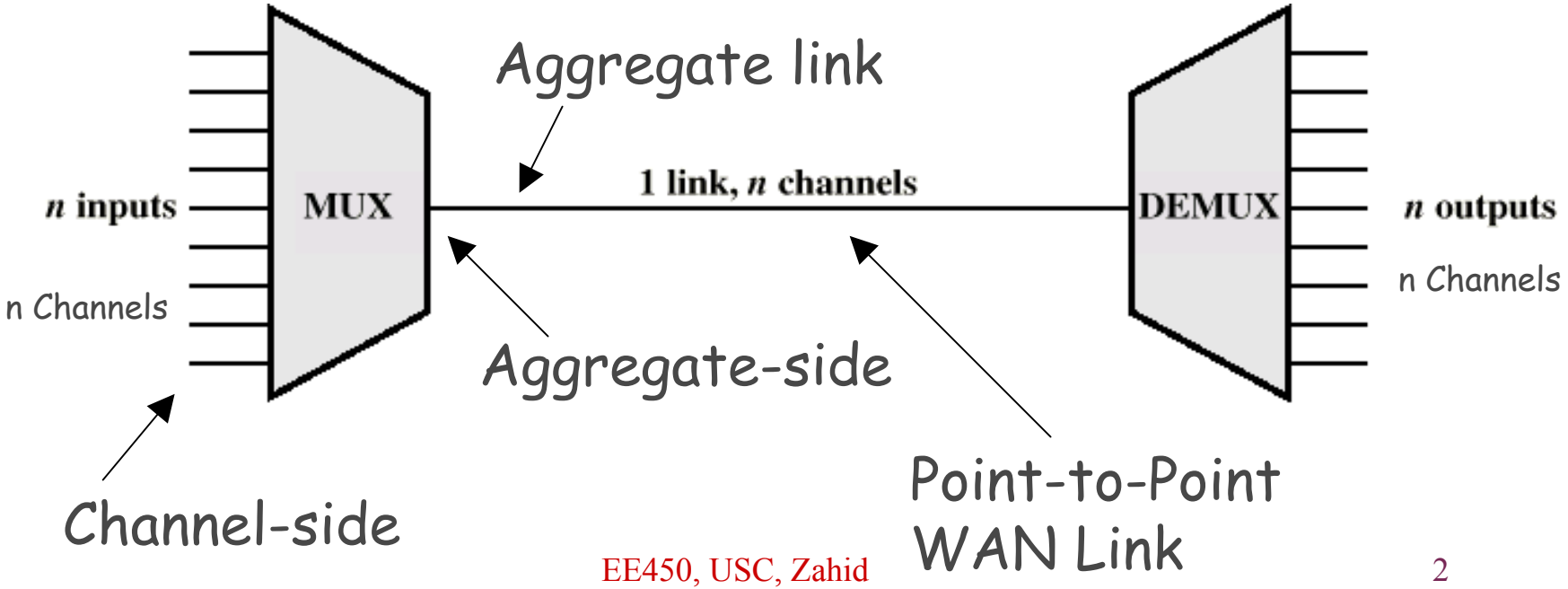
Multiplexing: "Resource Sharing"

