A Comparative Study of Perfect and Imperfect SIC in Downlink PD-NOMA based on Sharing Bandwidth

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Abstract. In this paper, a scheme for sharing bandwidth- non-orthogonal multiple access (SB-NOMA) based on coordinated multi-point (CoMP) is proposed to improve total sum capacity and user capacity. The proposed algorithm is implemented in a cellular network platform, and the performance is analysed via two cases. First, the network performance is evaluated considering both channel conditions and interference effects, which is addressed as the worst-case condition. The total network capacity is evaluated assuming Channel Estimation Error (CEE) and Imperfect Successive Interference cancelation (SIC). Second, the network is tested assuming ideal case condition materialized by canceling the effect of inter-channel interference (ICC) of the Base Station (BS) on Near User (NUE). The simulation results show that the capacity increases for SB-NOMA with installed by increasing the number of Cooperative BS (CBSs), where (2bits/Hz/s) is the gain in total capacity that is achieved by increasing the CBSs by one. Moreover, power allocation to the proposed scheme shown (0.15 - 0.85) represents the best value for maintaining capacity achievement.

Keywords: sharing bandwidth-domain non-orthogonal multiple access (SB-NOMA), coordinated multi-point (CoMP), successive interference cancelation (SIC), inter-channel interference (ICC), cooperative base stations (CBSs).

1. Introduction

The large increase in communications and multiple applications in various fields, such as big data traffic and the Internet of Things (IoT), require investigations from researchers over the next generation. It is required to improve the data rate, to meet the capacity requirements for 5G compared to 4G, where the data rate is 10 to 100 Gbps in 5G [1][2] and [3]. To achieve this data rate, researchers focus on designing non-orthogonal multiple access with power domain (PD-NOMA) technologies because of its high spectral efficiency, and among all the technologies, it is the best for 5G applications[4]. Also, PD-NOMA is...
known to be an important system in enabling massive networking such as the 5G network, because huge networks can not rely upon orthogonal multiple access (OMA) as shown in [5] and [6].

In downlink PD-NOMA, a different power is assigned to users within the same resource and two or more users are paired together using the same frequency, time, or spread code [7]. Also, those signals were multiplexed and superimposed into the power domain. This scheme implements successive interference cancellation (SIC) techniques on a user receiver to delete strong signals from weaker signal users. At the strongest signal user side, the user cannot implement the SIC and decode it is signal hence bearing in mind the users of the lowest signal as noise [8] and [9].

1.1 Literature and Motivation

Many studies on PD-NOMA were focused on one cell PD-NOMA, and the support was not enough to a Far User (FUE), whereas the multi-cell situation did not gain much interest. In [10], the authors used the same resource sharing which allowed total network or/and some users would have a huge capacity. Using PD-NOMA significantly increases capacity due it relying on a user set and power domain scheme that plays an essential role. However, the scheme is not sufficient for providing capacity when the number of users grows because the power ratio of the users converges, so that the SIC process cannot be performed optimally. Moreover, the performance decreases due to the difficulty of canceling the interference of the other user. At [11], a modern NOMA-assisted Cloud/Centralized radio access network (C-RAN) network was proposed. This showed that the proposed architecture could dramatically boost the efficiency of FUE. However, the performance of the FUE suffers from several BSs. In [12], researchers worked on the broadcast channel (BC) and multiple access channel (MAC) that depends on data sharing with two BS only for support of FUE. However, these techniques suffer from extreme intercellular interference (ICI), mainly with FUE. Moreover, FUE’s spectral efficiency of FUE with OMA performed best than NOMA when the FUE location is relatively close to BS due to the residual interference between the FUE of the NOMA transmission. While [13] focuses on the design of NOMA clustering schemes based on Power Allocation (PA) and User Equipment (UE) sorting. However, the ICI agnostic PA scheme is not sufficient for providing fairness due to the actuality that multiple cells produce ICI of each neighbouring cell that may cause the system to break down.

So, interference control of the multi-cell case needs to be researched. With the CoMP network, several BSs cover the users that enhance FUE performance by minimizing inter-cell interference. In [14], researchers worked on the CoMP NOMA scheme with superposition coding (SC) is proposed. Specifically, SC is used to support an FUE and users close to the BSs simultaneously. Also, dispersed analogy beamforming is shown the transmission to recognize the requirements of FUE operation efficiency. While CoMP NOMA’s performance without diversity techniques when serving the FUE user is much worse than that of the proposed NOMA scheme.

