Measuring the Relative Strength of Two Signals

- P_1 (V_1): the power (voltage) of signal 1
- P_2 (V_2): the power (voltage) of signal 2
- dB$= 10\log_{10}\frac{P_2}{P_1}$
- Power $\propto$ voltage^2
- dB$= 20\log_{10}\frac{V_2}{V_1}$

Examples of dB

- Suppose a signal travels through a transmission medium and its power is reduced to one-half
- $P_2 = 0.5P_1$
- Attenuation $= 10\log_{10}\frac{P_2}{P_1} = 10\log_{10}0.5 \approx -3$ dB

In other words, a loss of 3 dB is equivalent to losing one-half the power

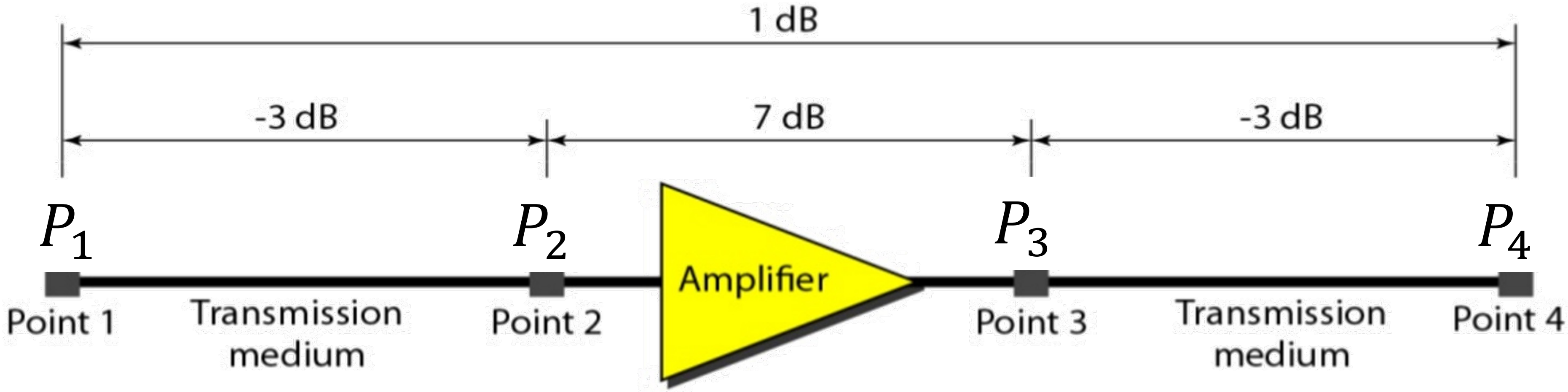
- 0 dB = no change

Examples of dB

- dB can also be used to represent amplification (gain of power)
- A signal travels through an amplifier, and its power is increased 10 times
- $P_2 = 10P_1$
- Amplification $= 10\log_{10}\frac{P_2}{P_1} = 10\log_{10}10 = 10$ dB

Examples of dB

- dB can be added



$$10\log_{10}\frac{P_4}{P_1} = 10\log_{10}\left(\frac{P_4}{P_3}\times\frac{P_3}{P_2}\times\frac{P_2}{P_1}\right)$$
$$= 10\left(\log_{10}\frac{P_4}{P_3} + \log_{10}\frac{P_3}{P_2} + \log_{10}\frac{P_2}{P_1}\right)$$
$$= 10\log_{10}\frac{P_4}{P_3} + 10\log_{10}\frac{P_3}{P_2} + 10\log_{10}\frac{P_2}{P_1}$$

How to Model Attenuation? Free Space Loss

→ a hypothetical antenna which having the same radiation in all directions (i.e. uniform radiation).

- For isotropic antenna:
- $P_r = (\frac{\lambda}{4\pi d})^2 P_t = (\frac{c}{4\pi d f})^2 P_t$
- P_r: the received power (in Watt)
- P_t: the transmitted power (in Watt)
- d: the distance between the two antennas (in m)
- λ: the wavelength (in m)

(c : light speed)

How to Model Attenuation? Free Space Loss

- For isotropic antenna:
- $\left(\frac{P_t}{P_r}\right)_{dB} \approx 20\log d + 20\log f - 147.56\ dB$

Example

- Determine the isotropic free space loss at 4 GHz for the shortest path to a synchronous satellite from earth (35863 km)
- Path loss $\approx 20\log d + 20\log f - 147.56\ dB$
  $= 20\log 35863000 + 20\log(4\times10^{9}) - 147.56\ dB$

  $\approx 195.6\ dB$
- Given transmission power, how to calculate the received power?

dBm, A Unit of Power

dBm = dBmW (power level is expressed in decibels with reference to milliwatts)

- $\text{Power}_{\text{dBm}} = 10\log_{10}\frac{\text{Power}_{\text{mW}}}{1\text{mW}}$
- Example: convert -30dBm to mW
- $10\log_{10}P = -30 \Rightarrow P = 10^{-3}\text{mW}$
- Transmission power of FM radio stations: 80 dBm (100 kW)
- Transmission power of cell phones: 27 dBm (500 mW)
- Transmission power of Wi-Fi in laptops: 15dBm (32 mW)
- $\text{Power}_{\text{dBW}} = 10\log_{10}\frac{\text{Power}_{\text{W}}}{1\text{W}}$

Why dBm (dBW)?

