

Communication between more  
than two devices sharing a link

# Why Share?

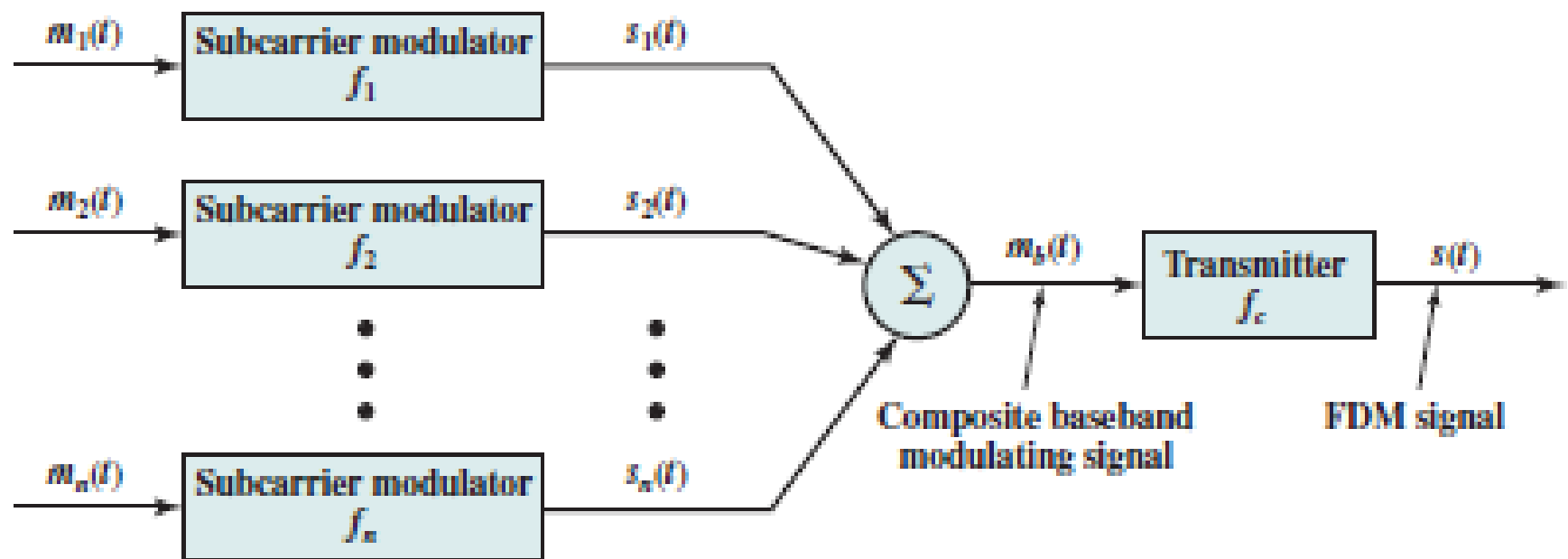
- Creating separate physical link between each transmitter-receiver pair is infeasible
- In most cases, a single transmitter-receiver pair does not utilize the whole bandwidth of a link
- Bandwidth can be shared between multiple pairs to increase line efficiency and reduce cost
- Approaches
  - Multiplexing
    - Create multiple “logical” channel out of a single physical channel
  - Contention based protocols
    - Contend for use of channel when needed, no a-priori agreement or permission given
  - Controlled access protocols
    - Agree beforehand who has right to send when
    - Ex. — Reservation, Polling, Token Passing

# Multiplexing

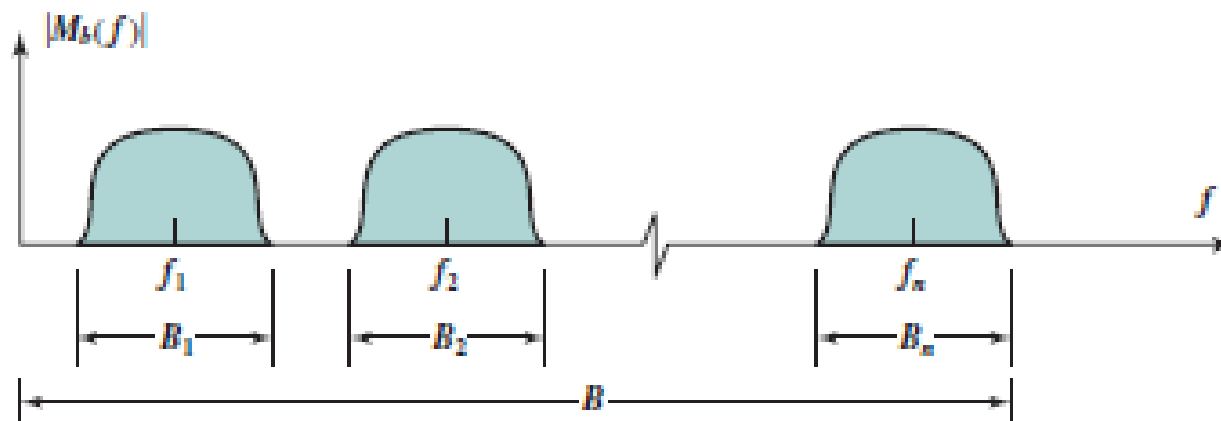
- Create more than 1 channel out of a link
- Each channel has a “share” of the link (in time, frequency, wavelength etc.)
  - Time Division Multiplexing (TDM) – each channel assigned a time slot
  - Frequency Division Multiplexing (FDM) –each channel assigned a frequency band
  - Wavelength Division Multiplexing (WDM) – each channel assigned a wavelength (optical communication only)
- Different sender-receiver pairs can use the different channels

