251-0292: A Hand-on Introduction to Wireless Networks

Lectures 4 and 5: MAC

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Outline

- Data link fundamentals (refresher)
- Channel sharing options
  - In time, space, and frequency
  - Code-division multiple access (CDMA)
- Contention-based access
- Wireless-specific challenges
  - Hidden and exposed terminal problems
  - Transmit power and CCA threshold
- Wireless systems and standards

Datalink Functions

- Framing: encapsulating a network layer datagram into a bit stream.
  - » Add header, mark and detect frame boundaries, …
- Media access: controlling which frame should be sent over the link next.
  - » Easy for point-to-point links; half versus full duplex
  - » Harder for multi-access links: who gets to send?
- Logical link control: managing the frame transfer, e.g.
  - » Error detection and correction to deal with bit errors
  - » Flow control: avoid that the sender outruns the receiver

Framing

- Similar design as in wired networks.
  - » But must be more robust because of noise, …
- Typical structure:
  - » Preamble: synchronize clocks sender and receiver
  - » Header: usual information
  - » Data packet
  - » Trailer: padding, CRC, ..
- Can also have some differences:
  - » Different transmit rates for different parts of packet
  - » Control information for physical layer

Error Control: Error Detection versus Error Recovery

- Detection: only detect errors
  - » Make sure corrupted packets get thrown away, e.g. Ethernet
- Recovery: also try to recover from lost/corrupted packets
- Wireless networks typically use error recovery.
  - » Errors are much more common than in wired
- First step is to detect packet loss:
  - » Use of error detection codes, e.g. CRC
  - » Timeouts to detect packet loss
- Recovery mechanism based on:
  - » Positive acknowledgements
  - » Timeouts on the transmit side
  - » Negative acknowledgements

Automatic Repeat Request - ARQ

- All packets are acknowledged and missing ACK results in retransmit
  - » Very common in wireless
- Many variants:
  - » Stop and wait: one packet at a time
  - » Go Back N: sender keeps sending and retransmits, starting with the unacknowledged packet
  - » Selective Repeat: only packets that are not acknowledged are retransmitted
- When should what variant be used?

Flow Control

- Assures that transmitting entity does not overwhelm a receiving entity with data
- Protocols with flow control mechanism allow multiple PDUs in transit at the same time
- PDUs arrive in same order they're sent
- Sliding-window flow control
  - » Transmitter maintains list (window) of sequence numbers allowed to send
  - » Receiver maintains list allowed to receive

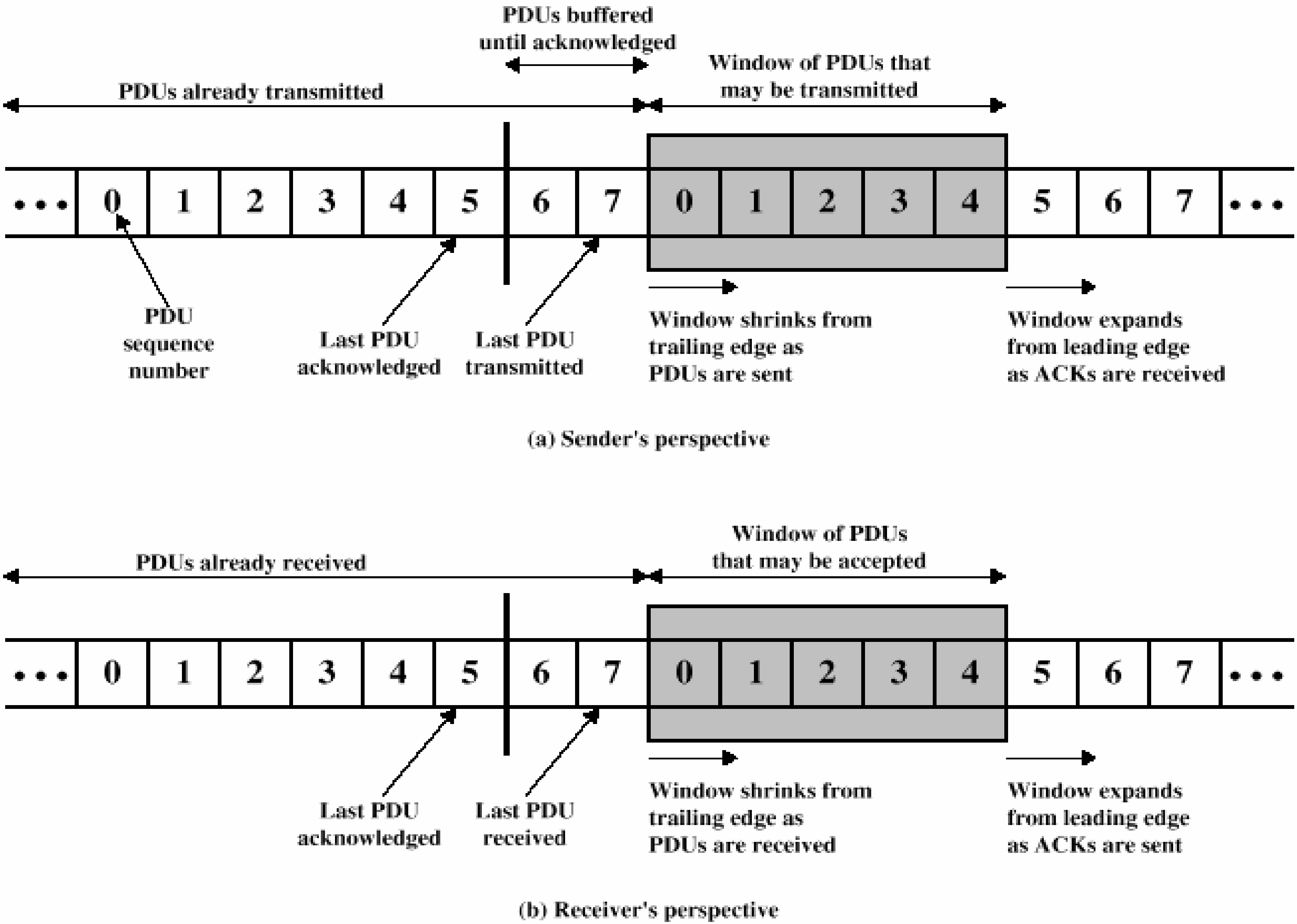
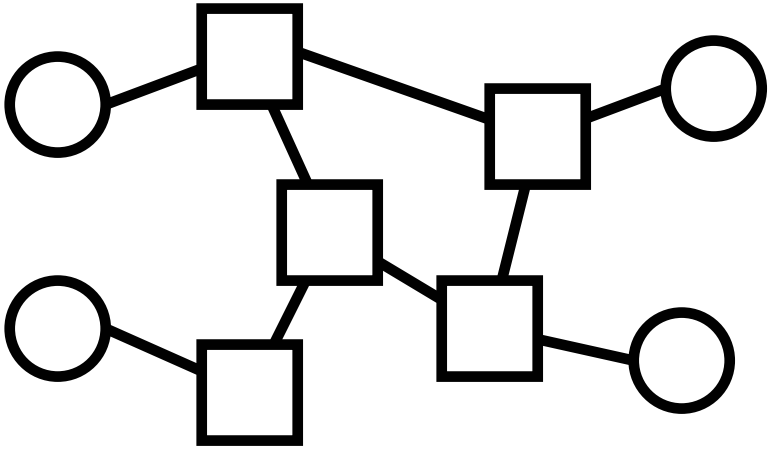


