ECE 1150: Computer Networks

Multiplexing

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Objectives of This Unit

- Multiplexing techniques

- T-carrier, E-carrier, SONET system

- Modes of transmission
  - Frequency division duplex (FDD)
  - Time division duplex (TDD)

- Required reading: Chapter 2, Section 2.5 in textbook by Tanenbaum (available online)

Multiplexing

- **Sending multiple signals simultaneously** on the same medium
  - Multiple TV channels on one coax cable, or
  - Multiple radio stations on the same air space
- Extremely important **milestone** in data communication
  - Drastically **reduced** need for **cabling**
    - Cabling costs are one of the biggest fixed cost components of data communications in wired networks

Multiplexing Categories

- Frequency division multiplexing (FDM)
  - Send signals in different frequency bands
  - Orthogonal frequency division multiplexing
  - Wavelength division multiplxing

- Time division multiplexing (TDM)
  - Send signals at different times

- Code Division Multiplexing (CDM)
  - Used in 3G cellular systems
 - Each signal has a different code

Frequency Division Multiplexing

- Each signal is modulated to a <u>different carrier</u> frequency

- Carrier frequencies separated so signals do not overlap (guard bands)

- **Example: broadcast radio**
  - FM radio stations also use FDM to share the frequency spectrum (88 MHz and 108 MHz) between radio statios
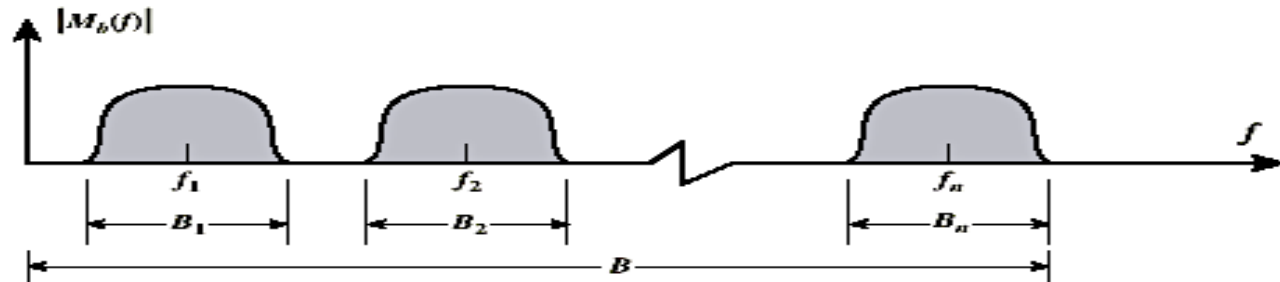
- Channel **allocated even if no data**
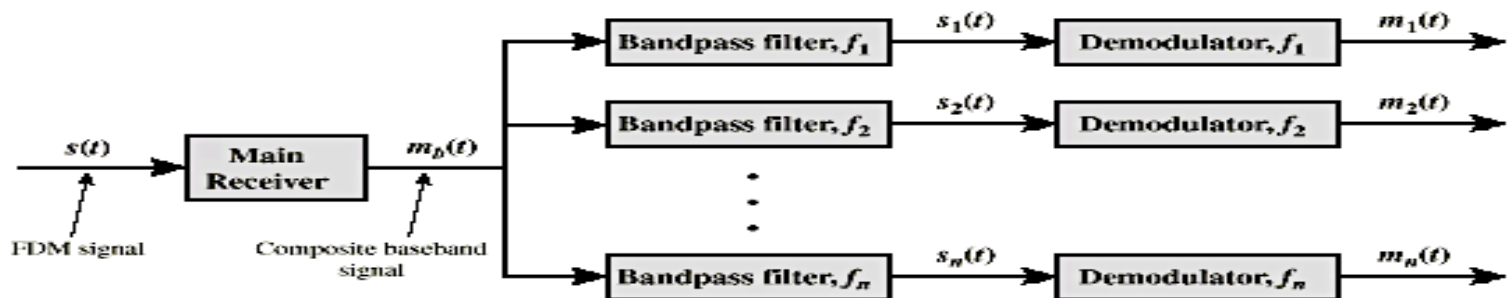
FDM of Three Voiceband Signals
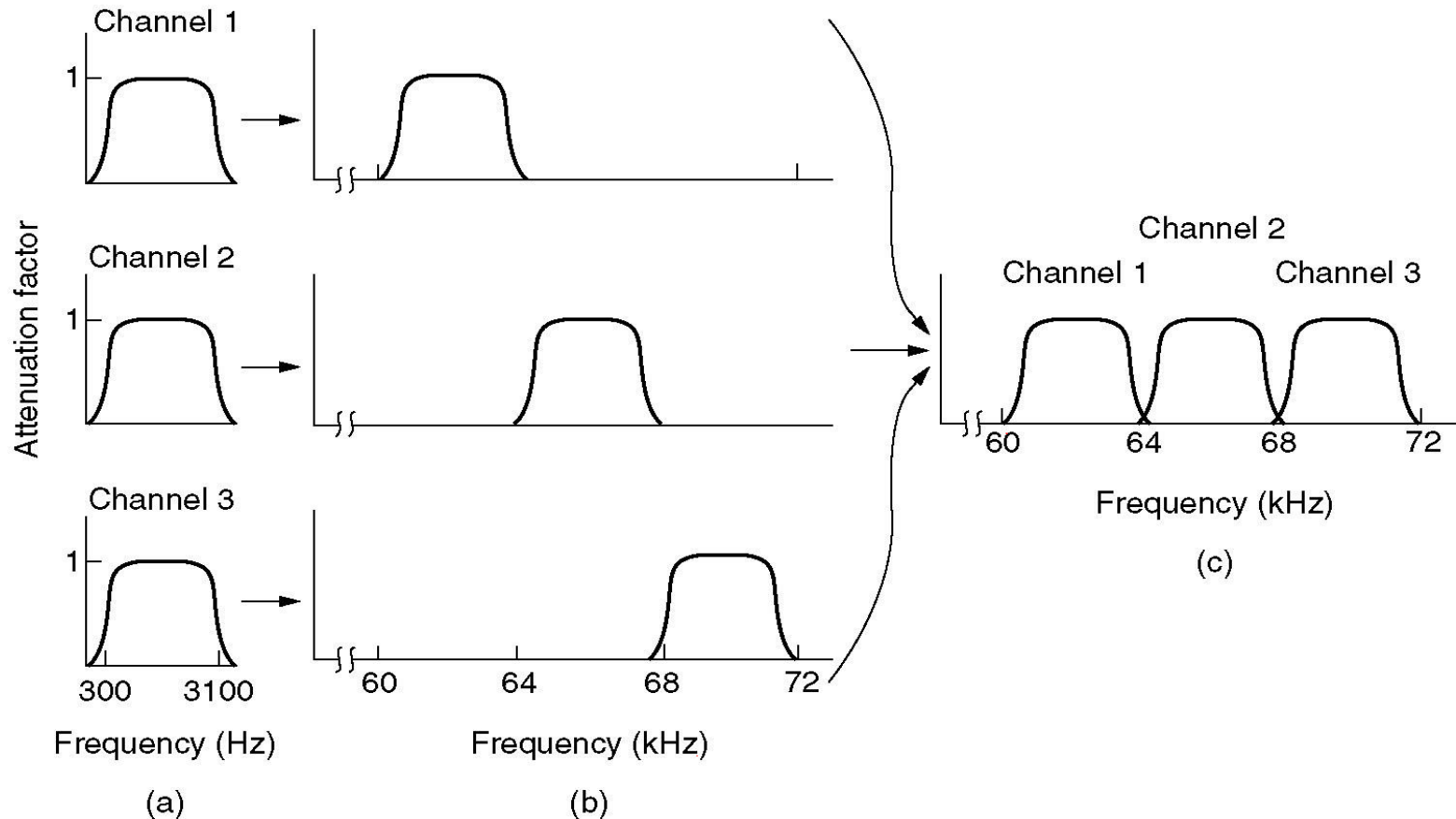
FDM System
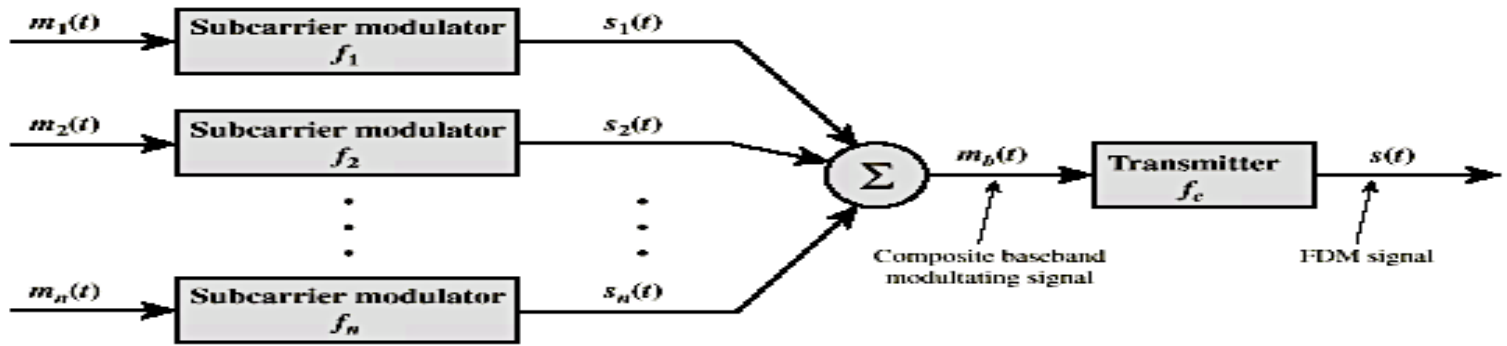
(a) Transmitter