EE450: Introduction to Computer Networks

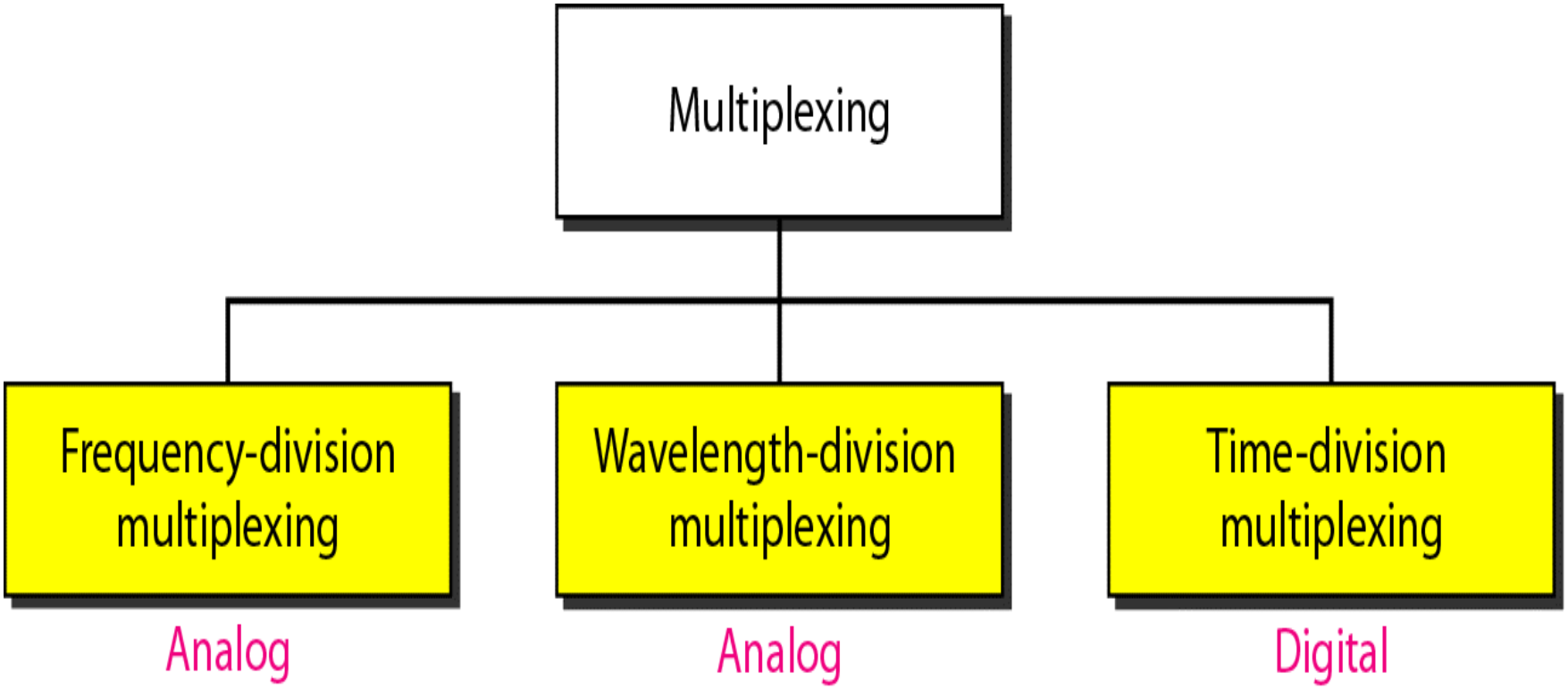
Professor A. Zahid

Multiplexing

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



Categories of Multiplexing

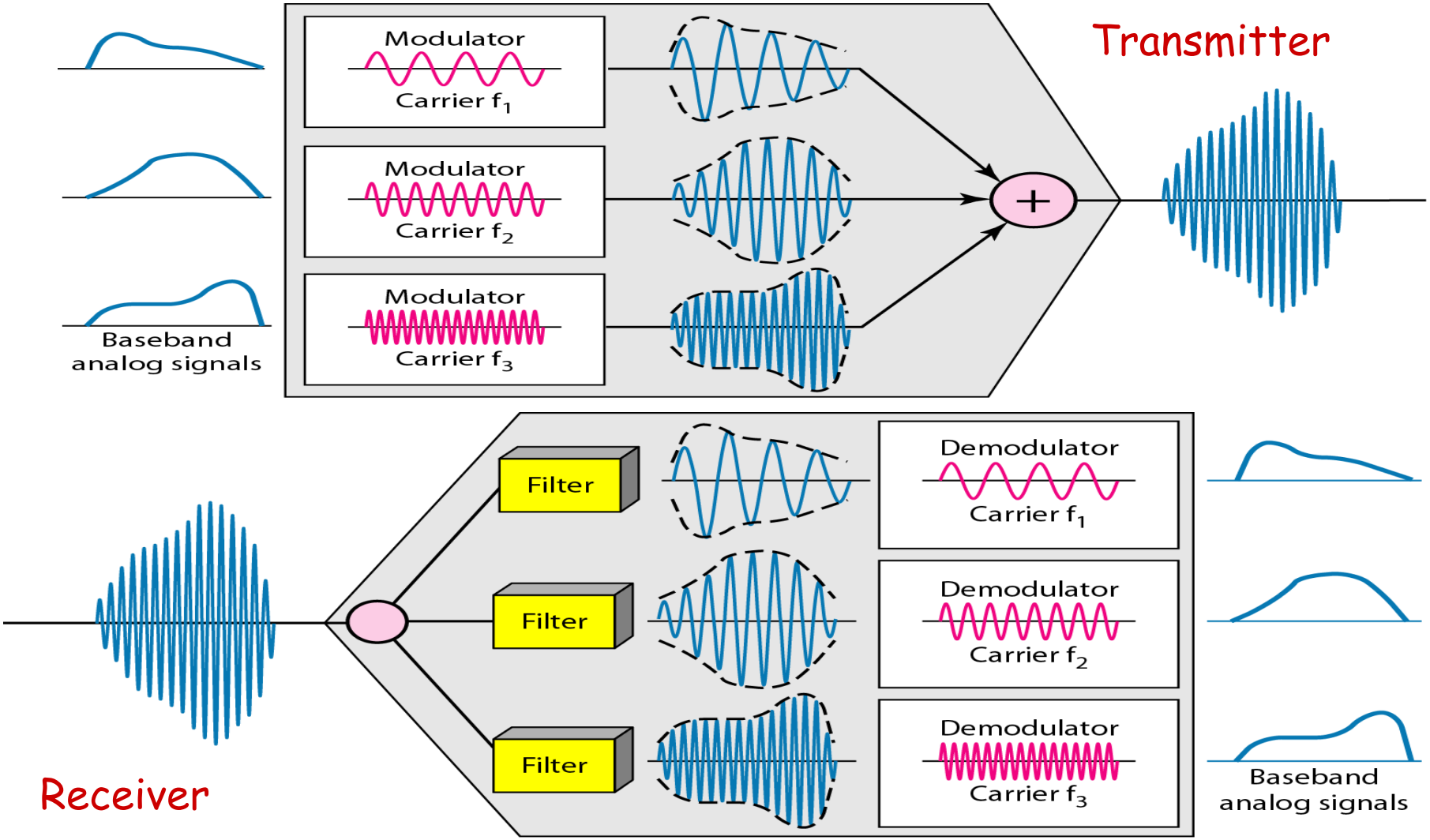


Synchronous TDM
Statistical TDM

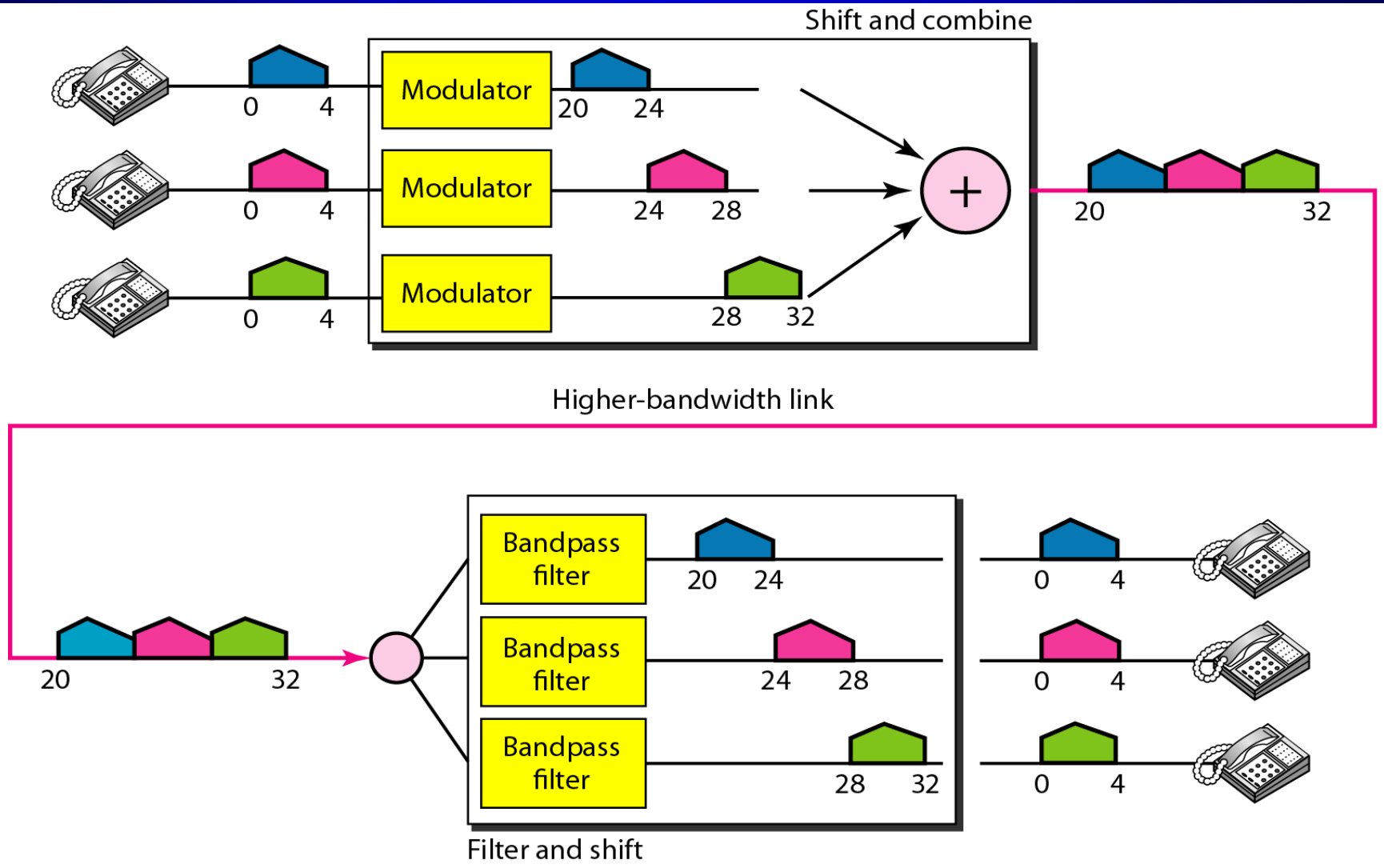
Frequency Division Multiplexing

- 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

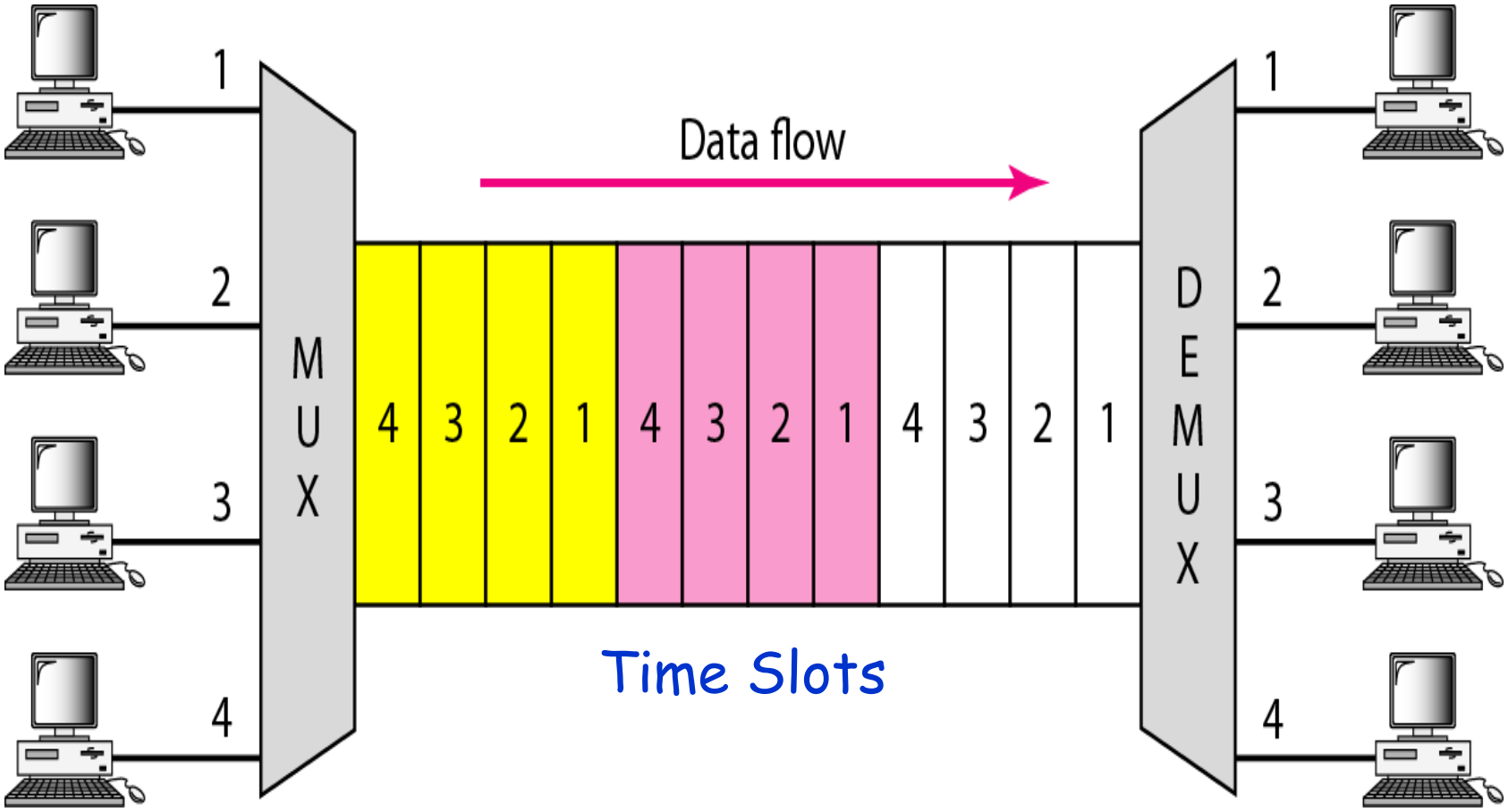
FDM Process


Transmitter
Modulator
Carrier f_1
Modulator
Carrier f_2
Modulator
Carrier f_3
+
Baseband analog signals
Receiver
Filter
Filter
Filter
Demodulator
Carrier f_1
Demodulator
Carrier f_2
Demodulator
Carrier f_3
Baseband analog signals

Example: FDM of Voice Signals



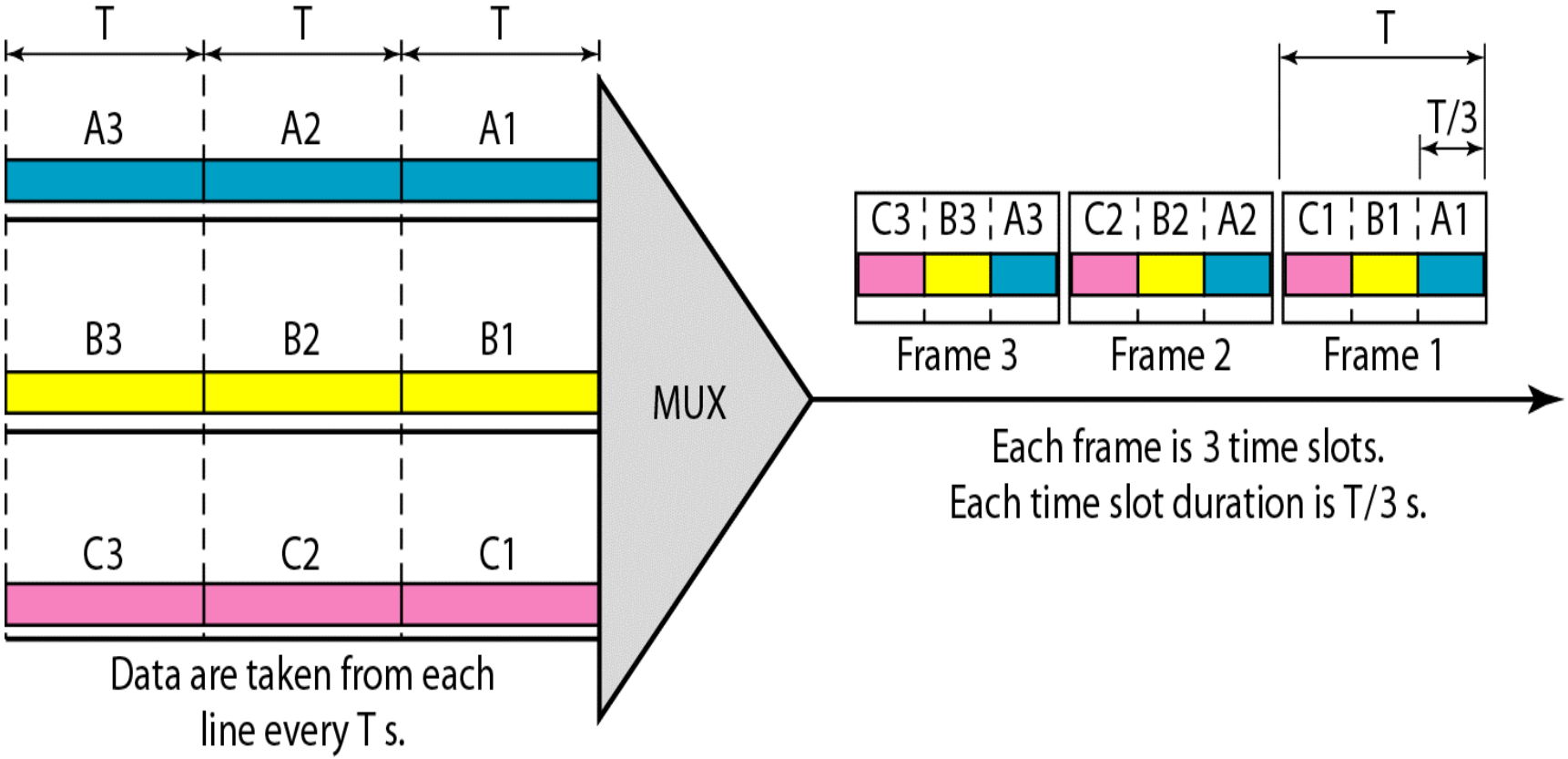
Time Division Multiplexing (TDM)



Synchronous TDM

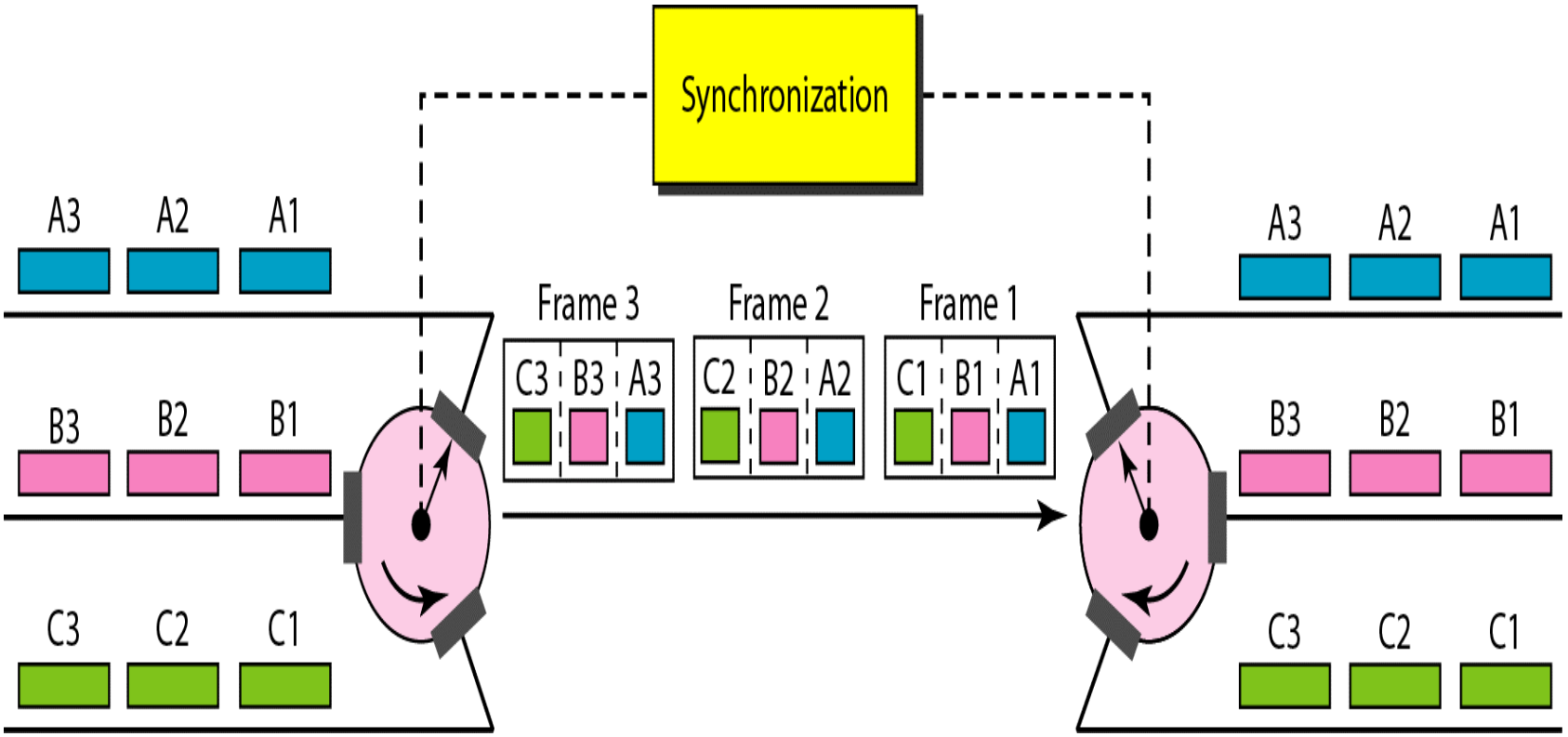
- Data rate of medium exceeds data rate of digital signal to be transmitted
- Multiple digital signals interleaved in time
- May be at bit level or block of bits
- Time slots pre-assigned to sources and fixed
- Time slots allocated even if source is idle
- Time slots do not have to be evenly distributed amongst sources

Synchronous TDM (Cont.)

