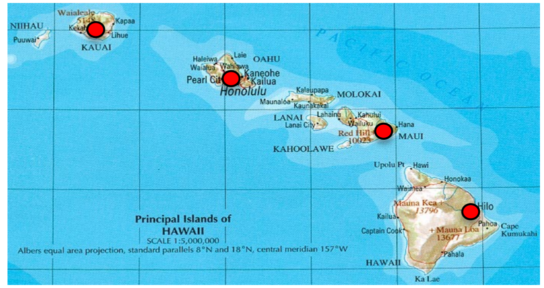


Class Meeting: Lectures 17 and 18: Wireless Networks

COS 461: Computer Networks

Kyle Jamieson

Wireless is increasingly prevalent

Smart Home

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

Vehicular Networks

Cellular Networks

Today

- Wireless Networks
  - What makes wireless networks different?
- ALOHA: taking turns
- MACA: sensing other transmissions

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

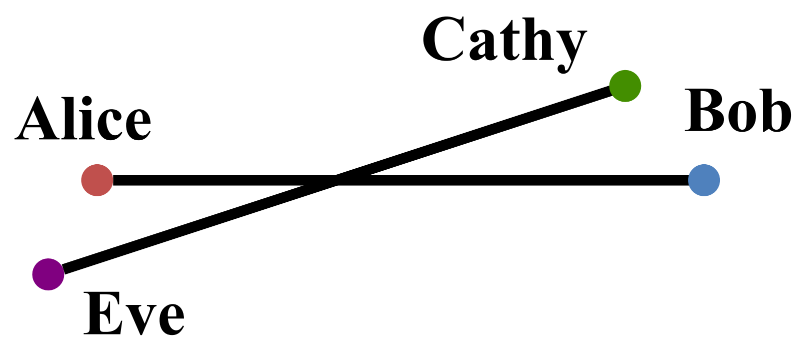
Wireless is less reliable

- In wired networks, link **bit error rate** < 10^{-12}
- Wireless networks are **far from that target**
  - Bit error rates of **10^{-6} and above** are common!
  - ***Why?***

Wireless is a shared medium

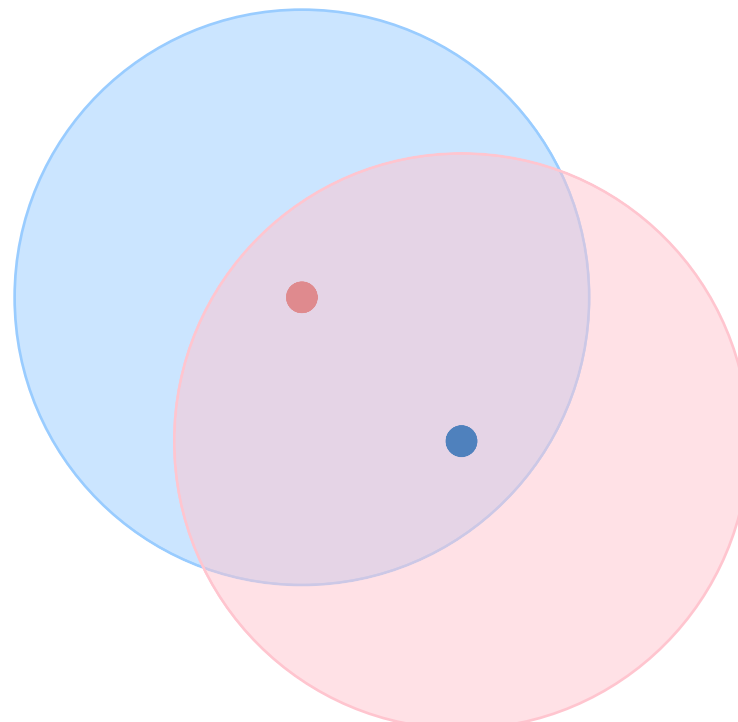
- **Wired networks:**

Alice and Bob's conversation is **independent of** Cathy and Eve's conversation



- **Wireless networks:**

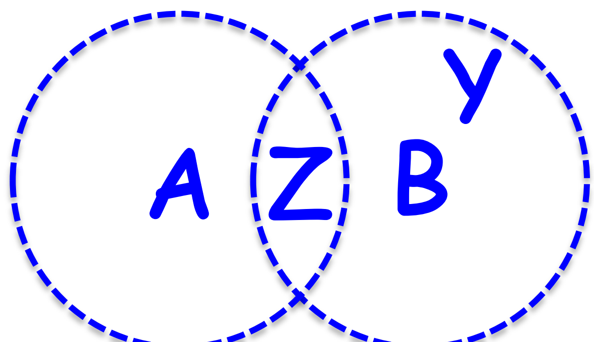
Close by **wireless** conversations **share the same wireless medium**



Simplification: Uniform Circular Connectivity Radio Model

- **Model uniform, circular** radio propagation
  - Fixed transmit power → all same ranges indicated by circles drawn around nodes

