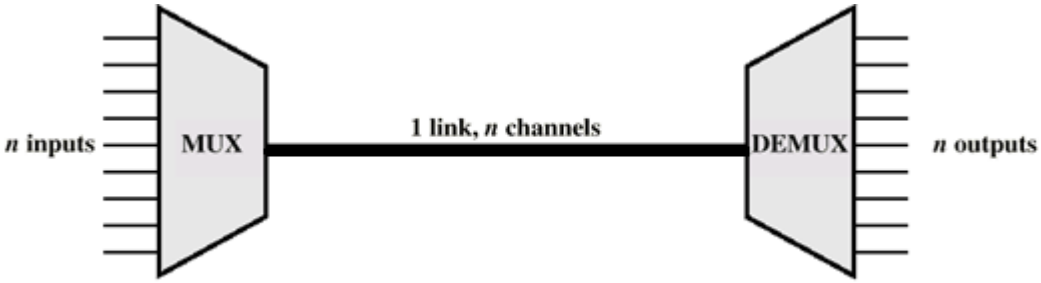
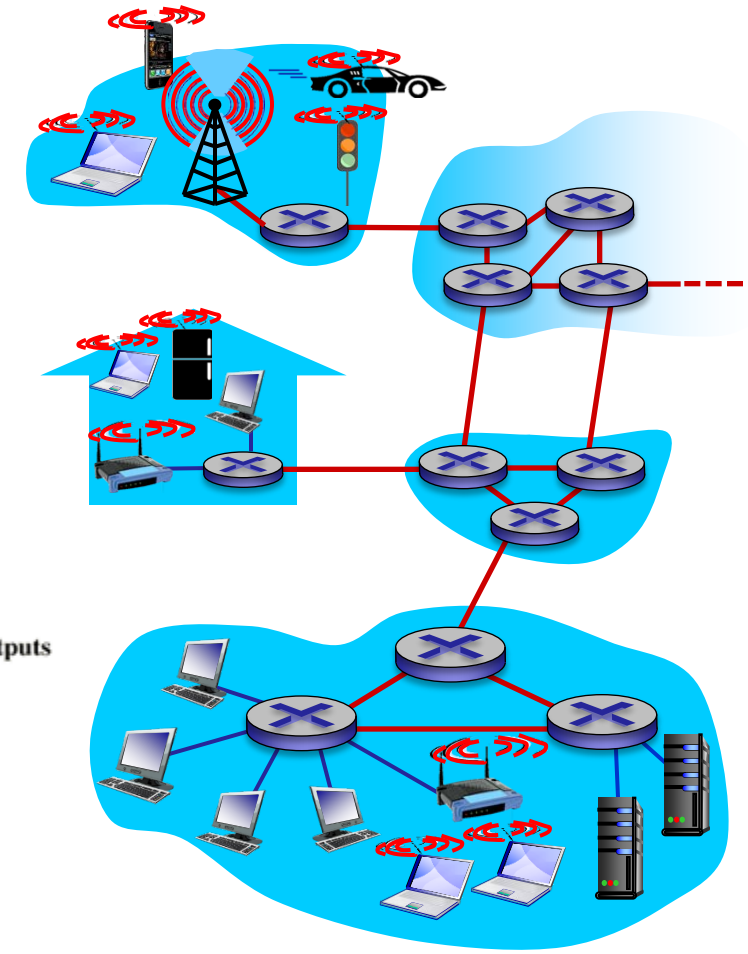
Chapter 8

Multiplexing

Introduction

- Sharing of high capacity transmission medium between several transmissions
- Various approaches, including FDM & TDM & CDM