- If the transmit power is P_t dBm (dBW) and the path loss is L dB, then what is the received power?
- Receive power $= P_t - L$ dBm (dBW)

A Real Scenario

- Transmit wireless signal from mainland to an island
- Low tide ⇒ transmission quality is better
- High tide ⇒ transmission quality is worse
- Why?

Achieving Single Channel, Full Duplex Wireless Communication

J. I. Choi, M. Jain, K. Srinivasan, P. Levis, and S. Katti

In ACM MobiCom' 10

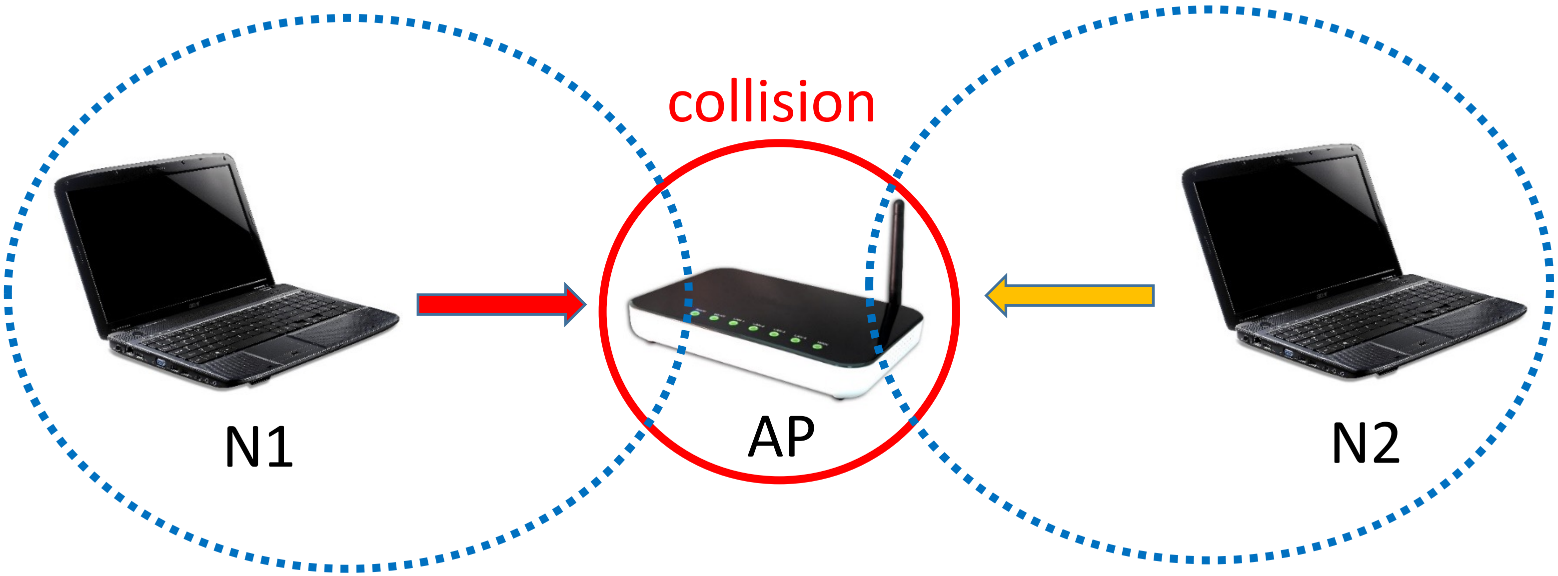
Full Duplex

- Definition
  - Both parties can communicate to the other simultaneously
- Examples
  - Telephone
- Traditional way
  - Use two channels
- Goal
  - Implement full duplex wireless communication by a single Channel

Applications

- Detecting Hidden Terminals
- Reducing Congestion with MAC Scheduling
- Routing in Multihop Networks
- Cognitive Radios

Detecting Hidden Terminals (Traditional)

