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Joint Power Allocation for a Novel Positioning-communication Integrated Signal

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***Abstract*—This paper develops a positioning-communication joint power allocation method for a novel positioning-communication integrated signal called Multi-Scale Non-Orthogonal Multiple Access (MS-NOMA). One of the main differences between the MS-NOMA and the traditional positioning signal is MS-NOMA supports configurable powers for different positioning users (P-Users) to obtain better ranging accuracy and signal coverage. In this paper, the proposed joint power allocation method minimizes the average range measurement error of all P-Users in the network. Meanwhile, it guarantees QoS (Quality of Services) requirements, which BER (Bit Error Rate) is selected to evaluate, and total transmit power budget of all users, including P-Users and communication users (C-Users). The numerical results show the effectiveness of the proposed joint power allocation method.**

***Index Terms*—MS-NOMA, ranging accuracy, signal coverage**

I. Introduction

Nowadays, the Location Based Service (LBS) is growing rapidly and attracting much more attention. The traditional satellite positioning systems are not suitable in complicated environments, such as the urban and indoors, because of poor signal coverage. Wi-Fi, Bluetooth and Wireless sensor networks based positioning system have good coverage in complicated environments with dense placements of the nodes. But they usually need to establish and update fingerprint library which limits their usages [1].

Cellular communication network has good coverage both indoors and outdoors. However, the positioning accuracy can not meet some high-accuracy requirements by using the communication signal directly as the communication system is not designed for positioning purpose specifically. For example, the Positioning Reference Signal (PRS) in the cellular network can not fully meet commercial requirements [2]. It is mainly because the PRS is not continuously transmitted which can not be tracked for accurate phase (range) measuring within a limited bandwidth.

To this end, we proposed a positioning-communication integrated signal, called Multi-Scale Non-Orthogonal Multiple Access (MS-NOMA) [3], which superposes a low power positioning signal on the communication one without much interference based on the NOMA principle. In time domain, the MS-NOMA signal is Code Division Multiple Access (CDMA) to obtain corresponding spreading gains and ensure a continuous transmission. In frequency domain, Orthogonal Frequency Division Multiplexing Access (OFDMA) is employed for different positioning users (P-Users) as Fig. 1 shows.

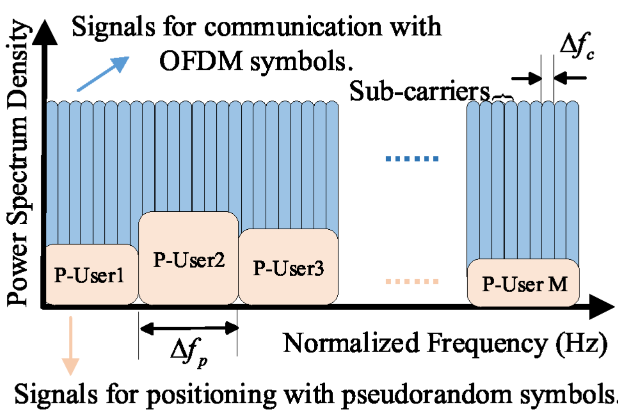


Fig. 1: The MS-NOMA architecture in frequency and power domains.

The reason for distinguishing different P-Users is: the superposed positioning signal interferes communication signal like normal NOMA as well. To reduce this interference, the power of the positioning signal must be limited under a certain threshold to satisfy the QoS (Quality of Services) of communication. While for P-Users, higher power is needed for more accurate range measuring. As the P-Users are located at different locations, gNBs could transmit positioning signals with different powers to different P-Users to meet the requirements of both C-Users and P-Users.

Different from our previous study [3], in this paper, we aim to design a power allocation model of MS-NOMA signal for higher ranging accuracy over the whole network under QoS constrains. As the interaction between communication and positioning signals, the powers of different P-Users must be allocated carefully. In a conventional OFDM system, it is proved that water-filling over the subcarriers is the optimal power allocation strategy [4]. However, it does not consider interference between different types of users. In [5], where the second user transmit over spectrum holes left in the primary system, an optimal power allocation strategy is proposed, which maximizes the downlink capacity of the second user while the interference introduced to the primary user remains within a tolerable range. In NOMA system, the power allocation is mostly investigated for signal demodulation and relay transmission [6]. But these algorithms can not be used in our problem, which has more complicated models (different target functions and constraints).

