Wireless Networks:
Sharing the Wireless Medium

COS 316, Lecture 15

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Today

1. **How do wireless and wired networks differ?**
2. Medium access control: Provisioned protocols
3. Contention-based medium access control

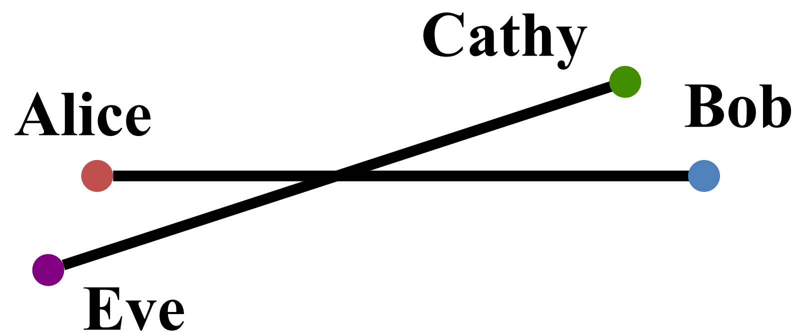
Wireless is less reliable

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

Wireless is a shared medium

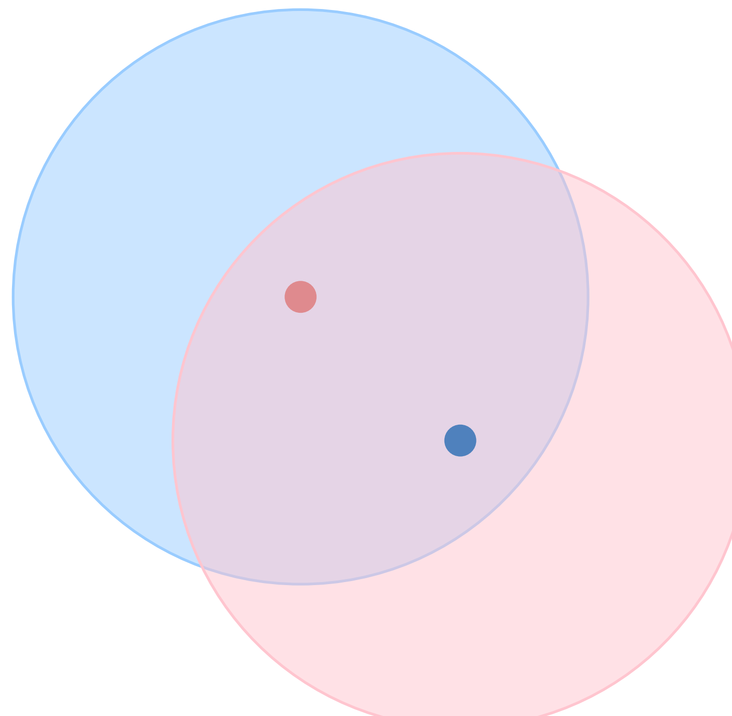
- **Wired networks:**

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

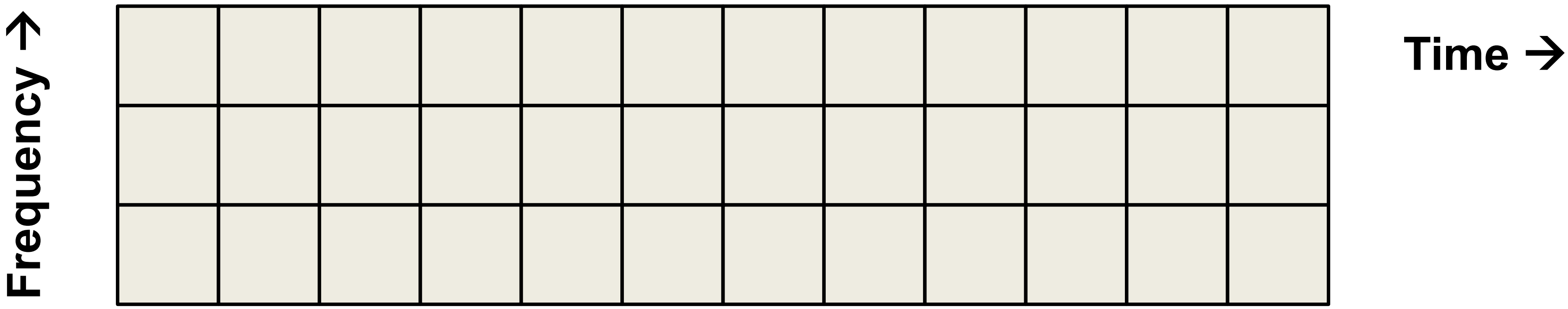


- **Wireless networks:**

