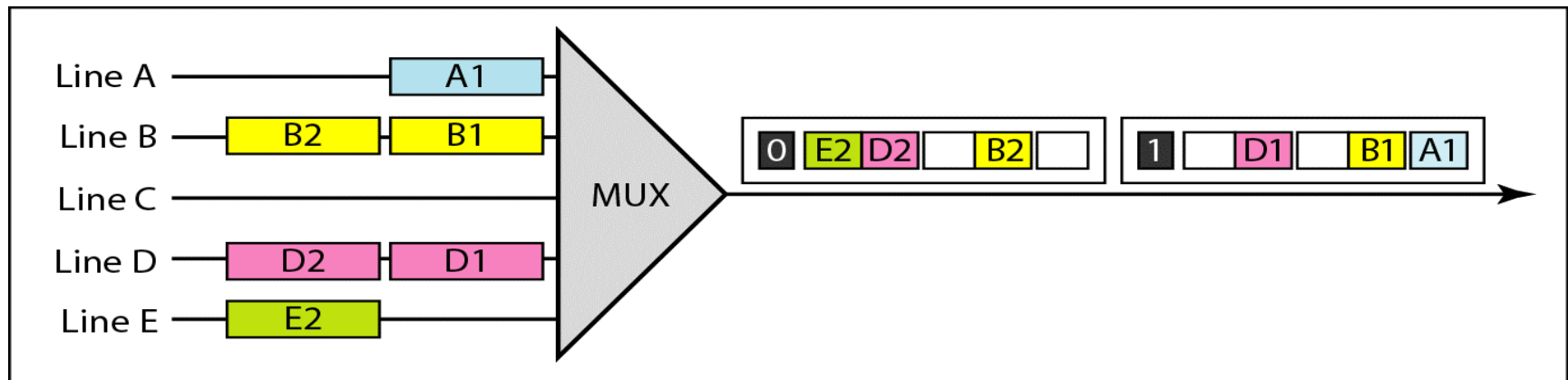
a. Synchronous TDM
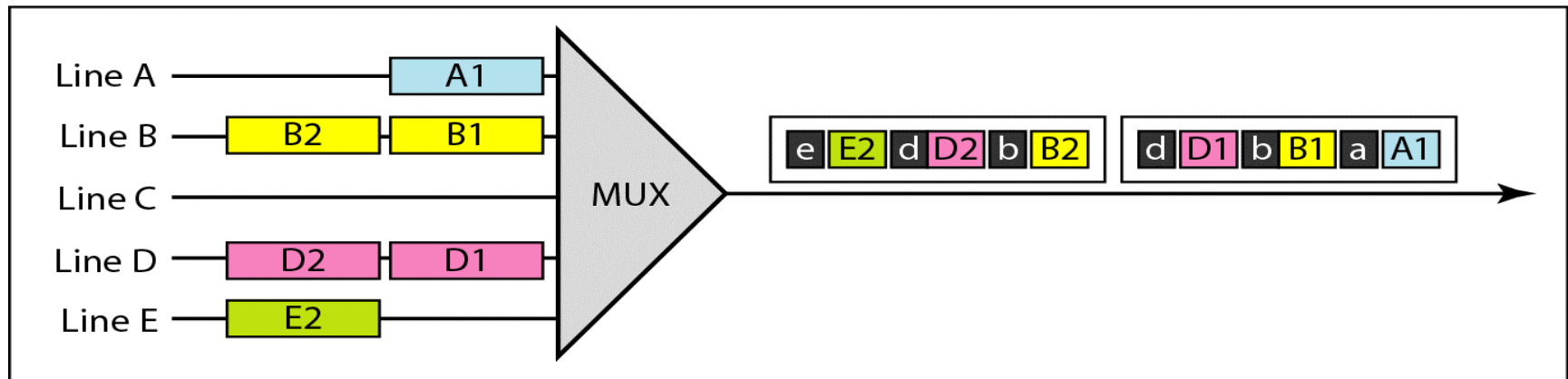
b. Statistical TDM

Performance of Statistical TDM

# of Inputs = 10
Rate of each input (active) = 1000 bps
**% of time a source is active = 50%**
Case 1: Multiplexer capacity = 5000 bps
Case 2: Multiplexer capacity = 7000 bps

|	Capacity = 5000 bps		Capacity = 7000 bps	
Input	**Output**	**Backlog**	**Output**	**Backlog**
6	5	1	6	0
9	5	5	7	2
3	5	3	5	0
7	5	5	7	0
2	5	2	2	0
2	4	0	2	0
2	2	0	2	0
3	3	0	3	0
4	4	0	4	0
6	5	1	6	0
1	2	0	1	0
10	5	5	7	3
7	5	7	7	3
5	5	7	7	1
8	5	10	7	2
3	5	8	5	0

Conclusions

- TDM – Guarantees the User a bandwidth but on the contrary wastes valuable carrier capacity. Suitable for streamy type traffic like voice (digitized)

