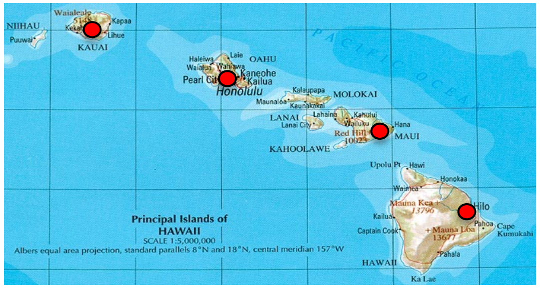


Wireless Networks: ALOHANET, MACA

COS 461: Computer Networks

Lecture 17

Kyle Jamieson

Wireless is increasingly prevalent

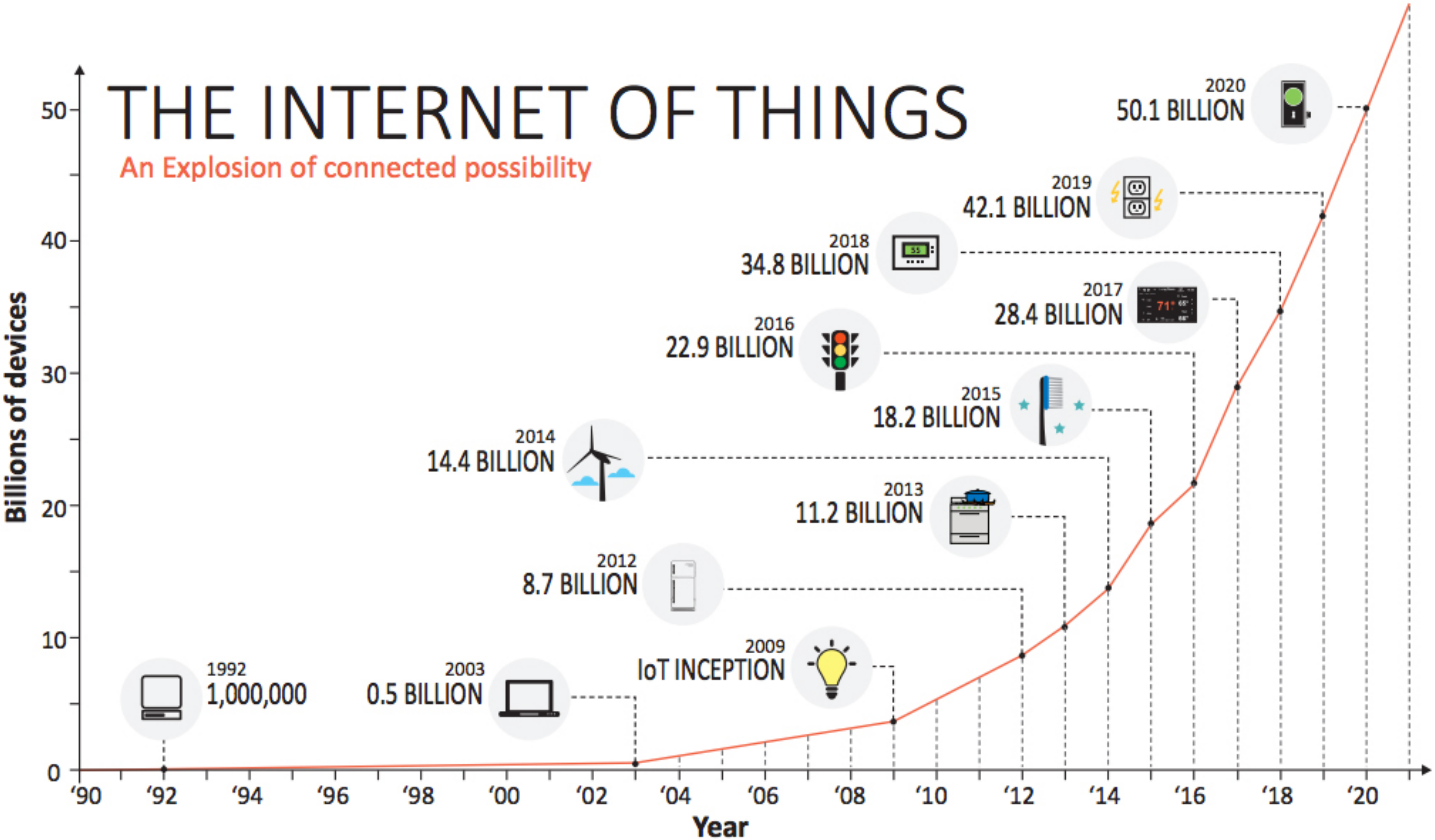
- Health and Fitness
- Virtual Reality
- UAVs
- Internet of Things
- Sensors

Smart Home

Vehicular Networks

Cellular Networks

Next demand driver: Billions of Wireless devices

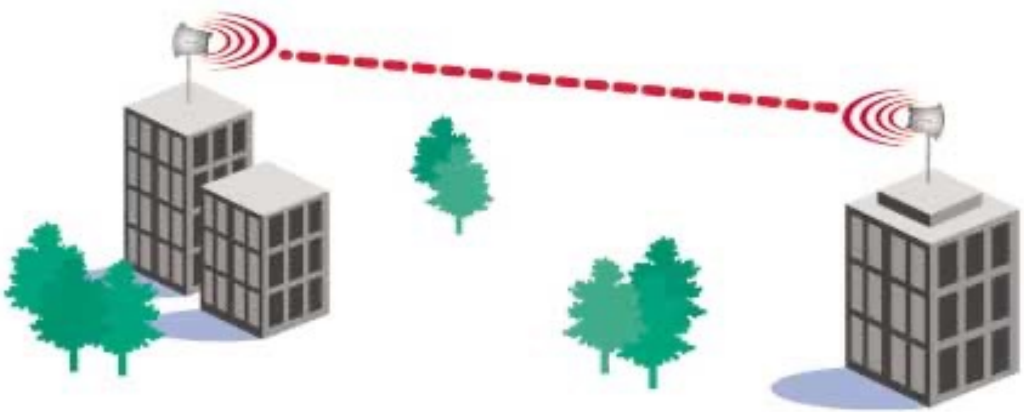


Wireless Links

- Interference / bit errors
  - More sources of corruption vs wired
- Multipath propagation
  - Signal does not travel in a straight line
- (Often) a ***broadcast*** medium
  - All traffic to everyone nearby
- Power trade-offs
  - Important for mobile, battery-powered devices

