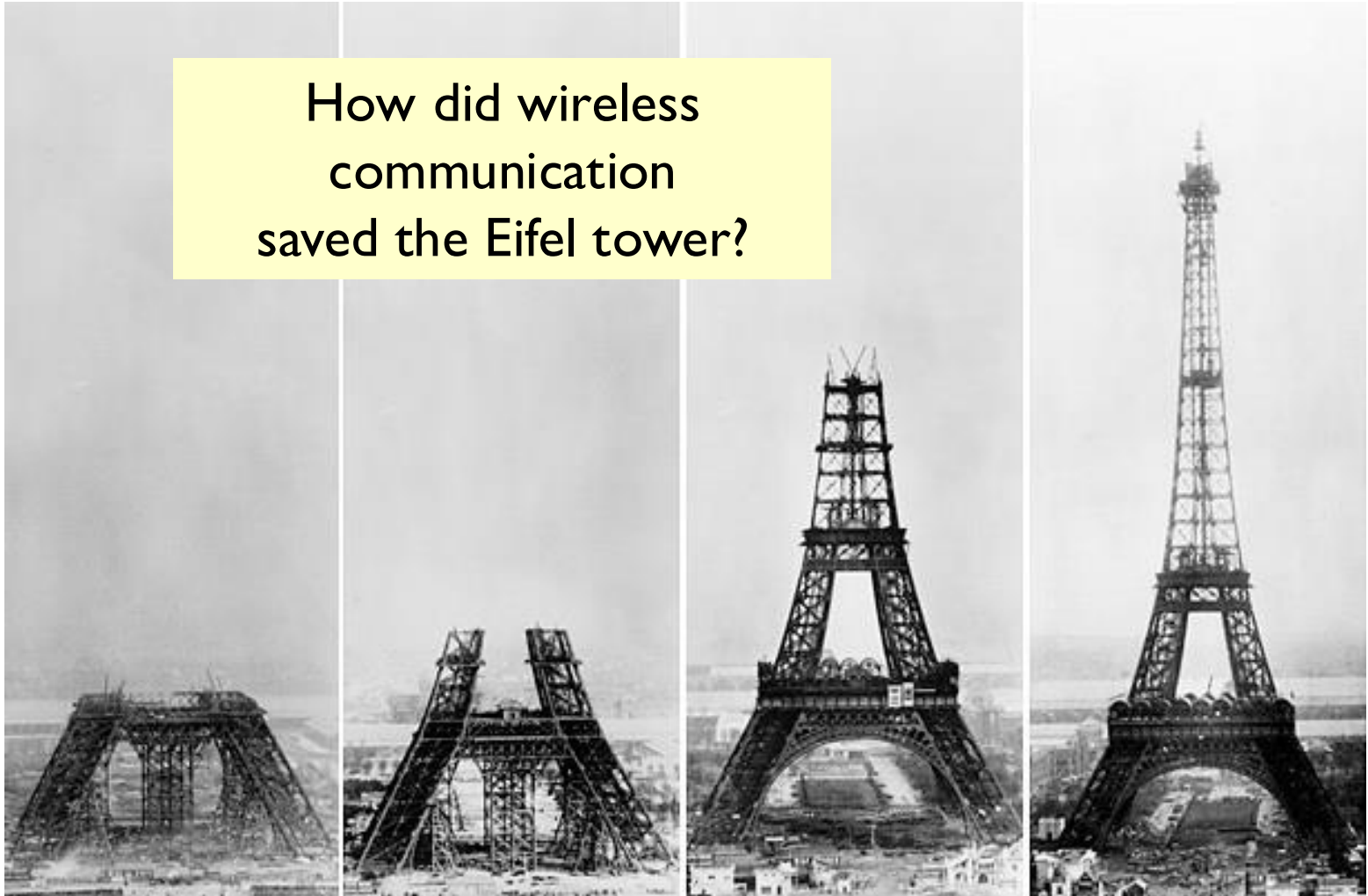


CS/ECE 439: Wireless Networking

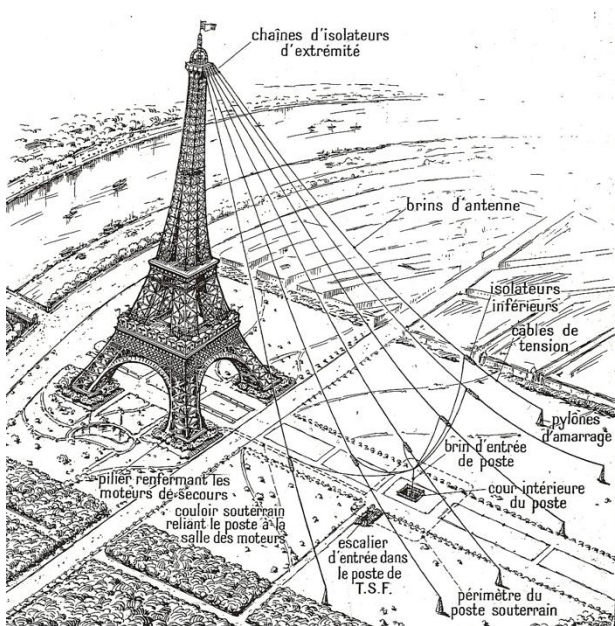
Wireless Challenges

The Power of Radio

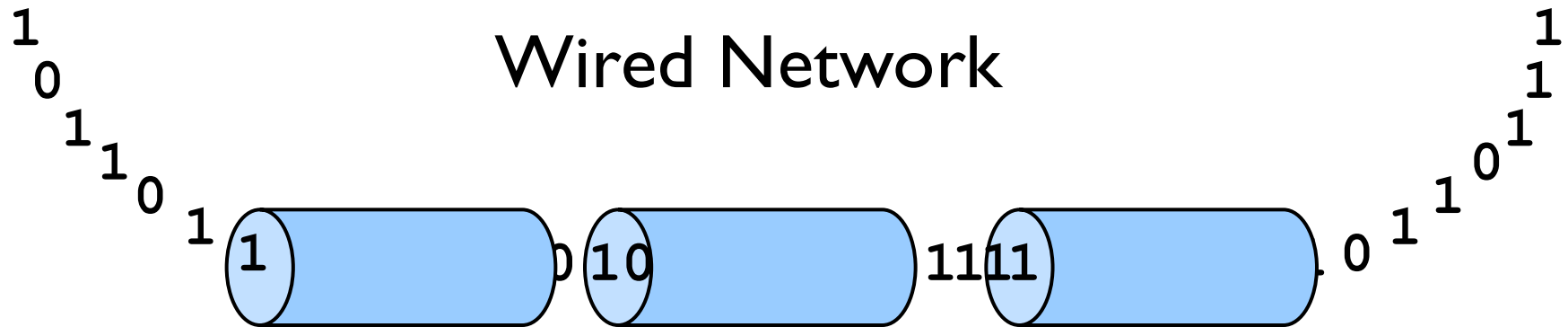
How did wireless
communication
saved the Eifel tower?



The Power of Radio



Why is wired networking challenging?

