

18-452/18-750  
Wireless Networks and Applications  
Lecture 8: LAN MAC Protocols  
Wireless versus Wired

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Spring Semester 2017  
<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

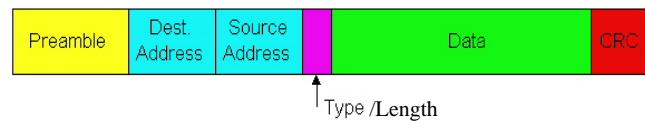
- **Framing:** encapsulating a packet into a bit stream.
  - » Add header, mark and detect frame boundaries, ...
- **Logical link control:** managing the transfer between the sender and receiver, e.g.
  - » Error detection and correction to deal with bit errors
  - » Flow control: avoid that the sender 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

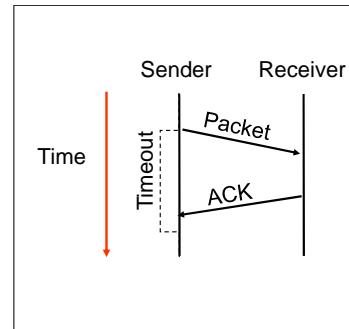
- **Use of redundancy:**
  - » Very common at physical layer – see PHY lectures
  - » Spread spectrum, OFDM, etc.
- **Use of Automatic Repeat Request (ARQ)**
  - » Use time outs to detect loss and retransmit
- **Many variants:**
  - » Stop and wait: one packet at a time
  - » Go Back N: sender keeps 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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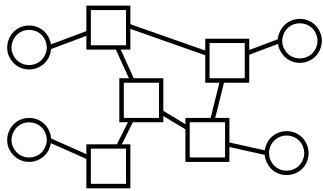
## Media Access Control

- 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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## Datalink Architectures



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

Switched ethernet, mesh and ad hoc networks



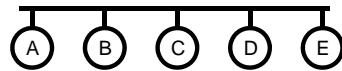
- Media access control.
- Scalability.

Traditional ethernet, Wifi, cellular, ...

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## Multiple Access Networks

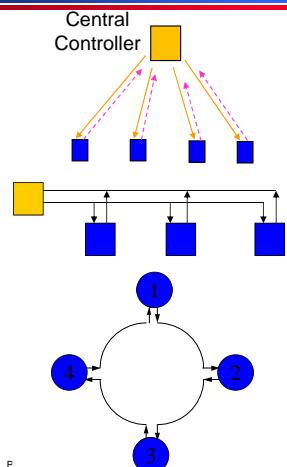


- Who gets to send a packet next?
- **Scheduled access: explicit coordination ensures that only one node transmits**
  - » Looks cleaner, more organized, but ...
  - » Coordination introduces overhead – requires communication (oops)
- **Random access: no explicit coordination**
  - » Potentially more 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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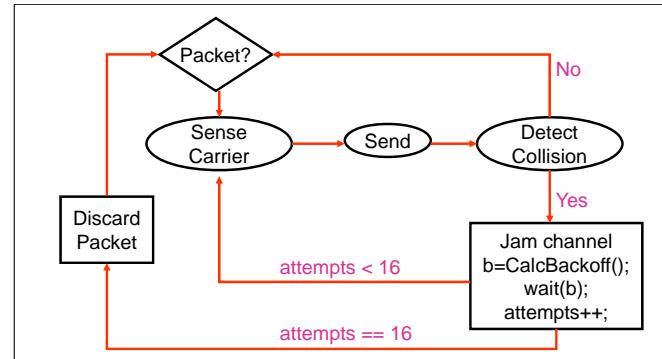
## “Regular” Ethernet CSMA/CD

- 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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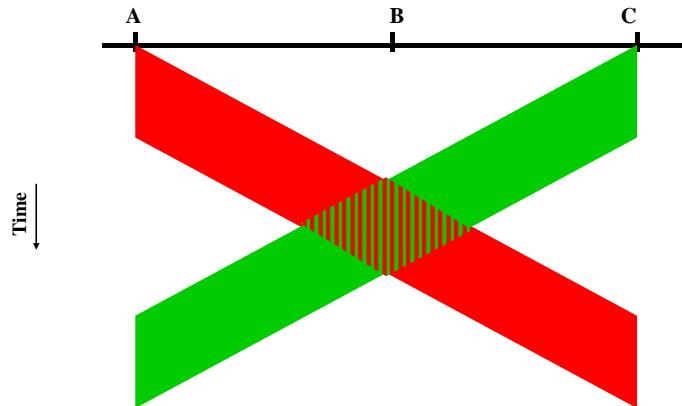
## How to Handle Transmission When Line is Sensed Busy

- **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?