# Frequency Division Multiplexing (FDM)

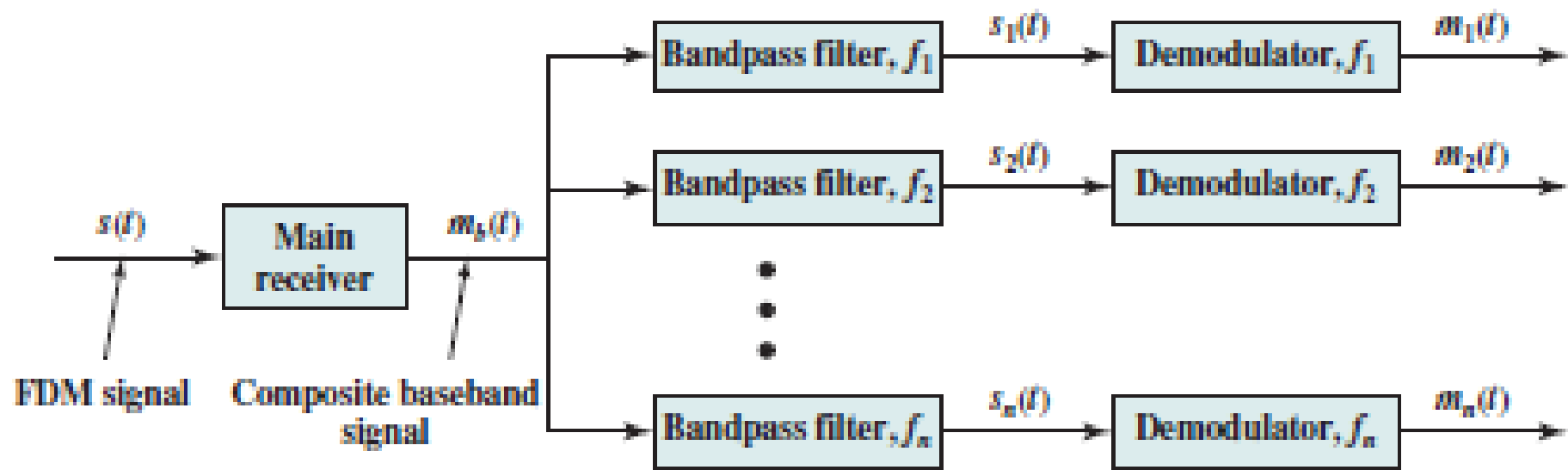
- Possible when useful bandwidth of medium exceeds required bandwidth of channel
- Each signal is modulated to a different carrier frequency
  - So a number of carrier signals used
  - Each called a subcarrier
- Sum the resulting analog, modulated signals to get a composite baseband signal
- Carrier frequencies separated by **guard bands** so signals do not overlap
- Channel allocated even if there is no data