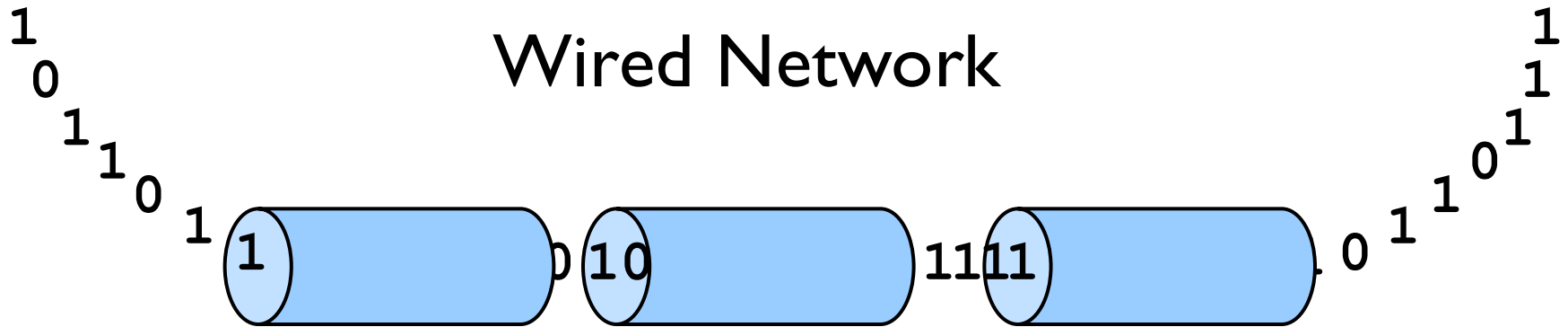


- ▶ Speed of light
- ▶ Shared infrastructure
- ▶ Things break
- ▶ Dynamic range
- ▶ Security

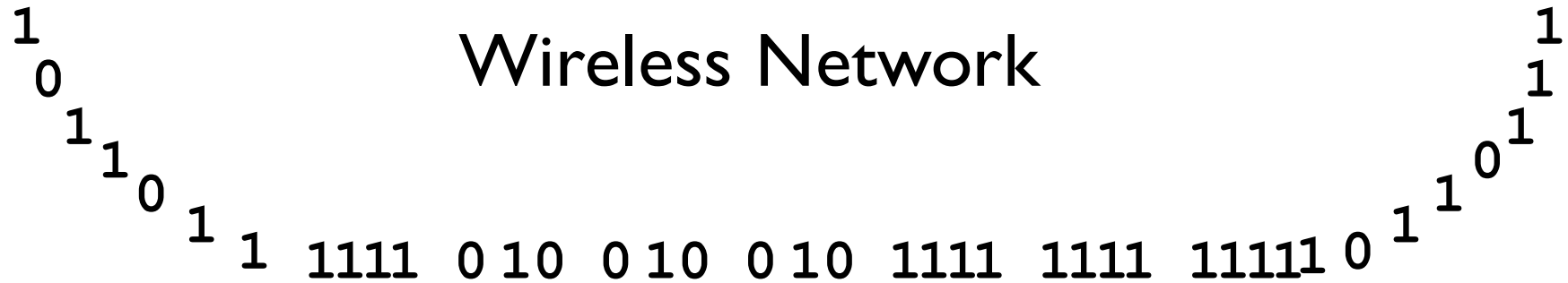
Getting the data through
the pipes

Why is wireless networking challenging?

Wired Network



Wireless Network



Same problems, but the
pipes are gone!

Why use wireless?

There are no wires!

Several significant advantages

- ▶ No need to install and maintain wires
 - ▶ Reduces cost – important in offices, hotels, ...
 - ▶ Simplifies deployment – important in homes, hotspots, ...
- ▶ Supports mobile users
 - ▶ Move around office, campus, city, ... - users get hooked
 - ▶ Remote control devices (TV, garage door, ..)
 - ▶ Cordless phones, cell phones, ..
 - ▶ WiFi, GPRS, WiMax, ...



What's so hard about wireless?

There are no wires!

- ▶ **Wired networks**
 - ▶ Links are constant, reliable and physically isolated
- ▶ **Wireless networks**
 - ▶ Links are variable, error-prone and share the ether with each other and other external, uncontrolled sources

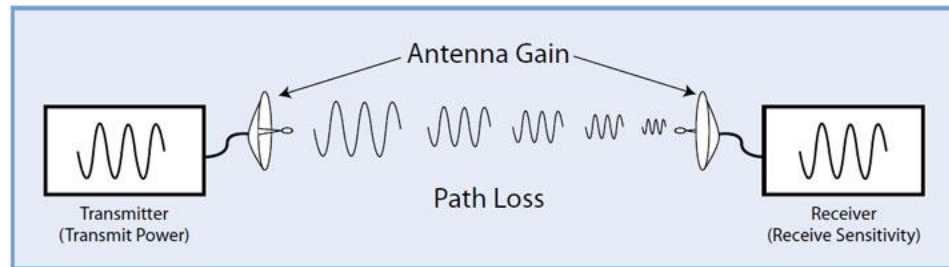


Challenges of wireless

- ▶ Path loss
- ▶ Multipath propagation
- ▶ Internal interference (from other users)
- ▶ External interference

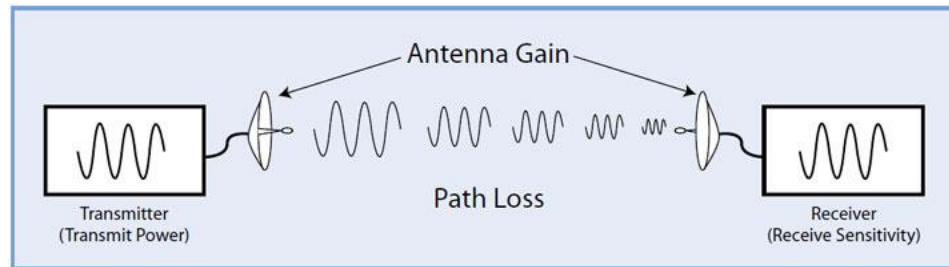


Path Loss



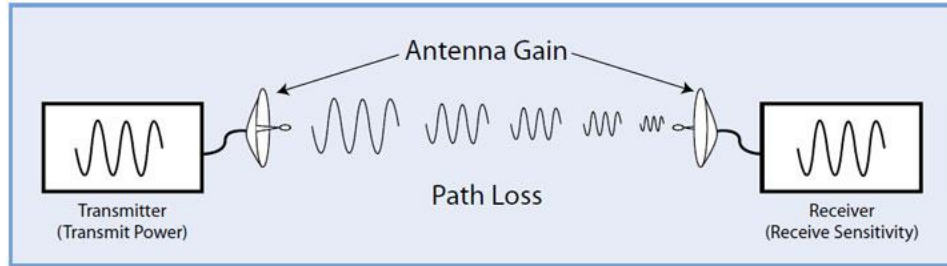
- ▶ Signal attenuation as a function of distance
 - ▶ Signal-to-noise ratio decreases, make signal unrecoverable
 - ▶ SNR — Signal Power/Noise Power
 - ▶ SINR – Signal-to-Interference-Noise-Ratio
- ▶ Signal power attenuates by about $\sim r^2$ factor for omnidirectional antennas in free space
 - ▶ r is the distance between the sender and the receiver