Wireless Links: High Bit Error Rate

- Decreasing signal strength
  - Disperses as it travels greater distance
  - Attenuates as it passes through matter

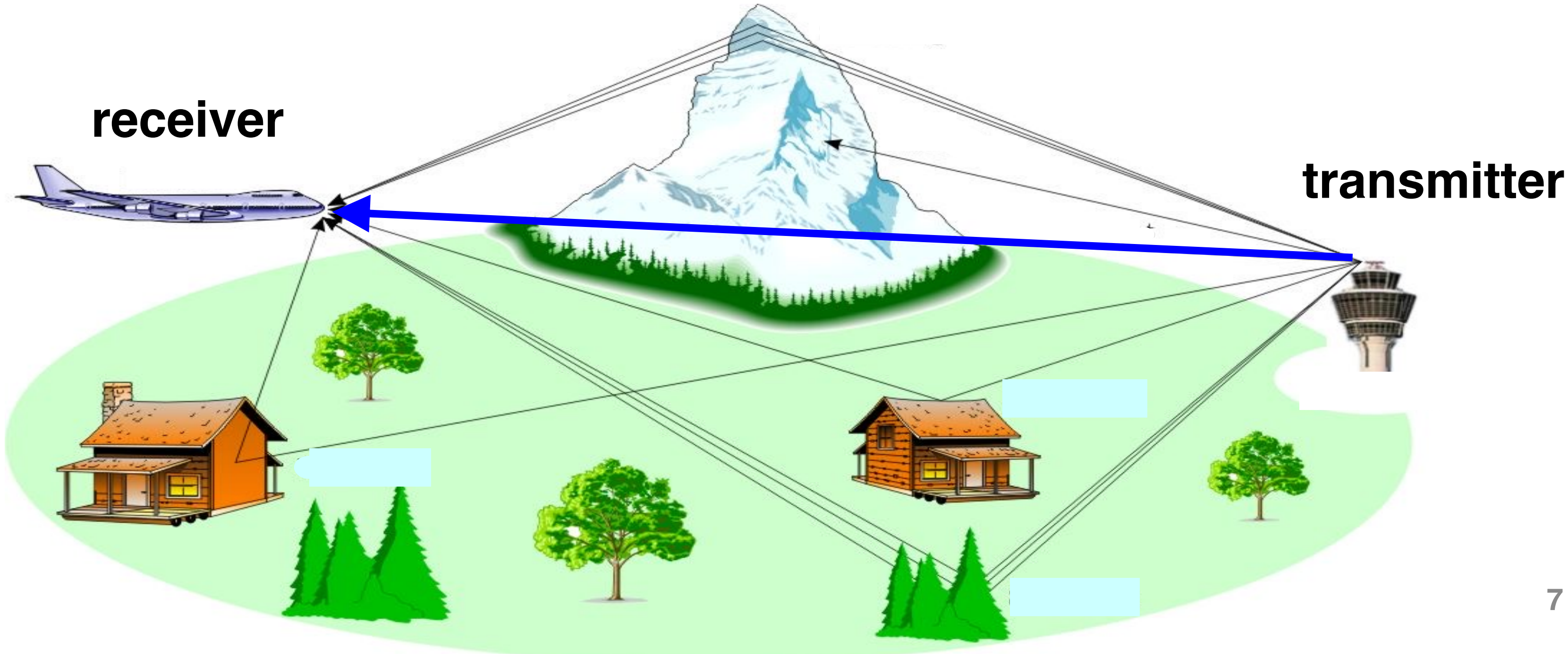


Wireless Links: High Bit Error Rate

- Interference from other sources
  - Radio sources in same frequency band
  - E.g., 2.4 GHz wireless phone interferes with 802.11b wireless LAN
  - Electromagnetic noise (e.g., microwave oven)

Wireless Links: High Bit Error Rate

- Multi-path propagation
  - Electromagnetic waves reflect off objects
  - Taking many paths of different lengths
  - Causing blurring of signal at the receiver



Dealing With Bit Errors

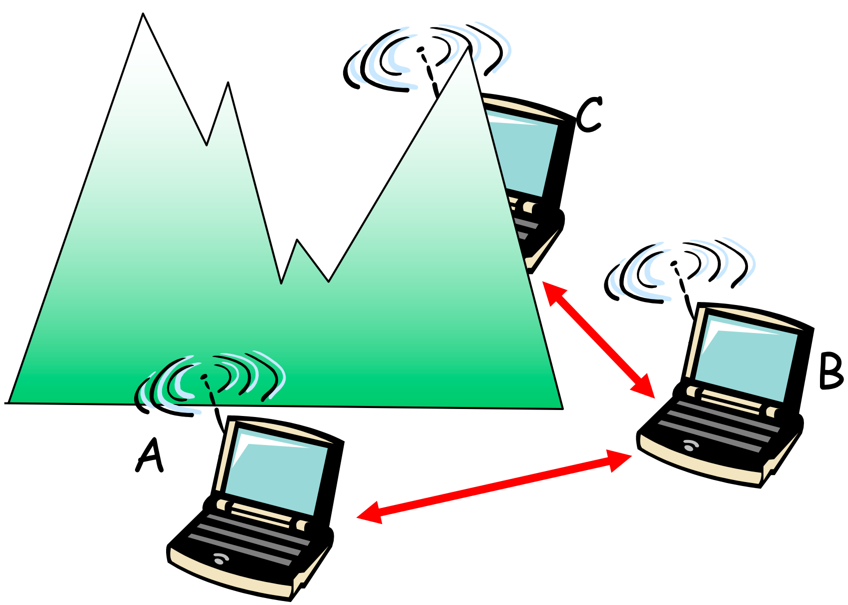
- Wireless vs. wired links
  - Wired: most loss is due to queuing congestion
  - Wireless: higher, time-varying bit-error rate

- Dealing with high bit-error rates
  - Sender could increase transmission power
    - More interference with other senders
  - Stronger error detection and recovery
    - More powerful error detection/correction codes
    - Link-layer retransmission of corrupted frames

Wireless Broadcast: Hidden Terminals

- Wired broadcast links
  - E.g., Ethernet bridging, in wired LANs
  - All nodes receive transmissions from all other nodes

