

18-452/18-750 Wireless Networks and Applications

Lecture 8: LAN MAC Protocols Wireless versus Wired

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<http://www.cs.cmu.edu/~prs/wirelessS17/>

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Outline

- Data link fundamentals
 - » And what changes in wireless
- Ethernet
- Aloha
- Wireless-specific challenges
- 802.11 and 802.15 wireless standards

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Datalink Functions

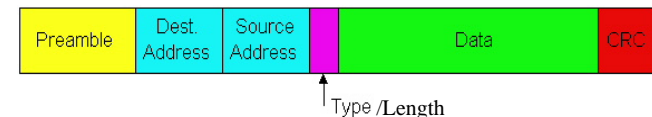
- Framing: encapsulating a packet into a bit stream.
 - » Add header, mark and detect frame boundaries, ...
- Logical link control: managing the transfer between the sender and receiver, e.g.
 - » Error detection and correction to deal with bit errors
 - » Flow control: avoid that the sender outruns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

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Framing

- Typical structure of a “wired” packet:
 - » Preamble: synchronize clocks sender and receiver
 - » Header: addresses, type field, length, etc.
 - » The data to be send, e.g., an IP packet
 - » Trailer: padding, CRC, ..



- How does wireless differ?
 - » Different transmit rates for different parts of packet
 - » Explicit multi-hop support
 - » Control information for physical layer
 - » Ensure robustness of the header

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Error Control: Error Detection and Error Recovery

- **Detection: only detect errors**
 - » Make sure corrupted packets get thrown away, e.g. Ethernet
 - » Use of error detection codes, e.g. CRC
- **Recovery: also try to recover from lost or corrupted packets**
 - » Option 1: forward error correction (redundancy)
 - » Option 2: retransmissions
- **How does wireless differ?**
 - » Uses CRC to detect errors, similar to wired
 - » Error recovery is much more important because errors are more common and error behavior is very dynamic
 - » What approach is used?

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Error Recovery in Wireless

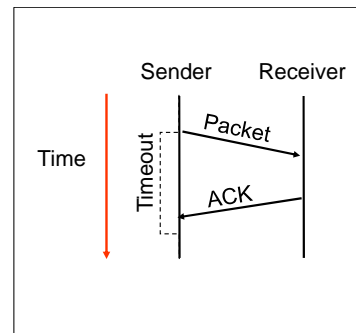
- **Use of redundancy:**
 - » Very common at physical layer – see PHY lectures
 - » Spread spectrum, OFDM, etc.
- **Use of Automatic Repeat Request (ARQ)**
 - » Use time outs to detect loss and retransmit
- **Many variants:**
 - » Stop and wait: one packet at a time
 - » Go Back N: sender keeps sending and retransmits, starting with the unacknowledged packet
 - » Selective Repeat: only packets that are not acknowledged are retransmitted
- **When should what variant be used?**
 - » Noise versus bursty (strong) interference

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Stop and Wait

- Simplest ARQ protocol
- Send a packet, stop and wait until acknowledgement arrives
- Will examine ARQ issues later in semester



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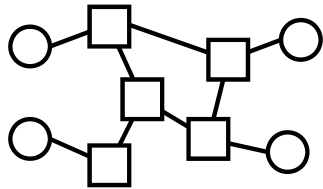
Media Access Control

- **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, at multiple layers
- **Multiple access networks**
 - » Multiple hosts are sharing the same transmission medium
 - » Need to control access to the medium
 - » Taking turn versus contention based protocols
- **What is different in wireless?**
 - » Is store and forward used?
 - » Is multiple access used?

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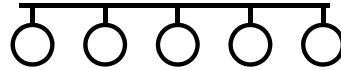
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Datalink Architectures



- Routing and packet forwarding.
- Point-to-Point error and flow control.

Switched ethernet, mesh and ad hoc networks



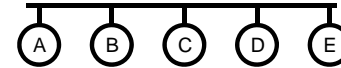
- Media access control.
- Scalability.

Traditional ethernet, Wifi, cellular, ...

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Multiple Access Networks

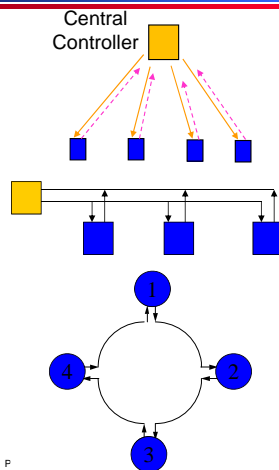


- Who gets to send a packet next?
- Scheduled access: explicit coordination ensures that only one node transmits
 - » Looks cleaner, more organized, but ...
 - » Coordination introduces overhead – requires communication (oops)
- Random access: no explicit coordination
 - » Potentially more efficient, but ...
 - » How does a node decide whether it can transmit?
 - » Collisions are unavoidable – also results in overhead
 - » How do you even detect a collision?