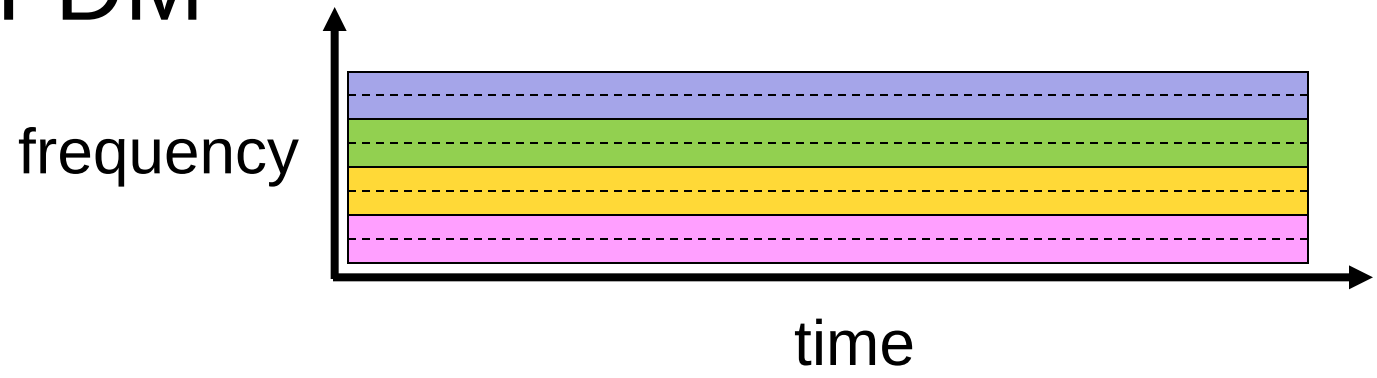




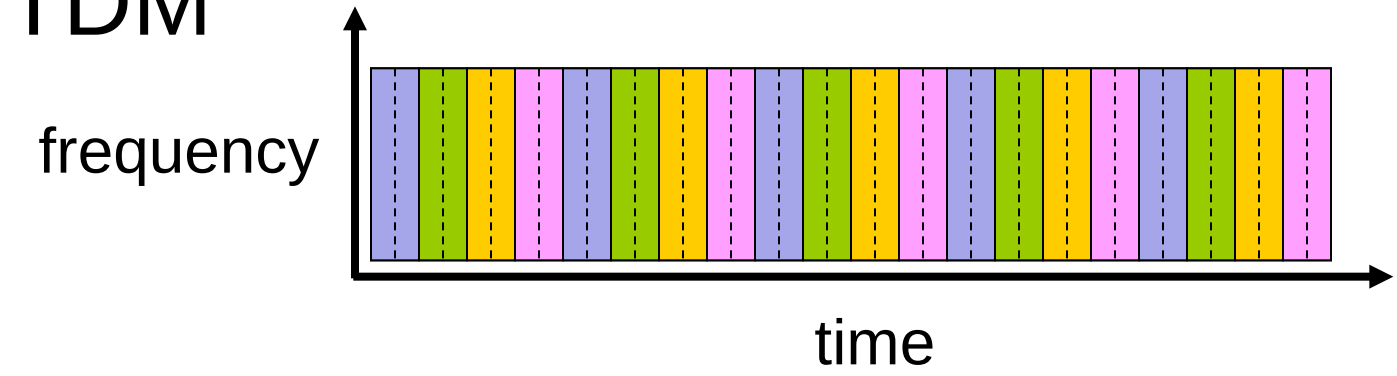
FDM & TDM

4 channels 

FDM



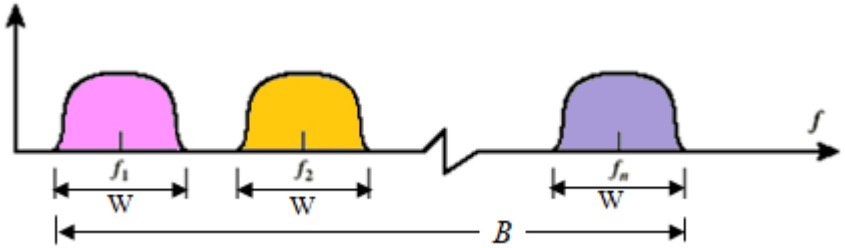
TDM

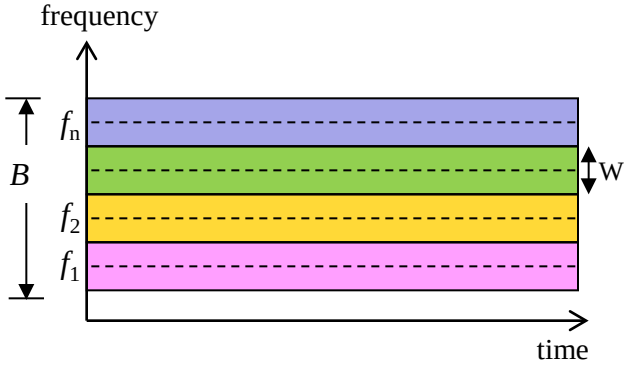


FDM (1)

- Typical FDM Example
  - Lots of low BW analog signals simultaneously transmitted on high BW link
  - Each signal is “shifted” in frequency by modulating a carrier signal

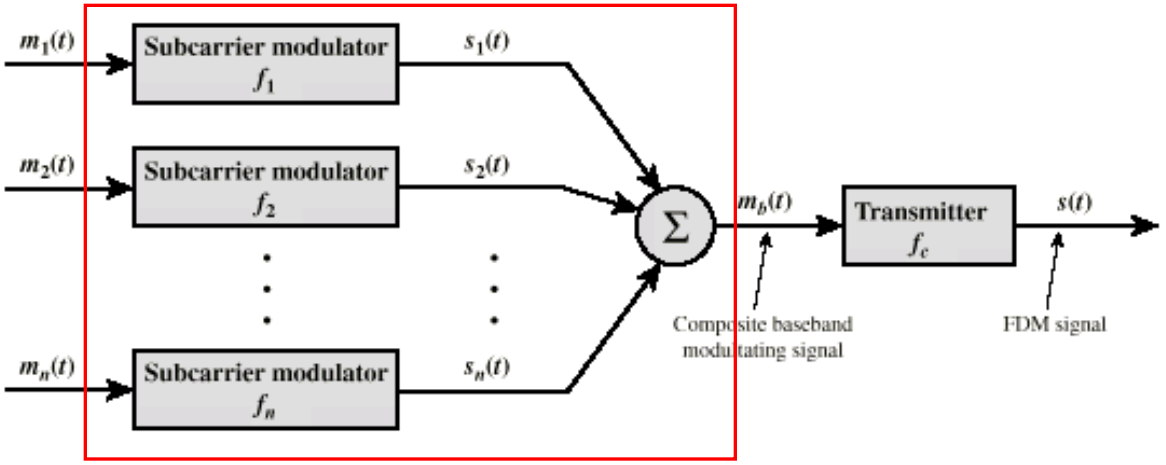
  - Shifted signals can be sent simultaneously since they do not overlap in frequency



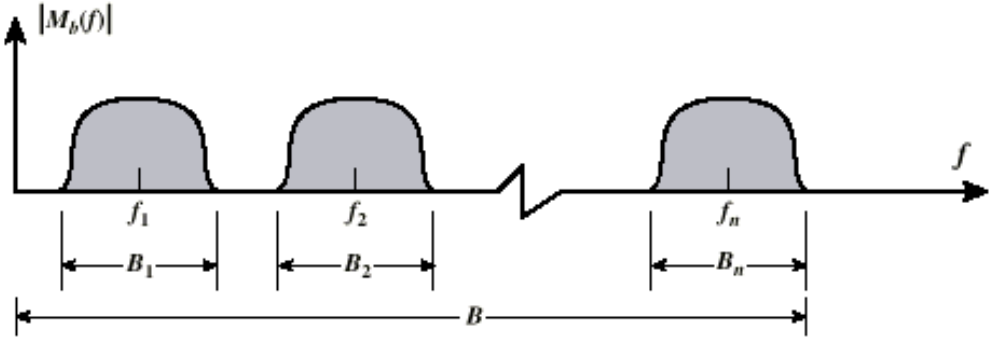


  - At receiver, filters separate the “shifted” signals; demodulation recovers signals

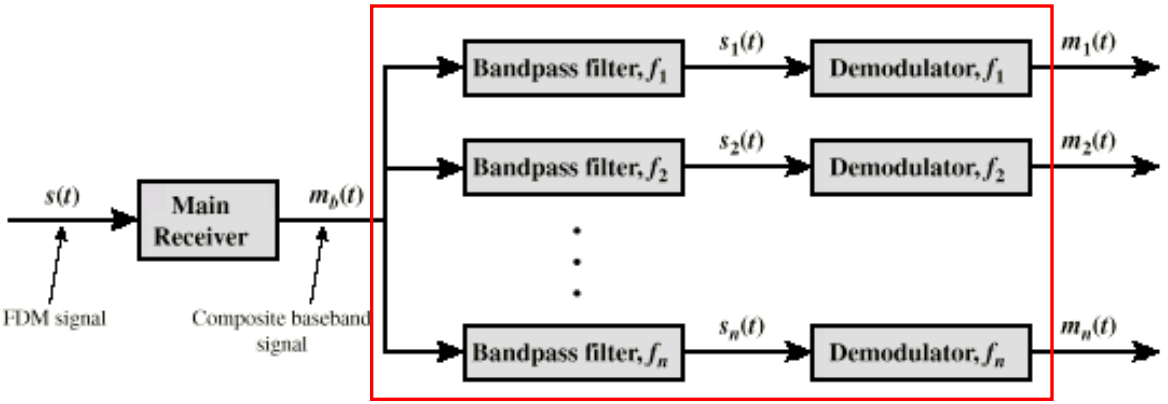
FDM (2)