- Wireless broadcast: *hidden terminal* problem

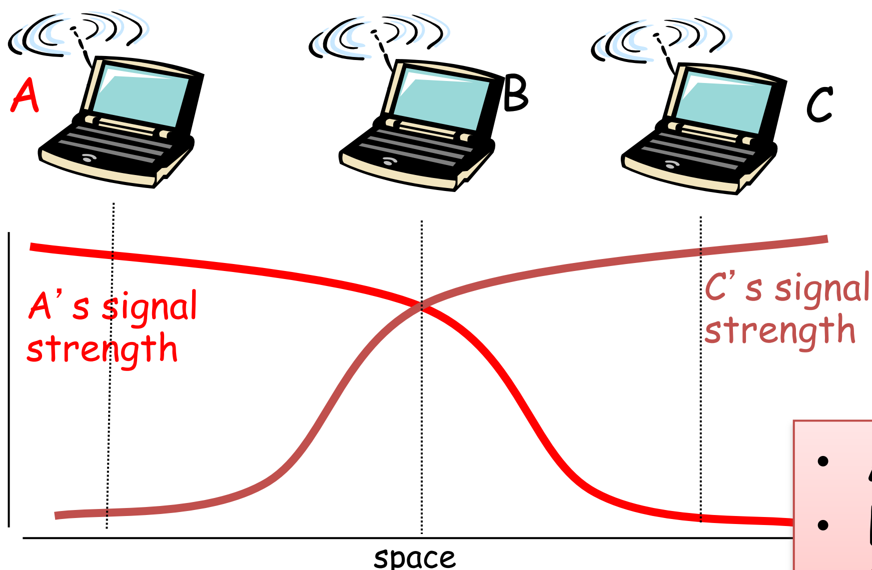


- A and B hear each other
- B and C hear each other
- But, A and C do not

So, A and C are unaware of their interference at B

Wireless Broadcast and Interference

- Interference matters **at the receiver**



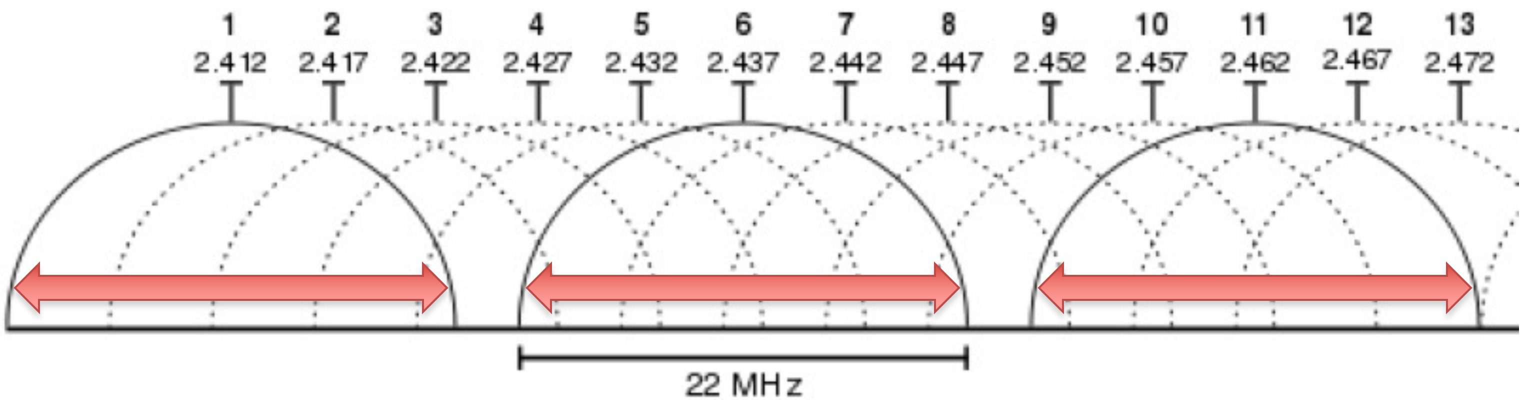
- A and B hear each other
- B and C hear each other
- But, A and C do not

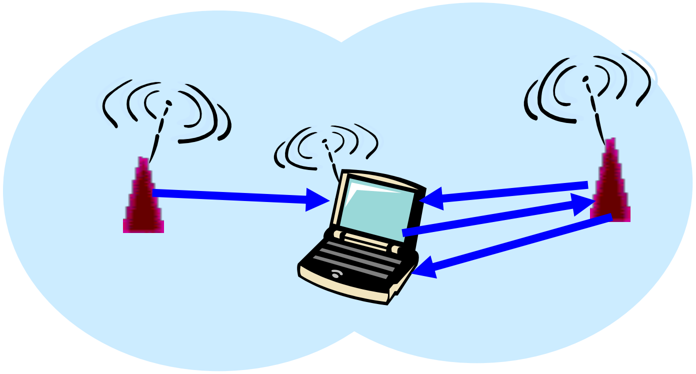
So, A and C are unaware of their interference at B

Wi-Fi: 802.11 Wireless LANs

Channels and Association

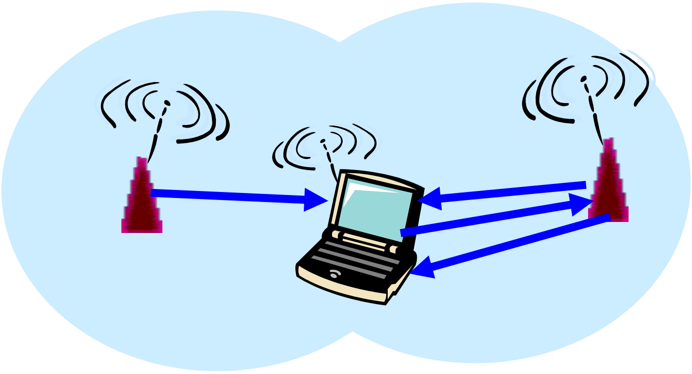
- Multiple channels at different frequencies
  - Network administrator chooses frequency for AP
  - Interference if channel is same as neighboring AP





