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# Joint Uplink Power Allocation Method in Wireless Communication and Positioning Integrated System

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**ABSTRACT** With the development of wireless communication, there are usually both communication and positioning requirements. In our previous work, we studied the power allocation algorithm for positioning user (P-User) based on Multi-Scale Non-Orthogonal Multiple Access (MS-NOMA) downlink signal where all communication users (C-Users) have the same power. In the uplink case, the power allocation scheme for both C-User and P-User needs to be considered jointly as all C-Users may have different power. In this paper, we analyze the Quality of Service (QoS) and ranging accuracy based on the MS-NOMA signal by deriving their simple expressions. Then, a two stage joint iterative power allocation algorithm (JIPAA) is proposed. In the first stage, considering the QoS of C-User requirement and total power limitation, the power of P-Users is allocated to obtain optimal ranging performance. In the second stage, the power of C-Users is allocated to minimize the power consumption. With the iterative process, the optimal power of each C-User and P-User is calculated. The numerical results show that the proposed JIPAA algorithm dramatically promotes ranging accuracy under the same energy consumption.

**INDEX TERMS** Multi-scale non-orthogonal multiple access (MS-NOMA), power allocation, quality of service (QoS), ranging accuracy.

## I. INTRODUCTION

High precision positioning technology promotes the development of modern society significantly. Nowadays, the Location Based Services (LBS) are growing rapidly and attracting more attention for the proliferation of mobile devices [1], [2]. Due to the shelter of wall, satellite signal will be obviously weakened after passing through the building [3]. Therefore, the well known Global Navigation Satellite Systems (GNSS) [4], such as the Global Positioning System (GPS) and the Beidou System (BDS) can only be used in open areas and the accuracy of traditional GNSS is greatly reduced indoors [5], [6]. The emerging Wi-Fi, Bluetooth or Wireless Sensor Networks (WSNs) based positioning techniques have good coverage and performance indoors only with dense

placements of the nodes [7]–[9]. And it is costly to collect and maintain the fingerprint database as well [10], [11].

Wireless communication network can provide good coverage and signal quality both outdoors and indoors [12] for its infrastructure is professionally designed. In addition, because it is ready-made for communication purpose, it is cost-effective to be used for positioning purpose. However, the positioning accuracy of traditional methods using communication signal directly cannot meet some high-accuracy requirements. The reason is that the communication system is not designed for positioning purpose specifically [13], [14]. For example, the Positioning Reference Signal (PRS) in cellular network is proposed which guarantees the user to measure the Reference Signal Time Difference (RSTD) between different cells to estimate approximate positioning [18]. However, as PRS is not transmitted continuously, it is difficult to achieve accurate range measuring [16], [17].

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When the positioning signals are supposed on the communication signals based on Non-orthogonal Multiple Access (NOMA) techniques, positioning signals can be continuous and easy to be tracked. What's more, NOMA techniques can improve spectral efficiency and achieve higher transmission rates in communications compared to traditional Orthogonal Multiple Access (OMA) [18]. Therefore, NOMA has drawn much attention on Internet-of-things (IoT), vehicle technology, etc. [19], [20].

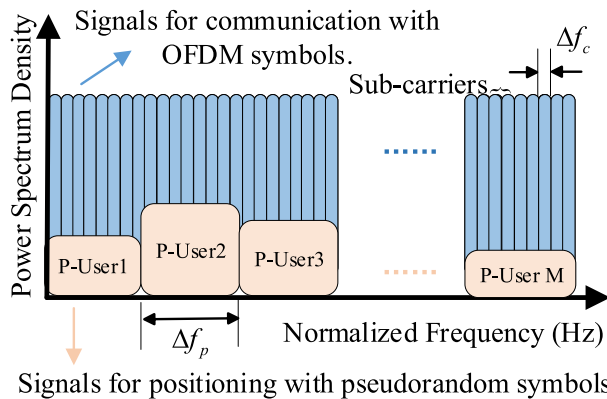


FIGURE 1. The proposed MS-NOMA downlink signal.

In our previous work, we proposed a positioning-communication integrated signal, called Multi-Scale Non-Orthogonal Multiple Access (MS-NOMA) [21], which superposes a low power positioning signal on the communication one without much interference based on the NOMA principle, as Fig.1 shows. In the proposed MS-NOMA downlink signal,  $\Delta f_c$  and  $\Delta f_p$  represent the sub-carrier spacing of communication and positioning user (C-User and P-User), respectively. For the maximum spectrum effectiveness, they are designed as  $\Delta f_p = G\Delta f_c$ ,  $G \in \mathbb{N}_+$ . We assume both C-User and P-User each occupy a separate sub-carrier. So that there are maximum  $N = B/\Delta f_c - 1$  and  $M = B/\Delta f_p - 1$  users for communication and positioning purpose, respectively, where  $B$  represents the total bandwidth.

The power allocation algorithm for MS-NOMA downlink signal is studied in [22]. The power of communication signal is set to be same, while the positioning signal power of different P-Users is specially allocated to obtain optimum ranging accuracy. Different from the downlink broadcasting signals, the uplink signals may have different power to decrease the inter-cell interference and power consumption [23]. Moreover, the transmitting power of user equipment is limited. The power of different kinds of users should be allocated to minimize ranging error and reduce power consumption at the same time. Therefore, the power allocation scheme for MS-NOMA uplink signal is also important. In this work, the structure of MS-NOMA uplink signal is proposed and the power allocation system is remodeled. Last, the derivation of ranging error is shown clearly in this work.