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



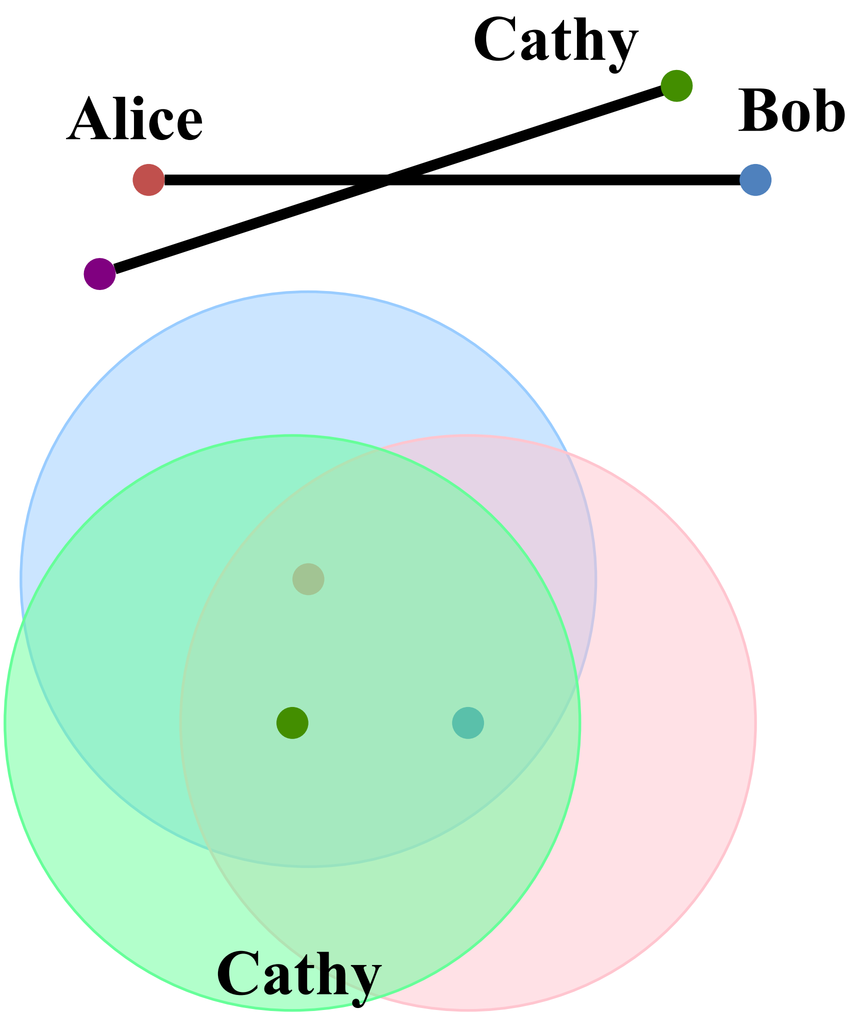
- **Equal** interference and **communication** ranges

Why is a point-to-point link the wrong abstraction for building wireless networks?