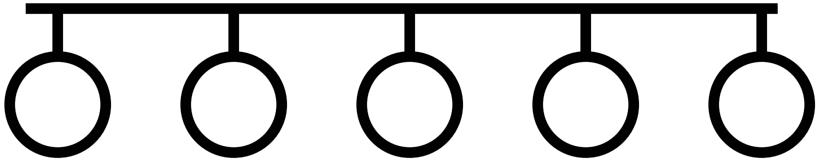
Figure 8.17 Sliding-Window Depiction

Media Access Control

- How do we transfer packets between two hosts connected to the same network?
- Using point-to-point "links" with "switches" -- store-and-forward.
  - » Very common in wired networks
  - » Also in some wireless or in hybrid networks
  - » In wireless, links can interfere if the share the same spectrum
- Multiple access networks -- contention based.
  - » Multiple hosts are sharing the same transmission medium
  - » Used in LANs and wireless
  - » Need to control access to the medium
  - » Mostly Thursday lecture

Datalink Architectures





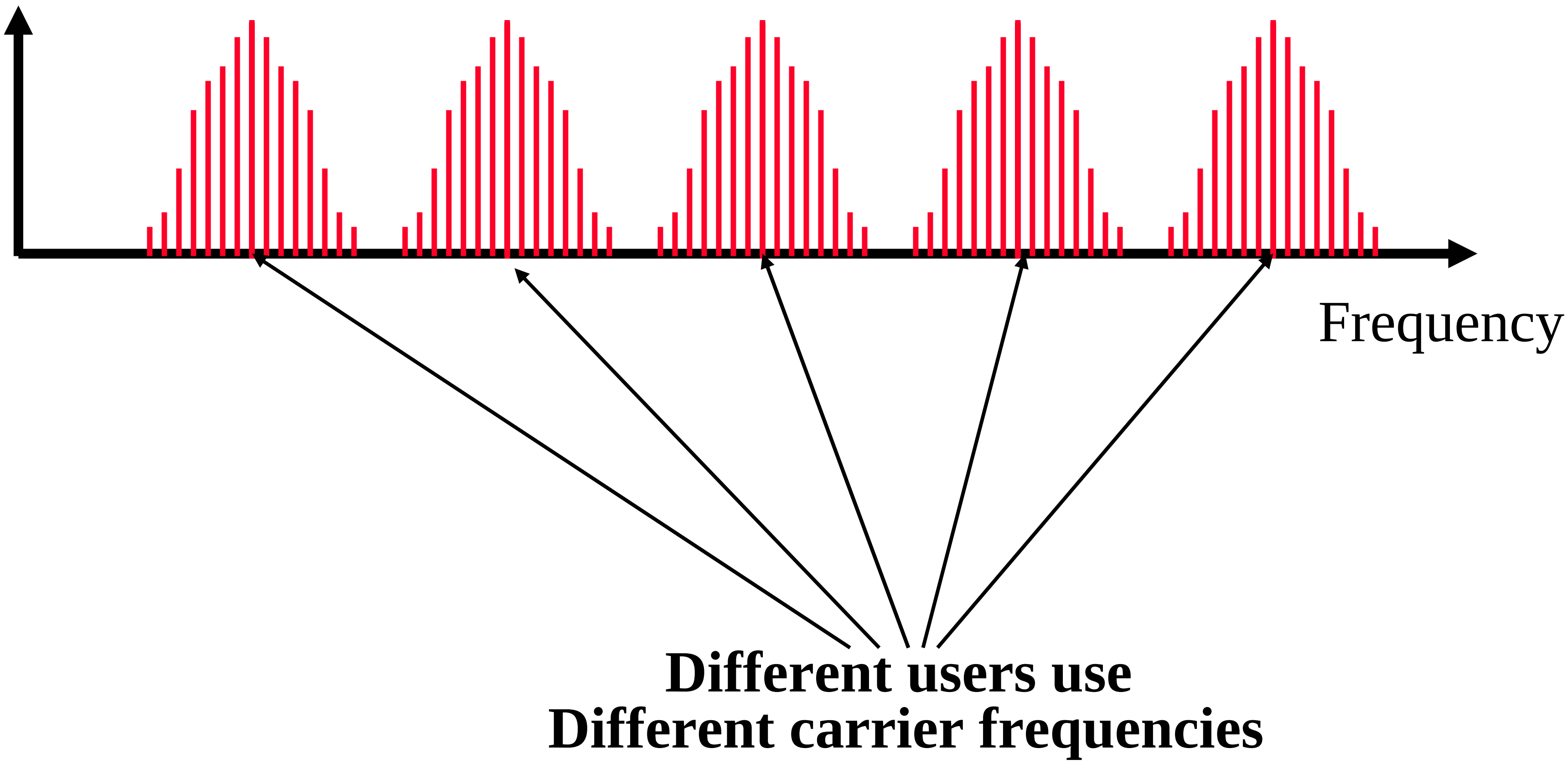
- Packet forwarding.
- Error and flow control.

