Resource Allocation for Non-Orthogonal Multiple Access with Coordinated Multipoint Support

Zhi-Xuan Huang, Yen Chun Peng, Yi-Chia Lo, Jung-Chun Kao, and Hsi-Hsun Su
Department of Computer Science, National Tsing Hua University, Hsinchu, Taiwan

***Abstract*—Current mobile networks are based on orthogonal multiple access (OMA), in which at most one user is served in a resource block (RB). Unlike OMA, non-orthogonal multiple access (NOMA) enables an RB to be accessed by multiple users concurrently, thus improving RB usage efficiency. In this paper, we study resource allocation for NOMA when coordinated multipoint (CoMP) transmission is supported and users have minimum rate requirements. Given a NOMA/user pair, we derive closed-form formulas for optimal power allocation that maximizes utility, which is a weighted sum of rates of the two users. We also develop an efficient method for user pairing, in order to maximize the number of users whose rate requirements are met. Simulation results show that our method results into better performance in terms of the number of well-served users and total utility.**

***Keywords*—non-orthogonal multiple access (NOMA), power allocation, resource allocation**

I. Introduction

Contemporary mobile networks such as Long Term Evolution-Advanced (LTE-Advanced) are based on orthogonal multiple access (OMA). In OMA-based mobile networks, resource blocks (RBs) are orthogonal to each other; an RB cannot be used by two or more user equipments (UEs) concurrently. Compared to OMA, non-orthogonal multiple access (NOMA) can offer superior spectrum efficiency and serve more UEs because NOMA allows an RB to be used by multiple UEs concurrently. With two-user NOMA technology in the downlink direction illustrated in Fig. 1, the base station multiplexes two UEs' signals over an RB and UEs use successive interference cancellation (SIC) to extract their own signal from the superposed signal.

Over the past few years, several studies about NOMA have been made. In [3], the authors discuss the basic concept and practical considerations of NOMA with SIC at the receiver side. Their goals are twofold: One is to clarify the basic concept behind downlink NOMA as a potential candidate multiple access for future radio access (FRA); the other is to discuss practical issues of NOMA, such as power allocation, SIC error propagation and combination with multiple input multiple output (MIMO). In [1], the authors investigate the system-level performance of downlink NOMA with power-domain user multiplexing at the transmitter side and SIC on the receiver side. Besides, they combine with single-user MIMO for LTE enhancements.

In [4], the authors present a NOMA concept for cellular FRA. NOMA superposition coding (SC) could be based on OMA as well as the LTE baseline, because it can enhance the spectrum efficiency. Numerical results verified that the NOMA with SIC can improve both the system capacity and edge UEs' throughput performance. Moreover, the authors introduce the concept, performance evaluation gains and the experimental trials related to NOMA in [4], [5].

In [6], the authors use the matching theory to solve the resource allocation problem for a downlink NOMA system. To maximize total throughput, they divide the problem into two sub-problems—sub-channel assignment (or called user pairing) and power allocation. In this system, a base station (BS) has a set of sub-channels; one sub-channel can be allocated to multiple users and one user can access multiple sub-channels. The sub-channel assignment sub-problem is formulated as a two-side matching problem and is solved by a suboptimal, Gale-Shapley-based algorithm, called USMA. The power allocation sub-problem is dealt with by using a water-filling algorithm.

There are other algorithms for the resource allocation problem in downlink NOMA. In [10], sub-channel assignment uses the binary dislocation principle (BDP). For the power allocation sub-problem, the authors adopt iterative water power allocation, fixed power allocation, and fractional transmit power allocation. In [11], the power allocation sub-problem is solved by an iterative, two-phase, water-filling-based method; while sub-channel assignment is solved by a greedy algorithm which assigns each sub-channel an equal number of users.

Edge UEs are often far away from base stations. With NOMA technology alone, edge UEs may not attain their own quality of service (QoS) requirements. To solve this problem, coordinated multi-point (CoMP) transmission is used in [7] and [8] to improve throughput of edge UEs. CoMP can be classified into two subclasses—joint processing (JP) and coordinated scheduling/beamforming (CS/CB). JP can be further divided into joint transmission (JT) and dynamic point selection (DPS). JT (or called JT-CoMP) enables coordination of transmission among multiple base stations, which turns inter-cell interference into useful signal. JT can outperform other subclasses, which motivates us to take JT into account in this paper.

In [9], the authors combine NOMA and CoMP for a two-cell, three-user, downlink scenario: Given two near users and one edge user, two BSs transmit Alamouti coded signals to the edge user, while each BS also transmits signals to a user near to the BS. Note that [9] does not take user pairing into account; instead, user pairing is given in advance.