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



Medium access: The Problem

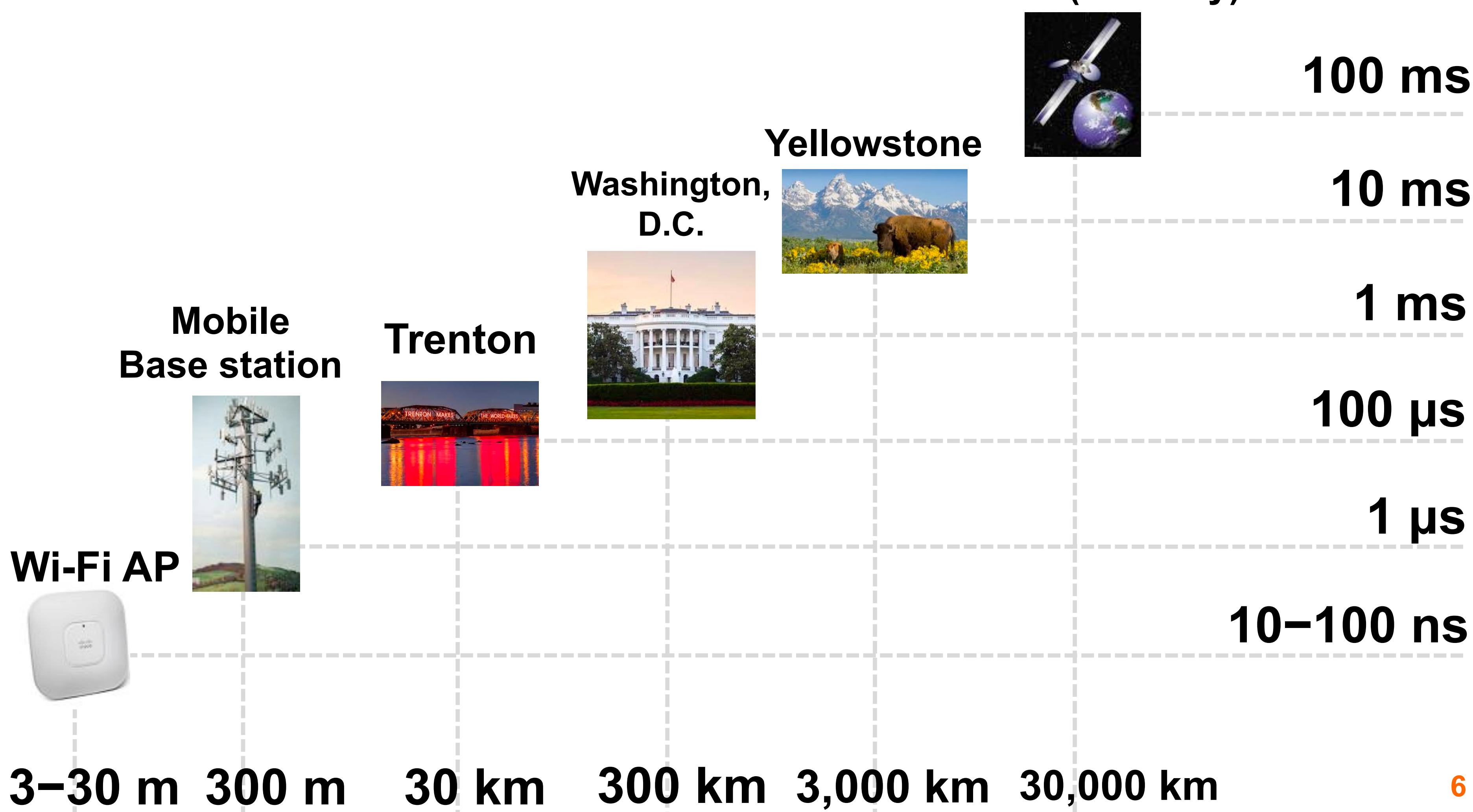


- Receiver must hear ≤1 strong transmission at a time, else ***collision*** **(transmissions are lost)**

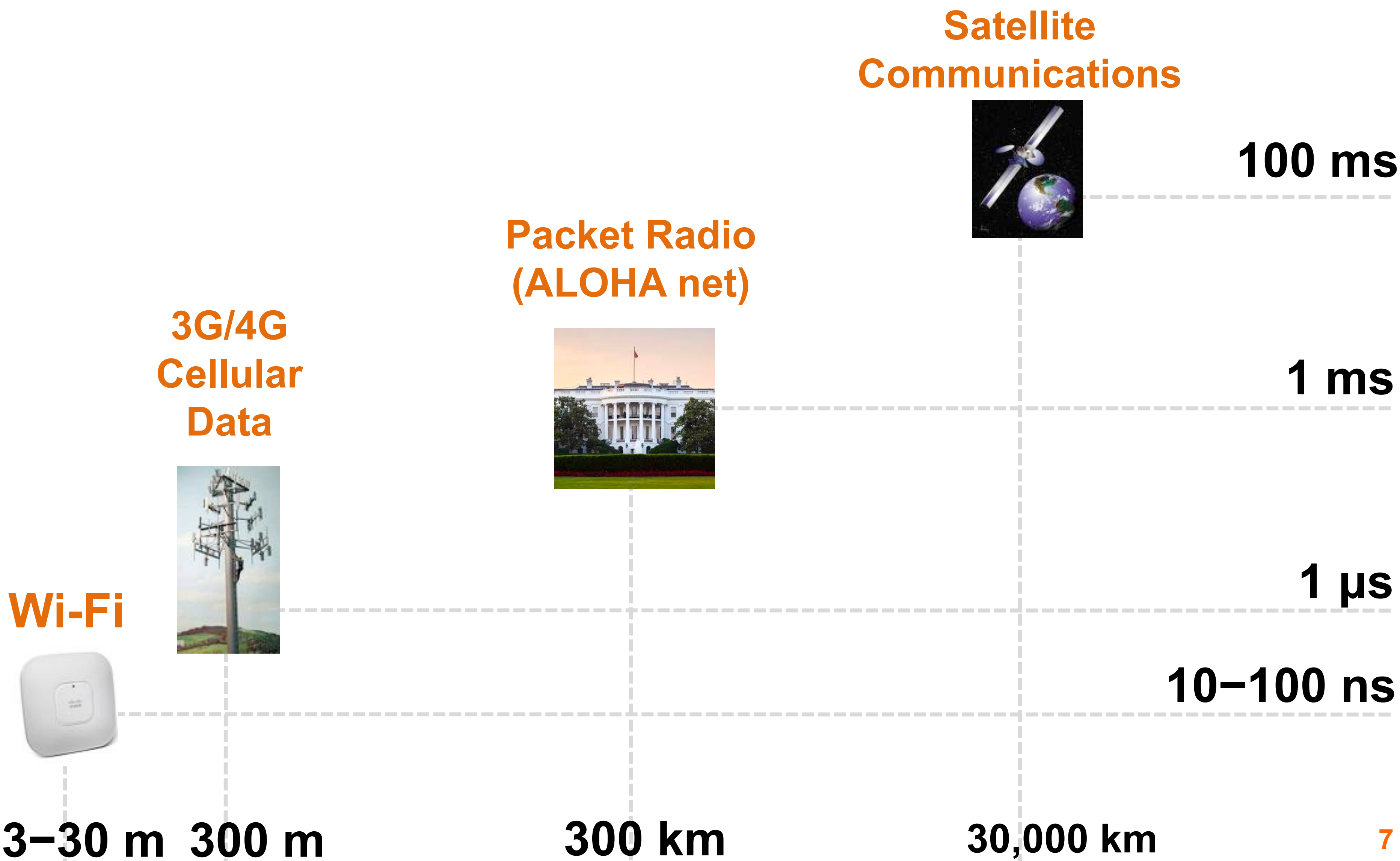
- **Two questions:**
  1. **How** should the shared medium be **divided?**
  2. **Who** gets to use each such unit of division, and **when?**
- A ***medium access control*** **(MAC)** ***protocol*** specifies the above

Physical Limitation: Finite speed of light

From Princeton to...



Vastly Different Timescales, Same Medium Access Protocol!



