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A Novel Opportunistic NOMA in Downlink Coordinated Multi-Point Networks

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Abstract—The non-orthogonal multiple access (NOMA) is regarded as a promising multiple access technique for 5G networks. In this research, we consider the joint transmission (JT) NOMA for a Coordinated Multi-Point (CoMP) system, and propose a novel opportunistic NOMA (ONOMA) scheme. This aims to improve the efficiency of the successive interference cancellation (SIC) decoding in conventional NOMA. Besides, by comparing with the JT-NOMA in CoMP system, the data rate of the ONOMA is shown in the numerical results under the ideal and non-ideal scenarios.

I. INTRODUCTION

Coordinated Multi-Point (CoMP) transmission is currently an area of intensive research, as this is considered as one of the key technology enhancements for LTE-A. However, as the number of cell-edge users increases, the spectral efficiency of the CoMP system degrades [1], [2]. Recently, a promising non-orthogonal multiple access (NOMA) scheme was proposed for CoMP in an attempt to address this problem [3].

The NOMA technique has been recognized as a promising multiple access techniques for 5G networks because of its superior spectral efficiency [4]. By using NOMA, which combines the superposition coding (SC) at transmitters with the successive interference cancellation (SIC) at receivers [5], [6], all the users in CoMP system are able to decode their desired signal even though they are sharing a same frequency channel at same time. This approach can offer significantly enhanced spectrum efficiency.

The complexity of SIC in NOMA and the number of users in CoMP system is always directly proportional. Thus, the successive manner of SIC becomes complicated and intense for a large numbers of users. In order to reduce the complexity of SIC decoding and meanwhile to improve the capacity of the CoMP system, we propose an opportunistic NOMA (ONOMA) scheme. According to our numerical results, it is obvious that when comparing the JT-NOMA with the ONOMA, we can reduce the complexity of SIC at receivers, and also significantly enhance the capacity of the CoMP system in the high signal-to-interference (SIR) scenarios.

II. NOMA IN CoMP

We consider a downlink CoMP network which includes B single-antenna access points (APs) and K single-antenna users. Let $\mathbf{h}_{k,b}$ denote the channel from the b^{th} AP to the k^{th} user, and $\mathbf{h}_{k,b}$ is the i.i.d circular symmetric complex Gaussian random variable, representing Rayleigh fading; \mathbf{s}_k and \mathbf{n}_k denote the k^{th} user's desired message and white Gaussian

noise with variance σ_z^2 respectively. We assume that: (a) all APs have the perfect channel state information (CSI) of all users (b) each user can estimate the channel perfectly via the reference signal (c) the power of \mathbf{s}_k is normalised.

A. Joint Transmission NOMA (JT-NOMA) in CoMP

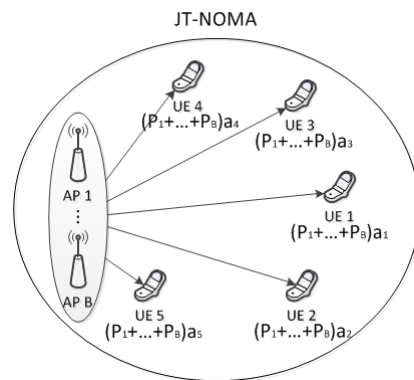


Figure 1. JT-NOMA in CoMP

For the JT-NOMA in CoMP, the APs will jointly transmit the signal to the target users (as shown in Fig.1); more specifically, the b^{th} AP ($1 \leq b \leq B$) in CoMP broadcasts $\sum_{i=1}^K \sqrt{a_i P_b} \mathbf{s}_i$ to the K users, where P_b denotes the normalised transmit power at b^{th} AP and a_i denotes the power allocation coefficient (PAC) to \mathbf{s}_i . According to the JT-CoMP [1], we assume that all APs will allocate the same transmit power to \mathbf{s}_i , where $a_i P_1 = \dots = a_i P_B = a_i \mathcal{P}$, then the observation at the k^{th} user ($1 \leq k \leq K$) is given by

$$\mathbf{r}_k = \sum_{i=1}^K \hat{\mathbf{h}}_k \sqrt{a_i \mathcal{P}} \mathbf{s}_i + \mathbf{n}_k \quad (1)$$