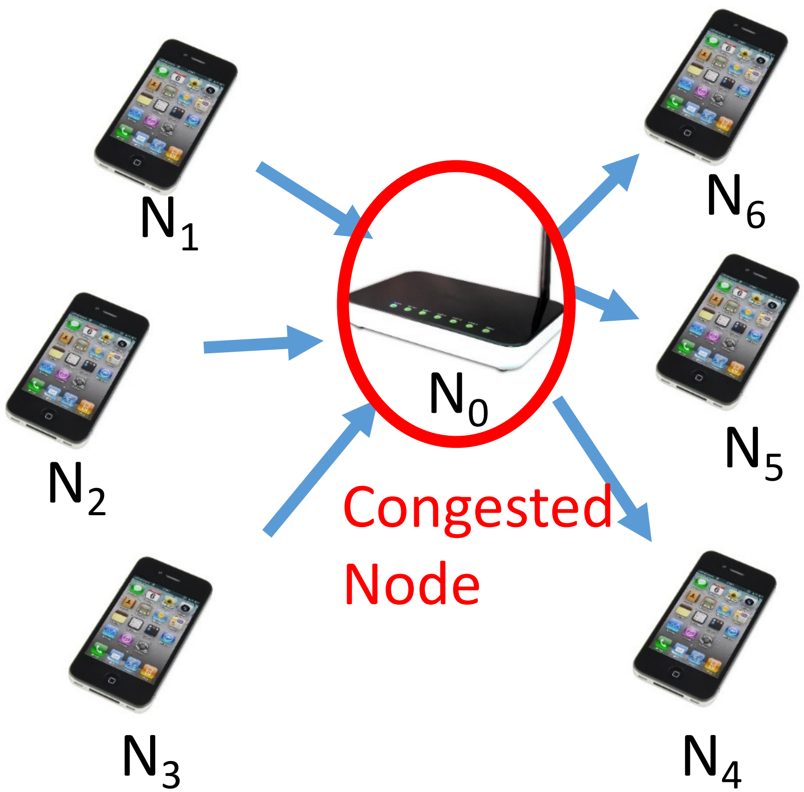


- Hidden terminal problem
  - N2 cannot hear N1's transmission to the AP
  - N2 starts to send data to the AP at the same time
  - Collision

Detecting Hidden Terminals (Full Duplex)

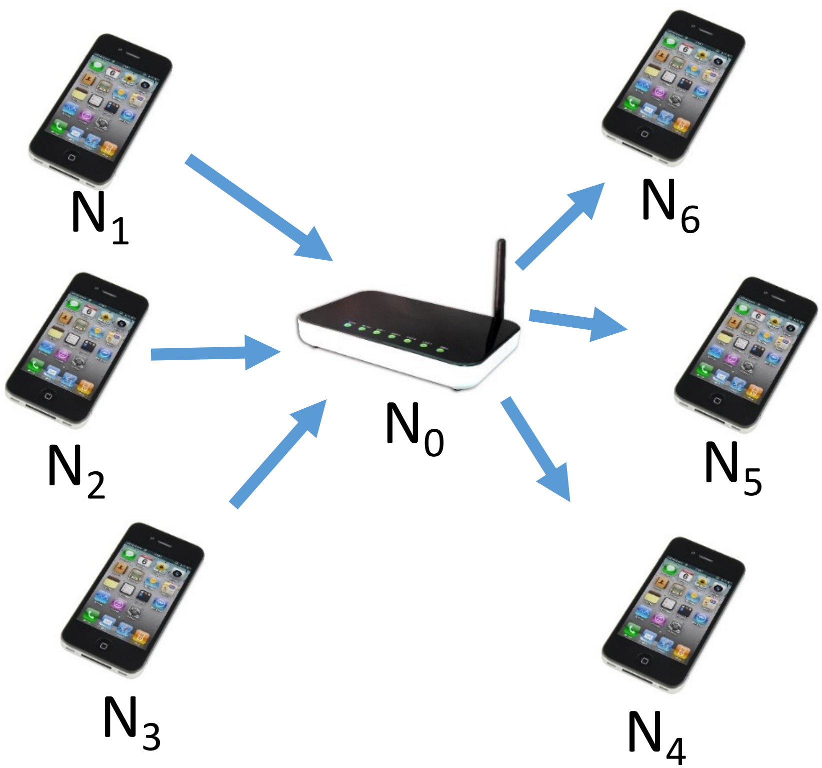
- When N1 starts to transmit data to the AP the AP starts to transmit data back to N1 simultaneously
- N2 hears the transmission from the AP and delays its transmission, thereby avoiding a collision

Reducing Congestion with MAC Scheduling (Traditional)



- Nodes N_1,N_2,N_3 have data to send to nodes N_4,N_5,N_6
- All data has to pass through N_0
- N_0 gets ¼ the total transmission opportunities
- This restricts the aggregate network throughput to ¼ the capacity of one link

Reducing Congestion with MAC Scheduling (Full Duplex)



- N_0 can transmit and receive at the same time.
- Network throughput is much improved

Cognitive Radios

- Definition
  - an intelligent radio that can be programmed and configured dynamically.
- Difficulties
  - The secondary users are allowed to use the spectrum only if the primary users are not using it. So the challenge is when it is okay for secondary users to use the spectrum.
- Full Duplex
  - Enable the secondary user to scan for any primary users while it is using the spectrum.

Challenges

- The signal from a local transmitting antenna is hundreds of thousands of times stronger than the signal from other nodes

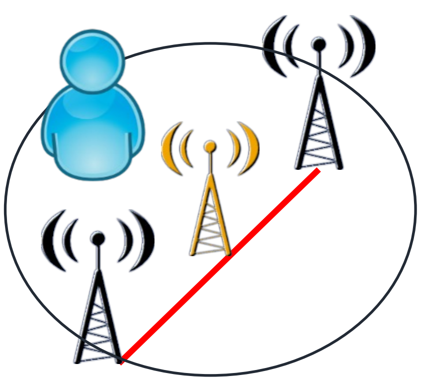
Antenna Cancellation: A Naïve Approach

Antenna Cancellation: A Naïve Approach

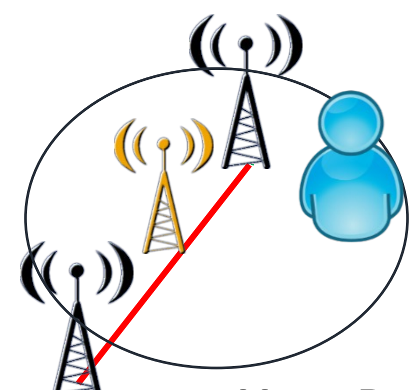
- Trivial thought on building this system:
  - Cancel the transmit signal at receiver
  - Each device has two sending antennas, TX1 and TX2, and one receiving antennas
- Make destructive interference
  - Same signal with phase difference π

