Non-orthogonal Multiple Access with Practical Interference Cancellation for MIMO Systems

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Abstract

The concept of non-orthogonal multiple access (NOMA) is presented as a candidate radio access technology for systems beyond the 4th generation (4G) mobile communication systems. NOMA, which is different from the current long term evolution (LTE) radio access schemes, utilizes the power domain for user multiplexing at the transmitter side and adopts a successive interference cancellation (SIC) receiver as the baseline receiver scheme considering the expected mobile device evolution in the future. In this paper, we investigate the link-level performance of NOMA in the cellular downlink multiple-input multiple-output (MIMO) systems by taking into account the practical ordered SIC (OSIC) schemes. The goal is to clarify the performance gap of NOMA scheme with the ideal and practical SIC, and to examine the possibility of applying practical NOMA with SIC to the cellular systems in the near future.

Keywords: non-orthogonal multiple access, ordered successive interference cancellation, multiple-input multiple-output, cellular system

1 Introduction

In the 4th generation (4G) mobile communication systems, such as long term evolution (LTE), WiMAX, and LTE-Advanced, orthogonal access based on orthogonal frequency division multiple access (OFDMA) or single carrier (SC)-FDMA is adopted. Orthogonal access is a reasonable choice for achieving good system throughput performance with a simplified receiver design. However, due to the vastly increased need for high-volume services such as image transfer, video streaming and cloud based services, a new mobile communications system with further enhancement of the system throughput is required for the systems beyond 4G. In order to fulfill such requirements, non-orthogonal multiple access (NOMA) with a successive interference cancellation (SIC) receiver in downlink is presented as one of several promising candidate radio access technologies [10].

For downlink NOMA, non-orthogonality is achieved by introducing power-domain, either in time/frequency/code domains, for user multiplexing. User de-multiplexing is obtained through the allocation of large power difference between users at transmitter side, and implementation of SIC at receiver side. In this case, all users can use overall transmission bandwidth to achieve higher spectrum efficiency, as well as better user fairness achieved by assigning enough bandwidth to the users under poor channel conditions compared with orthogonal access. Furthermore, NOMA is suitable for the situation of massive connectivity since it can support more simultaneous connections.

In previous works [11], [4], [1], [9], [6], system-level performance of NOMA is evaluated by assuming perfect SIC at the receiver side. However, in order to clarify the performance gap of NOMA scheme with the ideal and practical SIC and to examine the possibility of applying NOMA with SIC to the future cellular systems, we investigate the link-level performance of NOMA by considering the practical ordered SIC (OSIC).
The remainder of the paper is organized as follows. Section II provides the state of the art technologies on NOMA. Section III presents the system model of NOMA in the cellular downlink multiple-input multiple-output (MIMO) systems, and also introduces the practical OSIC schemes for NOMA. Section IV analyzes the simulation results. Finally, Section V concludes the paper.

2 State of the Art Technologies on NOMA

The basic NOMA scheme with SIC for a two user equipment (UE) case in the cellular downlink is illustrated by Fig.1 [10]. The transmit signal for $UE_i (i = 1, 2)$ at the base station (BS) is $x_i$, with transmission power $p_i$. The sum of transmit power is restricted to $p$. Thus, the transmit signals are superposed as

$$y_i = h_ix_i + w_i$$

where $h_i$ is the complex channel coefficient between $UE_i$ and BS. $w_i$ denotes the receiver Gaussian noise including inter-cell interference. The power density of $w_i$ is $N_0$. In the NOMA downlink, the order of decoding is by increasing channel gain normalized based on noise and inter-cell interference power, i.e., $|h_i|^2/N_0$. In an 2-UE case as shown in Fig. 1, we assume that $|h_1|^2/N_0,1 > |h_2|^2/N_0,2$, therewith $UE_1$ firstly decodes $x_2$ and deletes its component from received signal $y_1$. Then, $UE_2$ decodes $x_2$ without interference cancellation since it has the first decoding order. The throughput of $UE_i$, is given as

$$R_1 = \log_2 \left( 1 + \frac{P_1|h_1|^2}{N_0,1} \right), \quad R_2 = \log_2 \left( 1 + \frac{P_2|h_2|^2 + P_1|h_2|^2 + N_0,2}{P_1|h_2|^2 + N_0,2} \right)$$

The throughput of each UE can be controlled by adjusting the power ratio $p_1/p_2$ by BS.

