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

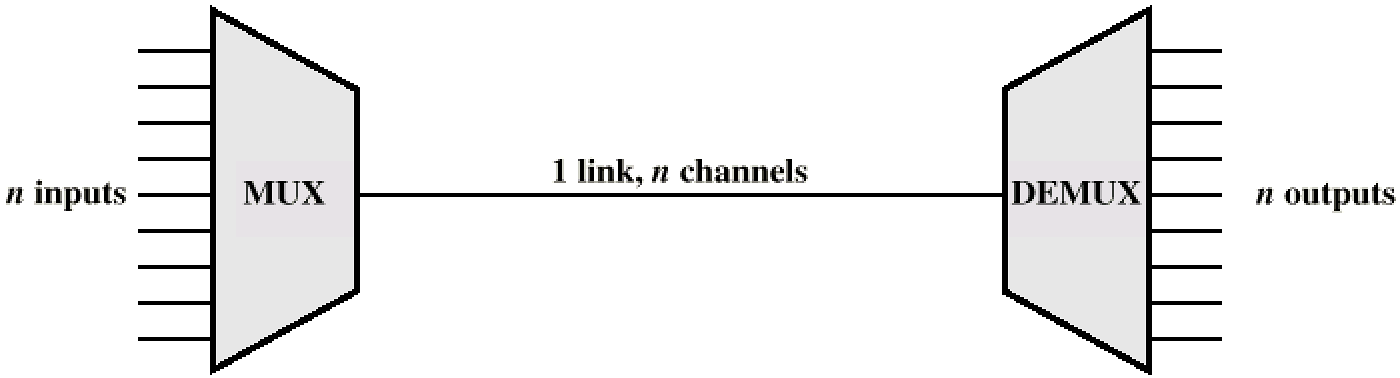
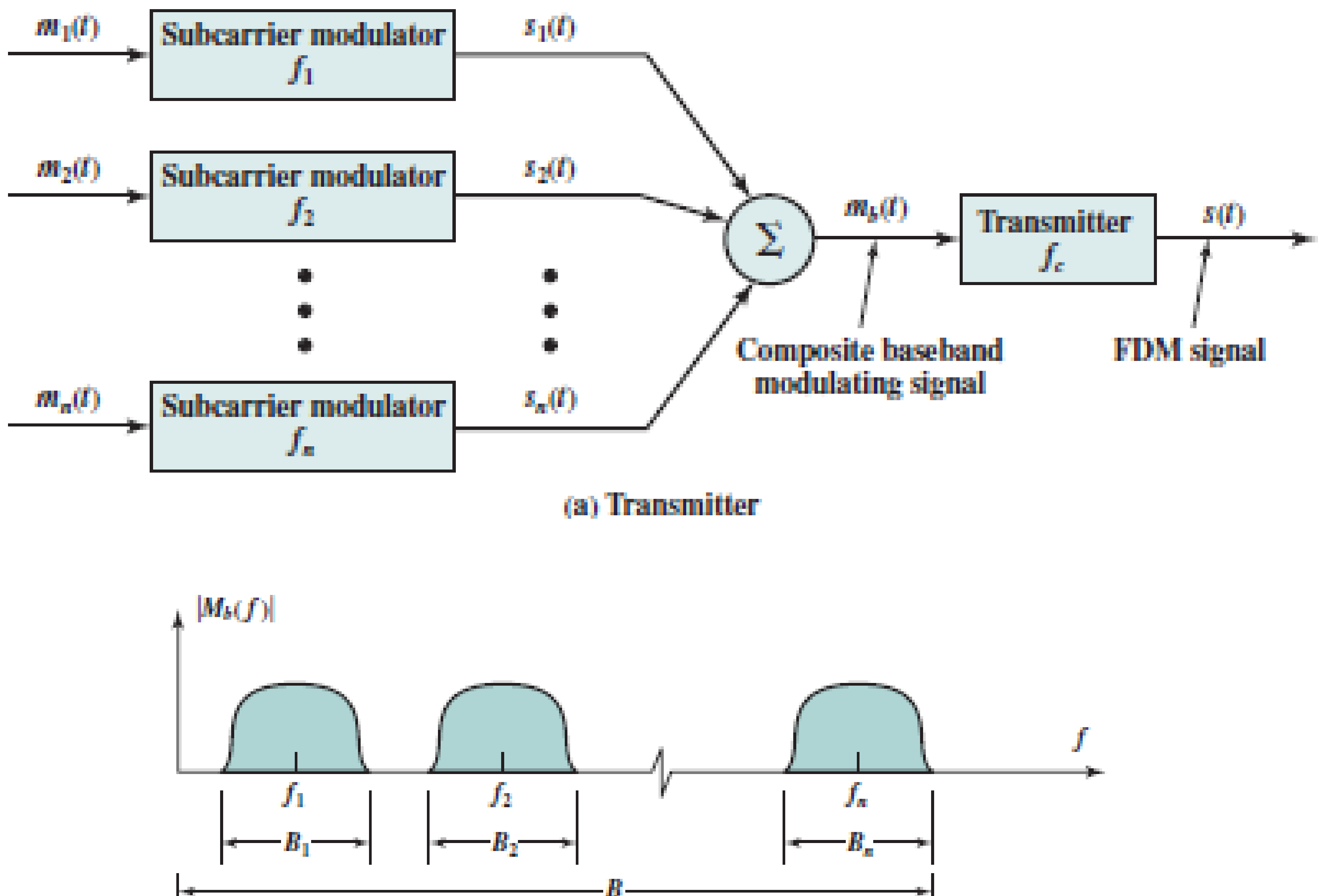


