



University of Pittsburgh

ECE 1150: Computer Networks

Multiplexing

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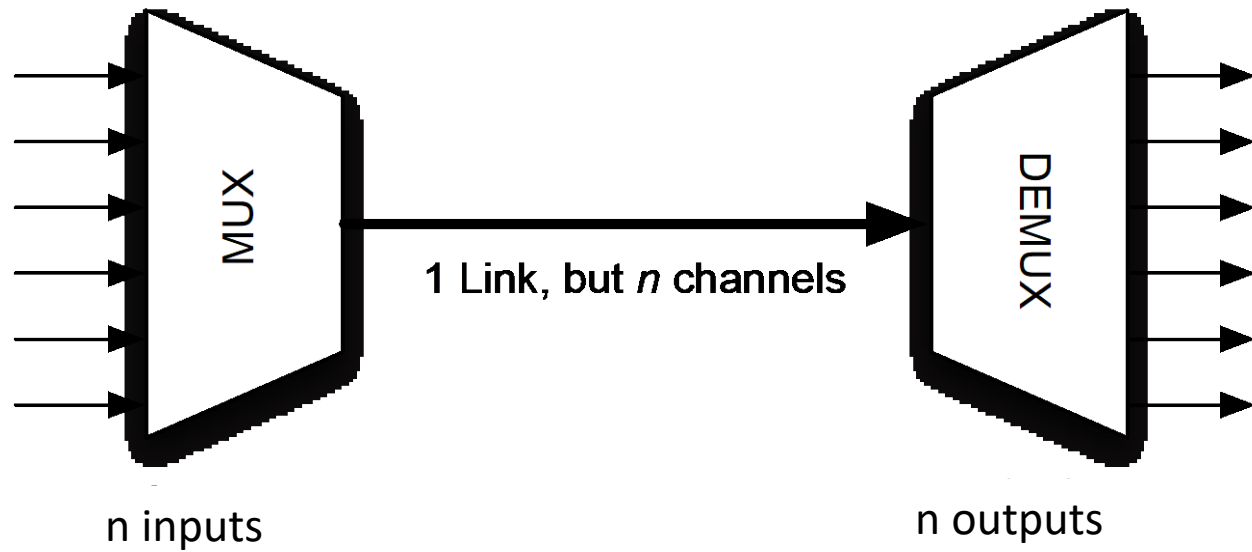
Objectives of This Unit

- Multiplexing techniques
- 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 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