Because there is mutual interference between C-Users and P-Users in the MS-NOMA signal, the optimal water-filling

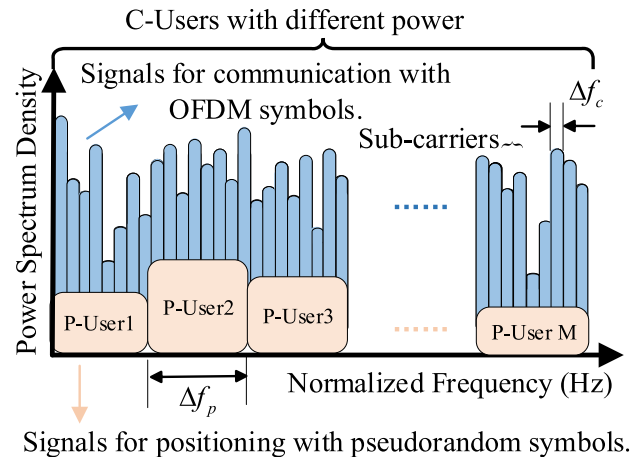


FIGURE 2. The proposed MS-NOMA uplink signal.

over the sub-carriers algorithm, which is usually used in the Orthogonal Frequency Division Multiplexing (OFDM) power allocation problem, cannot be used to solve our problem [24]. In [25], considering the energy efficiency of users, a joint power and bandwidth allocation method with clone immune algorithm is proposed. To solve the optimization problem of power allocation and transmission mode selection under imperfect Channel State Information (CSI), an optimal energy-aware joint power allocation and mode selection scheme is proposed [26]. What's more, a resource allocation scheme is studied for NOMA enhanced heterogeneous networks (HetNets) [27]. In [28], to reduce the physical-layer latency and achieve target data rates, a user selection and power allocation scheme based on greedy scheduling for single-cell downlink NOMA system is studied. NOMA has been merged with backscatter communications to meet the link requirements of massive devices in IoT networks [29]. In [30], a novel resource optimization framework is proposed to maximize the spectral efficiency of NOMA IoT networks. The main optimization problem is divided into two sub-problems by decoupling technique to solve the non-convex problem. In [31], the author proposes a joint optimization problem to promote spectrum and energy efficiency. The optimal solution is derived and a low complexity scheme is proposed as comparison to demonstrate the advantages of the optimal solution. However, the power allocation algorithm in traditional NOMA system is not suitable for our problem because these algorithms are mainly focus on the power allocation for communication system which do not consider the interference between different types of users. Therefore, the power allocation algorithm for MS-NOMA uplink signal is necessary to be investigated.

The main contributions of this paper are:

- Firstly, we model the power allocation problem of MS-NOMA uplink signal as a joint optimization problem, where the power of both P-Users and C-Users should be allocated specifically.
- Secondly, the joint optimization problem is divided into two optimization sub-problems and the solutions of two

sub-problems are derived. Then the Joint Iterative Power Allocation Algorithm (JIPAA) is used to obtain the solution of the original problem.

- Last, a series of numerical analysis is presented to evaluate the performances of JIPAA algorithm. Another power allocation algorithm based on traditional uplink power control scheme is proposed to demonstrate the advantages of JIPAA algorithm.

The rest of this paper is organized as follows: the system model and features of MS-NOMA on uplink occasion are explained in detail in section II. The proposed algorithm JIPAA are elaborated in section III. At last, some numerical results are presented in section IV.

*Notations:* In this paper, the subscript like  $c$  of  $P_{c,n}$  and  $p$  of  $P_{p,m}$ , indicates that this variable belongs to C-user or P-User, respectively. The subscript like  $n$  of  $P_{c,n}$  and  $m$  of  $P_{p,m}$ , indicates that this variable belongs to the  $n^{th}$  C-user or  $m^{th}$  P-User, respectively. What's more, the subscript like  $k$  of  $P_{p,m,k}$  in the Algorithm 1, indicates that the number of iterations. The subscript  $th$  indicates that this variable is a threshold.

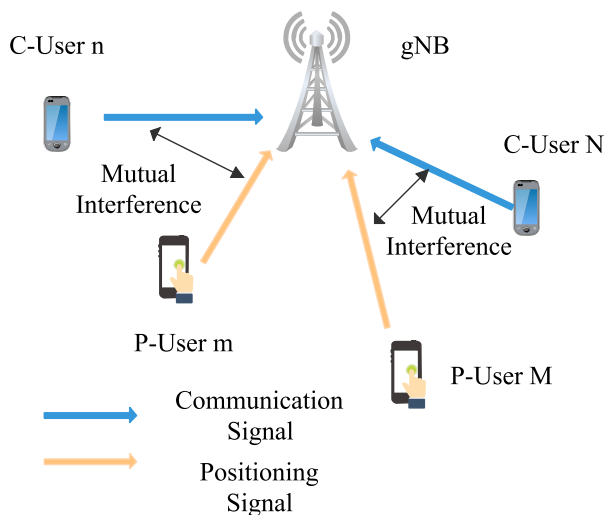


FIGURE 3. Power allocation scenario for communication and positioning integrated network.

## II. SYSTEM MODEL

Considering the typical communication and positioning scenario with M P-Users and N C-Users as Fig. 3 shows. Without any loss of generality, the following assumptions are used: 1) Each spreading sequence of different P-Users is independent. 2) The channel states are available through a zero-delay and error-free feedback channel which are known by the Base-Station (BSs) and users. 3) There is no mutual

interference between P-Users. Also, a C-User does not have interference to the other C-Users. Therefore, the main problem we concerned is the mutual interference between C-Users and P-Users.