- STDM – Utilizes unused time slots. Suitable for Bursty-type traffic such as data
  - More efficient use of capacity
  - When times are busy, user suffers delay
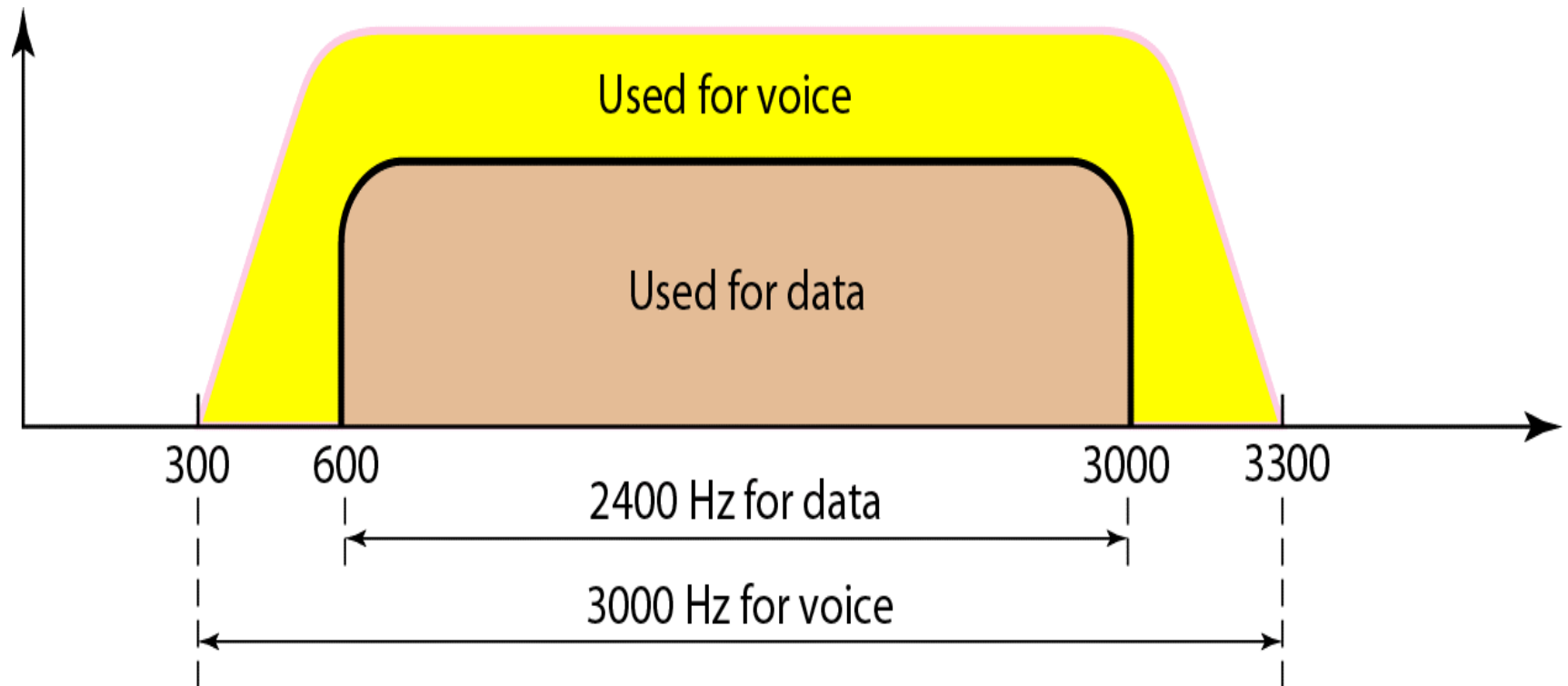
Wave-Length Division Multiplexing
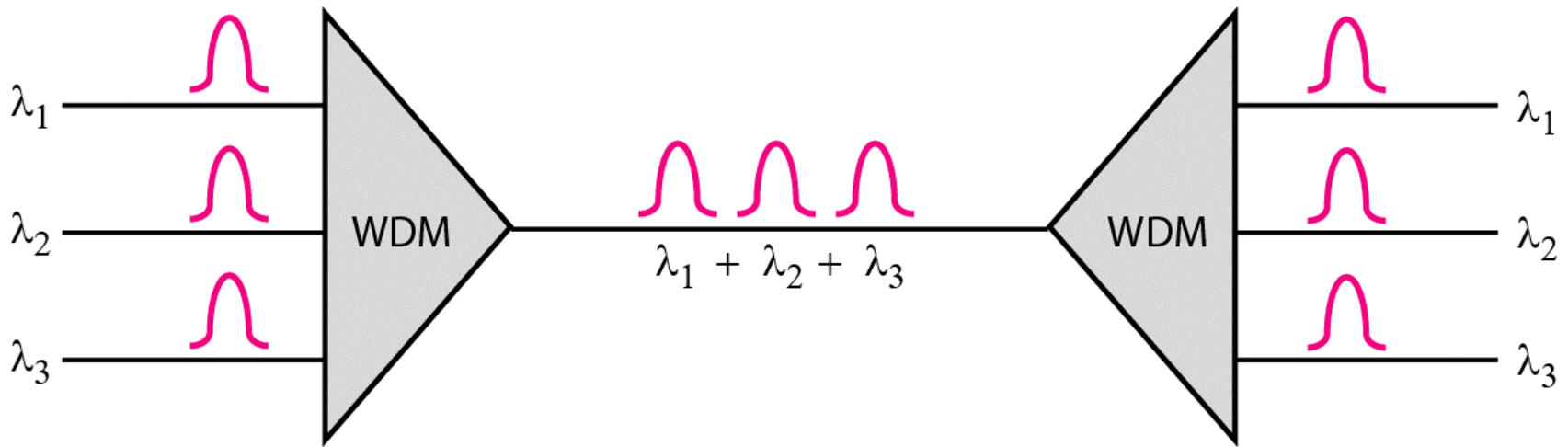
Prisms in wavelength-division multiplexing and de-multiplexing
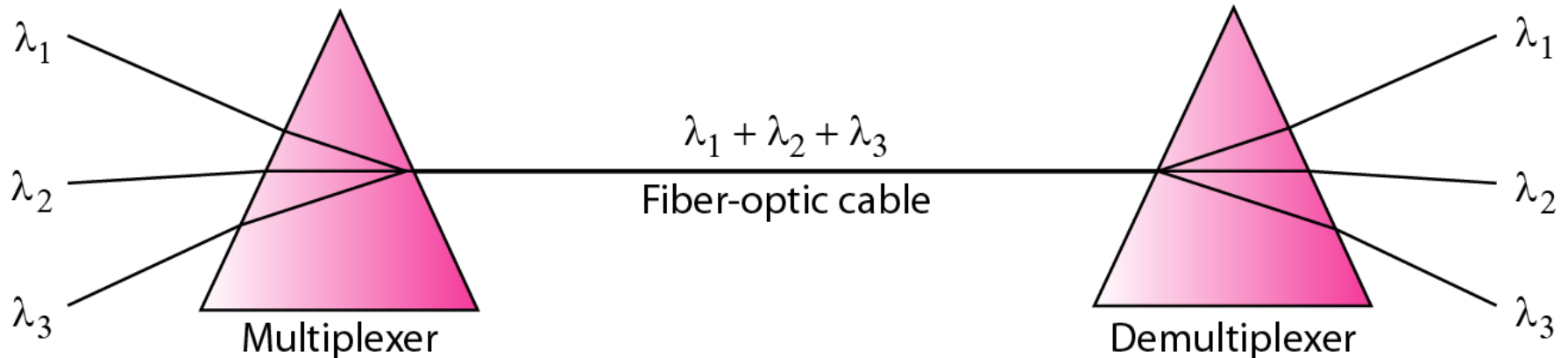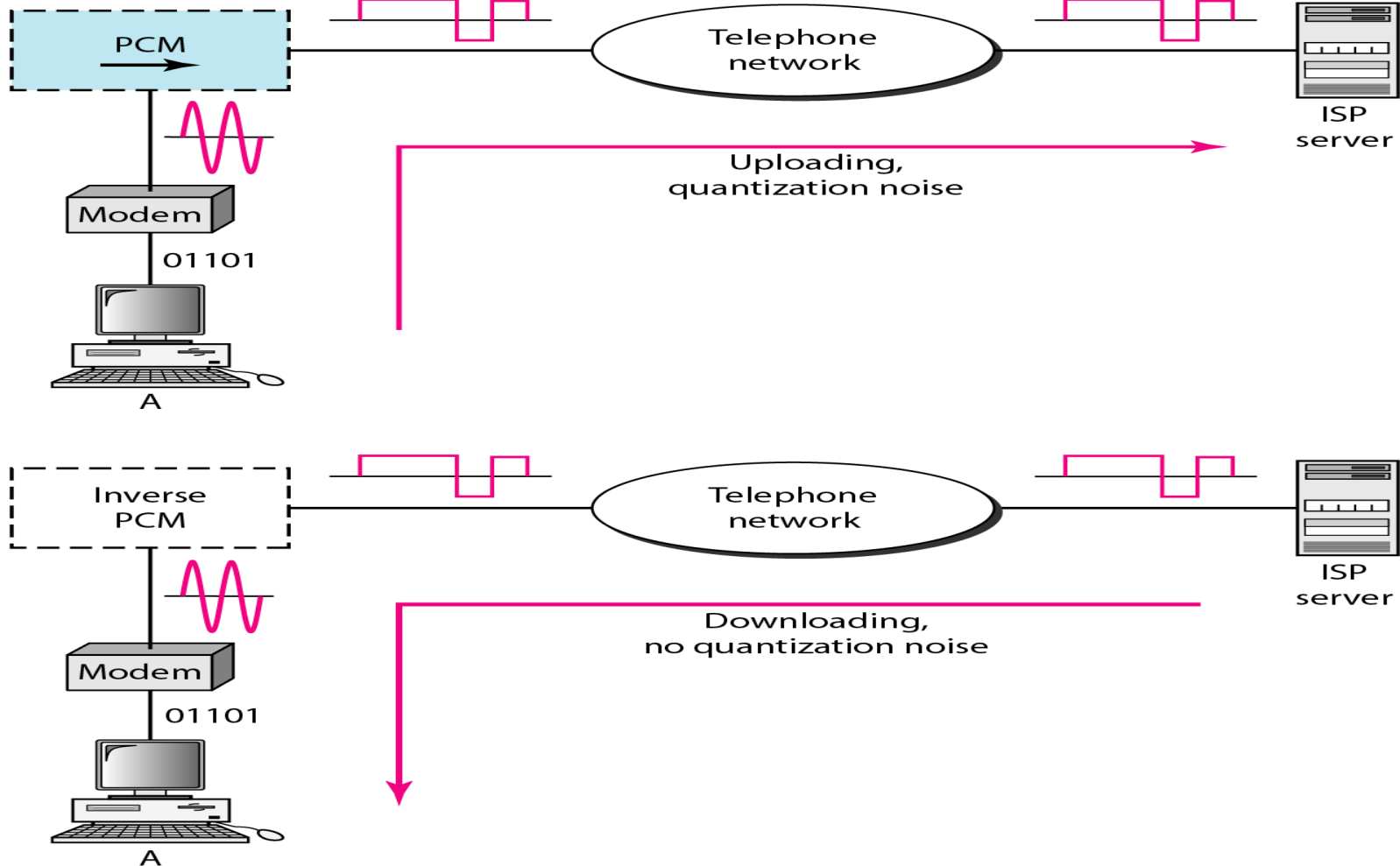
Access Technologies