Figure 8.1 Multiplexing

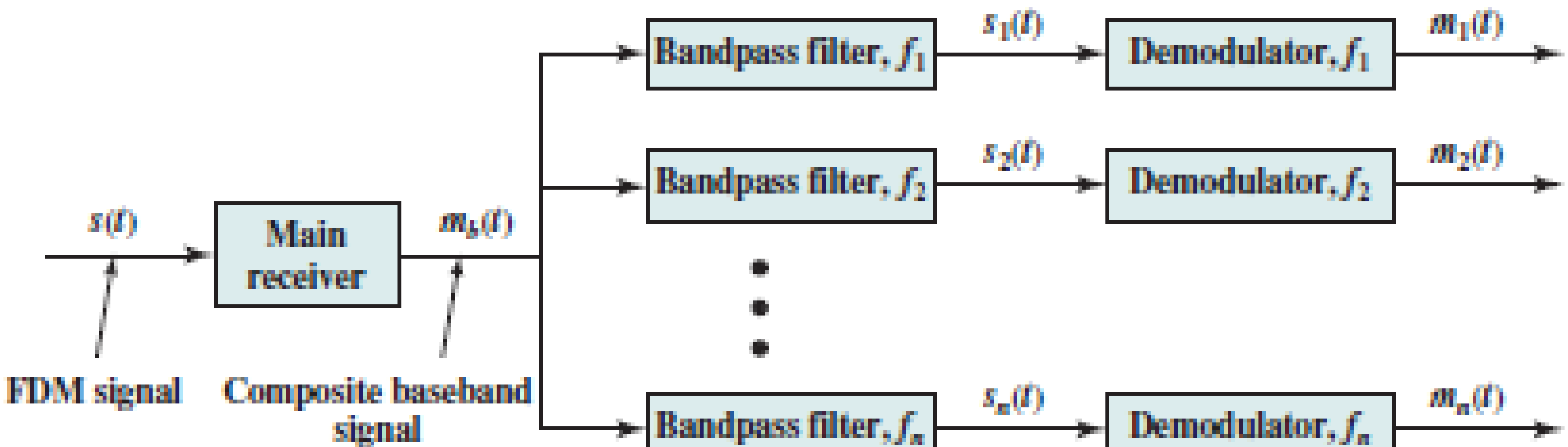
Frequency Division Multiplexing (FDM)