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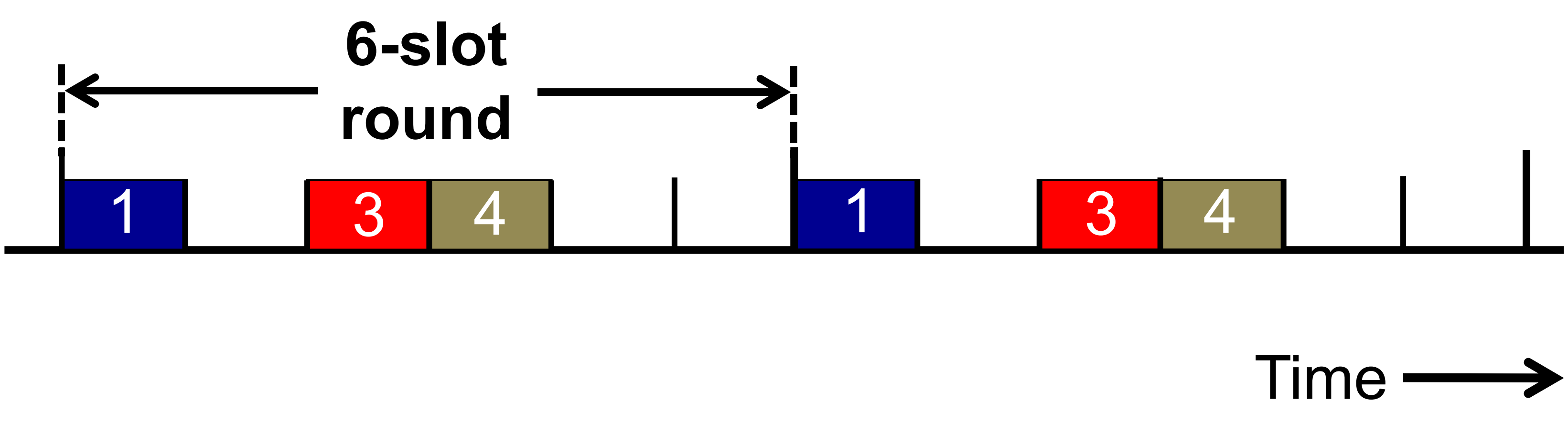
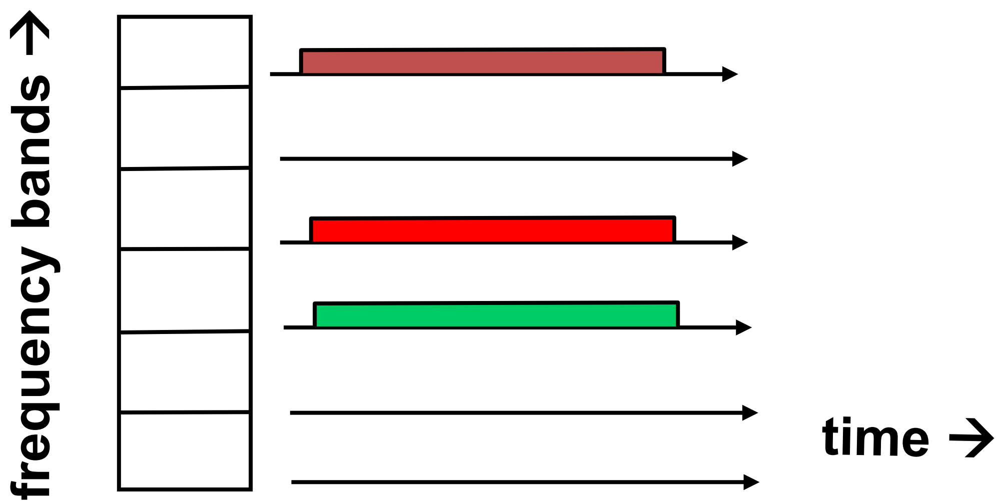
TDMA: Time Division Multiple Access

- Channel time is divided into fixed-period, repeating ***rounds***
- Each user gets a fixed-length ***slot*** (packet time) in each round
  - Send across all frequencies during this slot
  - **Unused slots are wasted**
- **Out-of-band:** Mechanism for allocating/de-allocating slots
- ***e.g.:*** six stations, only 1, 3, and 4 have data to send



FDMA: Frequency Division Multiple Access

- Channel's frequency range (for all time) divided into frequency ***bands***
  - Each user gets a fixed frequency band (**unused frequency slots are wasted**)
- ***e.g.:*** six stations, only #1, #3, and #4 have data to send



TDMA and FDMA: Considerations

- **Advantages**

1. Users are **guaranteed** to be able to send bits, continuously (FDMA) or periodically (TDMA)

- **Disadvantages**

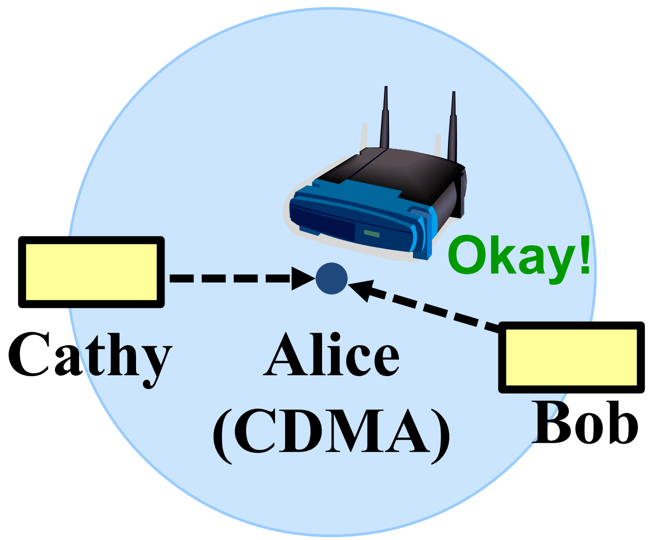
1. Unused time slots or frequency bands **reduce channel utilization**

2. An out-of-band mechanism is needed to allocate slots or bands (which **requires another channel**)

3. Guard bands or guard times **reduce channel utilization**

CDMA: Code Division Multiple Access

- All users transmit over the **same frequencies,** and **at the same time:**



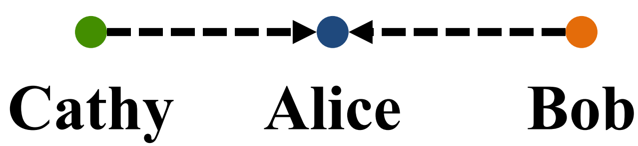
- Allows multiple users to coexist and transmit simultaneously with **no interference**