Combining NOMA with JT-CoMP can not only improve RB usage efficiency but also enhance transmission rates to edge users. However, none of the aforementioned papers explicitly considers both user pairing and power allocation for the downlink transmission with both NOMA and JT-CoMP supported. To fill the gaps, we consider both user pairing and power allocation explicitly, while taking minimum rate requirements of users into account. The primary goal is to maximize the number of users that attain their rate requirements; the secondary goal is to maximize total utility. For utility maximization, we derive closed-form formulas for optimal transmission power and develop a utility-based power allocation method. To serve as many users as possible at rates beyond their requirements, we develop an efficient user pairing method, which is based on matching.

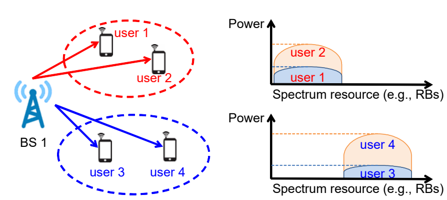

Fig. 1. The basic idea of downlink NOMA illustration.

The rest of the paper is organized as follows. We discuss the system model in Section II. Our utility-based power allocation method and our matching-based user pairing method are described in sections III and IV, respectively. Simulation results are shown in Section V. We give some concluding remarks in Section VI.

II. Network Model

We consider a wireless network with multiple cells, each with multiple users. In the network, NOMA and joint transmission (JT) CoMP are supported in the downlink direction. To reduce the complexity of joint scheduling, we deal with the two *pairwise* scenarios—2-NOMA and 2-JT—in tandem. In the 2-NOMA scenario, each base station (BS) can serve pairs of users by using NOMA technology. In the 2-JT scenario, each of BS pairs can jointly serve pairs of users by using both NOMA and JT-CoMP technologies. Note that user pairing and BS pairing are part of joint scheduling; they are not pre-determined in advance.

Fig. 2a illustrates a user pair in the 2-NOMA scenario, in which a BS serves two users concurrently with the same radio resource (i.e., in the same frequency sub-band and the same time slot). Given a user pair (or called a NOMA pair), the user with better channel gain is called the *strong user* and the user with poorer channel gain is the *weak user*.

Fig. 2b illustrates a pair of users in the 2-JT scenario, in which two base stations serve the two users in a cooperative manner: The *main base station* (BS 1) serves a strong user (user 1) and a weak user (user 2) with the same radio resource by NOMA technology; meanwhile, the *subordinate base station* (BS 2) coordinately serves the weak user by JT-CoMP. JT-CoMP enables coordination of transmission among these base stations and turns inter-cell interference into useful signal. In general, each base station can serve as a main base station for the users in its cell and also serve as a subordinate base station for all users in adjacent cells. However, for cost and synchronization reasons, this paper assumes that a BS can cooperate, by JT-CoMP, with at most one base station at a time. That is, no base station can cooperate with two or more base stations at the same time.

The entire radio resource is equally divided into L resource blocks (RBs). For simplicity, this paper focuses on the case when each cell has M users, although our method can be applied to cells with distinct numbers of users. The maximum transmission power per BS is denoted by P_{BS}, which is equally divided into all RBs. That is, the transmission power a BS allots to every RB is $P_{\mathrm{RB}} = P_{\mathrm{BS}}/L$, which is also called the per-RB power budget. It is assumed that a user is assigned at most an RB and two users shares an RB by NOMA technology.

The channel coefficient from BS b to user m is denoted by $h_{b,m}$. The (squared) channel gain is denoted by $G_{b,m} = |h_{b,m}|^2$. For simplicity, the channel gain is also denoted by G_m when there is no ambiguity. The noise power at user m is N_m Watts per RB.

Each user has its minimum rate requirement. The minimum rate requirement of user m is denoted by r_m. The signal-to-interference-plus-noise ratio (SINR) corresponding to r_m is denoted by $\eta_m = 2^{r_m} - 1$. A *well-served* user is a user whose minimum rate requirement is attained. A well-served user pair is a pair of users whose minimum rates are both attained when they share the same RB by NOMA.

By pairing users and allocating power, we aim to find out as many well-served users as possible while maximizing total utility. More precisely, the primary goal is to maximize the number of well-served users (with the help of NOMA and JT-CoMP). If there exist multiple optimal solutions for the primary goal, among these solutions we consider the secondary goal which is to maximize total utility. The utility of an OMA transmission is defined as its achievable rate; whereas the pairwise utility of a NOMA transmission is a weighted sum of achievable rates of the NOMA pair. Exact definition of NOMA transmission's utility will be given later in this section.