(a) Transmitter



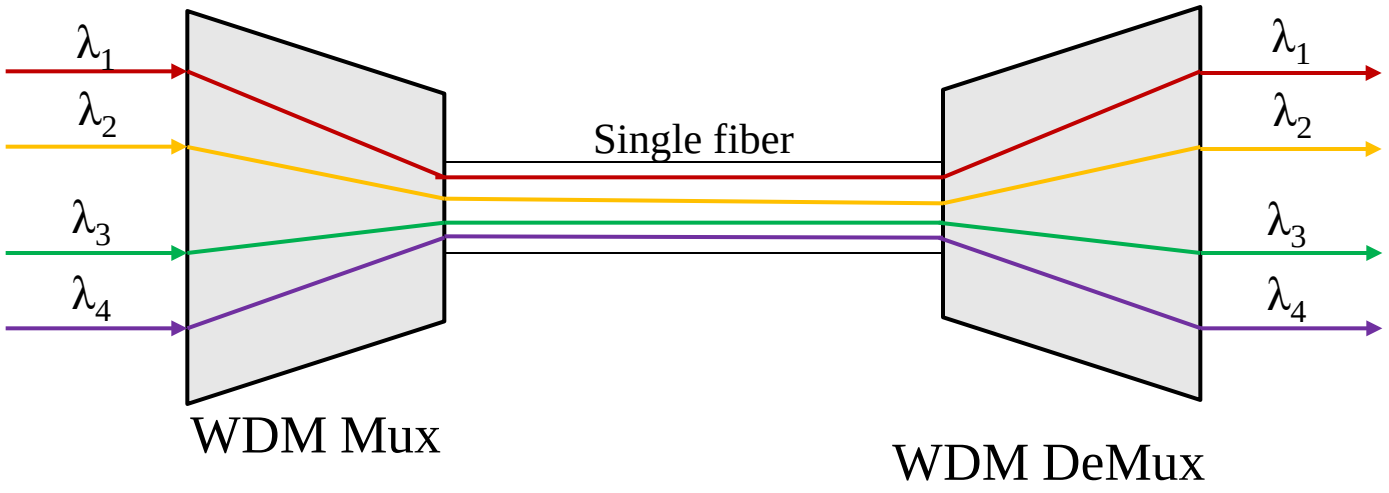
(b) Spectrum of composite baseband modulating signal



(c) Receiver

Wavelength Division Multiplexing (WDM)

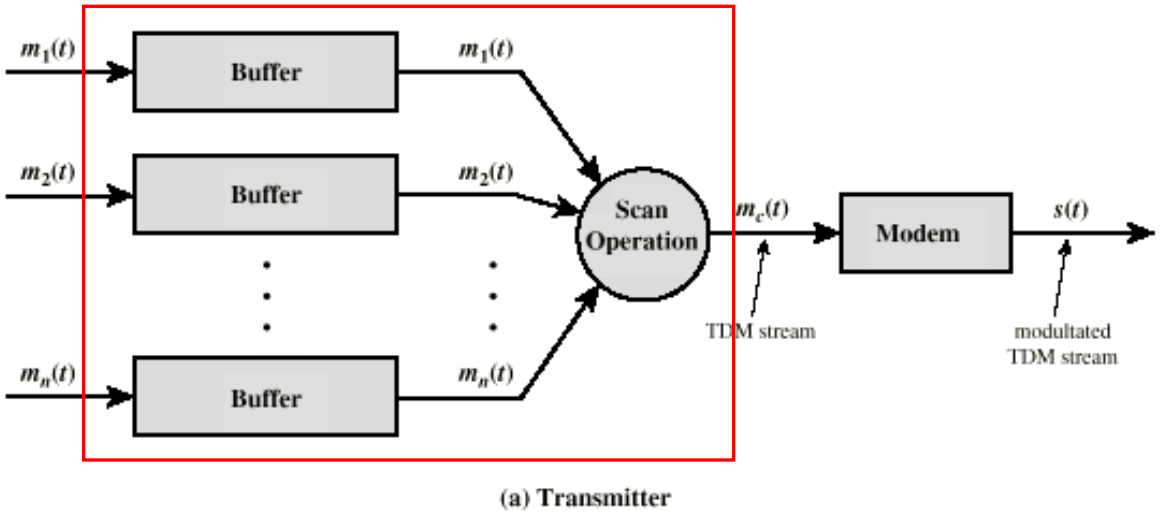
- Multiple beams of light with different wavelengths (1550 nm range) are transmitted on the same fiber.
- A kind of FDM
- The bit streaming through the fiber consists of multiple colors (wavelength), each carrying a separate data channel



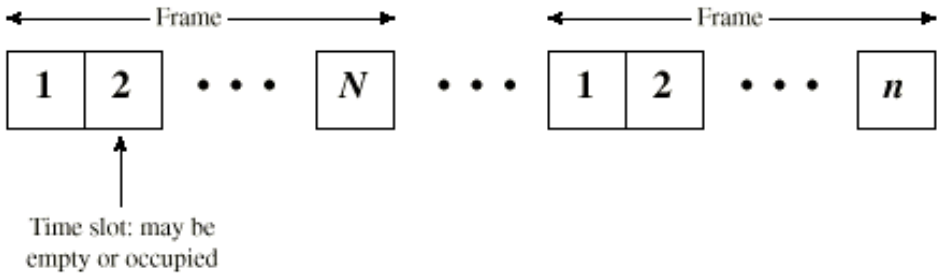
Synchronous TDM (1)

- A number of lower rate digital data is simultaneously transmitted on high data rate digital transmission medium, according to a time division manner.
- Sources are scanned in round-robin fashion; each source has fixed slot for transmission
- At destination, the received stream is distributed to the corresponding receivers