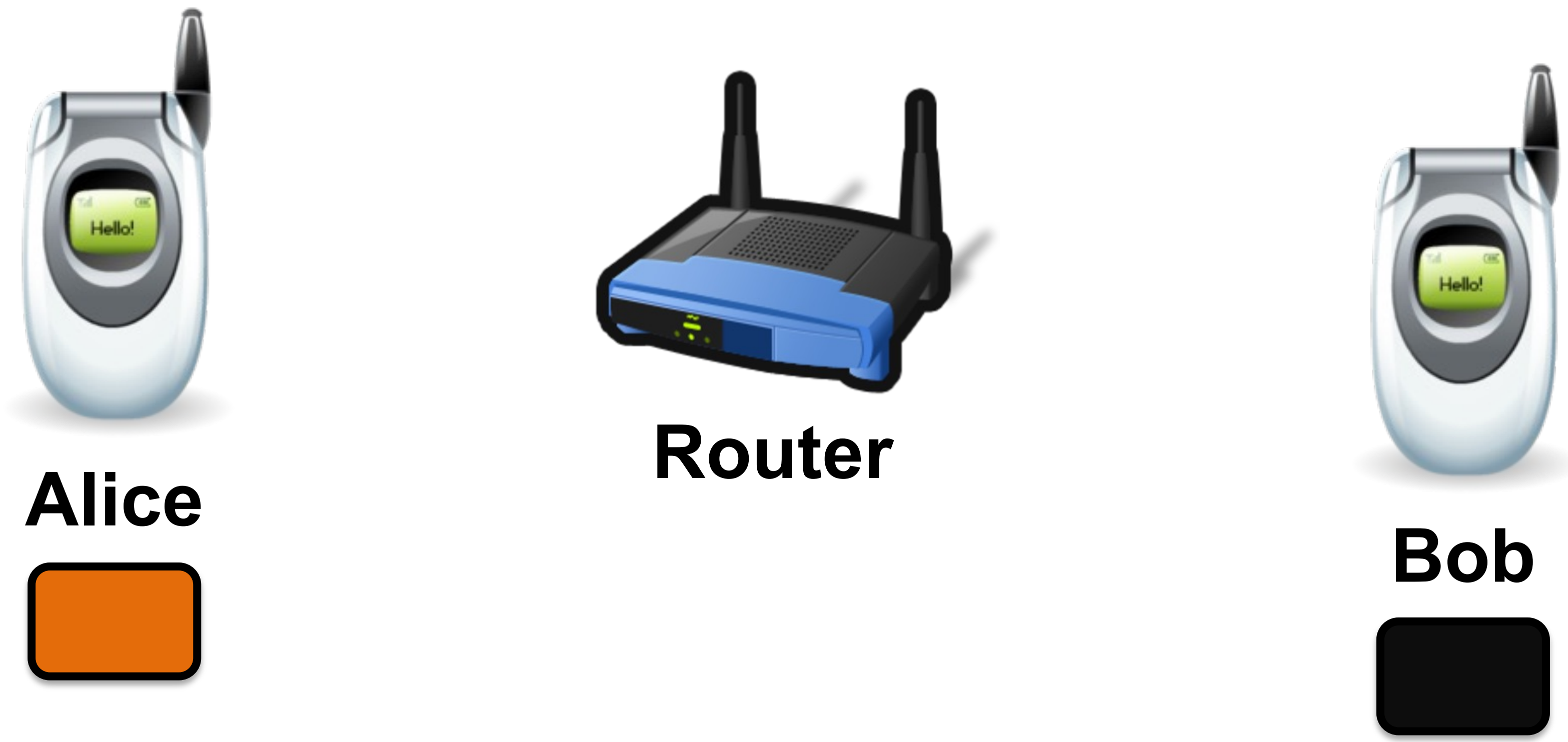
Reason #1: Interference

- Noise is naturally present in the environment from many sources

- Interference can be from other users of the same technology, other technologies altogether