- Dial-up: 56 Kbps Modems

- ADSL : Asymmetric Digital Subscriber Line

- Broadband Cable Access

- Wireless Access

- Dedicate Access (T1 or T3, Business lines)

Dial-up Telephone Line Bandwidth

Used for voice

Used for data

300   600   2400 Hz for data   3000   3300

3000 Hz for voice

Dial-up (Asymmetric 56 Kbps)

Quantization noise limits the data rate

PCM

Modem

01101

A

Telephone network

Uploading, quantization noise

ISP server

Inverse PCM

Modem

01101

A

Telephone network

Downloading, no quantization noise

ISP server

DSL Technologies

- Digital Subscriber Line is a technology that can provide Internet Access and Plain Old Telephone Services (POTS) over the existing single twisted pair telephone lines. It <u>may</u> also be able to deliver Video-on-Demand

- DSL is deployed by the telephone companies

- Multiple Flavors of DSL include:
  - ADSL : Asymmetric DSL (most suitable for residential access)
  - HDSL : High Data Rate DSL
  - IDSL : ISDN DSL
  - SDSL : Symmetric DSL
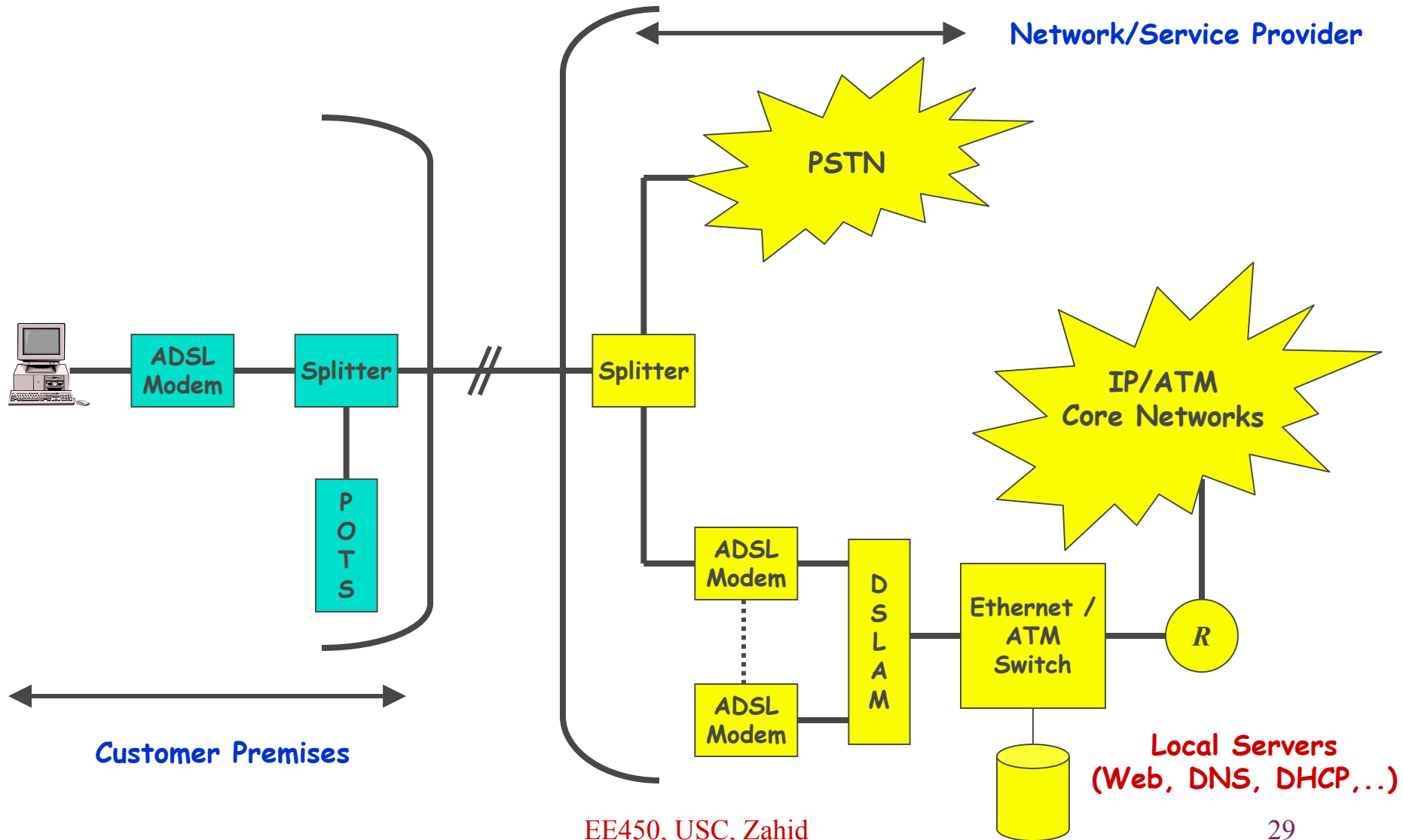 - VDSL : Very High Data Rate DSL