Representing bits as binary levels

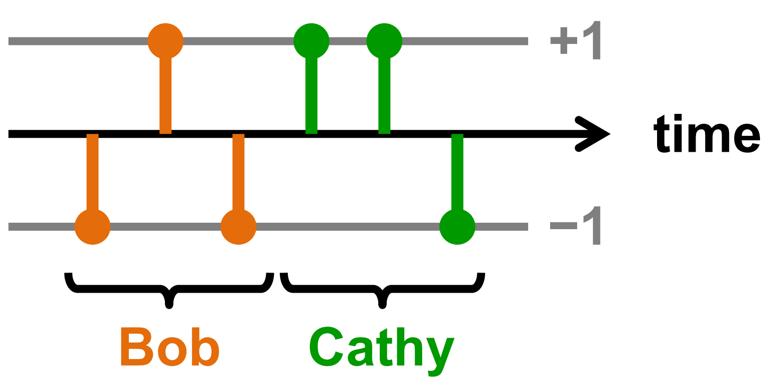
- Let's represent bits with two (binary) **levels** as follows:

  0 bit ←→ +1 level   1 bit ←→ −1 level

- **Scenario: Alice** receives data from **Bob** and **Cathy:**

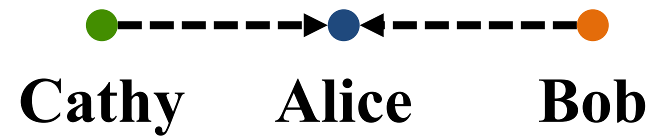


  – **TDMA *e.g.*: Bob** sends bits **`101`**, **Cathy** sends **`001`:**



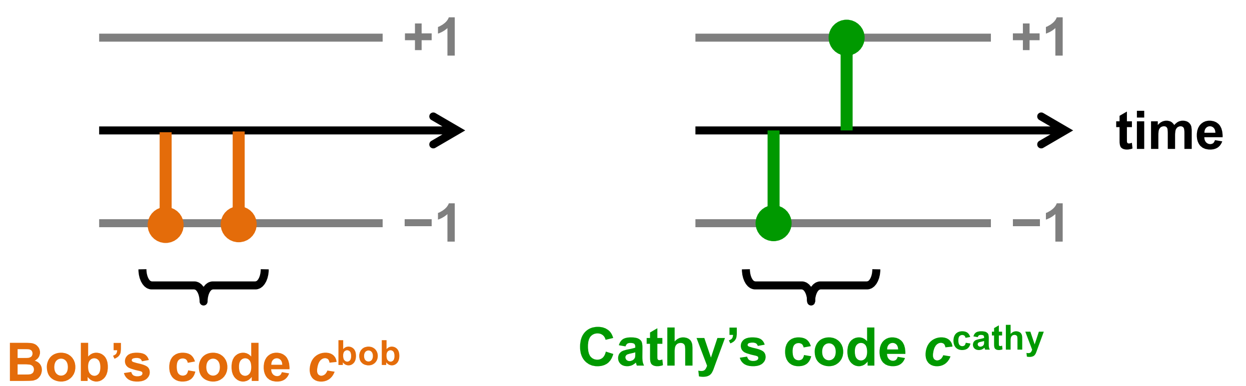
TDMA timeslots:

CDMA: User codes

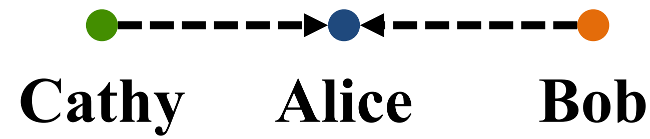


- Assign each user a unique binary sequence of bits: ***code***
  - Call each code bit a ***chip*** (convention)
  - Call the code length ***M***