To the best of our knowledge, there are few studies about power allocation in positioning systems which makes our study very challenging. In this paper, we propose a positioning-communication joint power allocation algorithm subject to various constraints for the MS-NOMA signal. The main contributions are:

- We model the joint power allocation problem for a novel positioning-communication integrated signal, i.e. MS-NOMA, as a convex optimization problem. It uses QoS and power budget constraints to protect the primary users (C-Users), and minimize the average ranging error of the P-Users in the network.
- We give the proposed joint power allocation scheme and derive the power allocation solution.
- A series of numerical analysis are done to evaluate the performance of the proposed joint power allocation method. The results show that the proposed method can effectively allocate power to satisfy the requirements of both communication and positioning purpose.

II. System model

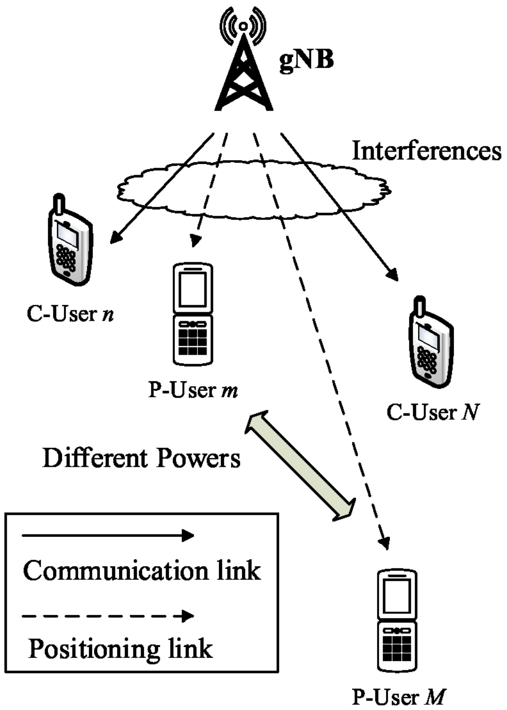


Fig. 2: Power allocation scenario for positioning signals in typical communication network.

Consider a power allocation scenario for positioning signals in typical communication network as Fig. 2 shows. Assume there are N C-Users and M P-Users, respectively. The sub-carrier spacing of the communication and positioning signals are defined as Δf_c and Δf_p as Fig. 1 shows, respectively. Without any loss of generality, we assume both P-User and C-User occupy an own separate sub-carrier and $\Delta f_p = G\Delta f_c$, $G \in \mathbb{N}_+$. 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 is the the total bandwidth.

Notice that the positioning signals located on different sub-carriers are orthogonal, so there is no interference between P-Users. However, like normal NOMA signals, there are interferences between communication signals and positioning signals. The mutual interference could be represent from two aspects: 1) Bit Error Rate (BER) for the interference of positioning signal to communication one; and 2) ranging accuracy for the interference of communication signal to positioning one.

A. Interference threshold under QoS constraint

Without any loss of generality, we assume the powers for all C-Users are identical and each spreading sequence for different P-Users is independent. Then, the BER of the n^{th} C-User is [7]:

$$BER(n) = K\text{erfc}\left(\frac{\lambda |h_c^{(n)}|^2 P_c T_c}{\sum_{m=1}^{M} I_m^{(n)}\left(P_{p,m}, h_c^{(n)}\right) + 2N_0}\right) \quad (1)$$

where K and λ are determined by the modulation and coding schemes. P_c is the power of the communication signal. $P_{p,m}$ is the power of the m^{th} positioning signal. T_c is the period of the communication symbol. N_0 is the environment noise's single-sided Power Spectral Density (PSD). $h_c^{(n)}$ is the instantaneous channel gains between the gNB and the n^{th} C-User which is assumed known through a delay- and error-free feedback channel. $I_m^{(n)}\left(P_{p,m}, h_c^{(n)}\right)$ represents the interference introduced by the m^{th} P-User to the n^{th} C-User which satisfies [3]:

$$I_m^{(n)}\left(P_{p,m}, h_c^{(n)}\right) = |h_c^{(n)}|^2 P_{p,m} T_p \text{sinc}^2\left(m - \frac{n}{G}\right) \quad (2)$$

where T_p is the period of the positioning symbol.