- Media access control.
- Scalability.

Creating Multiple Channels

- Multiple channels can coexist if they transmit at a different frequency, or at a different time, or in a different part of the space.
  - » Three dimensional space: frequency, space, time
- Space can be limited (using wires or) using transmit power of wireless transmitters.
- Frequency multiplexing means that different users use a different part of the spectrum.
  - » Again, similar to radio: 95.5 versus 102.5 station
- Time division multiplexing means that users send at different times.
  - » Static partitioning of time
- Duplexing: splitting the time/frequencies between the up and down link.

Frequency Division Multiplexing

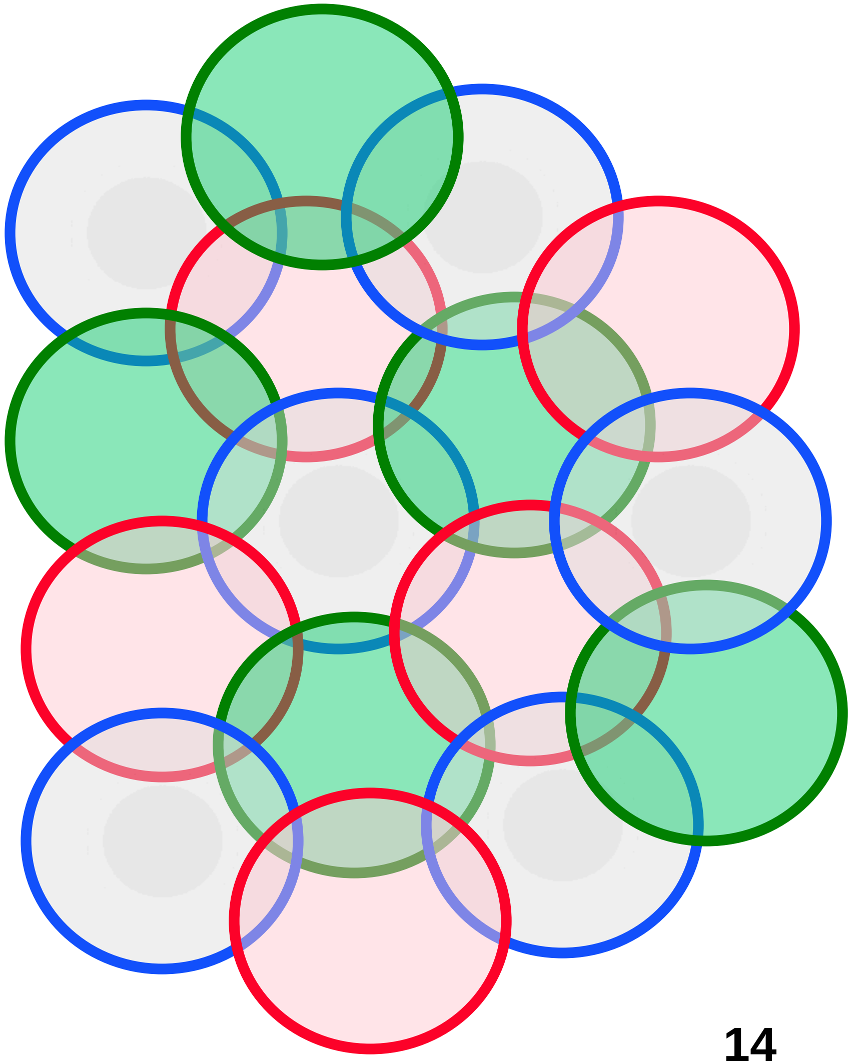


FDM Example: AMPS

- **US analog cellular system in early 80's.**
- **Each call uses an up and down link channel.**
  - » **Channels are 30 KHz**
- **About 12.5 + 12.5 MHz available for up and down link channels per operator.**
  - » **Supports 416 channels in each direction**
  - » **21 of the channels are used for data/control**
  - » **Total capacity (across operators) is double of this**

