Virtual User Pairing Non-Orthogonal Multiple Access in Downlink Coordinated Multipoint Transmission

Denny Kusuma Hendraningrat, Muhammad Basit Shahab, and Soo Young Shin, *Senior Member, IEEE*

**Abstract**

In this paper, joint transmission coordinated multipoint (JT-CoMP) is exploited by using virtual user pairing non-orthogonal multiple access (VP-NOMA), termed as JT-CoMP VP-NOMA. The technique combines both VP-NOMA for enhancing ergodic sum capacity (ESC) and JT-CoMP for inter-cell interference mitigation. To show the performance gains, ESC of a three-cell scenario is analyzed as a key performance metric. The analytical and simulation results of JT-CoMP VP-NOMA are compared with orthogonal multiple access (OMA), non-orthogonal multiple access (NOMA), and VP-NOMA. It is shown that the proposed JT-CoMP VP-NOMA outperforms the other schemes in the viewpoint of ESC.

**Index Terms**

Non-orthogonal multiple access (NOMA), coordinated multipoint (CoMP), virtual user pairing, ergodic sum capacity (ESC).

**I. INTRODUCTION**

FIFTH generation of cellular technology (5G) is the next phase of mobile telecommunication standard which aims at higher performance gains compared to existing 4G [1],[2]. Among many candidate technologies for 5G, non-orthogonal multiple access (NOMA) has recently gained much research interest as a candidate MA technique for 5G and beyond, which focuses on improving the spectrum efficiency by supporting multiple users over a particular channel resource, unlike conventional orthogonal MA (OMA) schemes [3]-[5]. The signals of multiple users are superimposed in the power domain, where successive interference cancellation (SIC) is used...
at the receivers for data recovery [6],[7]. Most of the works on NOMA pair a near user with a far user, where equal number of near and far users is assumed, so that each user can find a pair. However, the distribution of users in a cell is random in general; number of far users can be more than near users or vice versa. In [8]-[10], a virtual user pairing based NOMA (VP-NOMA) was suggested by considering a scenario with more far users than near users. In such scenario, VP-NOMA pairs a single near user with multiple far users over non-overlapping frequency bands. The analysis however was performed for a single cell scenario.

In multi-cell scenarios, inter-cell interference is one of the critical issues as it degrades the system performance i.e., user throughput and cell capacity. Therefore, inter-cell interference mitigation techniques are critical in multi-cell scenarios [11]-[16]. In this context, joint transmission coordinated multi-point (JT-CoMP) has emerged as an important technology, where multiple BS in the neighboring cells cooperate with each other to support a common cell edge (far) user, thereby improving its achievable throughput.

The existing works on JT-CoMP in multi-cell scenarios consider one near user in each neighboring cell, while a single common far user. This is true if we assume less number of far users compared to the near users in the network, which is not always true. By considering a three-cell NOMA scenario, where each neighboring cell has a NOMA pair (a near and a far user), such that the system model now contains three near and three far users, a JT-CoMP VP-NOMA scheme is proposed to enhance the performance of JT-CoMP.

The main contributions of this paper are listed as follows.

- This paper proposes a JT-CoMP VP-NOMA scheme by applying JT-CoMP on a generalized system model where each neighboring cell employs VP-NOMA.
- As conventional CoMP systems consider one common far user supported by neighboring BS [13],[14], the proposed work supports multiple users located in the cell edge, which is more suitable considering NOMA.
- Closed-form solutions of ESC for the proposed JT-CoMP VP-NOMA are analyzed, and compared with OMA, NOMA, and VP-NOMA by considering imperfect SIC [17] and imperfect channel state information (CSI) [18].

The rest of this paper is organized as follows: Section II presents the considered system model for JT-CoMP VP-NOMA, while the associated transmission protocol is explained in Section III. Closed-form solution for the ESC through comprehensive mathematical analysis is provided in Sec IV. Section V provides simulation results and discussion. Finally, Section VI concludes the
II. System Model

In [11]-[16], CoMP as an interference avoidance scheme based on cell coordination is discussed. In addition, JT-CoMP coordinates more than one transmit BSs to serve a specific user [13]-[16]. So, it is expected not only to mitigate inter-cell interference for CoMP-users but also may increase capacity performance.