Path Loss



- ▶ The exponent in the factor is dependent on antenna placement
 - ▶ Closer to 2 for well-aimed directional antennas
 - ▶ A focused beam avoids extra multipath loss, so attenuation stays closer to ideal free space
 - ▶ Exponent > 2 when antennas are placed on the ground
 - ▶ Signal bounces off the ground and reduces the power of the signal
- ▶ At very high frequencies (mmWave, 24+ GHz), path loss and blockage become severe enough that propagation itself becomes the central challenge

Attenuation and Errors



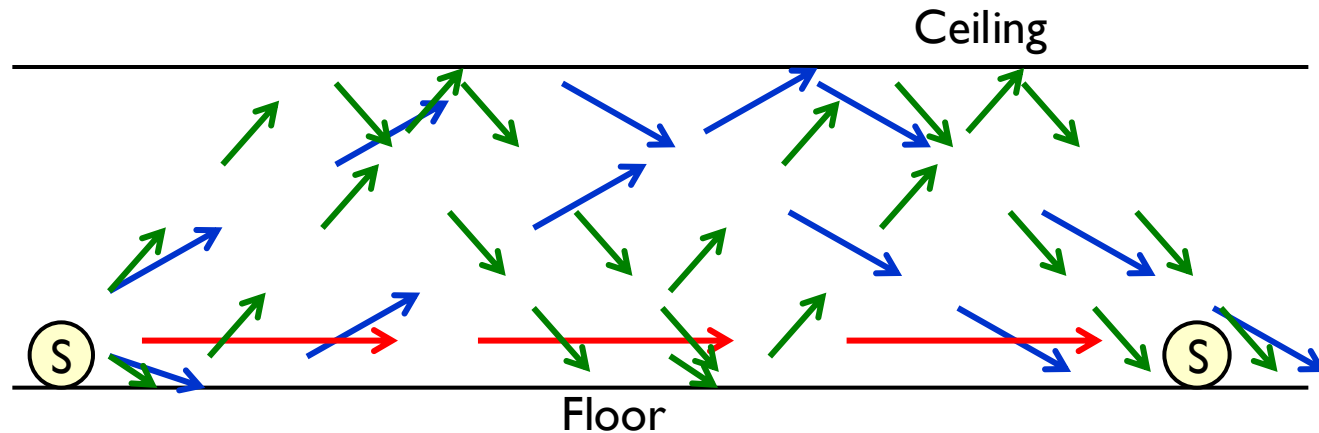
- ▶ **Wired networks**

- ▶ Error rate = 10^{-10}

- ▶ **Wireless networks**

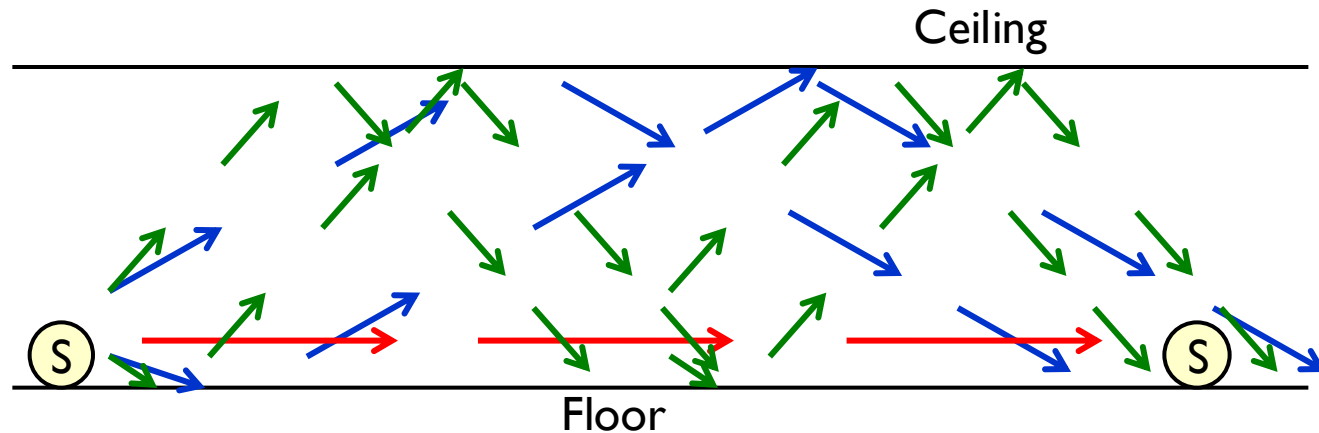
- ▶ Not even close!
 - ▶ Signal attenuates with distance and is affected by noise
 - ▶ Probability of a successful reception depends on $\text{SINR} = \frac{S}{I+N}$
 - ▶ Modulation and coding schemes introduce redundancy to allow for decoding

Multipath Effects



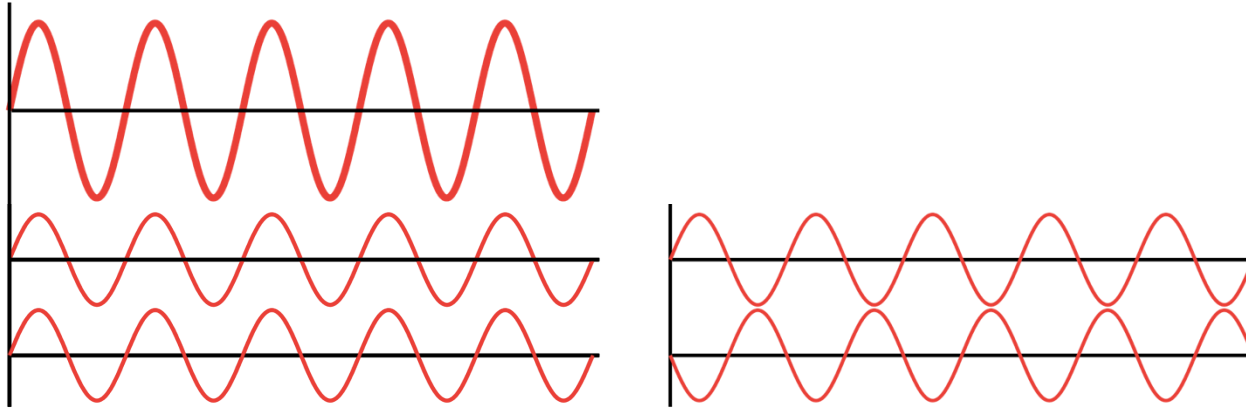
- ▶ Signal reflects off surfaces, effectively causing self-interference
- ▶ What happens to the signals that take different paths?
 - ▶ Different distance = different attenuation = different signal strength