To ensure the QoS of the C-User, the BER for each C-User should be limited under a certain threshold as:

$$BER(n) \le \beta_{th}^{(n)}, \ n = 1, ..., N \quad (3)$$

By taking (1) to (3) and rearranging items, we have the interference caused by all P-Users to the n^{th} C-User as:

$$\begin{aligned}\sum_{m=1}^{M} I_m^{(n)}\left(P_{p,m}, h_c^{(n)}\right) &\le \frac{\lambda |h_c^{(n)}|^2 P_c T_c}{\text{erfc}^{-1}\left(\beta_{th}^{(n)}/K\right)} - 2N_0 \\ &\triangleq I_{th}^{(n)}, \ n = 1, ..., N\end{aligned} \quad (4)$$

where $I_{th}^{(n)}$ is defined as the interference threshold of the n^{th} C-User which is determined by the QoS threshold $\beta_{th}^{(n)}$.

B. The ranging accuracy of the P-User

The communication signal will affect the performance of the range measuring as well. Notice that the positioning signal is continuous in the MS-NOMA signal, the receiver can track the signal by a delay locked loop (DLL). We assume BPSK modulation is used for the positioning signal, then the ranging error of the DLL can be approximated as [3], [8]:

$$\sigma_{t,m}^2 \approx \alpha T_p^2 \frac{CPR_m}{B_{fe}} \left(\frac{1}{\overline{E_b^{(m)}}/N_0} + \frac{B}{B_{fe}} \right) \tag{5}$$

where α is determined by the loop parameters. B_{fe} is the double-sided front-end bandwidth. $\overline{E_b^{(m)}} = |h_p^{(m)}|^2 P_c T_c$ is the energy of the communication symbol at the m^{th} P-User's end, where $h_p^{(m)}$ is the instantaneous channel gains between the gNB and the m^{th} P-User which is assumed known similar to $h_c^{(n)}$. $CPR_m = \frac{\kappa P_c}{P_{p,m}}$ is defined as the communication-to-positioning ratio of the m^{th} P-User, where $\kappa = 2G - 1 \approx 2G$ represents the amount of C-Users over the m^{th} P-User's bandwidth with $G \gg 1$.

C. The total power limitation

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

$$\sum_{m=1}^{M} P_{p,m} + NP_c \le P_{\text{Total}} \tag{6}$$

where P_{Total} represents the total transmit power of all users. Let's define the power budget of all P-Users as $P_{th} = P_{\text{Total}} - NP_c$, then we have:

$$\sum_{m=1}^{M} P_{p,m} \le P_{th} \tag{7}$$

III. The Proposed Joint Power Allocation Scheme

Our goal is to obtain a best positioning performance under a QoS constraint and total transmit power budget. So, the average ranging error for all P-Users is minimized by finding the power values $P_{p,m}$ $(m = 1, ..., M)$ under given QoS thresholds $\beta_{th}^{(n)}$ $(n = 1, ..., N)$ and the total transmit power budget P_{Total}. We formulated it as a convex optimization problem by maximizing the negative value of the average ranging error as:

$$\text{OP1} : \max_{P_{p,m}} \frac{1}{M} \sum_{m=1}^{M} -\alpha T_p^2 \frac{CPR_m}{B_{fe}} \left(\frac{1}{\overline{E_b^{(m)}}/N_0} + \frac{B}{B_{fe}} \right) \tag{8}$$

$$\text{s.t.} \sum_{m=1}^{M} I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right) \le I_{th}^{(n)},\ \forall n \in \{1, ..., N\} \tag{9}$$

$$\sum_{m=1}^{M} P_{p,m} \le P_{th} \tag{10}$$

$$P_{p,m} \ge 0,\ \forall m \in \{1, ..., M\} \tag{11}$$

OP1 can be solved by the Lagrange duality method. For the sake of convenience, we use λ to replace $-\alpha T_p^2/M$. Then the Lagrangian of OP1 can be written as [9]:

$$\begin{aligned} &\mathcal{L}(\{P_{p,m}\}, \mu, \nu) \\ &= \lambda \sum_{m=1}^{M} \frac{CPR_m}{B_{fe}} \left(\frac{1}{\overline{E_b^{(m)}}/N_0} + \frac{B}{B_{fe}} \right) \\ &+ \sum_{n=1}^{N} \mu_n \left(I_{th}^{(n)} - \sum_{m=1}^{M} I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right) \right) \\ &+ \nu \left(P_{th} - \sum_{m=1}^{M} P_{p,m} \right) \end{aligned} \tag{12}$$

where ν is the dual variable associated with the transmit power budget constraint given in (7). $\mu = \{\mu_n, 1 \le n \le N\} \geqslant 0$ is a vector of dual variables each associated with one corresponding interference constraint given in (4).