where $\hat{\mathbf{h}}_k$ is the equivalent channel coefficient to the k^{th} user and $\hat{\mathbf{h}}_k = \sum_{b=1}^B \mathbf{h}_{k,b}$. Without loss of generality, we assume that: $|\hat{\mathbf{h}}_1|^2 \leq \dots \leq |\hat{\mathbf{h}}_K|^2$. According to the SC in NOMA, the PACs to the K users are sorted as: $a_1 \geq \dots \geq a_K$; then each receiver employs the SIC technique and is able to perfectly decode the messages of the users in the weaker channels [5], [6]. For example, the messages from \mathbf{s}_1 to \mathbf{s}_{k-1} can be detected by the k^{th} user in sequence: when the k^{th} user is detecting the \mathbf{s}_i ($i < k$), the messages from \mathbf{s}_{i+1} to \mathbf{s}_K will be treated as noise at the k^{th} user; before detecting the \mathbf{s}_{i+1} , the \mathbf{s}_i will be removed from its observation.

As a result, the required successive times of SIC (I) for the K users are sorted as: $I_1 \leq \dots \leq I_K$. At user k , the rate of detecting s_k is given by

$$R_k = \log \left[1 + \frac{|\dot{\mathbf{h}}_k|^2 a_k}{\sum_{m=k+1}^K |\dot{\mathbf{h}}_k|^2 a_m + \sigma^2 \mathcal{P}^{-1}} \right] \quad (2)$$

The K users' sum-rate for conventional JT-NOMA network can be expressed as

$$R_{sum} = \sum_{k=1}^{K-1} \left\{ \log \left(1 + \frac{|\dot{\mathbf{h}}_K|^2 a_K}{\sigma^2 \mathcal{P}^{-1}} \right) \right. \quad (3)$$

$$\left. + \log \left(1 + \frac{|\dot{\mathbf{h}}_k|^2 a_k}{\sum_{m=k+1}^K |\dot{\mathbf{h}}_k|^2 a_m + \sigma^2 \mathcal{P}^{-1}} \right) \right\} \quad (4)$$

where the term in (3) is the data rate of the user in the weakest channel.

B. Opportunistic NOMA Strategy in CoMP

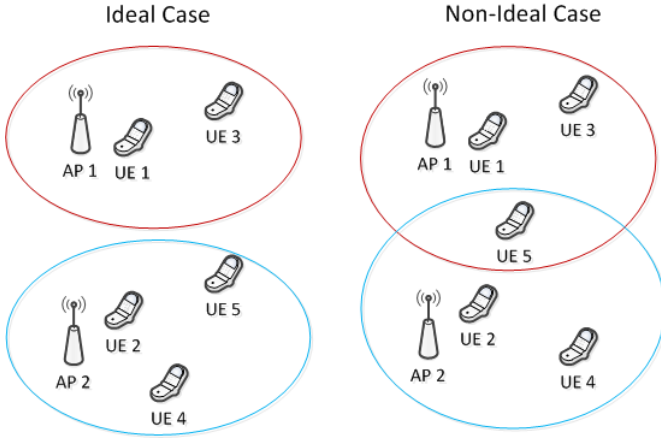


Figure 2. Ideal case and non-ideal case of ONOMA in CoMP system

Let $P_{k,b}$ denote the transmit power allocated to s_k on the b^{th} AP, where $P_{k,b} = a_k \mathcal{P}$ and $P_{min} \leq P_{k,b} \leq P_{max}$. The opportunistic NOMA transmission cells (ONOMA cell) will be generated via the following steps:

- **Step 1.** The B APs separately broadcast the reference signal s_r to the K users, with transmit power P_{max} .
- **Step 2.** Via the B reference signals, each user generates the first reference power matrix (FRPM). The k^{th} user's FRPM is expressed as $\eta_k = \{P_{max} |\mathbf{h}_{k,1}|^2, \dots, P_{max} |\mathbf{h}_{k,B}|^2\}$, where the maximum element is denoted as η_k^{max} .
- **Step 3.** The B APs separately broadcast the reference signals again, with transmit power P_{min} .
- **Step 4.** Each user generates the second reference power matrix (SRPM). The k^{th} user's SRPM is expressed as $\hat{\eta}_k = \{P_{min} |\mathbf{h}_{k,1}|^2, \dots, P_{min} |\mathbf{h}_{k,B}|^2\}$, where the minimum element is denoted as $\hat{\eta}_k^{min}$.
- **Step 5.** Each user implements **Algorithm 1** to generate its APs selection set (APSS), and feeds it back to the B APs. The APSS of the k^{th} user, which is denoted as λ_k ,

indicates the indexes of the APs that are preferred by the k^{th} user.