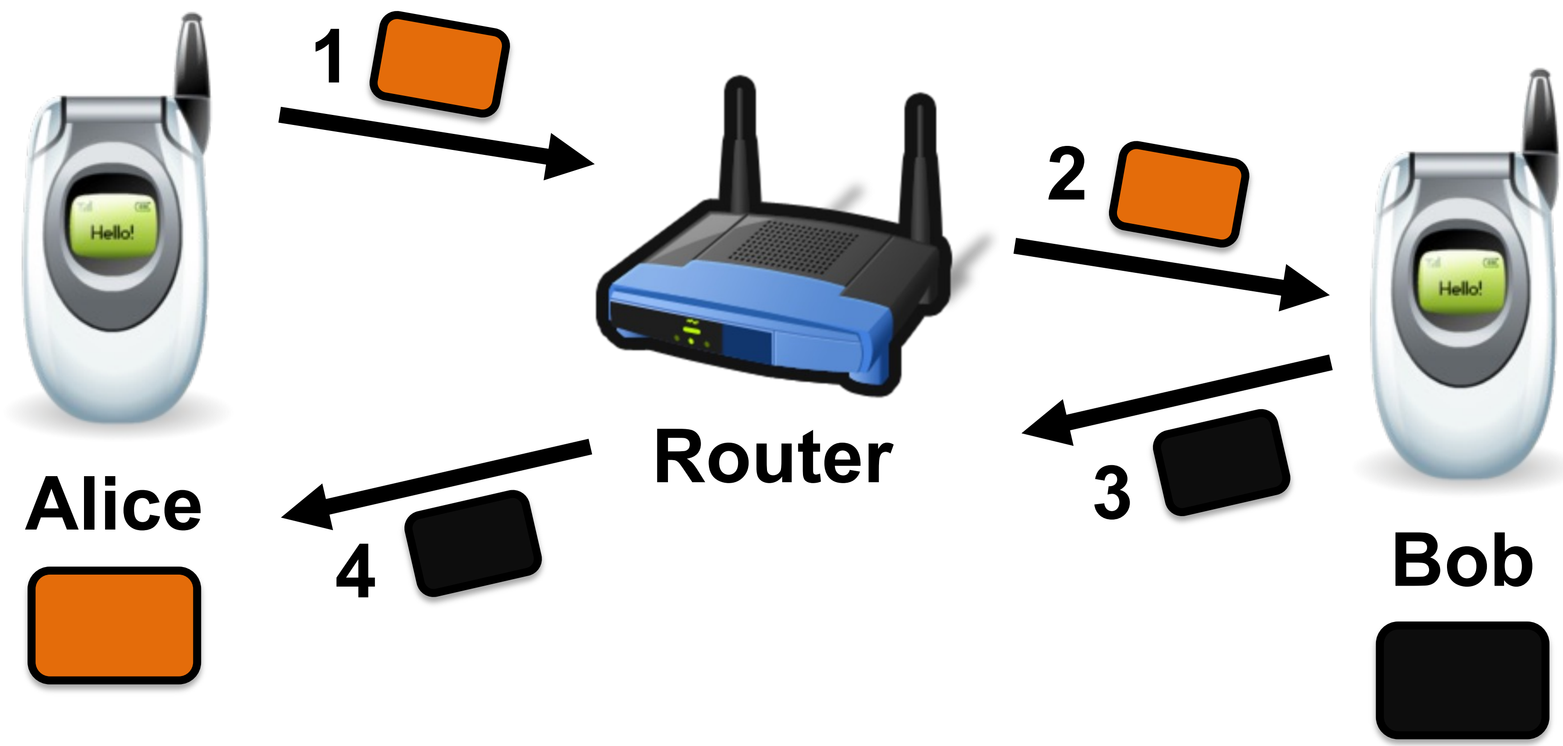


Reason #2: Can leverage broadcast



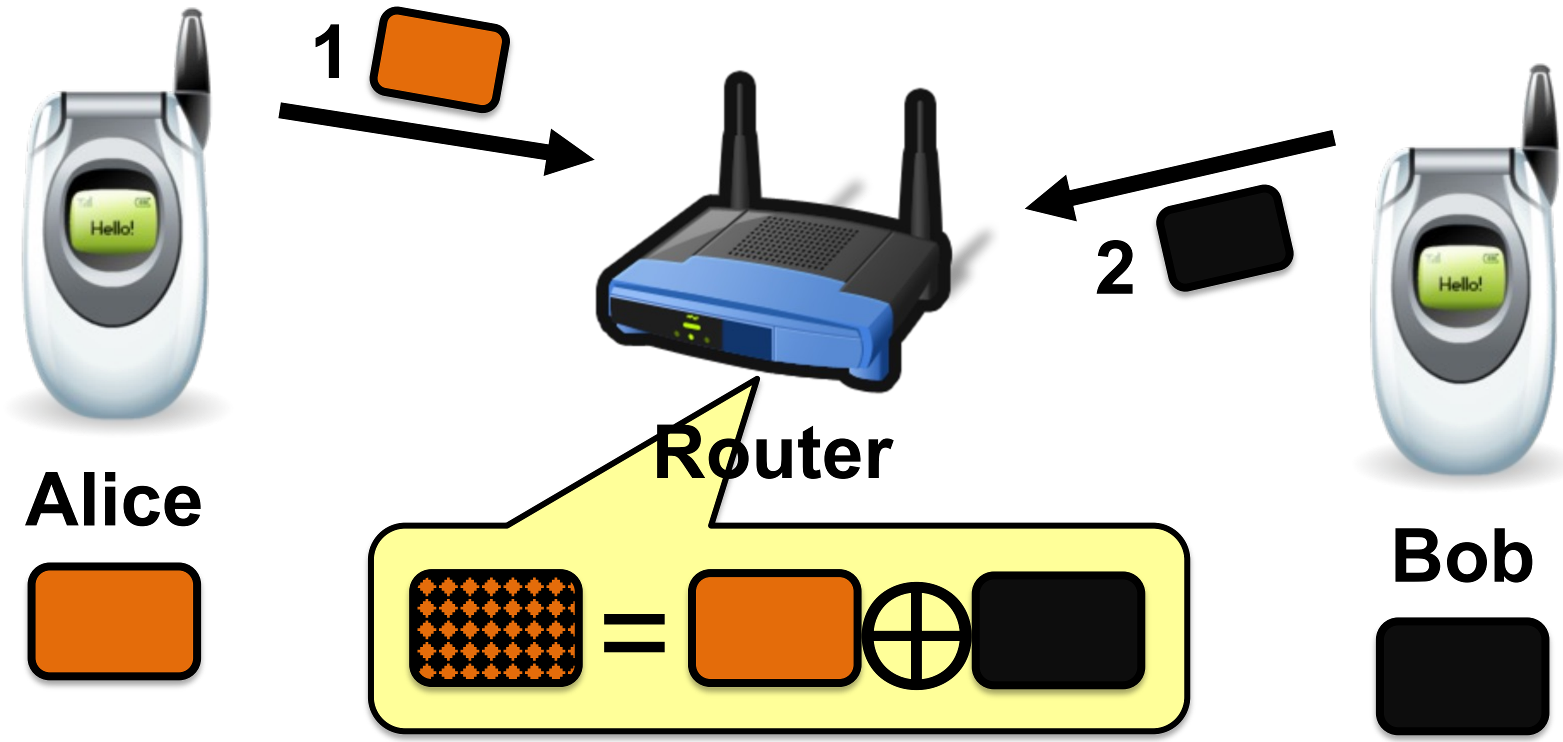
- Want to exchange packets, but out of direct range