![Figure 1: Basic NOMA applying SIC in downlink](image)

2.1 NOMA-Beamforming

In order to further increase the system capacity, the extension of NOMA by applying Beamforming (BF) has been proposed [10]. Fig. 2 shows the proposed NOMA-BF scheme in downlink. In this scheme, the BS generates multiple beams for different NOMA user groups. At UE receiver side, two interference cancellation schemes, i.e., SIC and interference rejection combining (IRC) [8], are jointly utilized. In the proposed scheme, SIC is used for intra-beam user multiplexing, which means interference cancellation among UEs belong to a group with same precoding weights. The multiple access scheme within this group is same with basic NOMA scheme. The IRC is used for inter-beam interference suppression among UE groups applying different precoding weights. However, the performance of IRC degrades when the spatial correlation between the desired and interference signals is large, which is similar to space division multiple access (SDMA) using an adaptive array antenna receiver [7]. Therefore, an appropriate user grouping scheme is required to optimize the system performance.
2.2 NOMA-Multiuser Scheduling

In NOMA, the scheduling affects the system capacity and user fairness (i.e., cell-edge average user throughput) greatly. The proportional fair (PF)-based scheduler [3] can achieve a good tradeoff between the sum average user throughput and the cell-edge average user throughput. In [11], in order to further enhance the user fairness, a weighted PF-based multiuser scheduling applying fractional frequency reuse (FFR) is proposed for NOMA. FFR [2], which allows users under different channel conditions to utilize different reuse factors, is a promising method for mitigating the inter-cell interference. In [4], a clustering algorithm is proposed for multiuser NOMA-BF system. This clustering algorithm, which selects two users with high channel correlation and a large channel gain difference, can reduce the interference from other beams and from the other user in the same beam as well. Another user grouping method, pre-defined user grouping, is presented in [1]. In which, the users are divided into different users groups according to their channel gains and the pre-defined thresholds. The users can be paired together only if they belong to different groups. Pre-defined user grouping can decrease the amount of signaling for NOMA downlink.

2.3 NOMA-Power Allocation

In NOMA, the power allocation to certain users affects the system performance due to inter-user interference. Therefore, the appropriate power allocation schemes are essential for NOMA. Reference [9] provides one optimal and two suboptimal methods for NOMA-power allocation. The optimal method applies the iterative water-filling power allocation algorithm [5] to achieve the maximized user throughput. However, due to the computationally complex of this optimal method, two simple but suboptimal power allocation schemes are considered.
The first method is the fixed power allocation. Assuming that users are sorted in order of the decreasing normalized channel gain, $|h_i|^2/N_0,i$. The $i$-th sorted user index is denoted as $\pi(i)$. The transmission power of user $\pi(i)$ is set to

$$p(\pi(i)) = \alpha_{fix}p(\pi(i + 1))$$

(3)

where $\alpha_{fix}(0 < \alpha_{fix} \leq 1)$ controls the system throughput and user fairness. As $\alpha_{fix}$ increases, the system tends to allocate more power to the users with good channel conditions.

The second method is fractional power allocation which is motivated by the fractional transmission power control for LTE uplink. In this method, power control compensates for a part of the variation in the channel conditions among users. The transmission power of user $i$ is

$$p(i) = p_{total}\left(\frac{|h_j|^2}{N_0,j}\right)^{-\alpha_{ft pc}}\left(\sum_{j=1}^{\pi(i) - 1}\frac{|h_j|^2}{N_0,j}\right)^{-1}$$

(4)

where $j$ is the interference user index and $\alpha_{ft pc}(0 \leq \alpha_{ft pc} \leq 1)$ is the decay factor. When $\alpha_{ft pc} = 0$, equal power allocation is achieved. As $\alpha_{ft pc}$ increases, more power is allocated to the user with a low channel gain $|h_i|^2/N_0,i$.