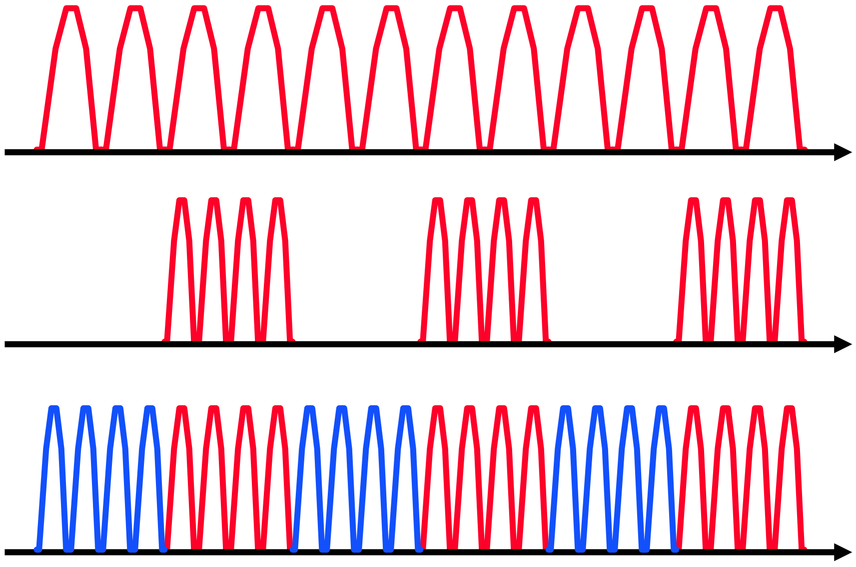
Frequency Reuse in Space

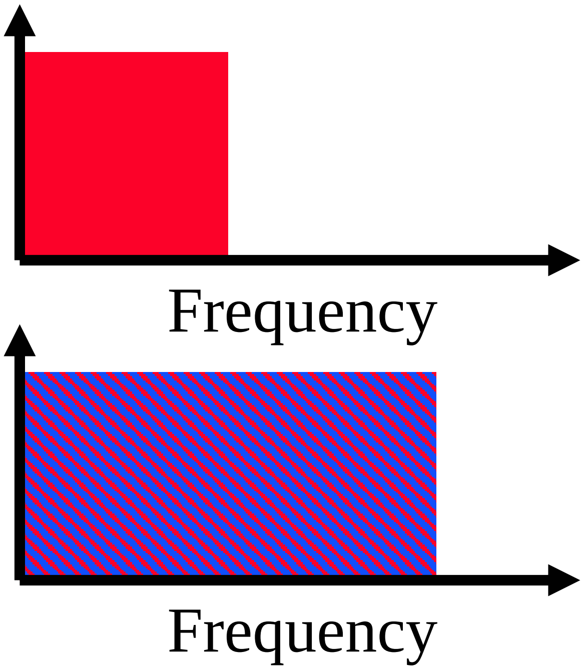
- Frequencies can be reused in space
  - » Distance must be large enough
  - » Example: radio stations
- Basis for "cellular" network architecture
- Set of base stations" connected to the wired network support set of nearby clients
  - » Star topology in each circle
  - » Cell phones, 802.11, …



Time Division Multiplexing

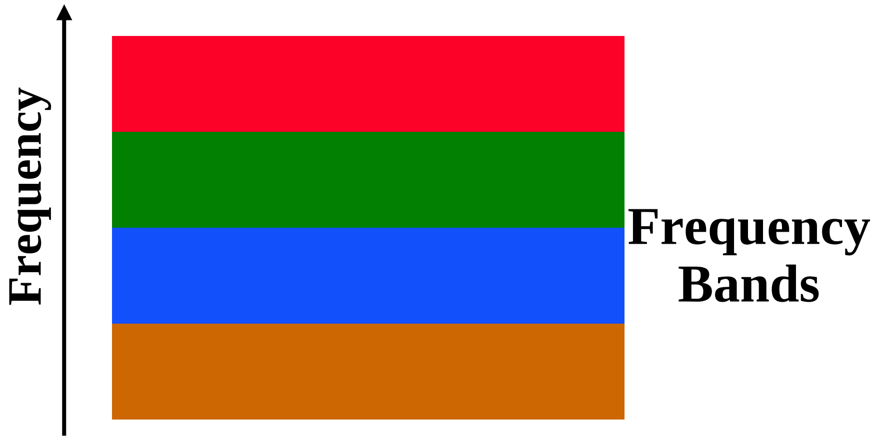
- Different users use the wire at different points in time.
- Aggregate bandwidth also requires more spectrum.

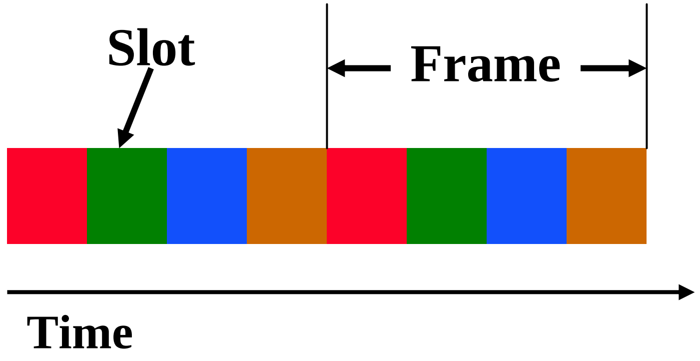




Frequency versus Time-division Multiplexing

- With frequency-division multiplexing different users use different parts of the frequency spectrum.
  - I.e. each user can send all the time at reduced rate
  - Example: roommates
  - Hardware is slightly more expensive and is less efficient use of spectrum
- With time-division multiplexing different users send at different times.
  - I.e. each user can sent at full speed some of the time
  - Example: a time-share condo
  - Drawback is that there is some transition time between slots; becomes more of an issue with longer propagation times
- The two solutions can be combined.