Antenna Cancellation: A naïve approach

Transmit and receive signal in a single channel



User A



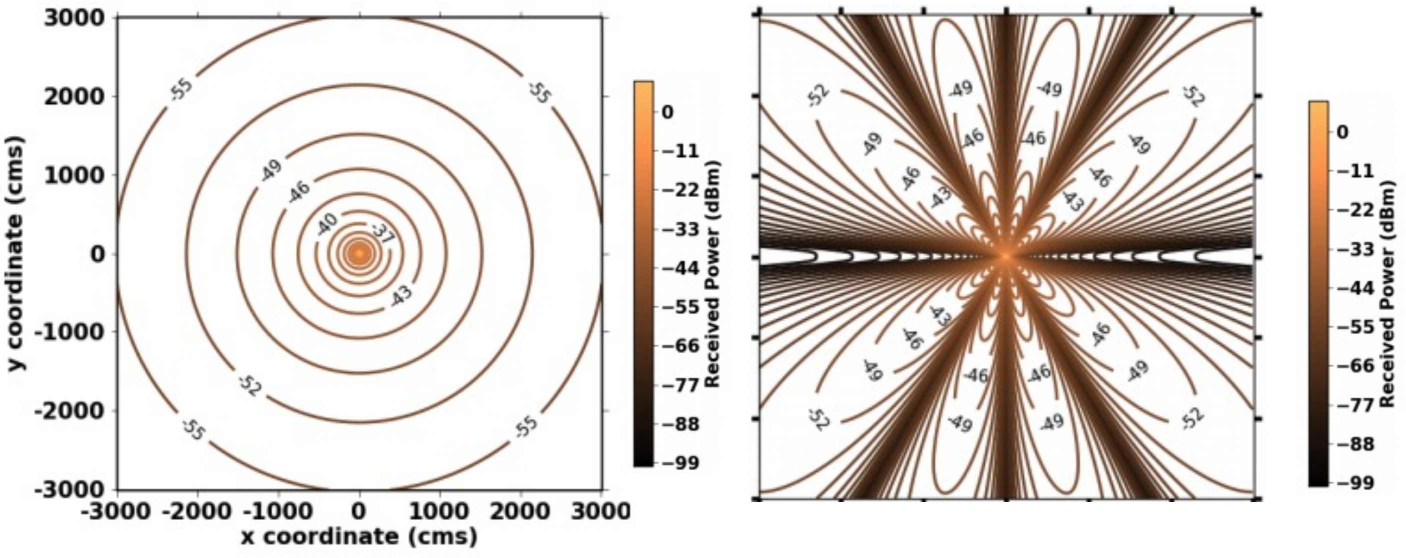
User B

Antenna Cancellation: A Naïve Approach

Can B receive the signal?

Antenna Cancellation: A Naïve Approach

- **Serious problem of destructive interference:**



The Root Cause of Previous Failure

- Sending two signals with a phase difference 180° between them
- Or, simply put,