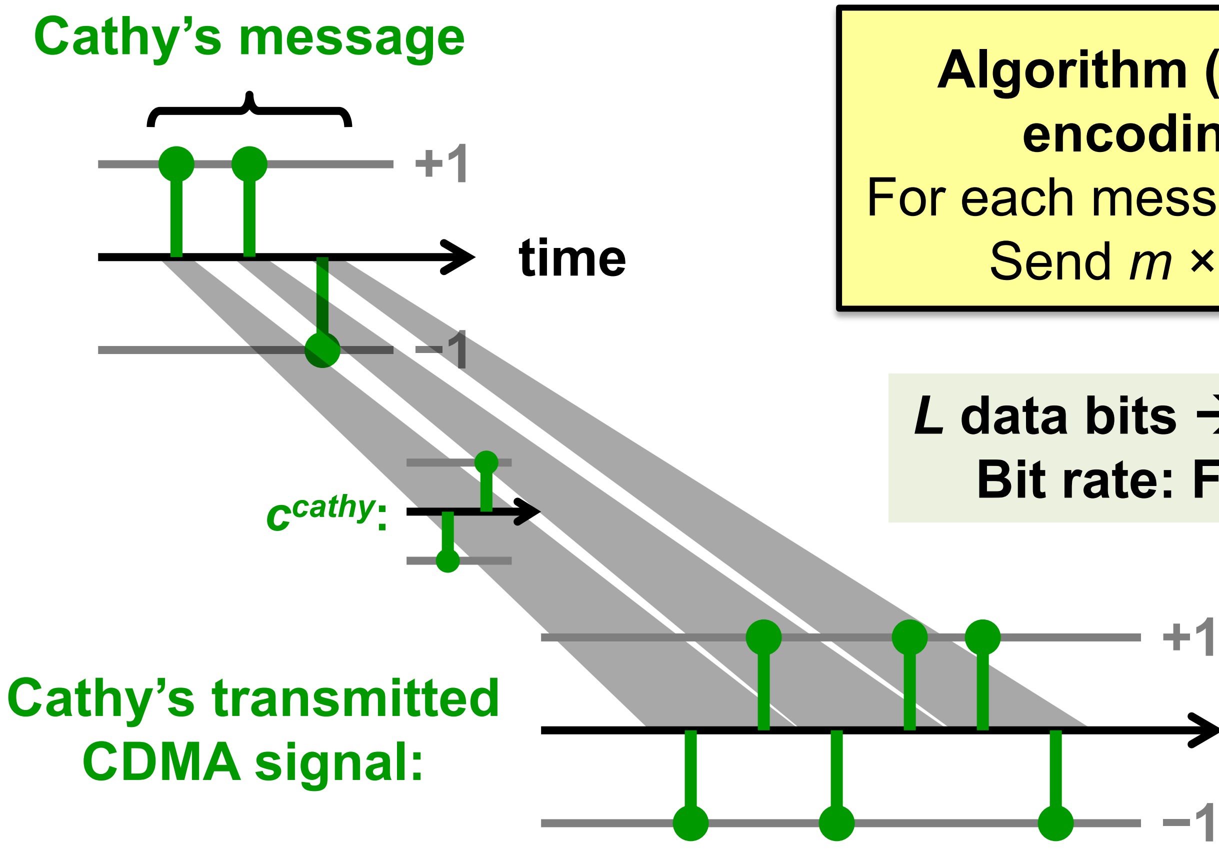
- **CDMA example:**



CDMA: Cathy Sending



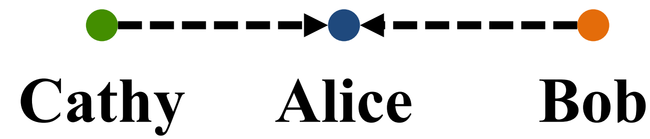
- Suppose Cathy alone sends message bits **`001`**:



Algorithm (CDMA encoding):
For each message bit *m*:
Send $m \times c^{user}$

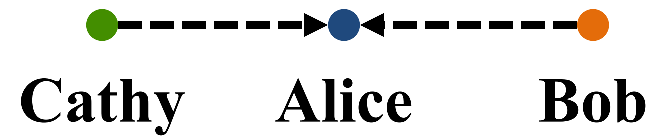
L data bits → $M \times L$ CDMA chips
Bit rate: Factor of M slower

CDMA: Assumptions

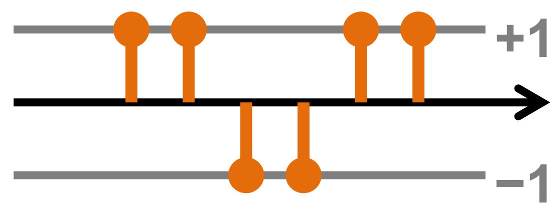


- Let's assume we have a way of:
  - Synchronizing **Cathy's** and **Bob's** **data bits** in time
  - Synchronizing **Cathy's** and **Bob's** **CDMA chips** in time
  - Estimating and correcting the **effect of the wireless channel** between **Cathy** and **Bob** to **Alice**

What Alice Hears



Bob's transmitted CDMA signal:



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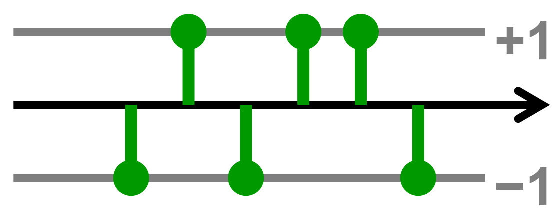
Cathy's transmitted CDMA signal:



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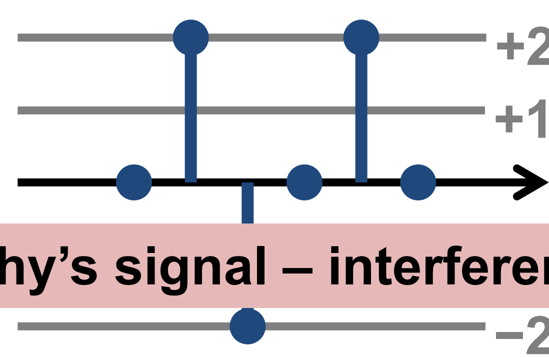
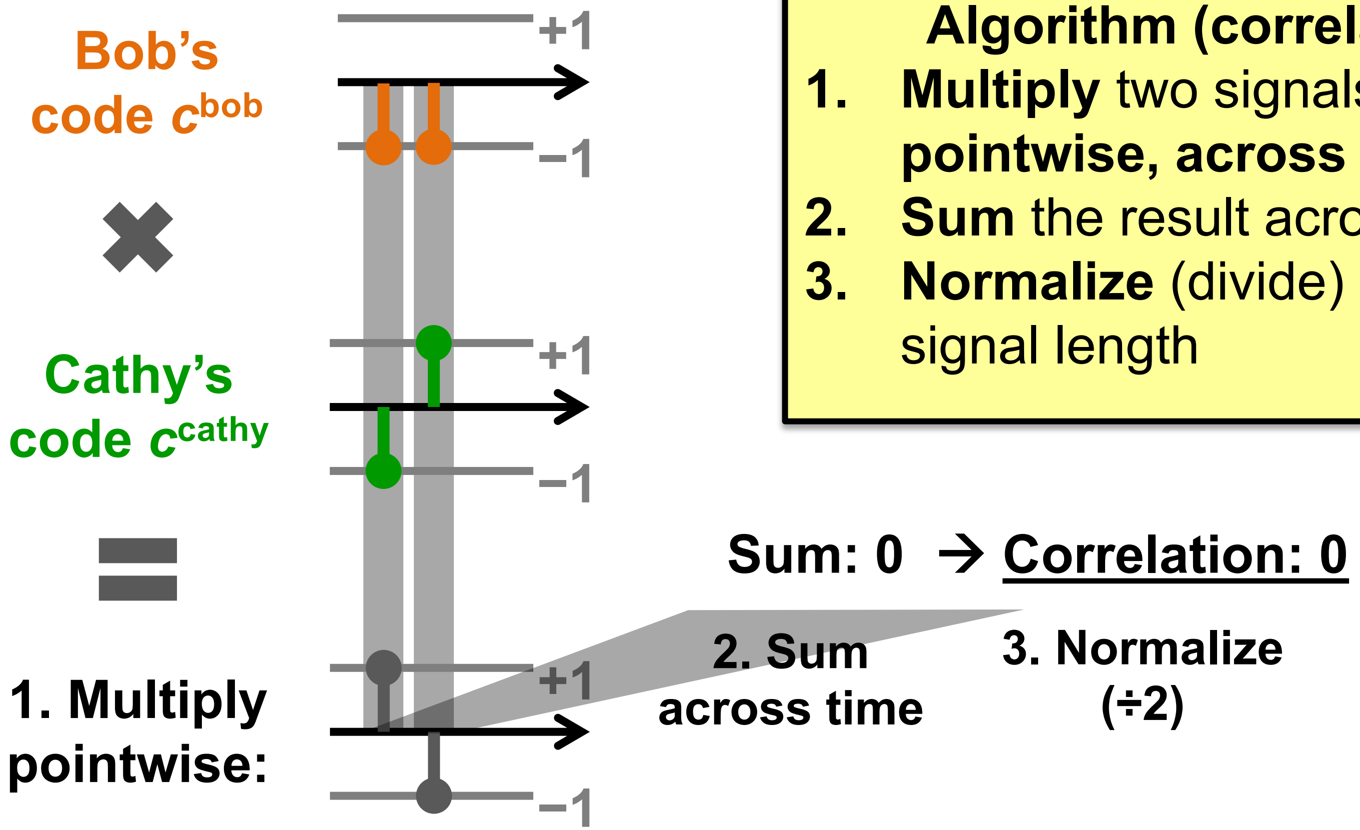
What Alice hears:



Result: Neither Bob nor Cathy's signal – interference!