Multipath Effects



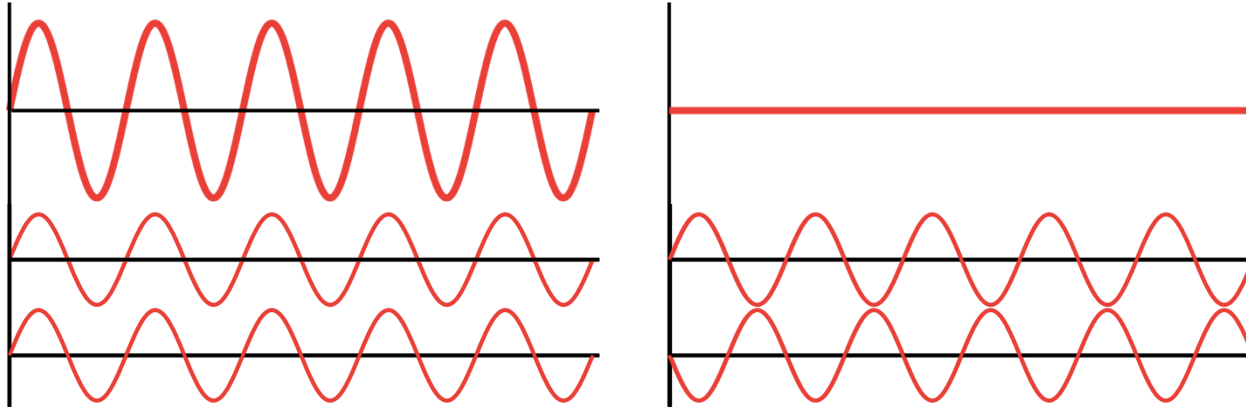
- ▶ Signal reflects off surfaces, effectively causing self-interference
- ▶ What happens to the phase of the different signals?
 - ▶ Different distance = different travel time = different place in received signal

Multipath Effects



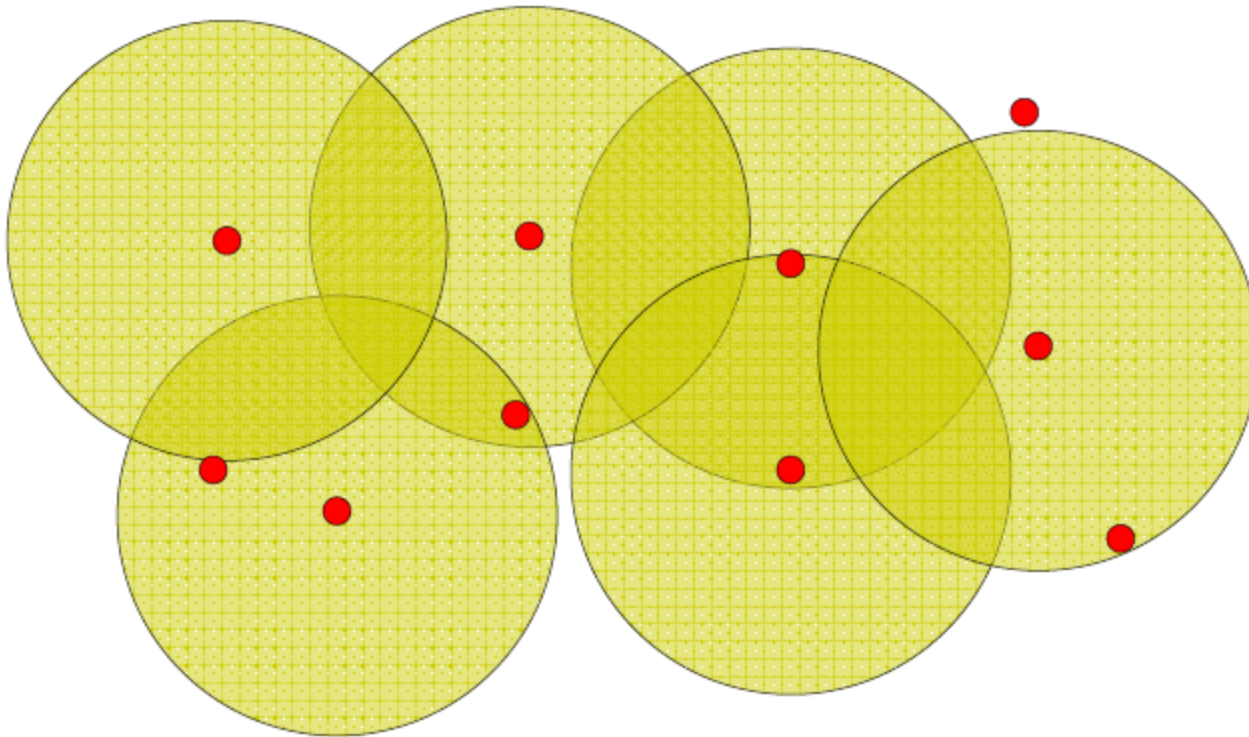
- ▶ What if signals are still in phase at the receiver?
 - ▶ In phase signals enhance the received signal strength!

Multipath Effects

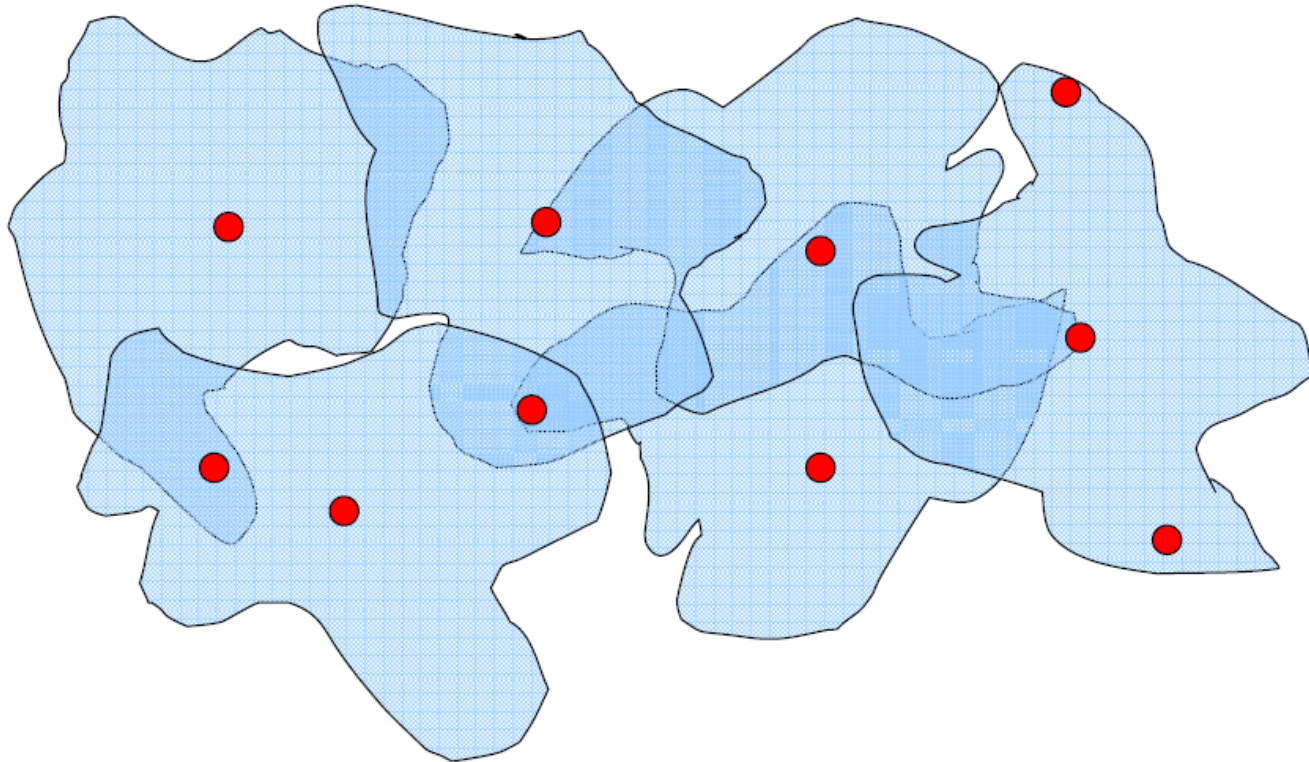


- ▶ What if signals are out of phase?
 - ▶ Orthogonal signals cancel each other and nothing is received!