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Scheduled Access MACs



- Polling: controller polls each nodes
- Reservation systems
 - » Central controller
 - » Distributed algorithm, e.g. using reservation bits in frame
- Token ring: token travels around ring and allows nodes to send one packet
 - » Distributer version of polling
 - » FDDI, ...

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Outline

- Data link fundamentals
 - » And what changes in wireless
- Ethernet
- Wireless-specific challenges
 - » Ethernet review
 - » How wireless differs
- Aloha
- 802.11 and 802.15 wireless standards

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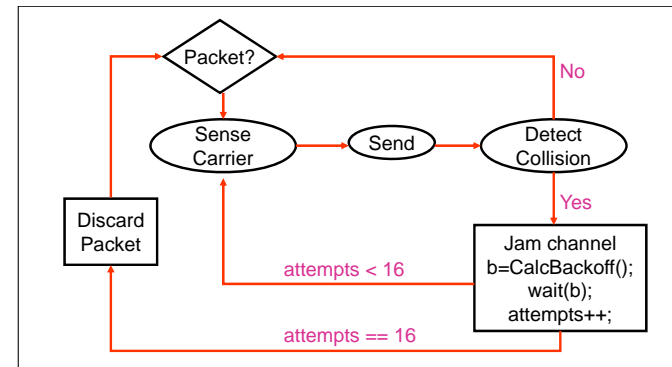
“Regular” Ethernet CSMA/CD

- **Multiple Access:** multiple hosts are competing for access to the channel
- **Carrier-Sense:** make sure the channel is idle before sending – “listen before you send”
- **Collision Detection:** collisions are detected by listening on the medium and comparing the received and transmitted signals
- **Collisions results 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

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Carrier Sense Multiple Access/ Collision Detection (CSMA/CD)



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Ethernet Backoff Calculation

- **Challenge:** how do we avoid that two nodes retransmit at the same time collision
- **Exponentially increasing random delay**
 - » Infer “number” senders from # of collisions
 - » More senders → increase wait time
- **First collision:** choose K from {0,1}; delay is K x 512 bit transmission times
- **After second collision:** choose K from {0,1,2,3}
- **After ten or more collisions,** choose K from {0,1,2,3,4,...,1023}

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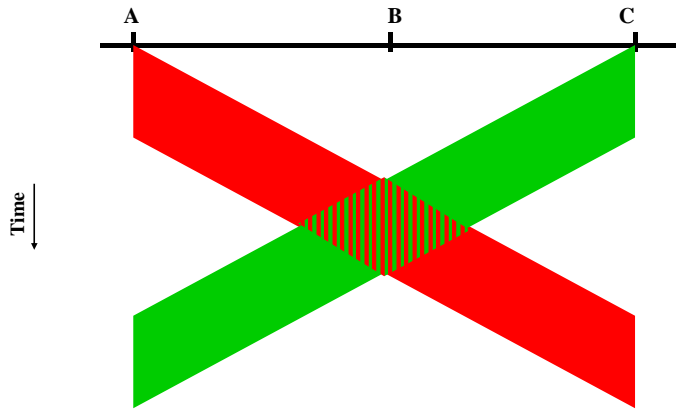
How to Handle Transmission When Line is Sensed Busy

- **p-persistent scheme:**
 - » Transmit with probability p once the channel goes idle
 - » Delay the transmission by t_{prop} with the probability (1-p)
- **1-persistent scheme:** p = 1
 - » E.g. Ethernet
- **nonpersistent scheme:**
 - » Reschedule transmission for a later time based on a retransmission delay distribution (e.g. exp backoff)
 - » Senses the channel at that time
 - » Repeat the process
- **When is each solution most appropriate?**