- **Step 6.** Based on the APSS-feedbacks, the b^{th} AP adds the indexes of the users that select it in their APSSs, into its user schedule set (USS), ω_b .
- **Step 7.** The CoMP system generates ONOMA cells based on the USSs and inform the k^{th} user with $\{\omega_b, b \in \lambda_k\}$.

Let Ψ_k denote the interference from the inter-NOMA cells, which do not have the overlapping area with the k^{th} ONOMA cell, then the observation at k^{th} user is given by

$$r_k = \sum_{b \in \lambda_k} \mathbf{h}_{k,b} \sum_{i \in \omega_b} \sqrt{a_i \mathcal{P}} s_i + \Psi_k + n_k \quad (5)$$

where $\Psi_k = \sum_{j=1, j \notin \lambda_k}^B \mathbf{h}_{k,j} \sum_{n \in \omega_j} \sqrt{a_n \mathcal{P}} s_n$.

Remark 1. The b^{th} ONOMA cell includes the b^{th} AP and the users in ω_b .

Algorithm 1 Opportunistic APSS Generation Algorithm

Initialization.

Input: η_k , $\hat{\eta}_k$, $\lambda_k = \text{null}$ and $n = 1$.

if $\hat{\eta}_k^{min} > \eta_k^{max}$ (e.g. $P_{min} |\mathbf{h}_{k,q}|^2 > P_{max} |\mathbf{h}_{k,p}|^2$),
add the index of $\hat{\eta}_k^{min}$ to λ_k (e.g. $\lambda_k = \{q\}$);

else

for $n = 1 : K$,

compare $\eta_k\{n\}$ with $\hat{\eta}_k^{min}$

if $\eta_k\{n\} > \hat{\eta}_k^{min}$

add n to λ_k

else

$\lambda_k = \lambda_k$

end for

output: λ_k

1) *Ideal Case:* For the ideal case, each UE only selects one AP in APSS, so that there is no overlapping area between the different NOMA cells, as the example shown in Fig. 2. In such case, the b^{th} AP only implements NOMA strategy to the users in ω_b , and the USSs of the 2 APs are expressed as $\omega_1 = \{1, 3\}$ and $\omega_2 = \{2, 4, 5\}$, respectively. The transmitted signal from the 1st ONOMA cell may cause the interference to the 2nd ONOMA cell, however, as the maximum power of the interference signal is smaller than the minimum power of the desired signal (e.g. $P_{min} |\mathbf{h}_{1,1}|^2 > P_{max} |\mathbf{h}_{1,2}|^2$ or $P_{min} |\mathbf{h}_{4,2}|^2 > P_{max} |\mathbf{h}_{4,1}|^2$), the desired signal is decodable by using SIC [5], [6]. If $a_m < a_k$ where $m \in \bigcup_{b \in \lambda_k} \omega_b$, the rate of detecting s_k at user k can be expressed as follows:

$$R_k = \log \left(1 + \frac{|\mathbf{h}_{k,b}|^2 a_k}{\sum_{m \in \omega_b} |\mathbf{h}_{k,b}|^2 a_m + \Psi_k + \sigma^2 \mathcal{P}^{-1}} \right) \quad (6)$$

where $\Psi_k = \sum_{j=1, j \neq b}^B |\mathbf{h}_{k,j}|^2 \sum_{n \in \omega_j} a_n$.

Let ρ denote the transmit SNR, where $\rho = \mathcal{P}\sigma^{-2}$ and define G_b as the user with maximum PAC in ω_b , then the sum-rate for the K users is given by

$$R_{sum} = \sum_{b=1}^B \left\{ \log \left(1 + \rho |\mathbf{h}_{G_b,b}|^2 a_{G_b} \right) + \sum_{k \in \omega_b, k \neq G_b} \log \left[1 + \frac{a_k}{\sum_{m \in \omega_b} a_m + \Psi_{\mathbf{k}} + (\rho |\mathbf{h}_{k,b}|^2)^{-1}} \right] \right\} \quad (7)$$

2) *Non-ideal Case* : For the non-ideal case, two or more NOMA cells may have the overlapping area (as shown in Fig.2) and that is because some users select multiple APs. Here we define \mathcal{O}_b as the NOMA cells which are overlapping with the b^{th} ONOMA cell. After the CoMP obtaining the APSS-feedbacks, the ONOMA will be implemented via the following steps:

- **Step 1.** Each AP computes the size of λ .
- **Step 2.** Let $L(\Omega)$ denote the number of elements in set Ω . If $L(\lambda_1) \geq \dots \geq L(\lambda_K)$, then the PACs to the K users will be sorted as $a_1 \geq \dots \geq a_K$. For the g users whose APSSs are the same, their PACs will be sorted based on the equivalent channel coefficients, e.g. let $[\hat{\mathbf{h}}_1, \dots, \hat{\mathbf{h}}_g]$ denote the g users' equivalent channels, where $\hat{\mathbf{h}}_g = \sum_{b \in \lambda_g} \mathbf{h}_{g,b}$, if $|\hat{\mathbf{h}}_1|^2 \leq \dots \leq |\hat{\mathbf{h}}_g|^2$, then $a_1 \geq \dots \geq a_g$.
- **Step 3.** The CoMP system computes the USS, and find the user with the largest APSS size in each USS.
- **Step 4.** For the b^{th} ONOMA cell, compare the size of each APSS in \mathcal{O}_b NOMA cells with the largest size of APSS in the b^{th} ONOMA cell (\bar{L}_b). If a user in \mathcal{O}_b has a larger APSS size than \bar{L}_b , the index of the user will be listed into a set $\hat{\omega}_b$.
- **Step 4.** The b^{th} AP broadcasts $\sum_{i \in \{\omega_b \cup \hat{\omega}_b\}} \sqrt{a_i} \mathcal{P} s_i$ to the users in b^{th} ONOMA cell.
- **Step 5.** Each user in CoMP detects its observation. By using SIC, the message with larger PAC will get higher detecting priority.

Assume that $a_m < a_k$, then $m \in \bigcup_{b \in \lambda_k} \omega_b$ but $m \notin \bigcup_{b \in \lambda_k} \hat{\omega}_b$. As a result, the rate of detecting s_k at user k can be expressed as follows:

$$R_k = \log \left\{ 1 + \frac{|\hat{\mathbf{h}}_k|^2 a_k}{\sum_{b \in \lambda_k} \mathbf{h}_{k,b} \sum_{m \in \omega_b} a_m + \Psi_{\mathbf{k}} + \sigma^2 \mathcal{P}^{-1}} \right\} \quad (9)$$

where $\Psi_{\mathbf{k}} = \sum_{j=1, j \neq k}^B |\mathbf{h}_{k,j}|^2 \sum_{n \in \{\omega_j \cup \hat{\omega}_j\}} a_n$. The sum-rate for the K users is given by

$$R_{sum} = \sum_{b=1}^B \left\{ \log \left(1 + \rho |\hat{\mathbf{h}}_{G_b}|^2 a_{G_b} \right) + \sum_{k \in \omega_b, k \neq G_b} \log \left(1 + \frac{|\hat{\mathbf{h}}_k|^2 a_k}{\sum_{b \in \lambda_k} \sum_{m \in \omega_b} |\mathbf{h}_{k,b}|^2 a_m + \Psi_{\mathbf{k}} + \rho^{-1}} \right) \right\} \quad (10)$$

$$\quad (11)$$

where the term in (10) is the data rate of the user in the weakest channel of b^{th} ONOMA cell.

III. MINIMUM SUCCESSIVE TOPOLOGY IN ONOMA

In Fig.3, we use the branch network to indicate the successive process of SIC in ONOMA strategy. Note that for the non-ideal cases, the user-node which has multi-branches, such as node 1 in Fig.3, means it is in the overlapping area. The set of nodes $\{1 \dots N_b\}$ indicates the users in the b^{th} ONOMA cell, and their PACs are sorted as $a_1 > \dots > a_{N_b}$.

It is obvious in the branch network that from AP-node b to the user-node N_b , it need to pass through N_{b-1} user nodes, that means by using SIC process, the user N_b requires to detect the messages of user 1 to user N_{b-1} in sequence before detecting its own message. The successive times of SIC at user N_b is equal to the number of the user-nodes from 1 to N_b ; in other words, there is $I_{N_b} = N_b$. Note that the distance between any two nodes does not represent the real channel distance (or channel strength), it only indicates the successive times of SIC, e.g. the successive times of SIC at user 3 are 3.