What is a Wireless “Link”, really?

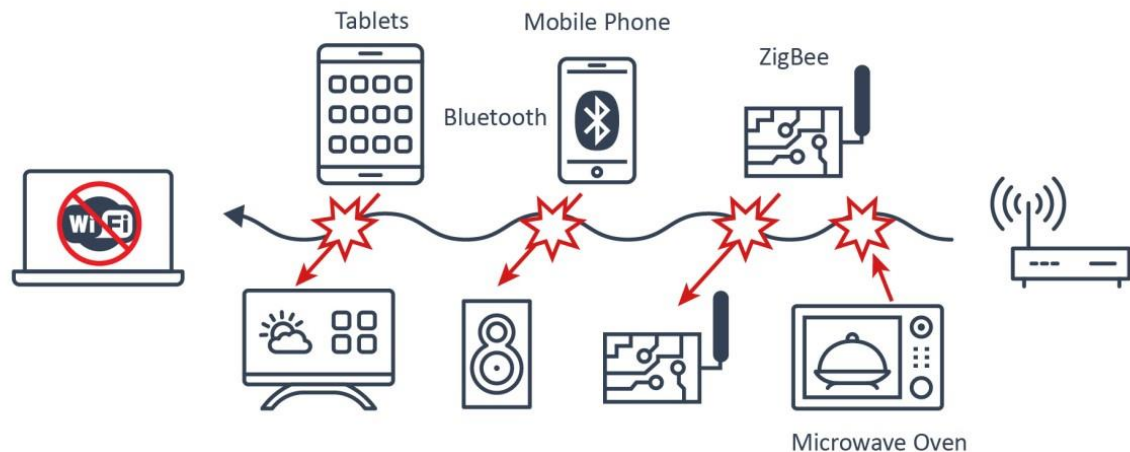


What is a Wireless “Link”, really?



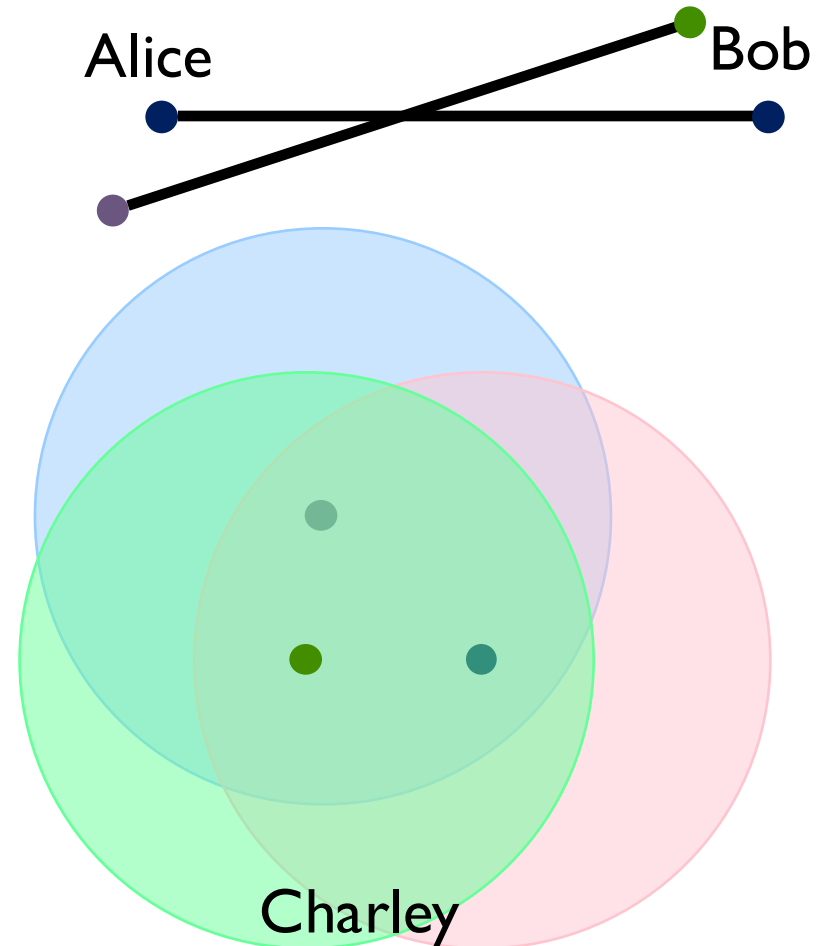
Links – Wireless Interference

- ▶ **Internal interference (from other users)**
 - ▶ Hosts within range of each other collide with one another's transmission
- ▶ **External interference**
 - ▶ Microwave is turned on and blocks your signal



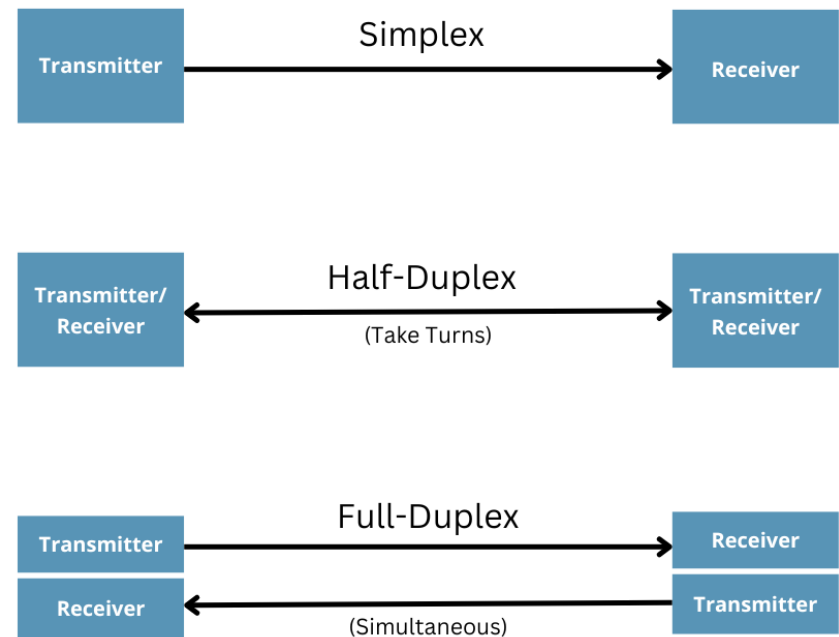
Interference

- ▶ Noise is naturally present in the environment from many sources
- ▶ Interference can be from other users or from malicious sources
- ▶ Impacts the throughput users can achieve



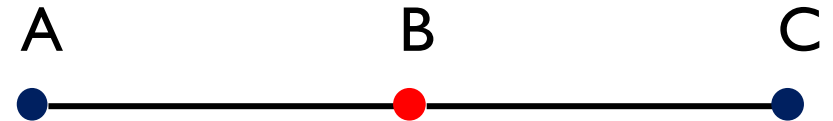
Wireless is a shared medium

- ▶ Transmitters broadcast
- ▶ Devices can operate either in transmit or receive mode
 - ▶ Current research is trying to overcome this limitation
- ▶ How do you coordinate access to the medium?