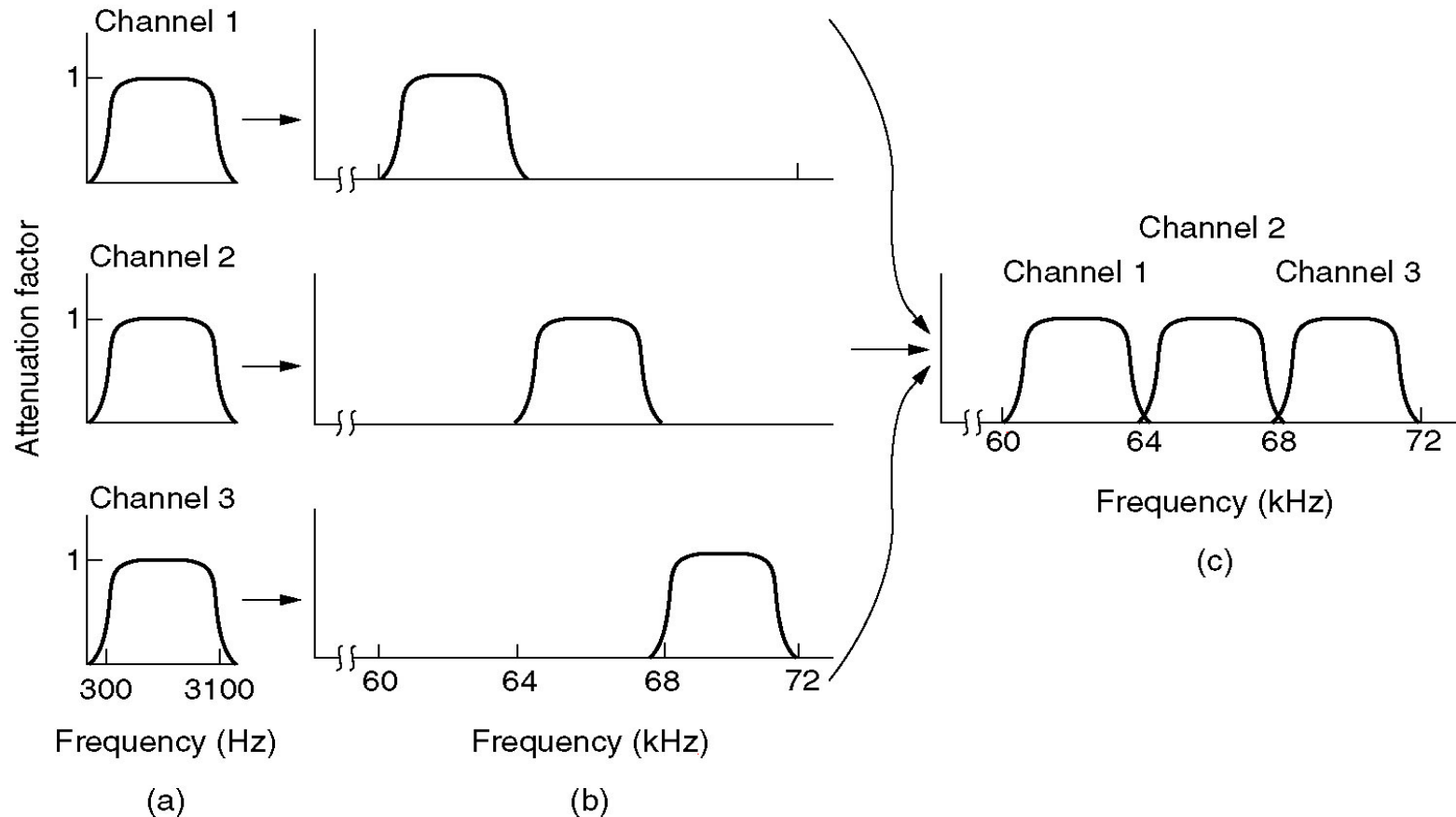
Multiplexing Categories

- Frequency division multiplexing (FDM)
 - Send signals in different frequency bands
 - Orthogonal frequency division multiplexing
- Wavelength division multiplexing
- Time division multiplexing (TDM)
 - Send signals at different times
- Code Division Multiplexing (CDM)
 - Used in 3G cellular systems
 - Each signal has a different code