This study helps design sharing bandwidth non-orthogonal multiple access (SB-NOMA) from either a different point of view, via total sum capacity analysis, which illustrates the essential research of imperfect SIC and CEE. The contributions of this paper are as follows:

First, the FUE is paired between the NUE and other CBSs. The SB-NOMA system is investigated using imperfect CSI. While defects of the SIC process are also considered in the description of a CEE with the Rayleigh fading channel. Finally, the simulation and analysis results are described to provide the information efficiency of SB-NOMA, with and without CEE and SIC.
The rest of this paper is planned according to Section 2, which describes the SB-NOMA system. Section 3 offers explanations for the total sum capacity of NUEs and FUE. Then, Section 4 provides a detailed SB-NOMA performance analysis in the presence of CEE. Finally, Section 5 concludes this paper to sum up.

2. System Model

The adopted SB-NOMA system is shown in figure (1), where C presents the number of BSs. This model is simulated in two cases, where each case is tested with perfect and imperfect SIC taking into account CEE. The interference may be considered for case I when the other BSs effect NUE. In other words, the $r^{th}$ FUE is paired with the $j^{th}$ NUE, who receives a signal from several BSs and is considered to be Co-Channel Interference (CCI) from the NUE point of view. This case is referred to as a worst-case condition. While in case II, interference from other BSs with all paired NUE has been avoided, only FUE received signals and is considered to joint transmission from the CBSs, while the NUE is assumed to be protected from CCI. This is considered as the ideal network case condition, where significant capacity gain may be accomplished. This situation can be obtained by using an appropriate user grouping method for both NUE and FUE; accordingly, they can prevent the interference. Details of SB-NOMA parameters are assumed and provided in Table I. This scenario for SB-NOMA has been simulated and analyzed using a nemo software platform and Matlab.

![System Model](image.png)

Figure 1. A system model of SB-NOMA, NOMA, and OMA, with C=3[1].
Table 1. SB-NOMA PARAMETERS

| Parameter                                         | Value                      |
|---------------------------------------------------|----------------------------|
| Number of cells                                   | 3                          |
| Cell radius                                       | 1000 m                     |
| Channel model                                     | Rayleigh fading model       |
| Channel estimation                                | Perfect and imperfect       |
| Number of transmitter antennas BS and user        | 1                          |
| Number of receiver antennas BS and user           | 1                          |
| Power allocation factor for NEU and FUE           | 0.15 and 0.85              |
| Imperfect SIC (κ)                                 | −25 dB                     |
| BS height                                         | 5 m                        |
| Path loss exponent                                | 4                          |
| Bandwidth (BW)                                    | 1 MHz                      |

2.1 SB-NOMA with perfect SIC

In the SB-NOMA system, all users can share the same resources, which could be (a frequency, a time, or a spread code) [8]and[9]. For SB-NOMA scheme, let us suppose $G_r$, $1 \leq r \leq R$, represents the $r^{th}$ group of user to SB-NOMA system, that involves choosing one FUE and many NUEs. Choosing the only NUE of $G_r$ is represented with $\text{FUE}_r$, $1 \leq r \leq R$. To make the system matters easier, just a single BS needs to relate with one NUE. Therefore, a single SB-NOMA set depends on total C severe NUEs, and only FUE is shown in Figure 2. This user setting should keep the difference between the gains of the NUE and FUE channels. Note that keeping the gain of the channel difference between all users is a significant issue in maximizing capacity in the SB-NOMA scheme. The FUE$_1$ will share the same resource with NUE$_1$, NUE$_2$, and NUE$_3$ within the SB-NOMA group $G_1$, where FUE is considered to be users of the CoMP network, while NUE is considered not to be users of the CoMP network. Then SC is implemented through the SB-NOMA system for each $BS_i$. Finally, the following signal data is transmitted by $BS_i$ [3].

$$x_i = \sqrt{\beta_1 s_i} + \sqrt{\beta_2 s_r}$$ (1)

Where $s_i$ is the desired signal for NUE$_i$ from $BS_i$, $s_r$ is the desired signal for FUE$_r$, and $\beta_1$, $\beta_2$ is the normalized power allocation to $i^{th}$ and $r^{th}$ user with conditions $\beta_2 + \beta_1 = 1$ and $\beta_1 \leq \beta_2$, respectively. For ease, $\beta_1$ and $\beta_2$ are stable for all BS.
2.2 SB-NOMA Case I

2.2.1 Near User With Perfect SIC

In this system, the BS\textsubscript{i} served only NUE\textsubscript{i}, which means NUE\textsubscript{i} is taken into account not to be users of the CoMP network through any BS\textsubscript{i}. Additionally, that observed received signal for NUE\textsubscript{j}, can be represented as follows [1][7] and [13].