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Collisions



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Dealing with Collisions

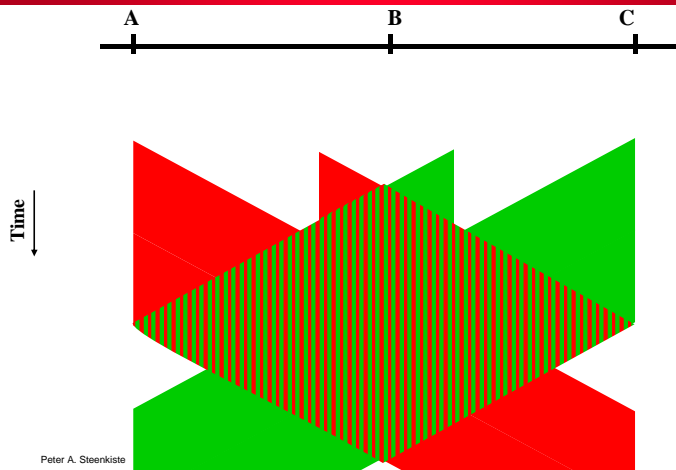
- Collisions will happen: nodes can start to transmit “simultaneously”
 - » Vulnerability window depends on length of wire
- Recovery requires that both transmitters can detect the collision reliably
 - » Clearly a problem as shown on previous slide
- How can we guarantee detection?

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1. Limit length wire
2. Minimum packet size

Detect Collisions



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So What about Wireless?

- Depends on many factors, but high level:
- Random access solutions are a good fit for data in the unlicensed spectrum
 - » Lower control complexity, especially for contention-based protocols (e.g., Ethernet)
 - » There may not always be a centralized controller
 - » May need to support multi-hop
 - » Also used in many unlicensed bands
- Cellular uses scheduled access
 - » Need to be able to guarantee performance
 - » Have control over spectrum – simplifies scheduled access
 - » More on this later in the course

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Summary

- **Wireless uses the same types of protocols as wired networks**
 - » But it is inherently a multiple access technology
- **Some fundamental differences between wired and wireless may result in different design choices**
 - » Higher error rates
 - » Must support variable bit rate communication
 - » Signal propagation and radios are different

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- **Data link fundamentals**
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- **Ethernet**
- **Aloha**
- **Wireless-specific challenges**
- **802.11 and 802.15 wireless standards**

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Why ALOHA



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Pure ALOHA

- **Developed in University of Hawaii in early 1970's.**
- **It does not get much simpler:**
 1. **A user transmits at will**
 2. **If two or more messages overlap in time, there is a collision – receiver cannot decode packets**
 3. **Receive waits for roundtrip time plus a fixed increment – lack of ACK = collision**
 4. **After a collision, colliding stations retransmit the packet, but they stagger their attempts randomly to reduce the chance of repeat collisions**
 5. **After several attempts, senders give up**
- **Although very simple, it is wasteful of bandwidth, attaining efficiency of at most $1/(2e) = 0.18$**

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Poisson Process Informal: memory less

- A Poisson process of “rate” $\lambda > 0$ is a counting process $a(t)$ which satisfies the following conditions:
 1. The process has independent increments in disjoint intervals
 - i.e., $a(t_1+\Delta t)-a(t_1)$ is independent of $a(t_2+\delta t)-a(t_2)$ if $[t_1, t_1+\Delta t]$ and $[t_2, t_2+\delta t]$ are disjoint intervals
 2. The increments of the process are stationary.
 - i.e., $a(t_1+\Delta t)-a(t_1)$ does not depend on t_1
 3. The probability of exactly one event occurring in an infinitesimal interval Δt is $P[a(\Delta t) = 1] \cong \lambda \Delta t$
 4. The probability that more than one event occurs in any infinitesimal interval Δt is $P[a(\Delta t) > 1] \cong 0$
 5. The probability of zero events occurring in Δt is $P[a(\Delta t) = 0] \cong 1 - \lambda \Delta t$

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Poisson Distribution

- Above definitions lead to: Probability $P(k)$ that there are exactly k events in interval of length T is,

$$P(k) = \frac{(\lambda T)^k e^{-\lambda T}}{k!}$$

- We call the above probability the “Poisson distribution”
- Its mean and variance are:

$$E(k) = \lambda T$$

$$\sigma_k^2 = E(k^2) - E^2(k) = \lambda T$$

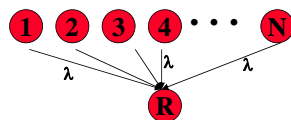
- Many nice properties, e.g. sum of a N independent Poisson processes is a Poisson process

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Pure ALOHA: Model

- Let there be N stations contending for use of the channel.
- Each station transmits λ packets/sec on average based on a Poisson arrival process
- All messages transmitted are of the same fixed length, m , in units of time
- Let new traffic intensity be $S \equiv N\lambda m$
- Since all new packets eventually get through, ‘ S ’ is also the network throughput