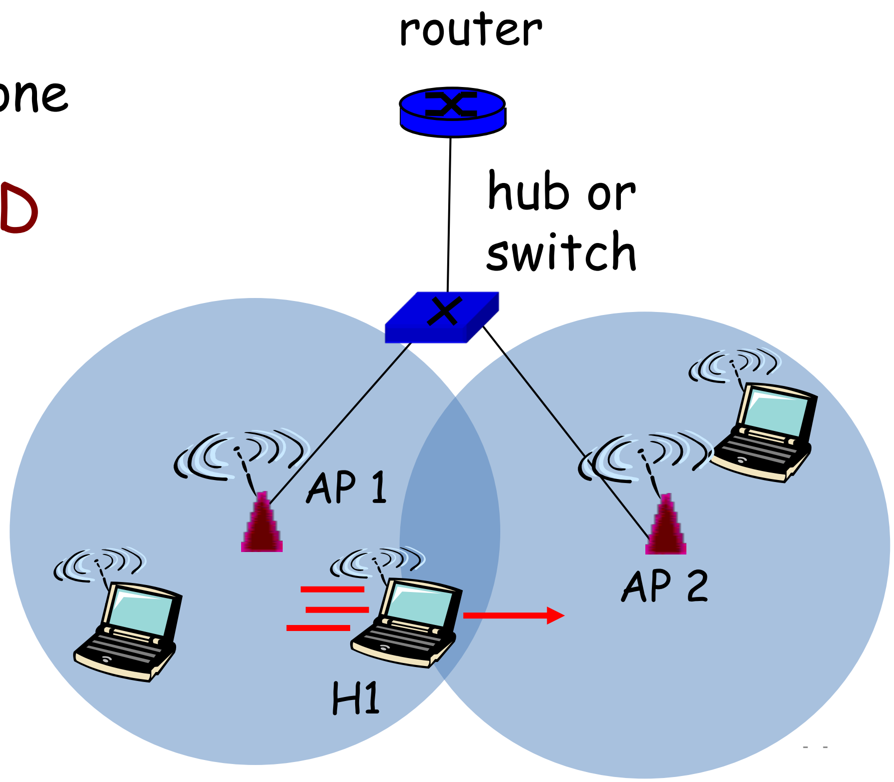
Channels and Association

- Multiple channels at different frequencies
  - Network administrator chooses frequency for AP
  - Interference if channel is same as neighboring AP
- Access points send periodic beacon frames
  - Containing AP's name (*SSID*) and MAC address
  - Host scans channels, listening for beacon frames
  - Host selects an access point: association request/response protocol between host and AP



Mobility Within the Same Subnet

- H1 remains in same IP subnet
  - IP address of the host can remain same
  - Ongoing data transfers can continue uninterrupted
- H1 recognizes the need to change
  - H1 detects a weakening signal
  - Starts scanning for stronger one
- Changes APs with same SSID
  - H1 disassociates from one
  - And associates with other
- Switch learns new location
  - Self-learning mechanism

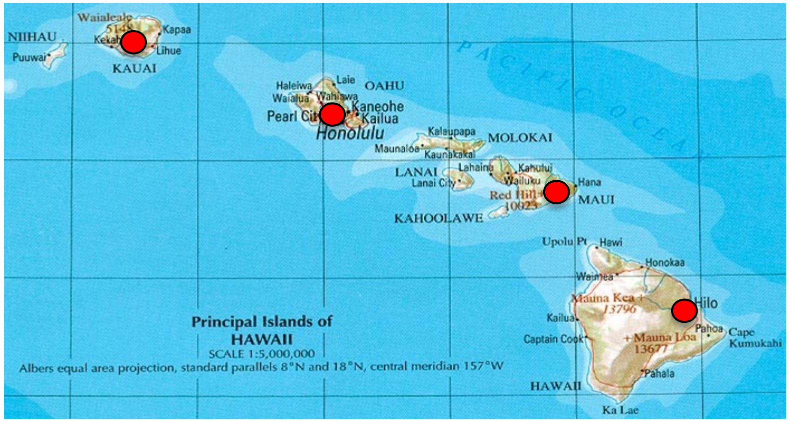


Medium access: a Timeline

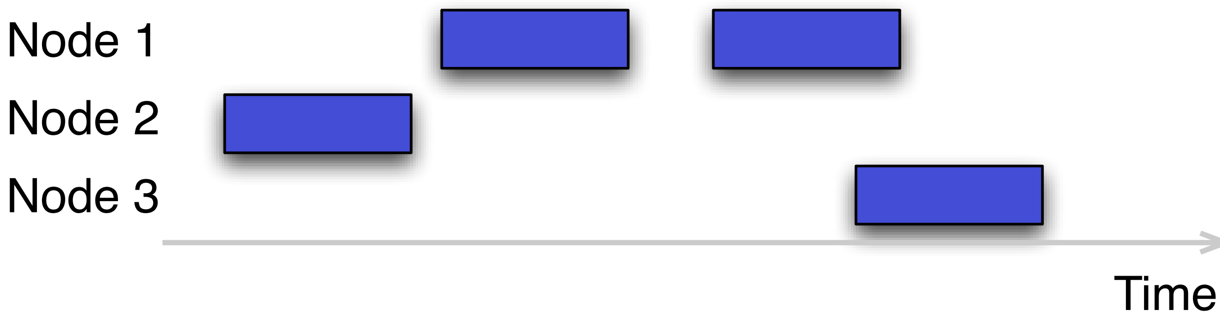
Packet radio	Wireless LAN	Wired LAN	
ALOHAnet			*1960s*
Amateur packet radio		Ethernet	*1970s*

ALOHAnet: Context

- Norm Abramson, 1970 at the University of Hawaii
  - Seven campuses, on four islands
  - Wanted to **connect** campus terminals and mainframe
  - Telephone costs high, so built a **packet radio network**