\[
y_j = \sum_{i=1}^{c} h_{ij} \left(\sqrt{\beta_1 s_i} + \sqrt{\beta_2 s_r} \right) + n_j \tag{2}
\]

\[
y_j = h_{ij} \left(\sqrt{\beta_1 s_j} \right) + \sum_{i \neq j}^{c} h_{ij} \left(\sqrt{\beta_1 s_i} + \sqrt{\beta_2 s_r} \right) + n_j \tag{3}
\]

Where \(h_{ij} \sim \text{CN}\left(0, \sigma_{ij}^2 \right)\) is denoted as BS\textsubscript{i} of observed NUE\textsubscript{i} channel coefficient following Rayleigh fading, \(d_{ij}\) distance between transmitting BS\textsubscript{i} and NUE\textsubscript{i}, path loss exponent parameter is denoted as \(\nu\), and \(n_j\) noise indicated at NUE\textsubscript{i}. Also, SIC is implemented for all select NUE\textsubscript{i} to delete the FUE received signal. When the FUE signal is completely isolated, then determined at NUE\textsubscript{i} written as follows [1] and [8].

\[
\text{SINR}_j = \frac{\beta_1 \rho |h_{ij}|^2}{\rho \sum_{i \neq j} \beta_i |h_{ij}|^2} \tag{4}
\]

Where \(\rho\) is denoted the transmit SNR and signal to interference noise ratio (SINR).

2.2.2 Far User With Perfect SIC

The signal received with the FUE measured is given as follows.
\[ y_r = \sum_{i=1}^{c} h_{i_r} \left( \sqrt{\beta_1} s_i + \sqrt{\beta_2} s_r \right) + n_r \]  

(5)

Where \( h_{i_r} \sim \text{CN}(0, \sigma_{i_r}^2) \) is referred to as the BSi channel coefficient to the FUEr, \( d_{i_r} \) distance between transmitting BSi and far user, and \( n_r \sim \text{CN}(0,1) \) denoted/ noise at FUEr. By applying the SB-NOMA system, the SINR meaning of the respective user is seen differently from (4) below:

\[ \text{SINR}_r = \frac{\beta_2 p \sum_{i=1}^{c} |h_{i_r}|^2}{\beta_1 p \sum_{i=1}^{c} |h_{i_r}|^2} \]  

(6)

2.2.3 SB-NOMA With Imperfect CSI and SIC

In the SB-NOMA system, Let us suggest that the calculated channel between BSi to NUEi and FUE is depicted as \( \hat{h}_{i,j} \) and \( \hat{h}_{i,r} \). The channel estimation error can be determined as [1]:

\[ \epsilon_{i,j} = h_{i,j} - \hat{h}_{i,j} \]  

(7)

\[ \epsilon_{i,r} = h_{i,r} - \hat{h}_{i,r} \]  

(8)

Where \( \epsilon_{i,j} \sim \text{CN}(0, \sigma_{\epsilon_{i,j}}^2) \) and \( \epsilon_{i,r} \sim \text{CN}(0, \sigma_{\epsilon_{i,r}}^2) \) is BS channel estimation errors, at NUE and FUE, respectively. Therefore, at the distribution of \( \hat{h}_{i,j} \) and \( \hat{h}_{i,r} \) can then be represented as \( \text{CN} \left( \hat{h}_{i,j} \right) \) and \( \text{CN} \left( \hat{h}_{i,r} \right) \), respectively. According to the channel estimation error, the received signal and the SINR calculation that can represent the following:

2.2.4 The Received Signals For The Near User

Total received BSi signals with CEE at the observed NUEj are given as [14]:

\[ y_j = \sum_{i=1}^{c} \left( \hat{h}_{i,j} + \epsilon_{i,j} \right) \left( \sqrt{\beta_1} s_i + \sqrt{\beta_2} s_r \right) + n_j \]  

(9)

\[ = \hat{h}_{i,j} \left( \sqrt{\beta_1} s_i + \sqrt{\beta_2} s_r \right) + \sum_{i \neq j} \hat{h}_{i,j} \left( \sqrt{\beta_1} s_i + \sqrt{\beta_2} s_r \right) + \epsilon_{i,j} \left( \sqrt{\beta_1} s_i + \sqrt{\beta_2} s_r \right) + n_j \]  

(10)

Where SINR is needed to decode the FUE signal at the NUE in the involvement of a CEE. And then, NUE’s SINR may be written to decode its own signal with CEE inclusion.
\[
SNIR_j = \frac{\beta_j \rho |h_{ij}|^2}{\beta_j \rho \sum_{i \neq j} |h_{ij}|^2 + \rho \sum_{i=1}^{c} \sigma_{e_{ij}}^2 + \rho \kappa}
\]  

(11)

Where \( \kappa \) is denoted remaining interference attributable to the NUE\(_{j} \) signal cannot be completely canceled at NUE\(_{j} \), because of estimation error during SIC operation. Imperfect SIC can occur due to errors in the channel’s estimation, poor pairing, and/or errors in the SIC method.