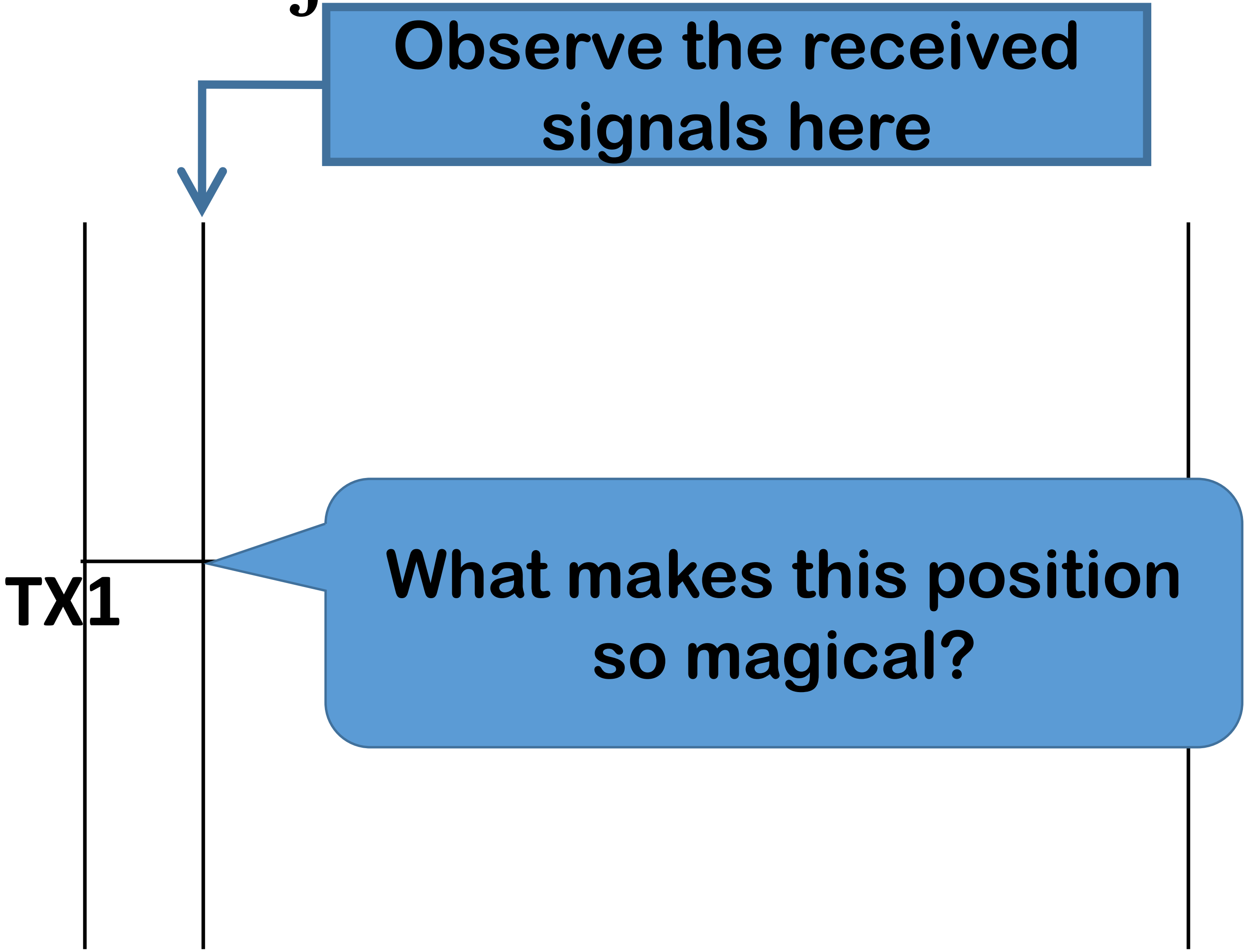
We are sending **OPPOSITE signals**

The Intuition about the Solution

- Instead, can we transmit **the same** signal in the two TXs?

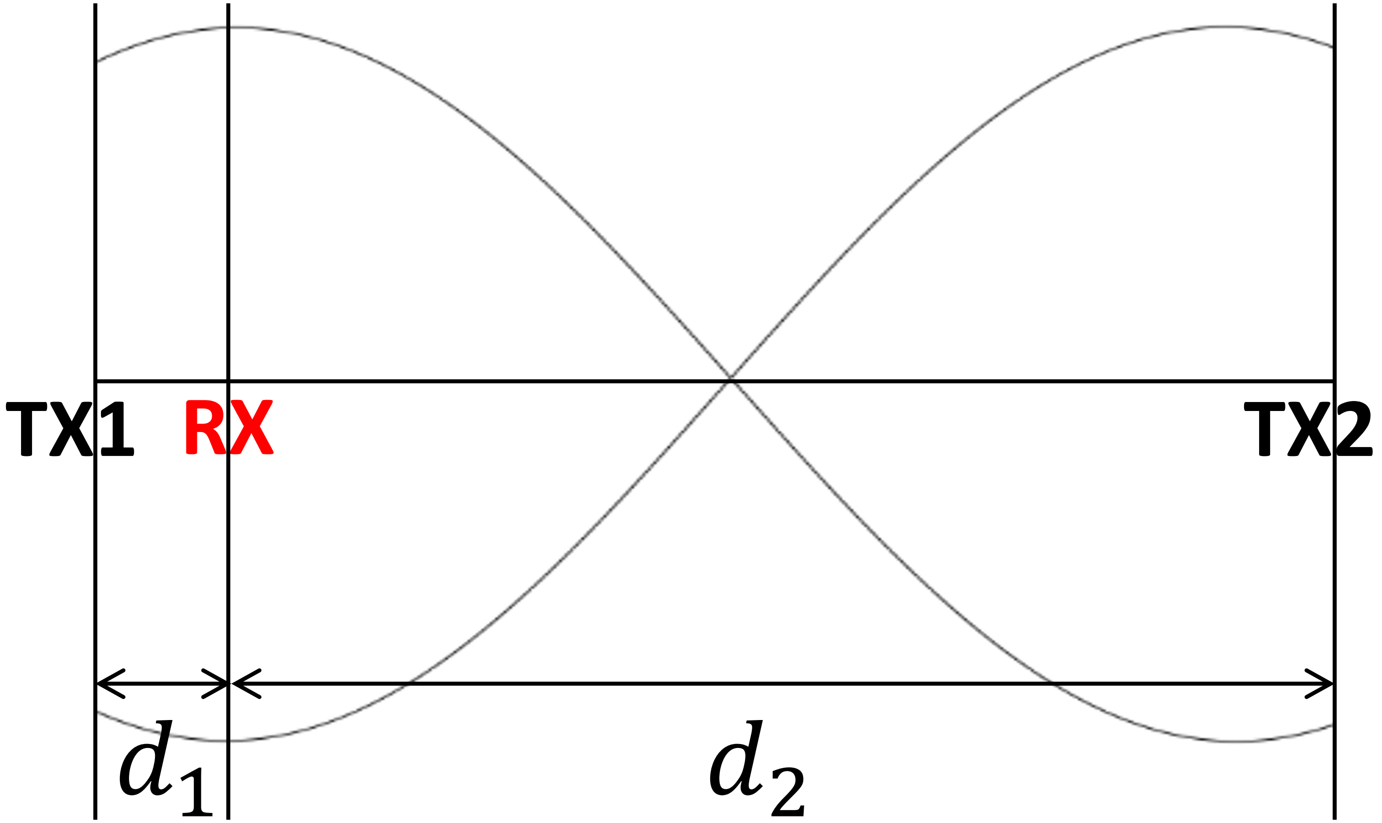
- Goal: the received signals of RX are **opposite** (a 180° phase difference)