The reasons that we use these assumptions are: 1) The common Pseudo-Random Noise (PRN) Code, Gold Code is often used to distinguish different users in GPS system. When the register series reaches 7, there are 11610 different Gold codes to be used, which is far larger than the number of P-Users. 2) This assumption is used to guarantee the network can obtain perfect CSI which is common in many researches. 3) Each positioning signal is lied on a different sub-carrier and all positioning signals are designed orthogonally. What's more, the inter-cell interference can be eliminated by many mature techniques.

### A. THE RANGING ERROR OF P-USER

The receiver could use a Delay Locked Loop (DLL) to track the positioning signal. Taking the coherent early-late discriminator for example [32], the tracking/ranging error of the positioning signal  $m$  can be written as (1), shown at the bottom of the page.

In (1),  $m$  represents the  $m^{th}$  P-User,  $f$  is the integration variable which represents frequency,  $a$  is determined by the loop parameters,  $B_0$  is the central frequency of MS-NOMA signal,  $B_{fe}$  is the double-sided front-end bandwidth,  $N_0$  is the single sided normalized Power Spectral Density (PSD) of environment noise,  $\Delta f_p$  is the signal bandwidth of the  $n^{th}$  P-User,  $D$  is the early-late spacing of DLL,  $T_p$  is the period of the positioning symbol,  $P_{p,m}$  is the signal power of the  $m^{th}$  P-User and  $h_{p,m}$  is the instantaneous channel gains between the BS and the  $m^{th}$  P-User.  $G_s(f)$  is the PSD of the communication signals received by BS which satisfies:

$$G_s(f) = \sum_{n=1}^N |h_{c,n}|^2 P_{c,n} T_c \sin^2 [(f - n\Delta f_c) T_c] \quad (2)$$

where  $P_{c,n}$  is the signal power of the  $n^{th}$  C-User and  $T_c$  is the period of the communication symbol.  $G_p^m(f)$  is the PSD of positioning signal  $m$  which satisfies:

$$G_p^m(f) = T_p \sin^2 [(f - m\Delta f_p) T_p] \quad (3)$$

By taking (2) and (3) into (1), (1) can be simplified as:

$$(\sigma_\rho^m)^2 \approx \frac{aT_p}{P_{p,m}B_{fe}} \left( \frac{N_0}{2|h_{p,m}|^2} + \frac{\sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \sin^2(\frac{n}{G}\pi)}{|h_{p,m}|^2 B_{fe}} \right) \quad (4)$$

$$(\sigma_\rho^m)^2 = \frac{a \int_{B_0-B_{fe}/2}^{B_0+B_{fe}/2} [N_0 + G_s(f + m\Delta f_p)] G_p^m(f + m\Delta f_p) \sin^2(\pi f D T_p) df}{|h_{p,m}|^2 P_{p,m} \left[ 2\pi \int_{B_0-B_{fe}/2}^{B_0+B_{fe}/2} f G_p^m(f + m\Delta f_p) \sin(\pi f D T_p) df \right]^2} \quad (1)$$

The first item in (4) is caused by the noise, and the second one is caused by the communication signals from all C-Users. The detailed derivation of (1) is shown in Appendix A.

**B. THE COMMUNICATION QUALITY OF C-USER**

To evaluate the interference of the positioning signals to communication one, we assume the inter-cell interference between the communication signals could be ideally eliminated. The Bit Error Rate (BER) of the  $n^{th}$  C-User is employed to evaluate the QoS:

$$BER(n) = \text{Kerfc} \left( \frac{\lambda |h_{c,n}|^2 P_{c,n} T_c}{f_n + 2N_0} \right) \quad (5)$$

where

$$f_n = \sum_{m=1}^M |h_{p,m}|^2 T_p P_{p,m} \sin^2 \left( m - \frac{n}{G} \right) \quad (6)$$

$K$  and  $\lambda$  are determined by the modulation and coding schemes,  $\text{erfc}$  is the Gauss error function,  $h_{c,n}$  is the instantaneous channel gains between the BS and the  $n^{th}$  C-User,  $P_{c,n}$  is the signal power of the  $n^{th}$  C-User,  $T_c$  is the period of the communication symbol, and  $f_n$  represents the interference of all P-Users to  $n^{th}$  C-User.

The BER of the  $n^{th}$  C-User is required to be smaller than a threshold  $BER_{target}$  which is determined by the QoS:

$$BER(n) \leq BER_{target} \quad (7)$$

**C. TOTAL POWER CONSTRAINT**

The total transmit power is often limited. In MS-NOMA signal, we have:

$$\sum_{n=1}^N P_{c,n} + \sum_{m=1}^M P_{p,m} \leq P_{budget} \quad \forall m \in M \quad \forall n \in N \quad (8)$$

where  $P_{budget}$  is the total transmit power of the two types of users in this communication-positioning integrated system.

**III. POWER ALLOCATION ALGORITHM**

In general, our goal is to achieve best ranging performance under the least power consumption with the QoS constraint of C-User. However, it is difficult to solve this optimization problem because there are two kinds of users whose power both needs to be allocated in the MS-NOMA. Therefore we divide this optimization problem into two optimization problems. And in each problem, one kind of user's power is allocated and the other kind of user's power is fixed. After the above two optimization problems are solved, the iterative method is used to obtain the solution of the original problem.

In the first optimization problem, only  $P_{c,n}$  is allocated and the signal power of P-User  $P_{p,m}$  is fixed. Therefore, (7) can be transformed into:

$$P_{c,n} \geq \frac{\text{erfc}^{-1} (BER_{target}/K) (f_n + 2N_0)}{\lambda |h_{c,n}|^2 T_c} \triangleq P_{th,n} \quad (9)$$

where  $\text{erfc}^{-1}$  is the inverse function of Gauss error function. As long as the signal power of the  $n^{th}$  C-User  $P_{c,n}$  is larger

than its power threshold  $P_{th,n}$ , the communication quality of the  $n^{th}$  C-User is guaranteed.