(b) Spectrum of composite baseband modulating signal

(c) Receiver

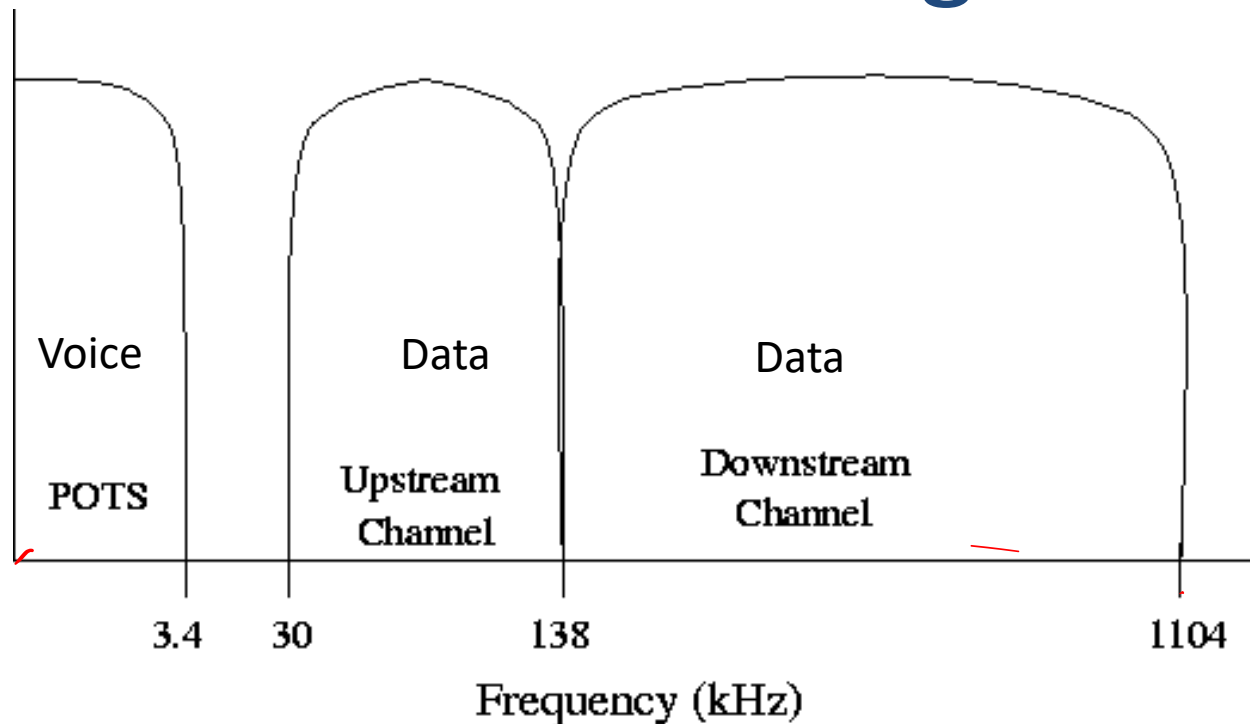At receiver, band pass filter to get the desired signal and filter the rest

Interent

- ADSL

- Cable

- Fiber

Asymmetrical Digital Subscriber Line (ADSL)

- Link between subscriber and telephone network - local loop – central office

- Asymmetric
  - Greater capacity downstream than upstream

- Frequency division multiplexing
  - Lowest frequencies for voice
    - called Plain Old Telephone Service (POTS)
  - Two bands for data (smaller band for upstream, wider band for downsteam)

ADSL Channel Configuration

Voice

POTS

Data

Upstream
Channel

Data

Downstream
Channel

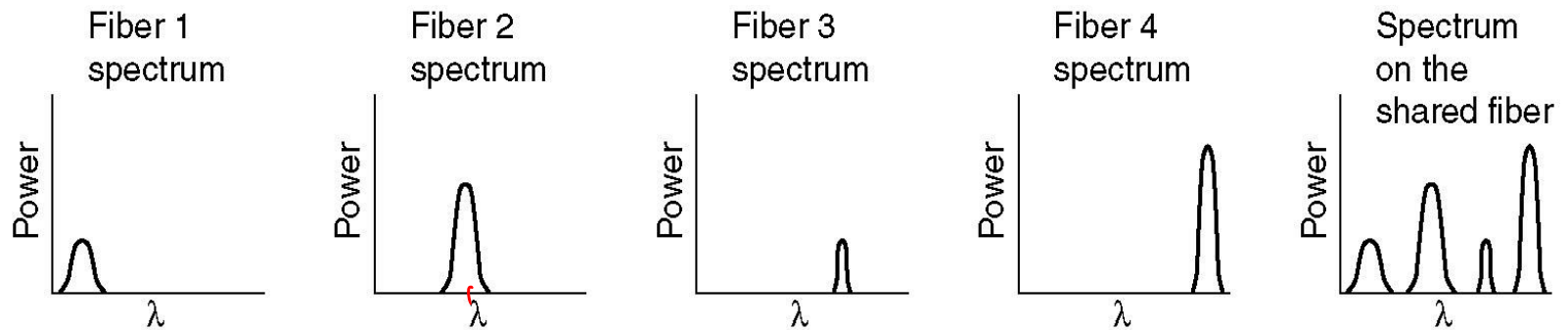3.4   30   138   1104

Frequency (kHz)