Tool: Correlation



Algorithm (correlation):

1. **Multiply** two signals **pointwise, across time**
2. **Sum** the result across time
3. **Normalize** (divide) by the signal length

Tool: Correlation

Cathy's code c^{cathy}

✖

Cathy's code c^{cathy}

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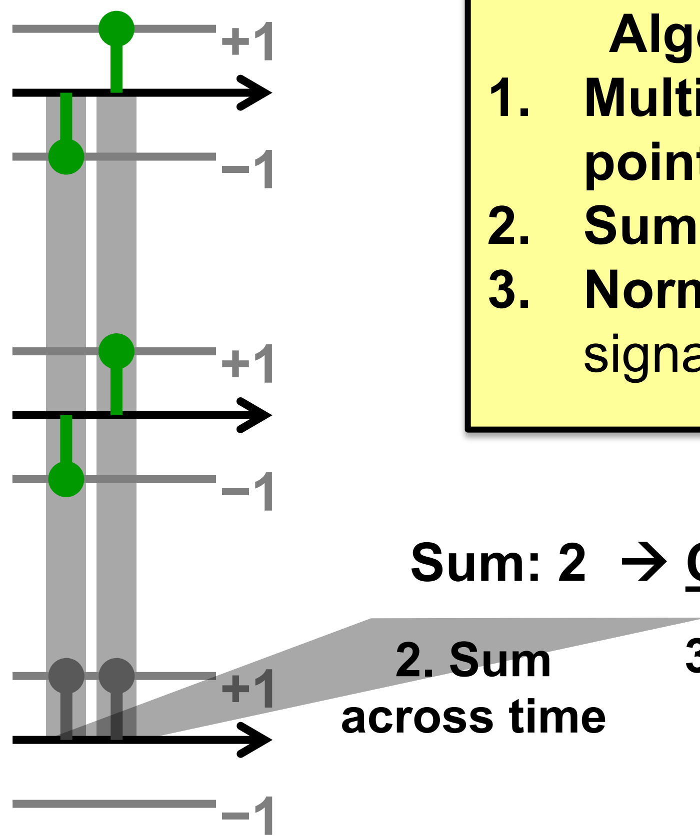
1. Multiply pointwise:



Algorithm (correlation):

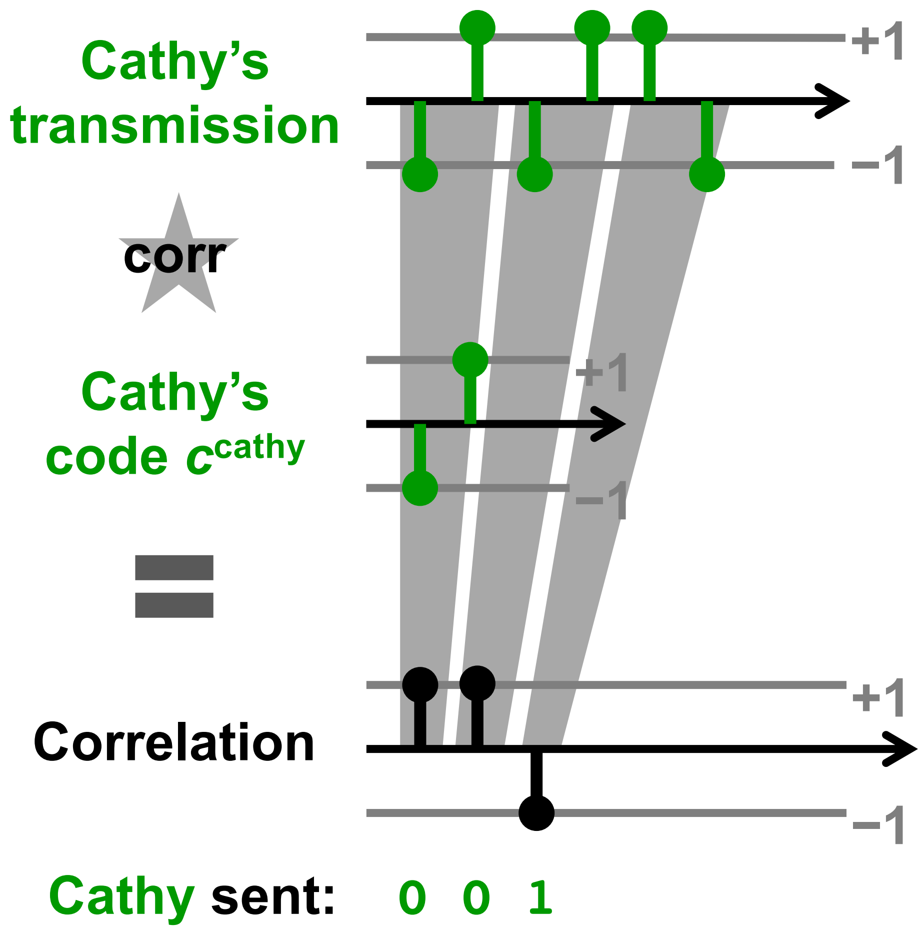
1. **Multiply** two signals **pointwise, across time**
2. **Sum** the result across time
3. **Normalize** (divide) by the signal length

