Full/Half-Duplex Relay Selection for Cooperative NOMA Networks

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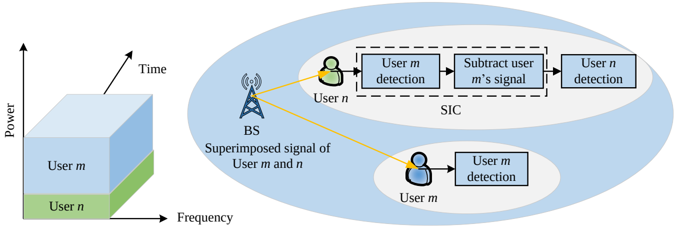
Outline

- Background
- Network model
- Relay selection scheme
- Outage Probability
- Numerical Results
- Conclusions

From OMA to NOMA

1. **Question**: What is multiple access?
2. **Orthogonal multiple access (OMA)**: e.g., FDMA, TDMA, CDMA, OFDMA.
3. New requirements in 5G
   - High spectrum efficiency.
   - Massive connectivity.
4. **Non-orthogonal multiple access (NOMA)**: to break orthogonality.
5. Standard and industry developments on NOMA
   - **Whitepapers for 5G**: DOCOMO, METIS, NGMN, ZTE, SK Telecom, etc.
   - **LTE Release 13**: a two-user downlink special case of NOMA.
   - **Next generation digital TV standard ATSC 3.0**: a variation of NOMA, termed Layer Division Multiplexing (LDM).

NOMA Basics



1. Realize the multiple access in the same resource block (time/frequecy/code), but with **different power levels** [1].
2. Apply successive interference cancellation (SIC) at the receiver.

[1] **Y. Liu**, Z. Qin, M. Elkashlan, Z. Ding, A. Nallanathan and L. Hanzo, "Non-Orthogonal Multiple Access for 5G and Beyond", ***Proceedings of the IEEE***; vol. 105, no. 12, pp. 2347-2381, Dec. 2017.

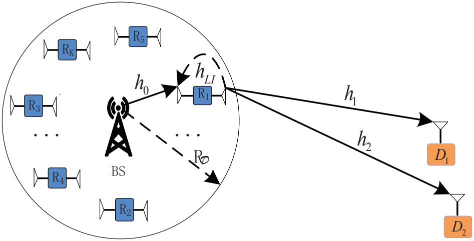
Motivations for NOMA Relay selection

1. Applying the **relay selection (RS) technique** to cooperative communication systems can take advantages of the space diversity and improve the spectral efficiency.

2. Although cooperative NOMA is capable of enhancing the performance gains for far user, it results in additional bandwidth costs for the system. One promising solution is to adopt the **full-duplex (FD) relay** technology, which receives and transmits simultaneously in the same frequency band.

3. **A single-stage RS (SRS) scheme** is proposed to maximize the data rate of distant user for **HD/FD NOMA** networks.

Network model



1. Network model for the NOMA transmission consisting of one base station (BS), K **relays** and **two users (i.e., the nearby user** D_1 **and distant user** D_2**)**.
2. Assuming that the BS is located at the origin of a disc and the location of the relays are modeled as homogeneous poisson point processes **(HPPPs)**.
3. The decode-and-forward **(DF)** protocol is employed at each relay and only one relay is selected to assist BS conveying the information to the NOMA users in each time slot.

SINRs for NOMA users

- According to NOMA protocol, SIC is employed at i-th relay R_i to first decode the signal x_2 of D_2 , and then decode its own information x_1. Hence, signal-to-interference-plus-noise ratio (SINR) at R_i to detect x_1 and x_2 are given by

$$\gamma_{D_2 \to R_i} = \frac{|h_0|^2 a_2 \rho}{|h_0|^2 a_1 \rho + \varpi |h_{LI}|^2 \rho + 1}, \tag{1}$$

$$\gamma_{D_1 \to R_i} = \frac{\rho |h_0|^2 a_1}{\varpi \rho |h_{LI}|^2 + 1} \tag{2}$$

respectively, where $\varpi = 0$ and $\varpi = 1$ denote that the relay can work in HD mode and FD mode, respectively.
$h_0 = \frac{|h_{SR_i}|^2}{\sqrt{1+d_{SR_i}^{\alpha}}}$, $d_{SR_i}^{\alpha}$ is the distance between the BS and R_i and α denotes the path loss exponent. ρ is the transmit signal-to-noise radio (SNR).