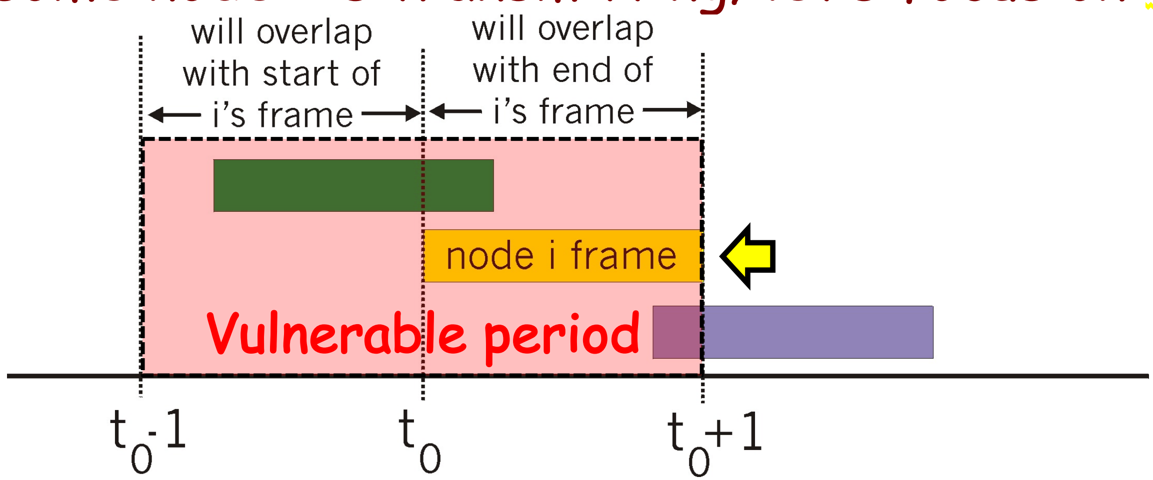
Medium Access Control: "Unslotted ALOHA"



- **Suppose:** Chance packet **begins in time interval** Δt **is** $\lambda \times \Delta t$
  - N senders in total, send frames of time duration 1
- **Then:** λ frames/sec *aggregate rate* from **all** N **senders**
  - *Individual rate* λ/N for **each sender**

Unslotted ALOHA: Performance

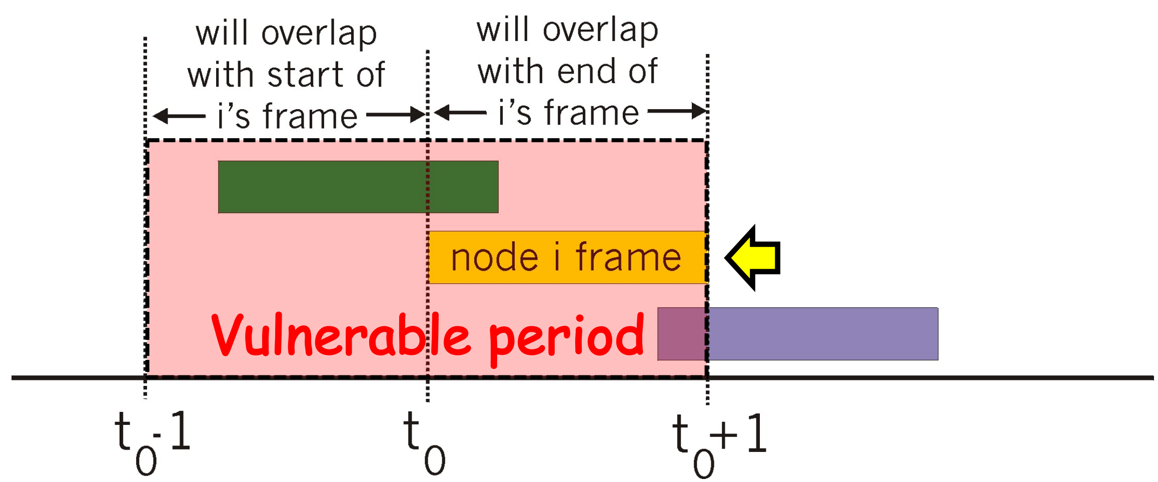
- Suppose some node *i* is transmitting; let's focus on ***i*'s frame**



I. Others send in [t_0–1, t_0]: overlap *i*'s frame **start** → **collision**
II. Others send in [t_0, t_0+1]: overlap *i*'s frame **end** → **collision**
III. Otherwise, **no collision**, node *i*'s frame is delivered

- Therefore, *vulnerable period* of length 2 around *i*'s frame

Unslotted ALOHA: Performance



- *What's the chance no one else sends in the vulnerable period (length 2)?*

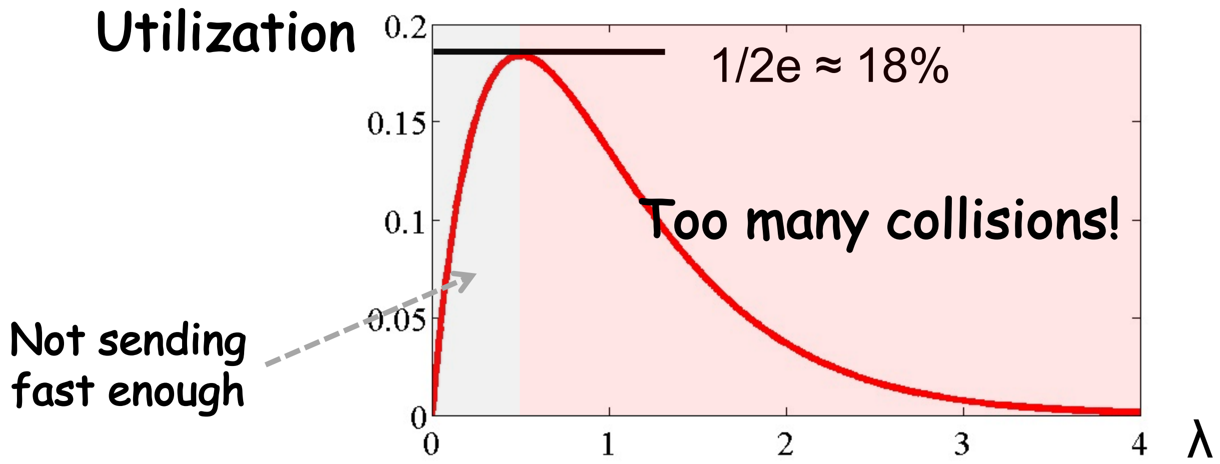
$$\Pr(\text{no send from } \mathit{one} \text{ node in } 2) = 1 - \frac{2\lambda}{N}$$

$$\Pr(\text{no send } \mathit{at\ all} \text{ in } 2) = \left(1 - \frac{2\lambda}{N}\right)^{N-1}$$

$$\lim_{N\to\infty}\left(1 - \frac{2\lambda}{N}\right)^{N-1} \to e^{-2\lambda}$$

Unslotted ALOHA: Utilization

- ***Utilization:*** For what fraction of the time is there a non-colliding transmission present on the medium?