- 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



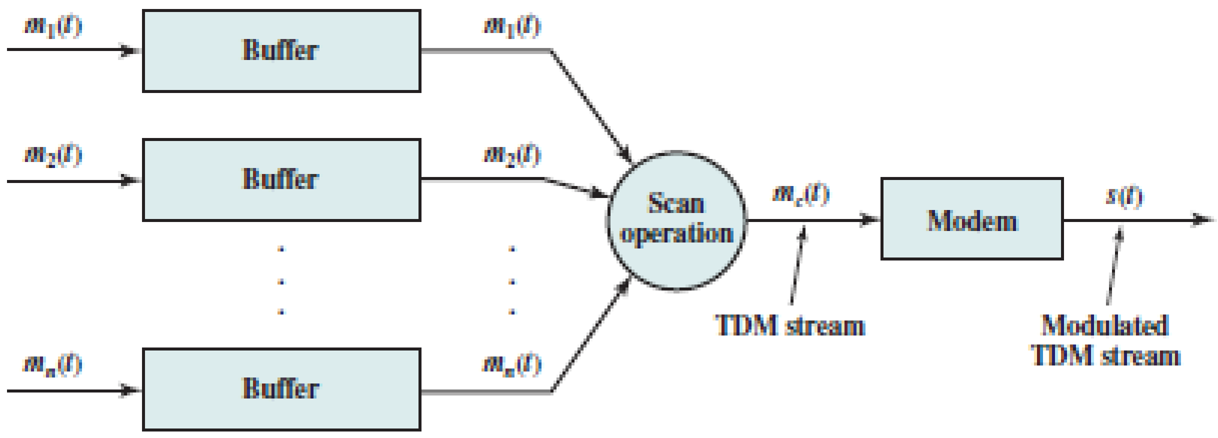
$s(t)$
Main receiver
$m_b(t)$
FDM signal
Composite baseband signal
Bandpass filter, f_1
Bandpass filter, f_2
Bandpass filter, f_n
$s_1(t)$
$s_2(t)$
$s_n(t)$
Demodulator, f_1
Demodulator, f_2
Demodulator, f_n
$m_1(t)$
$m_2(t)$
$m_n(t)$

(c) Receiver

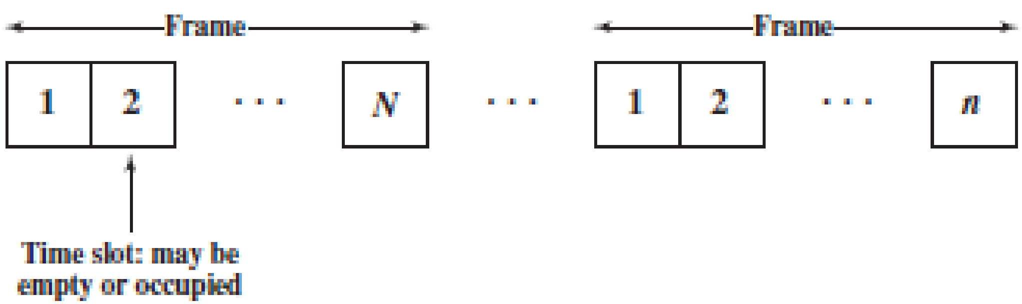
- Requires analog signaling & transmission
- Bandwidth = sum of subcarriers + guard bands
- Modulates signals so that each occupies a different frequency band
- Standard for radio broadcasting, analog telephone network, and television (broadcast, cable, & satellite)