- Oversimplified
- Asymmetric, downstream rate (e.g. 24Mb/s)
  is higher than upstream rate(e.g. 2.5Mb/s)

Wavelength Division Multiplexing (WDM)

- Same general architecture as (other) FDM
- Number of sources generating **laser beams** at different **wavelength** (**frequencies**, **colors**)
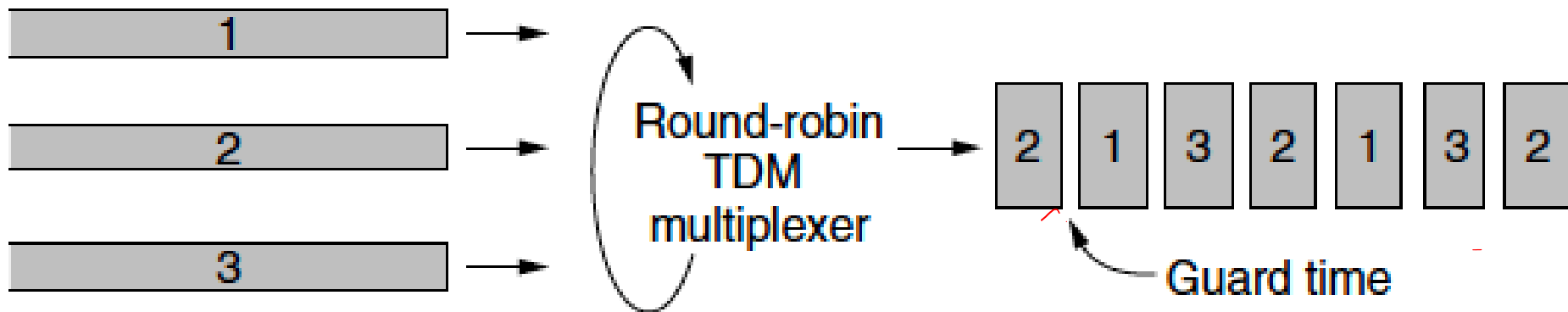- De-multiplexer separates channels at destination

# WDM is like FDM!
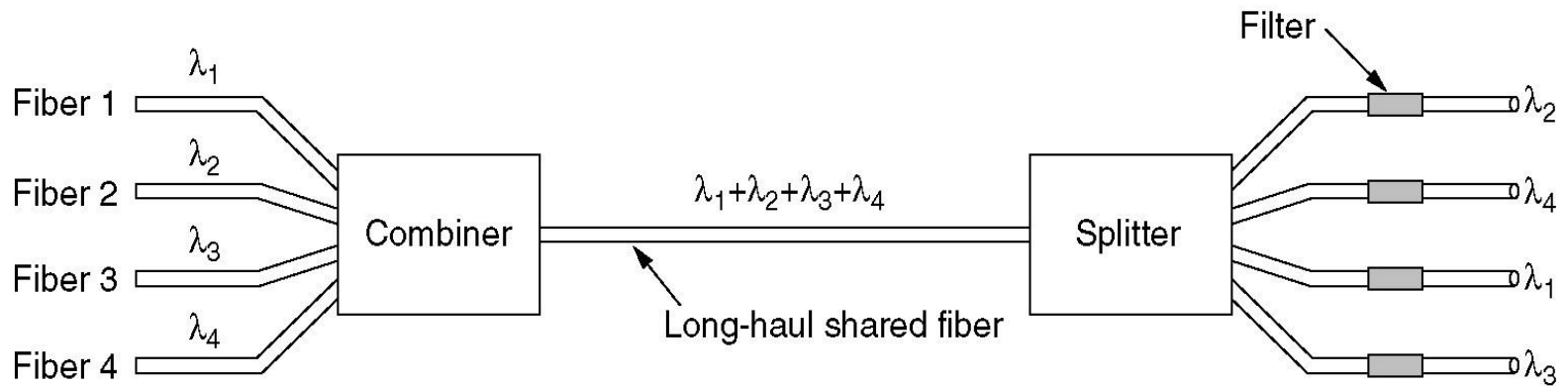
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Time Division Multiplexing

Time Division Multiplexing

- Different information channels are **assigned different time slots** (take turns)

- Requires a level of **synchronization** among the channels

- Organize channel sequences into **frames** – a number of slots

- Time slots are **allocated** to different information channels **even if no data is transmitted**