TDM Example: GSM

- Global System for Mobile communication.
  - » First introduced in Europe in early 90s
- Uses a combination of TDM and FDM.
- 25 MHz each for up and down links.
- Broken up in 200 KHz channels
  - » 125 channels in each direction
  - » Each channel can carry about 270 kbs
- Each channel is broken up in 8 time slots
  - » Slots are 0.577 msec long
  - » Results in 1000 channels, each with about 25 kbs of useful data; can be used for voice, data, control
- General Packet Radio Service (GPRS).
  - » Data service for GSM, e.g. 4 down and 1 up channel

Code Division Multiple Access

- **Users share spectrum and time, but use different codes to spread their data over frequencies.**
  - » **DSSS where users use different spreading sequences**
  - » **Use spreading sequences that are orthogonal, i.e. they have minimal overlap**
- **The idea is that users will only rarely overlap and the inherent robustness of DSSS will allow users to recover if there is a conflict.**
  - » **Overlap = use the same the frequency at the same time**
  - » **The signal of other users will appear as noise**

Code-Division Multiple Access (CDMA)

- **Basic Principles of CDMA**
  - » ***D*** **= rate of data signal**
  - » **Break each bit into *k chips***
    - – **Chips are a user-specific fixed pattern**
  - » **Chip data rate of new channel = *kD***

CDMA Example

- **If *k*=6 and code is a sequence of 1s and -1s**
  - » **For a ‘1’ bit, A sends code as chip pattern**
    - **<c1, c2, c3, c4, c5, c6>**
  - » **For a ‘0’ bit, A sends complement of code**
    - **<-c1, -c2, -c3, -c4, -c5, -c6>**
- **Receiver knows sender’s code and performs electronic decode function**

$$S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6$$

- **<d1, d2, d3, d4, d5, d6> = received chip pattern**
- **<c1, c2, c3, c4, c5, c6> = sender’s code**

CDMA Example

- User A code = <1, –1, –1, 1, –1, 1>
  - » To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - » To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code = <1, 1, –1, – 1, 1, 1>
  - » To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A's code
  - » (A's code) x (received chip pattern)
    - – User A '1' bit: 6 -> 1
    - – User A '0' bit: -6 -> 0
    - – User B '1' bit: 0 -> unwanted signal ignored