Synchronous TDM

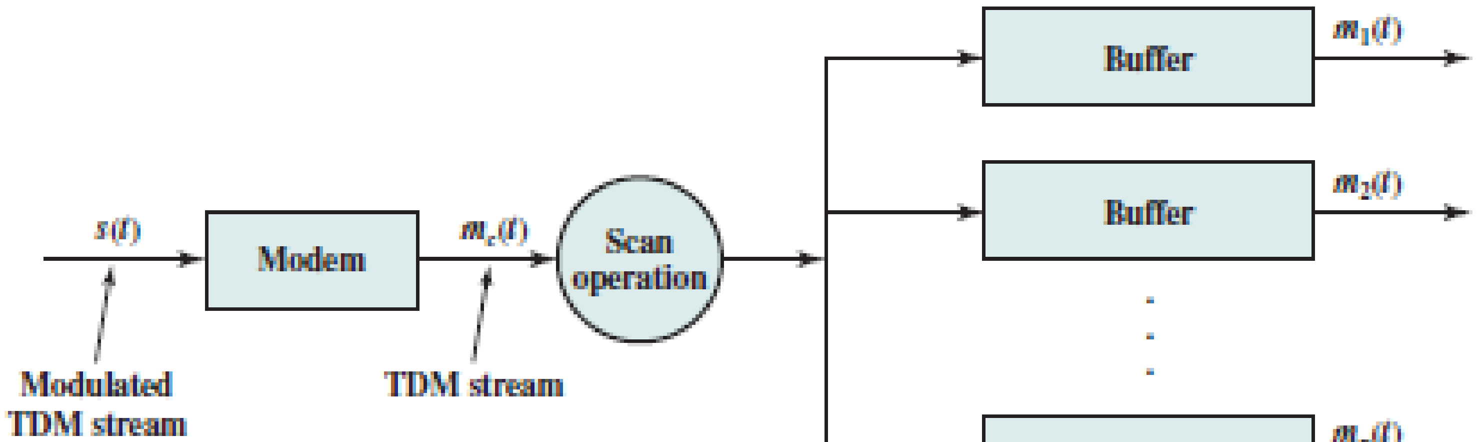
- Multiple digital signals interleaved in time
- TDM frame contains time slots
- Time slots pre-assigned to sources and fixed
- Multiplexer scans each source and puts its data in its time slot
- If there is no data for a source, the slot goes free
- Each slot contains 1 bit (*bit multiplexing*) or 1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



(a) Transmitter



(b) TDM frames


$s(t)$
Modem
$m_c(t)$
Scan operation
Modulated TDM stream
TDM stream
Buffer
Buffer
Buffer
$m_1(t)$
$m_2(t)$
$m_n(t)$

(c) Receiver

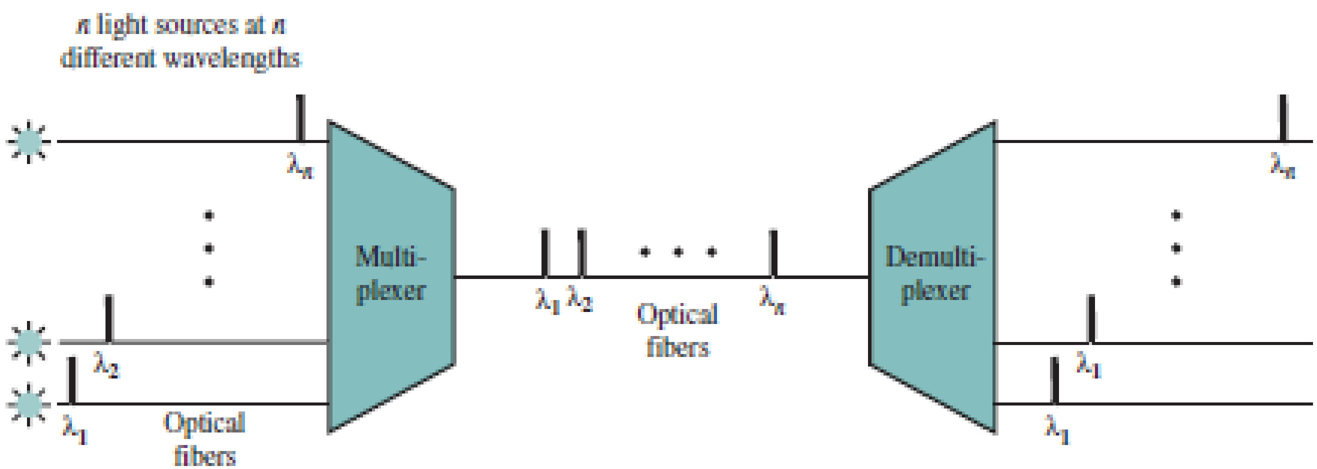
- Synchronization between mux and demux
  - Extra framing bit transmitted with each frame for clock synchronization
  - Framing bits define a *control channel*
- Requires data rate of the medium to be greater than sum of the data rates of signals to be transmitted