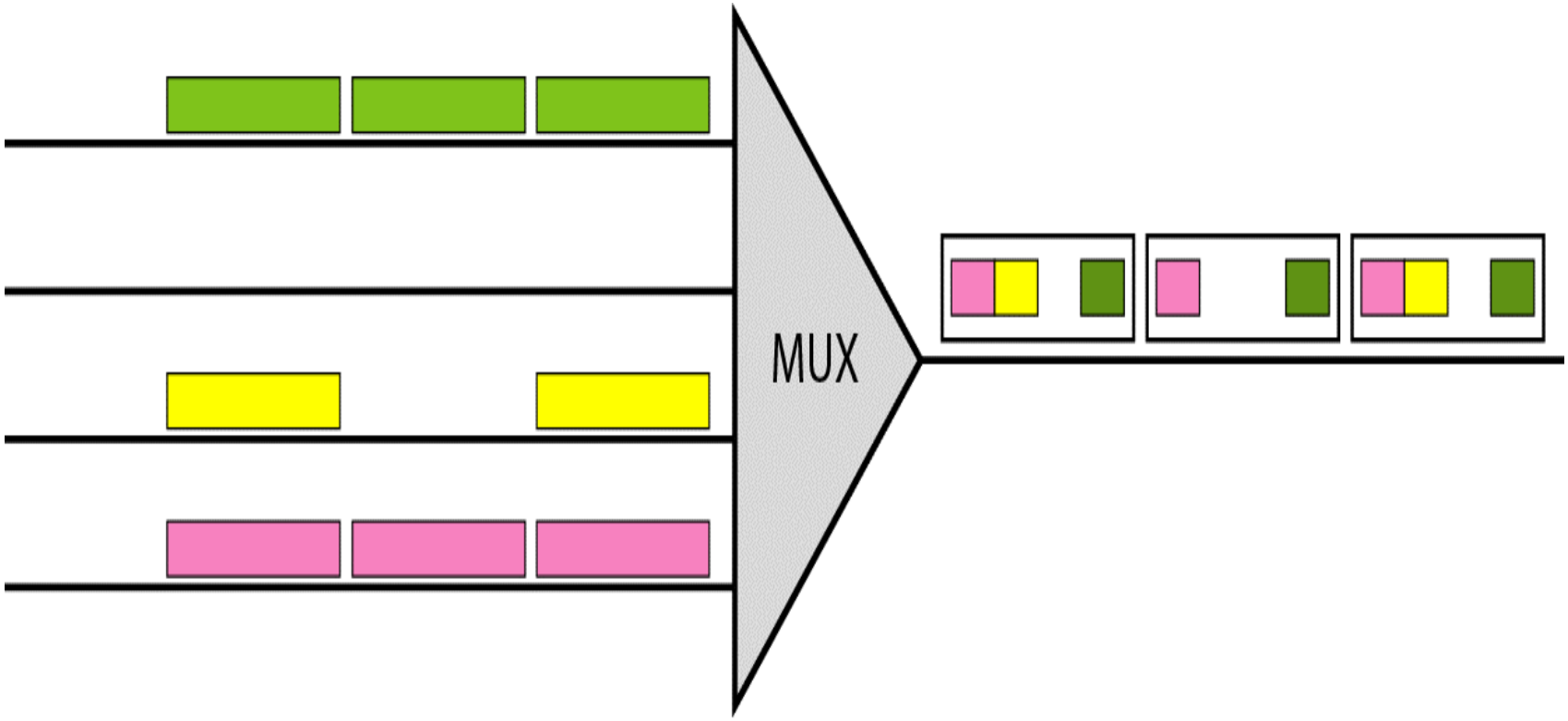


In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.

Synchronous TDM (Cont.)