The Hidden Terminal Problem

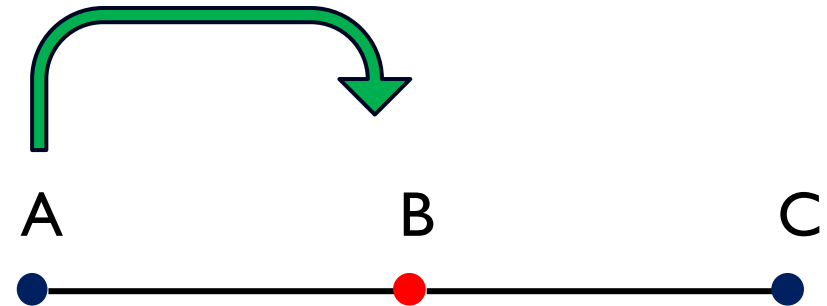
- ▶ B can hear both A and C
- ▶ A and C cannot hear each other



A and C are each in range of B, but out of range of each other

The Hidden Terminal Problem

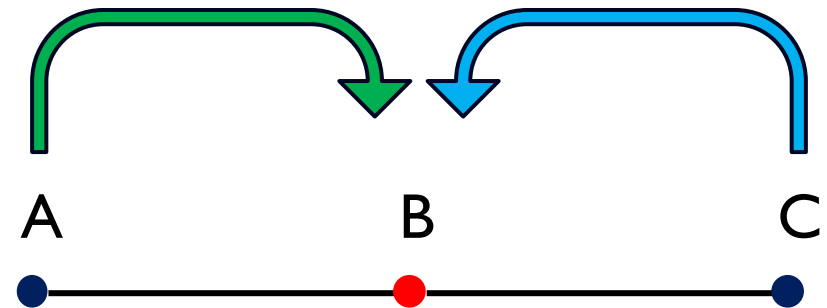
- ▶ B can hear both A and C
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- ▶ A transmits to B
 - ▶ C doesn't know A is transmitting



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The Hidden Terminal Problem

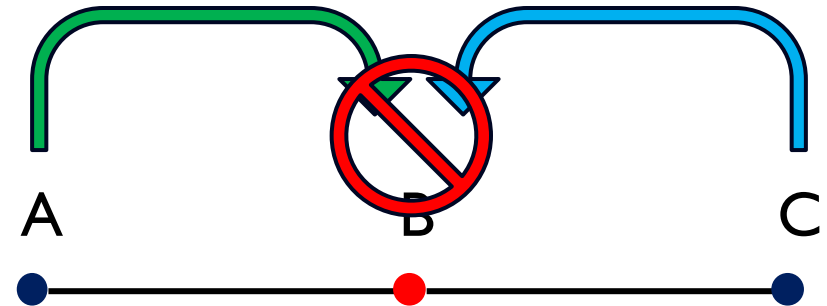
- ▶ B can hear both A and C
- ▶ A and C cannot hear each other
- ▶ A transmits to B
 - ▶ C doesn't know A is transmitting
- ▶ C transmits to B
 - ▶ Collision at B



A and C are each in range of B, but out of range of each other

The Hidden Terminal Problem

- ▶ B can hear both A and C
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- ▶ C transmits to B
 - ▶ Collision at B



A and C are each in range of B, but out of range of each other

Wireless Bit Errors

- ▶ The lower the SNR (Signal/Noise) the higher the Bit Error Rate (BER)
- ▶ How can we deal with this?
 - ▶ Make the signal stronger
- ▶ Why is this not always a good idea?
 - ▶ Increased signal strength requires more power
 - ▶ Increases the interference range of the sender, so you interfere with more nodes around you
- ▶ Error correction can correct **some** problems



Spread Spectrum

- ▶ Spreads the signal over a wider frequency band than required
 - ▶ Originally designed to thwart jamming
 - ▶ Two flavors: Direct Sequence (DSSS) and Frequency-Hopped (FHSS)
 - ▶ Original 802.11 used both: DSSS (83 MHz in 2.4 GHz) and FHSS (80 x 1 MHz sub-bands)

Communication Characteristics

- ▶ **Rate**

- ▶ Defines the communication speeds

- ▶ **Frequency**

- ▶ Defines the behavior in the physical environment

- ▶ **Range**

- ▶ Defines the physical communication area

- ▶ **Power**

- ▶ Defines the cost in terms of energy



Communication Characteristics

▶ Rate

- ▶ Defines the communication speeds

▶ Channel Bandwidth

- ▶ Defined by the specifications of the technology

▶ Available Bandwidth

- ▶ Defined by the current use of the communication channel

- Channel competition – MAC layer

- Bandwidth competition – Transport layer



Communication Characteristics

- ▶ **Frequency/signal characteristics**
 - ▶ Defines the behavior in the physical environment
 - ▶ Does the signal go through walls?
 - ▶ Is the signal susceptible to multipath fading?
- ▶ **Challenge**
 - ▶ Many technologies use the same frequency



Communication Characteristics

▶ Range

- ▶ Defines the physical communication area
- ▶ May be affected by buildings, walls, people
- ▶ May be affected by distance



Communication Characteristics

▶ Power

- ▶ Defines the cost in terms of energy
- ▶ Power can be adapted to save energy
 - ▶ Inversely affects range



Communication Characteristics

- ▶ **Rate**

- ▶ Defines the communication speeds

- ▶ **Frequency**

- ▶ Defines the behavior in the physical environment

- ▶ **Range**

- ▶ Defines the physical communication area

- ▶ **Power**

- ▶ Defines the cost in terms of energy

Everything is inter-related!



Medium Access Control

- ▶ Different transmitters/receivers use:
 - ▶ Different frequencies
 - ▶ FDMA – Frequency Division Multiple Access
 - ▶ Different time slots
 - ▶ TDMA – Time Division Multiple Access
 - ▶ Different codes
 - ▶ CDMA – Code Division Multiple Access
 - ▶ Randomly access the medium
 - ▶ CSMA/CA – Carrier Sense Multiple Access/Collision Avoidance
- ▶ Main goal: avoid collisions while making efficient use of the medium