(a) Transmitter



(b) Spectrum of composite baseband modulating signal



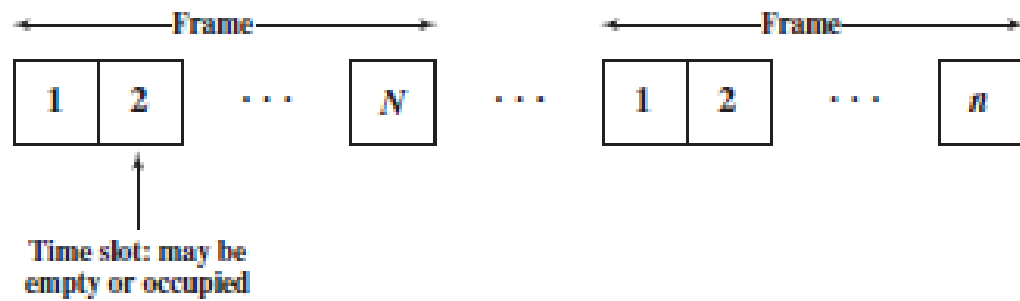
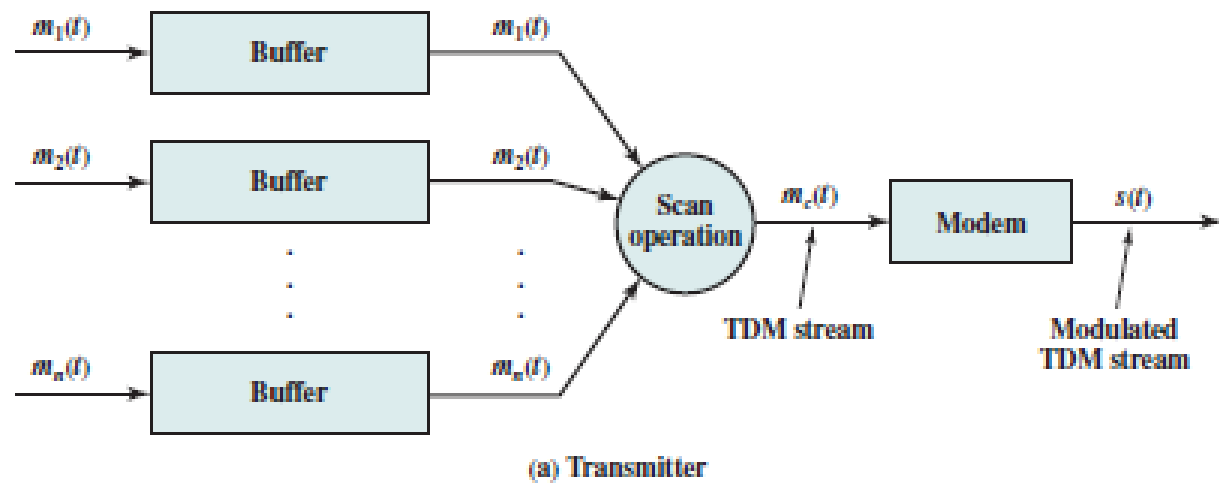
(c) Receiver

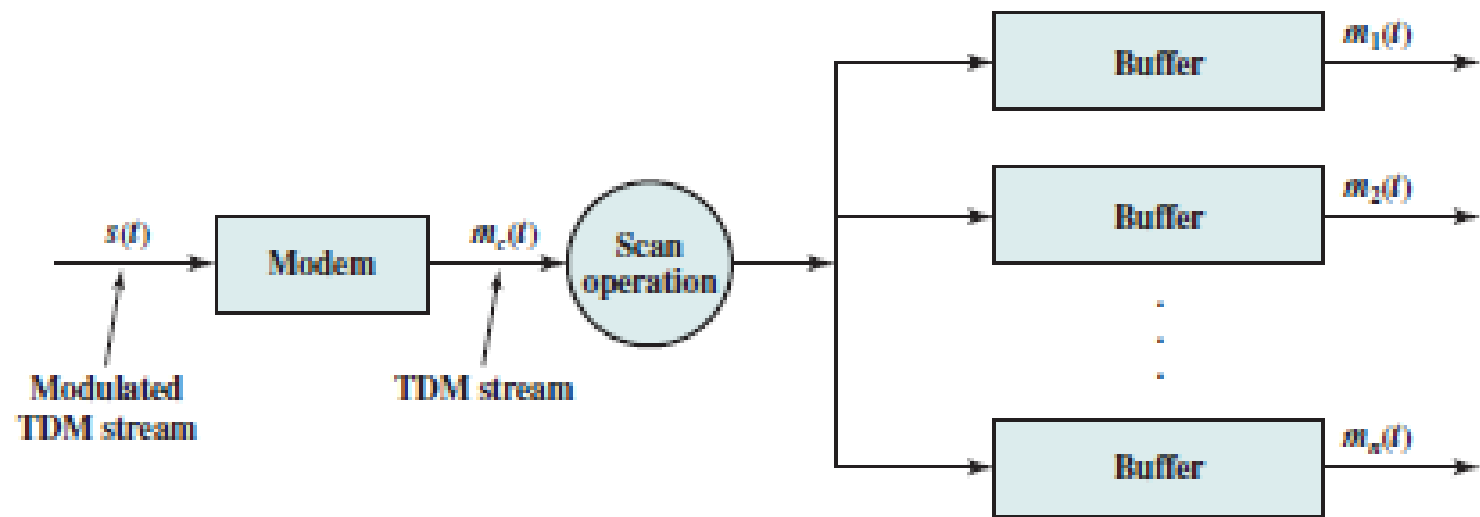
- Requires analog signaling & transmission
- Bandwidth = sum of subcarriers + guard bands
- Modulates signals so that each occupies a different frequency band
- Standard for radio broadcasting, analog telephone network, and television (broadcast, cable, & satellite)