Solution using wired abstraction

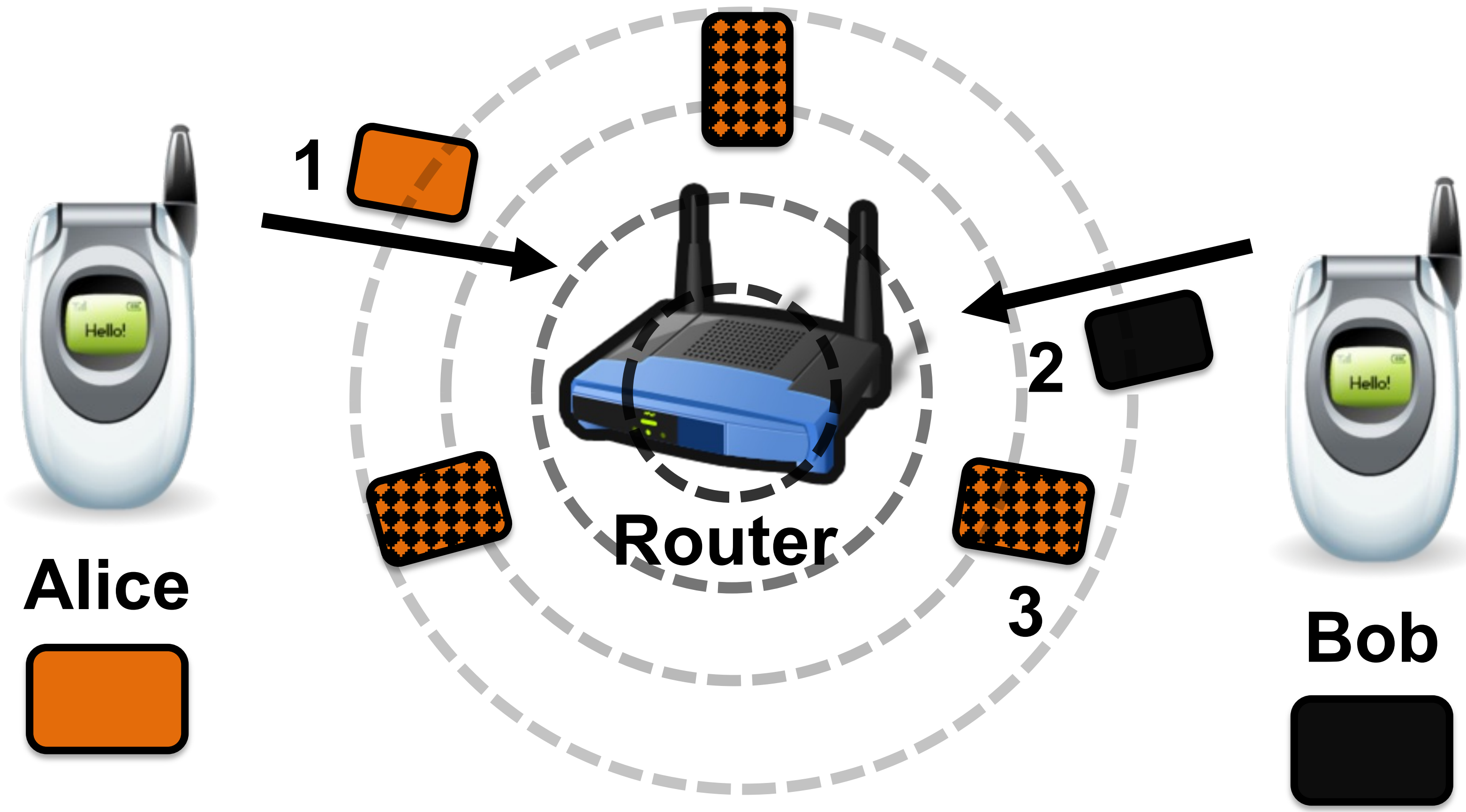


- Requires four transmissions in total

Idea: Router combines the packets



Router broadcasts the combination



- Requires just three transmissions in total

Sumary: Shared medium is very different

- Wireless' shared medium is **very different** than point-to-point wired links
- So need to **think about wireless networks differently**
- **Interference** is a **major problem**
- But also can leverage broadcast nature of wireless
  - Four to three transmissions increases throughput

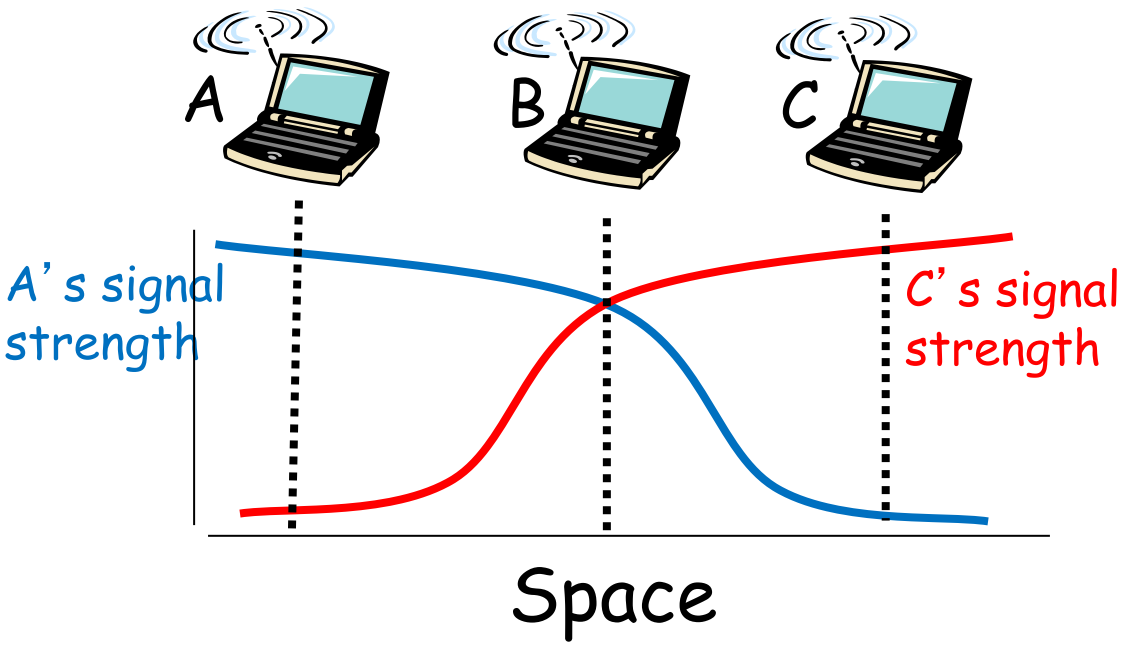
Dealing With Bit Errors

- 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 and Interference:

Interference matters at the receiver



Signal/Interference ratio:

$$\frac{\text{A's signal strength @ B}}{\text{C's signal strength @ B}}$$

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

Today

- Wireless Networks
  - What makes wireless networks different?

