ELC 4350: Principles of Communication

Non-Orthogonal Multiple Access (NOMA)

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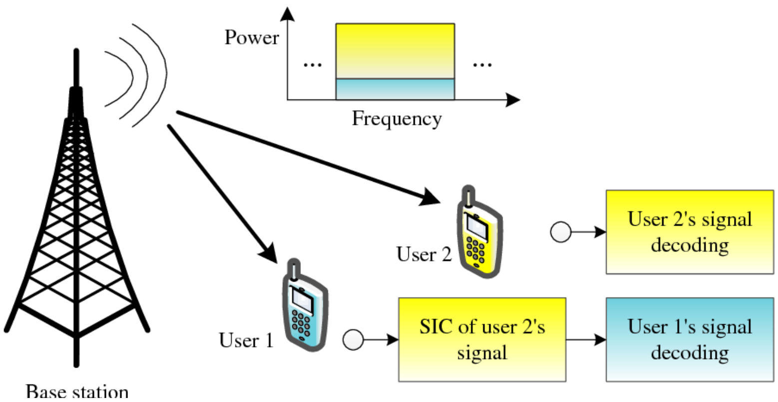
Motivation for NOMA

- Orthogonal multiple access has been widely used
  FDMA, TDMA, CDMA, OFDMA
- With more and more users, a promising solution is to break orthogonality
- Non-orthogonal Multiple Access (NOMA) has been proposed for
  5G Mobile Communications

Basic Ideas for NOMA



- All the uses are served at the same time, frequency and code
- Users with better channel conditions get less power
- Successive interference cancellation (SIC) is used at the receivers

Why NOMA is a Good Multiple Access Solution?

- Consider the scenarios:

  1. If one user only needs to be served with a low data rate, e.g., sensor, the use of orthogonal MA gives the sensor more than it needs.
  2. If one user has a very poor channel condition, the bandwidth allocated to it via orthogonal MA is not used efficiently.

- The use of NOMA can accommodate the 5G requirements
  – High system throughput
  – Low latency
  – Massive connectivity

NOMA Combined with Other Multiple Access Techniques

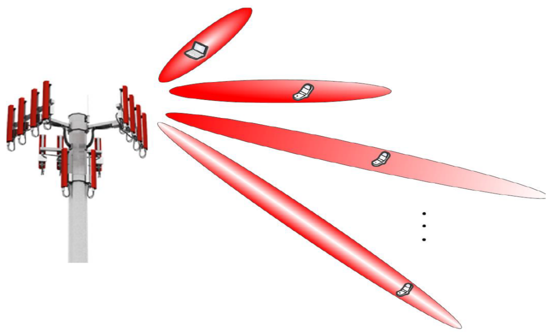


Figure: Assigning different beams to different users. Space Division MA.

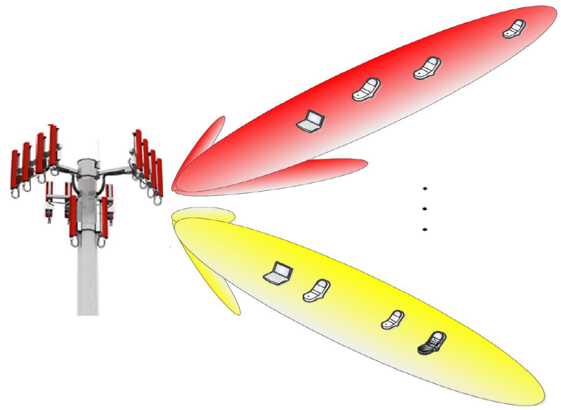


Figure: Beamforming with NOMA.

Downlink NOMA

- In the downlink of a wireless communication system, a base station transmits to multiple mobile users using the multi-carrier NOMA radio access technique.
- In NOMA, each frequency subchannel can be used by multiple users simultaneously, thereby improving spectral efficiency.
- On each subchannel, the base station uses superposition coding to combine the signals of multiple users that are distinguishable in the power domain.
- The users decode the received signals through SIC.

Downlink NOMA

- The signal transmitted by the base station (BS) is

$$x(t) = \sum_{k=1}^{K} \sqrt{\rho_k P} x_k(t)$$

where $x_k(t)$ is the individual signal for the kth user equipment (UE). P is the total transmission power and ρ_k is the power allocation coefficient for the kth UE, with $\sum_{k=1}^{K} \rho_k = 1$.

- The signal received by the kth UE is

$$y_k(t) = h_k x(t) + w_k(t)$$

Narrow-band communication. $w_k(t)$ is AWGN with single-sided power spectral density N_0.

Downlink NOMA

- Suppose that the first UE is the closest to the BS with the largest channel gain and the Kth UE is the farthest with the smaller channel gain, that is

$$|h_1| \geq |h_2| \geq \cdots \geq |h_K|.$$

- More transmission power is allocated to transmitting the signal to the UE with weaker channel gain. That is

$$\rho_1 \leq \rho_2 \leq \cdots \leq \rho_K.$$

Downlink NOMA

- With SIC, the farthest UE decodes its own signal first because it is allocated the most power as compared to signal to the others.
- The signal-to-interference-and-noise ratio (SINR) for the Kth UE is given by

$$\mathrm{SINR}_K = \frac{\rho_K P |h_K|^2}{\sum_{k=1}^{K-1} \rho_k P |h_K|^2 + N_0 W}$$

where W is the transmission bandwidth.