3 NOMA-MIMO Scheme with Practical SIC Schemes

3.1 System Model

We assume OFDM signaling although we consider non-orthogonal user multiplexing. Fig.3 illustrates the cell layout for the downlink NOMA-MIMO scheme of a 2-UE case. And Fig. 4 shows the block diagram of transmitter and receiver for the downlink NOMA-MIMO scheme. We assume there are 2 transmission antennas at the BS, in which each antenna transmits signal to 1 UE. The transmit signal $x_i$ for UE$i$ is

$$x_i = \sqrt{p_i}s_i$$

(5)

where $p_i$ is the allocated power, and $s_i$ is the transmitted data for UE$i$. After transmitting through a 2x2 channel $H$, the received signal $y_i$ for UE$i$ is represented as

$$y_i = H_{ii}x_i + \sum_{j \neq i} H_{ji}x_j + n_i$$

(6)

where $H_{ji}$ denotes the channel between the $j$-th antenna at BS to the $i$-th receiver, $x_j$ is the transmit signal for $UE_j$, which is the interference for $UE_i$, and $n_i$ is the Gaussian noise. After receiving, the signals are ranked for a decreasing order by the power. Channel estimation (CE) is performed for the interference signal $y_{ji}$ with the power $p_j > p_i$ (power of desired signal). Then, OSIC is employed until all the interference signal are cancelled. The estimated received signal is obtained for the $UE_i$. 
3.2 Practical OSIC Scheme

In this paper, we consider the practical OSIC schemes based on the zero-forcing (ZF) and the minimum mean squared error (MMSE) criteria. As in the system model, by assuming the power $p_2 \gg p_1$, the $UE_2$ can directly detect the signal without cancellation of the interference. For $UE_1$, the received signal $y_1$ is

$$y_1 = H_{11} \sqrt{p_1} s_1 + H_{21} \sqrt{p_2} s_2 + n_1 \quad (7)$$

where the interference is $H_{21} \sqrt{p_2} s_2$. We can get the weight factor of channel $H_{21}$, i.e., $\hat{H}_{21}$, by ZF or MMSE after getting the estimated channel $\tilde{H}_{21}$,

$$\hat{H}_{21}|_{ZF} = (\tilde{H}_{21} \tilde{H}_{21})^{-1} \tilde{H}_{21}, \hat{H}_{21}|_{MMSE} = (\tilde{H}_{21} \tilde{H}_{21} + \sigma_Z^2 I)^{-1} \tilde{H}_{21} \quad (8)$$

where $\sigma_Z^2$ is the noise variance. Then the estimated interference signal can be obtained as

$$\tilde{S}_2 \approx \sqrt{p_2} \tilde{H}_{21} y_1 = s_2 + \sqrt{p_2} \tilde{H}_{21} (H_{11} \sqrt{p_1} s_1 + n_1) \quad (9)$$

The received signal is updated by subtracting the estimated interference signal,

$$y'_1 = y_1 - \tilde{H}_{21} \sqrt{p_2} \tilde{s}_2 = H_{11} \sqrt{p_1} s_1 + n_1 \quad (10)$$

After the cancellation of interference signal with large power, $UE_1$ can detect the desired signal $s_1$ from the updated received signal.

4 Performance Analysis

We provide the link-level simulation with the bit error rate (BER) performance. The simulation parameters are summarized in Table I. Fig. 5 shows the BER comparisons of NOMA applying ideal and practical SIC schemes. From the simulation results, we can find that the BER performances become worse by applying practical OSIC schemes compared with perfect SIC situation, but which is acceptable in the low Eb/N0 area. MMSE-OSIC outperforms a little than ZF-OSIC in BER before 22dB of Eb/N0 value. And when Eb/N0 is larger than 22dB, the BER is similar between MMSE-OSIC and ZF-OSIC. However, due to the existing inter-user interference when the signal detection, the BER curve shows the error floor at high Eb/N0 area for both NOMA with perfect and practical SIC schemes. Therefore, more advanced signal detection scheme considering the existing inter-user interference is one of the topic for NOMA in practical cellular systems.

5 Conclusions

In this paper, we provide information for the state of the art technologies on NOMA. We also investigate the performance of NOMA under the consideration of practical OSIC schemes. The simulation results show that the BER of NOMA with practical OSIC degrades from the NOMA with perfect SIC. However, both of the NOMA schemes with perfect and practical SIC show the error floor of BER at high Eb/N0 area, which is due to the existing inter-user interference of signal detection. As a result, advanced signal detection schemes considering the existing inter-user interference are desired for applying NOMA in practical cellular systems.
Figure 5: BER performance of NOMA with perfect and practical SIC schemes

References


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