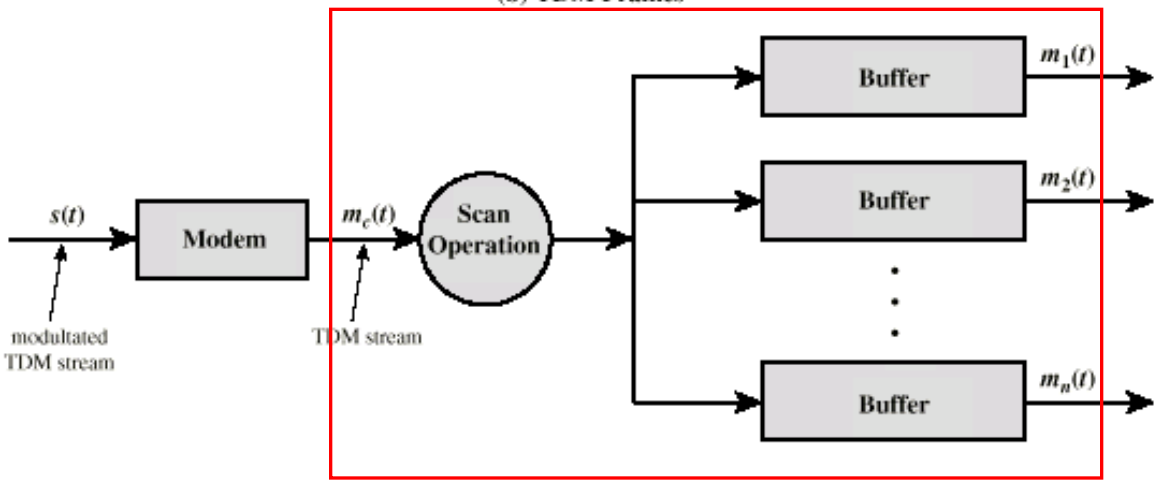
Synchronous TDM (2)



(a) Transmitter



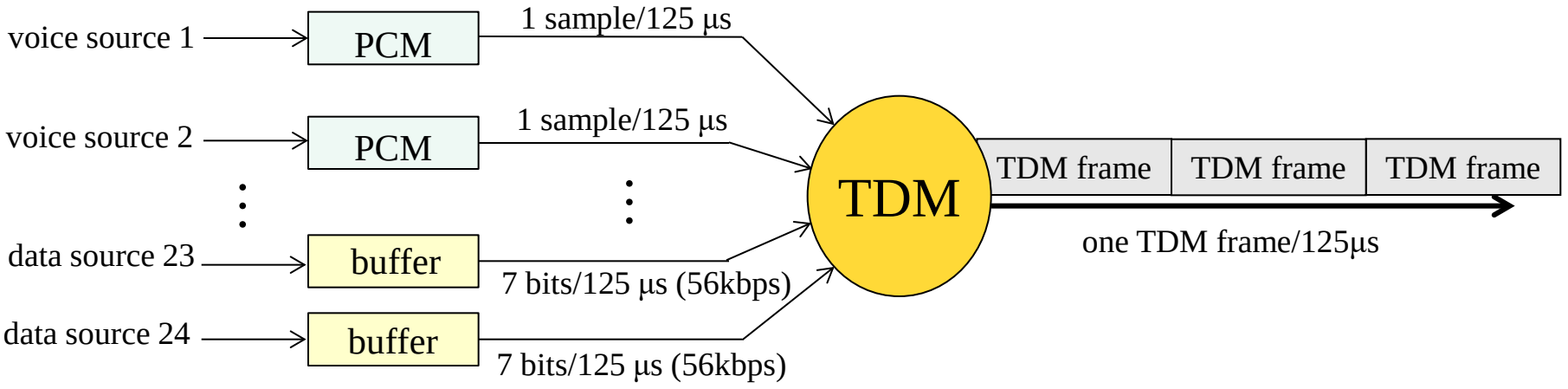
(b) TDM Frames



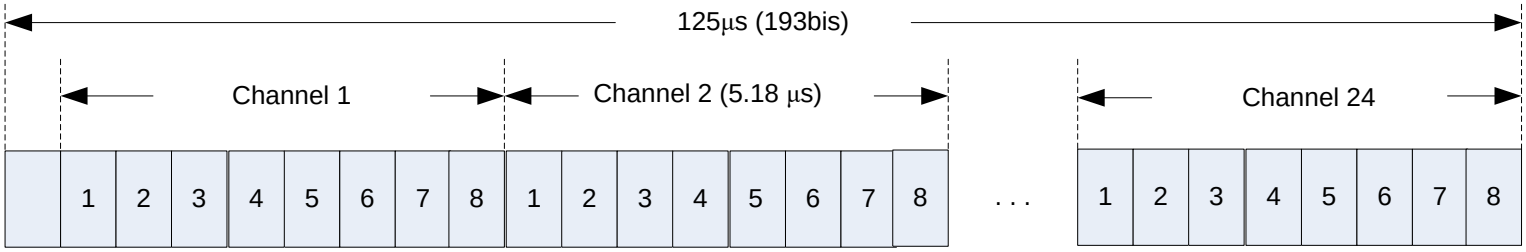
(c) Receiver

Synchronous TDM (3)

- Digital Carrier Systems
  - designed to transmit voice signals over high capacity transmission links, based on synchronous TDM
  - DS-1: basic frame format of the TDM hierarchy (in North America) : 24 voice-channels multiplexing



Synchronous TDM Example (DS-1)



- 193 (bits/frame) x 8000 (frames/sec) = 1.544 Mbps
- The first bit: a framing bit, used for synchronization
- Voice channel
  - 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
- When being used to provide digital data service
  - Channel 1 ~ 23 : data channel
    - Bits 1-7: used for 56 kbps service;
    - Bit 8: indicates whether the channel contains user data or system control data
  - Channel 24: a special sync byte for faster and more reliable reframing

Synchronous TDM (4)