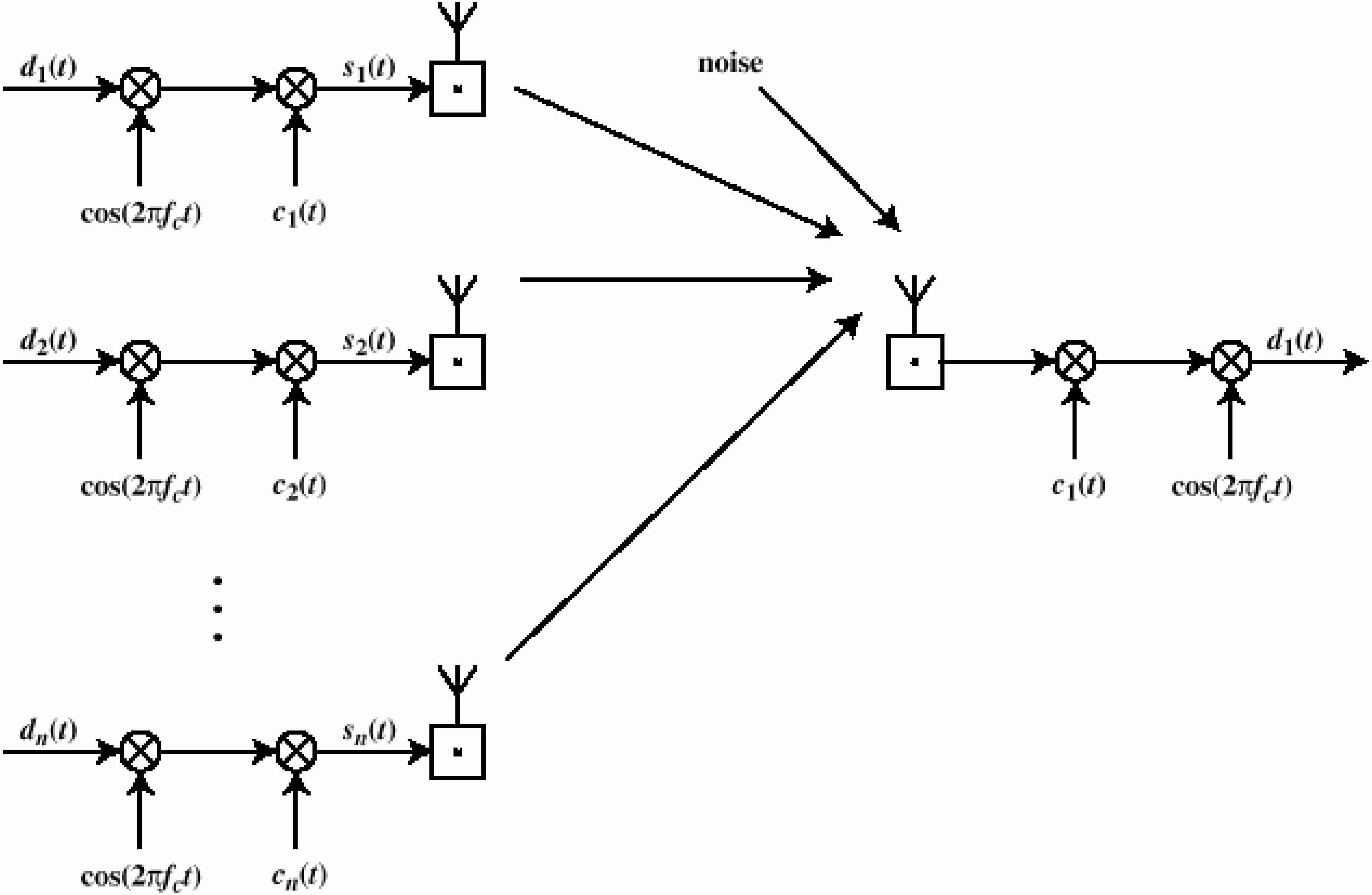


Figure 7.11 CDMA in a DSSS Environment

Categories of Spreading Sequences

- Spreading Sequence Categories
  - » Pseudorandom number/pseudo noise (PN) sequences based on a seed and a shared algorithm
  - » Orthogonal codes
- For FHSS systems
  - » PN sequences most common
- For DSSS systems not employing CDMA
  - » PN sequences most common
- For DSSS CDMA systems
  - » PN sequences
  - » Orthogonal codes

CDMA Discussion

- CDMA does not assign a fixed bandwidth to each user but a user's bandwidth depends on the load.
  - » More users results more "noise" and less throughput for each user, e.g. more information lost due to errors
  - » How graceful the degradation is depends on how orthogonal the codes are
  - » TDMA and FDMA have a fixed channel capacity
- Weaker signals may be lost in the clutter.
  - » This will systematically put the same node pairs at a disadvantage – not acceptable
  - » The solution is to add power control, i.e. nearby nodes use a lower transmission power than remote nodes

CDMA Example

- CDMA cellular standard.
  - » Used in the US, e.g. Sprint
- Allocates 1.228 MHz for base station to mobile communication.
  - » Shared by 64 “code channels”
  - » Used for voice (55), paging service (8), and control (1)
- Provides a lot error coding to recover from errors.
  - » Voice data is 8550 bps
  - » Coding and FEC increase this to 19.2 kbps
  - » Then spread out over 1.228 MHz using DSSS; uses QPSK

Supporting Bursty Data Traffic

- **Carving up bandwidth in fixed-bandwidth channels is not efficient for bursty traffic.**
- **Alternative is to do "dynamic time sharing" of a single channel, i.e. users send packets as they become available.**
  - » **Called "multiple access" protocols**
- **Challenge: users need contend for access to the channel.**
  - » **Class of "contention-based" MAC protocols**
  - » **When two users transmit at the same time, we have a collision, i.e. data is lost due to heavy interference**
- **Example: Ethernet or CSMA-CD.**
  - » **Carrier-sense Multiple-Access with Collision Detection**