In the following, we explain the pairwise utility in the 2-NOMA scenario and in the 2-JT scenario, respectively.

A. 2-NOMA Scenario

In the 2-NOMA scenario illustrated in Fig. 2a, a BS can concurrently serve two users in the same RB by using NOMA technology. Consider a *user pair* consisting of user 1 and user 2, where $G_1 \geq G_2$. In other words, user 1 is the strong user and user 2 is the weak user; the BS considers to serve the two users in the same RB with a (per-RB) power budget of P_{RB} Walts.

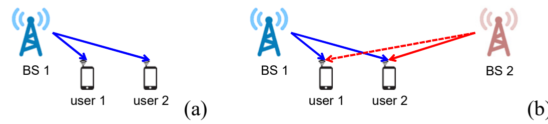

Fig. 2. (a) A pair of users in the 2-NOMA scenario. (b) A pair of users in the 2-JT scenario, in which solid lines indicate signal and dotted lines indicate interference. (For simplicity, users that are allocated other RBs are not drawn.)

For the weaker user (user 2), the SINR is $\frac{p_2 G_2}{N_2 + p_1 G_2}$, where p_m is the transmission power to user m from the BS. The achievable rate of the weak user is

$$R_2 = \log_2\left(1 + \frac{p_2 G_2}{N_2 + p_1 G_2}\right) = \log_2\left(1 + \frac{(P_{\mathrm{RB}} - p_1) G_2}{N_2 + p_1 G_2}\right) \quad (1)$$

where the last equality stems from $p_1 + p_2 = P_{RB}$.

Suppose that successive interference cancellation (SIC) is applied to the decoding process of the strong user. The strong user decodes its own signal after the weak user's signal has been reconstructed and removed from the received signal. Hence, the achievable rate of the strong user (user 1) is

$$R_1 = \log_2\left(1 + \frac{p_1 G_1}{N_1}\right) \quad (2)$$

The pairwise utility of the (NOMA) user pair is defined as a weighted sum of the achievable rates:

$$u = w_1 R_1 + w_2 R_2$$

where w_1 and w_2 are weights in $(0,1]$. Unequal weights are used to *a)* encourage strong users to pair with weak users that have poor channel gain and *b)* take error propagation in SIC into account. In this paper, the weak user's weight is always set to $w_2 = 1$. Unlike $w_2 = 1$, the strong user's weight in the 2-NOMA scenario is set to $w_1 = \alpha$, where

$$\alpha = e^{-\sigma_1/\sigma_2} \quad (3)$$

and $\sigma_m = N_m/G_m$ for $m \in \{1,2\}$. Given these weights, the pairwise utility of the user pair is equal to:

$$u(p_1) = \alpha \log_2\left(1 + \frac{p_1}{\sigma_1}\right) + \log_2\left(1 + \frac{P_{RB} - p_1}{\sigma_2 + p_1}\right) \quad (4)$$

In the 2-NOMA scenario, one reason of $w_1 = \alpha$ is because we consider the performance of NONA under error propagation. Due to space problem, we omit the proof and details.

B. 2-JT Scenario

In the 2-JT scenario illustrated in Fig. 2b, the main base station (BS 1) and the subordinate base station (BS 2) serve two users together. Without loss of generality, let us assume that a user pair consists of user 1 and user 2, where $G_{1,1} \geq G_{1,2}$. That is, the two BSs consider to allocate the same RB to users 1 and 2, where user 1 is the strong user and user 2 is the weak user. What follows explains achievable rate and pairwise utility for the user pair.

Suppose that the main base station allots its per-RB power budget (of P_{RB} Watts) to the user pair such that their pairwise utility is maximized, whereas the subordinate base station devotes the power budget to the weak user. The subordinate base station helps weak users only because weak users encounter low signal yet high interference.