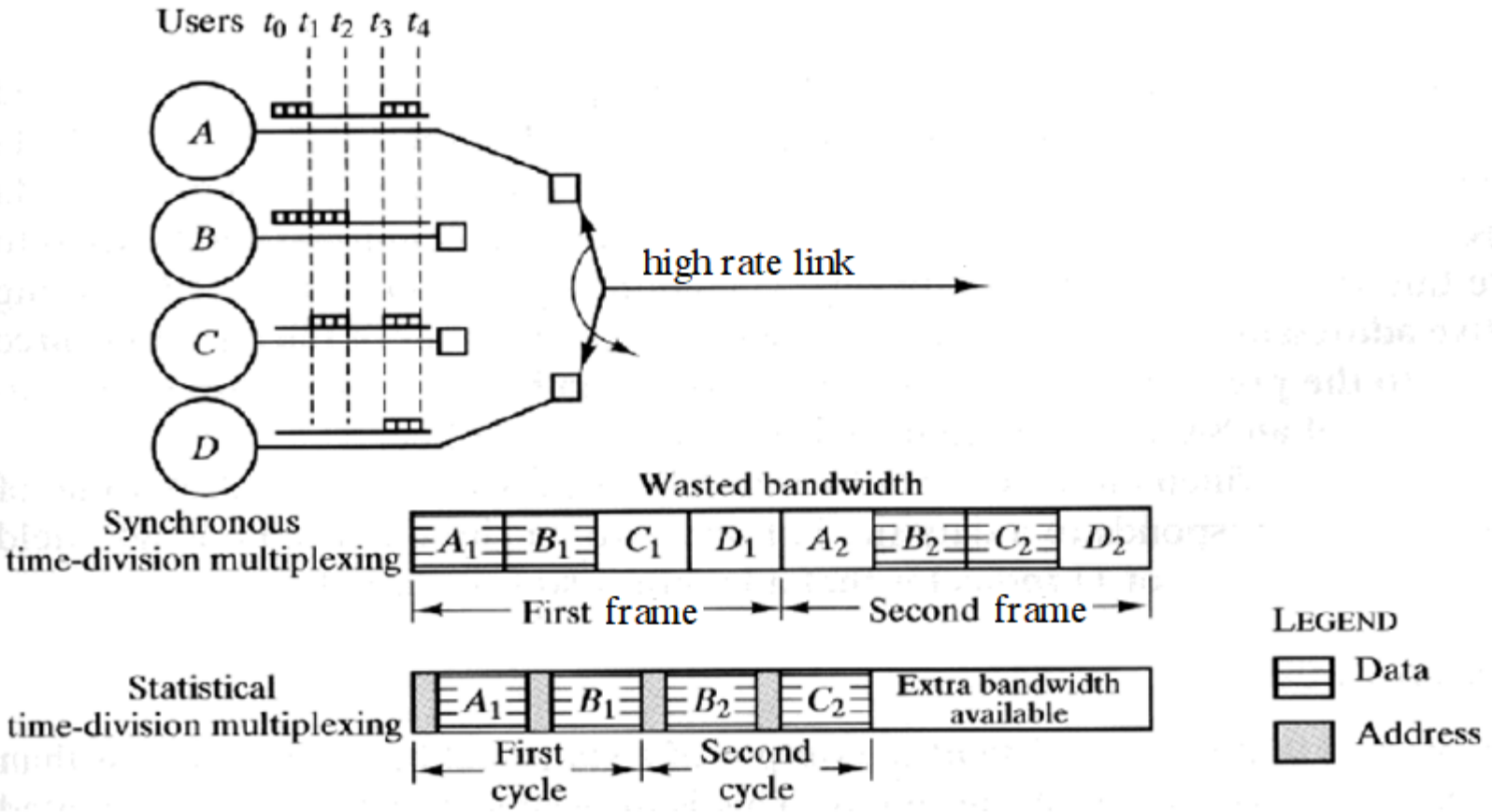
- TDM Carrier Standards

North American			International		
Frame format	Number of voice channels	Data rate (Mbps)	Level number	Number of voice channels	Data rate (Mbps)
DS-1	24	1.544	1	30	2.048
DS-1C	48	3.152	2	120	8.448
DS-2	96	6.312	3	480	34.368
DS-3	672	44.736	4	1920	139.264
DS-4	4032	274.176	5	7680	565.148

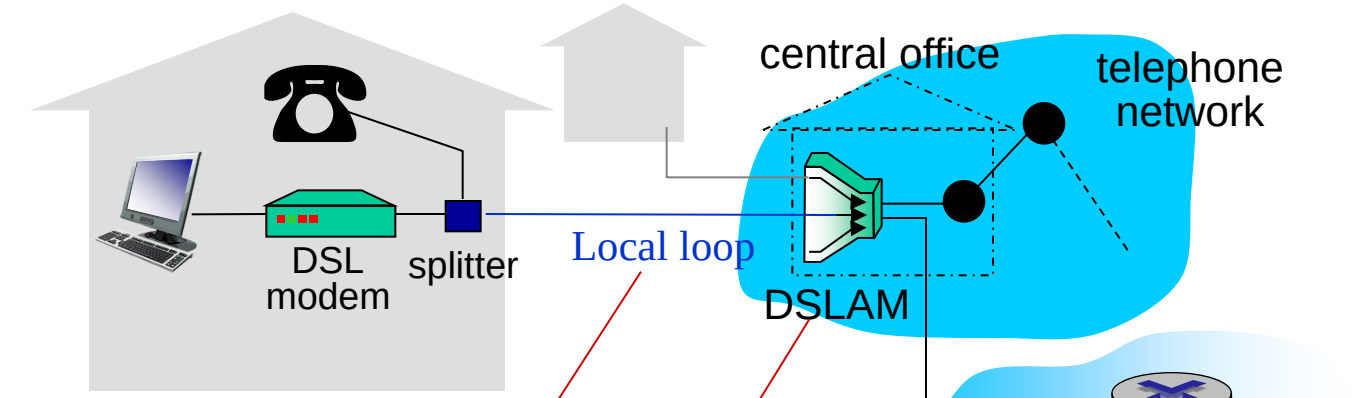
Statistical TDM (1)

- With synchronous TDM, the channel capacity is wasted when sources transmit intermittently (due to fixed assignment of channel)
- Statistical TDM (also known as asynchronous TDM and intelligent TDM) does not use fixed assignment; a source gets a time slot only if it is alive
- **Multiplexing Technique in Packet Switching Networks**

Statistical TDM (2)



DSL Broadband Access Config.



voice, data transmitted at different frequencies over dedicated line to central office

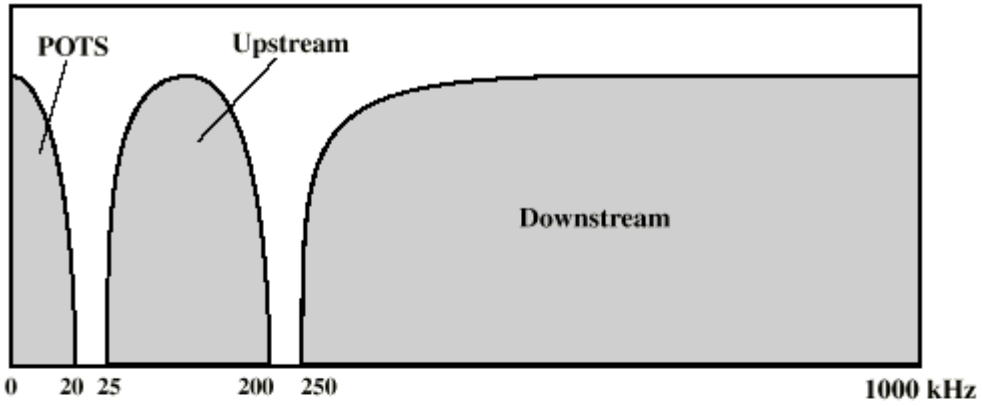
(FDM, FDD)