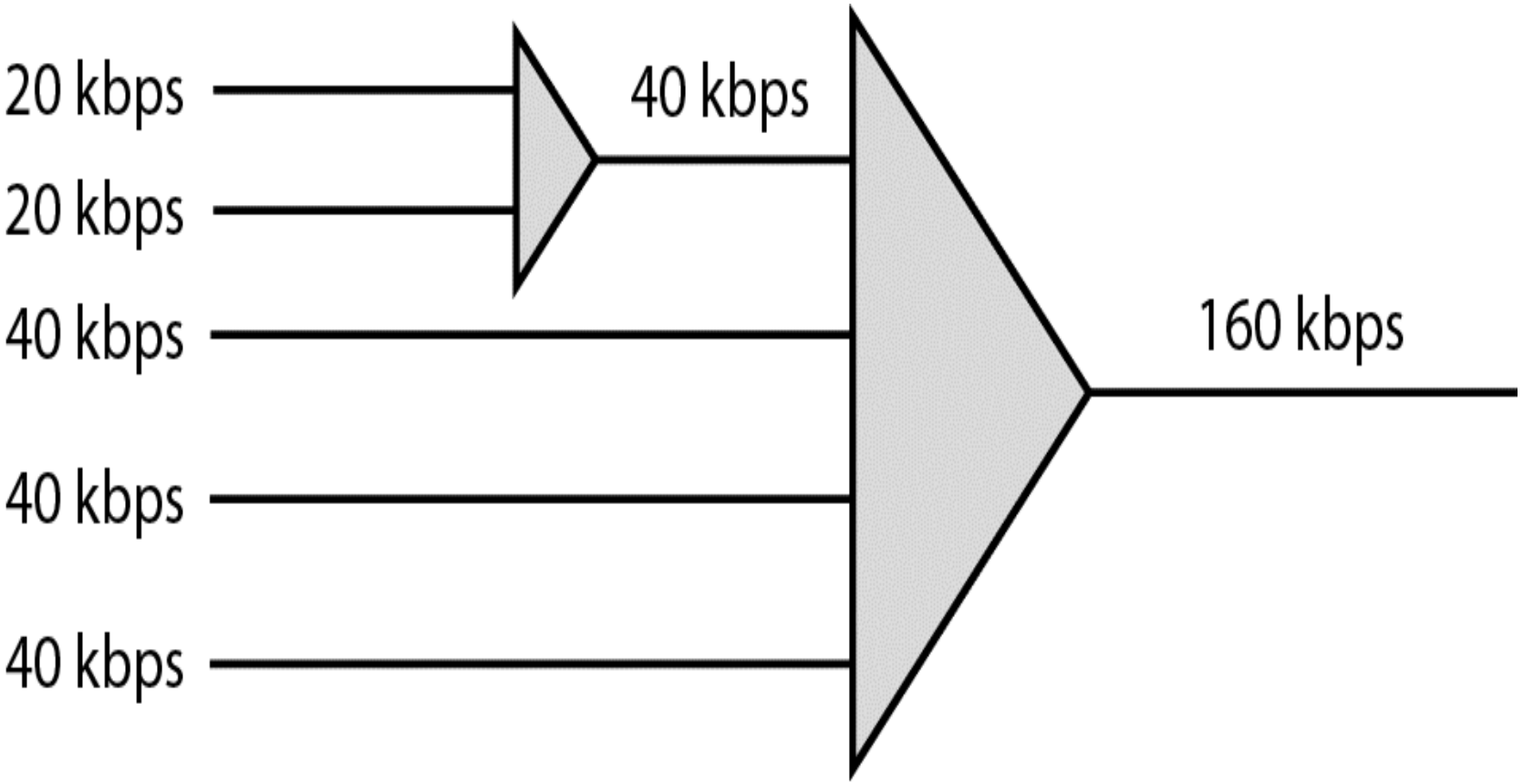


Empty Time Slots

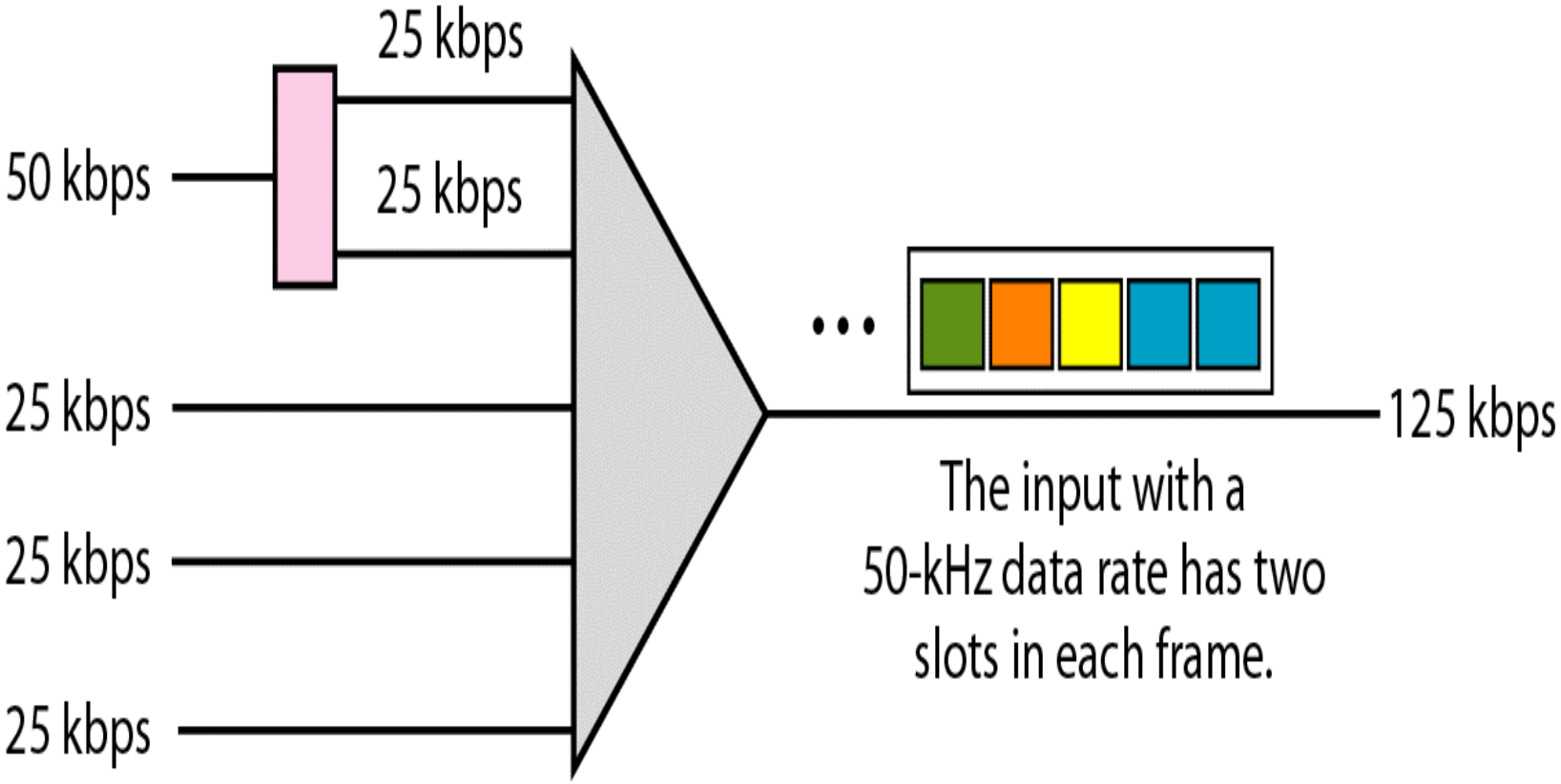


Empty TS can't be used by other Sources ⇒ Waste of Bandwidth

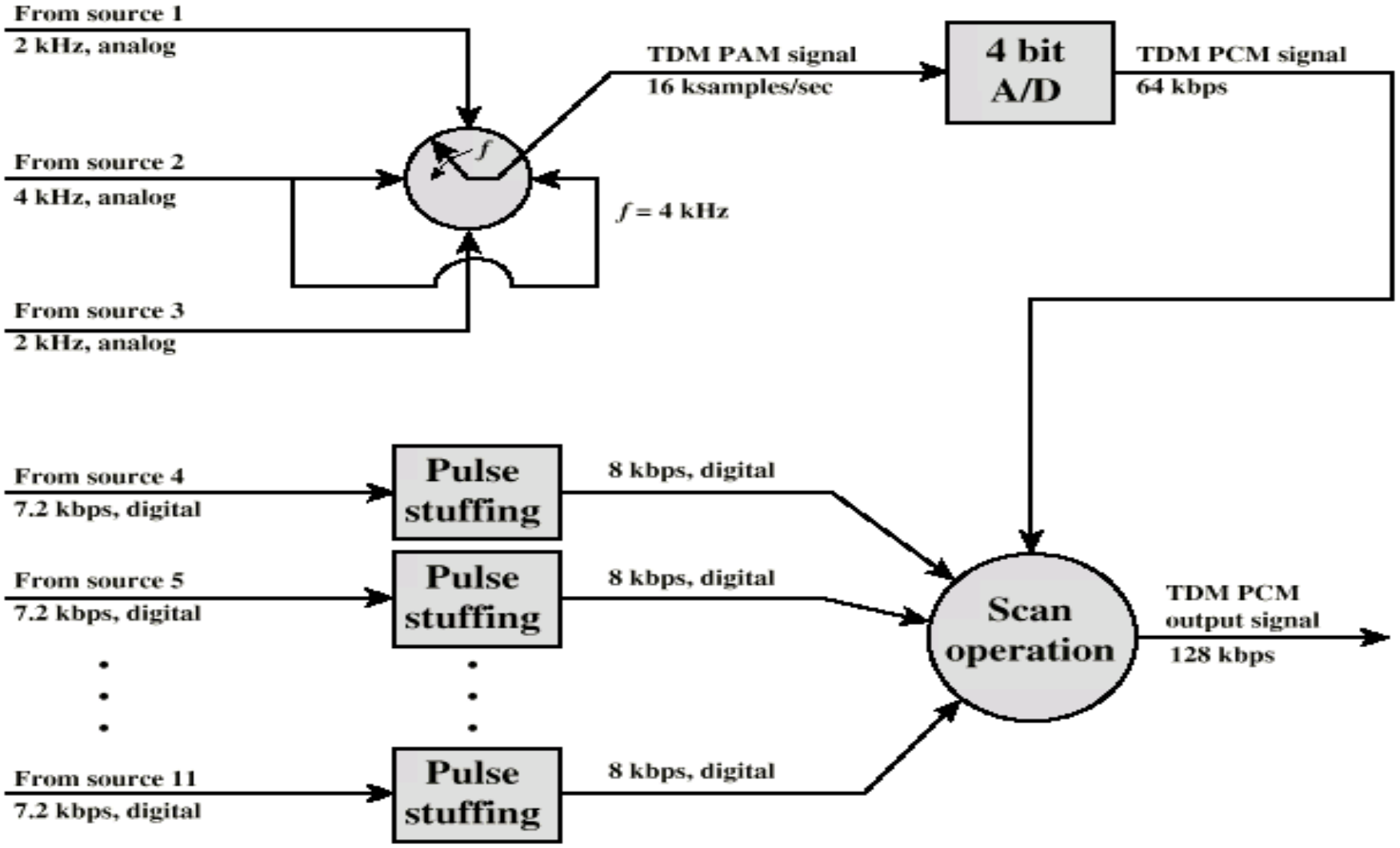
Multilevel Multiplexing



Multiple-Slot Multiplexing

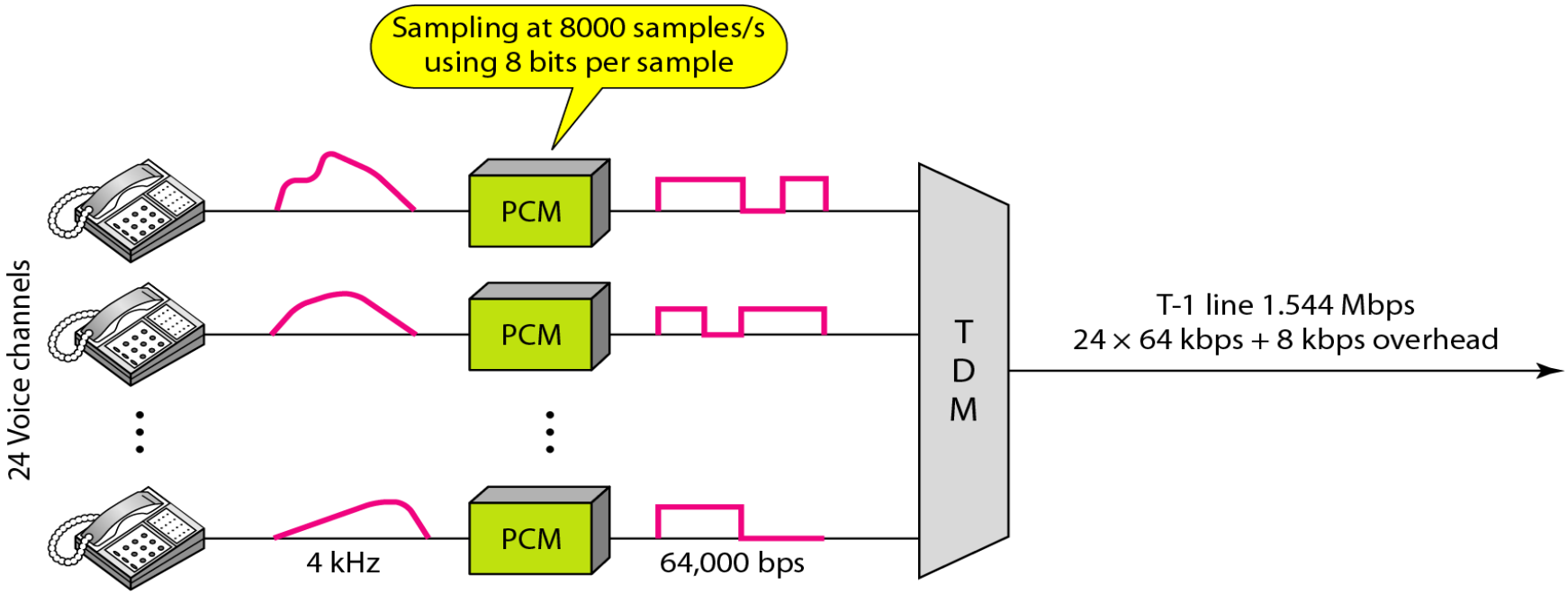


Example

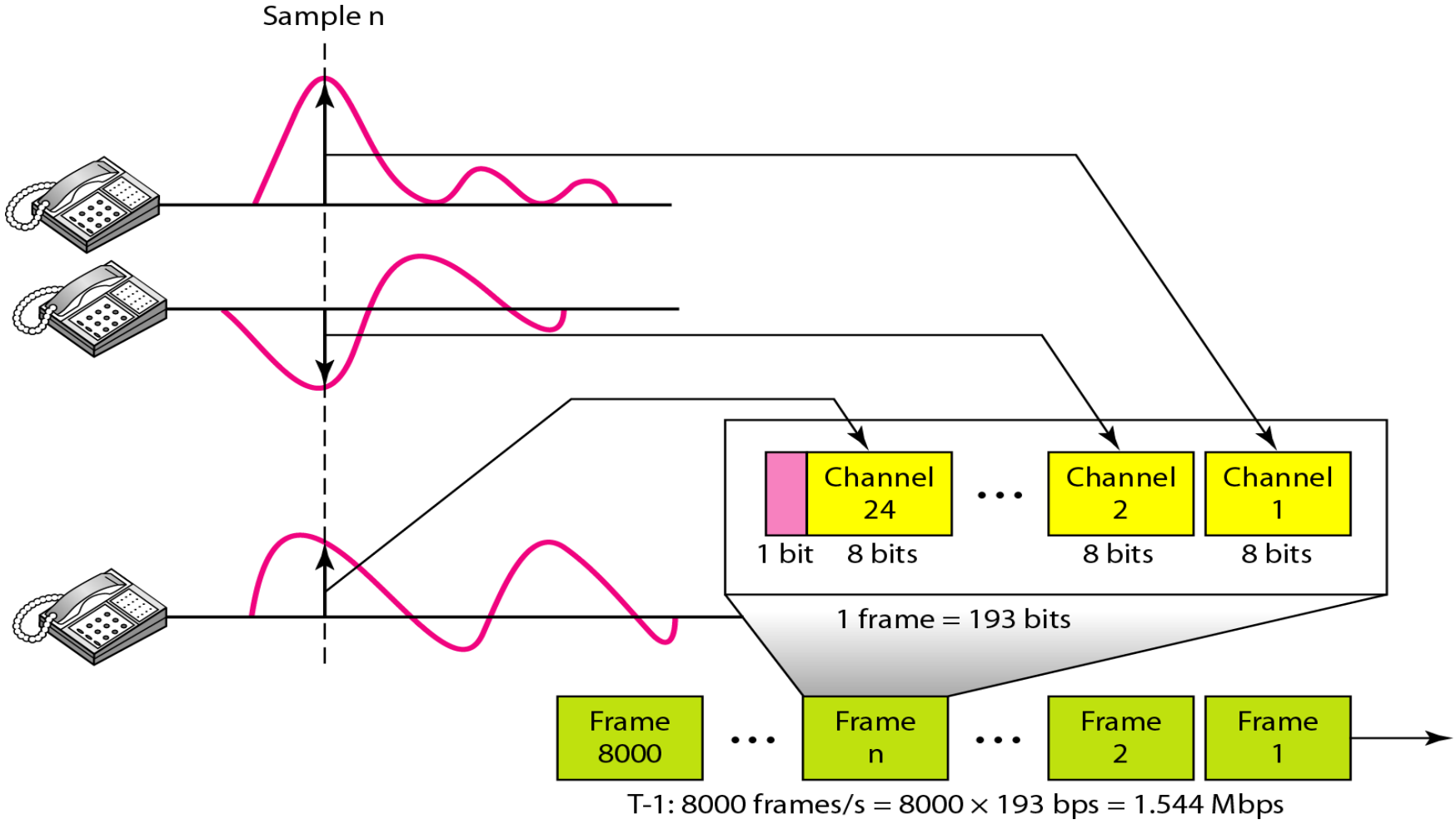

From source 1
2 kHz, analog
From source 2
4 kHz, analog
From source 3
2 kHz, analog
f
TDM PAM signal
16 ksamples/sec
f = 4 kHz
4 bit
A/D
TDM PCM signal
64 kbps
From source 4
7.2 kbps, digital
From source 5
7.2 kbps, digital
From source 11
7.2 kbps, digital
Pulse
stuffing
Pulse
stuffing
Pulse
stuffing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

Digital Carrier Hierarchy (US)