# Synchronous TDM

- Multiple digital signals interleaved in time
- TDM frame contains time slots
- Time slots pre-assigned to sources and fixed
- Multiplexer scans each source and puts its data in its time slot
- If there is no data for a source, the slot goes free
- Each slot contains 1 bit (*bit multiplexing*) or 1 byte (*byte multiplexing*) or blocks of bytes....
  - Can be anything fixed
- TDM frames transmitted using synchronous or asynchronous transmission







(c) Receiver

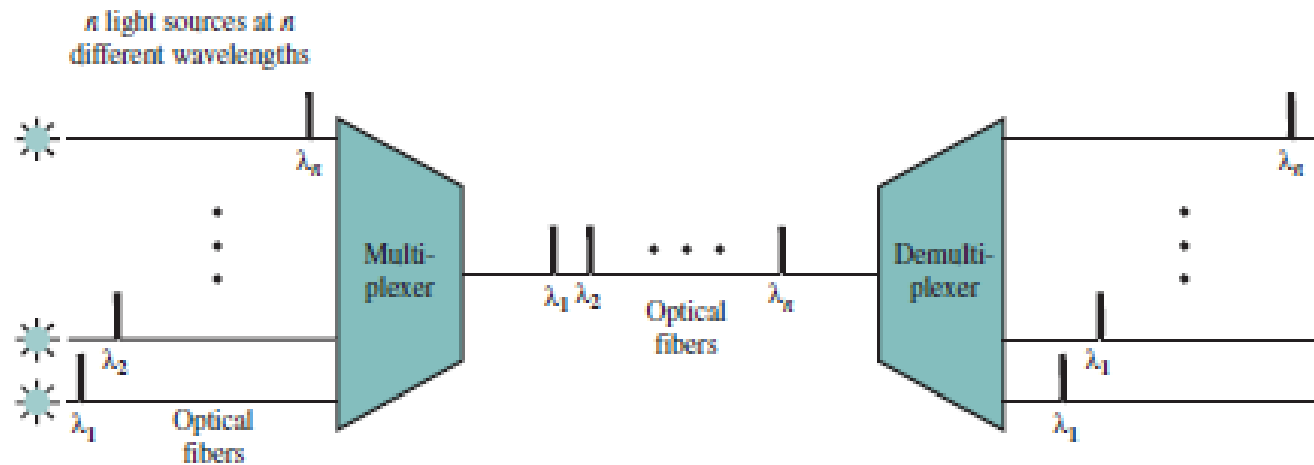
- Synchronization between mux and demux
  - Extra framing bit transmitted with each frame for clock synchronization
  - Framing bits define a *control channel*
- Requires data rate of the medium to be greater than sum of the data rates of signals to be transmitted

# Statistical TDM

- In Synchronous TDM many slots are wasted if there is no data to be transmitted in that channel
- Statistical TDM allocates time slots dynamically based on demand
- Data rate capacity required is below the sum of connected capacity
- Frames are more complex, and so is the mux and demux

# Wavelength Division Multiplexing (WDM)

- Used only for optical channels
- Each channel is modulated on carriers of a different wavelength (multiple beams of light)



# Contention Based Protocols

- Commonly called *Medium Access Control (MAC) Protocols*
- Defines protocols for multiple stations to access medium at multiple points and successfully send data
  - Needs to avoid collision, i.e. two or more stations accessing medium at the same time
- Examples:
  - Very early: ALOHA, Slotted ALOHA
  - Widely used in older Ethernet: CSMA/CD
  - Widely used in wireless: CSMA/CA and its variants

# ALOHA

- Developed in Univ. of Hawaii in early 70s
  - Interconnected the different islands
- For packet radio networks
- Transmission to and from a central station
- All sources transmit using same frequency, can transmit anytime
- If two sources transmit simultaneously, collision
- If collision, each station waits for a random time, then tries again

- How is collision detected?
  - Acknowledgement frames sent by receiver on a different frequency
  - If no ack received within some time, sender assumes collision
- Simple
- Very inefficient for larger no. of nodes or higher transmission rates