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

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

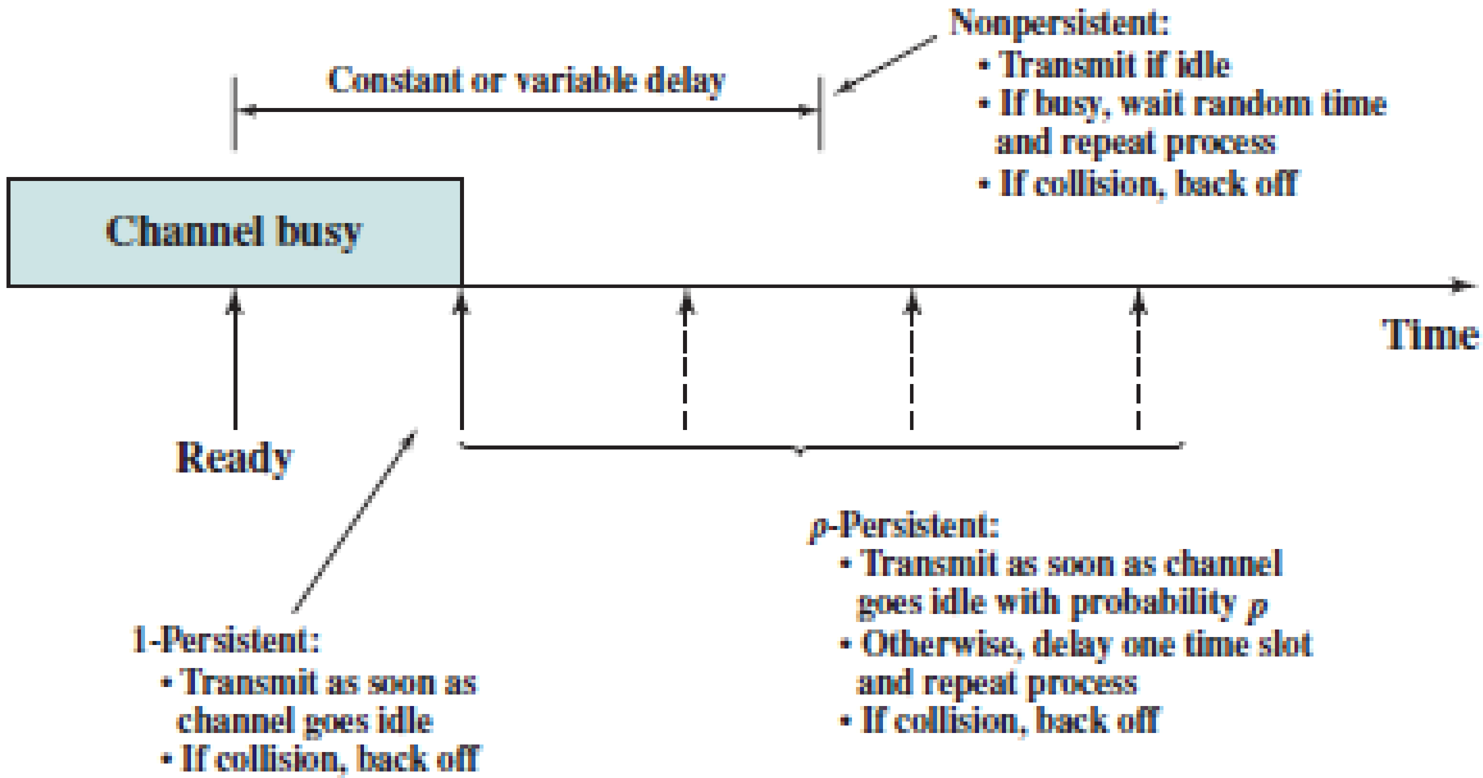
Slotted ALOHA

- 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?


Constant or variable delay
Nonpersistent:
• Transmit if idle
• If busy, wait random time and repeat process
• If collision, back off
Channel busy
Time
Ready
1-Persistent:
• Transmit as soon as channel goes idle
• If collision, back off
p-Persistent:
• Transmit as soon as channel goes idle with probability p
• Otherwise, delay one time slot and repeat process
• If collision, back off

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?)