Because the weaker user (user 2) has two signal sources, its SINR is $\frac{p_2 G_{1,2} + P_{\mathrm{RB}} G_{2,2}}{N_2 + p_1 G_{1,2}} = \frac{(P_{\mathrm{RB}} - p_1) G_{1,2} + P_{\mathrm{RB}} G_{2,2}}{N_2 + p_1 G_{1,2}}$, where N_2 is the noise power at the weak user. The achievable rate of the weak user is

$$R_2 = \log_2\left(1 + \frac{(P_{\mathrm{RB}} - p_1)G_{1,2} + P_{\mathrm{RB}}G_{2,2}}{N_2 + p_1 G_{1,2}}\right) \tag{5}$$

The strong user (user 1) decodes its own signal after the weak user's signal has been reconstructed. So its achievable rate is

$$R_1 = \log_2\left(1 + \frac{p_1 G_{1,1}}{N_1}\right) \tag{6}$$

Same as the 2-NOMA scenario, the pairwise utility of the two users in the 2-JT scenario is also defined as $u = w_1 R_1 + w_2 R_2$. The weak user's weight is set to $w_2 = 1$ again. After considering the impact of error propagation inherent in SIC, the strong user's weight is set to $w_1 = \beta$, where

$$\beta = \frac{\sigma_{2,1}}{\sigma_{2,1} - \sigma_{1,1}} e^{-\frac{\sigma_{1,1}}{\sigma_2^c}} \tag{7}$$

The constants in (7) are $\sigma_{1,1} = \frac{N_1}{G_{1,1}}$, $\sigma_{2,1} = \frac{N_1}{G_{2,1}}$, and $\sigma_2^c = \frac{N_2}{G_{1,2} + G_{2,2}}$.

Under the weights aforementioned, the pairwise utility in the 2-JT scenario can be computed:

$$u(p_1) = \beta \log_2\left(1 + \frac{p_1 G_{1,1}}{N_1}\right) + \log_2\left(1 + \frac{(P_{\mathrm{RB}} - p_1)G_{1,2} + P_{\mathrm{RB}}G_{2,2}}{N_2 + p_1 G_{1,2}}\right) \tag{8}$$

The resource allocation method we propose consists of two parts—a utility-based power allocation scheme and a matching-based user pairing scheme. In the following sections, we introduce the two parts, respectively. The primary objective of our proposed method is to maximize the number of well-served users. If there exist multiple optimal solutions for the primary objective, then we consider the secondary objective which is to maximize total utility.

Note that the two scenarios have distinct RB usage efficiency. In the 2-NOMA scenario, a BS could serve at most 2 users with a single RB and thus the RB usage efficiency is equal to $2/1 = 2$. Compared to the 2-NOMA scenario, the 2-JT scenario has a smaller RB usage efficiency which is equal to $2/2 = 1$. So BSs prefer to serve user pairs in the 2-NOMA scenario. The 2-JT scenario is considered only if user pairs cannot be well-served in the 2-NOMA scenario.

III. Utility-Based Power Allocation

Given an arbitrary user pair (which consists of a strong user and a weak user), we propose a power allocation scheme that maximizes the pairwise utility. Our proposed scheme applies to both the 2-NOMA and 2-JT scenarios. The only difference is the weights and bounds used in the two scenarios.

Our power allocation scheme is essentially a few if-else expressions and closed-form formulas for the power allocation that maximizes pairwise utility. Because we derive the closed-formulas for optimal transmission power in the two scenarios, our power allocation scheme has a computational complexity of O(1). The following two subsections explain the formulas we derive for the two scenarios, respectively.

A. 2-NOMA Scenario

Suppose that we are given a user pair consisting of a strong user (user 1) and a weak user (user 2). The goal of our power allocation scheme is to maximize the pairwise utility u, which is defined above in (4).

Define $g = u \ln 2$. By (4), we obtain:

$$g = \alpha \ln\left(1 + \frac{p_1}{\sigma_1}\right) + \ln\left(1 + \frac{P_{RB} - p_1}{\sigma_2 + p_1}\right) \tag{9}$$

Maximizing the utility u is equivalent to maximizing the function g. To find its maximum, we take the derivation of g:

$$\frac{dg}{dp_1} = \frac{(\alpha\sigma_2 - \sigma_1) - (1-\alpha)p_1}{(\sigma_1 + p_1)(\sigma_2 + p_1)} \tag{10}$$

Note that the denominator of (10) is always positive, because the transmission power p_1 is always non-negative. So the zero of $\frac{dg}{dp_1}$ depends on the numerator.