Time Division Multiplexing

Not link layer frame, but PHY layer construct

frame

slot

frequency
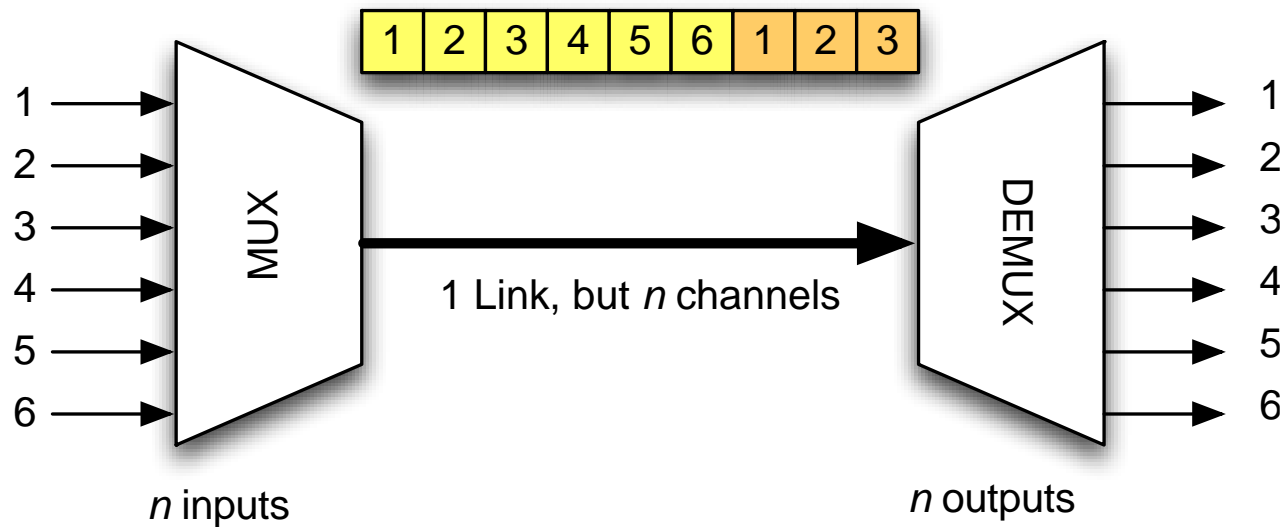
time
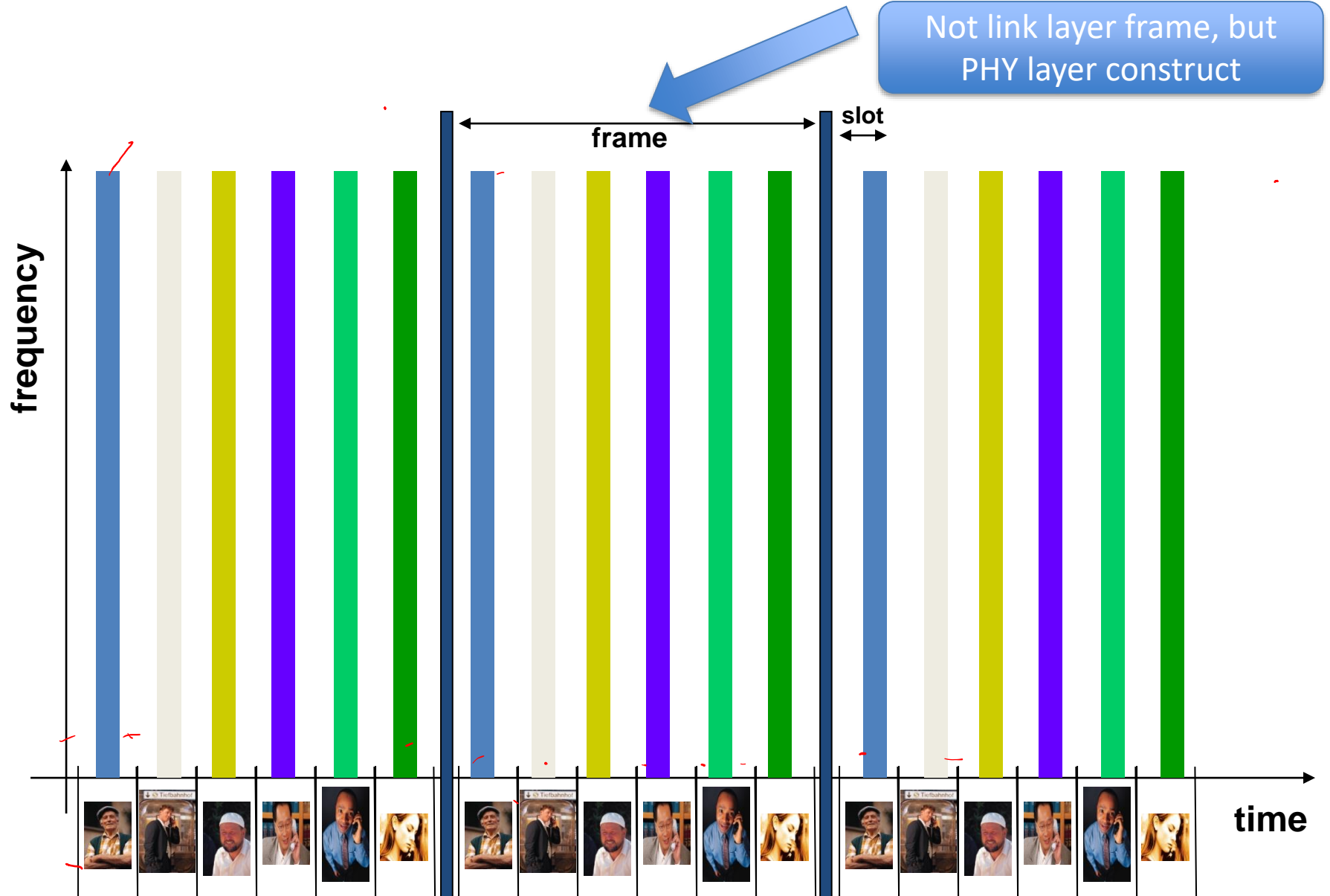
TDM