  $L = 2DR/V$ where

  D = maximum distance between two machines

  R = data rate

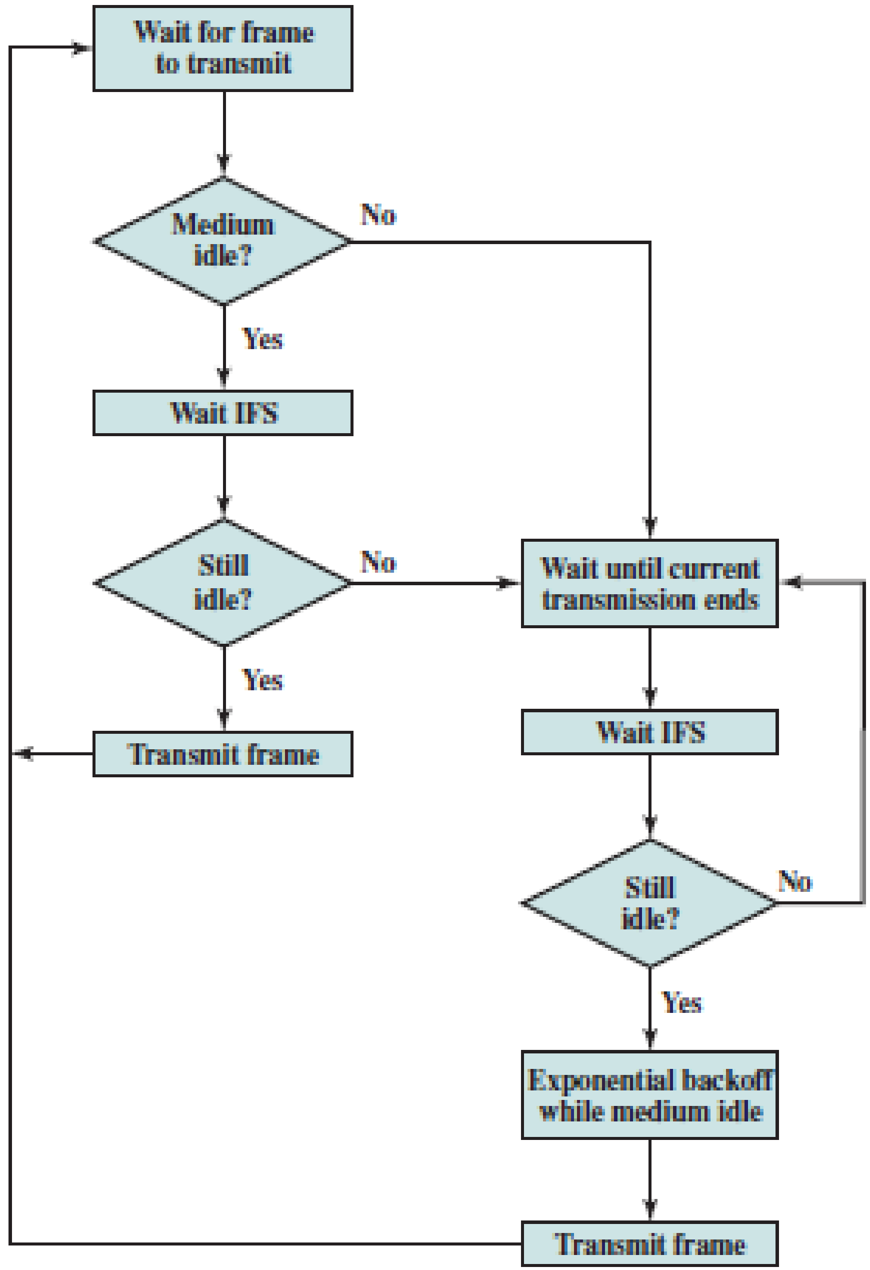
  V = propagation delay

CSMA/CA (Collision Avoidance)

- Problems in collision detection in wireless media
  - Weak received signal
  - Hidden terminal problem
  - 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.