The first optimization problem tends to reduce the power of all signals as much as possible. Since the power of positioning signal is much smaller than that of communication one, it is necessary to decrease the power of communication signals only. To ensure the QoS of C-User, BER of each C-User is supposed to be under a certain threshold  $BER_{target}$ . And ranging error of each P-User should be under a certain threshold  $\sigma_{th}^2$ . With the above objective function and two constraints, the first optimization problem can be obtained as:

$$\begin{aligned} \text{OP1: } \min & \left( \sum_{n=1}^N P_{c,n} \right) \\ \text{s.t. } & P_{c,n} \geq P_{th,n} \quad \forall n \in N \\ & (\sigma_{\rho}^m)^2 \leq \sigma_{th}^2 \quad \forall m \in M \end{aligned} \quad (10)$$

OP1 is a linear optimization problem and it is clear that  $(\sigma_{\rho}^m)^2$  is a monotone decreasing function with  $P_{c,n}$ . The objective function tends to reduce  $P_{c,n}$ , and the first constraint should take the equal sign. Therefore, with the proper ranging error  $\sigma_{th}^2$ , the solution of OP1 is shown as (11). Otherwise, OP1 has no feasible solution.

$$P_{c,n} = P_{th,n}, \quad \forall n \in N \quad (11)$$

The goal of OP2 is to obtain best ranging performance for all P-Users under QoS requirement and total transmit power limitation. Therefore, the total ranging accuracy of all P-Users in the network is minimized by finding the optimal power values  $P_{p,m} \forall m \in M$  under the given constraints. And the signal power of every C-User  $P_{c,n}$  is fixed.

As  $P_{p,m}$  is the variable in OP2 and the function  $\text{erfc}$  is difficult to be processed directly, (7) can be transformed into:

$$f_n \leq f_{th,n} \quad \forall n \in N \quad (12)$$

where

$$f_{th,n} = \frac{\lambda |h_{c,n}|^2 P_{c,n} T_c}{\text{erfc}^{-1} (BER_{target}/K) T_p} - 2N_0 \quad (13)$$

$f_{th,n}$  represents the threshold of all P-Users' interference to  $n^{th}$  C-User. Once (12) is satisfied, the QoS of the  $n^{th}$  C-User is guaranteed.

Then, OP2 can be formulated as:

$$\begin{aligned} \text{OP2: } \min & \left( \sum_{m=1}^M (\sigma_{\rho}^m)^2 \right) \\ \text{s.t. } & f_n \leq f_{th,n} \quad \forall n \in N \\ & \sum_{m=1}^M P_{p,m} \leq P_{total} \end{aligned} \quad (14)$$

where  $P_{total}$  is the total power threshold of all P-Users.

Obviously, the objective function of OP2 is a convex function, and OP2 is a convex optimization problem when  $P_{p,m} \geq 0$ . Like the optimization problem in [22], OP2 can be solved by Lagrange duality method. The solution of OP2 is (15), as shown at the bottom of the page, and the derivation can be seen in appendix B in detail.



**Algorithm 1** The Proposed JIPAA Algorithm

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1: Initiate  $\{P_{c,n,init}\} = P_{c,init}, \forall n \in N, k = 1.$ 
2: if ( $k = 1$ ) then
3:   For each P-Users  $m$ , calculate  $\tilde{P}_{p,m,1}$  using (15) and
    $\{P_{c,n,init}, n \in N\}.$ 
4:   For each C-Users  $n$ , calculate  $P_{c,n,1}$  using (11) and
    $\{\tilde{P}_{p,m,1}, m \in M\}.$ 
5:    $k = k + 1.$ 
6: else
7:   for ( $k = 2$  to  $iterK$ ) do
8:     For each P-Users  $m$ , calculate  $\tilde{P}_{p,m,k}$  using (15)
     and  $\{P_{c,n,k-1}, n \in N\}.$ 
9:     For each C-Users  $n$ , calculate  $P_{c,n,k}$  using (11)
     and  $\{\tilde{P}_{p,m,k-1}, m \in M\}.$ 
10:     $k = k + 1.$ 
11:   end for
12: end if
13: if  $|\tilde{P}_{p,m,k+1} - \tilde{P}_{p,m,k}| \leq \varepsilon$  and  $|P_{c,n,k+1} - P_{c,n,k}| \leq \varepsilon$ 
then
14:   break
15: end if
       return  $P_c = \{P_{c,n,k} \forall n \in N\}$  and  $\tilde{P}_m =$ 
        $\{P_{p,m,k} \forall m \in M\}$ 

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As for both OP1 and OP2 need to reduce  $P_{c,n}$ , the joint problem composed of OP1 and OP2 is convergent. Therefore, with the above solutions of OP1 and OP2, it is feasible to use the proposed JIPAA algorithm to implement the optimal allocation of  $P_{c,n}$  and  $P_{p,m}$ . Firstly, every element of the initial array  $P_{c,n}$  is set to be the same:

$$\{P_{c,n}, \forall n \in N\} = P_{c,init} \quad (16)$$

To initiate the JIPAA algorithm, the solution of OP2 is used to obtain  $P_{p,m,1}$  with  $P_{c,init}$  and the solution of OP1 is used to obtain  $P_{c,n,1}$  with  $P_{p,m,1}$ . Then, a two stage algorithm is proposed to obtain the optimal  $P_{p,m}$  and  $P_{c,n}$ . In the first stage,  $P_{c,n,1}$  is taken into OP2 to calculate  $P_{p,m,2}$ . In the second stage,  $P_{p,m,2}$  is taken into OP1 to calculate  $P_{c,n,2}$ . Repeat the above two steps until the differences of  $P_{c,n,k}$  and  $P_{c,n,k+1}$  is small enough, and it is same for  $P_{p,m}$ . The JIPAA algorithm is shown as Algorithm 1 in detail.