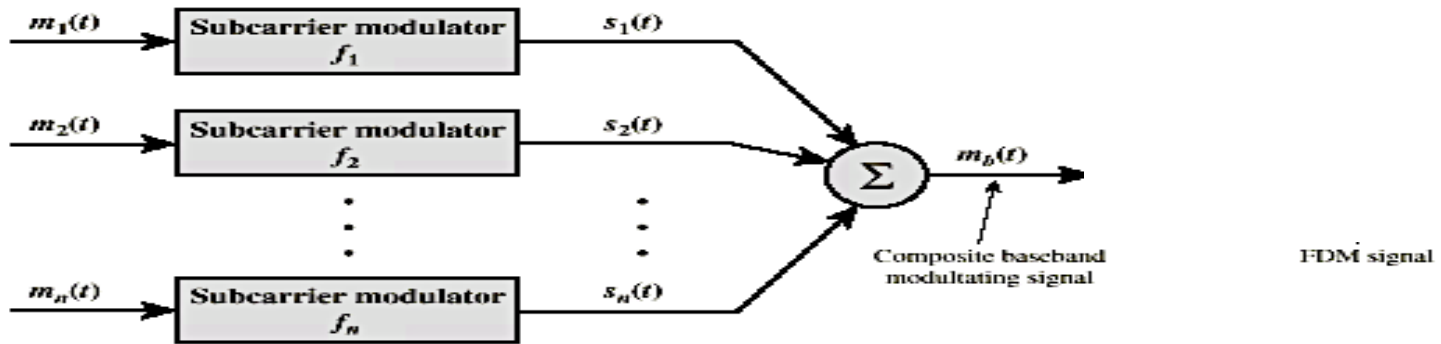
Frequency Division Multiplexing

- Each signal is modulated to a different carrier 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 stations
- Channel **allocated even if no data**