If p_1 had a unconstrained domain, i.e., $p_1 \in [0, \infty)$, the maximum of g would happen at the point $p_1 = \frac{\alpha\sigma_2 - \sigma_1}{1-\alpha}$. However, p_1 is actually constrained by a number of factors including the power budget ($0 \le p_1 \le P_{\mathrm{RB}}$) and the rate/SINR requirements of users. Deriving from (2) and the rate requirement of $R_1 \ge r_1$, we obtain that $p_1 \ge \eta_1 \sigma_1$ must hold true. Deriving from (1) and the rate requirement of $R_2 \ge r_2$, we know that $p_1 \le \frac{P_{\mathrm{RB}} - \eta_2 \sigma_2}{\eta_2 + 1}$ must be true. Combining these two bounds and the power budget P_{RB}, we obtain that for the constrained domain $[a, b]$, the maximum of g is at $p_1 = p_1^*$, where

$$p_1^* = \begin{cases} \frac{\alpha\sigma_2 - \sigma_1}{1-\alpha} & \text{, if } a \le \frac{\alpha\sigma_2 - \sigma_1}{1-\alpha} \le b \\ a & \text{, if } b \ge a > \frac{\alpha\sigma_2 - \sigma_1}{1-\alpha} \\ b & \text{, if } a \le b < \frac{\alpha\sigma_2 - \sigma_1}{1-\alpha} \end{cases} \tag{11}$$

the lower bound for p_1 is

$$a = \eta_1 \sigma_1 \tag{12}$$

and the upper bounds for p_1 is

$$b = \min(P_{\mathrm{RB}}, \frac{P_{\mathrm{RB}} - \eta_2\sigma_2}{\eta_2 + 1}) \tag{13}$$

Note that a cannot exceed b. If $a > b$, then the feasible set itself is empty and thus p_1 has no feasible solution. No feasible solution means that the user pair is never well-served.

Based on the above analysis, we summarize the steps of our utility-based power allocation scheme when it is applied to the 2-NOMA scenario. Given a user pair, our scheme first computes the lower bound a by (12) and the upper bound b by (13). If $a \le b$, it computes p_1^* by (11) and then calculates the maximum pairwise utility $u(p_1^*)$ by substituting p_1^* into (4) for p_1. If $a > b$, there is no feasible solution, the user pair is never well-served, and the pairwise utility is zero.

B. 2-JT Scenario

We assume that the main base station and the subordinate base station serve user 1 (the strong user) and user 2 (the weak user) in a certain RB in the way mentioned in Section II.B. Our goal is to maximize the pairwise utility u, which is defined in (8).

Same as the 2-NOMA scenario, we derive that p_1 must be in the interval $[c, d]$ to satisfy power and rate/SINR constraints, where

$$c = \eta_1 \sigma_{1,1} \tag{14}$$

$$d = \min(P_{\mathrm{RB}}, \frac{P_{\mathrm{RB}}\frac{\sigma_{1,2}}{\sigma_2^c} - \eta_2\sigma_{1,2}}{\eta_2 + 1}) \tag{15}$$

We also derive that the maximum of u is at $p_1 = p_1^*$, where

$$p_1^* = \begin{cases} \frac{\beta\sigma_{1,2} - \sigma_{1,1}}{1-\beta} & \text{, if } c \le \frac{\beta\sigma_{1,2} - \sigma_{1,1}}{1-\beta} \le d \\ c & \text{, if } \frac{\beta\sigma_{1,2} - \sigma_{1,1}}{1-\beta} < c \le d \\ d & \text{, if } c \le d < \frac{\beta\sigma_{1,2} - \sigma_{1,1}}{1-\beta} \end{cases} \tag{16}$$

Note that c cannot exceed d. If $c > d$, then p_1 has no feasible solution that satisfies power and rate/SINR constraints.

Based on the above analysis, we outline the steps of our power allocation scheme when applying to the 2-JT scenario. Given a user pair, our scheme first computes the lower bound c by (14) and the upper bound d by (15). If $c \le d$, it computes p_1^* by (16) and then calculates the maximum pairwise utility (which happens at the point $p_1 = p_1^*$) by (8). Otherwise, there is no feasible solution, the user pair cannot be well-served, and the pairwise utility is zero.

IV. Matching-Based User Pairing

We propose a user pairing scheme based on maximum weight matching, in order to achieve two classes of goals. The primary goal is to maximize the number of well-served users; the secondary goal is to maximize total utility. As illustrated in Fig. 3, our user pairing scheme consists of two stages in tandem. The first stage which corresponds to the 2-NOMA scenario is on a per-cell basis; it helps to maximize the number of well-served users (and total utility) for each cell. Unlike the first stage which is on a per-cell basis, the second stage is on a per-cell-pair basis. The second stage which corresponds to the 2-JT scenario aims to maximize the number of well-served users (and total utility) for each pair of adjacent cells. In the following subsections, we explain the two stages, respectively.

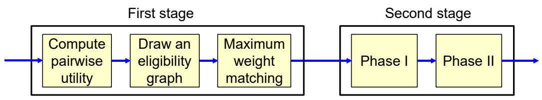

Fig. 3. Overview of our user pairing scheme.