#### IV. NUMERICAL RESULTS

In this section, we show some simulation results to evaluate the performance of the proposed JIPAA algorithm. In the simulation environment, the amount of P-Users is 20.

The amount of C-Users superposed on one P-User are 60, 80 and 100, respectively. The total bandwidth  $B = 18\text{MHz}$ ,  $25\text{MHz}$  and  $32\text{MHz}$ , respectively. The distance between each user and the BS (located at (0, 0)) is selected randomly from 10m to 200m. The single sided PSD of environment noise is set as  $3 * 10^{-13}$  (W/Hz). And the signal transmission is free propagation model. The traditional power allocation method is selected as comparison, which is elaborated in Appendix C. Monte Carlo experiments are repeated. In each experiment, the target BER  $BER_{target}$  is from 0.001 to 0.01 (19 times). And  $\sigma_{th}^2$  in (10), the threshold of  $(\sigma_{\rho}^m)^2$  is 0.25m. Usually,  $\sigma_{target}^2$  and  $\sigma_{th}^2$  should be same. But when they are same, through our simulation, we found that the power of P-Users in traditional method is allocated too low to demonstrate the advantages of the proposed JIPAA algorithm. So  $\sigma_{target}^2$  is set to be low enough to guarantee that the total power of positioning signals in traditional method is very close to that of the proposed JIPAA algorithm. Then, with the target BER and  $\sigma_{th}^2$ , the proposed JIPAA algorithm is used to obtain optimum  $P_{p,m}$  and  $P_{c,n}$ . What's more, with  $BER_{target}$  and  $\sigma_{target}^2$ , the  $P_{c,n}$  and  $P_{p,m}$  of traditional method is easy to be obtained using (38) and (39).

Firstly, we should notice that in the traditional method (shown in Appendix C), we use the  $BER_{target}$  to calculate the signal power of C-Users using (38). However, the  $BER_{target}$  is not the actual BER of C-Users because the interference between communication signal and positioning signal is not considered in the traditional method. The actual BER of C-Users should be calculated by (5) after having the solution which is calculated using (38). Like  $BER_{target}$ ,  $\sigma_{target}^2$  is not the actual ranging error of C-Users in the traditional method and it should be calculated by (4) after having the solution which is calculated using (39). In the following, if  $BER_{target}$  or "the target BER" are not specially stated, BER represents the actual BER of C-Users. So is the  $\sigma_{target}^2$  and ranging error represents the actual ranging error of P-Users. Last but not least, to understand these figures more clearly, we are supposed to point out that each curve has 19 points in Figure. 4, 5 and 7, which is corresponding to the simulation setting that "the target BER  $BER_{target}$  is from 0.001 to 0.01 (19 times)".

Then the power of C-User is concerned. As the power of positioning signals is much smaller than that of communication signals, we use the total power of the whole system instead. Fig. 4 shows the total power of the system with the target BER. It can be found that the power of the JIPAA algorithm is larger than that of the traditional power

$$\tilde{P}_{p,m} = \left[ \frac{aT_p}{\left( v + \sum_{n \in N_m} \tilde{\mu}_n \left( |h_{p,m}|^2 T_p \sin^2 \left( m - \frac{n}{G} \right) \right) \right) B_{fe}} \left( \frac{N_0}{2|h_{p,m}|^2} + \frac{\sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \sin^2 \left( \frac{n}{G} \pi \right)}{|h_{p,m}|^2 B_{fe}} \right) \right]^{1/2} \quad (15)$$

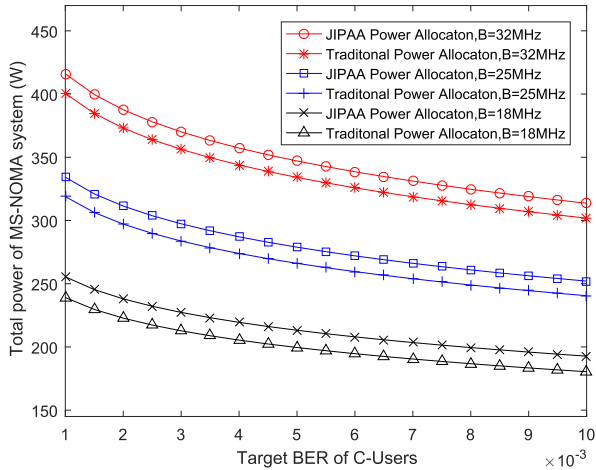


FIGURE 4. Total power of MS-NOMA system with target BER.

method when the target BER is same. And the extra total power consumed by the JIPAA algorithm is less than 15W, less than 5%. As the number of C-Users increases, the corresponding total power consumption will also increase. With the deterioration of communication quality, the total power will rapidly decrease. Last but not least, it is significant even the total power decreases, the extra power which the JIPAA algorithm consumes more than traditional method does not decrease obviously, which means the JIPAA algorithm performs more efficiently when the constraint of BER is stricter.

With the above analysis, we can get a conclusion that the power of two kinds of users that JIPAA algorithm consumes is close to the traditional method when the  $BER_{target}$  is same and  $\sigma_{target}^2$  is selected specifically. In the following we will discuss the performance of communication and ranging.