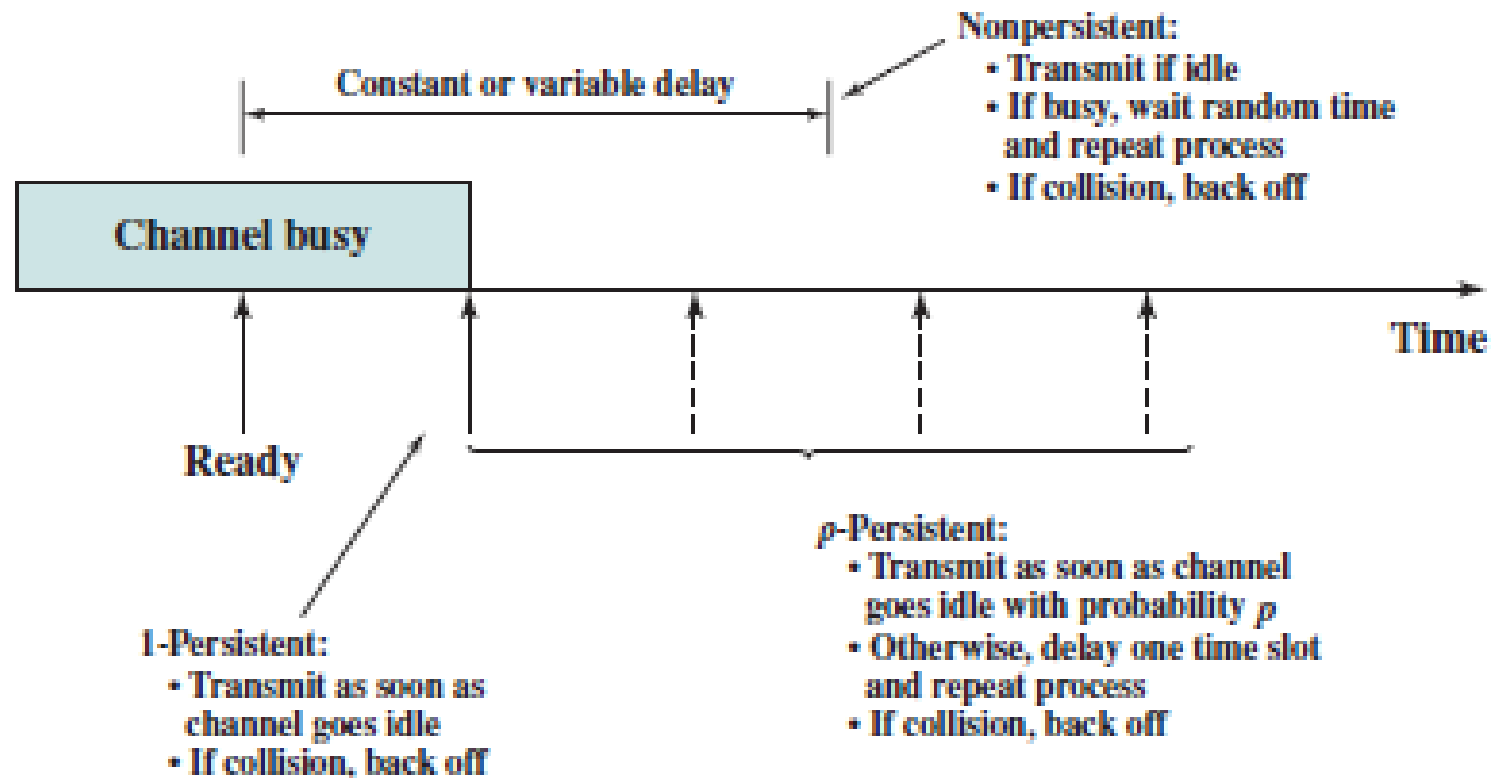
# Slotted ALOHA

- Time divided into slots
- Each source should start sending only at the beginning of a slot
- Collision possible only if two sources become ready at the same slot.
- Reduces no. of collisions over ALOHA (why?)

# Carrier Sense Multiple Access (CSMA)

- Broad Idea
  - Sense the medium to see if it is used (Carrier Sense)
  - If not (line idle), transmit
  - If yes, wait for some time, then repeat the above
- Types - nonpersistent, 1-persistent, p-persistent
  - Differs mostly in what a sender does when the medium is found to be busy
  - Tradeoff between line utilization and chance of collision

- Non-persistent CSMA
  - If medium is found idle, transmit
  - If medium found busy, wait for a random time drawn from a probability distribution, then sense line again
- 1-persistent CSMA
  - If medium is found idle, transmit
  - If medium found busy, continue to listen until the channel is sensed idle, then transmit immediately
- p-persistent CSMA
  - If medium is found idle, transmit with probability  $p$ , and delay 1 time unit with probability  $(1 - p)$ 
    - If delayed, repeat this step after the delay
  - If medium found busy, continue to listen until the channel is sensed idle, then use the rule for sending in idle channel
  - What is a good value of  $p$ ?



# CSMA/CD (CSMA with Collision Detection)

- Why needed?
  - Suppose two senders detect the channel idle at the same time and start to transmit
  - Both will end up transmitting a full damaged frame
- CSMA/CD
  - Sense medium
  - If medium is idle, transmit
  - If medium is busy, apply standard CSMA (non-persistent, p-persistent,...)
  - If collision detected during transmission (how?), transmit a short jamming signal to indicate collision to all and stop transmitting
  - After sending the jamming signal, wait for a random backoff time (Binary exponential backoff), then repeat above steps

- Binary Exponential Backoff
  - Time divided into slots
  - After k-th collision, pick a slot randomly within the next  $2^k$  slots to try transmitting again
  - So with increased congestion, transmitters choose from a larger range to reduce chance of collision
  - Usually gives up after a certain number of tries

