Outage Performance of Full/Half-Duplex User Relaying in NOMA Systems

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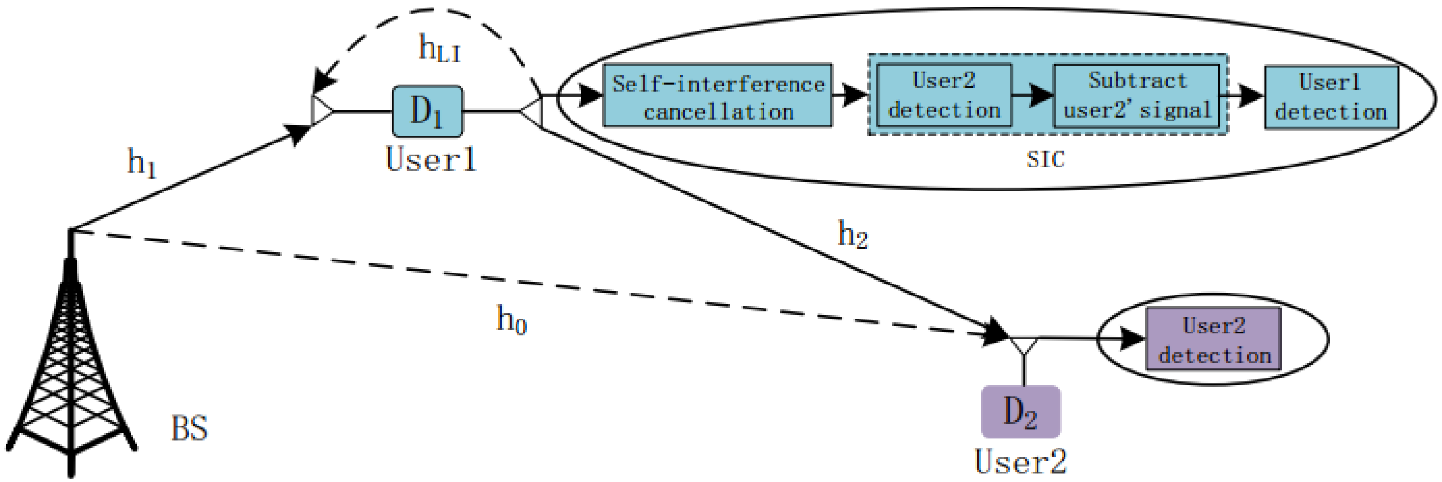
Outline

- Background
- System model
- Outage Probability
- Numerical Results
- Conclusions

Background

- Non-Orthogonal Multiple Access (NOMA) protocol can allow multiple users to share the same resource elements via different power levels
- Half-duplex (HD) NOMA provides performance gains for weak user, but it brings additional slot cost for the systems
- Full-duplex (FD) NOMA can be further realize more spectrally efficient systems
- HD/FD user relaying for NOMA are researched

System model



- System model for the NOMA transmission protocol considering one source (i.e the base station (BS)) that intends to communication with the far user D_2 under the assistance of the near user D_1
- D_1 works as a FD/HD decode-and-forward (DF) relaying to help far user
- Both no direct link and direct link scenarios between the BS and D_2 are considered.

System model---SINR for NOMA users

Applying NOMA principle, successive interference cancellation (SIC) is employed at D_1, the signal-to-interference-plus-noise ratio (SINR) at D_1 to detect D_2 's message x_2 is given by

$$\gamma_{D_1 \to D_2} = \frac{|h_1|^2 a_2 \rho}{|h_1|^2 a_1 \rho + \varpi |h_{LI}|^2 \rho + 1}. \qquad (1)$$

where ϖ denotes the switching operation factor between HD mode and FD mode with $\varpi = 0$ and $\varpi = 1$. ρ is the transmit signal-to-noise radio (SNR).