Sum: 2 → <u>Correlation: 1</u>

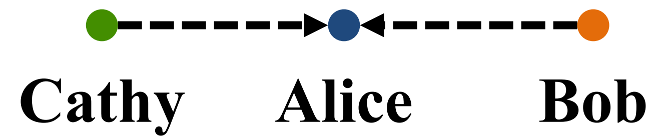
2. Sum across time

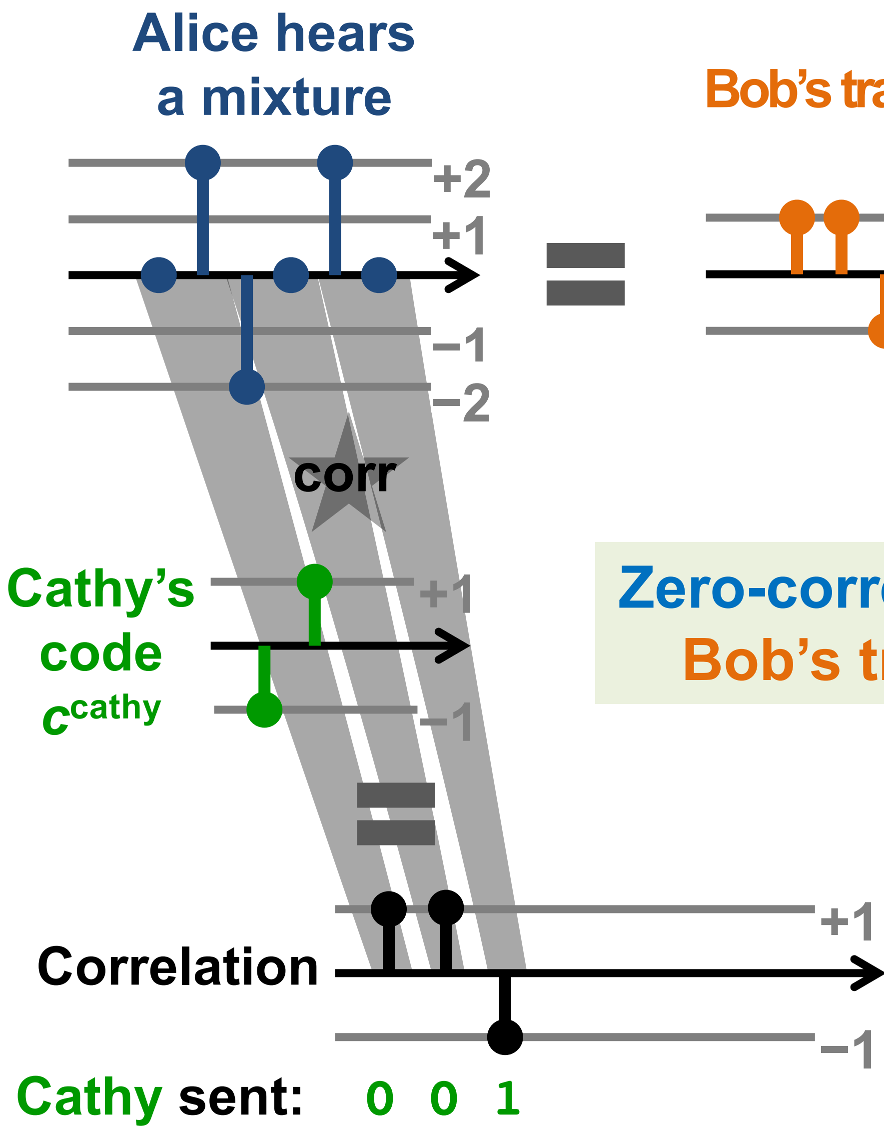
3. Normalize (÷2)

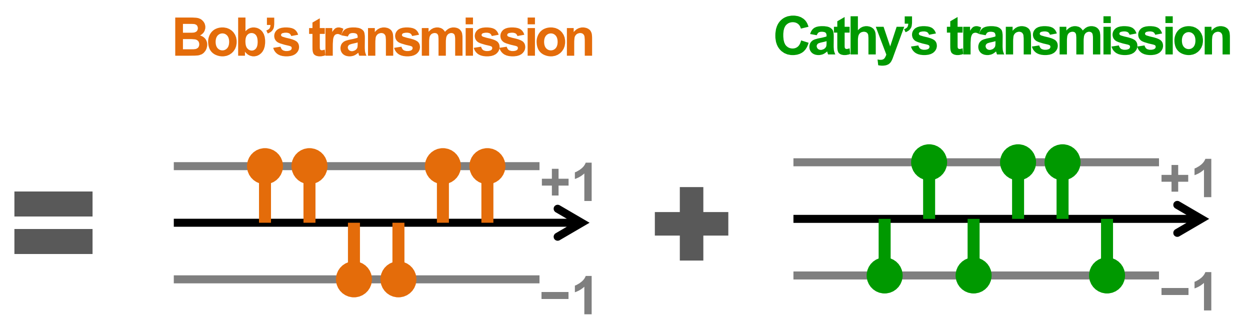
Correlating Cathy's Code with Cathy's CDMA transmission



Listening to Cathy







Zero-correlation with Bob's code cancels Bob's transmission from the mixture

CDMA: Conclusions

- Communicate **collision-free** over the **same time and same frequency**

- **Tradeoff: Lowered the bit rate**

- ***Was it a good tradeoff?***

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Idea: Use a single, shared channel

- Spread transmission across whole 100 MHz of spectrum
  - **Remove constraints** assoc. w/one channel per user
  - **Robust to multi-path fading**
    - Some frequencies likely to arrive intact
  - **Supports peer-to-peer communication**

- **Collisions:** Receiver must hear ≤1 strong transmission at a time

- So adopt **deference** from Ethernet
  - **Listen (*carrier sense*, CS)** before sending, **defer** to ongoing

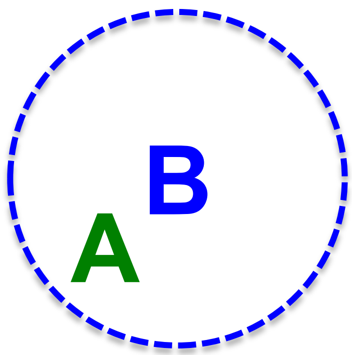
Concurrency versus Taking Turns

- **Far-apart** links should **send concurrently** (***spatial reuse***)

- Nearby links should **take turns:**

When Does CS Work Well?

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

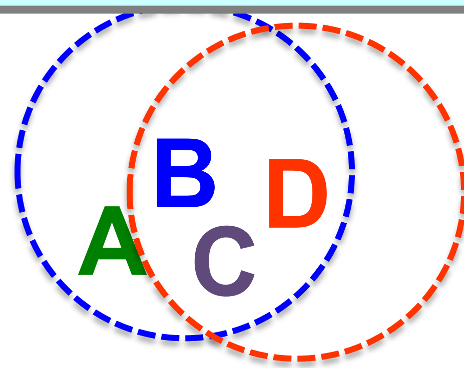


B transmits to A, while D transmits to C.