The Lagrange dual function of OP1 is then given by:

$$g(\mu, \nu) = \max_{P_{p,m} \ge 0} \mathcal{L}(\{P_{p,m}\}, \mu, \nu) \tag{13}$$

The dual optimization problem can be formulated as:

$$\min g(\mu, \nu) \tag{14}$$

$$\text{s.t.} \mu \succeq 0,\ \nu \ge 0 \tag{15}$$

Obviously, $\mathcal{L}(\{P_{p,m}\}, \mu, \nu)$ is linear in μ,ν for fixed $P_{p,m}$, and $g(\mu, \nu)$ is the maximum of linear functions. Thus, the dual optimization problem is always convex. In the following, the dual decomposition method introduced in [10] is employed to solve this problem. For this purpose, we introduce a transformation $\sum_{n=1}^{N} = \sum_{m=1}^{M} \sum_{n \in \mathbb{N}_m}$ to decompose the Lagrange dual function to M independent sub-problems as:

$$g(\mu, \nu) = \sum_{m=1}^{M} g_m(\mu, \nu) + \nu P_{th} \tag{16}$$

where

$$\begin{aligned} g_m(\mu, \nu) = \max_{P_{p,m}} \Bigg\{ &\lambda \sum_{n \in \mathbb{N}_m} \frac{P_{c,n}}{P_{p,m} B_{fe}} \left(\frac{1}{\overline{E_b^{(m)}}/N_0} + \frac{B}{B_{fe}} \right) \\ &+ \sum_{n \in \mathbb{N}_m} \mu_n \left(I_{th}^{(n)} - \sum_{m=1}^{M} I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right) \right) - \nu P_{p,m} \Bigg\} \end{aligned} \tag{17}$$

From (17), it is clear that the Lagrange dual function $g(\mu, \nu)$ can be decomposed into M independent optimization problems by giving

$$\text{OP2} : \max_{P_{p,m}} \lambda \sum_{n \in \mathbb{N}_m} \frac{P_{c,n}}{P_{p,m} B_{fe}} \left(\frac{1}{\overline{E_b^{(m)}}/N_0} + \frac{B}{B_{fe}} \right) - \nu P_{p,m} \tag{18}$$

$$\text{s.t.} \sum_{m=1}^{M} I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right) \le I_{th}^{(n)},\ n \in \mathbb{N}_m \tag{19}$$

The Lagrangian of OP2 is:

$$\tilde{\mathcal{L}}\left(P_{p,m},\tilde{\mu}_n\right)=\left\{\lambda\sum_{n\in\mathbb{N}_m}\frac{P_{c,n}}{P_{p,m}B_{fe}}\left(\frac{1}{\overline{E_b^{(m)}}/N_0}+\frac{B}{B_{fe}}\right)+\sum_{n\in\mathbb{N}_m}\tilde{\mu}_n\left(I_{th}^{(n)}-\sum_{m=1}^{M}I_m^{(n)}\left(P_{p,m},h_c^{(n)}\right)\right)\right\} \tag{20}$$

where $\tilde{\mu}_n$ is the non-negative dual variable associated with the constraint(19).

The Lagrange dual function of OP2 is given by:

$$\tilde{g}_m\left(\tilde{\mu}_n\right)=\max_{P_{p,m}}\tilde{\mathcal{L}}\left(P_{p,m},\tilde{\mu}_n\right) \tag{21}$$

The dual problem is then expressed as:

$$\min_{\mu_n}\tilde{g}_m\left(\tilde{\mu}_n\right) \tag{22}$$

$$\text{s.t.}\tilde{\mu}_n\geq 0 \tag{23}$$

The optimal power allocation solution $\widetilde{P}_{p,m}$ of OP2 can be obtained by using the Karush-Kuhn-Tucker (KKT) conditions as:

$$\widetilde{P}_{p,m}=\underbrace{\sigma_{\rho,m}}_{\text{ranging-factor}}\times\underbrace{\left(\sum_{n\in\mathbb{N}_m}\tilde{\mu}_nJ_n+\nu\right)^{-1/2}}_{\text{constraint-scale}} \tag{24}$$

where $\sigma_{\rho,m}$ and J_n can be found in Appendix A. The KKT condition guarantees the solution to the dual problem is the same as the solution to the original problem.