This paper proposes JT-CoMP VP-NOMA by combining VP-NOMA [8]-[10] and JT-CoMP for a NOMA cluster [16]. In the system model, we consider a three-cell scenario, where each cell consists of a BS, one near user and one far user; cell-1→(BS1, UE1, UE_A), cell-2→(BS2, UE2, UE_B), cell-3→(BS3, UE3, UE_C), as shown in Fig. 1. The users with integer subscripts are near users, whereas those with alphabetical subscripts are far users. The BS to user distance is defined as \( r_{ij} \), where \( i \in 1,2,3 \) represents the \( i \)th BS, and \( j \in 1,2,3 \) represents the \( j \)th user [19]. Furthermore, \( r_{ik} \) is \( UE_k (k \in A,B,C) \) distances from BS\(_i\). The maximum cell radius is normalized to \( R = 1 \). The distances \( d_{ij} \) and \( d_{ik} \) between users and BS antenna are calculated by using the concepts of trigonometry [19].

Based on [8]-[10], we implement a virtual user pairing scheme by pairing a near user \( UE_j \) with three far users \( UE_A, UE_B, \) and \( UE_C \). In the system model, we consider that the three far users receive signals from all BSs.

III. Transmission Protocol

Considering the system model in Fig. 1, transmission protocol of proposed scheme is shown in Fig. 2d. Each BS pairs its near user with all the three far users using VP-NOMA, such that near user gets the whole bandwidth while the three far users get non-overlapping parts of the whole bandwidth [8]-[10]. The same pattern is repeated in all the neighboring cells. In each cell, the near user performs SIC to recover its message signal, where as far users try to directly decode their signals by treating near user’s low power signal as noise. Since perfect knowledge of CSI is not always possible, so imperfect CSI and correspondingly imperfect SIC process need to be considered at each \( j^{th} \) near user. Imperfect CSI is modeled with channel estimation error, where a priory of variance of the error estimation is known. The channel estimation error for the near user can be modeled as \( h_{eij}=h_{ij}-\hat{h}_{ij} \). In addition, channel estimation error for the far user can be
written as $h_{\epsilon ik} = h_{ik} - \hat{h}_{ik}$. It is assumed channel over each link is independent Rayleigh flat fading with channel coefficients $h_{ij} \sim CN(0, \sigma_{ij})$, and $h_{\epsilon ik} \sim CN(0, \sigma_{\epsilon ik})$.

In wireless transmission, received power for the $UE_j$ need to consider as channel estimation gain $|\hat{h}_{ij}|^2$, where $\hat{h}_{ij}$ represents a channel estimation characteristic from the BS$_i$ antenna to the $UE_j$. In this paper, the channel estimation characteristic for the near user can be modeled as

Fig. 1. System model

Fig. 2. Considered scenarios: (a) OMA, (b) NOMA, (c) VP-NOMA, and (d) JT-CoMP VP-NOMA
\( \hat{h}_{ij} \sim CN \left( 0, \hat{\sigma}_{ij} = d_{ij}^{-v} - \sigma_{\varepsilon ij} \right) \) with mean zero and estimation variance \( \hat{\sigma}_{ij} \) for the link from BS\(_i\) antenna to UE\(_j\), where \( v \) represents the path-loss exponent and \( \sigma_{\varepsilon ij} \) represents the variance of the error estimation parameter for the link from BS\(_i\) antenna to UE\(_j\). In addition, we need consider \( |\hat{h}_{ik}|^2 \) as a channel estimation gain from \( d_{ik} \), where channel estimation characteristic for the far user can be written as \( \hat{h}_{ik} \sim CN \left( 0, \hat{\sigma}_{ik} = d_{ik}^{-v} - \sigma_{\varepsilon ik} \right) \).