ADSL

- Asymmetrical DSL was developed at BellCore in 1989. BellCore is currently Telcordia Tech. Inc.
- Asymmetric in the sense that the Downstream and the Upstream capabilities are not the same. It was designed to match the flow of data to and from the Internet
  - Downstream bandwidth supports up to ~ 8 Mbps
  - Upstream bandwidth supports up to ~ 1.5 Mbps
- Distance requirement between residence and the CO is ~ 18,000 ft (~ 5.5 km), the closer, the better, the higher
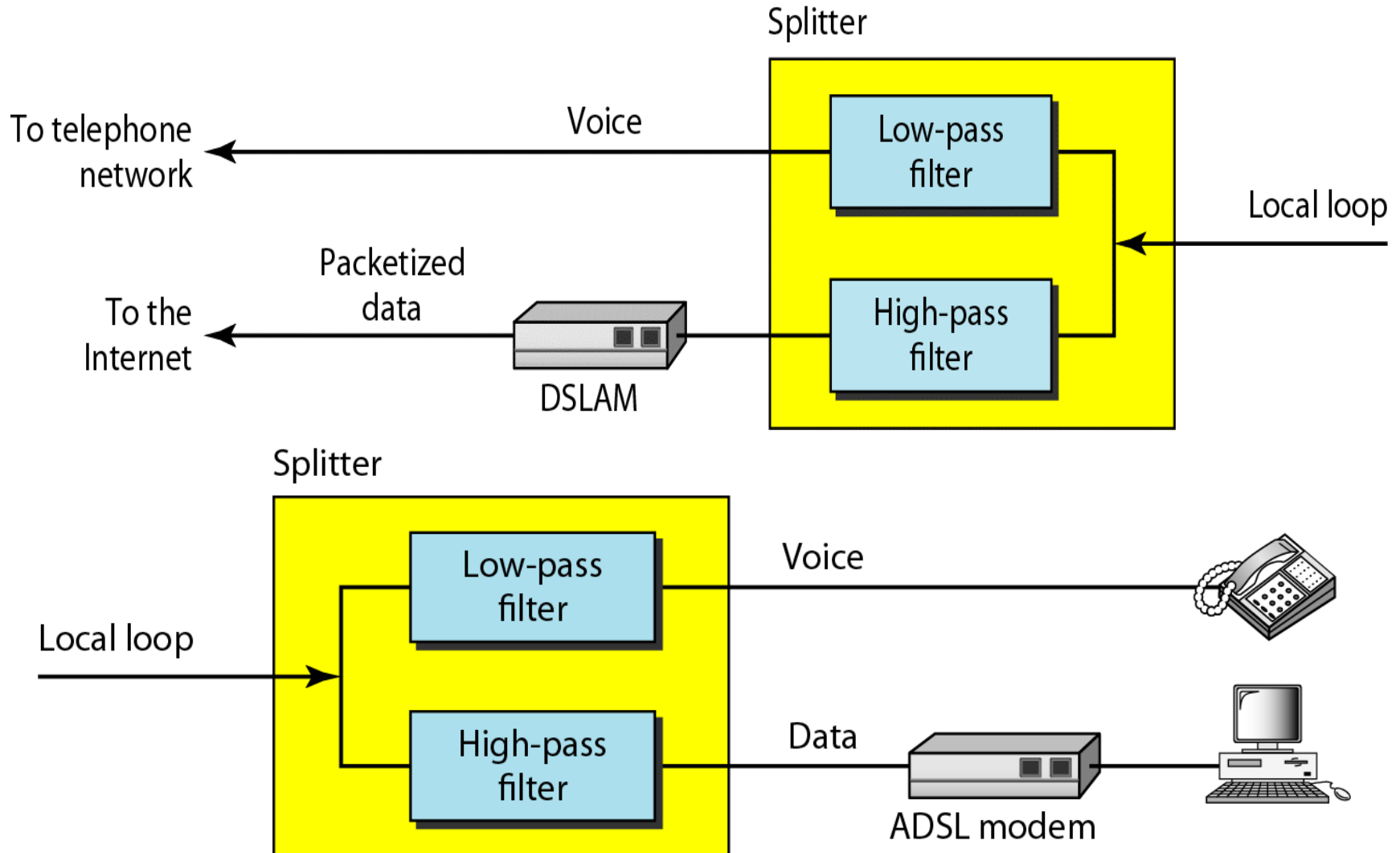
ADSL Bandwidth Allocations
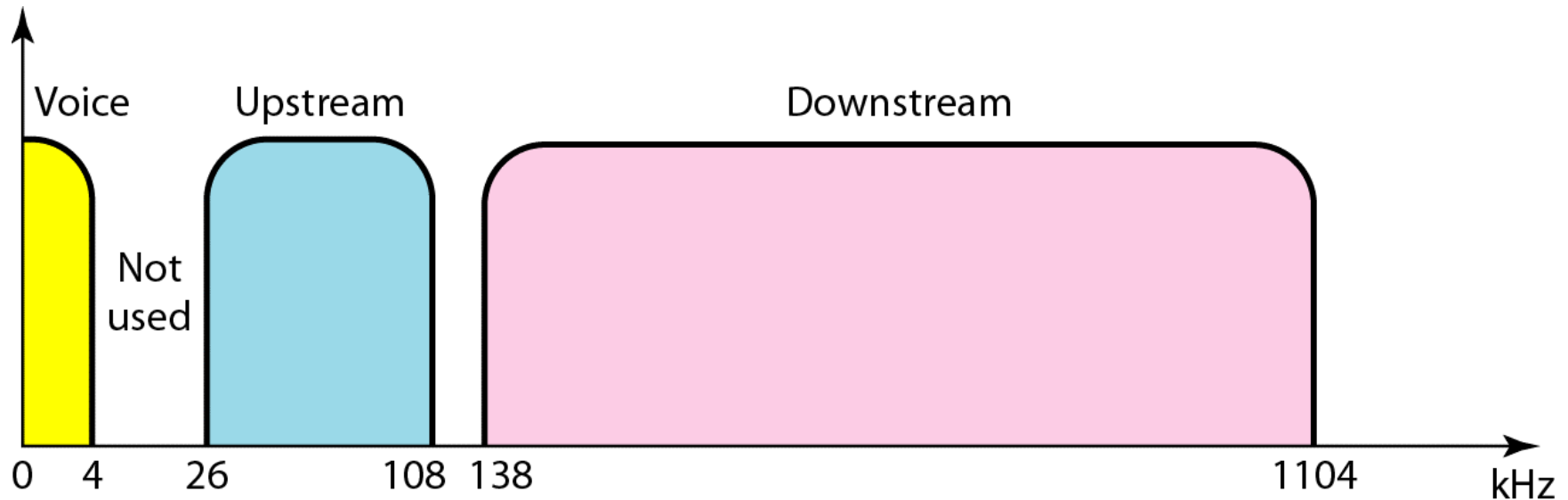
The bandwidth of the twisted pair copper wire
is divided, using FDM (Frequency Division Multiplexing)
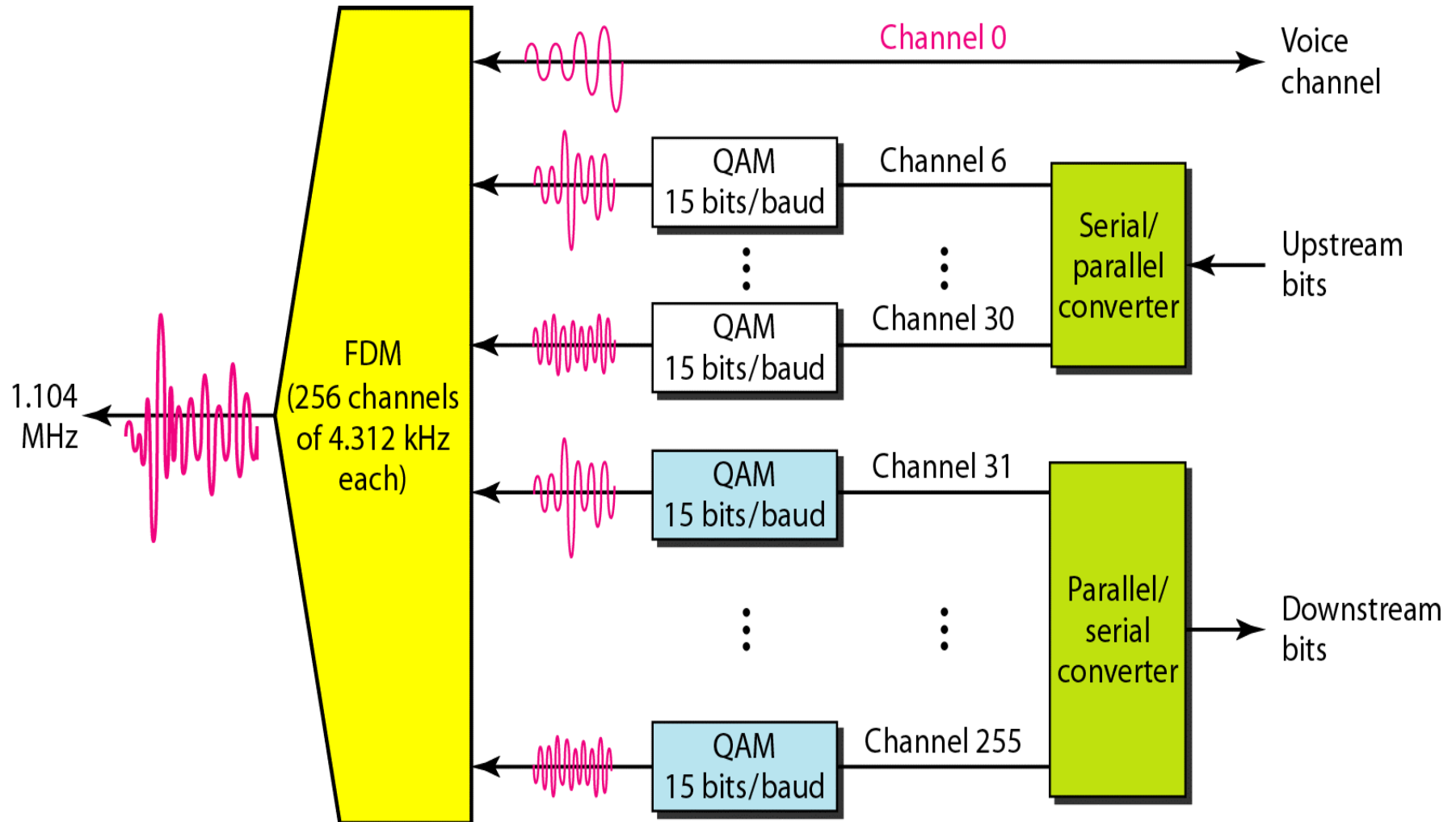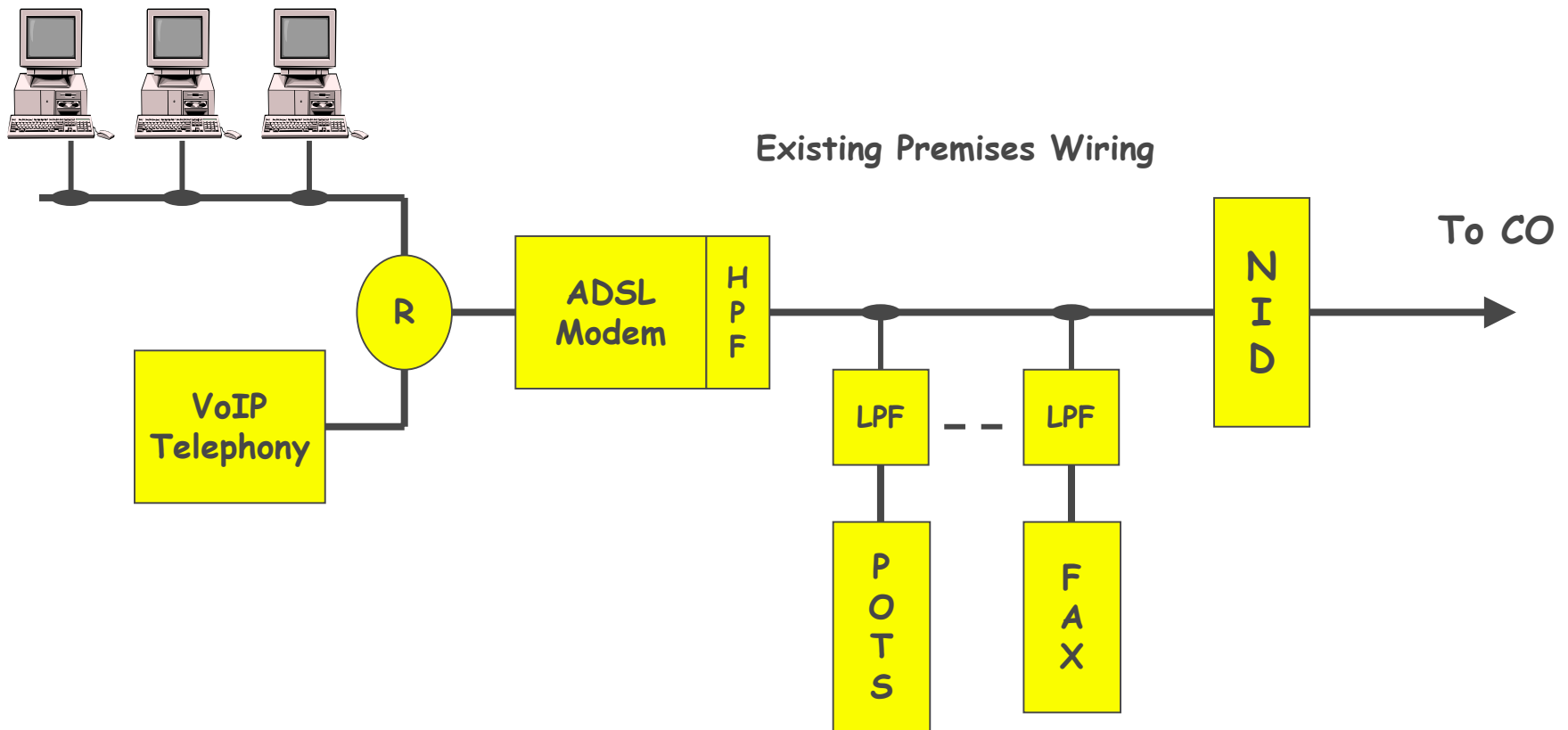into 3 non-overlapping sub-bands