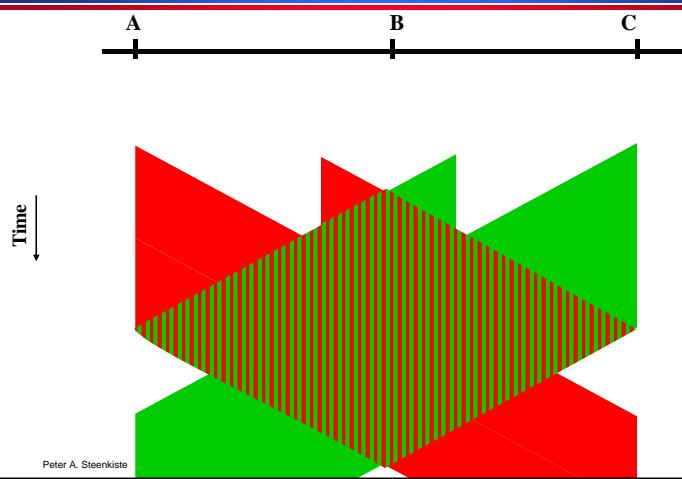
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1. Limit length wire

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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## 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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## Informal: memory less Poisson Process

- 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  $\Delta t$  is  $P[a(\Delta t) = 1] \approx \lambda \Delta t$
  4. The probability that more than one event occurs in any infinitesimal interval  $\Delta t$  is  $P[a(\Delta t) > 1] \approx 0$
  5. The probability of zero events occurring in  $\Delta t$  is  $P[a(\Delta t) = 0] \approx 1 - \lambda \Delta t$

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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:

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

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

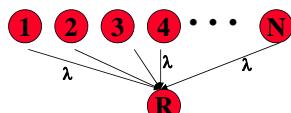
- Many nice properties, e.g. sum of  $N$  independent Poisson processes is a Poisson process

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## Pure ALOHA: Model

- Let there be  $N$  stations contending for use of the channel.
- Each station transmits  $\lambda$  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

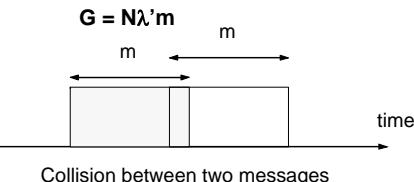


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## Pure Aloha: Vulnerability

- 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:

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

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

- 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,

$$\frac{S}{G} = e^{-2G} \quad \longrightarrow \quad S = Ge^{-2G}$$

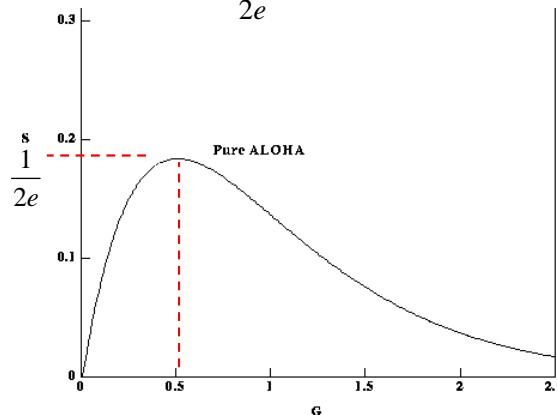
Maximum Throughput  
of Pure Aloha

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## Analysis Conclusion

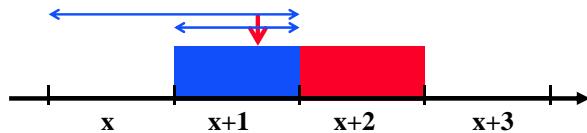
- $S$  is maximum at  $S = \frac{1}{2e}$  at  $G = 0.5$



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## Slotted ALOHA

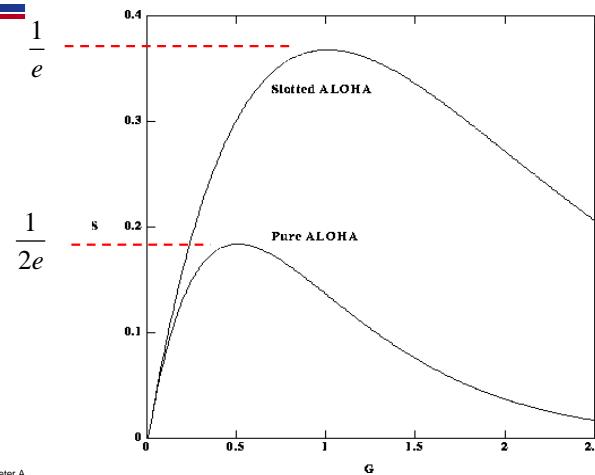
- Transmission can only start at the beginning of each slot of length  $T$
- Vulnerable period is reduced to  $T$   
» Instead of  $2xT$  in Aloha
- Doubles maximum throughput.