- CSMA/CD requires a minimum packet length  $L$  to detect collision (why?)

$$L = 2DR/V \text{ where}$$

$D$  = maximum distance between two machines

$R$  = data rate

$V$  = propagation delay

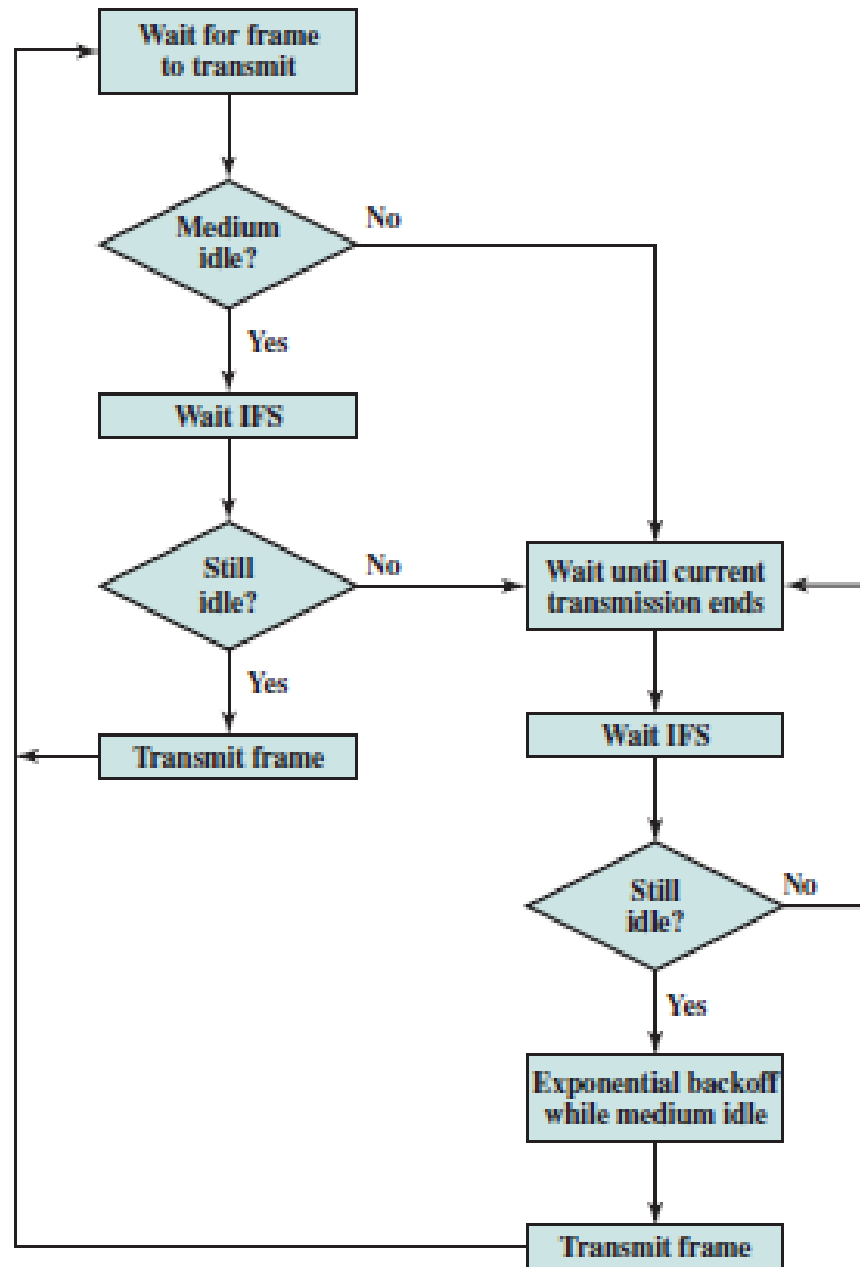
# CSMA/CA (Collision Avoidance)

- Problems in collision detection in wireless media
  - Collision is at receiver
  - Problem of transmit and receive at same channel
  - Weak received signal
  - Hidden/Exposed terminal problem
- Collision Avoidance proposed as a solution
- In wireless, a receiver can get a sender's signal only if it is within a certain range of the sender
  - Range depends on different things like transmitter power, frequency range used, atmospheric conditions etc.