ADSL Architecture

U/L and D/L ADSL

ADSL Technology (too much detail !)

Customer Premises Installation

Existing Premises Wiring

To CO

R

VoIP Telephony

ADSL Modem

H P F

LPF - - LPF

P O T S

F A X

N I D

- Most common installation approach, customer installable
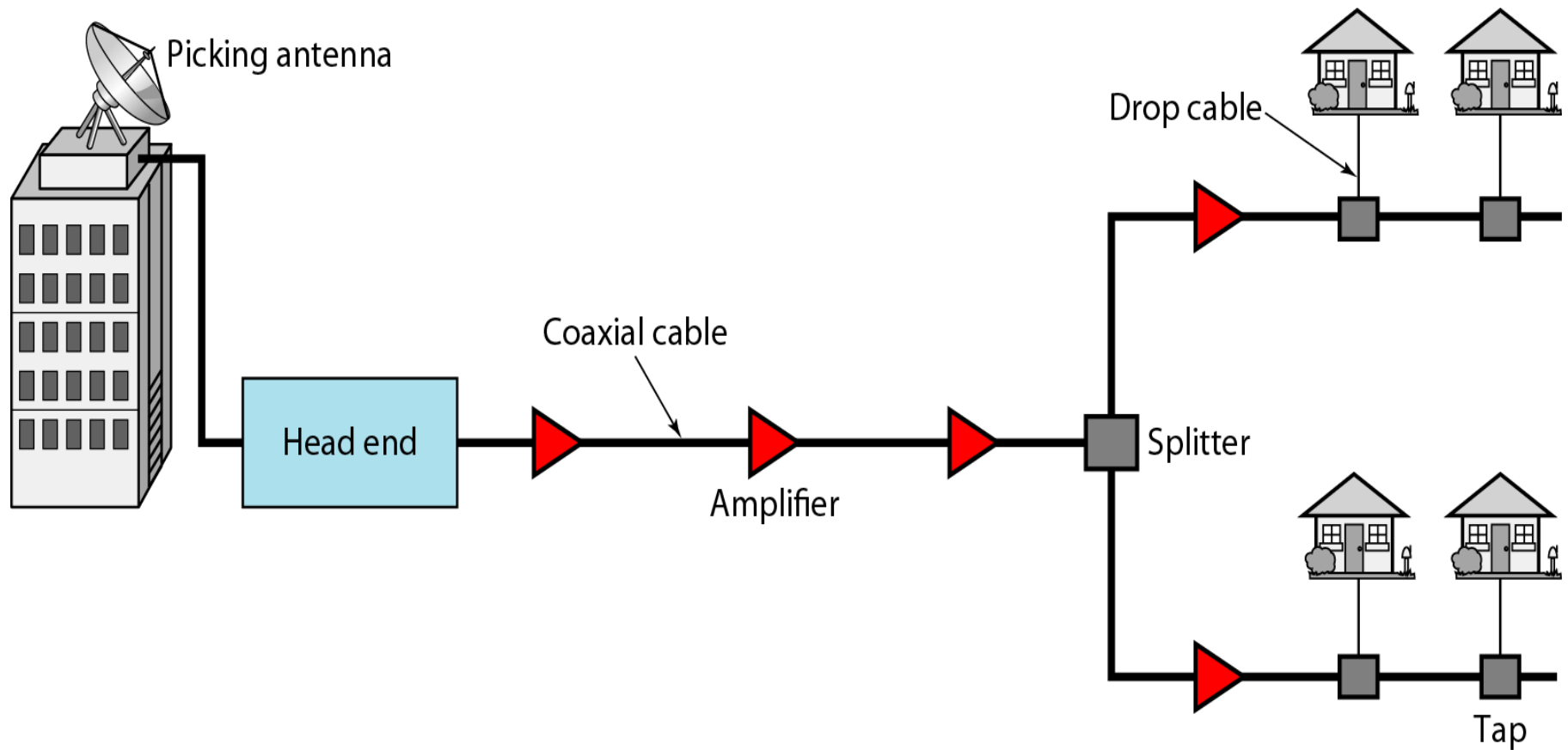- Requires "Miniatures" LPFs between the POTS device and the wall jack