The Solution
- Readjust the Position of RX



The Solution
- Reveal the Secret

- $d_2 - d_1 \; = \; 0.5\lambda \,(\approx 6cm \; at \; 2.48GHz\;)$

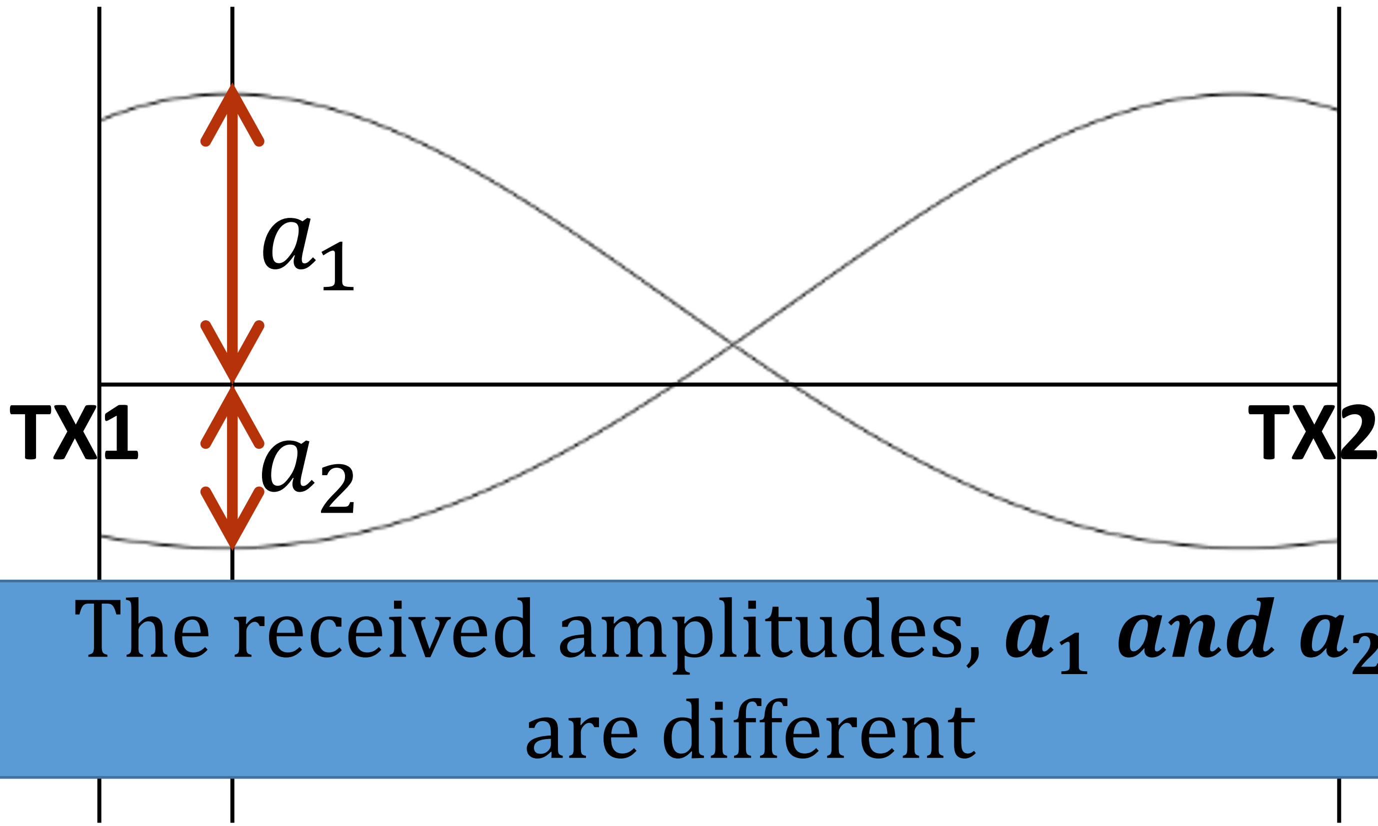


The Solution
- Readjust the Position of RX

- We have just achieved antenna cancellation!?
- How about power loss (path loss)?

Why Does Power Loss Matter?