Downlink NOMA

- Assuming perfect interference cancellation in SIC, the closest UE decodes its own signal after subtracting signals for others. We refer to the SNR as SINR as well, which is given by

$$\mathrm{SNIR}_1 = \frac{\rho_1 P |h_1|^2}{N_0 W}.$$

- In general, assuming perfect SIC, the SINR for the kth UE is given by

$$\mathrm{SINR}_k = \frac{\rho_k P |h_k|^2}{\sum_{i=1}^{k-1} \rho_i P |h_k|^2 + N_0 W}.$$

Downlink NOMA

- With successive interference cancellation, the achievable information rate of the kth user in bits per second per Hertz is

$$r_k = \log_2\left(1 + \frac{|h_k|^2 \rho_k}{|h_k|^2 \sum_{i=1}^{k-1} \rho_i + \alpha}\right)$$

  where $\alpha = N_0 W / P$ is the ratio of the noise power to the total transmission power.

- The achievable sum information rate is

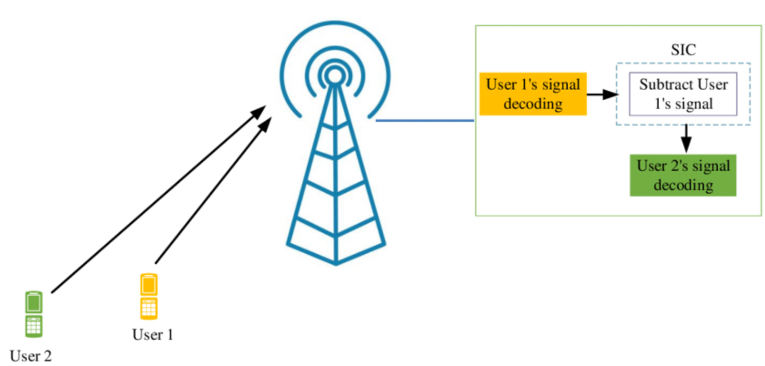
$$R = \sum_{k \in \mathcal{K}} r_k = \sum_{k \in \mathcal{K}} \log_2\left(1 + \frac{|h_k|^2 \rho_k}{|h_k|^2 \sum_{i=1}^{k} \rho_i + \alpha}\right)$$

Uplink NOMA

- In the uplink, the received signal at the BS is given by

$$y(t) = \sum_{k \in \mathcal{K}} h_k x_k(t) + w(t).$$

- We assume that the UEs are distributed in the cell coverage such that the received power levels from different UEs are well separated.



Uplink NOMA

- At the BS receiver, SIC is used such that the signal from the closest UE will be decoded first. The received SINR for the first UE is given by

$$\mathrm{SINR}_1 = \frac{P|h_1|^2}{\sum_{k=2}^{K} P|h_k|^2 + N_0 W}$$

where P is the transmission power of each UE.

- Assume perfect SIC. In general, the received SINR for the kth UE is given by

$$\mathrm{SINR}_k = \frac{P|h_k|^2}{\sum_{i=k+1}^{K} P|h_i|^2 + N_0 W}$$

Uplink NOMA

- The achievable information rate of the kth UE is

$$r_k = \log_2\left(1 + \frac{P|h_k|^2}{\sum_{i=k+1}^{K} P|h_i|^2 + N_0 W}\right)$$

- The achievable sum information rate is

$$R = \sum_{k\in\mathcal{K}} r_k = \sum_{k\in\mathcal{K}} \log_2\left(1 + \frac{|h_k|^2}{\sum_{i=k+1}^{K} |h_i|^2 + \alpha}\right)$$

NOMA Performance

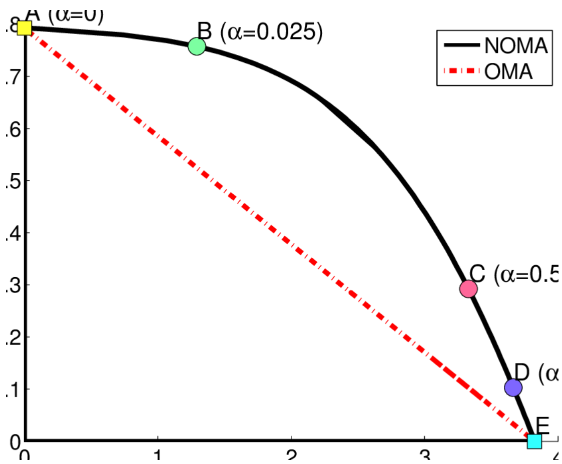


Figure: Capacity region of downlink NOMA.

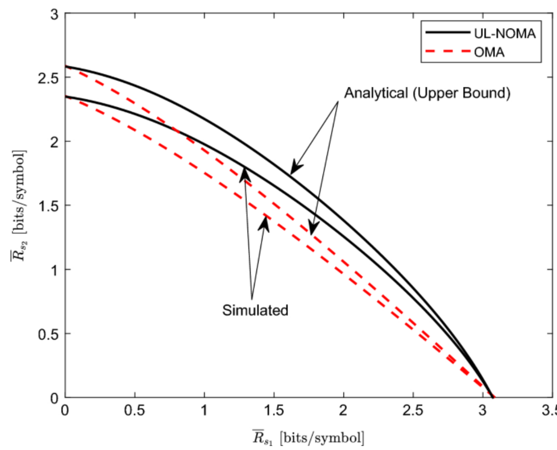


Figure: Capacity region of uplink NOMA.