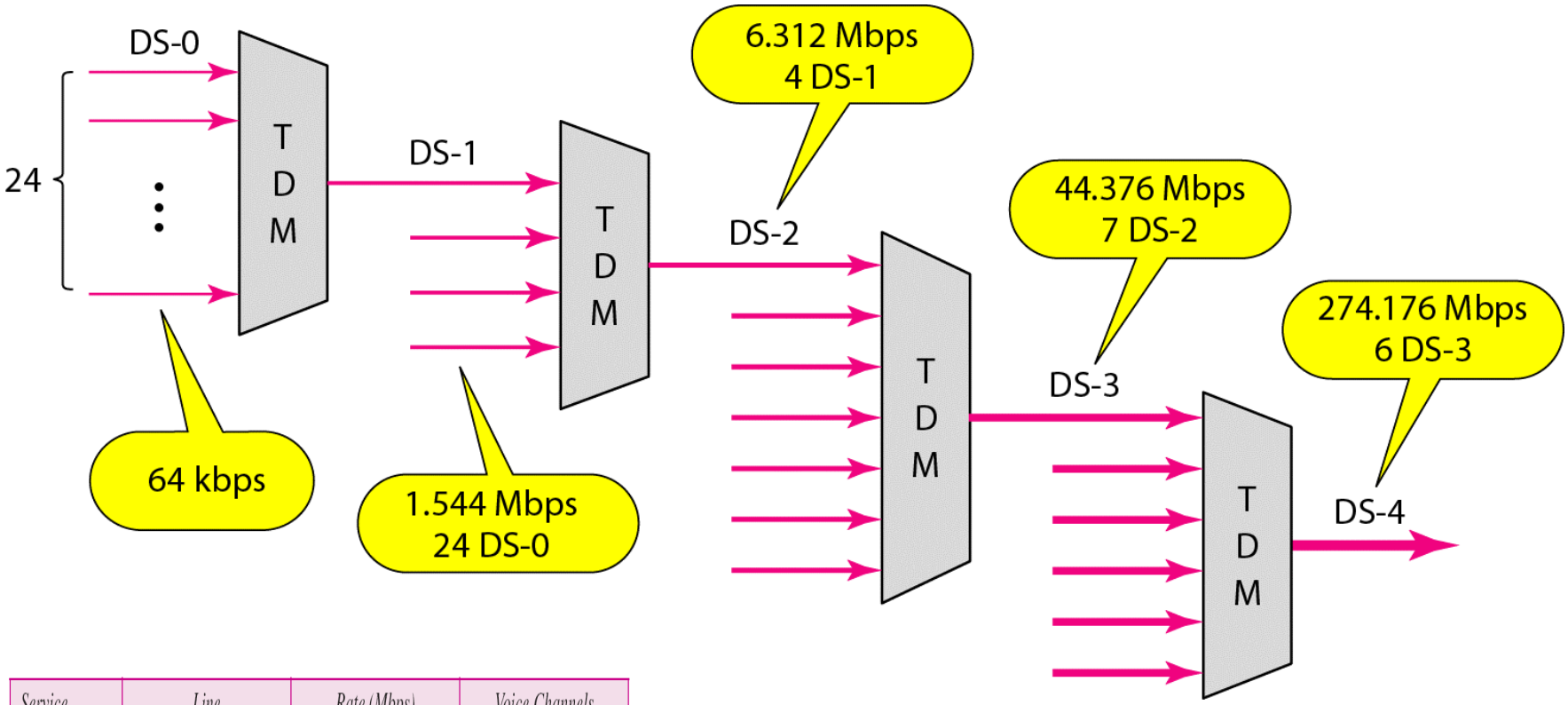
- US system based on DS-1 format
- Multiplexes 24 channels
- Each frame has 8 bits per channel plus one framing bit
  $\Rightarrow$ 193 bits/frame. Frame Duration is 125μseconds



T1 illustrated



Digital Hierarchy (US)



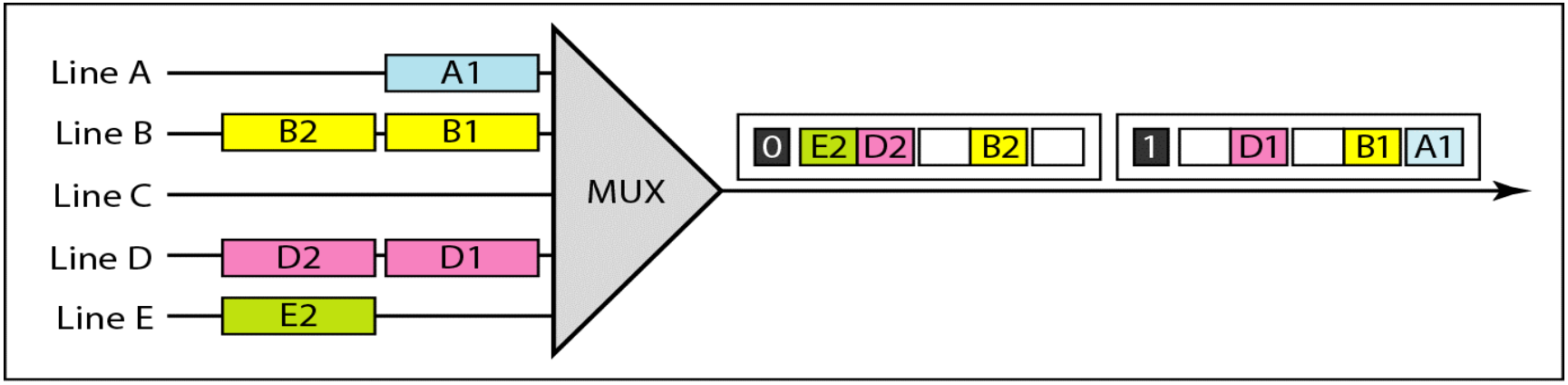
Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

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

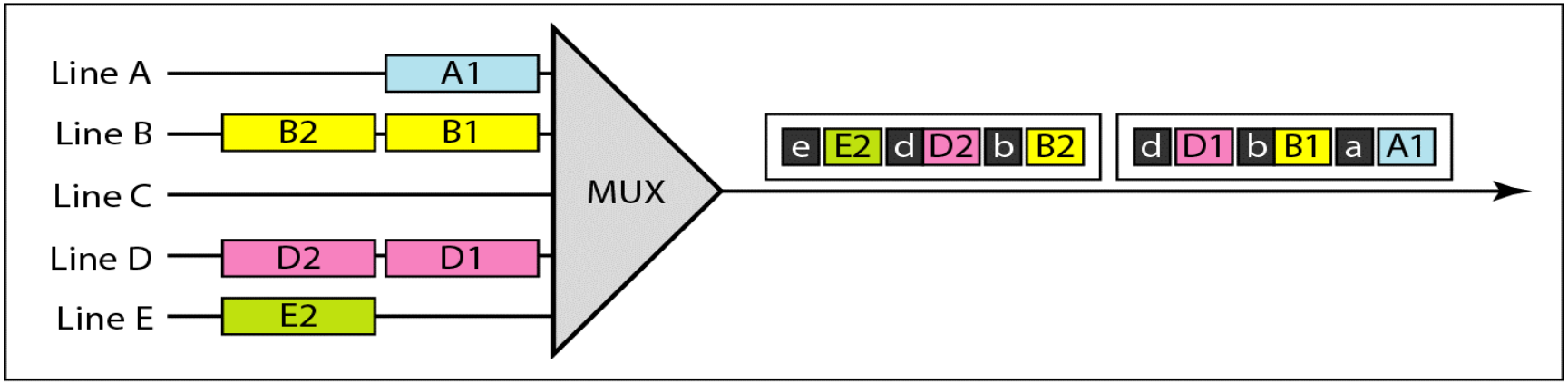
Statistical (Asynchronous) TDM

- 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

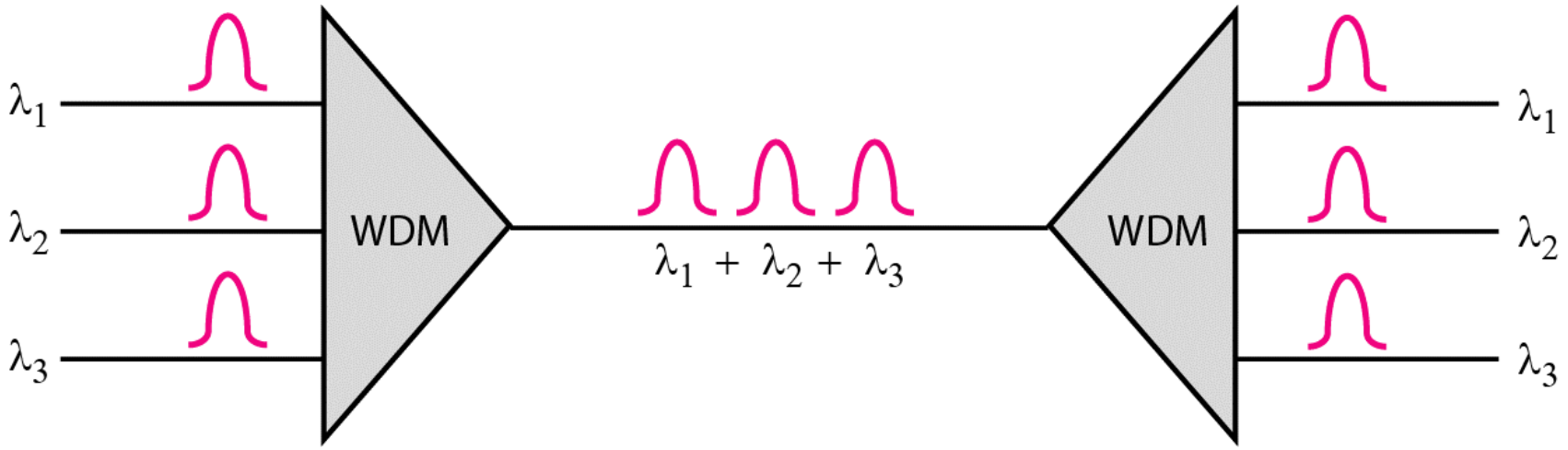
of Inputs = 10
Rate of each input (active) = 1000 bps
% of time a source is active = 50%
Case 1: Multiplexer capacity = 5000 bps
Case 2: Multiplexer capacity = 7000 bps