After SIC, the received SNR at D_1 to detect its own message x_1 is given by

$$\gamma_{D_1} = \frac{|h_1|^2 a_1 \rho}{\varpi |h_{LI}|^2 \rho + 1}. \qquad (2)$$

System model---SINR for NOMA users

For the direct link, the received SINR at D_2 to detect x_2 is given by

$$\gamma_{1,D_2} = \frac{|h_0|^2 a_2 \rho}{|h_0|^2 a_1 \rho + 1}. \quad (3)$$

For the relaying link, the received SNR can be given by

$$\gamma_{2,D_2} = |h_2|^2 \rho. \quad (4)$$

Assuming that the signals from the relaying link and direct link can be combined by maximal ratio combining (MRC) at D_2. The received SINR after MRC at D_2 can be given by

$$\gamma_{D_2}^{MRC} = |h_2|^2 \rho + \frac{|h_0|^2 a_2 \rho}{|h_0|^2 a_1 \rho + 1}. \quad (5)$$

Outage probability

- User Relaying without Direct Link

For D_1, according to the NOMA protocol, the complementary events of outage at D_1 can be explained as: D_1 can detect x_2 as well as its own message x_1. From the above description, the outage probability of D_1 for FD NOMA can be expressed as below:

$$P_{D_1,nodir}^{FD} = 1 - \mathrm{P_r}\left(\gamma_{D_2 \to D_1} > \gamma_{th_2}^{FD}, \gamma_{D_1} > \gamma_{th_1}^{FD}\right), \quad (6)$$

where $\varpi = 1.\ \gamma_{th_1}^{FD} = 2^{R_1} - 1$ with R_1 being the target rate at D_1 to detect x_1 and $\gamma_{th_2}^{FD} = 2^{R_2} - 1$ with R_2 being the target rate at D_1 to detect x_2.

Similar to (6), the outage probability of D_1 for HD NOMA is given by

$$P_{D_1,nodir}^{HD} = 1 - \mathrm{P_r}\left(\gamma_{D_2 \to D_1} > \gamma_{th_2}^{HD}, \gamma_{D_1} > \gamma_{th_1}^{HD}\right). \quad (7)$$

where $\varpi = 0.\ \gamma_{th_1}^{HD} = 2^{2R_1} - 1$ and $\gamma_{th_2}^{HD} = 2^{2R_2} - 1$ denote the targer SNR at D_1 to detect x_1 and x_2, respectively.

Outage probability

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- User Relaying without Direct Link

For D_2, the outage events can be explained for two reasons. The first is that D_1, cannot detect x_2. The second is that D_2 cannot detect its own message x_2 on the conditions that D_1 can detect x_2 successfully. Based on these, the outage probability of D_2 for FD NOMA can be expressed as below:

$$P_{D_2,nodir}^{FD} = \mathrm{P_r}\left(\gamma_{D_2 \to D_1} < \gamma_{th_2}^{FD}\right) + \mathrm{P_r}\left(\gamma_{2,D_2} < \gamma_{th_2}^{FD}, \gamma_{D_2 \to D_1} > \gamma_{th_2}^{FD}\right), \quad (8)$$

where $\varpi = 1$.

Similar to (8), the outage probability of D_2 for HD NOMA is given by

$$P_{D_2,nodir}^{HD} = \mathrm{P_r}\left(\gamma_{D_2 \to D_1} < \gamma_{th_2}^{HD}\right) + \mathrm{P_r}\left(\gamma_{2,D_2} < \gamma_{th_2}^{HD}, \gamma_{D_2 \to D_1} > \gamma_{th_2}^{HD}\right), \quad (9)$$

where $\varpi = 0$.

Outage probability

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- User Relaying with Direct Link

For D_1, the outage probability of D_1 will not be affected by the direct link between the BS and D_2.

For D_2, the outage events can be described below. One of the events is when x_2 can be detected at D_1, but the received SINR after MRC at D_2 in one slot is less than its target SNR. Another event is that neither D_1 nor D_2 can detect x_2. Therefore, the outage probability of D_2 for FD NOMA can be expressed as below:

$$P_{D_2,dir}^{FD} = \mathrm{P_r}\left(\gamma_{D_2}^{MRC} < \gamma_{th_2}^{FD}, \gamma_{D_2 \to D_1} > \gamma_{th_2}^{FD}\right) + \mathrm{P_r}\left(\gamma_{D_2 \to D_1} < \gamma_{th_2}^{FD}, \gamma_{1,D_2} < \gamma_{th_2}^{FD}\right), \quad (10)$$

where $\varpi = 1$.
$\varpi = 1$.