Tophat:
Q_TDM

If link capacity is R bps used in circuit switching, and there are N signals multiplexed over the link using TDM. What is the maximum rate of each signal ?

A	R bits per seconds

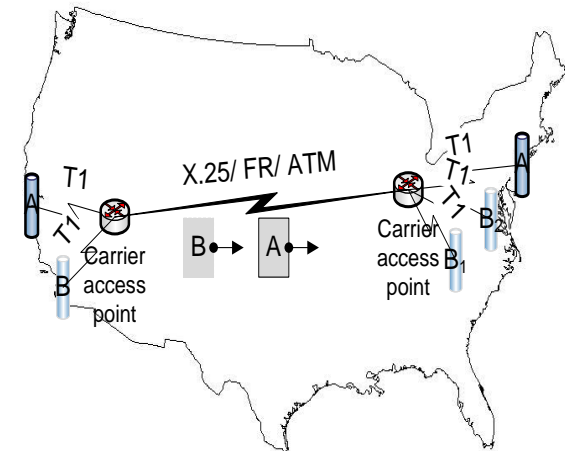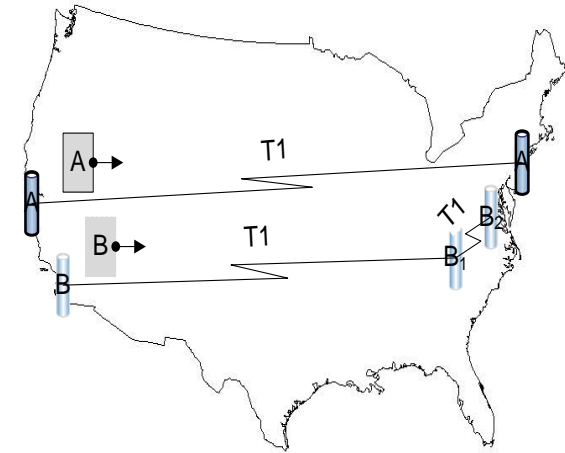| B	R/N bits per seconds

C	None of the above

Statistical TDM

- Allocate channel/bandwidth **on demand**
  - **Allocated only if there is data**
- STDM packetizes data
- Popular WAN systems:
  - X.25: rate up to 2 Mbps
  - Frame relay: rate up to 45 Mbps
  - Asynchronous Transfer Mode (ATM): rate up to 622.08 Mbps, use priority (voice packets get higher priority then email packets)

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CDM

- Code Division Multiplexing (CDM)
  - Signals are sent over same time and frequency but use different orthogonal codes that can be used at receiver to demultiplex
  - Used in 3G cellular systems – spread spectrum systems
- Check reading

Some Standardized Multiplexing Systems

- North American digital hierarchy

- ITU digital hierarchy

- Synchronous Digital Hierarchy for optical systems (SDH/SONET)

Recommended reading -- Section 2.2.4 in book: Computer Networks, A. S. Tanenbaum and D. J. Wetherall, 5th Ed

North American Digital Hierarchy: T-Carrier

- Digitally multiplexed **telecommunication carrier (T-Carrier)** system
  - Developed by Bell Labs and used in North America, Japan, South Korea
  - Multiplex voice and data
- **Basic unit** of T-carrier system is DS (Digital Signal)-0
  - **DS-0** transmission rate is **64Kbits/sec**, one voice circuit
   - Correspinds to the bit rate of one analog communication channel

T-Carrier

- T1 data circuit runs at 1.544Mbits/s – (DS-1)
  - 24 voice channels, speech signals encoded at 64Kbits/s,
  - Time Division Multiplexing (**TDM**)
- T2 carry multiple T1 channels resulting in 6.312Mbits/s