	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

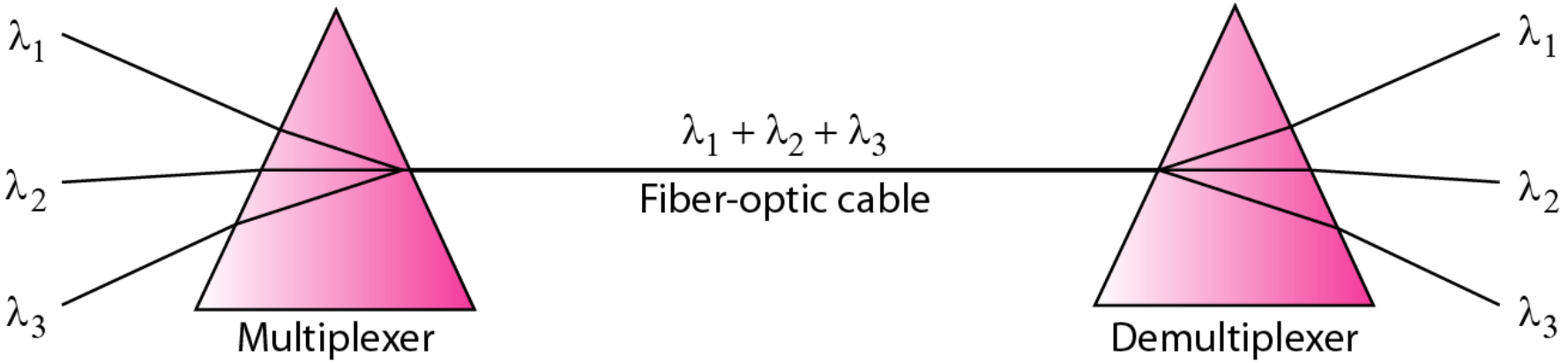
Conclusions

- 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



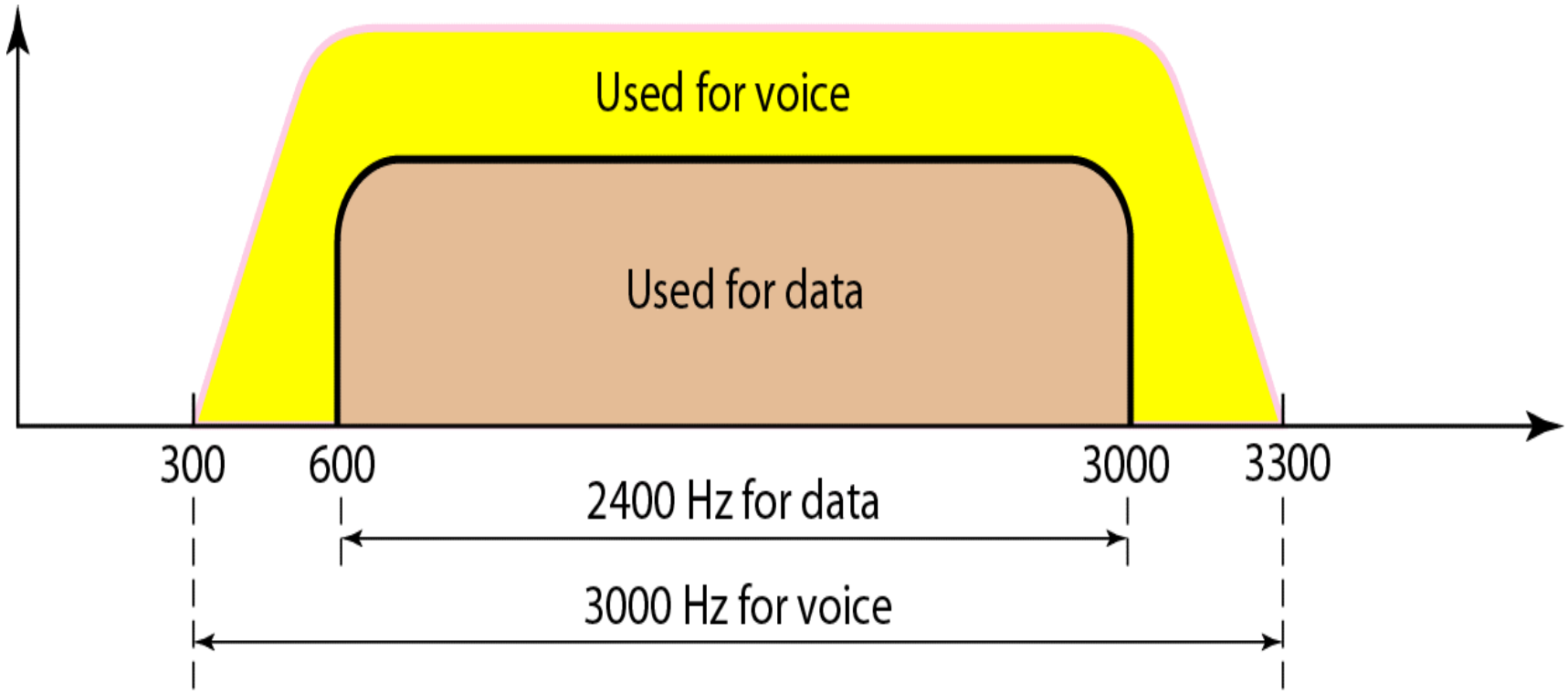
Prisms in wavelength-division multiplexing and de-multiplexing



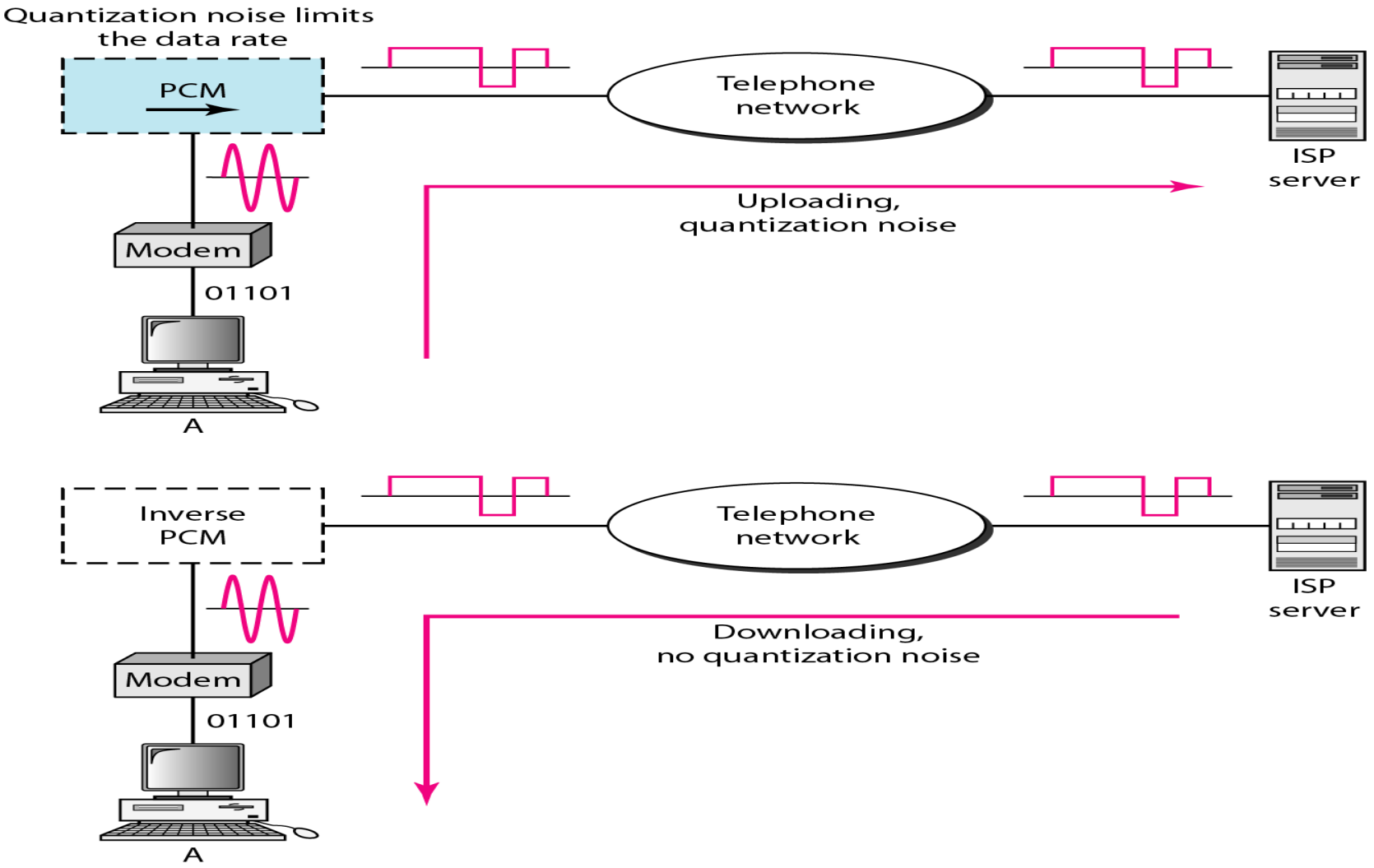
Access Technologies

- 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



Dial-up (Asymmetric 56 Kbps)



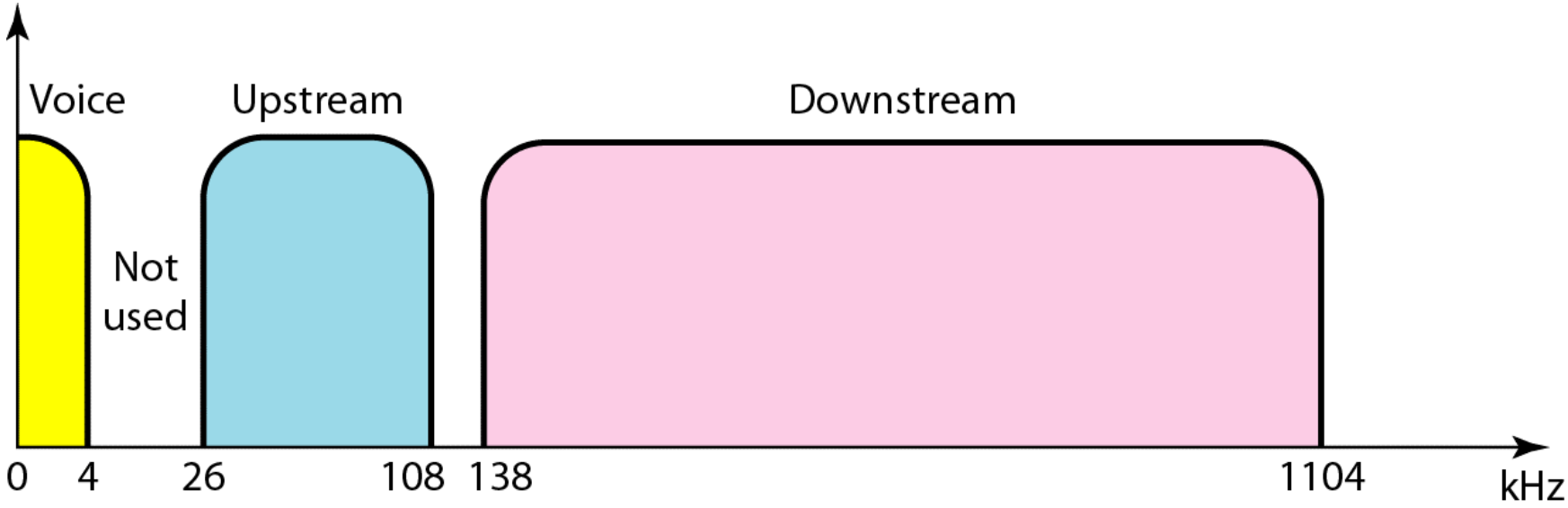
DSL Technologies

- 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 may 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

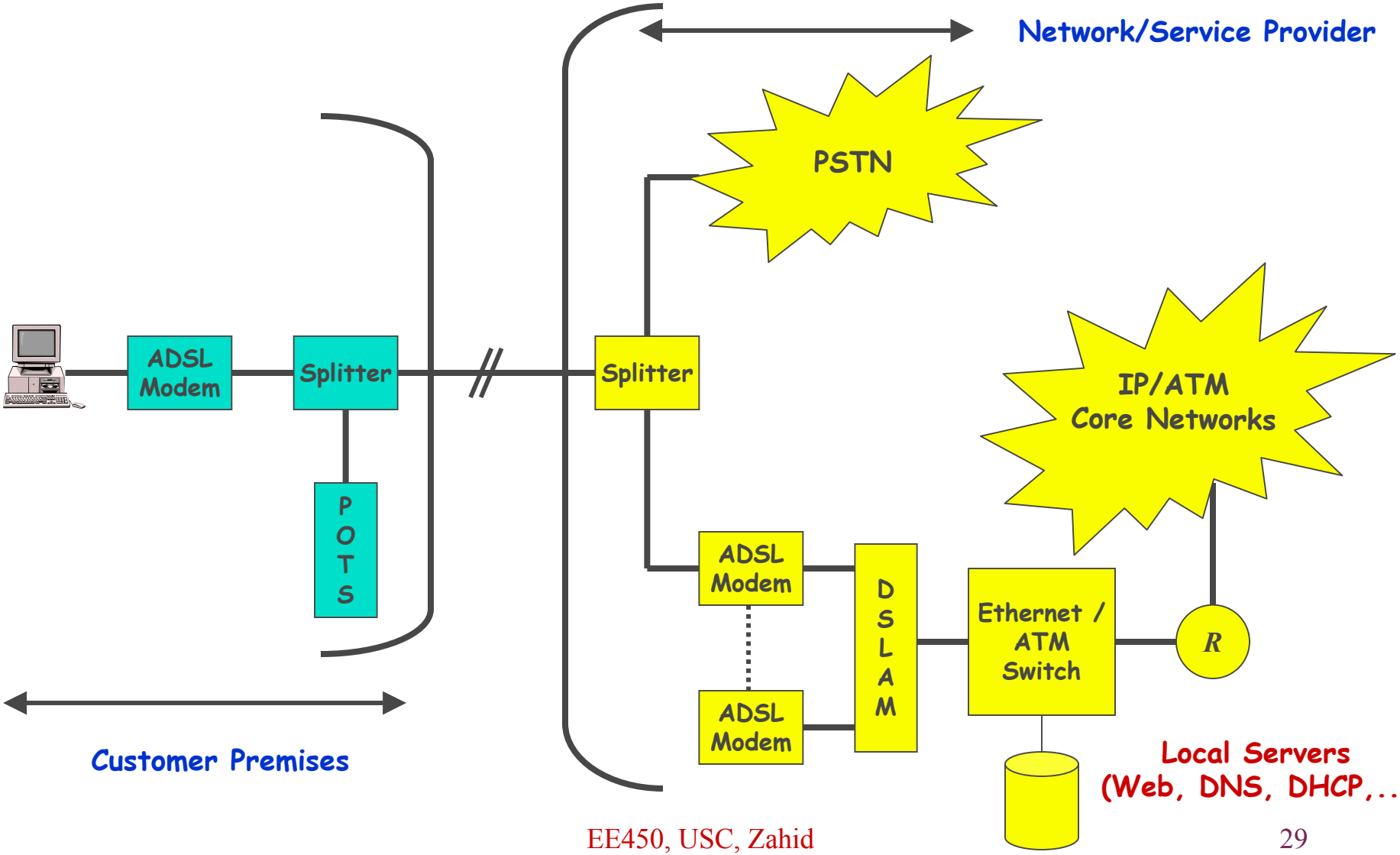
- Asymmetrical DSL was developed at BellCore in 1989. BellCore is currently Telcordia Tech. Inc.
- Asymmetric in the sense that the Downstream and the Upstream capabilities are not the same. It was designed to match the flow of data to and from the Internet
  - Downstream bandwidth supports up to ~ 8 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