SINRs for NOMA users

- Assuming that R_i can detect the two NOMA user's information. The SIC is also invoked by D_1 and the received SINR at D_1 to detect x_2 is given by

$$\gamma_{D_2 \to D_1} = \frac{|h_1|^2 a_2 \rho}{|h_1|^2 a_1 \rho + 1}. \tag{3}$$

Then, the received SNR at D_1 to detect its own information is given by

$$\gamma_{D_1} = \rho |h_1|^2 a_1. \tag{4}$$

The received SINR at D2 to detect x2 can be given by

$$\gamma_{D_2} = \frac{|h_2|^2 a_2 \rho}{|h_2|^2 a_1 \rho + 1}, \tag{5}$$

where $h_j = \frac{\left|h_{R_i D_j}\right|^2}{\sqrt{1+d_{R_i D_j}^{\alpha}}}$, $j \in (1, 2)$.

Relay selection schemes for NOMA

- **The single stage relay selection scheme**

Prior to the transmissions, a relay can be randomly selected by the BS as its helper to forward the information. The aim of SRS scheme is to ensure the data rate of D2 as large as possible for FD/HD NOMA.

Among the relays in the network considered, this relay selection strategy is to select a relay which can maximize the data rate for D_2, i,e.,

$$i^*_{SRS} = \arg\max_i \left\{ \min \left\{ \log\left(1+\gamma_{D_2 \to R_i}\right), \log\left(1+\gamma_{D_2 \to D_1}\right), \log\left(1+\gamma_{D_2}\right) \right\}, i \in S^1_R \right\}, \tag{6}$$

where S^1_R denotes the number of relays in the network.

Relay selection schemes for NOMA

- **The benchmark for relay selection scheme**

The random relay selection (RRS) scheme can be seen as a baseline for comparison purposes. In this case, the relay R_i is selected randomly to help the BS transmitting the information. That is to say that the RRS scheme is regarded as the special case for SRS scheme with K=1.

Outage probability

- **Outage probability of FD-based SRS scheme**

According to NOMA protocol, the complementary events of outage for this SRS scheme can be explained as: The relay i^*_{SRS} can detect x_2 as well as D_1 and D_2 can also detect x_2 successfully. From the above description, the outage probability of the SRS scheme for FD NOMA can be expressed as follows:

$$P^{FD}_{SRS} = \prod_{i=1}^{K} \left(1 - \Pr\left(W_i > \gamma^{FD}_{th_2}\right)\right), \tag{7}$$

where $\varpi = 1$ and $W_i = \min\{\gamma_{D_2 \to R_i}, \gamma_{D_2 \to D_1}, \gamma_{D_2}\}$. $\gamma^{FD}_{th_2} = 2^{R_{D_2}} - 1$ with R_{D_2} being the target rate of D_2.

Outage probability

- **Outage probability of HD-based SRS scheme**

Similar to (7), the outage probability of SRS for HD NOMA is given by

$$P_{SRS}^{HD} = \prod_{i=1}^{K} \left(1 - \Pr\left(W_i > \gamma_{th_2}^{HD}\right)\right), \tag{8}$$

where $\varpi = 0$ and $\gamma_{th_2}^{HD} = 2^{2R_{D_2}} - 1$ with R_{D_2} being the target rate of D_2.

Diversity analysis

To gain more insights for SRS scheme in the high SNR region, the diversity order analysis is provided according to the derived outage probabilities. The diversity order is defined as

$$d = -\lim_{\rho \to \infty} \frac{\log \left(P^{\infty} \left(\rho \right) \right)}{\log \rho}, \tag{9}$$

where $P^{\infty}(\rho)$ is the asymptotic outage probability.

Remarks:

1. The diversity order of the **SRS** scheme for **FD NOMA** is ***zero***, which is the same as the conventional FD RS scheme.
2. The diversity order of the **SRS** scheme for **HD NOMA** is $\boldsymbol{K}$, which provides a diversity order equal to the number of the available relays.
3. As can observed that the diversity orders of the **RRS** scheme for **FD/HD NOMA** are ***zero*** and ***one***, respectively.