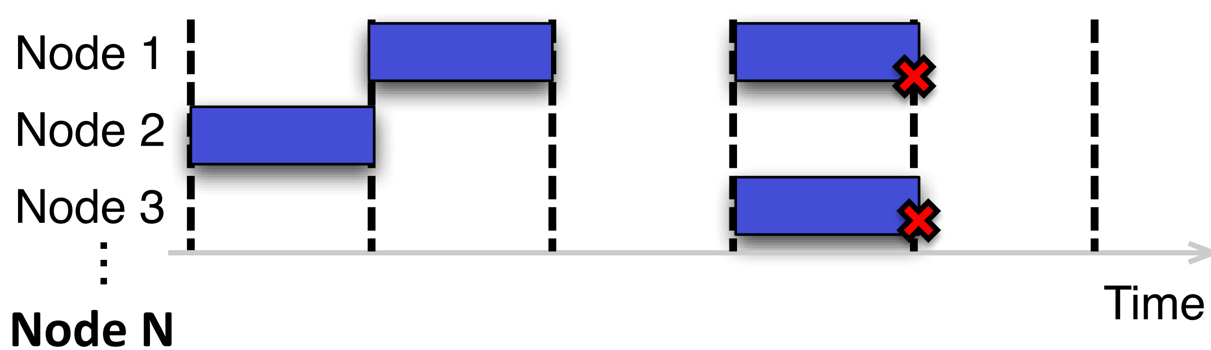
- Recall, λ is the **total rate** from **all senders**
- So, utilization $= \lambda \times \Pr(\text{no other transmission in } 2)$

$$= \lambda e^{-2\lambda}$$

Medium Access Control Refinement: "Slotted ALOHA"

- **Divide time into slots** of duration 1, synchronize so that nodes transmit only in a slot
  - Each of **N nodes** transmits w/prob. p in each slot
  - So **total transmission rate λ** = $N \times p$

- As before, if exactly one transmission in slot, can receive; if two or more in slot, no one can receive (collision)



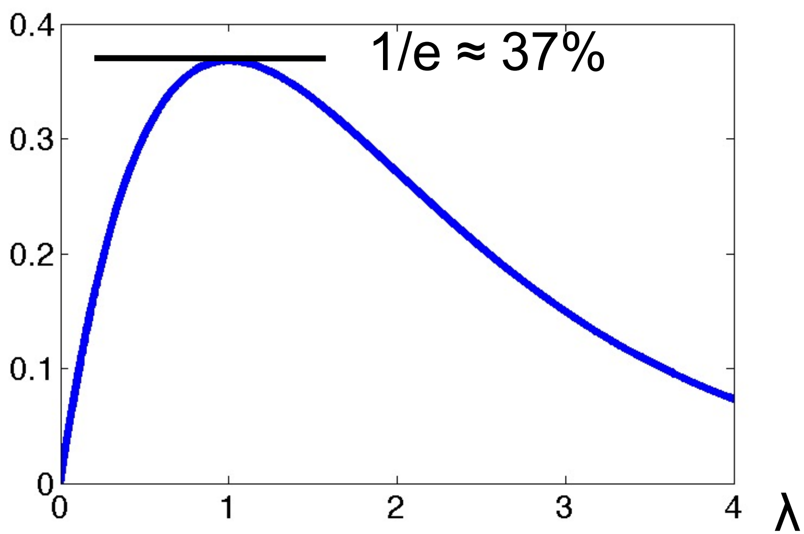
Slotted ALOHA: Utilization

(*N* nodes, each transmits with probability *p* in each slot)

What is the utilization as a function of aggregate rate $\lambda = N \times p$?

- Pr[A node is successful in a slot] = $p(1-p)^{N-1}$
- Pr[Success in a slot] = $Np(1-p)^{N-1}$