When Does CS Work Well?

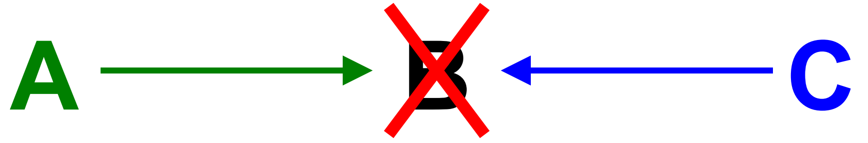
- **Both transmitters can carrier sense each other**
  - Carrier sense uses **thresholded correlation** value (like CDMA) to determine if medium occupied

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!

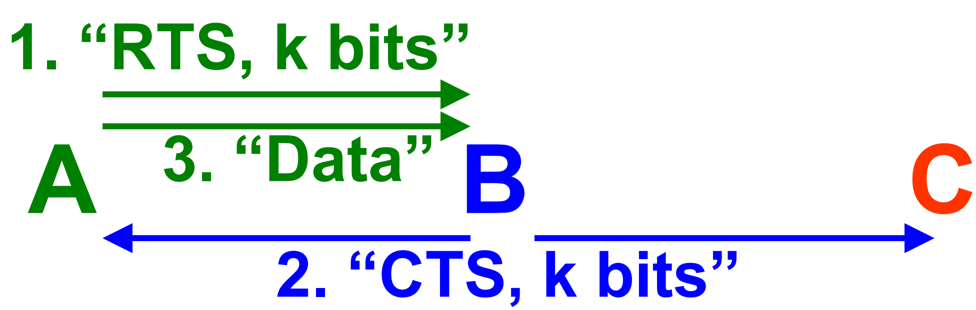
- **Key insight:** Collisions are spatially **located** at **receiver**

Exposed Terminal Problem

- If C transmits, does it cause a collision at A? No!
  - **Yet C cannot transmit while B transmits to A**
- **Same insight: Collisions spatially located at receiver**

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) with message length ***k***
  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**

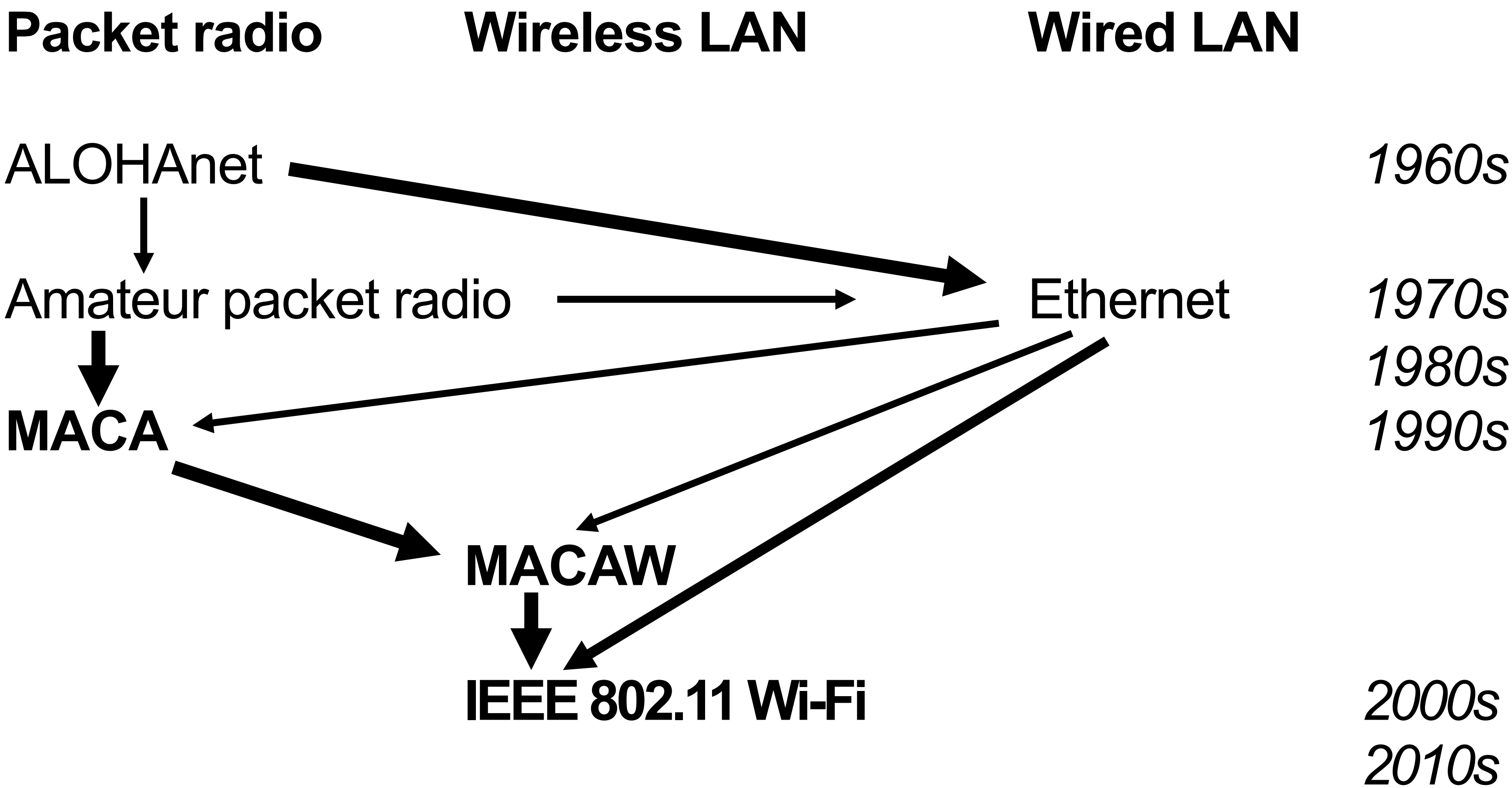
Deference to RTS, but not CS

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

Contention-Based Protocols: Timeline

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

Contention-Based Protocols: Timeline



Final Thoughts

- Contention-based protocols are widely used
  - Less administrative overhead, no planning a priori

- Provisioned protocols can be much more efficient
  - Nowadays we see a mixture
    - Contention-based **to set up** the provisioning