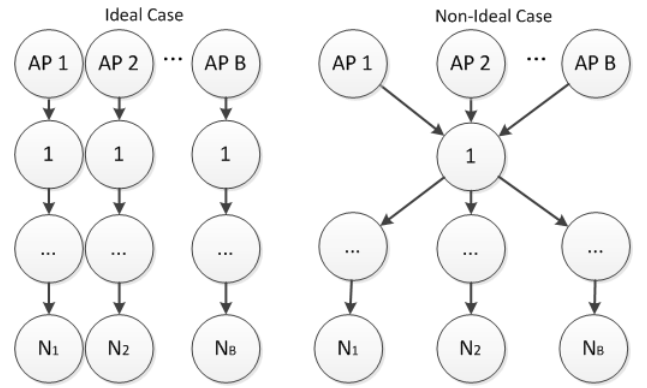


Figure 3. Successive Process of SIC

Corollary 2. For the ONOMA network which has B APs and K users, if the B ONOMA cells are symmetrical with each other, the sum successive times of SIC of the B ONOMA cells will be the minimum.

Proof: we first consider a CoMP system which has B symmetrical ONOMA cells. No matter the ideal or non-ideal ONOMA scenarios, the total SIC successive times in the b^{th} ONOMA cell can be expressed as $I_{sum}^{(b)} = \frac{N_b^2 + N_b}{2}$. As the B ONOMA cells are symmetrical, then

$$I_{sum}^{(1)} = \dots = I_{sum}^{(B)} = \frac{\mathcal{N}^2 + \mathcal{N}}{2} \quad (12)$$

$$I_{sum} = I_{sum}^{(1)} + \dots + I_{sum}^{(B)} = \frac{(\mathcal{N} + 1) \mathcal{N} B}{2} \quad (13)$$

Now move part of the users from one ONOMA cell to another, for example, move Q users from the 1^{st} ONOMA cell to the 2^{nd} ONOMA cell, so that the two ONOMA cells are no longer symmetrical with each other. In such case,

$$\bar{I}_{sum}^{(1)} = \frac{(\mathcal{N} - Q)^2 + \mathcal{N} - Q}{2} \quad (14)$$

$$\bar{I}_{sum}^{(2)} = \frac{(\mathcal{N} + Q)^2 + \mathcal{N} + Q}{2} \quad (15)$$

Based on (12) to (15), we can achieve that

$$\bar{I}_{sum} - I_{sum} = \left[\bar{I}_{sum}^{(1)} + \bar{I}_{sum}^{(2)} \right] - \left[I_{sum}^{(1)} + I_{sum}^{(2)} \right] = Q^2 > 0 \quad (16)$$

In the same way, it is easy to prove that if any of the B ONOMA cells are non-symmetrical with others, the sum successive times of SIC will be larger than that in the totally symmetrical B ONOMA cells. ■

IV. NUMERICAL RESULTS

We consider a system which includes 2 APs and 5 users ($B = 2$ and $K = 5$). Comparing with the JT-NOMA, the numerical result in Fig.4 shows the minimum successive of SIC (I_{min}) by using ONOMA with $K_{max} = 5$. The “ o ” in Fig.4 denotes the number of the users that in the overlapping area of the two NOMA cells.

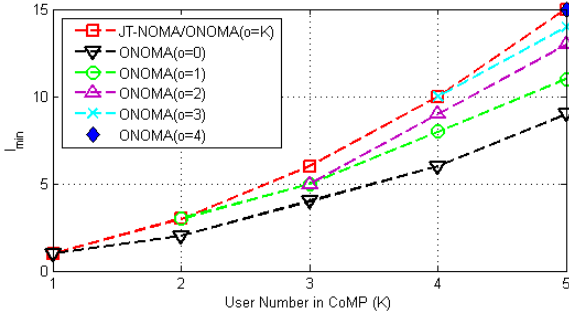


Figure 4. Minimum successive times of SIC

According to (6) and (9), it is obvious that the transmit rate is related to the topology of the NOMA cells. Here, we consider a non-ideal scenario that 1 user is in the overlapping area, and other 4 users are symmetrically distributed in the 2 NOMA cells, where $\omega_1 = \{1, 3, 5\}$ and $\omega_2 = \{1, 2, 4\}$, as shown in Fig. 5. The Rayleigh fading channel gain from the b^{th} AP to the k^{th} user is expressed as: $h_{k,b} = g\gamma_{k,b}$, where g is the normalised Rayleigh fading channel gain. The Rayleigh channel parameter $\gamma_{k,b} = \left[\sqrt{1 + (d_{k,b})^\alpha} \right]^{-1}$, where $d_{k,b}$ denotes the distance from the b^{th} AP to the k^{th} user, and α is the path loss factor.