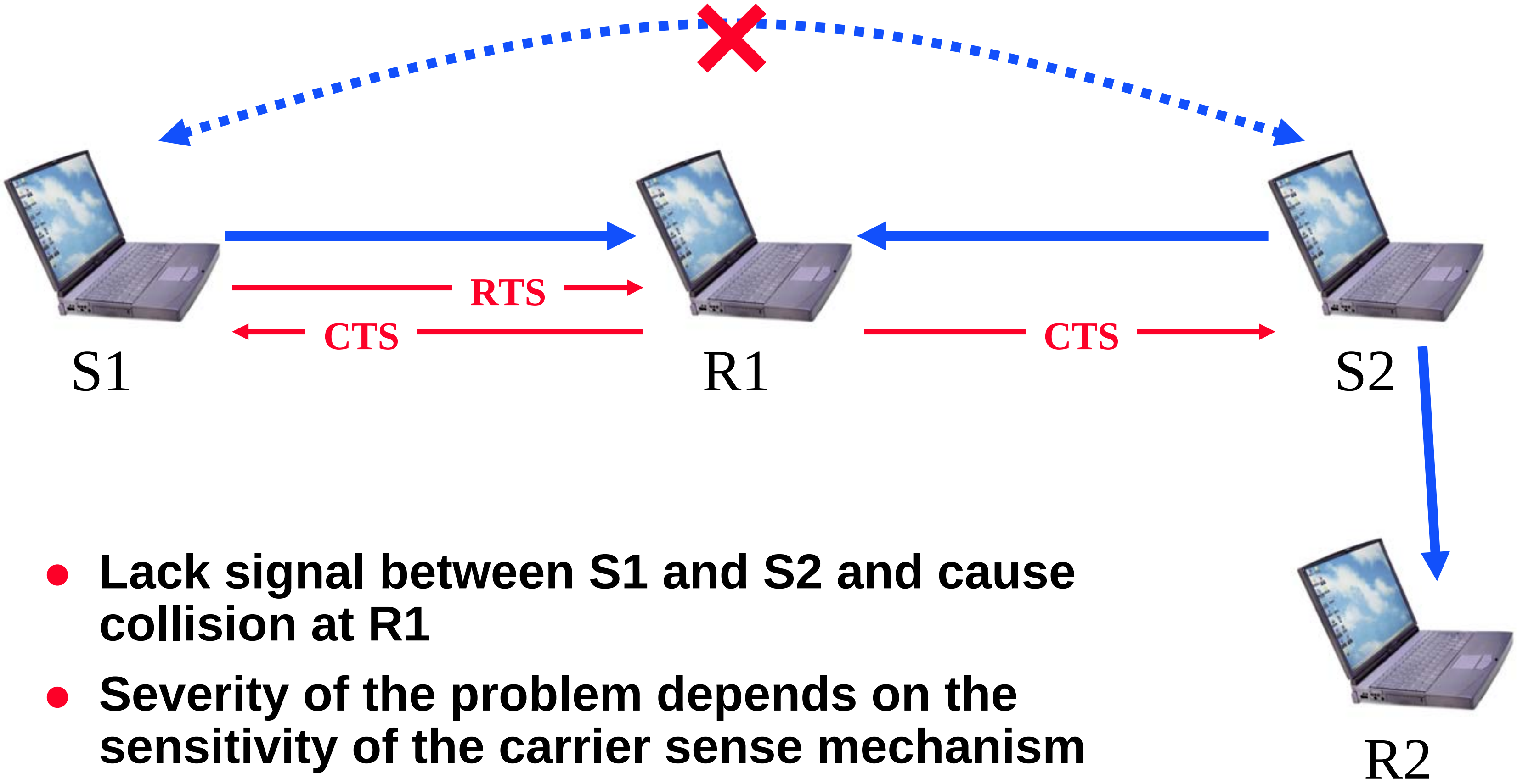
“Regular” Ethernet

- **Multiple access: multiple hosts are competing for access to the channel**
- **Carrier-sense: make sure the channel is idle before sending**
- **Collision detection: collisions are detected and result in 1) aborting the colliding transmissions and 2) retransmission of the packets**
- **Exponential backoff is used to reduce the chance of repeat collisions**
  - » **Also effectively reduces congestion**

"Wireless Ethernet"

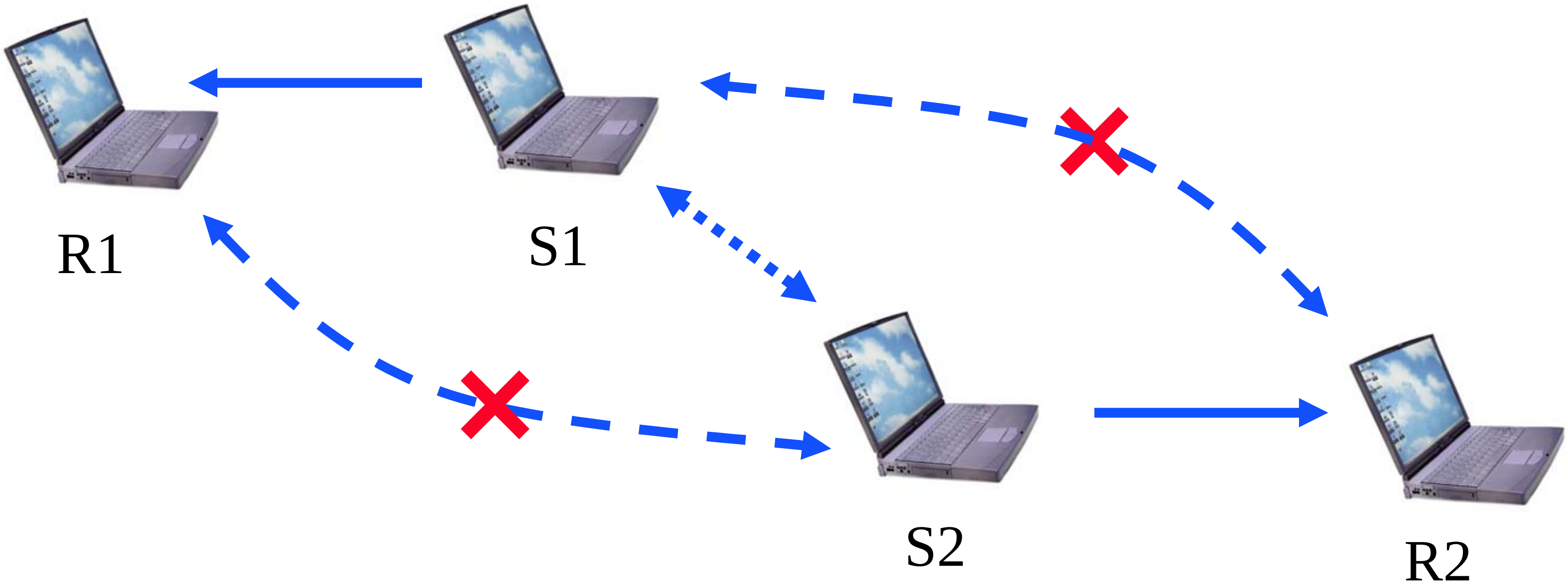
- Collision detection is not practical.
  - » Signal power is too high at the transmitter
  - » So how do you detect collisions?
  - » Lack of acknowledgement for the transmitted packet
- Signals attenuate significantly with distance so some nodes cannot hear each other – many consequences
  - » May result in failure of the carrier sense mechanism and collisions – hidden terminal problem
  - » May result in unnecessary carrier sense triggering – exposed terminal problem
  - » Strong signal from nearby node will overwhelm the weaker signal from a remote transmitter – capture effect
  - » Capture effect: nearby node will always win in case of collision - receiver may not even detect remote node
  - » Highly variable interference - unfairness