- **ALOHA: taking turns**

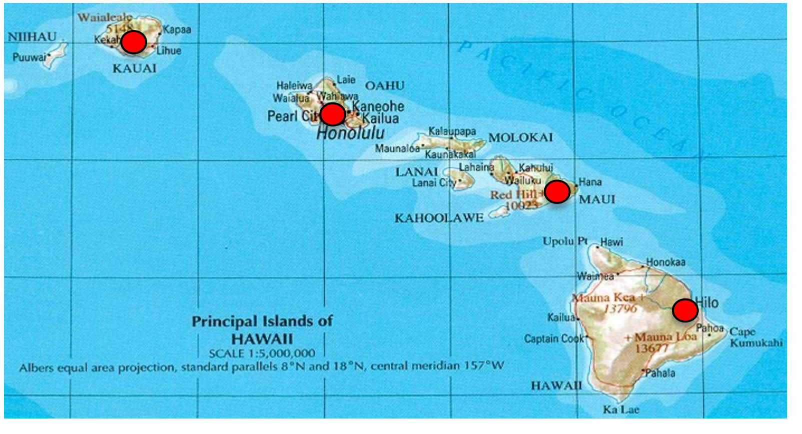
- MACA: sensing other transmissions

Wireless LANs: a Timeline

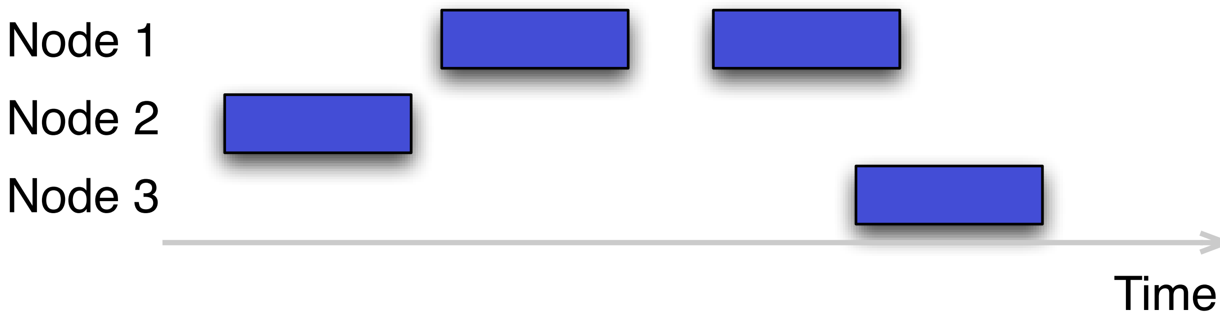
Packet radio	Wireless LAN	Wired LAN	
ALOHAnet			*1960s*
Amateur packet radio		Ethernet	*1970s*

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**



An *Unslotted ALOHA* Network



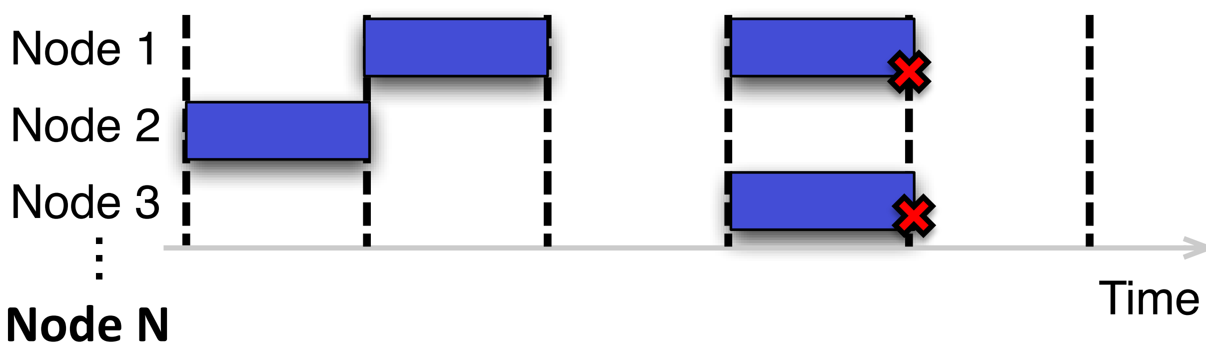
- **Suppose:** Chance new packet **in time** Δt: $\lambda \times \Delta t$
  - N senders in total, send frames of time duration 1

- **Then:** λ frames/sec *aggregate rate* from all N senders
  - *Individual rate* λ/N for **each sender**