Throughput Analysis

The delay-limited transmission mode is considered for FD/HD NOMA. On the basis of (6), (7), (8), (9), (10) and (11), the system sum throughput of FD/HD NOMA without/with direct link can be given by

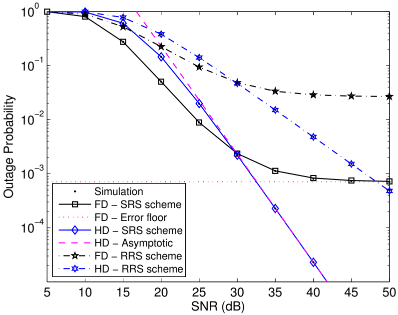
$$R_{SRS}^{FD} = \left(1 - P_{SRS}^{FD}\right) R_1 + \left(1 - P_{SRS}^{FD}\right) R_2 \tag{10}$$

$$R_{SRS}^{HD} = \left(1 - P_{SRS}^{HD}\right) R_1 + \left(1 - P_{SRS}^{HD}\right) R_2 \tag{11}$$

Duplex mode	**RS scheme**	**D**
FD NOMA	SRS	0
	RRS	0
HD NOMA	SRS	K
	RRS	1

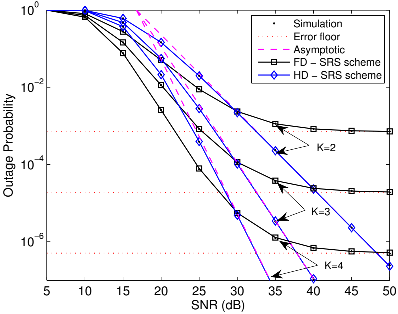
Table: Diversity orders for FD/HD NOMA networks.

Numerical Results



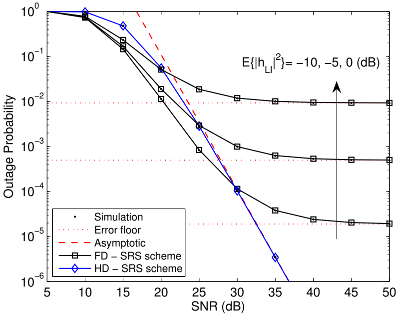
- As can be observed that the performance of the FD-based NOMA SRS scheme is superior to that of HD-based on the condition of low SNR region. Moreover, the outage performance of the SRS scheme outperforms the RRS schemes for FD/HD NOMA.
- One can observe the asymptotic curves well approximate the analytical performance curves in the high SNR region. It is worth noting that **an error floor** exists in FD-based NOMA SRS scheme, which verifies the conclusion in **Remark 1**.

Numerical Results



- It is shown that the number of relays in the networks considered strongly affect the performance of RS for FD/HD NOMA.
- With the number of relays increasing, the lower outage probability are achieved by this RS scheme.
- Another observation is that the HD-based RS scheme provides a diversity order that is equal to **the number of the relays** (K).This phenomenon is verified by the insights in **Remark 2**.

Numerical Results



- As observed from the figure, we can see that the value of **loop interference (LI)** also strongly affect performance of FD-based SRS scheme for NOMA, while HD-based SRS scheme is not affected.
- As the value of LI becomes larger, the outage performance of becomes more worse. In consequence, it is significant to consider the influence of LI in the practical FD NOMA network.

Conclusions

- This paper has investigated **FD/HD-based NOMA SRS scheme** insightfully.
- **Stochastic geometry** based techniques have been used for modeling the locations of relays.
- Due to the influence of residual LI at the relay, **a zero diversity order** has been obtained by the FD-based SRS scheme for NOMA. However, the HD-based SRS scheme achieved **a diversity of** K.
- It was demonstrated that the outage performance of FD-based SRS scheme outperforms HD-based **in the low SNR region**.

Research Opportunities and challenges for NOMA

1. MIMO-NOMA design.
2. Error Propagation in SIC.
3. Imperfect SIC and limited channel feedback.
4. Synchronization/asynchronization design for NOMA.
5. Different variants of NOMA.
6. Novel coding and modulation for NOMA.
7. Hybrid multiple access
8. Efficient resource management for NOMA
9. Security provisioning in NOMA
10. Grant free NOMA design for IoT

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Questions?

Thanks for your attention.