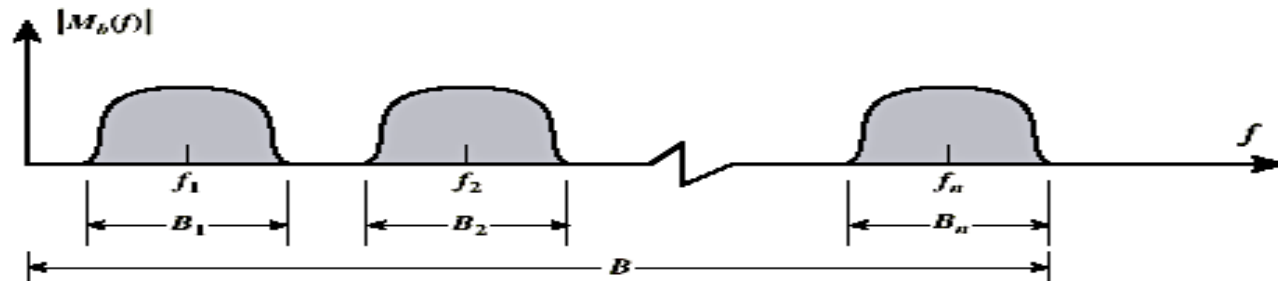
FDM of Three Voiceband Signals



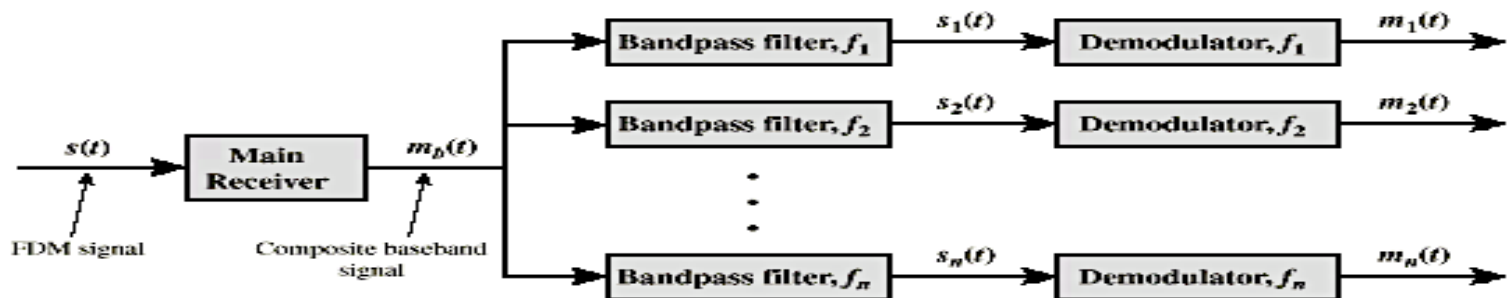
FDM System



(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

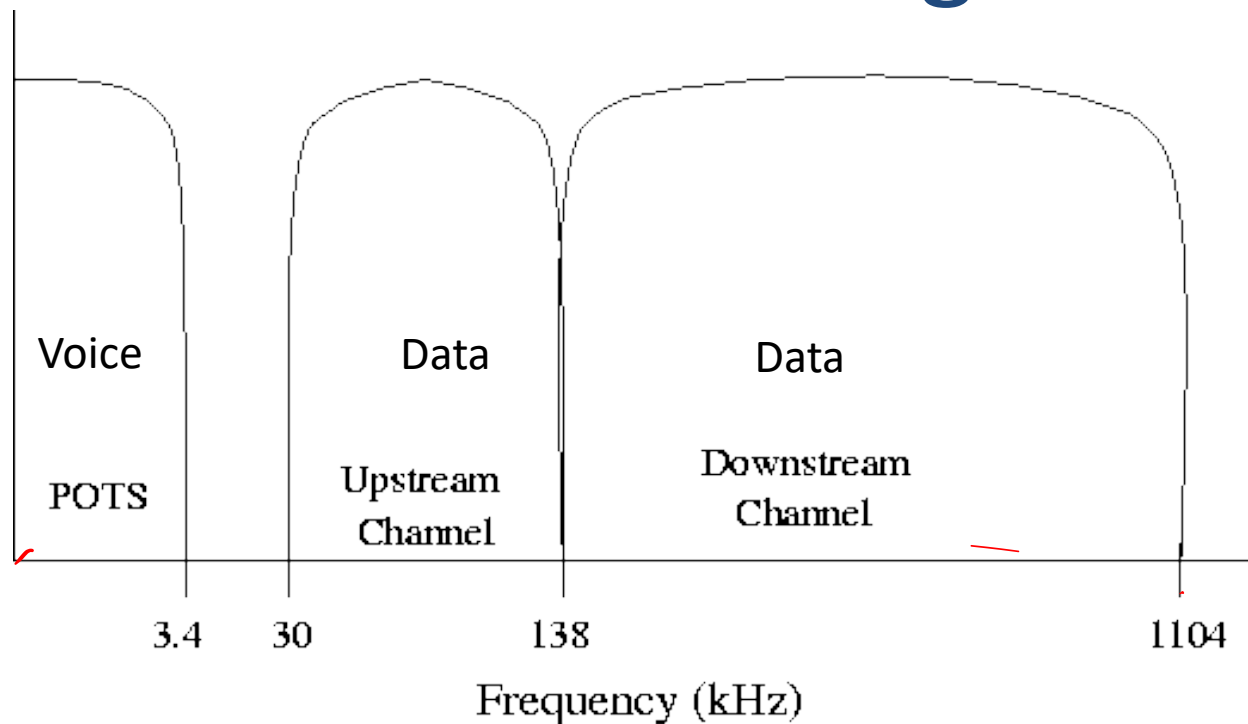
Interent

- **ADSL**: use the telephone network infrastructure
- **Cable**: use the cable television infrastructure
- **Fiber**: optical fiber path from the CO directly to the home.

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 downstream)