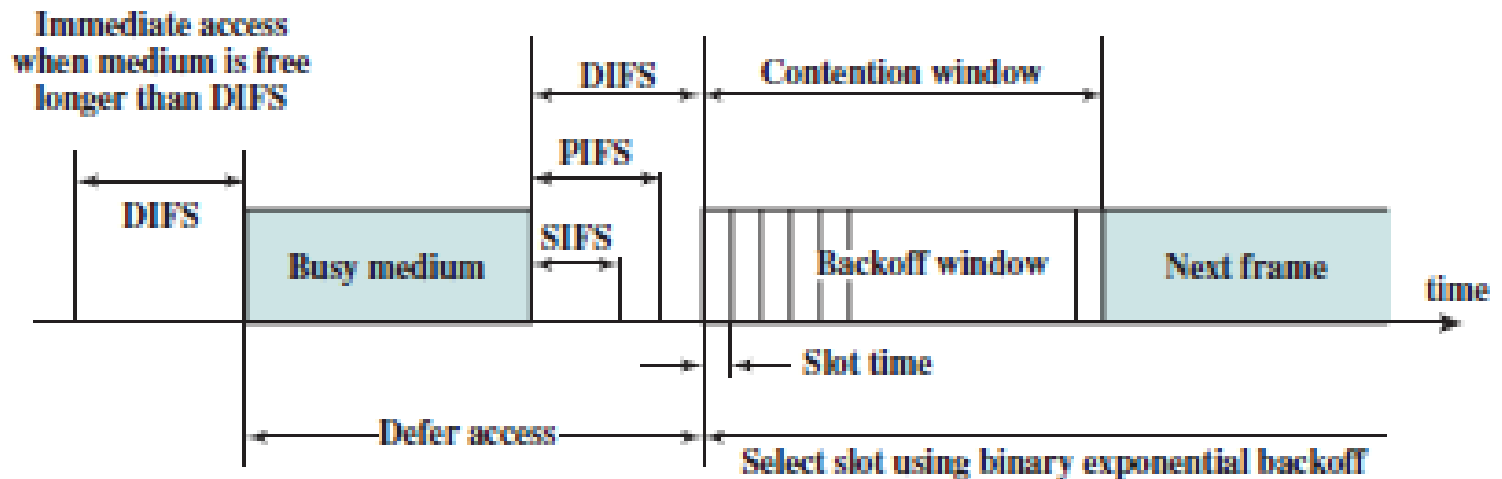


# Basic Transmission Steps

- Sense medium. If idle, wait for IFS (Inter Frame Space) time. If still idle, transmit.
- If medium is busy, defer transmission and monitor medium
- When medium found free again
  - Defer another IFS time
  - If still idle backoff, a random time and again sense medium
  - If still idle, transmit
  - During backoff time, if medium is found busy, halt the timer, resume when medium is free again
- If no ack received, assume collision



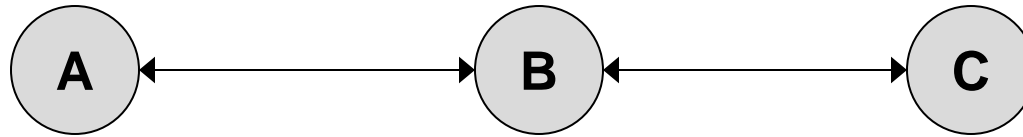
- Different IFS lengths to prioritize different types of processes



(a) Basic access method

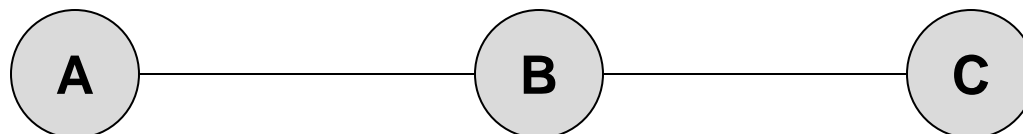
- Problems: Hidden Terminals and Exposed Terminal

# Hidden Terminal Problem



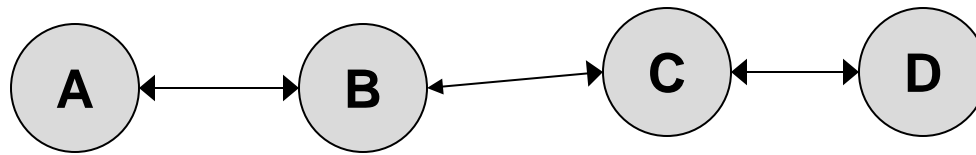
- B can communicate with both A and C
- A and C cannot hear each other (out of range)
- Problem
  - When A transmits to B, C cannot detect the transmission using the carrier sense mechanism
  - If C transmits, collision will occur at node B
- Solution
  - Hidden sender C needs to defer

# Solution for Hidden Terminal Problem



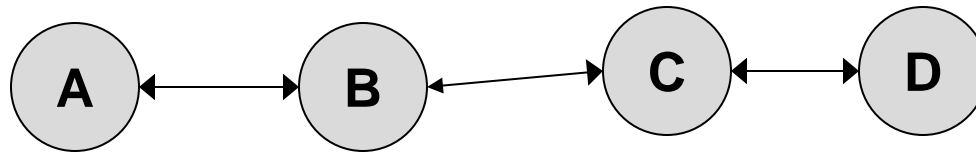
- When A wants to send a packet to B, A first sends a **Request-to-Send (RTS)** to B
- On receiving RTS, B responds by sending **Clear-to-Send (CTS)**
- When C overhears a CTS, it keeps quiet for the duration of the transfer
  - Transfer duration is included in both RTS and CTS
- But RTS/CTS are also frames and they can also collide! Why is this not a problem?