Hidden Terminal Problem



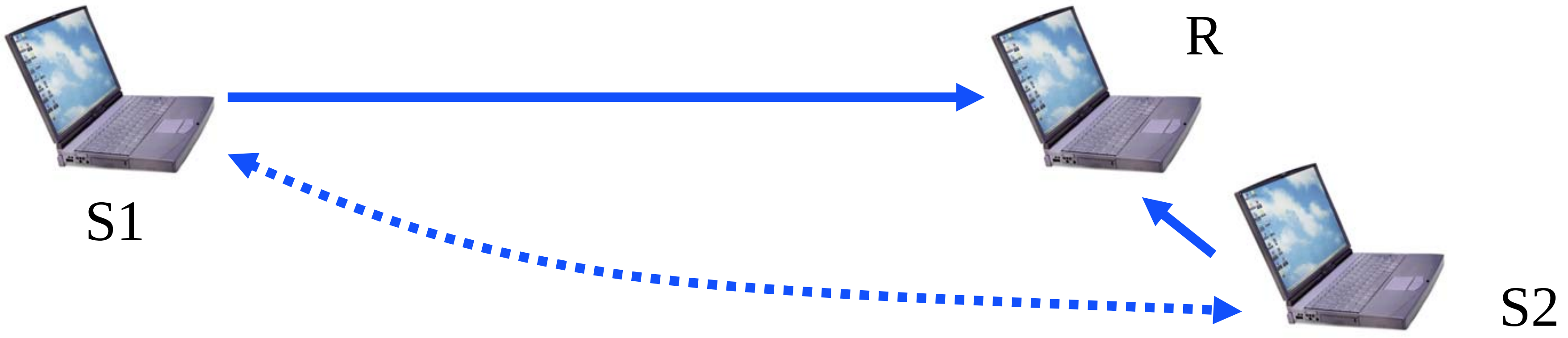
- **Lack signal between S1 and S2 and cause collision at R1**
- **Severity of the problem depends on the sensitivity of the carrier sense mechanism**
  - » **Clear Channel Assessment (CCA) threshold**

Exposed Terminal Problem



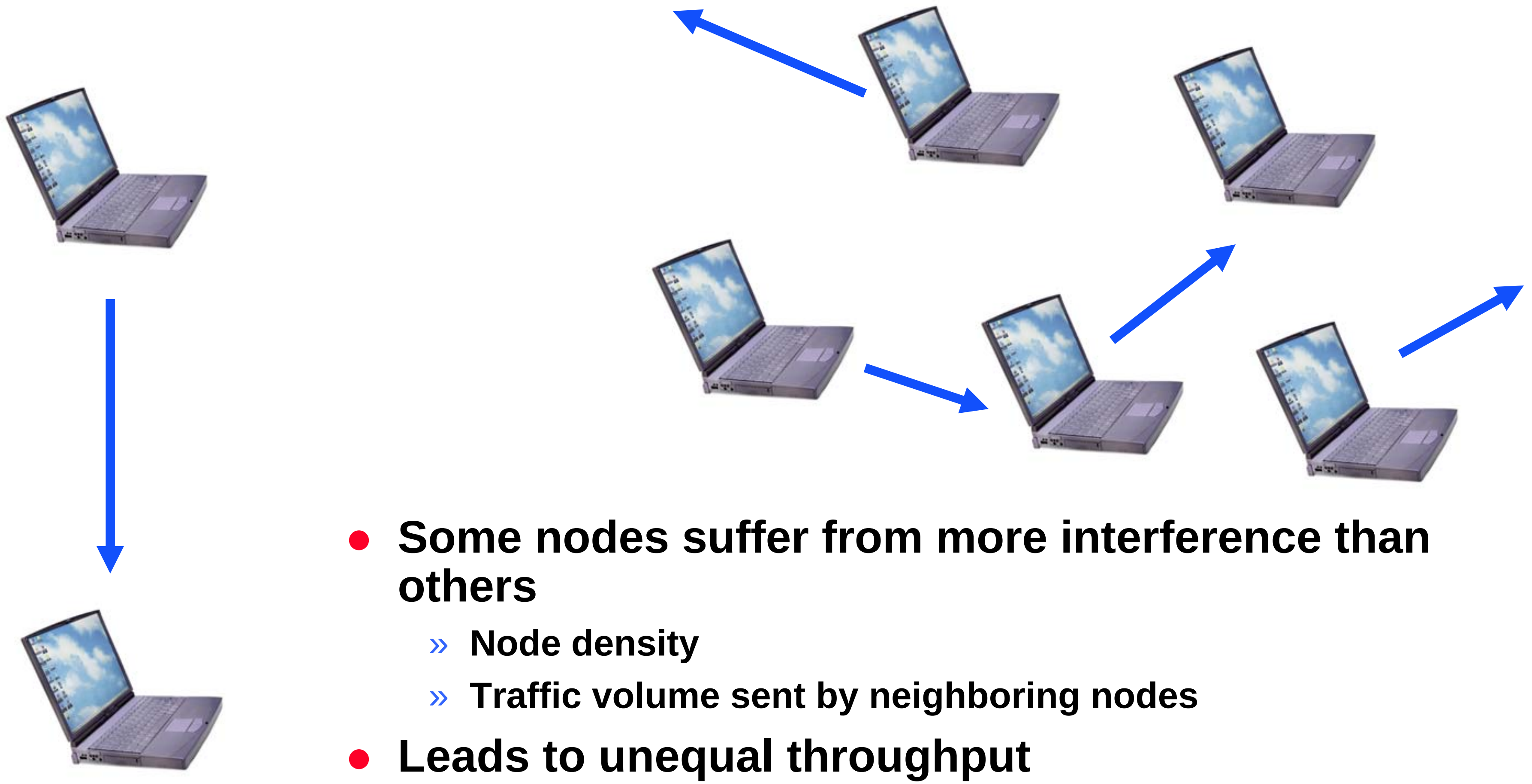
- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold

Capture Effect



- **Sender S2 will almost always "win" if there is a collision at receiver R.**
- **Can lead to extreme unfairness and even starvation.**
- **Solution is power control**
  - » **Diffucult to manage**

Wireless Packet Networking Problems



- Some nodes suffer from more interference than others
  - » Node density
  - » Traffic volume sent by neighboring nodes
- Leads to unequal throughput
- Similar to wired network: some flows traverse tight bottleneck while others do not