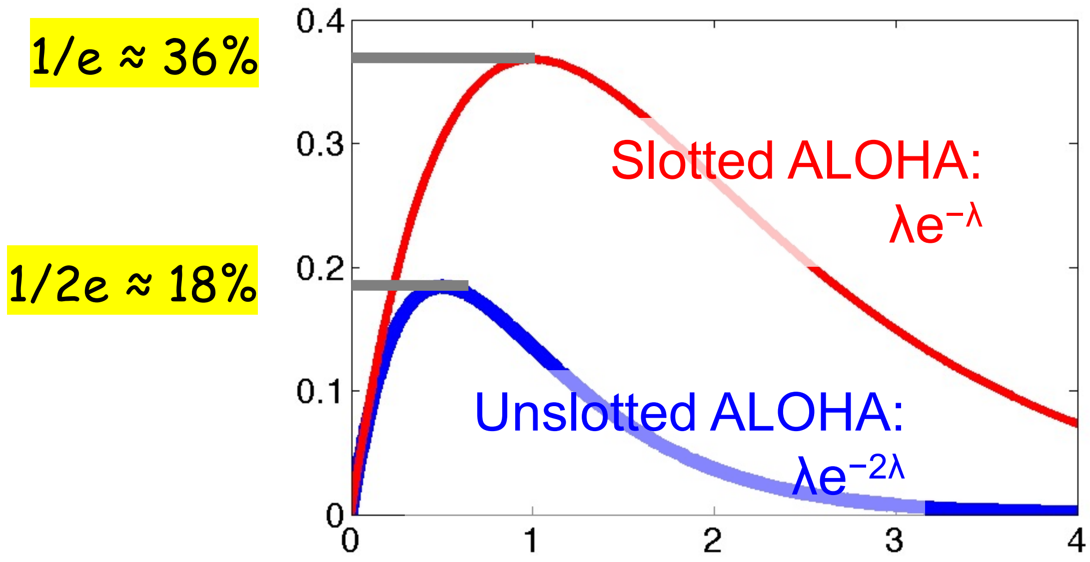
Utilization: $\lambda e^{-\lambda}$



$$\Pr(\text{success}) = \lambda\left(1 - \frac{\lambda}{N}\right)^{N-1}$$

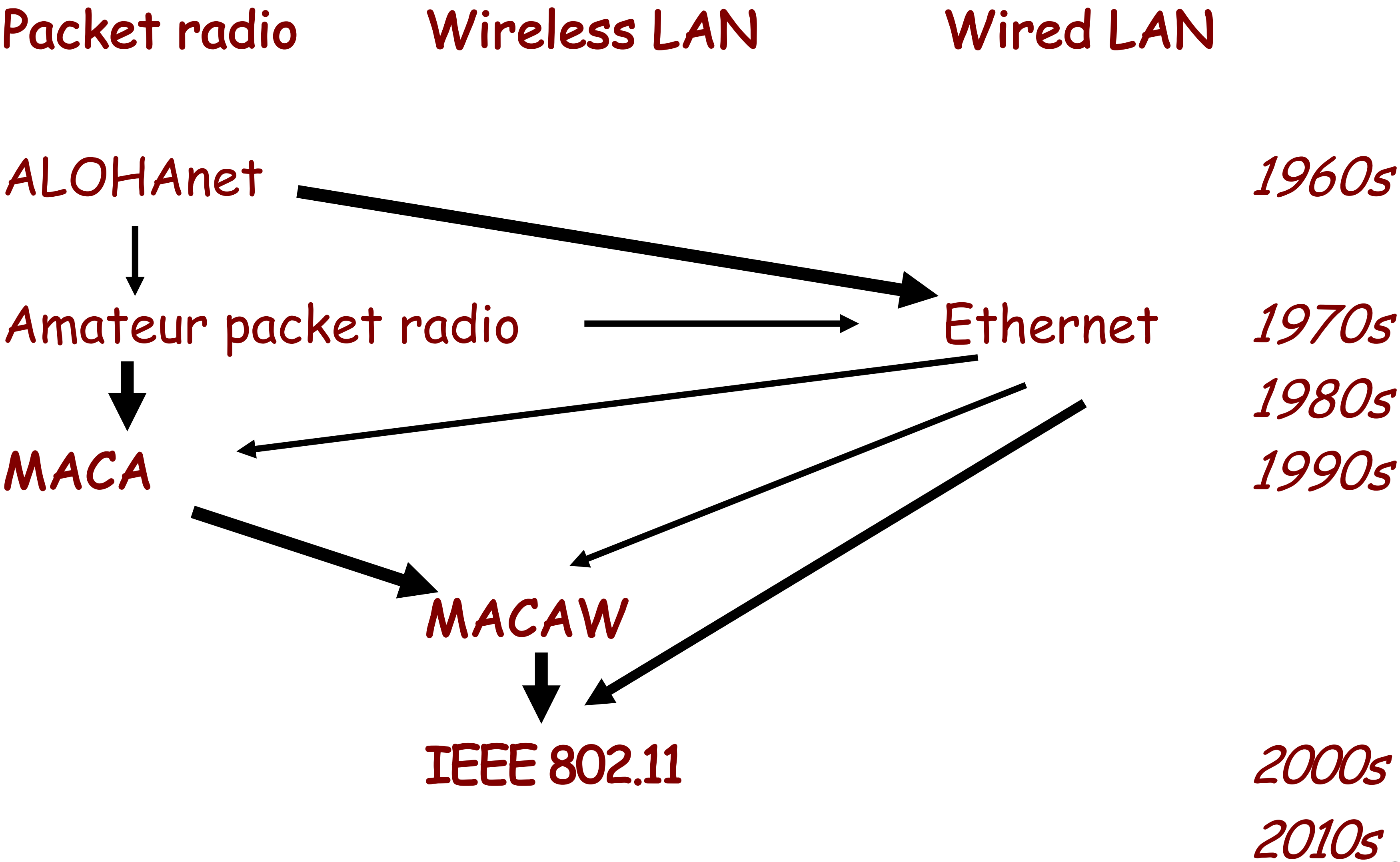
$$\lim_{N\to\infty} \lambda\left(1 - \frac{\lambda}{N}\right)^{N-1} = \lambda e^{-\lambda}$$

ALOHA Medium Access Control: Timeslots Double Throughput!



Just by forcing nodes to transmit on slot boundaries, we double peak medium utilization!

Medium access: Timeline

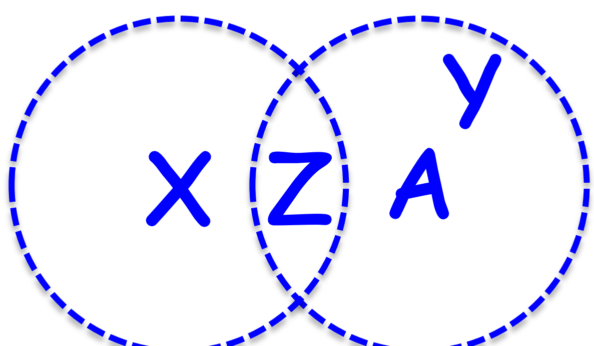


Assumptions

- Uniform, circular radio propagation
  - Fixed transmit power, all same ranges
  - Equal **interference** and **communication** ranges

Radios modeled as "conditionally connected" wires based on circular radio ranges

- Def'n: Node is connected to other node *iff other located within* circular radio range:



MACA: Goals

- Goals
  - Fairness in sharing of medium
  - Efficiency (total bandwidth achieved)
  - Reliability of data transfer at MAC layer

When Does Listen-Before-Talk *Carrier Sense* (CS) Work Well?

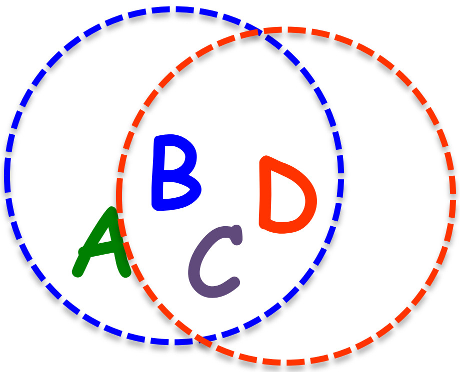
- Two pairs far away from each other
  - Neither sender carrier-senses the other

B transmits to A, while D transmits to C.

When Does CS Work Well?

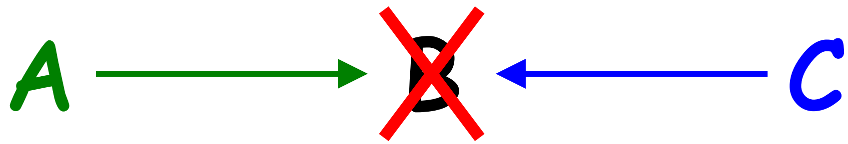
- Both transmitters can carrier sense each other

But what about cases in between these extremes?