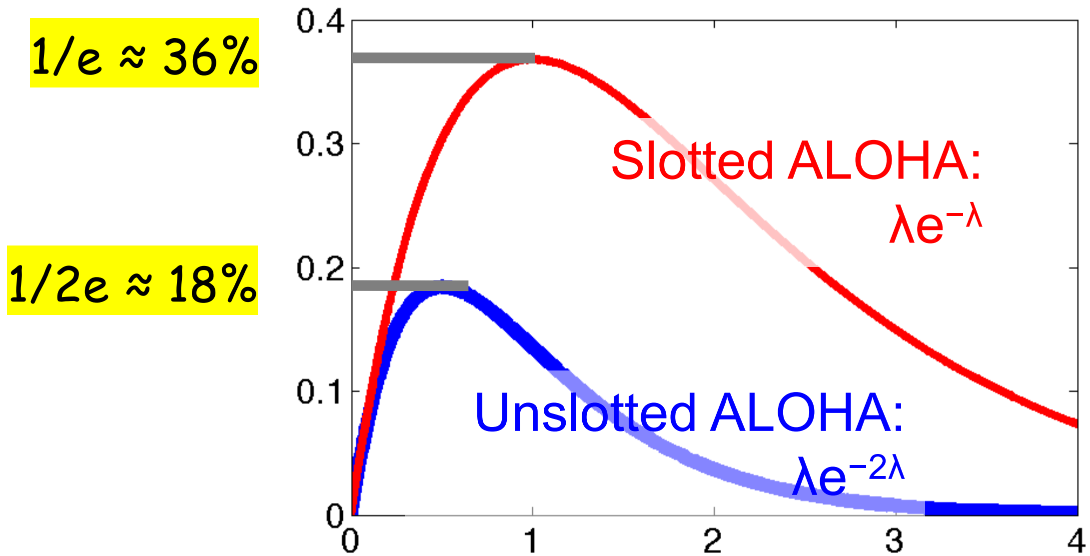
- **Collision and loss of data if the frames overlap (even a bit!)**

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)



ALOHA Medium Access Control: Timeslots Double Throughput!



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

Today

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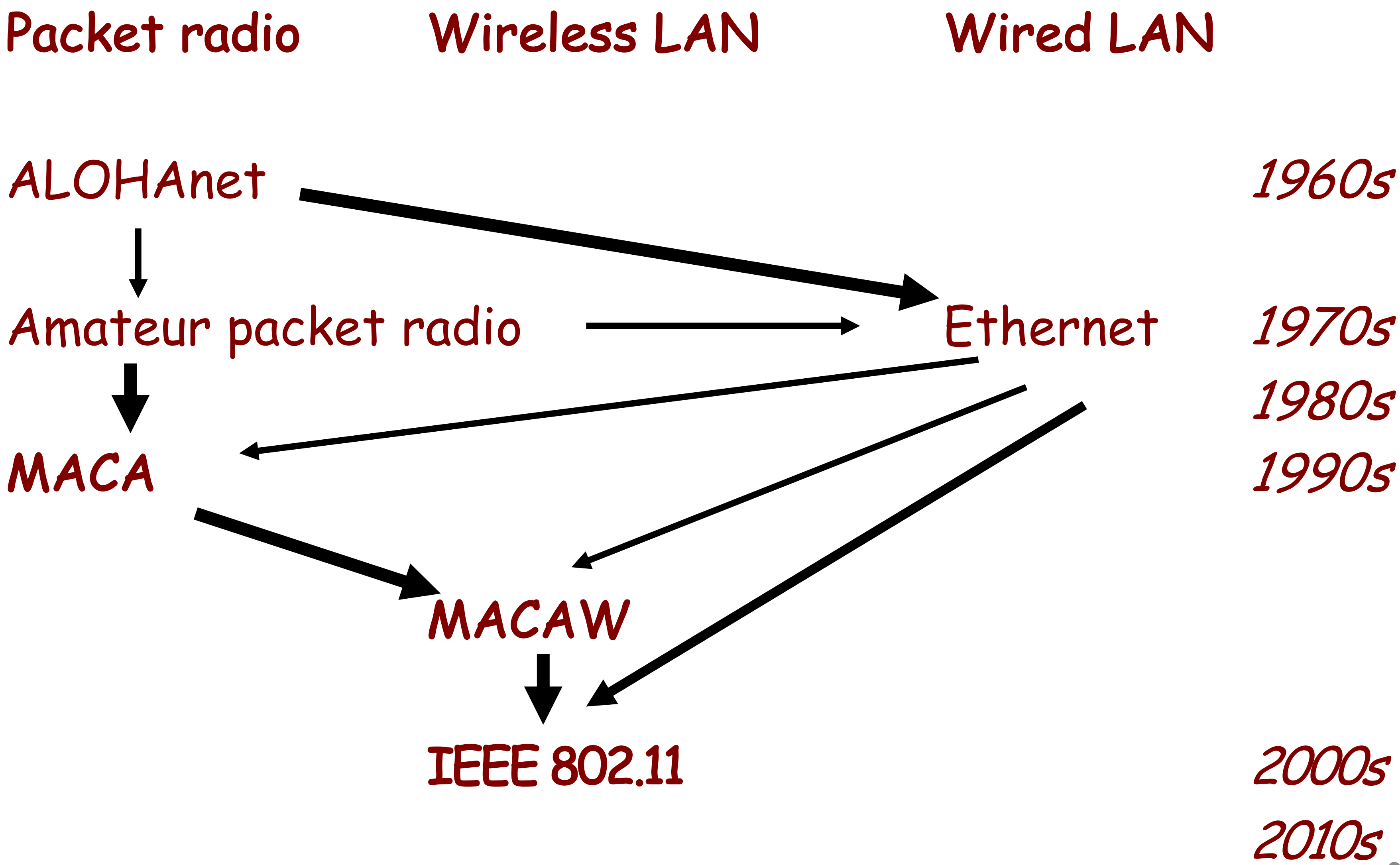
- **MACA: sensing other transmissions**

Wireless LANs: Timeline



MACA: Context & Goals

- Context
  - Listen-before-talk: carrier sense in widespread use in amateur packet radio

- Inventor Karn's 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?