ADSL Channel Configuration

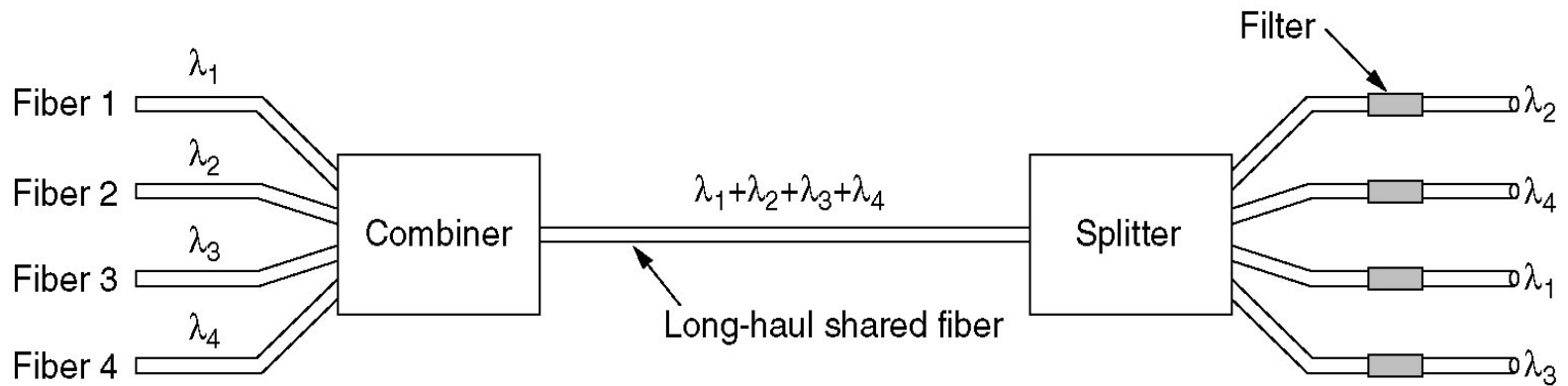
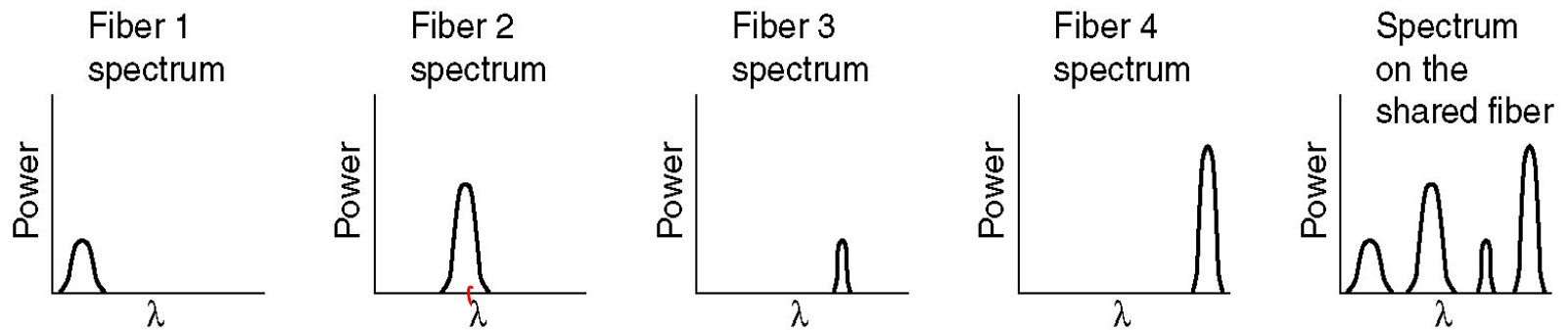


- Oversimplified
- Asymmetric, downstream rate (e.g. 24Mb/s) is higher than upstream rate(e.g. 2.5Mb/s)

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

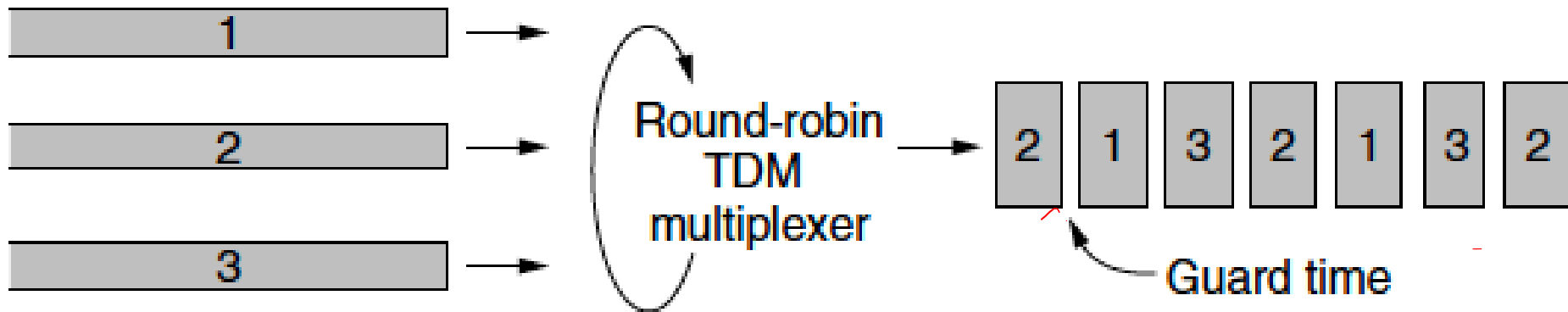
WDM is like FDM!