B transmits to A, D transmits to C, taking turns.

Hidden Terminal Problem



- C can't hear A, so C will transmit while A transmits
  - Result: Collision at B
- Carrier Sense insufficient to detect all transmissions on wireless networks!
- **Key insight:** Collisions are spatially located at receiver

Exposed Terminal Problem

- If C transmits, does it cause a collision at A?
  - Yet C cannot transmit while B transmits to A!

- Same insight: Collisions spatially located at receiver

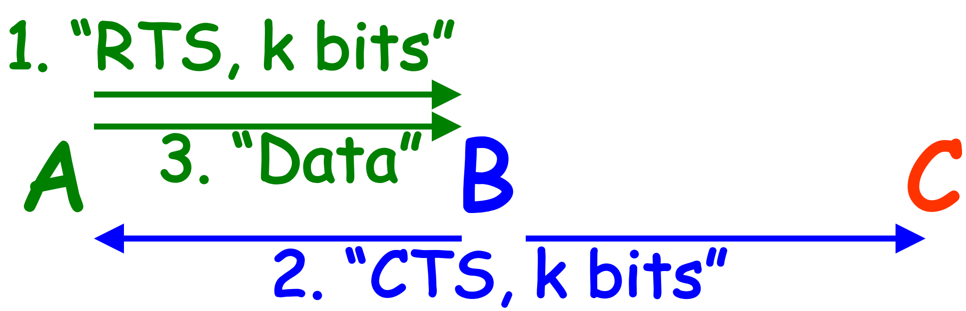
- One possibility: directional antennas rather than omnidirectional. Why does this help? Why is it hard?

MACA: Multiple Access with Collision Avoidance

- Carrier sense became adopted in packet radio
- But **distances** (cell size) remained large
- Hidden and Exposed terminals abounded
- **Simple solution:** use *receiver's* **medium state** to determine **transmitter behavior**

RTS/CTS

- Exchange of two short messages: *Request to Send* (RTS) and *Clear to Send* (CTS)
- **Algorithm**
  1. A sends an RTS (tells B to prepare)
  2. B replies an CTS (echoes message length)
  3. A sends its Data

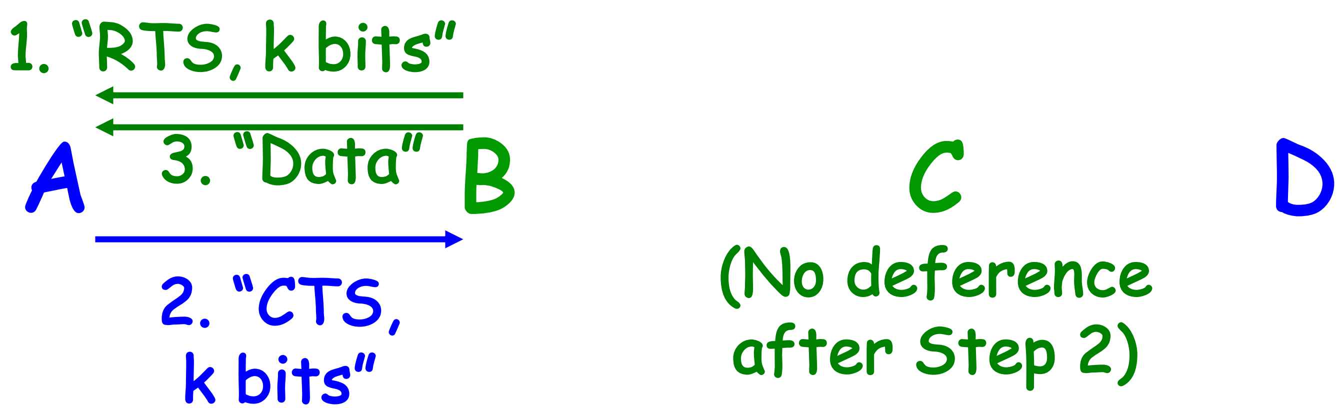


Deference to CTS

- Hear CTS → Defer for length of expected data transmission time
  - Solves hidden terminal problem

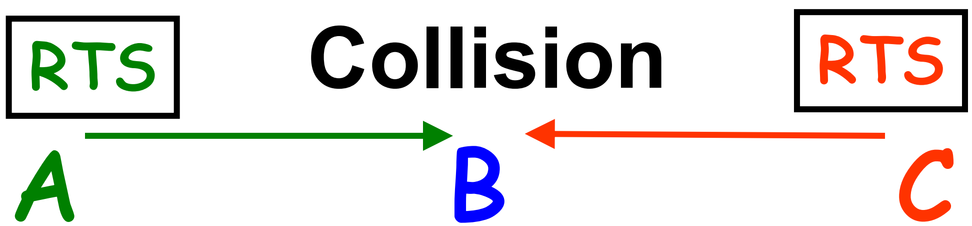
Deference to RTS, but not CS

- Hear RTS → Defer one CTS-time (*why?*)
- MACA: No carrier sense before sending!
  - Karn concluded useless because of **hidden** terminals
- So exposed terminals B, C can transmit concurrently:



Collision!

- A's RTS collides with C's RTS, both are lost at B
  - B will not reply with a CTS



- Might collisions involving data packets occur?
  - Not according to our (unrealistic) assumptions
  - But Karn acknowledges interference range > communication range

Bounded Exponential Backoff (BEB) in MACA

- When collisions arise, MACA senders **randomly backoff** like Ethernet senders then **retry the RTS**

- How long do collisions take to **detect** in the Experimental Ethernet?

- **What size** should we make MACA backoff slots?

BEB in MACA

- Current backoff constant: CW

- MACA sender:
  - $CW_0 = 2$ and $CW_M = 64$
  - Upon successful RTS/CTS, $CW \leftarrow CW_0$
  - Upon failed RTS/CTS, $CW \leftarrow \min[2CW, CW_M]$

- Before retransmission, wait a uniform random **number of RTS lengths** (30 bytes) in $[0, CW]$
  - 30 bytes = 240 μs

Summary

- Wireless networks: de facto means of accessing the Internet
- Alohanet, MACA packet radio network design insights
- Evolution from ALOHAnet, Ethernet, MACA, toward IEEE 802.11 Wi-Fi