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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 Aloha 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

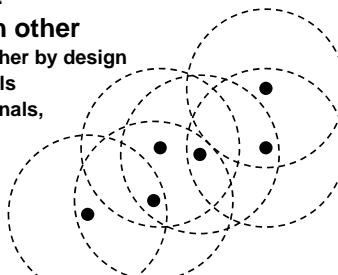
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## Implications for Wireless Ethernet

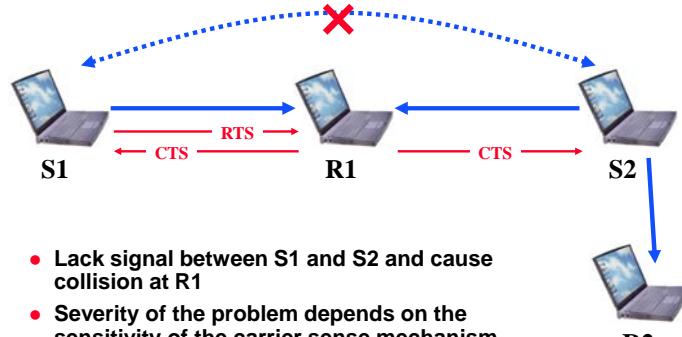
- Collision detection is not practical
  - » Ratio of transmitted signal power to received power is too high at the transmitter
  - » Transmitter cannot detect competing transmitters (is deaf while transmitting)
  - » So how do you detect collisions?
- Not all nodes can hear each other
  - » Ethernet 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

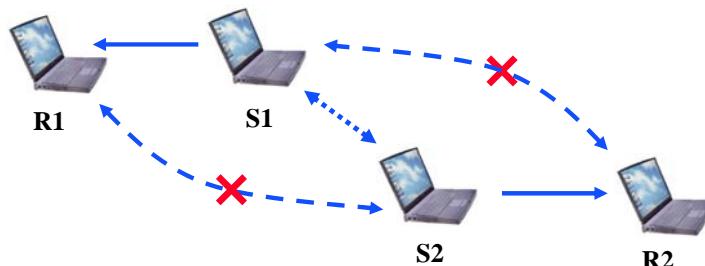


- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
  - » Clear Channel Assessment (CCA) threshold

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## Exposed Terminal Problem

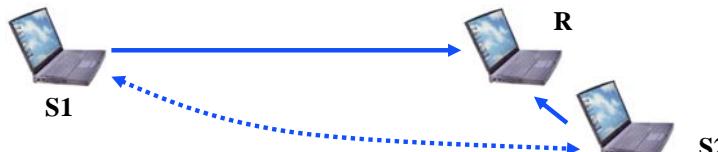


- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold
  - » Higher CCA reduces occurrence of exposed terminals, but can create hidden terminal scenarios

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## Capture Effect

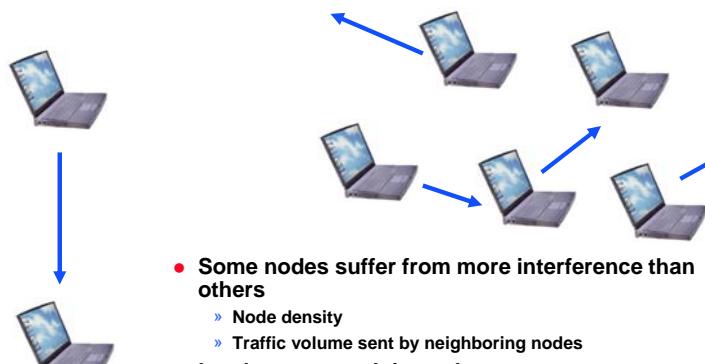


- Sender S2 will almost always “win” if there is a collision at receiver R.
- Can lead to extreme unfairness and even starvation.
- Solution is power control
  - » Very difficult to manage in a non-provisioned environment!

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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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