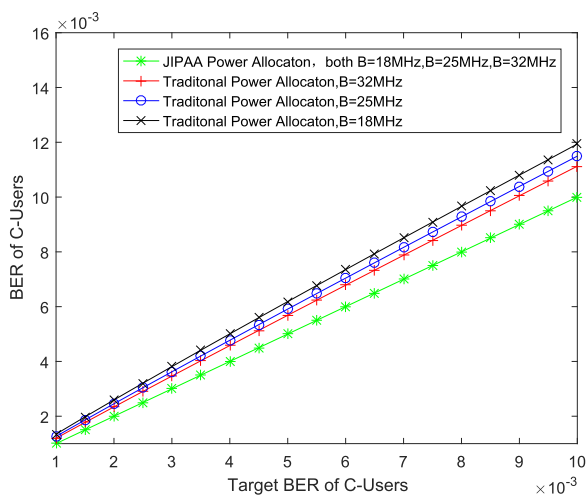


FIGURE 5. BER of C-Users with target BER.

The purpose of Fig. 5 is to evaluate the communication quality. Fig. 5 shows the average BER of all C-Users with the growing of  $BER_{target}$ . From the “\*” curve, it can be found that the BER of C-Users based on the JIPAA algorithm is

equal to the target BER when  $B = 18, 25, 32\text{MHz}$ , which is consistent with the theoretical analysis of OP1 in (11). However, according to the other three curves, the BER of C-Users in traditional method is larger than the  $BER_{target}$  when  $B = 18, 25, 32\text{MHz}$ . When  $B = 18\text{MHz}$ , the improvement of BER in JIPAA can reach 16.2%. Moreover, in traditional method, the BER of  $B = 18\text{MHz}$  is larger than that of  $B = 25\text{MHz}$ . The reason is that the number of C-Users increases with the growing of  $B$ , while the number of P-Users remains same. And the interference of positioning signals to C-Users decreases. But the JIPAA algorithm can prevent this phenomenon effectively.

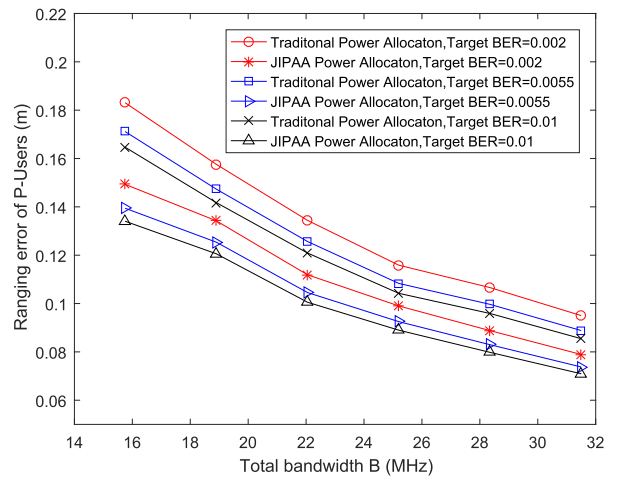


FIGURE 6. Ranging error of P-Users with total bandwidth B.

In Fig. 6, the total bandwidth is set from 15MHz to 32MHz and the vertical axis is the average ranging error of 19 simulations under different  $BER_{target}$ . It can be found that the ranging error of traditional method is larger than that of JIPAA. The reason is that the interference of communication signals to P-Users is not considered in the theoretical derivation of the traditional method. When the total power consumption of P-Users is close in both methods, the proposed JIPAA algorithm can effectively reduce the ranging error. With the growing of the target BER of C-Users, both the ranging error of two algorithms will decrease. This is because that when the target BER increases, which means that the QoS of C-Users becomes worse, the total power of C-Users decreases. And the interference of C-Users to P-Users will reduce. Last, with the growing of  $B$ , the ranging error of the JIPAA algorithm decreases obviously. The reason is that the number of P-Users stay unchanged, each P-user will occupy a wider band with the larger total bandwidth.

In Fig. 7, each color represents a different total bandwidth  $B$ . Between the two same color curves, one is the JIPAA algorithm and the other is the traditional method. Each point in these curves represents the simulation results under different  $BER_{target}$ . The relationship between the ranging error of P-Users and the total power consumption is shown in Fig. 7. It is clear that when the JIPAA algorithm consumes the same power like traditional method, the former can significantly

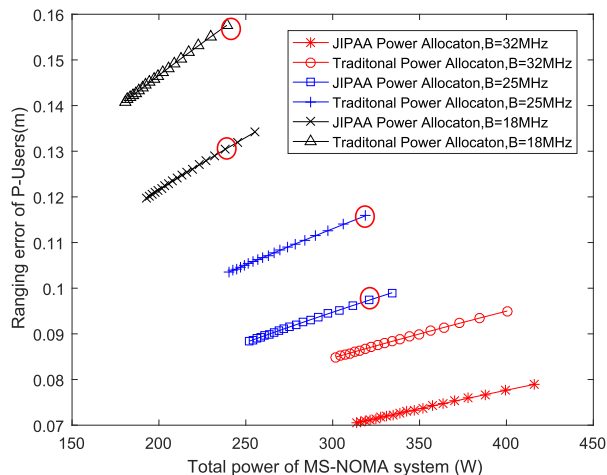


FIGURE 7. Ranging error of P-Users with the total power of MS-NOMA system.

decrease the ranging error of P-Users compared to the latter. When the total power consumption is close, the drop of JIPAA compared to the traditional method is considered. When  $B = 18\text{MHz}$  it is about 16.3% and when  $B = 25\text{MHz}$  it is about 16.0% (indicated by the ellipse).