DSL access multiplexer

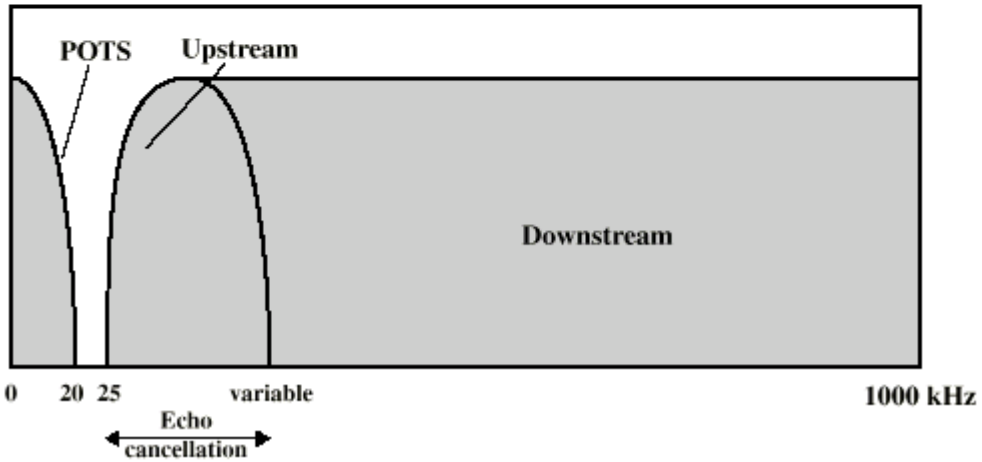
Asymmetrical Digital Subscriber Line (ADSL)

- Link between subscriber and network (Local loop)
- Uses currently installed twisted pair cable
  - Can carry broader spectrum (1 MHz or more)
- Asymmetric
  - Greater capacity downstream than upstream
- Frequency division multiplexing
  - Lowest 25kHz for voice
  - For upstream and downstream, use echo cancellation or FDM to give two bands
  - Use FDM within each band

ADSL Channel Configuration



(a) Frequency-division multiplexing

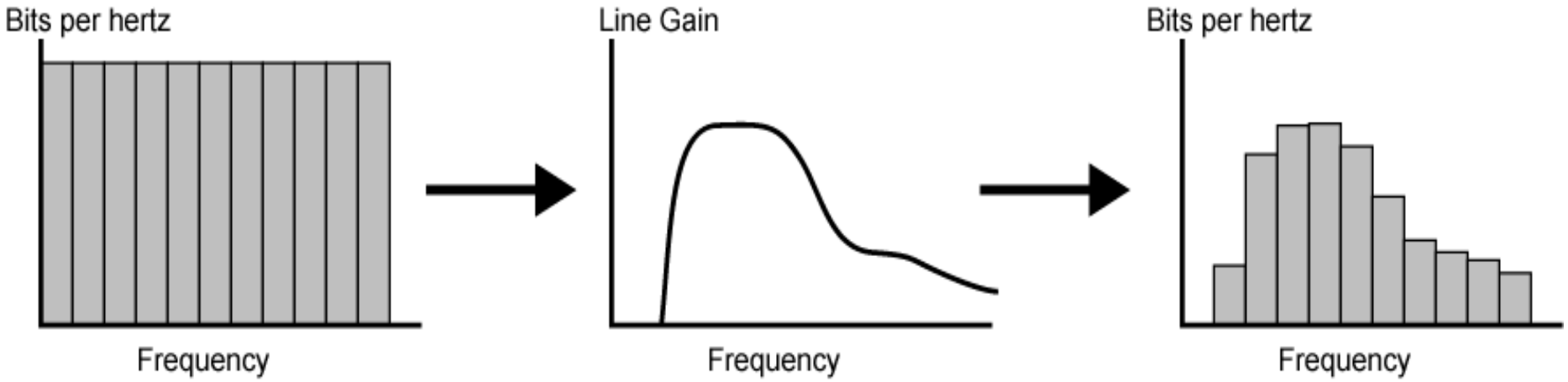


(b) Echo cancellation

Discrete Multitone (DMT)

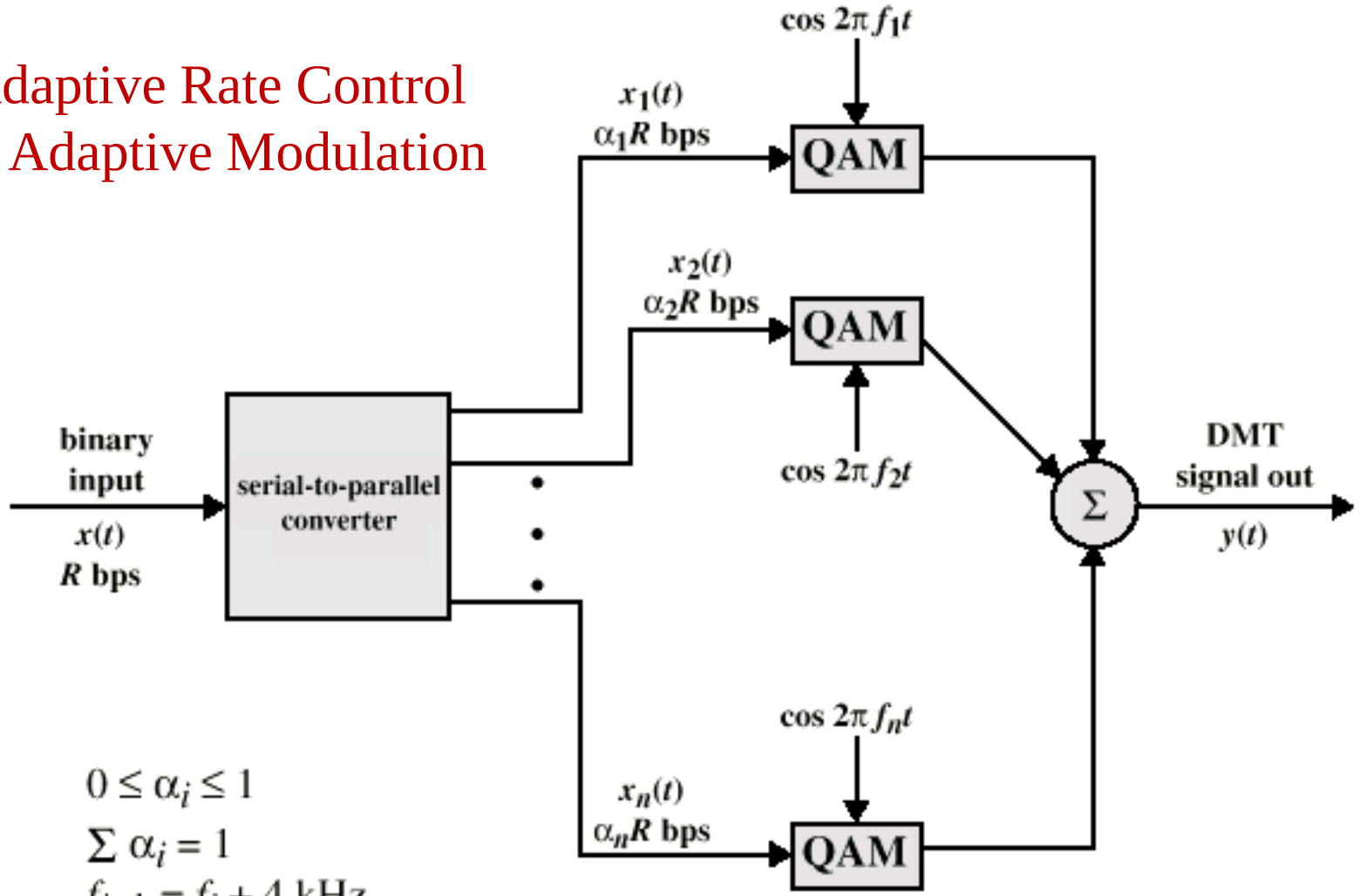
- Multiple carrier signals at different frequencies
- 4kHz subchannels
- Some bits on each channel
- Send test signal and use subchannels with better signal to noise ratio
- 256 downstream subchannels at 4kHz (60kbps)
  - 15.36Mbps
  - Impairments bring this down to 1.5Mbps to 9Mbps