### 2.2.5 The Received Signals For The Far User

Total received BSI signals with CEE at the observed FUE\(_{r} \) are given as [14]:

\[
y_r = \sum_{i=1}^{c} (\hat{h}_{i,r} + \epsilon_{i,r}) \left( \sqrt{\beta s_i} + \sqrt{\beta s_{r}} \right) + n_r.
\]

(12)

At FUE it is necessary to detect the multiple needed signals from any CBSs. Then, The FUE must, therefore, measure the received signals from all coordinated BSI. When the CEE occurs, the FUE\(_{r} \) from SINR is indicated as [2] [9] and [14].

\[
SNIR_{r} = \frac{\beta_2 \rho \sum_{i=1}^{c} |\hat{h}_{i,r}|^2}{\rho \sum_{i=1}^{c} \left( \beta_1 |\hat{h}_{i,j}|^2 + \sigma_{e_{i,r}}^2 \right)}
\]

(13)

From which SNIR\(_{r} \) is referred to as SINR at FUE\(_{r} \) to remove signal by looking at the whole group NUE\(_{s} \) as signal interference.

### 2.3 SB-NOMA Case II

In this case, FUE SINR can be determined as in the case I, for all circumstances (perfect and imperfect SIC with CEE). In contrast, NUE is assumed to perfectly canceling CCI. Hence NUE’s SINR, in this case, can be determined as follows:

#### 2.3.1 Near User With Perfect SIC

The NUE with case II, when the FUE signal is completely removed, the NUE\(_{i} \) SINR can be determined as follows [9]:

\[
\text{SINR}_i = \frac{\beta_1 \rho |h_{ij}|^2}{n_j}
\]

(14)

#### 2.3.2 Near User With Imperfect SIC

One received BS signal with CEE where SINR is needed to decode the FUE signal at the NUE in a CEE involvement. And then, NUE’s SINR may be written to decode its own signal with the inclusion of CEE can be determined as follows [7] and [14].
3. Total Sum Capacity Analysis

In this system, find total sum capacity from the SB-NOMA suggested over Rayleigh fading channel is implemented. These can be obtained by setting the CEE variance to zero for perfect CSI. For every group observed in SB-NOMA, NUE, with and without any BS interference.

3.1 SB-NOMA Case I

3.1.1 Sum Capacity of NUE

Given SINR instant obtained in (12). The capacities of the measured NUE$_j$ are written as follows

$$C_{j,NUE} = \log_2 \left( 1 + \frac{\beta_1 \rho |h_{j,j}|^2}{\rho \sum_{i \neq j}^c |\hat{h}_{i,j}|^2 + \rho \sum_{i=1}^c \sigma_{\epsilon_{i,j}}^2 + \rho \kappa} \right)$$

(16)

3.1.2 Sum Capacity of FUE

The FUE has used the SB-NOMA scheme involving $C$ total of BSs to increase spectral efficiency. To achieve, the FUE must also estimate the $C$ number of system signals, which may increase the probability of CEE. The capacities of the measured FUE$_r$ are written as follows [2].

$$C_{FUE} = \log_2 \left( 1 + \frac{\beta_2 \rho \sum_{i=1}^c |\hat{h}_{i,r}|^2}{\rho \sum_{i=1}^c \left( \beta_1 |\hat{h}_{i,r}|^2 + \sigma_{\epsilon_{i,r}}^2 \right)} \right)$$

(17)

3.2 SB-NOMA Case II

3.2.1 Sum Capacity of NUE

Given SINR instant obtained in (15). The capacities of the measured NUE$_j$ are written as follows

$$C_{j,NUE} = \log_2 \left( 1 + \frac{\beta_1 \rho |h_{j,j}|^2}{\rho \sum_{i=1}^c \sigma_{\epsilon_{i,j}}^2 + \rho \kappa} \right)$$