Considering cell-1, if we normalize total bandwidth with \( B = 1 \), then \( B_1 = B_2 = B_3 = \frac{B}{2} \), such that \( B_1 \cap B_2 \cap B_3 = \emptyset \), and \( B_1 + B_2 + B_3 = B = 1 \). Furthermore, we normalize total transmit power of BS by \( P = 1 \), and denote transmit SNR by \( \rho = \frac{P}{N_0} \), where \( N_0 \) represents AWGN. In this scenario, the BS power is divided for four users. If we assign \( \alpha \) as a power allocation factor for the near user (non-CoMP user) in each cell, and \( \beta \) as a power allocation factor for the far user (CoMP user) in each cell, then \( \beta = \left(1 - \alpha \right) \frac{3}{2} \), where \( \beta > \alpha \) and \( \alpha + 3\beta \leq 1 \). In addition, \( P_j = \alpha P \) and \( P_k = \beta P \) represent power allocation for the near and far user, respectively.

**IV. Ergodic Sum Capacity Analysis**

In this section, we determine the ESC performance of JT-CoMP VP-NOMA scheme by considering imperfect CSI and imperfect SIC. First, we calculate the achievable data rate of the near user in the sub-carrier \( B_1 \) as follows:

\[
C_{j \to B_1} = B_1 \log_2 \left( 1 + \frac{\alpha \rho |\hat{h}_{jj}|^2}{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1} \right)
\]

\[= B_1 \log_2 \left( \frac{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1}{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1} \right) \]

where \( \gamma \) denotes residual interference, representing imperfect SIC at the near user.

By using \( \log_n(x/y) = \log_n(x) - \log_n(y) \), (1) can be rewritten as

\[
C_{j \to B_1} = B_1 \left\{ \log_2 \left( \frac{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1}{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1} \right) \right. \\
- \log_2 \left( \frac{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1}{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{ij}|^2 + \rho \sum_{i=1}^{3} \sigma_{\varepsilon ij} + \rho \gamma + 1} \right) \right\}.
\]
In addition, the achievable data rate of $UE_A$, getting signals from all three BSs over the bandwidth $B_1$, can be calculated as

$$C_{A \rightarrow B_1} = B_1 \log_2 \left( 1 + \frac{\beta \rho \sum_{i=1}^{3} |\hat{h}_{iA}|^2}{\alpha \rho \sum_{i=1}^{3} |\hat{h}_{iA}|^2 + \rho \sum_{i=1}^{3} \sigma_{eiA} + 1} \right). \quad (3)$$

Hence, the achievable sum rate $C_{123A}^{\text{erg}}$ of sub-carrier $B_1$ is given as

$$C_{123A}^{\text{erg}} = \sum_{j=1}^{3} C_{j \rightarrow B_1} + C_{A \rightarrow B_1}. \quad (4)$$

Similarly, we can determine achievable sum rate in sub-carrier $B_2$ and $B_3$. Therefore, total ESC for all users is given as

$$C_{\text{total}}^{\text{erg}} = C_{123A}^{\text{erg}} + C_{123B}^{\text{erg}} + C_{123C}^{\text{erg}}. \quad (5)$$

Furthermore, from (2), the exact ergodic capacity $C_{j \rightarrow B_1}^{\text{exact}}$ in sub-carrier $B_1$ can be calculated by solving

$$C_{j \rightarrow B_1}^{\text{exact}} = E\{C_{j \rightarrow B_1}\}$$

$$= B_1 \left\{ \int_{0}^{\infty} \log_2 (x + a) f_{X_j}(x) dx - \int_{0}^{\infty} \log_2 (y + a) f_{Y_j}(y) dy \right\}, \quad (6)$$

where $E$ is expectation operator, and $a = \rho \sum_{i=1}^{3} \sigma_{ej} + \rho \gamma + 1$.