A. First Stage (Dealing with 2-NOMA Scenario)

At the beginning of our user pairing scheme, the set of users $\mathcal{M} = \{1, 2, \dots, M\}$ and the set of RBs $\mathcal{L} = \{1, 2, \dots, L\}$ are fed into the first stage, which is on a per-cell basis. For each cell, the first stage starts with computing pairwise utilities of all possible user pairs. That is, for each possible user pair, we compute α by (3), the optimal power p_1^* by (11), and the pairwise utility $u(p_1^*)$ by substituting the obtained p_1^* into (4) for p_1. Note that only the user pairs with positive pairwise utility could possibly be well-served.

The second step is to draw an eligibility graph according to the user pairs that could possibly be well-served. Let us denote the eligibility graph by $G = (V, E)$, where V and E are the sets of vertices and edges, respectively. A vertex in G is essentially a user; therefore, $|V| = M$. An edge in G corresponds to a user pair that could possibly be well-served: If a strong user and a weak user results in a positive pairwise utility, we add an edge connecting the two users/vertices to G. Take Fig. 4 as an example, where user/vertex identities are numerated according to their squared channel gains (that is, $G_1 > G_2 > \cdots > G_M$). Edge (1,2) in G implies the user pair in which user 1 is the strong user and user 2 is the weak user could be well-served. Edge (1,5) is not drawn because the user pair consisting of users 1 and 5 has zero pairwise utility.

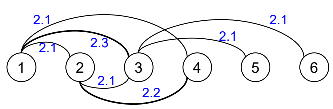

Fig. 4. An eligibility graph for a single cell. The numbers inside circles are user identities. The numbers along edges are edge weights.

In addition to drawing vertices and edges, we assign weights to edges in G, in a way that corresponds to our primary goal and our secondary goal. For any edge in G, say edge e, its weight is set to be:

$$W_e = 2 + \frac{\text{pairwise utility of } e}{\sum_{e' \in E} \text{pairwise utility of } e'} \tag{17}$$

The first term of the right-hand side in (17) is two, implying that two users are well-served if the corresponding user pair is allocated an RB. This term corresponds to our primary goal—maximization of the number of well-served users. The second term of the right-hand side in (17) is essentially a normalized pairwise utility, which corresponds to our secondary goal—maximization of total utility. Because the secondary goal is subordinate to the primary goal, we make the normalized pairwise utility smaller than two.

After drawing the eligibility graph G, the final step is to find out a maximum weight matching (MWM), denoted by S, by any existing MWM algorithm. Take Fig. 4 as an example. $S = \{(1,3), (2,4)\}$ is a maximum weight matching. Note that only $|\mathcal{L}|$ RBs are available. Therefore, if $|S| > |\mathcal{L}|$, we only keep the $|\mathcal{L}|$ largest weight edges in S. At the end of this stage, the edges left in S are the user pairs the base station decides to serve by NOMA technology. The users served and the RBs allocated to these users are removed from $\mathcal{M}$ and $\mathcal{L}$, respectively. This finishes the first stage. Take Fig. 4 as an example. At the end of the first stage, $\mathcal{M}$ becomes $\{5,6\}$ because user pairs $(1,3)$ and $(2,4)$ are assigned an RB each.

The computation complexity of the first stage is dominated by maximum weight matching. Since the maximum weight matching problem has a complexity of $O(|V|^2 \cdot |E|)$, the first stage is of $O(|V|^2 \cdot |E|)$ complexity.

B. Second Stage (Dealing with 2-JT Scenario)

At the beginning of the second stage, the set $\mathcal{M}$ contains the users that are unserved yet and the set $\mathcal{L}$ contains the RBs that are unoccupied yet. This per-cell-pair-basis stage is divided into two phases—phase I and phase II. Phase I scans all pairs of adjacent cells in order to select a portion of the cell pairs that will be handled in phase II. For each selected cell pair, phase II maximizes the number of well-served users and total utility in a way similar to the first stage aforementioned in Section IV.A.

1) Phase I

Phase I starts with computing the *potential* for all pairs of adjacent cells. Given a cell pair which consists of cells s and t, the potential ϕ_{st} is in essence the maximum number of users two-point JT-CoMP technology might serve for the cell pair. ϕ_{st} is defined as:

$$\phi_{st} = \min(M_s + M_t, 2L_{s,t})$$

where M_s and M_t are the numbers of unserved users in cell s and cell t, respectively, and $L_{s,t}$ is the number of unoccupied RBs the two cells (cells s and t) have in common.

