Techniques in Real Cellular Networks

MIMO Overview

Multiple-Input Multiple-Output (MIMO) involves using multiple antennas at both the transmitter and receiver ends to enhance communication performance. This setup allows for the transmission and reception of multiple data signals simultaneously over the same radio channel, significantly increasing network capacity.

Example: 2x2 MIMO

In a simple 2x2 MIMO system with two transmit antennas and two receive antennas, the received signals can be represented as:

$$y_1 = h_{11}x_1 + h_{21}x_2$$
$$y_2 = h_{12}x_1 + h_{22}x_2$$

hij represents the channel from the i-th transmit antenna to the j-th receive antenna. This configuration allows for two parallel streams of data, effectively doubling the potential data throughput compared to a single antenna system. The receiver can decode this signal easily since it has N equations with N unknowns.

Scaling Up: With N antennas on each side, MIMO can support N parallel data streams, enhancing data transmission capabilities further.

MU-Mimo is a multi-user MIMO. Typically base stations have a lot more antennas than receivers. So if we want to transmit to multiple devices in parallelly, then the H^-1 operation has to happen at the sender because the different devices won't have the whole H matrix to be able to decode. So, MIMO still works with the same number of parallel streams even with multiple devices. Just needs some additional computation.

Nulling and Interference Management

Nulling is a technique used to prevent data transmission to specific clients, which is particularly useful when a device is within range of multiple base stations. By adjusting the signal's phase and amplitude using a precoding matrix, it is possible to "null" or cancel out the signal at certain locations. This is achieved by setting the product of the channel matrix H and the precoding matrix P such that unwanted signals are minimized at specific receivers because they add up destructively. It is to be noted that signal cancellation is much harder than adding operation because radios are quite sensitive to small amounts of noise.

Channel State Information (CSI) and Reciprocity

Channel State Information (CSI) is crucial for optimizing transmission strategies like nulling. CSI can be estimated through various methods, including feedback from receivers or exploiting channel reciprocity—the idea that the channel characteristics are approximately the same in both directions.

Coherent Theory

The coherence time of a channel determines how long it can be considered constant. This duration depends on factors like user mobility and environmental changes. Maintaining accurate CSI within this period is crucial for effective MIMO operations

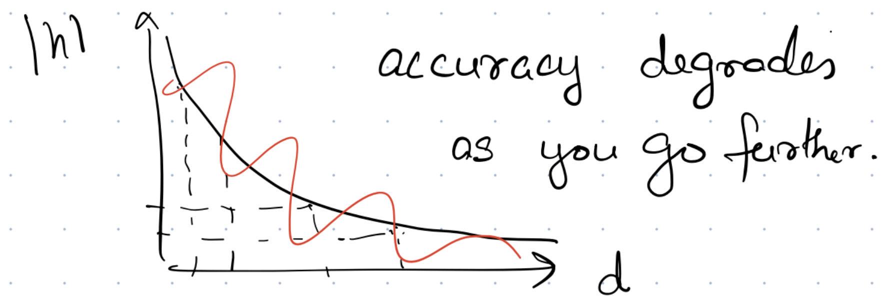
Localization Techniques

RSSI-Based Localization

Received Signal Strength Indicator (RSSI) is used in indoor localization where GPS signals are weak or unavailable. By measuring signal strength from multiple access points (APs), devices can estimate their location through techniques like trilateration or fingerprinting. With enough access points, RSSI gives room level accuracy and is easy to implement.

Fingerprinting involves creating a database of RSSI values at known locations during an offline phase. In real-time, current RSSI measurements are matched against this database to determine location. But this needs to be updated every time the environment is changed.

Trilateration uses signal strength from three or more APs to localize a device's position. The idea is pretty simple. As you get further away from an access point with a known location, your received power decreases. If the amount of senders in an area are dense enough, the device can narrow down its location.



Issues with RSSI:
Signal gets weaker due to obstacles (attenuation)
Device specific variation
multipath causes the assumed plot (1/d) to change
Accuracy degrades as you go further

Angle of Arrival

This method estimates a signal's direction by analyzing phase differences between multiple antennas spaced at half-wavelength intervals. This technique provides angular information that can enhance localization accuracy. If you have two antennas, the signal phase changes because of propagation delay. This phase difference can allow us to find the extra-distance that the signal had to travel to get to the second antenna. This allows us to get precise direction of the signal. The estimates are still affected by multipath and need to be corrected with other strategies.