Therefore, by using the probability density function of $f_{X_j}(x)$ and $f_{Y_j}(y)$ which are derived in [19], $C_{j \rightarrow B_1}^{\text{exact}}$ in sub-carrier $B_1$ can be calculated as

$$C_{j \rightarrow B_1}^{\text{exact}} = \frac{B_1}{\ln(2)} \left\{ \sum_{i=1}^{3} (\ln(a) - \exp(ak_{ij}) \text{Ei}(-ak_{ij})) \times \prod_{\substack{h=1 \atop h \neq i}}^{3} \frac{k_{hj}}{k_{hj} - k_{ij}} ight. \left. - \sum_{i=1}^{3} (\ln(a) - \exp(ak_{ij}) \text{Ei}(-ak_{ij})) \times \prod_{\substack{h=1 \atop h \neq i \atop h \neq j}}^{3} \frac{k_{hj}}{k_{hj} - k_{ij}} \right\}, \quad (7)$$

where $k_{ij} = \frac{1}{\alpha \rho \hat{\sigma}_{ij}}$ and $k_{hj} = \frac{1}{\alpha \rho \hat{\sigma}_{hj}}$. 
Similarly, by assuming $b = \rho \sum_{i=1}^{3} \sigma_{e_{ij}} + 1$, we can calculate the achievable data rate for $UE_A$ as

$$C_{A\rightarrow B_1}^{\text{exact}} = \frac{B_1}{\ln(2)} \left\{ \sum_{i=1}^{3} (\ln(b) - \exp(b l_{iA}) E_{i}(-b l_{iA})) \times \prod_{h=1, h\neq i}^{3} \frac{l_{hA}}{l_{hA} - l_{iA}} - \sum_{i=1}^{3} (\ln(b) - \exp(b m_{iA}) E_{i}(-b m_{iA})) \times \prod_{h=1, h\neq i}^{3} \frac{m_{hA}}{m_{hA} - m_{iA}} \right\},$$

(8)

where $l_{iA} = \frac{1}{(\alpha+\beta) \sigma_{iA}^2}$, $l_{hA} = \frac{1}{(\alpha+\beta) \sigma_{hA}^2}$, $m_{iA} = \frac{1}{\alpha \rho \sigma_{iA}^2}$, and $m_{hA} = \frac{1}{\alpha \rho \sigma_{hA}^2}$.

By combining (4), (5), (7) and (8), ESC for all users can be calculated as

$$C_{\text{total}}^{\text{exact}} = C_{123A}^{\text{exact}} + C_{123B}^{\text{exact}} + C_{123C}^{\text{exact}}.$$  

(9)

V. SIMULATION RESULTS AND DISCUSSION

In this section, we analyze the ESC of the proposed scheme in comparison with the conventional benchmark techniques.

Fig. 3 shows the simulation and analytical results for the ESC of JT-CoMP VP-NOMA in comparison with OMA, NOMA, and VP-NOMA. The results show that ESC of JT-CoMP VP-NOMA is higher than other schemes. This is because using both JT-CoMP and VP-NOMA
Fig. 4. Ergodic sum capacity of JT-CoMP VP-NOMA with respect to $U/E_1$ distance from $BS_1$ ($r_{11}$), and $\alpha=0.1$

Fig. 5. Ergodic sum capacity of JT-CoMP VP-NOMA with respect to power allocated for the near user ($\alpha$), and $r_{11}=0.5R$

together ensures better spectrum usage, and better interference management simultaneously, thereby enhancing the overall performance of the proposed scheme.

Fig. 4 shows the effect of user locations on the performance of the proposed scheme. Far users are kept fixed. Near users are initially close to the BS, and then moved away from the BS (towards the far users). It can be seen that JT-CoMP VP-NOMA achieves higher ESC if the distance between near and far user is large. When the near user moves towards the cell edge, the system capacity gets degraded. This is due to increased mutual interference between users and channel degradation of near user. Finally, Fig. 5 shows the effect of power allocation factors on
the ESC of the proposed scheme. The power allocation factor of near users is increased, which increases the overall capacity of the system, which is in line with the existing literature.

VI. CONCLUSION

In this paper, we propose a JT-CoMP VP-NOMA scheme to increase the ESC of a multicell NOMA system. The simulation results show that proposed JT-CoMP VP-NOMA achieves higher ESC compared to OMA, NOMA, and VP-NOMA. Moreover, ESC for proposed system increases if the power allocated for the near user and distance between the near user and the far user are increased.

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