# Exposed Terminal Problem



- B can communicate with A and C
- C can communicate with B and D
- A and C cannot hear each other
- Problem
  - When B transmits to A, C detects the transmission using the carrier sense mechanism
  - So C defers transmitting to D
  - But C could have sent to D, so blocked unnecessarily (C is the exposed terminal)

# Solution to Exposed Terminal Problem



- B sends **RTS** to A
- A sends **CTS** to B
- C hears **RTS**, but not **CTS**, assumes it is ok to send to D
- Does it fully solve the problem?

# Token Ring

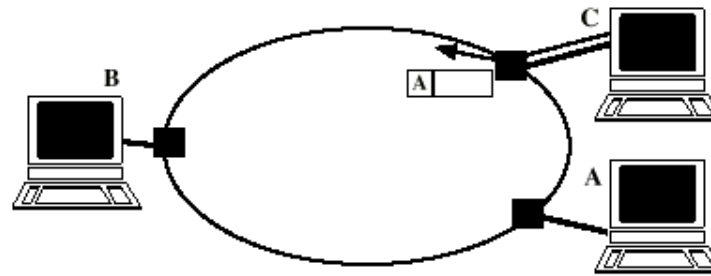
- Repeaters joined by point to point links in closed loop
  - Receive data on one link and retransmit on another
  - Links unidirectional
  - Stations attach to repeaters
- Data in frames
  - Circulate past all stations
  - Destination recognizes address and copies frame
  - Frame circulates back to source where it is removed
- Media access control determines when station can insert frame



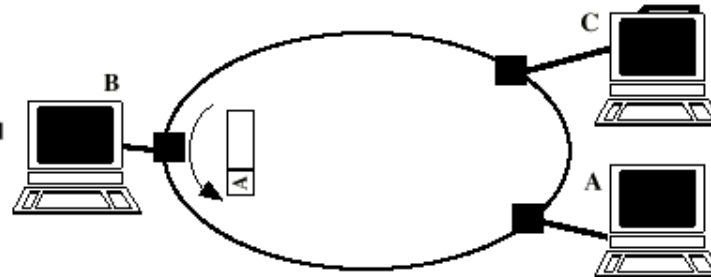
# Token Passing

- Special frame called Token
- A m/c can transmit only when it has the token
- If no transmission needed, pass token to neighbor
- If data to transmit, put data and destination in token, change control bit to indicate data frame, and pass to neighbor
- When frame received, if data frame and not destination, pass to neighbor. If data frame and destination, copy and pass to neighbor
- When sender receives back, it changes control bits to make it a token again, and passes to neighbor

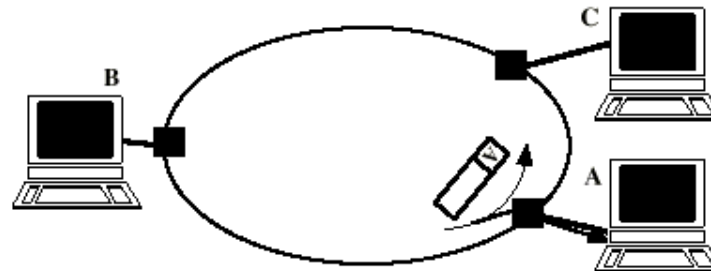
(a) C transmits frame addressed to A



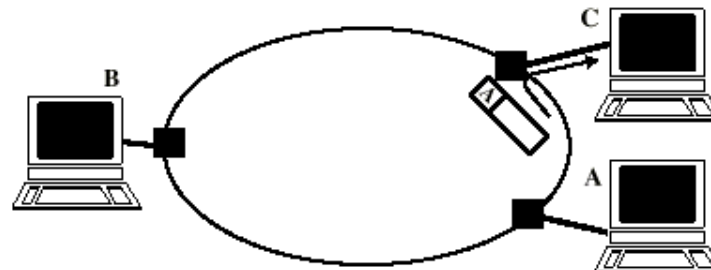
(b) Frame is not addressed to B; B ignores it



(c) A copies frame as it goes by



(d) C absorbs returning frame



- Used in old token ring networks (IEEE 802.4), not used much now
- However, token passing is an important concept in many different contexts

# Summary

- We have seen different methods for sharing one medium by more than one sender
- Each sender gets its own chance to send on its own channel to the receiver
  - Logical channels created for each sender-receiver pair pair out of the single physical channel
  - Note that full duplex communication will requires two channels
- Each logical channel appears as a dedicated channel for the sender to send to the receiver, so as if one sender and one receiver on one channel
- We already know from earlier how to make that work