DMT Bits per Channel Allocation



DMT Transmitter

Adaptive Rate Control
by Adaptive Modulation



$0 \le \alpha_i \le 1$

$\sum \alpha_i = 1$

$f_{i+1} = f_i + 4\ \text{kHz}$

4 kHz subchannel

xDSL

- High speed digital transmission of subscriber line
- HDSL (High Data Rate Digital Subscriber Line)
  - 1.544 or 2.048 Mbps
  - Cost-effective means of delivering T1 rate
  - Two twisted pairs
- SDSL (Single-Line Digital Subscriber Line)
  - 1.544 or 2.048 Mbps
  - Single twisted-pair cable (echo cancellation)
- VDSL (Very High Data Rate Digital Subscriber Line)
  - A scheme similar to ADSL at a much higher rate
  - DMT/QAM

Full Duplexing : FDD, TDD

- Simultaneous Transmission between two stations (full duplex)
- Frequency Division Duplex (FDD)
  - Separate frequency subband for each station
- Time Division Duplex (TDD)
  - Separate time slot for each station
  - Slot length: $T_p + T_b + T_g$

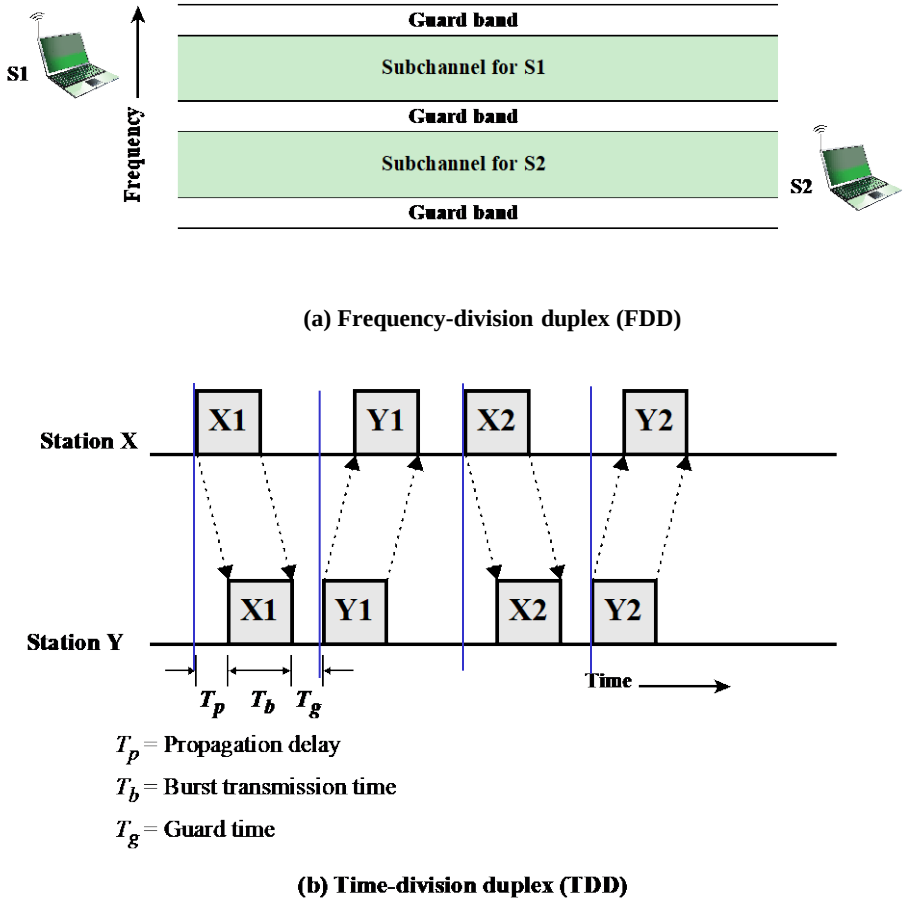
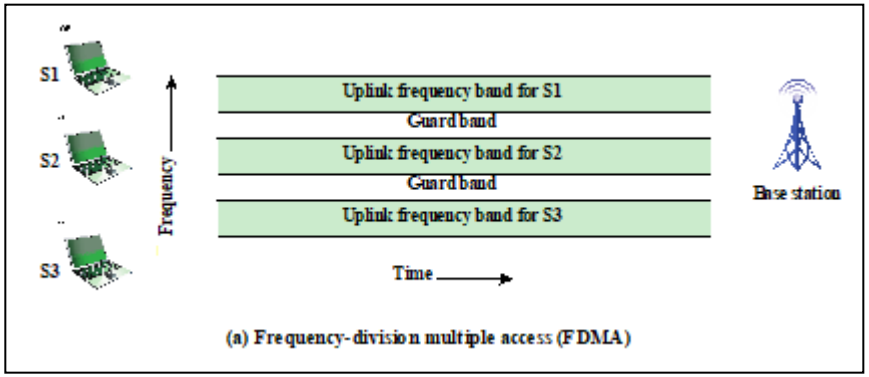