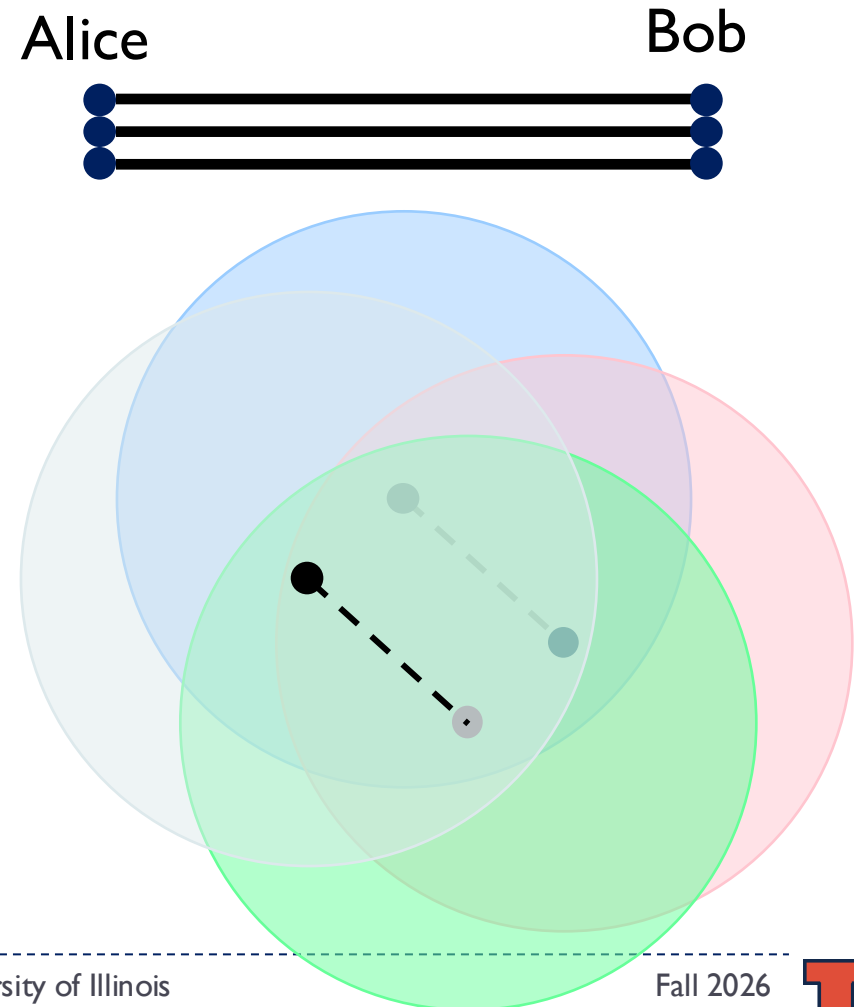
Wireless Losses

- ▶ Can be due to
 - ▶ Signal errors that lead to a packet that cannot be decoded
- OR
- ▶ Corruption of the transmitted information due to collisions, $SINR = S/(N+I)$ too low
- ▶ Understanding the reason behind a loss requires cross-layer information
 - ▶ Is it PHY?
 - ▶ Is it MAC?
- ▶ Information required by more than one layer



How Do We Increase Network Capacity?

- ▶ Easy to do in wired networks: simply add wires
 - ▶ Fiber is especially attractive
- ▶ Adding wireless “links” increases interference.
 - ▶ Frequency reuse can help ... subject to spatial limitations
 - ▶ Or use different frequencies ... subject to frequency limitations
- ▶ The capacity of the wireless network is fundamentally limited



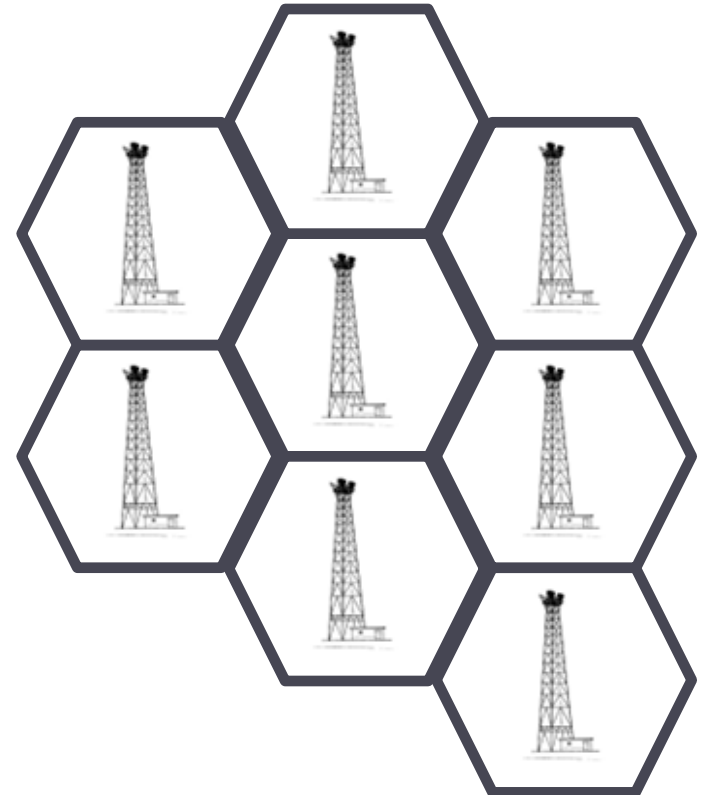
Cellular architecture

- ▶ **Deploy cells**

- ▶ Reuse frequencies across non-adjacent cells (details in PHY lecture)

- ▶ **Challenge**

- ▶ Provide consistent service even at the edge of the cell
 - ▶ Deal with intensity given the capacity of the cell



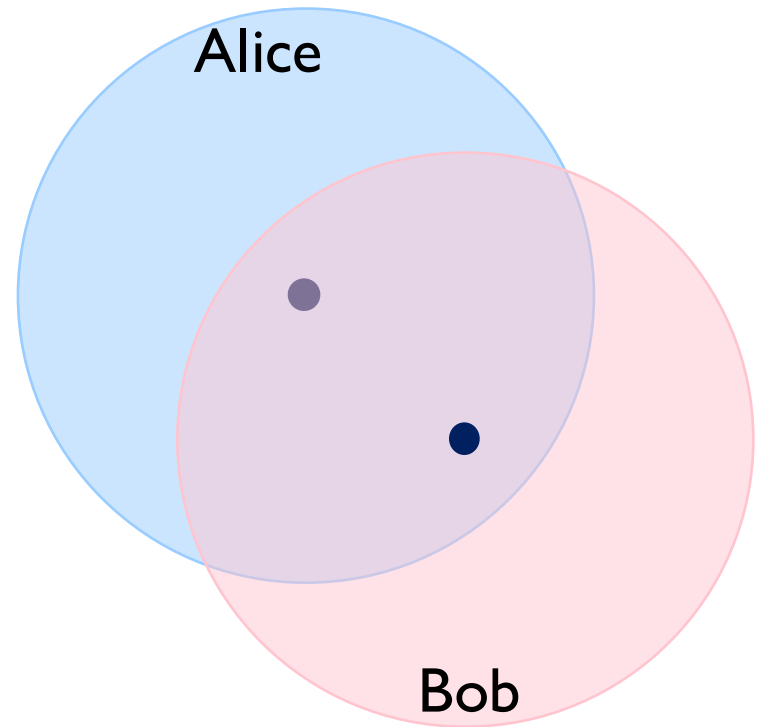
Wi-Fi architecture

- ▶ Could be chaotic or managed
- ▶ Limited spectrum – service guarantees hard to make
- ▶ Channel assignment, power control