The remaining task for solving OP1 is to obtain the optimal dual variables, which are the same in both OP1 and OP2. Applying the solution to OP2, we can obtain the optimal power allocation $\widetilde{P}_{p,m}$ in OP1. However, it is difficult to solve OP2 directly because we cannot obtain the closed-form expression for dual variables. It is observed that ν is the same for all the P-Users, μ_n is different for the n^{th} subcarriers belonging to the m^{th} positioning signal. Then we can solve the optimization problem using hierarchical algorithm by updating the values of the dual variables $\{\mu,\nu\}$ via subgradient methods, which guarantees the gradient-type algorithm to converge to the optimal solution [10].

Proposition: The subgradient of $\tilde{g}_m\left(\tilde{\mu}_n\right)$ is given by $I_{th}^{(n)}-\sum_{m=1}^{M}I_m^{(n)}\left(\widetilde{P}_{p,m},h_c^{(n)}\right)$, where $\widetilde{P}_{p,m}$ is the optimal solution obtained at $\tilde{\mu}_n$. When $\{\tilde{\mu}_n,\ \forall n=1,2\cdots,N\}$ are obtained, ν is updated by its subgradient which is given by $P_{th}-\sum_{m=1}^{M}\tilde{P}_{p,m}$. Then $\hat{P}_p=\left\{\widetilde{P}_{p,m},\forall m\right\}$ is the optimal solution obtained at ν under the given $\tilde{\mu}_n$ [11].

Using the above gradient, we can obtain the optimal power allocation by iterative Lagrangian multiplier $\{\mu,\nu\}$. The algorithm to solve OP1 can be summarized as Algorithm shows. Where k and k' are the iteration numbers. $iterN$ is the maximum iteration amount. a and b are the update step sizes. $\varepsilon>0$ is a given small constant.

Algorithm 1 The proposed joint power allocation algorithm

Initial the dual variable ν_1
for $k=1$ to $iterN$ **do**
  Initial $\mu_{n,1}$, for all n in parallel
  for $k'=1$ to $iterN$ **do**
    For each P-Users m, calculate $\tilde{P}_{p,m}$ using (24)
    Update $\mu_{n,k'}$ by its subgradient: $\tilde{\mu}_{n,k'+1}=\mu_{n,k'}-b\left(I_{th}^{(n)}-\sum_{m=1}^{M}I_m^{(n)}\left(\tilde{P}_{p,m},h_c^{(n)}\right)\right)$
    if $|\tilde{\mu}_{n,k'+1}-\mu_{n,k'}|\leq\varepsilon$ **then**
      break
    end if
  end for
  Update ν_{k+1} by its subgradient: $\tilde{\nu}_{k+1}=\nu_k-a\left(P_{th}-\sum_{m=1}^{M}\tilde{P}_{p,m}\right)$
  if $|\nu_{k+1}-\nu_k|\leq\varepsilon$ **then**
    break
  end if
end for
return $\hat{P}_p=\left\{\widetilde{P}_{p,m},\forall m\right\}$

IV. Numerical results

In this section, we present the numerical results to evaluate the proposed joint power allocation algorithm. The communication and positioning signals use QPSK and BPSK constellation, respectively. The carrier frequency is set to 3.5GHz and $\Delta f_c=15$kHz. The front-end bandwidth is set to twice of the total bandwidth, i.e. $B_{fe}=2B$. The free space propagation model is employed. The gNB is fixed at $(0,0)$ and 20 P-Users are randomly placed in a 10-200m annular area. 100 Monte Carlo runs are executed in each simulation. Two scenarios with different bandwidths of positioning signals are considered: 1) $B=15$MHz 2)$B=10$MHz, where $B=(M+1)\times\Delta f_p$. Without any loss of generality, we set $\beta_{th}^{(n)}=\beta_{th}$for any $n\in\{1,...,N\}$.