Multiplexing Categories

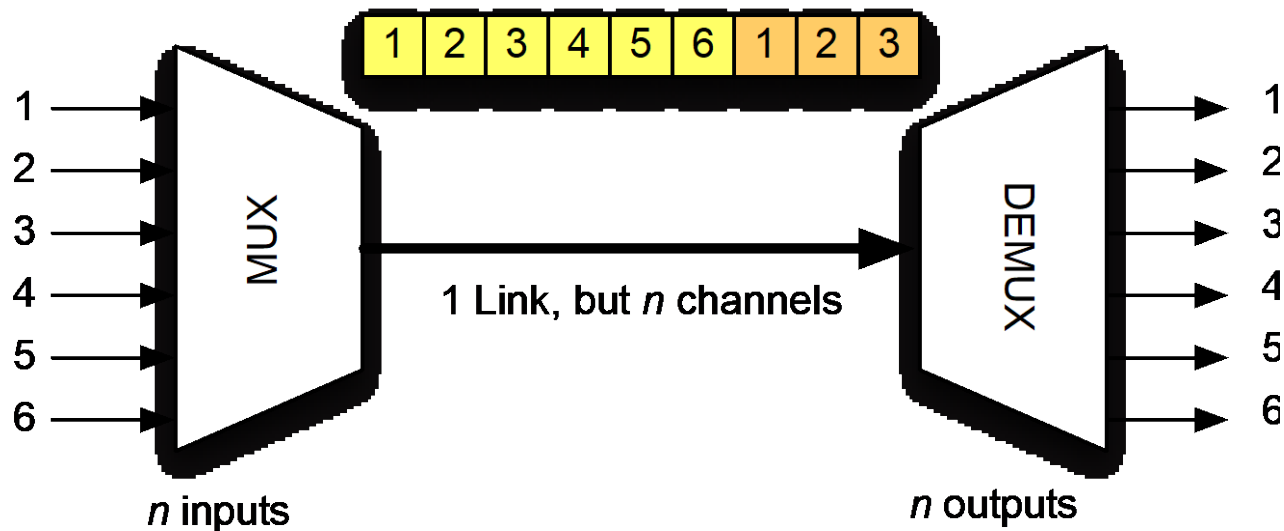
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Time Division Multiplexing



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**



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

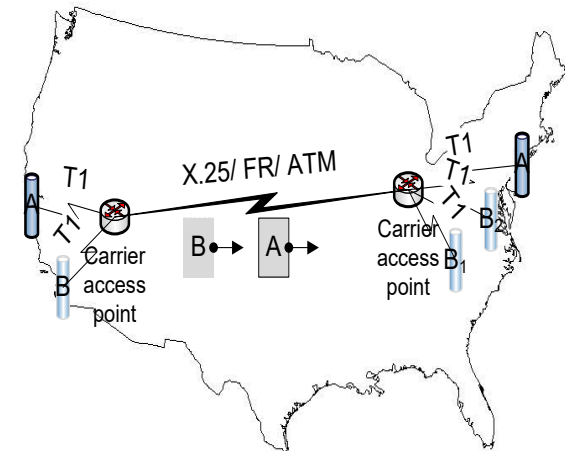
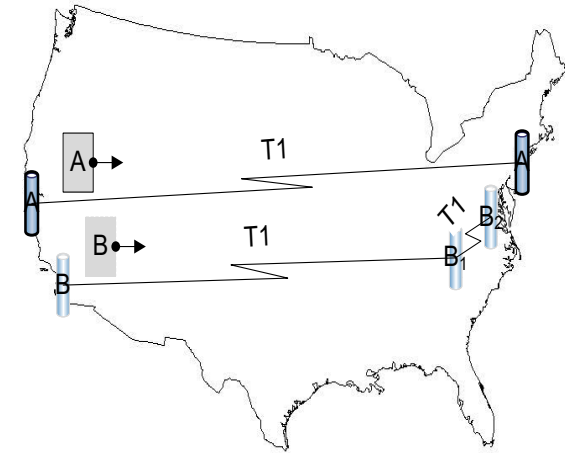
None of the above