No. of phone lines aggregated	T-carrier name	DS name	Data rate
1		DS-0	64 kbps
24	T-1	DS-1	1.544 Mbps
96	T-2	DS-2	6.312 Mbps
672	T-3	DS-3	44.736 Mbps

WAN Built Using T-carriers

Organization can lease dedicated circuits (T1 for example) to connect headquarters (HQ) with other branches
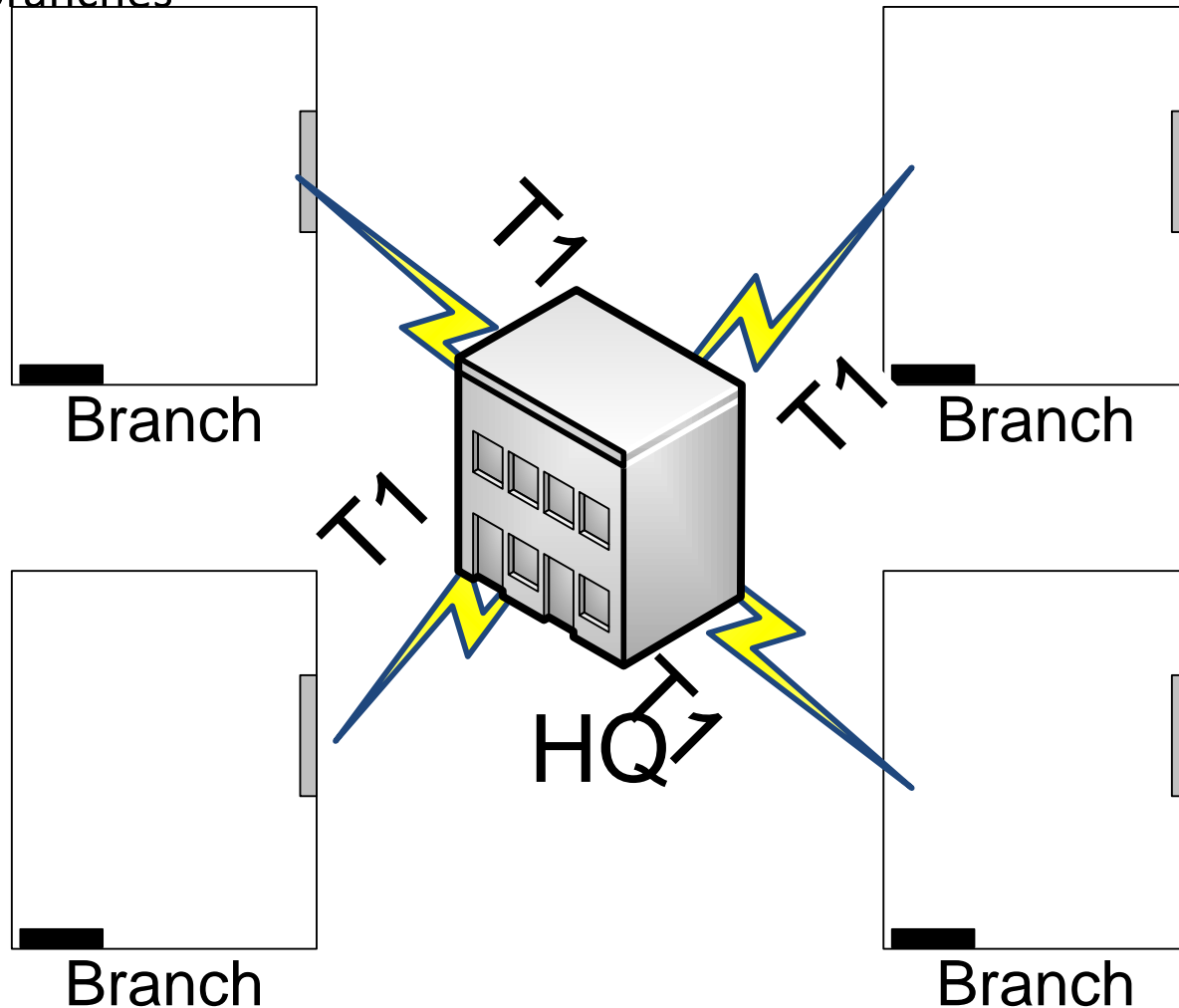
Source: Agrawal et al.