Similar to (10), the outage probability of D_2 for HD NOMA is given by

$$P_{D_2,dir}^{HD} = \mathrm{P_r}\left(\gamma_{D_2}^{MRC} < \gamma_{th_2}^{HD}, \gamma_{D_2 \to D_1} > \gamma_{th_2}^{HD}\right) + \mathrm{P_r}\left(\gamma_{D_2 \to D_1} < \gamma_{th_2}^{HD}, \gamma_{1,D_2} < \gamma_{th_2}^{HD}\right), \quad (11)$$

where $\varpi = 0$.

Diversity analysis

To obtain more insights, the diversity analysis is provided in terms of the outage probability investigated in the high SNR region.

$$d = -\lim_{\rho \to \infty} \frac{\log\left(P_D^{\infty}(\rho)\right)}{\log \rho}, \tag{12}$$

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

- User Relaying without Direct Link

Remark 1: The diversity order of D_1 and D_2 for FD NOMA is zero, which is the same as the conventional FD relaying. However, the diversity order of D_1 and D_2 for HD NOMA is one.

Remark 2: The error floors of two users are existent at high SNR region for FD NOMA without direct link.

Diversity analysis

- User Relaying with Direct Link

For D_2, since the direct link exists between the BS and D_2, the diversity order of D_2 for FD NOMA is one. However, the diversity order of D_2 for HD NOMA is two.

Remark 3: From the above explanation, the observation is that the direct link (BS D_2) to convey information is an effective way to overcome the problem $\rightarrow$ of zero diversity order for D_2.

- 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

$$R_{\Phi}^{FD} = \left(1 - P_{D_1,\Phi}^{FD}\right) R_1 + \left(1 - P_{D_2,\Phi}^{FD}\right) R_2, \tag{13}$$

and

$$R_{\Phi}^{HD} = \left(1 - P_{D_1,\Phi}^{HD}\right) R_1 + \left(1 - P_{D_2,\Phi}^{HD}\right) R_2, \tag{14}$$

respectively, where $\Phi \in (dir, nodir)$ denote the direct/nodirect scenarios.

Numerical Results

- User Relaying without Direct Link

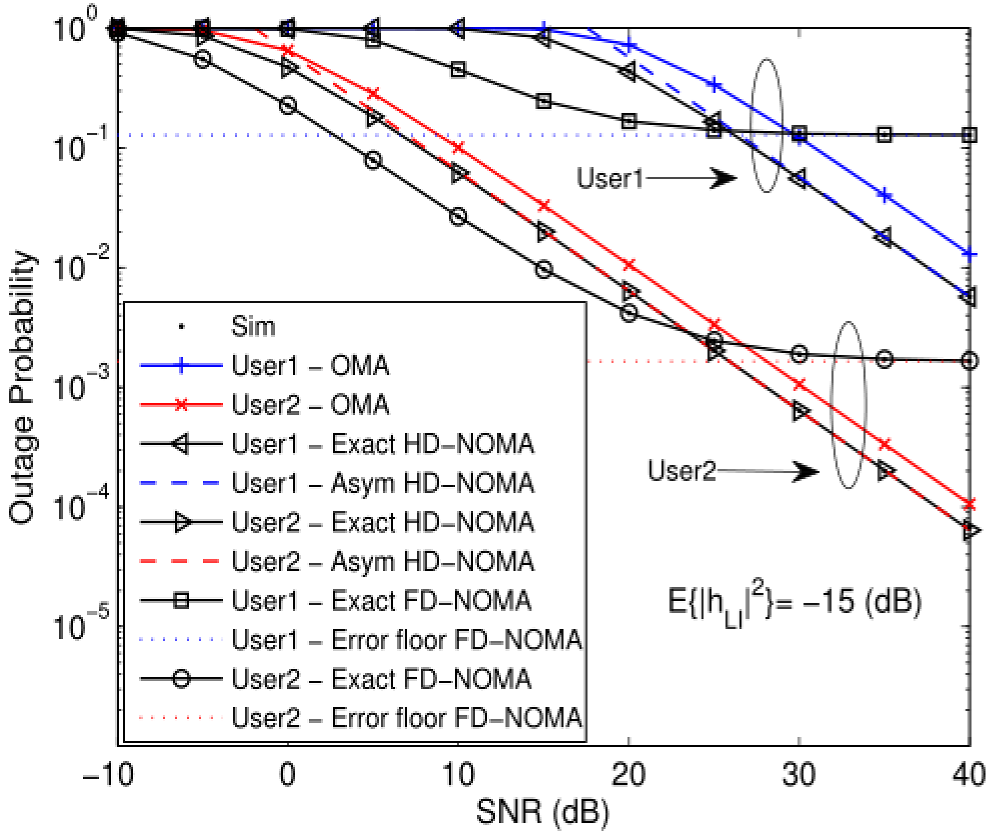

Fig. 1 Outage probability versus transmit SNR without direct link.