(18)
3.3 SB-NOMA Total Sum Capacity

That rth set with Gr, for SB-NOMA total sum capacity ensures overall C+1 involving users of FUER and NUEj is written as follows

\[ C_{\text{sum}} = C_{r,FUE} + \sum_{j=1}^{c} C_{j,NUE} \] (19)

4. Results and Analysis

This part details the results of SB-NOMA to enhance the total sum capacity with BSs. Increasing the number of CBSs gains more capacity enhancement, as seen in figure 3. It is shown that SB-NOMA with (C=3) still performs better than (C=2) in SB-NOMA for all the group NEUs despite interference from the other BSs. For SB-NOMA, it has been shown that the total capacity difference between perfect and imperfect SIC (with CEE = 0.01 and transmit SNR 25 dB) is around 5 bits / Hz / s, while for SB-NOMA (C = 2) with the same network condition is 3 bits / Hz / s. There is also a consistent dynamic for all NUEs, with perfect interference cancellation from the other BSs in case II. This implies that it is still possible to increase the sum capacity by growing CBS numbers in SB-NOMA. Comparing the results of the case I and II indicate that, the maximum total capacity equals 25 bits/ Hz / s can be gained at case II with C=3 and 30 dB of transmitting SNR. At the same network conditions, the maximum total capacity equals to 19 bits/ Hz / s is gained in case I.

![Figure 3. Total sum capacity assessment with two cases of SB-NOMA, (a) Case I, (b) Case II.](image)

The effect of the power allocation ratio to NUE and FUE SB-NOMA with error in channel estimation is assessed in figure 4. For \( \sigma_{e}^{2} = 0.05 \), the result shows that NUE1 is greater than FUE1 in term of capacity if the power allocation of FUE1 is less than 0.92. Hence, the FUE requirements to be assigned with very much higher power allocation than NUE (\( \beta_2 > \beta_1 \)).
Figure 5 discusses the total sum capacity relation for SB-NOMA at $C = 3$ and $C = 2$, showing the effect of CEE over different SNR transmission levels. Despite that organized BS can lead to increased interference and CEE, SB-NOMA with $C = 3$ outperforms $C = 2$ for all CEE values and different SNR situation. Also, figure 5 shows that a CEE provides significant degradation of the capacity at high-level $\rho$ versus low-level $\rho$. With $C = 3$, that degraded for total sum capacity around 2.9 and 3.66 when CEE increased from $\sigma^2_0 = 0.015$ to $\sigma^2_0 = 0.045$ with $\rho = 20$dB and $\rho = 30$dB respectively. Additionally, taking advantage of the PD-NOMA platform, even more enhancement of the sum capacity can still be increased by adjusting organized BSs across SNR and all CEE parameters.

Figure 5. Sum capacity assessment over different power allocation (case I),(a) NUE,(b) FUE.

Figure 5. Total sum capacity assessment over different SNR (case I),(a) $C=2$,(b) $C=3$. 
In figure 6, FUE and NUE sum capacity, in contrast with the impact of CEE and increasing the number of CBS's are depicted. The NUE1 SB-NOMA with \( C = 2 \) outperforms NUE1 SB-NOMA with \( C = 3 \) at the whole CEE condition. Therefore, NUE1 at three CBS needs more accurate signals estimated. Also, by increasing the number of CBS, FUE with \( C = 3 \) has a higher capacity than \( C = 2 \) because FUE with \( C = 3 \) shares the available resource with all CBS.

![Figure 6. Sum capacity comparison of NUE1 and FUE in case I.](image)

5. Conclusion

In this paper, SB-NOMA is simulated and analysed for both perfect and imperfect SIC at the system level. The analyses considered the channel condition materialized by case I when the other BSs affect NUE in terms of CCI, while in case II, interference from other BSs with all paired NUE has been avoided. The analytical methods for NUE, FUE’s total capacity, are based on assessing the system within two and three cells. The results suggest that SB-NOMA case II performs better the case I mainly if FUE is organized between NUEs without ICI. The SB-NOMA may be further improved by growing its capacity number of CBSs, for SIC situations both perfect and imperfect. It is observed that SB-NOMA with three CBS growth capacity more than two CBS with SB-NOMA. The power allocation factor is essential for SB-NOMA also. The result of power allocation to the proposed scheme shown (0.15 - 0.85) represents the best value for maintaining capacity achievement; FUE requires better-allocated power than NUE. Furthermore, seen that the CEE and imperfect SIC can give rise to a breakdown of SB-NOMA for the total sum capacity. The effect of the CEE at FUE is less insignificant than at NUE since using the received signal from across all CBS.

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