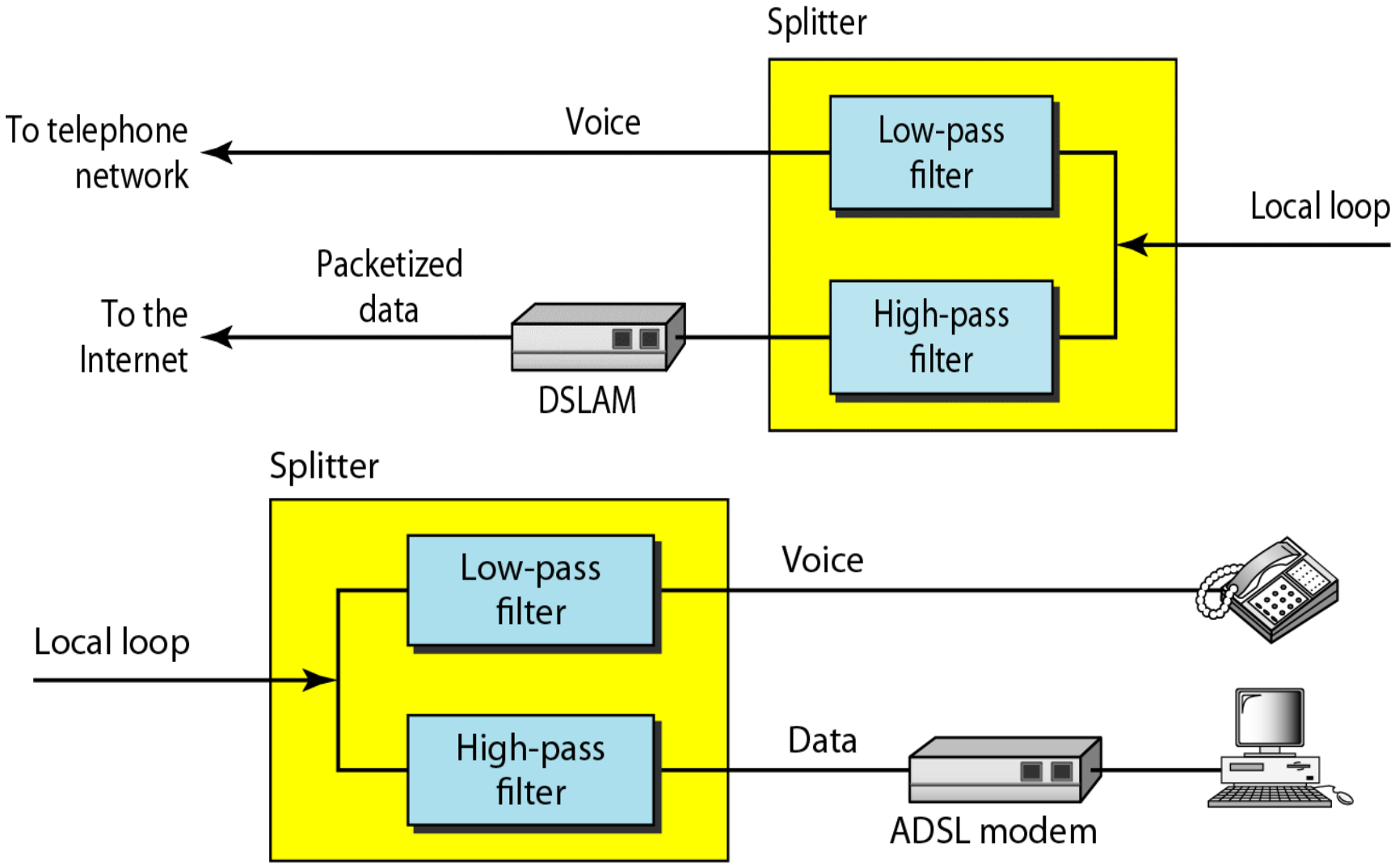


The bandwidth of the twisted pair copper wire is divided, using FDM (Frequency Division Multiplexing) into 3 non-overlapping sub-bands

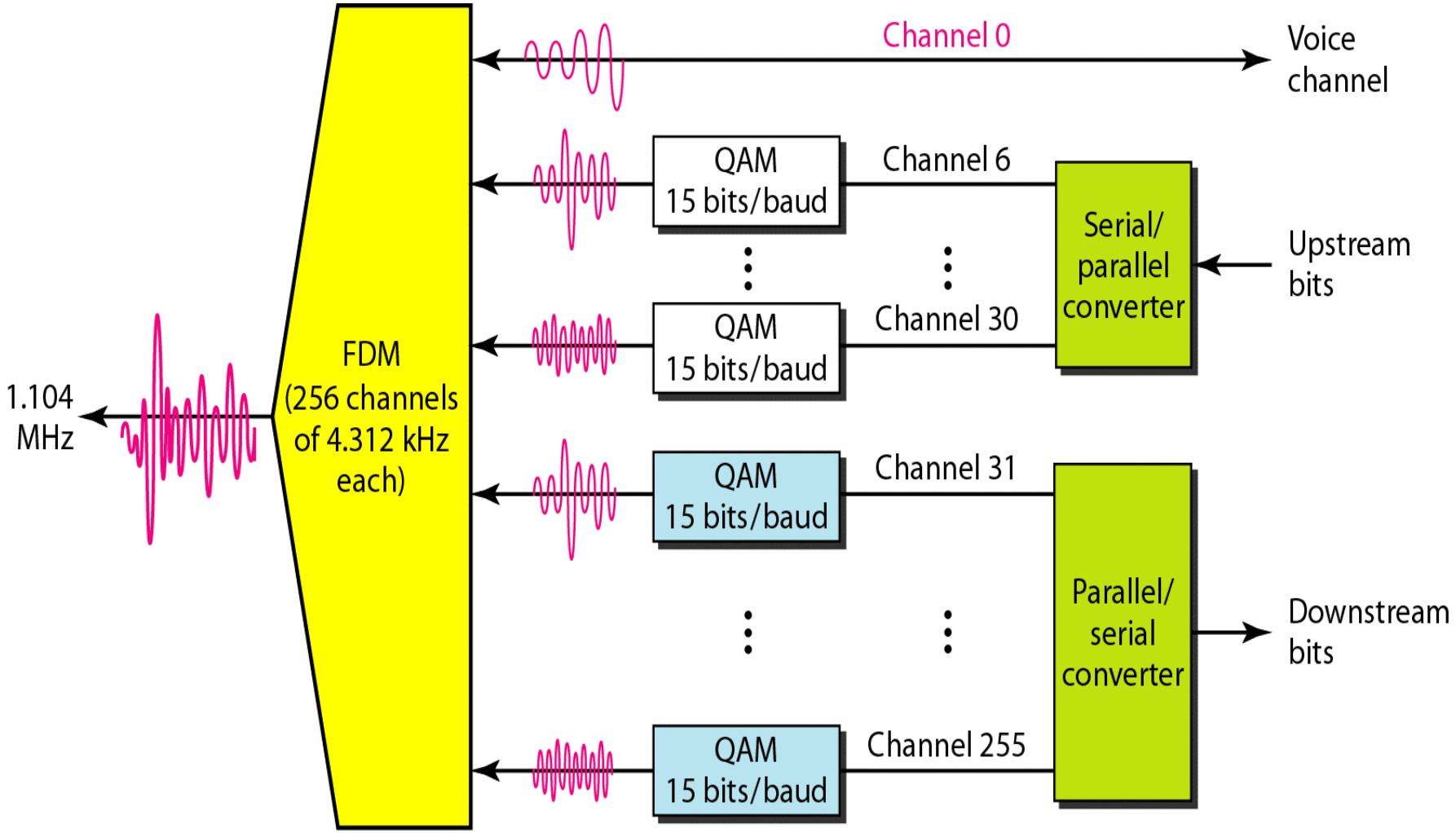
ADSL Architecture



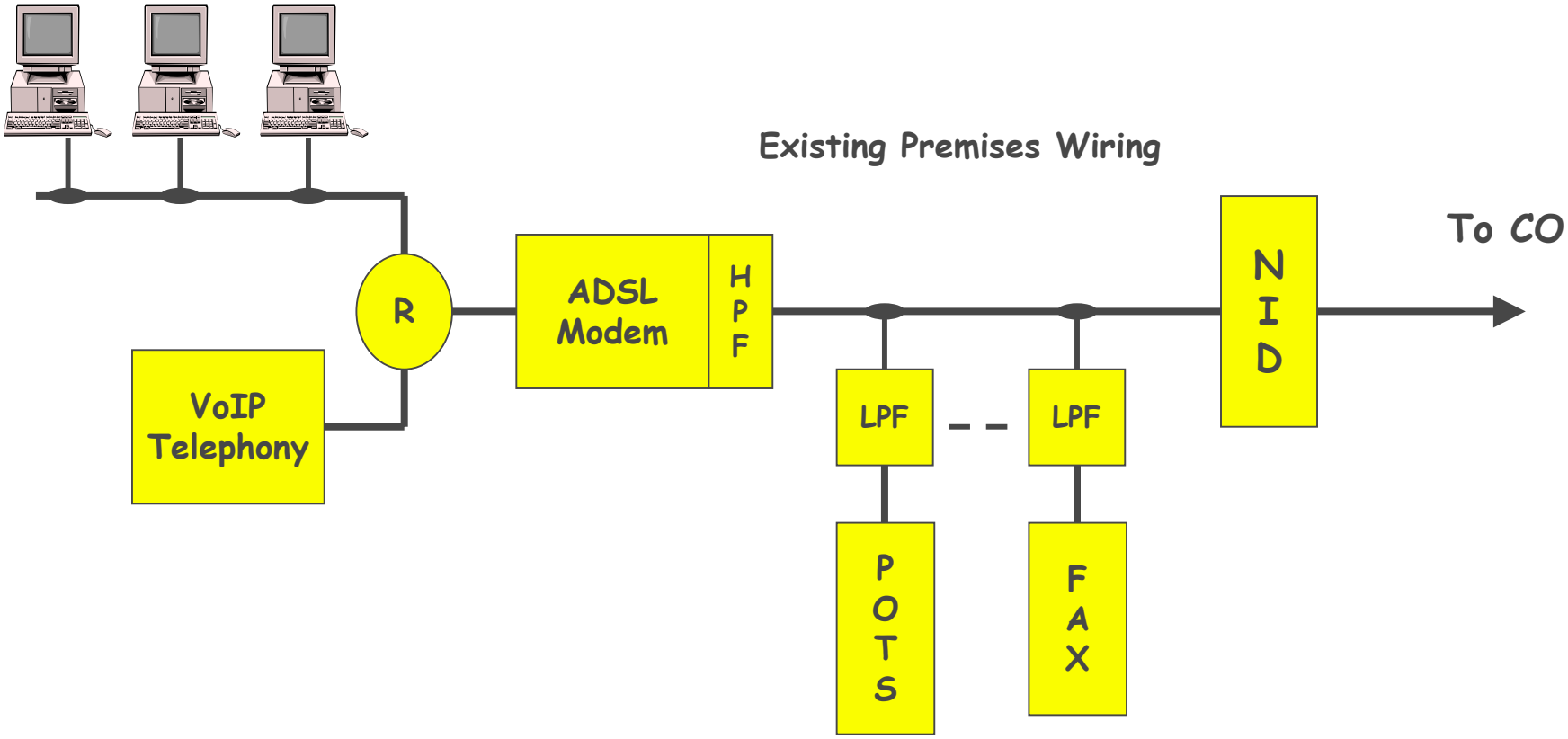
U/L and D/L ADSL



ADSL Technology (too much detail !)