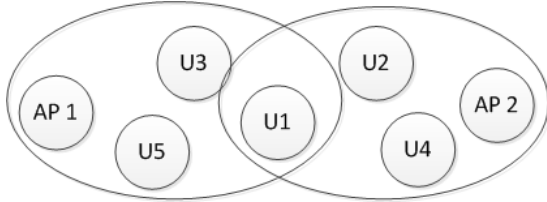


Figure 5. Minimum successive topology

The Fig.6 shows the transmit rate of each user and the sum rate in the considered system. The fixed channel is

considered in the numerical results, the Rayleigh channel parameters in the inter-cells are set as: $\{\gamma_{1,1}, \gamma_{3,1}, \gamma_{5,1}\} = \{\gamma_{1,2}, \gamma_{2,2}, \gamma_{4,2}\} = \{0.5, 0.6, 0.8\}$; the Rayleigh channel parameters in the intra-cell are set as: $\{\gamma_{2,1}, \gamma_{4,1}\} = \{\gamma_{3,2}, \gamma_{5,2}\} = \{0.1, 0.05\}$. Let $a_i = \frac{K-i+1}{\mu}$, where μ is a parameter to ensure $\sum_{i=1}^{K} a_k = 1$, then $\{a_1, a_2, a_3, a_4, a_5\} = \{\frac{1}{15}, \frac{2}{15}, \frac{3}{15}, \frac{4}{15}, \frac{5}{15}\}$. The results in Fig.7 show the comparison of the data rate performance between JT-NOMA and ONOMA strategy. The numerical results are considered under the infinite SIR scenarios. It is obvious in Fig.7 that the ONOMA can achieve much better sum-rate performance than the JT-NOMA when the inter-cell interference is small.

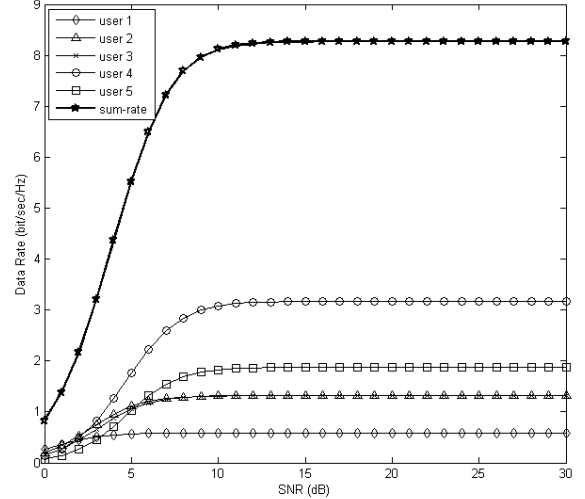


Figure 6. Data rate performance of ONOMA (the topology is shown in Fig.5)

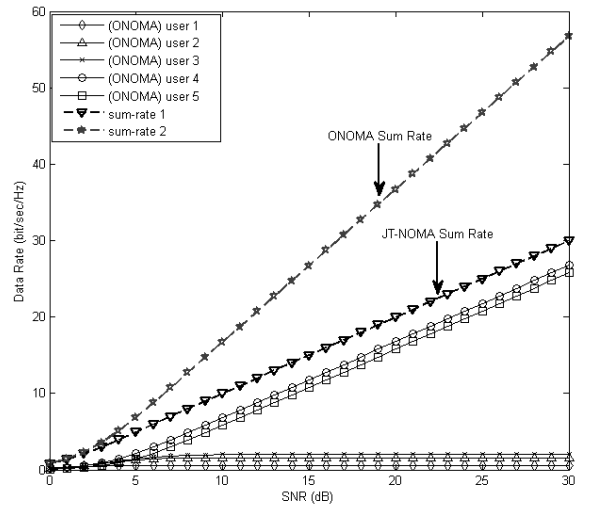


Figure 7. Comparison of the data rate performance between JT-NOMA and ONOMA under high SIR scenarios

V. CONCLUSION

In this paper, we introduce a novel opportunistic NOMA strategy in multiuser CoMP system which aims to reduce the complexity of signal processing and improve the capacity of the system. The relationship between the topology of the ONOMA cell and the complexity of SIC decoding process is analysed. Comparing with the conventional JT-NOMA in CoMP, the numerical results show that the proposed ONOMA can reduce the complexity of SIC and improve the system capacity under the high SIR scenarios.

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