- As can be observed that the performance of FD NOMA exceeds the HD NOMA and OMA on the condition of low SNR region. This is because loop interference is not the dominant impact factor for FD NOMA in low SNR region.
- It is shown that error floors exist in FD NOMA, which verify the conclusion in **Remark 2** and obtain the zero diversity order.

Numerical Results

- User Relaying with Direct Link

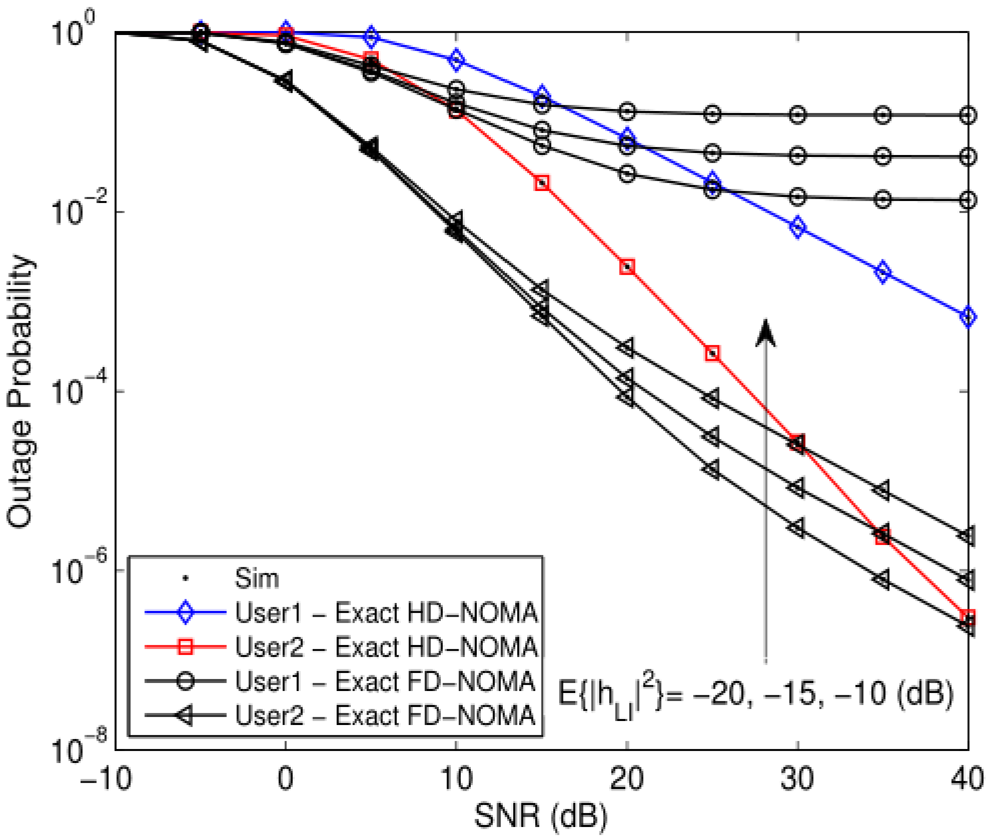

Fig. 2 Outage probability versus transmit SNR for different values of LI with direct link

- We observe that D_2 obtains one diversity order by using the direct link, which overcomes the problem of zero diversity order inherent to FD cooperative system.
- It is observed that the superiority of FD NOMA is no longer apparent with the values of LI increasing.

Conclusions

- This paper has investigated FD/HD user relaying in cooperative NOMA systems and two cooperative relaying scenarios have been considered insightfully.
- Due to the influence of residual loop interference, the diversity orders achieved by two user were zero for FD NOMA.
- The direct link between the BS and the far user was utilized to convey the information and one diversity order was obtained for the far user.
- It was shown that FD NOMA was superior to HD NOMA at low SNR region rather than at high SNR region.
- Furthermore, the superior of FD NOMA was not apparent with the loop interference value increasing.

Thank you !