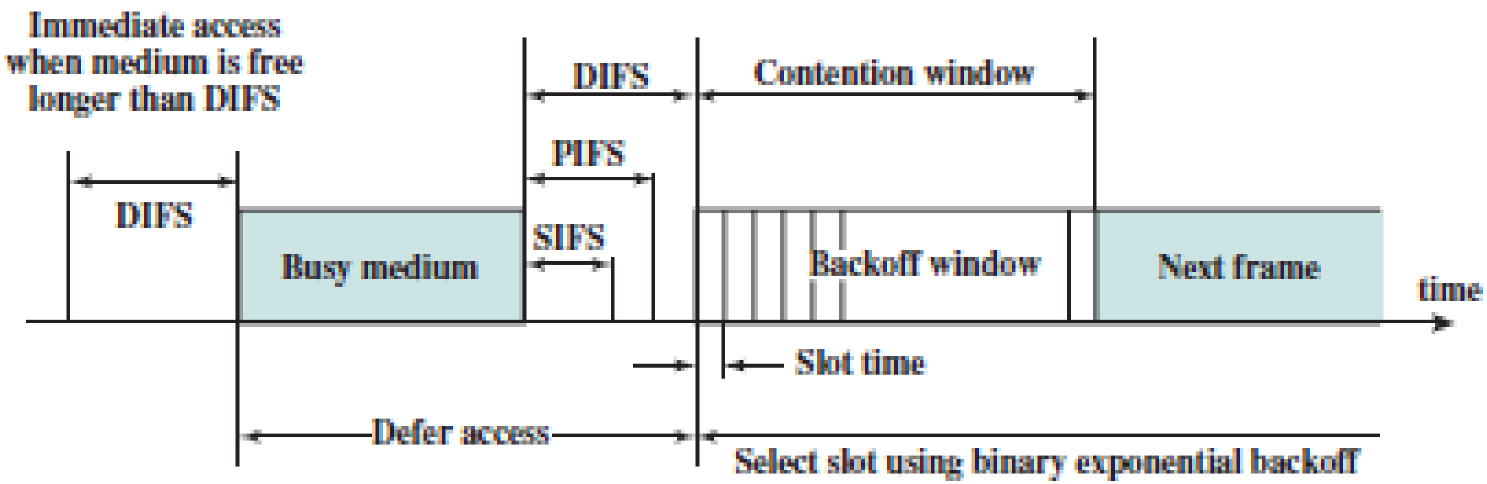
Basic Transmission Steps

- 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



Wait for frame to transmit
Medium idle?
No
Yes
Wait IFS
Still idle?
No
Yes
Transmit frame
Wait until current transmission ends
Wait IFS
Still idle?
No
Yes
Exponential backoff while medium idle
Transmit frame

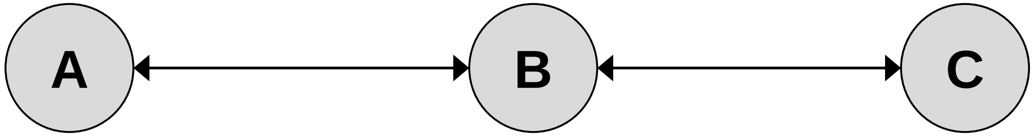
- Different IFS lengths to prioritize different types of processes



(a) Basic access method

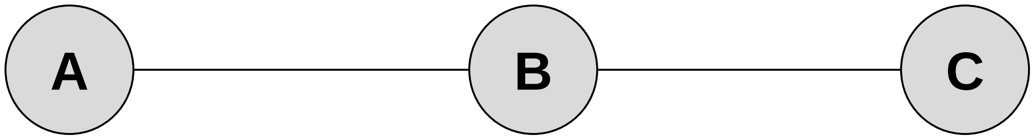
- Problems: Hidden Terminals and Exposed Terminal

Hidden Terminal Problem



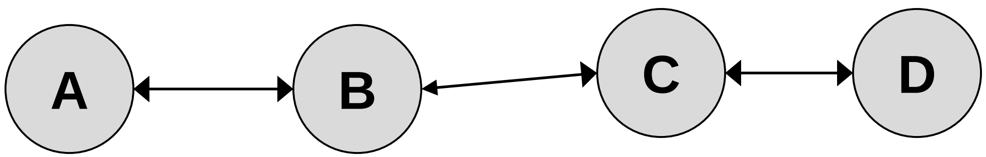
- B can communicate with both A and C
- A and C cannot hear each other (out of range)
- Problem
  - When A transmits to B, C cannot detect the transmission using the carrier sense mechanism
  - If C transmits, collision will occur at node B
- Solution
  - Hidden sender C needs to defer