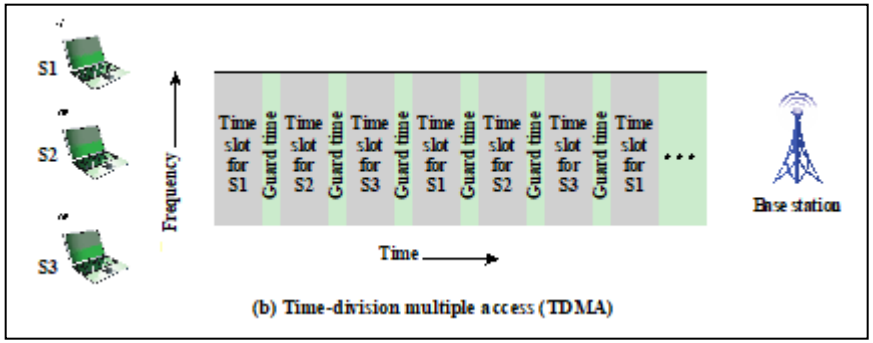
Figure 8.18 Duplex Access Techniques

Multiple Access: FDMA, TDMA

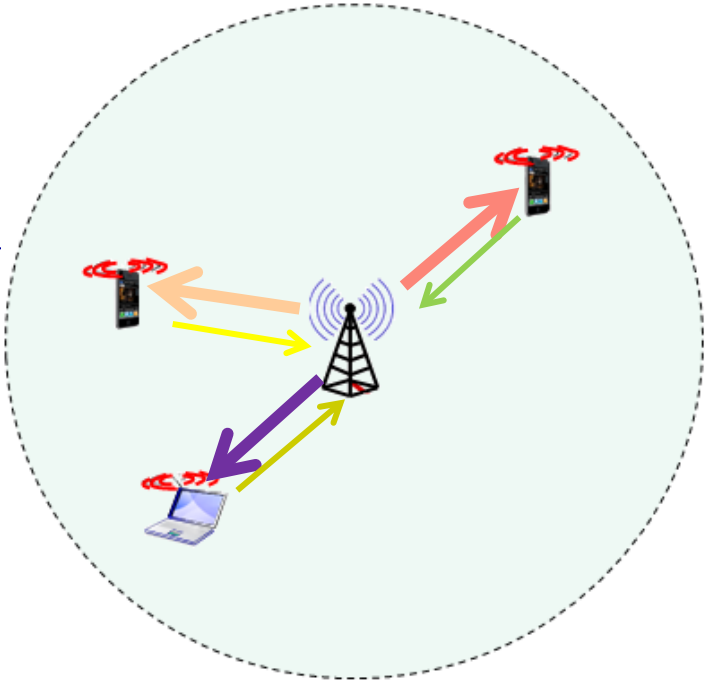
- Transmission medium sharing between multiple stations
- Frequency Division Multiple Access (FDMA)
  - Separate subchannel for each station

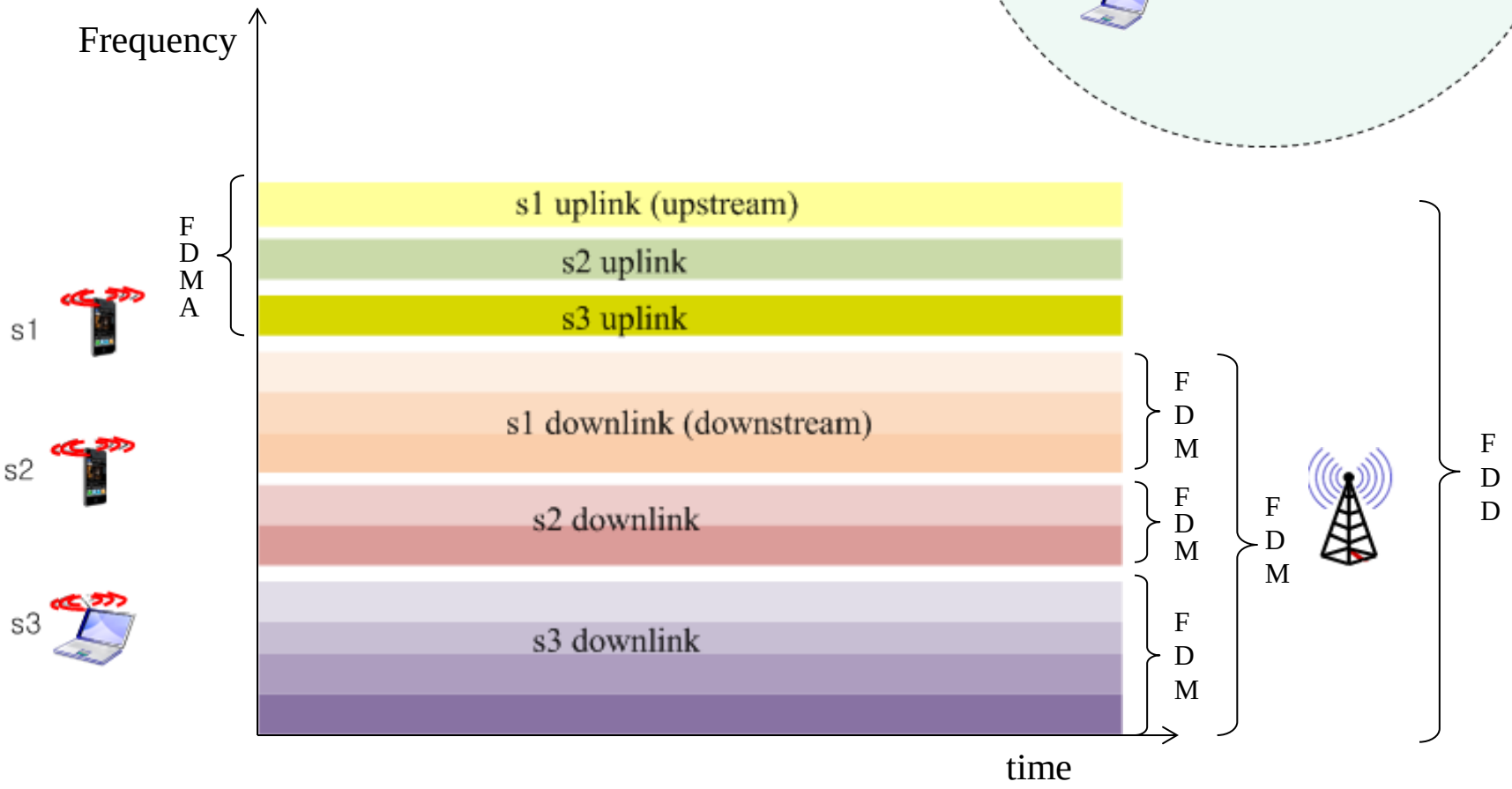


- Time Division Multiple Access (TDMA)
  - Separate time slot for each station



FDM, FDD, FDMA




Frequency
s1 uplink (upstream)
s2 uplink
s3 uplink
s1 downlink (downstream)
s2 downlink
s3 downlink
s1
s2
s3
FDMA
FDM
FDM
FDM
FDD
time