Problems with ADSL

- Phone wires attenuate and distort voice signals.
  - To equalize the lines over the frequency range for voice communications (0~4KHz), the telephone companies install inductors (loading coils) in their longer lines to improve voice communications.
  - The price is that high speed data will suffer
  - Need to remove those loading coils

- Signal dispersion and Inter-Symbol interference at high data rates

- POTS and ADSL interference

- Echoes due to un-terminated taps
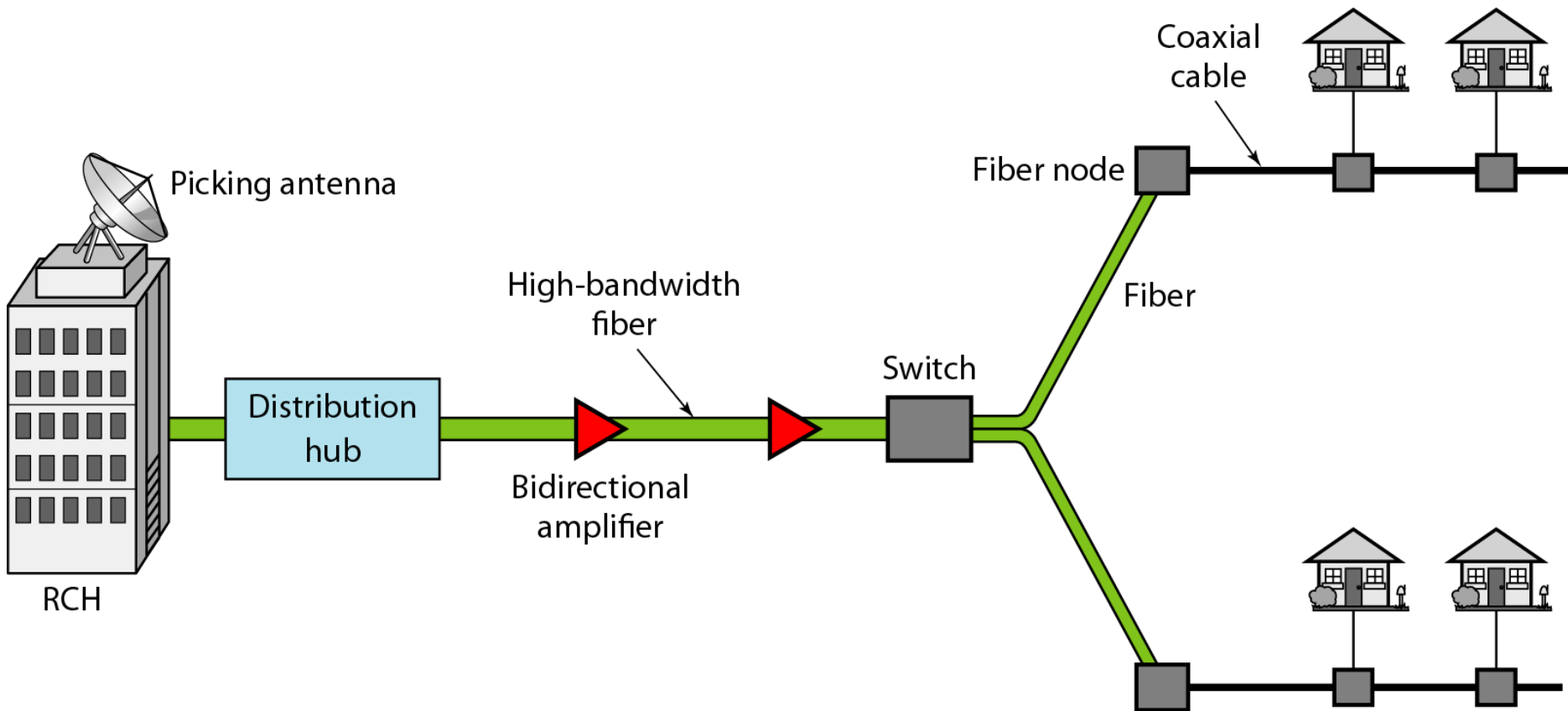
- Near-end and far-end cross talks

Cable Access

- Based on (residential) cable television (CATV) technology
  - 80~100 million homes are "Passed" by CATV in USA

- Provide for Integrated Services
  - Data
  - TV Broadcasting (Analog & Digital), VoD
  - Audio (music, voice)