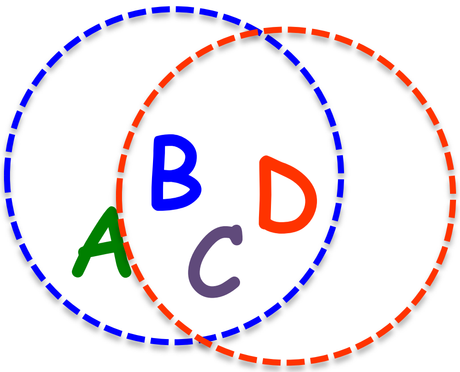
- Two pairs far away from each other
  - Neither sender carrier-senses the other

B transmits to A, while D transmits to C.

When Does CS Work Well?

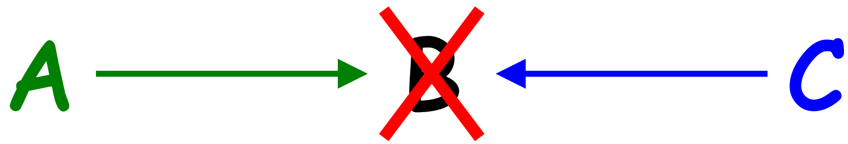
- Both transmitters can carrier sense each other

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

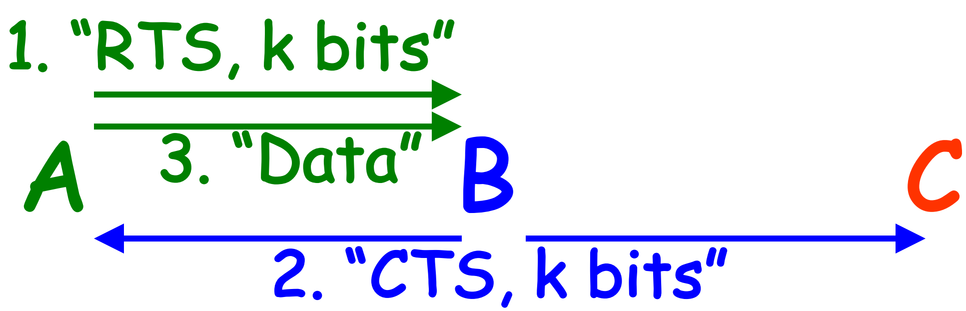
- If C transmits, does it cause a collision at A?
  - Yet C cannot transmit while B transmits to A!
- Same insight: Collisions spatially located at receiver
- One possibility outside our system model: directional antennas rather than omnidirectional. Why does this help? Why is it hard?

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 RTS (tells B to prepare for expected data)
  2. B replies CTS (echoes message length)
  3. A sends its Data

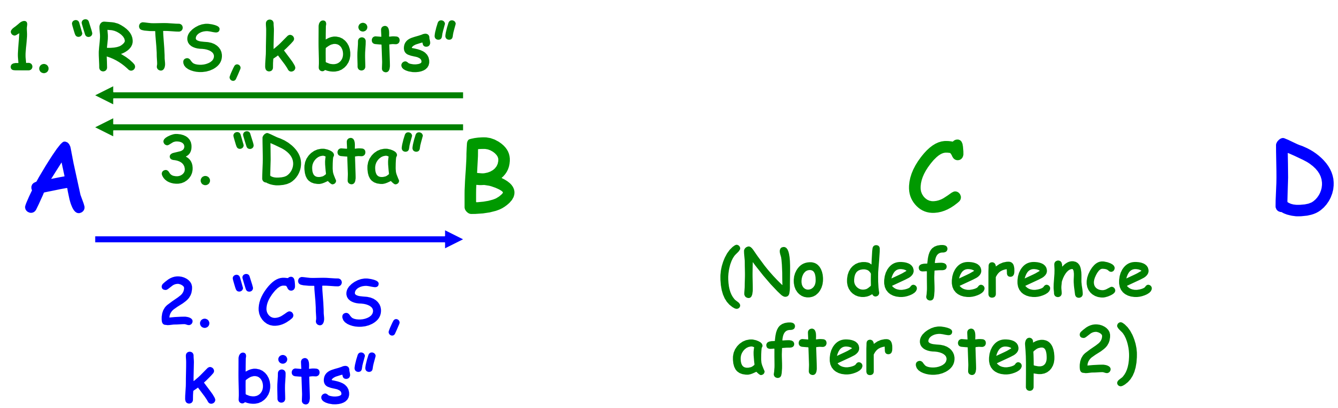


Deference to CTS

- Hear CTS → Defer your transmissions for the transmission time of the expected data
  - 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:



Summary of Today

- Wireless networks: de facto means of accessing the Internet
  - Evolution from ALOHAnet, to Ethernet, to MACA, toward IEEE 802.11 Wi-Fi