- In fact, the previous example will look like …



The received amplitudes, $\boldsymbol{a_1}$ $\boldsymbol{and}$ $\boldsymbol{a_2}$,
are different

The Solution -Use Different Transmission Powers

- Use less transmission power for the closer TX

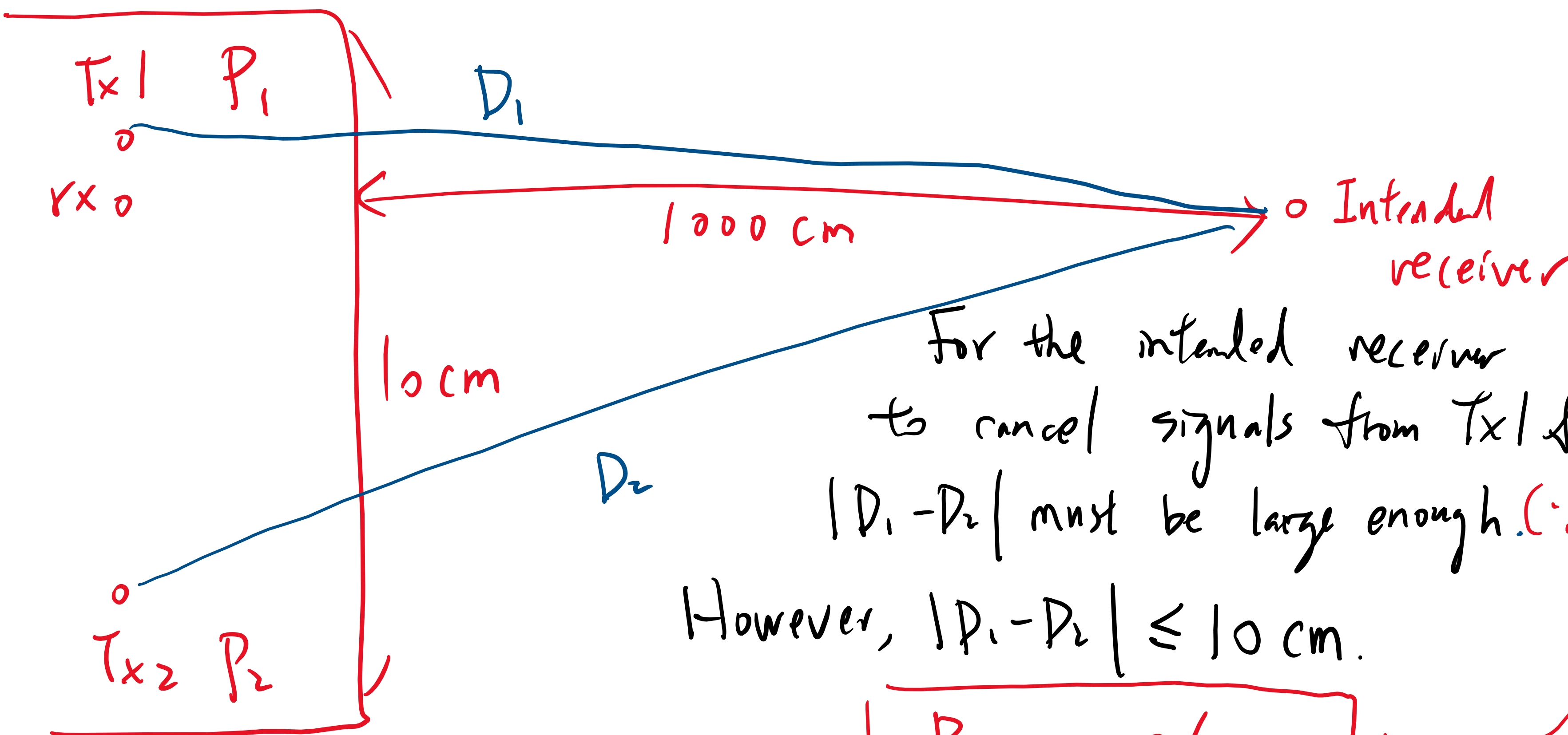
Antenna Cancellation:

1. Place RX so that $|d_2 - d_1| = 0.5\lambda$
2. Assign a lower power for the closer TX

Some Practical Consideration

- Recall the failed naïve approach
- Can the intended receiver receive the signal?
- Intuitively, it can
  - A simple mind experiment
- Comparing with single TX, a maximum degradation of 6dB

Why the two TXs cannot cancel each other at the intended receiver



For the intended receiver to cancel signals from Tx1 & 2, $|D_1 - D_2|$ must be large enough. ($\because$

However, $|D_1 - D_2| \leq 10$ cm.