- Asymmetric Bandwidth Allocation
  - High-speed D/L
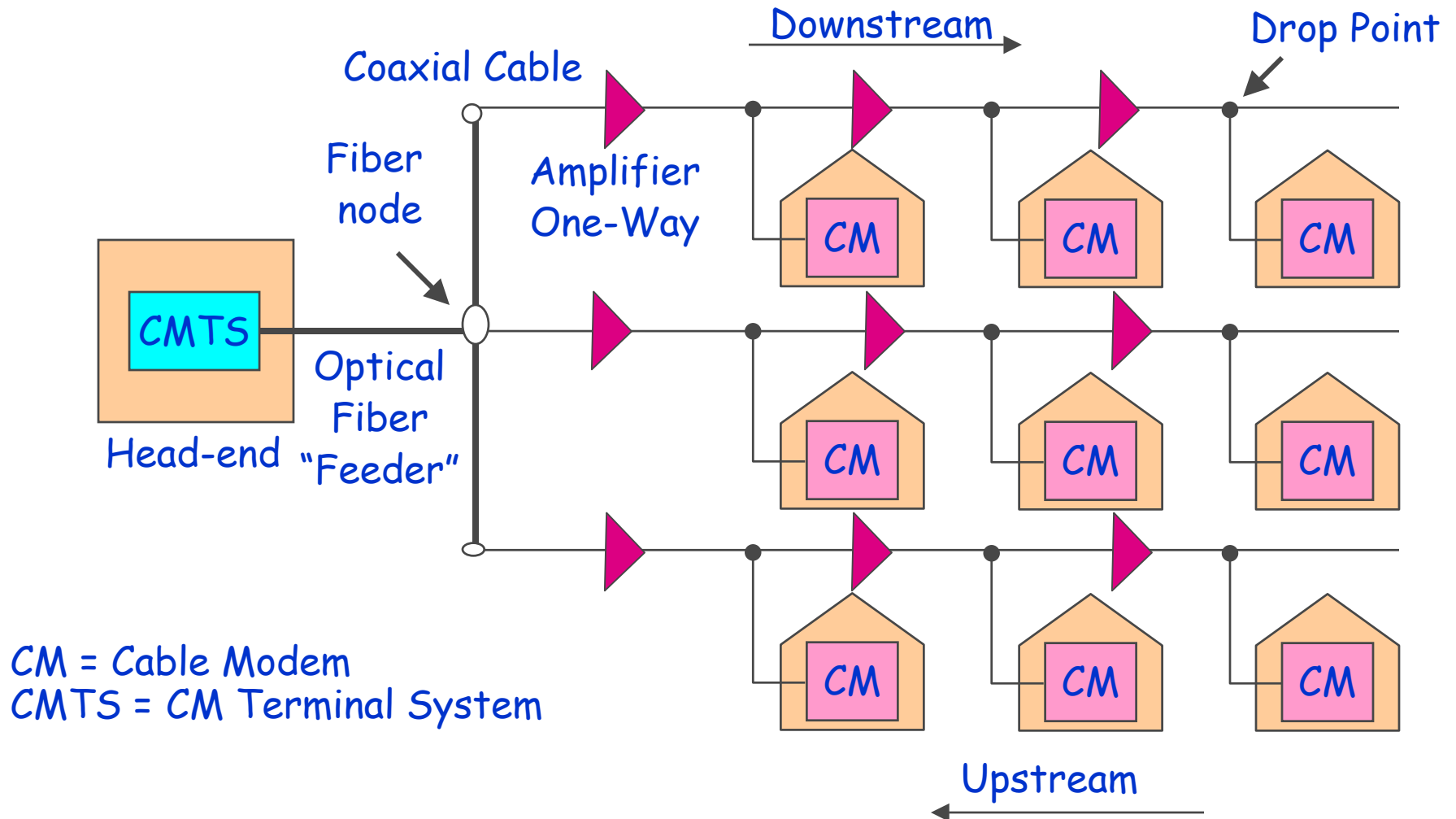 - Low-speed U/L

- Always ON!
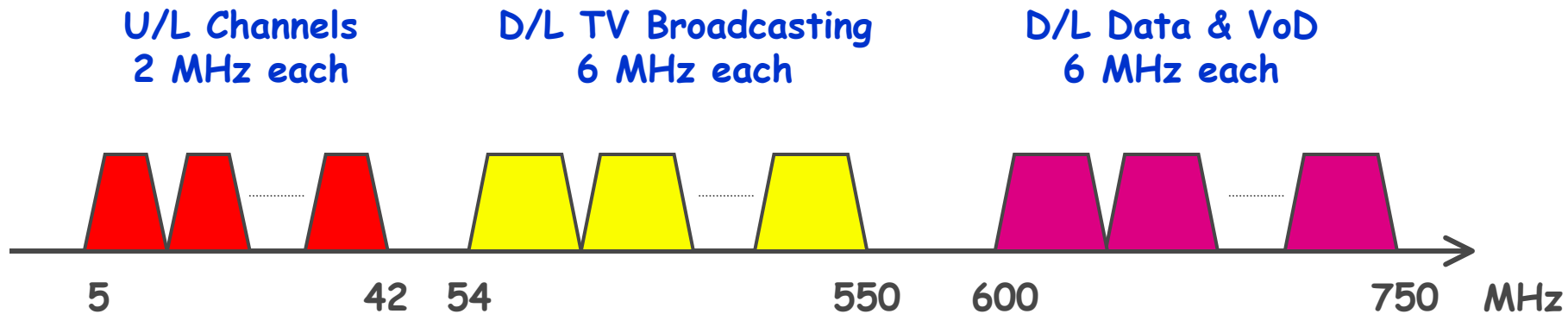
Traditional Cable TV Network

Picking antenna

Head end

Coaxial cable

Amplifier

Splitter

Drop cable

Tap

Hybrid/Fiber Cable (HFC)

One-way HFC Architecture

CM = Cable Modem
CMTS = CM Terminal System

Cable Bandwidth Allocations

U/L Channels
2 MHz each

D/L TV Broadcasting
6 MHz each

D/L Data & VoD
6 MHz each

5   42   54   550   600   750   MHz

- Currently, the band from 54MHz to 550 MHz is used for Analog TV broadcasting
  * Each Analog Channel is 6 MHz wide $\Rightarrow$ 80~85 Channels
- D/L Channels in the band 600~750 MHz band is used for Internet Data and VoD
  * Each Digital Channel is 6 MHz wide. Data is Modulated using 64-QAM
  * Each Channel can support 6 bps/Hz $\Rightarrow$ Each Channel can support ~ 36 Mbps
  * With FEC and Channel Separation, each Channel can support 27~30 Mbps
- U/L Channels in the band 5~42 MHz band is used for Data/Voice/VoIP
  * Each Digital Channel is 2 MHz wide. Data is Modulated using QPSK
  * Each Channel can support 2 bps/Hz $\Rightarrow$ Each Channel can support ~ 4 Mbps
  * U/L Channels are shared. Users may compete for the same Channel

Two-Way Cable Access

Internet

D/B

R

S

G

PSTN

Ethernet Switch

Demod

Splitter

Mod

O/E

National Feed

Local News/ Commercials

Combiner

E/O

FN

SPLITTER

CABLE MODEM