ITU Digital Multiplexing Hierarchy-- E-Carrier

- European standard, adopted by the ITU
- Based on **TDM**
- Common transmission rates
  - E0 = 64 kbps
  - E1 = 2.048 Mbps = 30 E0's
  - E2 = 8.448 Mbps = 120 E0's
  - E3 = 34.368 Mbps = 480 E0's
  - E4 = 139.264 Mbps = 1920 E0's
  - E5 = 565.148 Mbps = 7680 E0's

SONET/SDH (TDM WAN)

SONET: physical layer protocol used over the wide-area optical fiber links

- Synchronous Optical Network (SONET) (American National Standards Institute - ANSI)
  - Same as Synchronous Digital Hierarchy (SDH) - ITU
- **TDM** system **for optical links** using lasers
- Signal Hierarchy
  - Unit: Synchronous Transport Signal level 1 (STS-1) or **Optical Carrier** level 1 (OC-1)
  - Multiple STS-1 combined into STS-N signal to provide high rate

SONET/SDH

- Hierarchy of optical transmission rates
- Goal: different carriers interwork (wavelength, timing, framing structure)

SONET service names	Data rate	Data + overhead
OC-1	50.112 Mbps	51.84 Mbps
OC-3	150.336 Mbps	155.52 Mbps
OC-12	601.344 Mbps	622.08 Mbps
OC-48	2.405376 Gbps	2.488320 Gbps
OC-192	9.621504 Gbps	9.953280 Gbps
OC-768	38.486016 Gbps	39.813120 Gbps

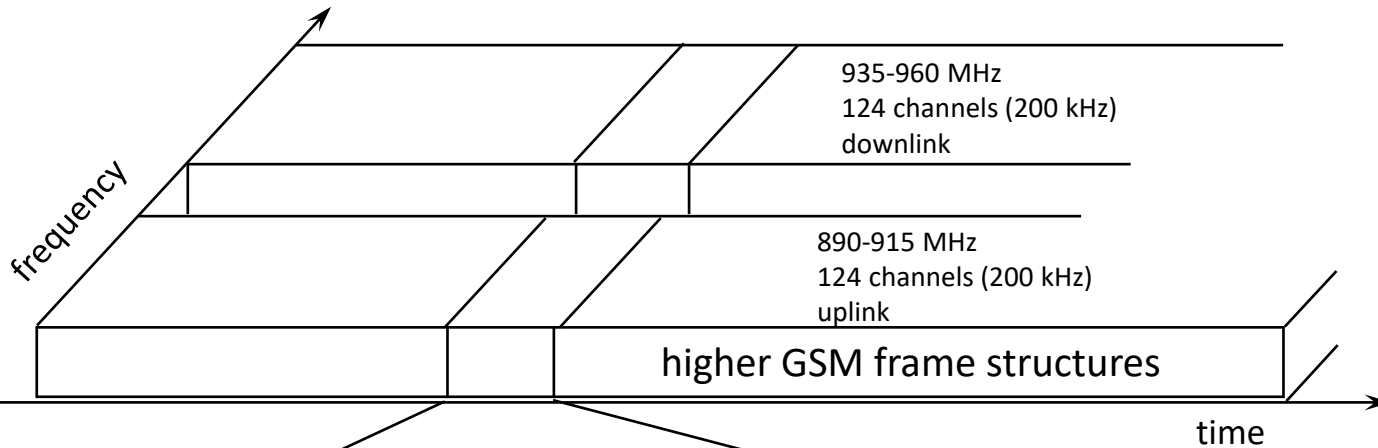OC-1 can carry DS-3 or group of lower rate signals

Mode and Multiplexing – Uplink and Downlink

- Mode: How duplex transmissions (2-way communications) share a channel during conversation
  - Duplex: transmission can occur in any directions
    - Uplink: e.g. mobile to base station
    - Downlink: e.g. base station to mobile

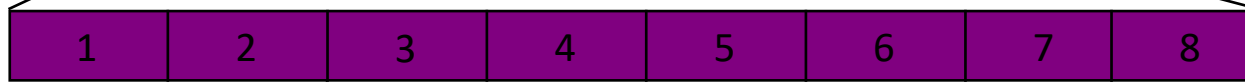# Mode and Multiplexing – Uplink and Downlink

- Duplex – two way communication
  - Time division duplex (TDD): each direction of communication is on a different time slot

  - Frequency division duplex (FDD): two different frequencies
    - Cellular system example: transmission from mobile to base station is on frequency F1, and from base station to mobile is on frequency F2.

GSM - TDMA/FDM/FDD

frequency

935-960 MHz
124 channels (200 kHz)
downlink

890-915 MHz
124 channels (200 kHz)
uplink

higher GSM frame structures

time

Spectrum broken up
into 124 channels
User gets one channel
for uplink (mobile to
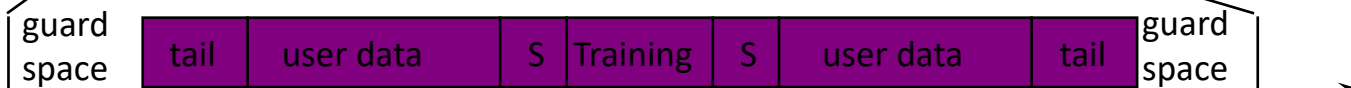base station) another
channel for downlink
(base station to mobile

GSM TDMA frame

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

4.615 ms

8 users share one
channel

GSM time-slot (normal burst)

| guard space | tail | user data | S | Training | S | user data | tail | guard space |

3 bits   57 bits   1   26 bits   1   57 bits   3

546.5 µs

577 µs