Solution for Hidden Terminal Problem



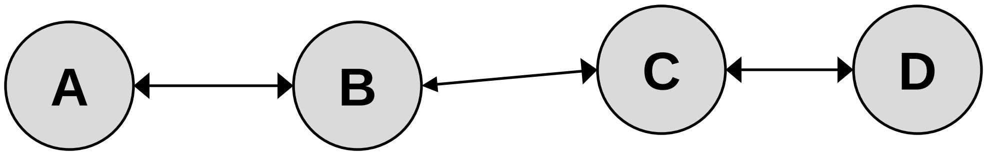
- When A wants to send a packet to B, A first sends a Request-to-Send (RTS) to B
- On receiving RTS, B responds by sending Clear-to-Send (CTS)
- When C overhears a CTS, it keeps quiet for the duration of the transfer
  - Transfer duration is included in both RTS and CTS
- But RTS/CTS are also frames 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



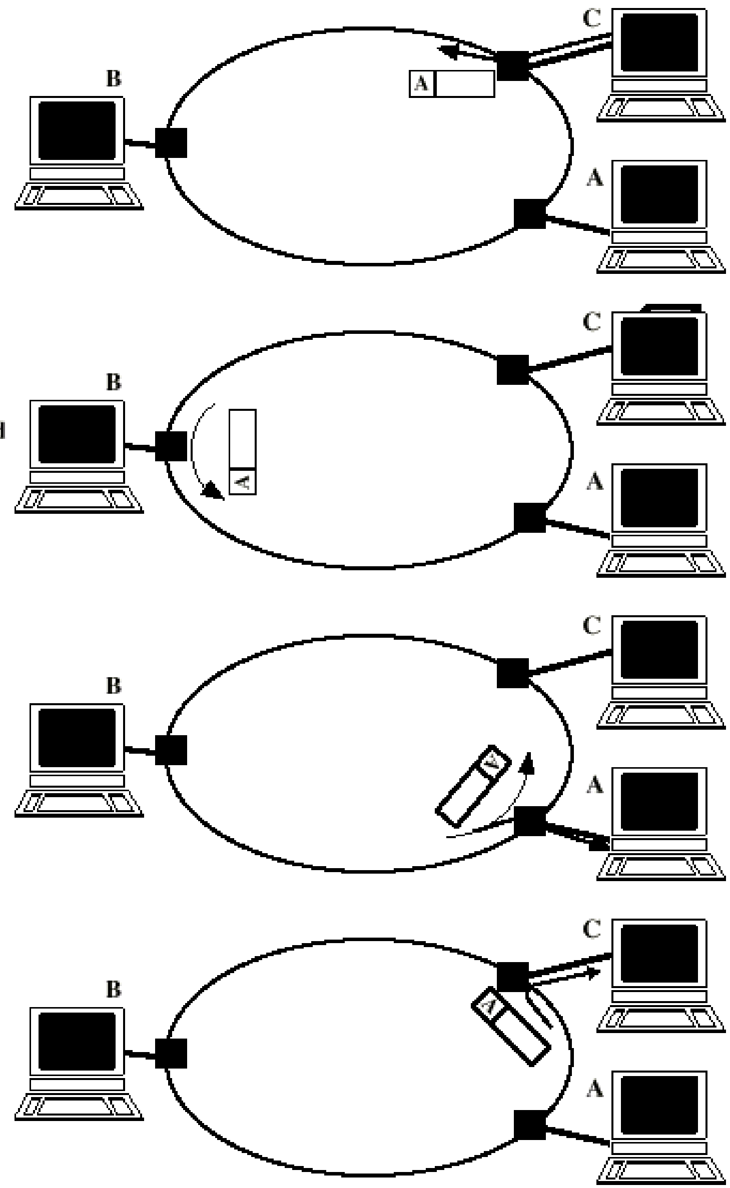
- B sends RTS to A
- A sends CTS to B
- C hears RTS, but not CTS, assumes it is ok to send to D
- Does it fully solve the problem?

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