$$\boxed{\frac{P_2}{P_1} = 10^{0.6} > 3}$$

Another Practical Consideration

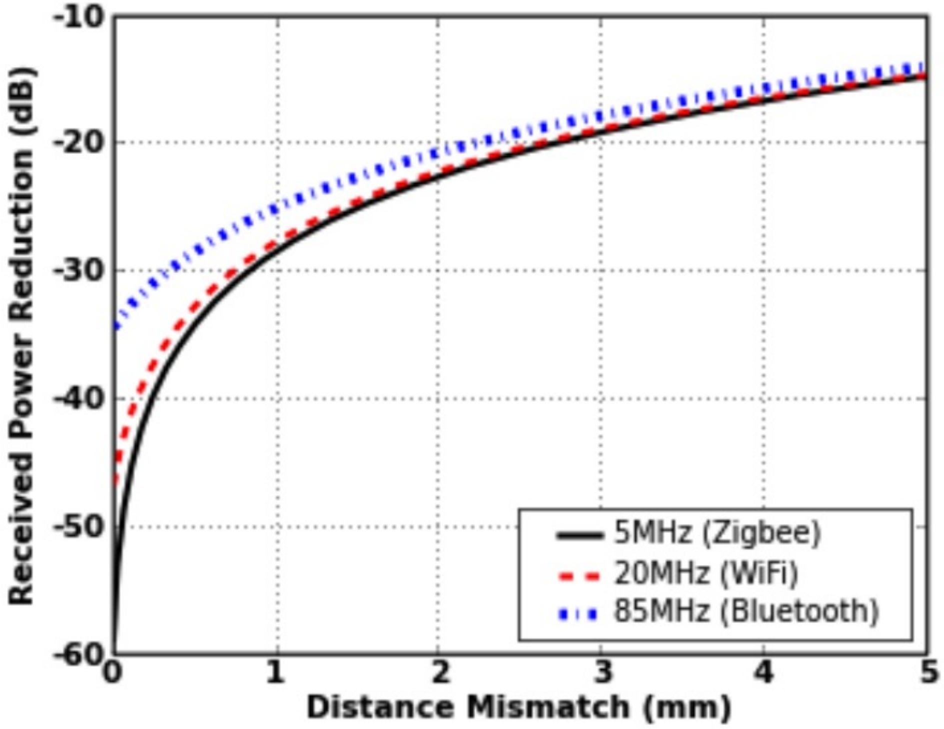
- So far, we use a single frequency tone
- In reality, we use multiple frequencies
    - Bandwidth
    - ➢ We have **many different** wavelengths
- Where should we place RX?

An Example

- Assume using a channel with
  - Lower frequency: 2400 MHz
    - Wavelength ≈ 125.00mm
  - Center frequency: 2410 MHz
    - Wavelength ≈ 124.48mm
  - Upper frequency: 2420 MHz
    - Wavelength ≈ 123.96mm
- If RX is placed w.r.t. the center frequency …
  - The maximum placement error < 1mm

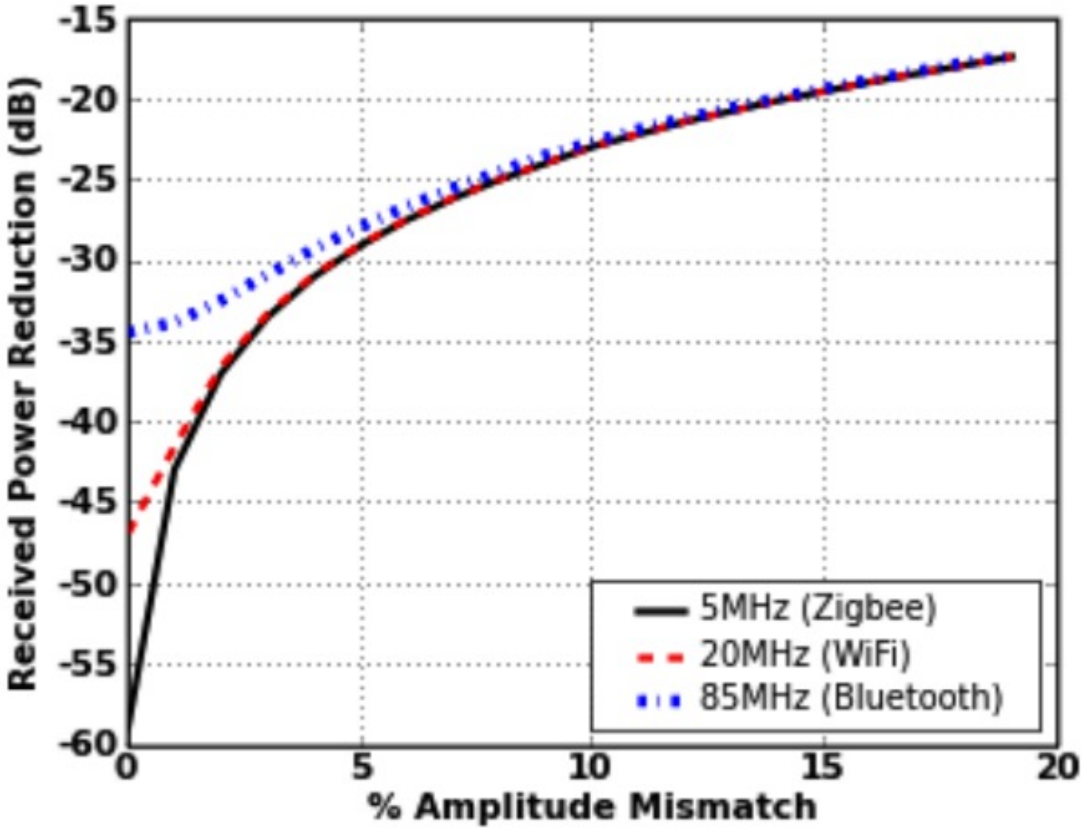
Is 1mm Too Big?

- We can still get a reduction of 46.9 dB
  - In theory, under a certain model



Yet Another Practical Consideration

- We cannot assign perfect powers to TXs
  - Does it matter?



Antenna Cancellation in Practice