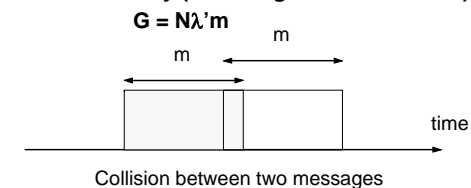


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Pure Aloha: Vulnerability

- Simplification: assume the retransmitted messages are independent Poisson process as well
- The total rate of packets attempting transmission = newly generated packets + retransmitted ones = $\lambda' > \lambda$
- The total traffic intensity (including retransmissions) is ,



- The “vulnerable period” in which a collision can occur for a given packet is $2 \times m$ sec

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Pure Aloha: Analysis

- Calculate "Probability of no collision" two ways:

1. Probability that there is no arrival in interval $2 \times m$:

$$P(\text{no arrival in } 2 \times m \text{ sec}) = e^{-2N\lambda'm} = e^{-2G}$$

2. Since all new arrivals eventually get through, we have

$$\lambda/\lambda' = S/G = \text{Fraction of transmissions that are successful}$$

- So, $S/G = \text{Probability of no collision} = P(\text{no arrival in } 2m \text{ sec})$

- Thus,

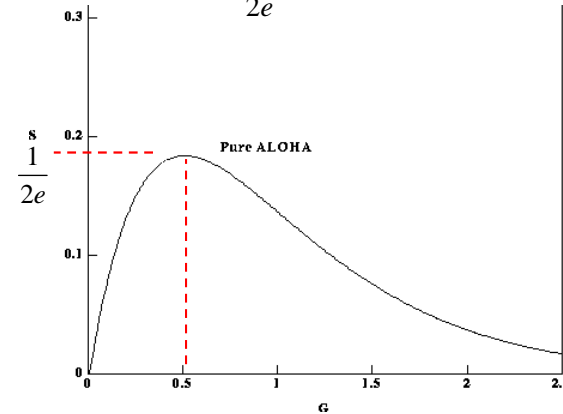
$$\begin{aligned} S/G &= e^{-2G} \\ S &= Ge^{-2G} \end{aligned} \longrightarrow \text{Maximum Throughput of Pure Aloha}$$

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Analysis Conclusion

- S is maximum at $S = \frac{1}{2e}$ at $G = 0.5$

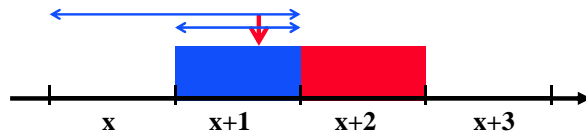


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Slotted ALOHA

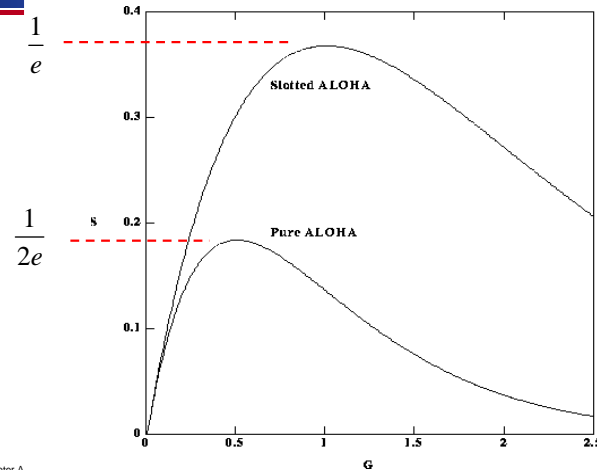
- Transmission can only start at the beginning of each slot of length T
- Vulnerable period is reduced to T
 - » Instead of $2 \times T$ in Aloha
- Doubles maximum throughput.



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Analysis Results Slotted ALOHA



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Discussion of ALOHA

- Maximum throughput of ALOHA is only very low $1/(2e) = 18\%$, but
- Has very low latency under light load
- Slotted Alohas has twice the performance of basic Aloha, but performance is still poor
 - » Slotted design is also not very efficient when carrying variable sized packets!
 - » Slightly longer delay than pure Aloha
- Still, not bad for an absolutely minimal protocol!
- How do we go faster?

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Wireless Ethernet is a Good Idea, but ...