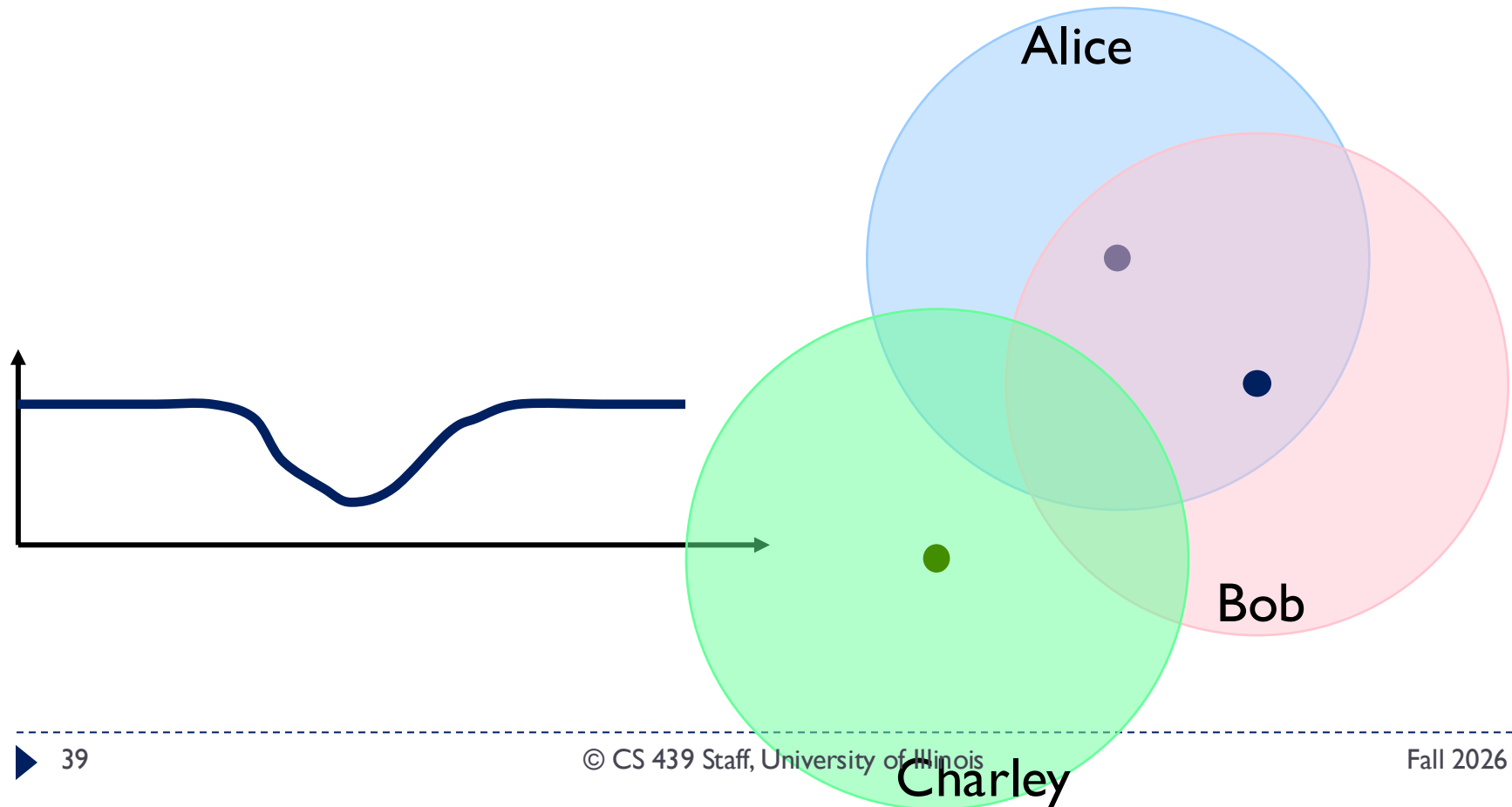
Mobility Affects the Link Throughput

- ▶ Quality of the transmission depends on distance and other factors
 - ▶ Covered later in the course
- ▶ Affects the throughput mobile users achieve
- ▶ Worst case is no connectivity!



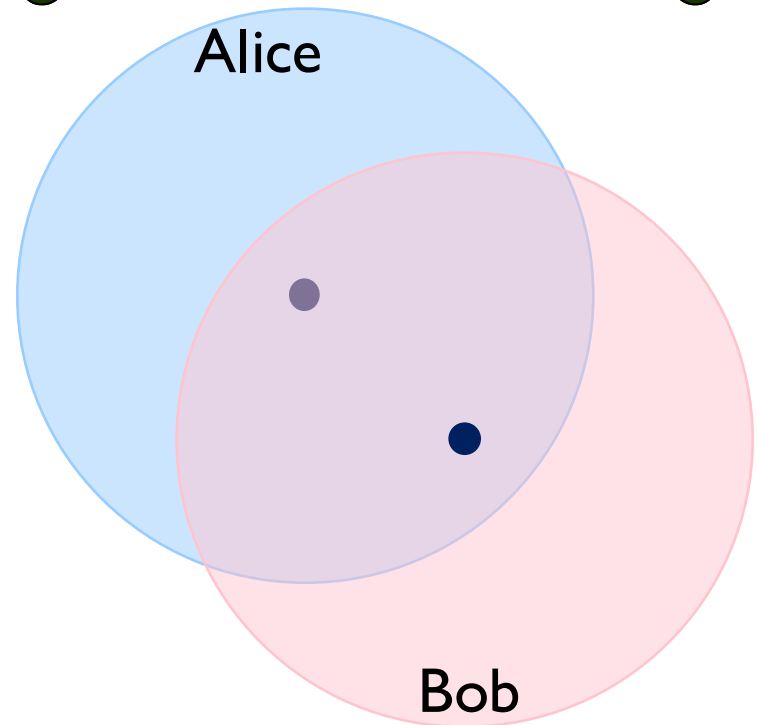
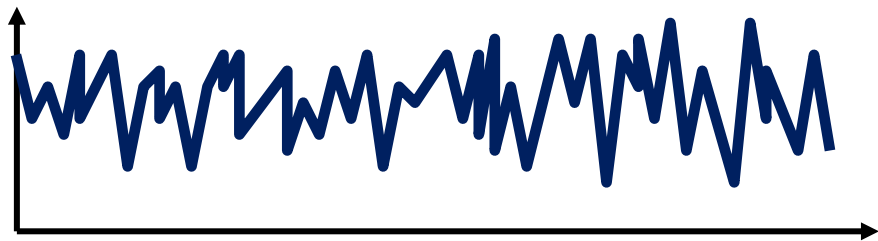
Mobility is an Issue even for Stationary Users

- ▶ Mobile people and devices affect the transmission channel of stationary nodes



And It Gets Worse ...

- ▶ The impact of mobility on transmission can be complex
- ▶ Mobility also affects addressing and routing



Wireless environments: a very naïve model

- ▶ The world is flat
- ▶ A radio's transmission area is circular
 - ▶ Signal strength is a simple function of distance
- ▶ All radios have equal range
- ▶ If I can hear you, you can hear me (symmetry)
- ▶ If I can hear you at all, I can hear you perfectly
- ▶ Not all that different from wires, with broadcast communication added