V. CONCLUSION

In this paper, the power allocation algorithm for MS-NOMA uplink signal is studied. Different from the downlink situation where only the power of communication signal needs to be allocated, it's necessary to allocate the power of both communication signal and positioning signal at the same time. An optimization problem is proposed, which tries to achieve best ranging performance and minimize the power consumption under the QoS constraint. To solve this multi-variable problem, original problem is divided into two optimization sub-problems. The first optimization problem tries to allocate the power of C-Users to reduce total power consumption. The second optimization problem allocates the power of P-Users to obtain optimum ranging performance. With the solutions of the above two problems, the JIPAA algorithm is proposed with the idea of iteration. What's more, based on the traditional uplink power control principle, a traditional power allocation method is proposed as comparison.

Numerical simulation results are presented to validate our analysis. The results show that the ranging error of the proposed JIPAA algorithm can reach 0.071m (when  $B = 32\text{MHz}$ ), while the ranging error of the traditional method is around 0.085m, the drop can reach 16.5% under the same power consumption.

APPENDIX A  
DERIVATION OF  $(\sigma_p^m)^2$

Note

$$A_0^m = \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} f G_p^m(f + m\Delta f_p) \sin(\pi f D T_p) df \quad (17)$$

$$A_1^m = \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} N_0 G_p^m(f + m\Delta f_p) \sin^2(\pi f D T_p) df \quad (18)$$

$$A_2^m = \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} a_2^m df \quad (19)$$

where  $a_2^m = G_s(f + m\Delta f_p) G_p^m(f + m\Delta f_p) \sin^2(\pi f D T_p)$ .

Then, (1) can be written as:

$$(\sigma_p^m)^2 = \frac{a(A_1^m + A_2^m)}{|h_{p,m}|^2 P_{p,m} (2\pi)^2 (A_0^m)^2} \quad (20)$$

Notice that there are multiple P-Users, i.e. the bandwidth of the positioning signal for one P-User is much smaller than the total bandwidth  $B$ . Moreover, the front-end bandwidth is larger than  $B$  as well. So we have  $B_{fe} \gg 2/T_p$ . Consequently, a DLL's narrow early-late spacing  $D$  can be applied.<sup>1</sup> When  $D \rightarrow 0$ ,  $\sin(\pi f D T_p)$  in (17) - (19) can be replaced by Taylor expansion around 0. Then, by taking (2) and (3) into (17) - (19) and rearranging items, we have

$$\begin{aligned} A_0^m &= \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} f G_p^m(f + m\Delta f_p) \sin(\pi f D T_p) df \\ &= \pi D T_p^2 \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} f^2 \sin^2(f T_p) df \\ &= \frac{D B_{fe}}{2\pi} \end{aligned} \quad (21)$$

$$\begin{aligned} A_1^m &= \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} N_0 G_p^m(f + m\Delta f_p) \sin^2(\pi f D T_p) df \\ &= \frac{N_0 D^2 T_p B_{fe}}{2} \end{aligned} \quad (22)$$

$$A_2^m \approx T_p D^2 \sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \sin^2\left(\frac{n}{G}\pi\right) \quad (23)$$

The detailed calculation process of  $A_2^m$  is shown as (24), shown at the bottom of the next page. Taking (17) - (19) into (20), (4) can be obtained.

APPENDIX B  
SOLUTION OF OP2

The Lagrangian function of OP2 is shown as (25):

$$\begin{aligned} \mathcal{L}(\{P_{p,m}\}, \mu, \nu) &= \sum_{m=1}^M (\sigma_p^m)^2 + \sum_{n \in N} u_n (f_n - f_{th,n}) \\ &+ \nu \left( \sum_{m=1}^M P_{p,m} - P_{total} \right) \end{aligned} \quad (25)$$

where  $\mu = \{\mu_n, n = 1 \dots N\}$  and  $\nu$  are the dual variables.

<sup>1</sup>If  $B_{fe}$  is not large enough, the DLL correlation peak will be flattened which will deteriorate the performance of the phase discriminator.

The Lagrange dual function of OP2 is then given by:

$$g(\mu, \nu) = \min_{P_{p,m} \geq 0} \mathcal{L}(\{P_{p,m}\}, \mu, \nu) \quad (26)$$

And the dual optimization problem is shown as:

$$\begin{aligned} \max g(\mu, \nu) \\ \text{s.t. } \mu \geq 0, \nu \geq 0 \end{aligned} \quad (27)$$

The Lagrange dual function can be rewritten as:

$$g(\mu, \nu) = \sum_{m=1}^M g_m(\mu, \nu) - \nu P_{total} \quad (28)$$

where

$$g_m(\mu, \nu) = \min_{P_{p,m} \geq 0} \left\{ (\sigma_\rho^m)^2 + \sum_{n \in N_m} u_n (f_n - f_{th,n}) + \nu P_{p,m} \right\} \quad (29)$$

And  $N_m = \{(m-1)(2G-1) + 1, \dots, m(2G-1)\}$ .

With the translation  $\sum_{n=1}^N = \sum_{m=1}^M \sum_{n \in N_m}$ ,  $g(\mu, \nu)$  can be transformed into M independent sub-problems:

$$\begin{aligned} \text{OP3: } \min_{P_{p,m} \geq 0} (\sigma_\rho^m)^2 + \nu P_{p,m} \\ \text{s.t. } f_n \leq f_{th,n} \quad \forall n \in N_m \end{aligned} \quad (30)$$

The Lagrange function of OP3 is:

$$\tilde{\mathcal{L}}(\{P_{p,m}\}, \mu, \nu) = (\sigma_\rho^m)^2 + \sum_{n \in N_m} \tilde{u}_n (f_n - f_{th,n}) + \nu P_{p,m} \quad (31)$$

The Lagrange dual function of OP3 is given by:

$$\tilde{g}(\mu, \nu) = \min_{P_{p,m} \geq 0} \tilde{\mathcal{L}}(\{P_{p,m}\}, \tilde{\mu}_n) \quad (32)$$