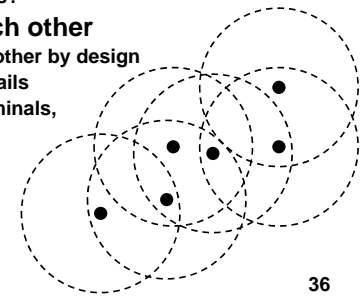
- Attenuation varies with media
 - » Also depends strongly on distance, frequency
- Wired media have exponential dependence
 - » Received power at d meters proportional to 10^{-kd}
 - » Attenuation in dB = $k d$, where k is dB/meter
- Wireless media has logarithmic dependence
 - » Received power at d meters proportional to d^{-n}
 - » Attenuation in dB = $n \log d$, where n is path loss exponent; $n=2$ in free space
 - » Signal level maintained for much longer distances?
- But we are ignoring the constants!
 - » Wireless attenuation at 2.4 GHz: 60-100 dB
 - » In practice numbers can be much lower for wired

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Implications for Wireless Ethernet

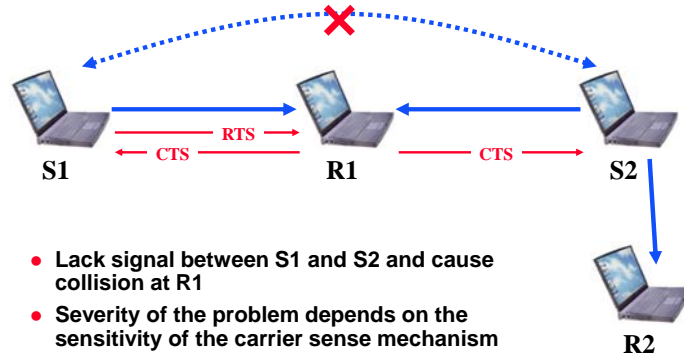
- Collision detection is not practical
 - » Ratio of transmitted signal power to received power is too high at the transmitter
 - » Transmitter cannot detect competing transmitters (is deaf while transmitting)
 - » So how do you detect collisions?
- Not all nodes can hear each other
 - » Ethernet nodes can hear each other by design
 - » "Listen before you talk" often fails
 - » Hidden terminals, exposed terminals, Capture effects
- Made worse by fading
 - » Changes over time!



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Hidden Terminal Problem

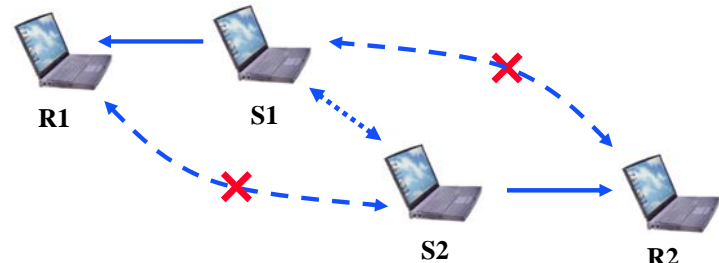


- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
 - » Clear Channel Assessment (CCA) threshold

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Exposed Terminal Problem

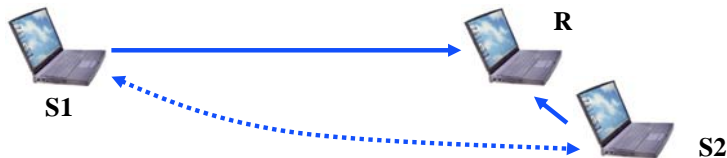


- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold
 - » Higher CCA reduces occurrence of exposed terminals, but can create hidden terminal scenarios

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Capture Effect

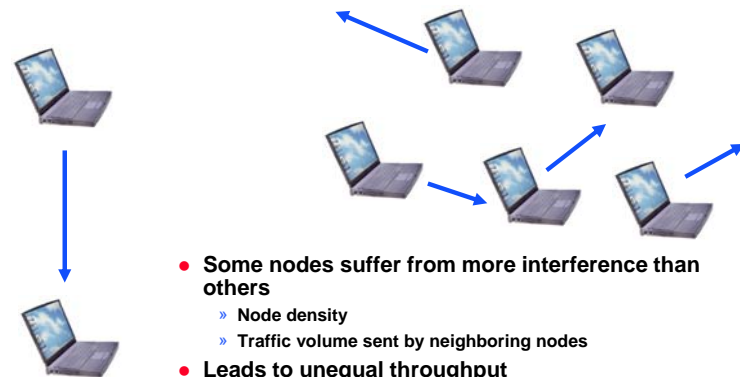


- Sender S2 will almost always "win" if there is a collision at receiver R.
- Can lead to extreme unfairness and even starvation.
- Solution is power control
 - » Very difficult to manage in a non-provisioned environment!

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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

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