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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 than 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

Some Standardized Multiplexing Systems

- North American digital hierarchy (T-Carrier)
- ITU digital hierarchy (E-Carrier)
- 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

Dedicated circuits involve leasing circuits from common carriers
(create point to point lines between organization location)

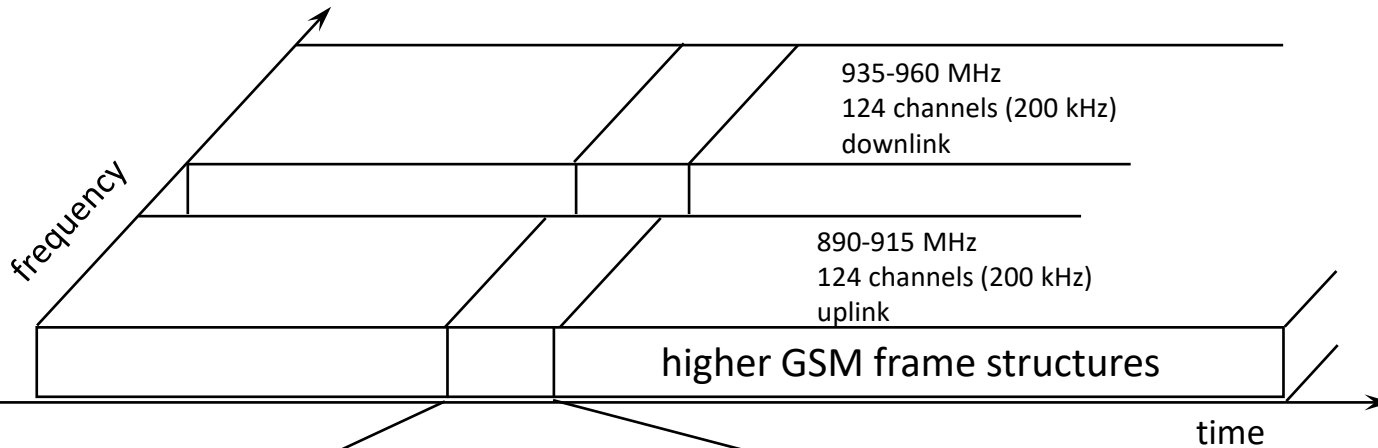
Mode and Multiplexing – Uplink and Downlink

- 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



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

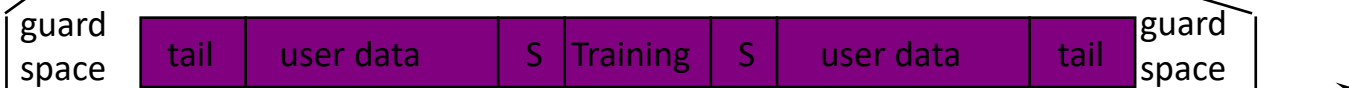
GSM TDMA frame



8 users share one channel

4.615 ms

GSM time-slot (normal burst)



546.5 μ s

577 μ s

Summary

- Multiplexing techniques enable multiple messages transmission at the same time by dividing frequency, wavelength, time, code ,..
 - TDM, FDM, WDM, CDMA,..
- Duplexing techniques allow for two way transmission
 - FDD, TDD