Then the dual problem is shown as:

$$\begin{aligned} \max \tilde{g}_m(\mu_n) \\ \text{s.t. } \mu_n \geq 0 \end{aligned} \quad (33)$$

By using the Karush-Kuhn-Tucker (KKT) conditions, we can get:

$$\begin{aligned} \frac{\partial \tilde{\mathcal{L}}}{\partial P_{p,m}} \\ = -\frac{aT_p}{P_{p,m}^2 B_{fe}} \left( \frac{N_0}{2|h_{p,m}|^2} + \frac{\sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \sin^2\left(\frac{n}{G}\pi\right)}{|h_{p,m}|^2 B_{fe}} \right) + \nu \\ + \sum_{n \in N_m} \tilde{\mu}_n \left( |h_{p,m}|^2 T_p \sin^2\left(m - \frac{n}{G}\right) \right) = 0 \end{aligned} \quad (34)$$

After solving (34), (15) can be obtained and KKT conditions guarantees that the dual problem has the same solution as the original problem. However,  $\mu$  and  $\nu$  is still needed. Using hierarchical algorithm by updating the values of the dual variables,  $\tilde{\mu}_n$  and  $\nu$  can be calculated via subgradient methods [22]. The subgradient of  $\tilde{\mu}_n$  is given as follows.

$$\begin{aligned} g(\mu, \nu) = \min_{P_{p,m} \geq 0} \mathcal{L}(\{P_{p,m}\}, \mu, \nu) \leq \mathcal{L}(\{P_{p,m}\}, \mu, \nu) \\ = \sum_{m=1}^M (\sigma_\rho^m)^2 + \sum_{n=1}^N \mu_n (f_n - f_{th,n}) + \nu (P_{p,m} - P_{total}) \\ = g(\mu', \nu') + \left( \sum_{n=1}^N (\mu_n - \mu_n') \right) (f_n - f_{th,n}) \\ + (\nu - \nu') (P_{p,m} - P_{total}) \end{aligned} \quad (35)$$

From (35), the subgradient of  $\tilde{g}_m(\tilde{\mu}_n)$  is  $(f_n - f_{th,n})$ .

### APPENDIX C TRADITIONAL POWER ALLOCATION METHOD

In the previous research of uplink power allocation for communication system, the uplink power of user is supposed to be strong enough to achieve effective Signal Noise Ratio (SNR), which guarantees the BSs could receive the signal of users

$$\begin{aligned} A_2^m &= \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} G_s(f + m\Delta f_p) G_p^m(f + m\Delta f_p) \sin^2(\pi f D T_p) df \\ &= \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} T_p \sum_{n=1}^N |h_{c,n}|^2 P_{c,n} T_c \sin^2[(f + m\Delta f_p - n\Delta f_c) T_c] \sin^2(f T_p) \sin^2(\pi f D T_p) df \\ &\stackrel{G \gg 1}{\approx} T_c T_p D^2 \sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \int_{B_0 - B_{fe}/2}^{B_0 + B_{fe}/2} \sin^2[(f + m\Delta f_p - n\Delta f_c) T_c] \sin^2(f T_p) df \\ &\approx T_c T_p D^2 \sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \sin^2\left[\pi\left(m - \frac{n}{G}\right)\right] \times \int_{(Gm-n-1)}^{(Gm-n+1)} \sin^2[(f + m\Delta f_p - n\Delta f_c) T_c] \sin^2(f T_p) df \\ &\approx T_p D^2 \sum_{n=1}^N |h_{c,n}|^2 P_{c,n} \sin^2\left(\frac{n}{G}\pi\right) \end{aligned} \quad (24)$$



correctly [33]. Based on this, here we propose a traditional power allocation method for the MS-NOMA as comparison.

In the traditional method, where the power of communication signal is allocated to compensate the transmission path loss, only the environment noise is considered while the interference of positioning signal is not involved. The traditional power allocation of positioning signal is the same as communication signal, where the interference of C-Users is not involved. Here the  $BER_{target}$  and  $\sigma_{target}^2$  is used to guarantee that the uplink signals of both C-Users and P-Users can achieve effective SNR when arriving at BSs. Therefore, the appropriate  $BER_{target}$  of C-Users and target ranging error  $\sigma_{target}^2$  of P-Users are selected to allocate the power of communication signal and positioning signal, shown as (36) and (37).

$$BER_{target} = \text{Kerfc} \left( \frac{\lambda |h_{c,n}|^2 P_{c,n} T_c}{2N_0} \right) \quad (36)$$

$$\sigma_{target}^2 = \frac{aT_p}{P_{p,m} B_{fe}} \left( \frac{N_0}{2|h_{p,m}|^2} \right) \quad (37)$$

Easily, the power of each C-User and P-User can be obtained:

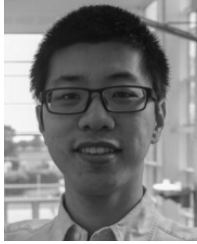
$$P_{c,n} = \frac{(2N_0) \text{erfc}^{-1}(BER_{target}/K)}{\lambda T_c |h_{c,n}|^2} \quad (38)$$

$$P_{p,m} = \frac{aN_0 T_p}{2\sigma_{target}^2 B_{fe} |h_{p,m}|^2} \quad (39)$$

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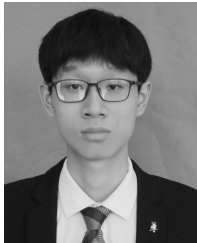
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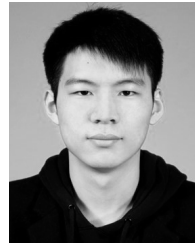
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