The rest of phase I is the same as the first stage of our scheme (aforementioned in Section IV.A), except that vertices, edges, and edge weights of the eligibility graph in phase I is defined in a different way from that in the first stage. In the eligibility graph of phase I, a vertex corresponds to a cell (rather than a user), an edge corresponds to a pair of adjacent cells (rather than a user pair), and the weight of edge (s,t) is set to be the potential ϕ_{st} (rather than 2 plus the normalized pairwise utility), where s and t are two adjacent cells. If cells s and t are not adjacent or they have a zero potential, the eligibility graph has no edge connecting s and t.

After drawing the eligibility graph, the last step in phase I is to find out a maximum weight matching of the eligibility graph, which is denoted by S'. The elements in S' are the cell pairs that are selected to be handled in phase II.

2) Phase II

Phase II deals with the 2-JT scenario and decides which the user pairs to be served, on a per-cell-pair basis. For each cell pair in S', what phase II does is the same as the first stage of our scheme (mentioned in Section IV.A), except that the eligibility graph in phase II considers two cells (rather than one cell) as a whole and pairwise utility of each user pair is computed by different formulas. What follows emphasizes the different parts; whereas, the details of similar parts are omitted.

At the beginning of phase II, the set $\mathcal{M}$ contains the (unserved) users that are not allocated any RB in the first stage, the set $\mathcal{L}$ contains the RBs that are unoccupied yet, the set S' contains the cell pairs that should be handled by jointly NOMA and JT-COMP. For each cell pair in S', say cells s and t, phase II first lists all the (unserved) users in cell s and computes the pairwise utility of all pairs of (unserved) users in cell s with the formulas we derive for the 2-JT scenario. More precisely, for each user pair phase II computes β by (7), the optimal power p_1^* by (16), and the pairwise utility $u(p_1^*)$ by substituting the obtained p_1^* into (8) for p_1. In addition to cell s, phase II also lists all (unserved) users in cell t and computes pairwise utility of each (unserved) user pair in cell t.

Next, we draw an eligibility graph according to the user pairs whose pairwise utility is positive. After that, we find out a MWM of the eligibility graph, which is denoted by S''. The MWM corresponds to the user pairs that are served in the 2-JT scenario.

The computation complexity of both phases I and II of the second stage is dominated by maximum weight matching. Hence, the second stage has the same complexity analysis as the first stage does.

V. Performance Evaluation

By simulation, we compare the performance of *our method* with the performance of several existing algorithms including the channel state sorting-pairing algorithm (*CSS-PA*) [10] and the population-based meta-heuristic search algorithm (*meta-heuristic*) [11]. Both CSS-PA and meta-heuristic are designed for the 2-NOMA scenario only.

We also show the performance of the first stage of our method alone, which is abbreviated by *stage 1* for simplicity. Our method consists of two stages. Stage 1 deals with the 2-NOMA scenario only, whereas the second stage deals with the 2-JT scenario. The performance gap of our method from stage 1 shows the benefit brought by utilizing CoMP technology. Important performance metrics include the number of well-served users and total utility. Because users have their own rate demands, we assume that RBs are allocated to well-served users only.

The simulation is set as follows. We consider seven cells, each with a radius of 500 meters and with a base station located in the center of the cell. In all cells, users are randomly deployed. The maximum transmit power of BS is set to 40 dBm, which is equally distributed to 20 RBs. The path loss model in dB is set to be $133.6 + 35\log_{10} d[\text{km}]$. The bandwidth per RB is 180 kHz. Noise spectral density is -174 dBm/Hz. The minimum rate requirements of users vary from 1 to 8 bps/Hz; the minimum rate requirements depend on the OMA's capacity of individual users (when the users are allocated an exclusive RB each). Denoting the OMA's capacity of user m by C_m, the rate requirement of user m, $m \in \mathcal{M}$, is set to be:

$$r_m = \begin{cases} 8 & \text{, if } C_m \geq 16 \\ 4 & \text{, if } 8 \leq C_m < 16 \\ 2 & \text{, if } 4 \leq C_m < 8 \\ 1 & \text{, if } C_m < 4 \end{cases} \qquad (18)$$

As shown in Fig. 5, both our method and stage 1 performs significantly better than the other algorithms in terms of the number of well-served users, which is our primary goal of our method. It is also observed that the outperformance of our method and stage 1 becomes larger as the total number of users increases. In this performance metrics, our method is the champion, stage 1 is runner-up, meta-heuristic is the third place, and CSS-PA performs worst. Besides, it is observed that the performance difference between our method and stage 1 is obvious, except when the number of users is large but the number of RBs is limited. With 20 RBs, two-user NOMA technology can serve at most 40 users; CoMP technology improves user throughputs at cell edge areas but it cannot break the upper bound.