Customer Premises Installation



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

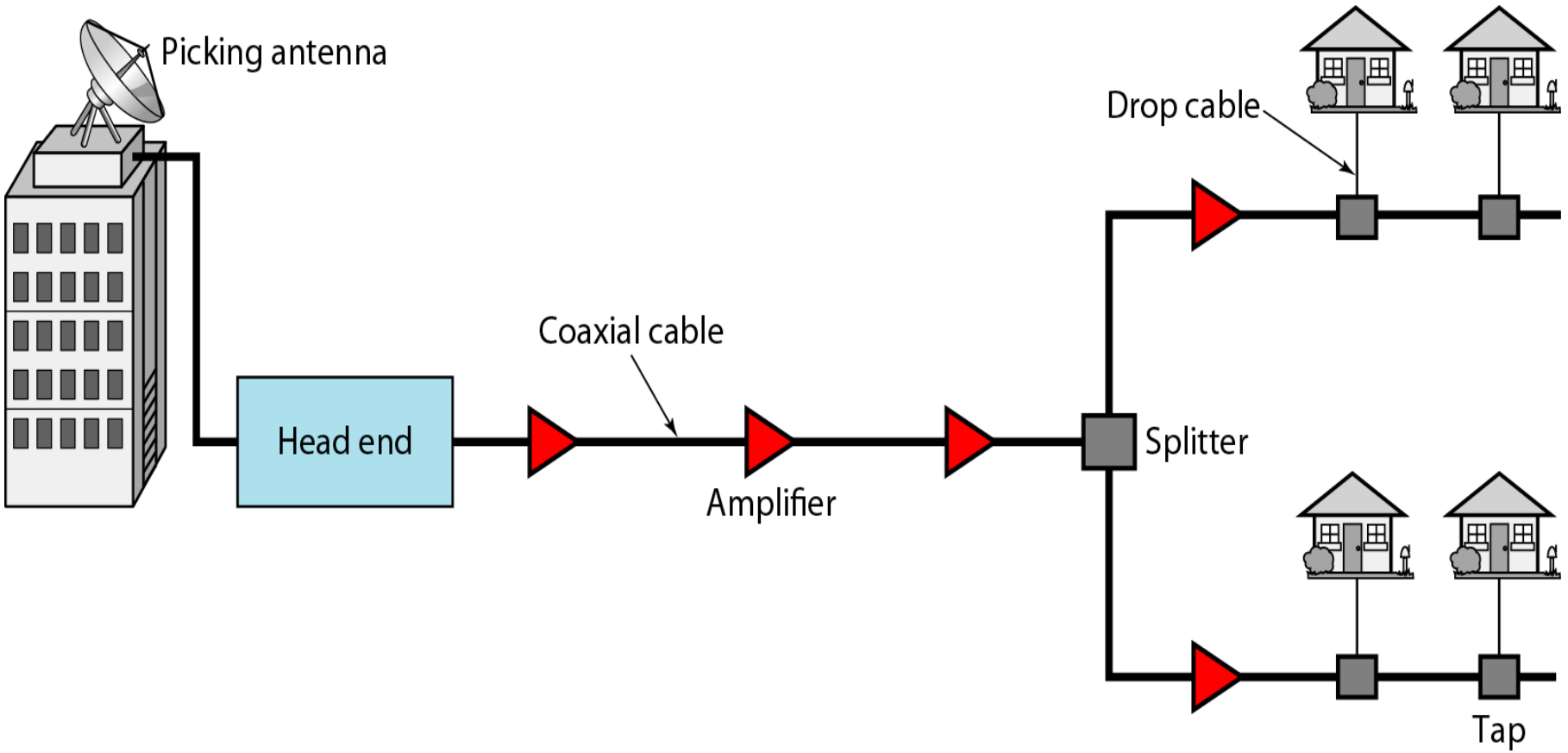
Problems with ADSL

- 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

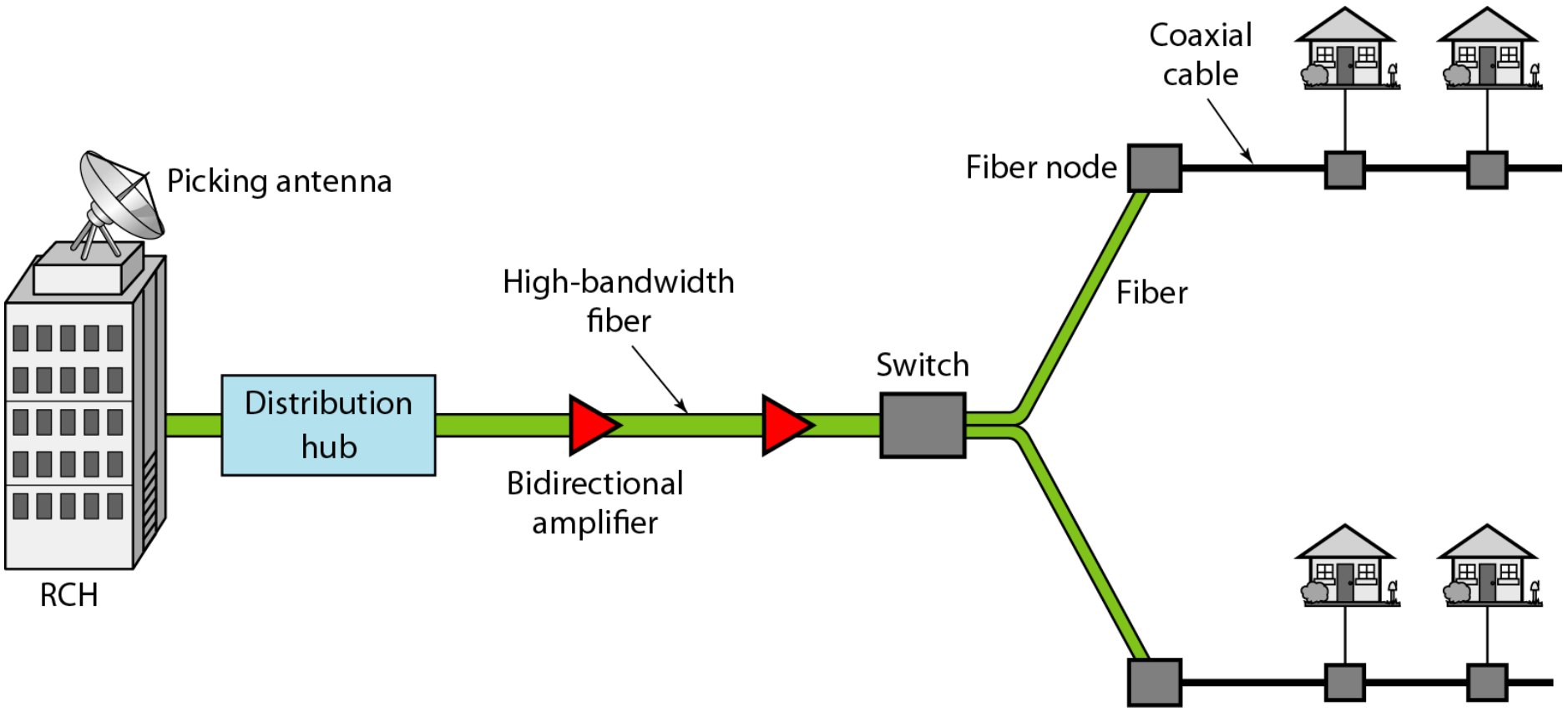
Cable Access

- 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!

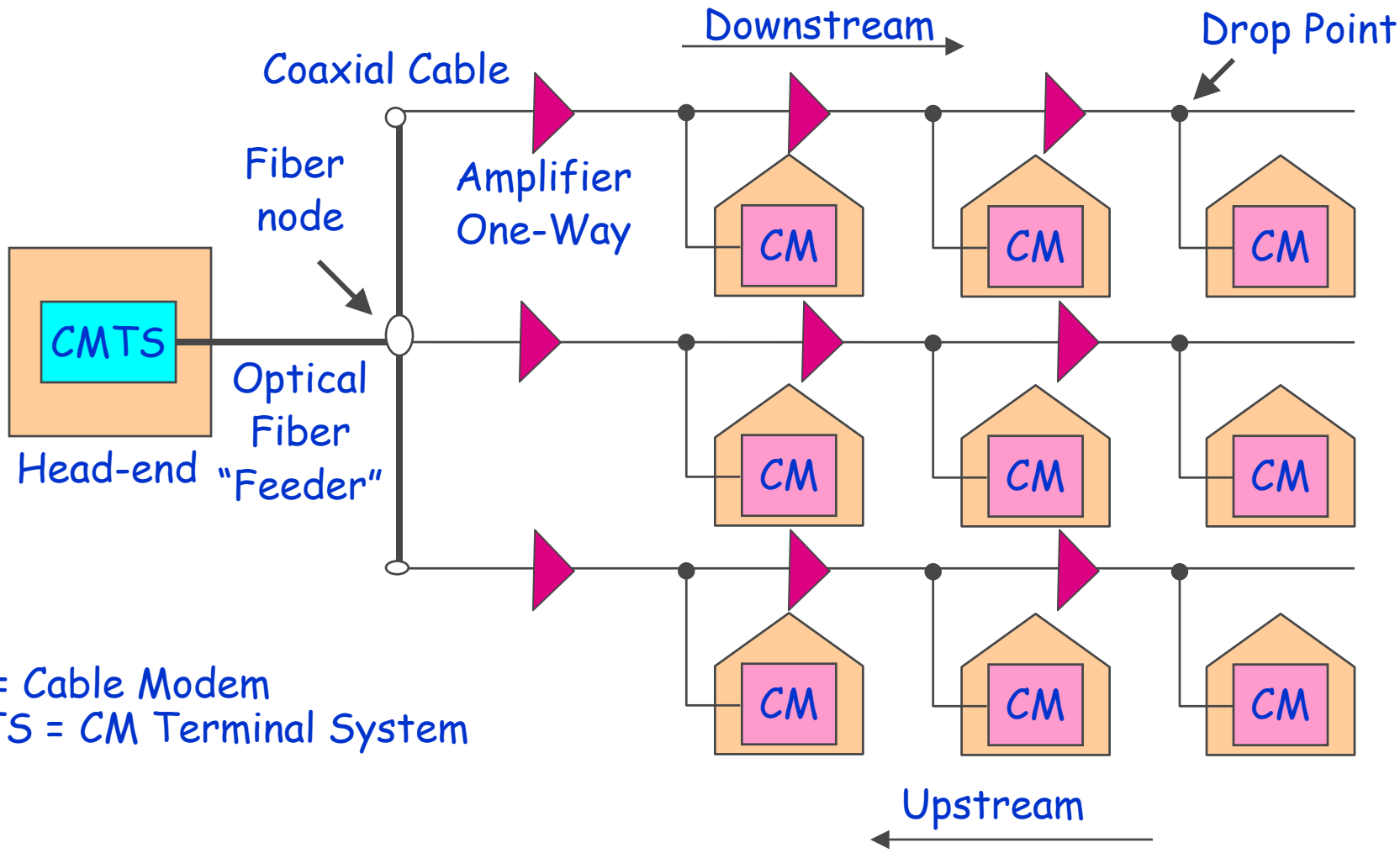
Traditional Cable TV Network



Hybrid/Fiber Cable (HFC)

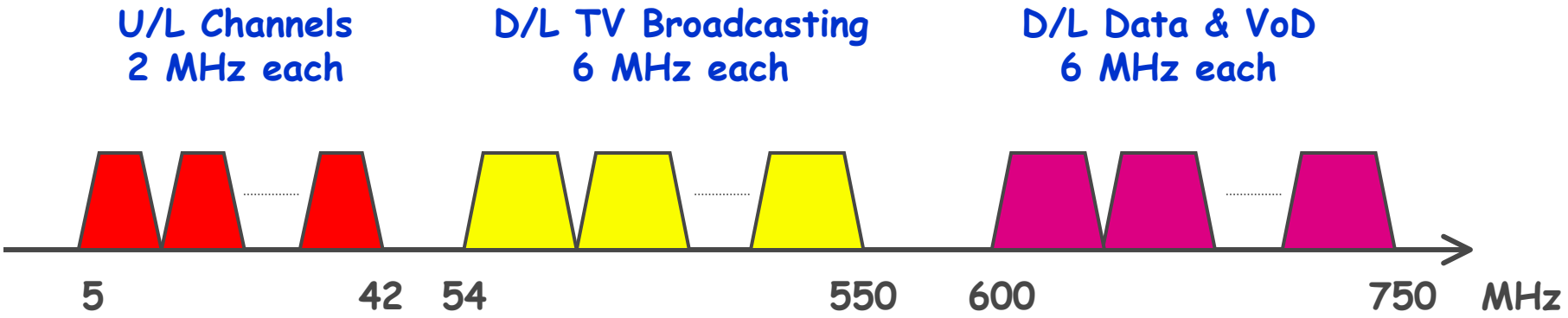


One-way HFC Architecture



CM = Cable Modem
CMTS = CM Terminal System

Cable Bandwidth Allocations



- Currently, the band from 54MHz to 550 MHz is used for Analog TV broadcasting
  - * Each Analog Channel is 6 MHz wide ⇒ 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 ⇒ 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 ⇒ Each Channel can support ~ 4 Mbps
  - * U/L Channels are shared. Users may compete for the same Channel

Two-Way Cable Access