The above observations in terms of the number of well-served users also apply to total utility. As shown in Fig. 6, our method is the champion again in terms of total utility, stage 1 is runner-up, meta-heuristic is the third place, and CSS-PA performs worst.

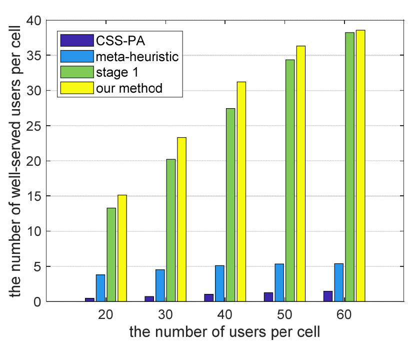

Fig. 5. The number of well-served users per cell.

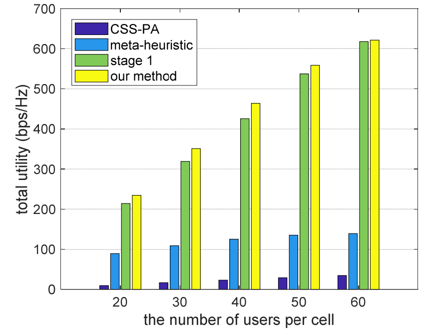

Fig. 6. The total utility.

VI. Conclusion

This paper considers a mobile network with NOMA and JT-CoMP supported in the downlink direction. We consider both user pairing and power allocation for users with minimum rate requirements. Our goals are to maximize the number of well-served users and to maximize total utility. Given a user pair, we have derived closed-form formulas for optimal transmission power that maximize utility. To serve as many users as possible at rates beyond their demands, we have developed a matching-based user pairing method. Simulation results show that our scheme outperforms existing methods.

Acknowledgment

Jung-Chun Kao is the corresponding author. This work was supported in part by the Ministry of Science and Technology, Taiwan, under grants no. MOST 106-2221-E-007-024-MY3 and MOST 109-2634-F-009 -023.

References

[1] Y. Saito, A. Benjebbour, et al., "System-level evaluation of downlink non-orthogonal multiple access (NOMA) for non-full buffer traffic model," *IEEE CSCN*, Tokyo, 2015

[2] A. Benjebbour, A. Li, K. Saito, Y. Saito, Y. Kishiyama and T. Nakamura, "NOMA: From concept to standardization," *IEEE CSCN*, Tokyo, 2015

[3] A. Benjebbour, Y. Saito, Y. Kishiyama, A. Li, A. Harada and T. Nakamura, "Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access," *Intelligent Signal Processing and Communications Systems*, Naha, 2013

[4] A. Benjebbour, K. Saito, A. Li, Y. Kishiyama and T. Nakamura, "Non-orthogonal multiple access (NOMA): Concept, performance evaluation and experimental trials," *Wireless Networks and Mobile Communications*, Marrakech, 2015

[5] A. Benjebbour, A. Li, K. Saito, Y. Saito, Y. Kishiyama and T. Nakamura, "NOMA: From concept to standardization," *IEEE CSCN*, Tokyo, 2015

[6] B. Di, S. Bayat, L. Song and Y. Li, "Radio Resource Allocation for Downlink Non-Orthogonal Multiple Access (NOMA) Networks Using Matching Theory," *IEEE GLOBECOM*, San Diego, CA, 2015

[7] M. Sawahashi, Y. Kishiyama, A. Morimoto, D. Nishikawa and M. Tanno, "Coordinated multipoint transmission/reception techniques for LTE-advanced [Coordinated and Distributed MIMO]," in *IEEE Wireless Communications*, vol. 17, no. 3, pp. 26-34, June 2010

[8] Q. Li, R. Q. Hu, Y. Qian and G. Wu, "Cooperative communications for wireless networks: techniques and applications in LTE-advanced systems," in *IEEE Wireless Communications*, vol. 19, no. 2, April 2012

[9] J. Choi, "Non-Orthogonal Multiple Access in Downlink Coordinated Two-Point Systems," in *IEEE Communications Letters*, Feb. 2014

[10] H. Zhang, D.-K. Zhang, W.-X. Meng, C. Li, "User Pairing Algorithm with SIC in Non-Orthogonal Multiple Access System," *IEEE ICC*, May 2015.

[11] M.-J. Yang and H.-Y. Hsieh, "Moving Towards Non-Orthogonal Multiple Access in Next-Generation Wireless Access Networks," *IEEE ICC*, June 2016.