Fig. 3 shows the average ranging errors under different QoS requirements. It is clear that the average ranging errors decrease with the increase of the tolerable BER. Meanwhile, there is higher ranging accuracy with higher bandwidth. Notice that the curves bound to certain values when the tolerable BER increases. It is because the power budget limits the improvement of the performance. Namely, the power budget limits the increasing of the positioning signals' powers. This can be also observed by the different power budget curves (the diamond and star curves). The bound of the diamond curve is larger than the star one's which has a smaller power budget. On the other hand, the curve converges slowly with a smaller bandwidth. The reason is the power of the positioning signal with a small bandwidth will concentrated in narrower range. Consequently, there will be more powers of P-Users that leak to the neighbor C-Users as (2)-(4)show which leads to more interferences.

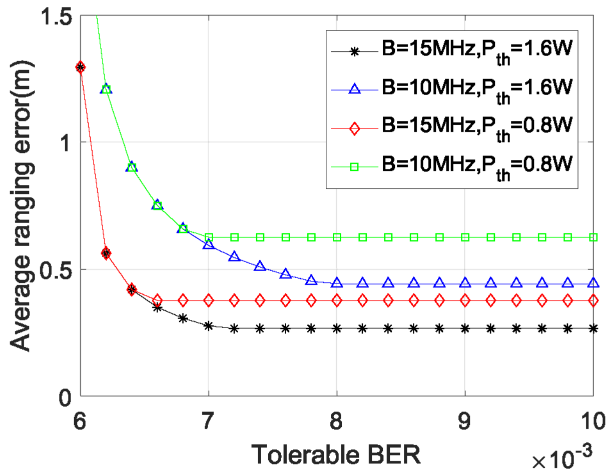


Fig. 3: Average ranging errors under different QoS requirements.

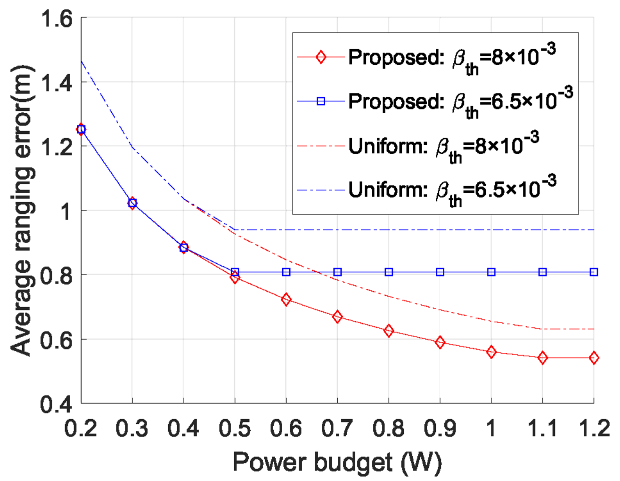


Fig. 4: Average ranging errors under different power budgets (B = 10MHz).

From Fig. 4, it shows that the average ranging error decreases with the increase of the power budget. The larger total power budget, i.e. higher constraint-scale results to a lower average measurement error. Similarly to Fig. 3, the curves bound to certain values when the power budget increases as well. This means the QoS constraint becomes dominant and the average ranging errors do not decrease although the total power increases. If we have a strictly QoS constraint (larger β_{th}), the ranging error bound will be higher. Besides, Fig. 4 compares the proposed joint power allocation method with the uniform loading method in [12]. It shows the average ranging error of the proposed method is much smaller than that of uniform loading method under the same constraints.

Table I illustrates the allocated powers of all P-Users in a simulation run. And we sequence them according to their distances to the gNB. It is clear that the farther distance, the stronger power allocated. Fig. 5a compares the ranging accuracy by using the proposed method and the uniform loading method. Although the ranging errors of the first 4 P-Users by using our proposed method are slightly larger than the uniform loading method, the ranging errors of the rest P-Users are greatly smaller. The ranging accuracy increases 20.49% for P-User20 and only decreases 4.02% for P-User1. Overall, the average ranging error of the proposed method is much smaller than the uniform loading one. The reason of larger errors of the first P-Users is: The farther P-Users need stronger powers to obtain an accurate ranging. To reduce the interferences caused by the stronger positioning signals, the nearer P-Users must be allocated weaker powers. Besides, Fig. 5b shows the BER of all C-Users after the power allocation. We can see all C-Users' BERs are under the tolerable BER threshold which means the superposed positioning has limited interference to the communication signals.

V. Conclusions

In this paper, we proposed a positioning-communication joint power allocation method for a novel positioning-communication integrated signal called Multi-Scale Non-Orthogonal Multiple Access (MS-NOMA). The average ranging error of the P-Users over the network is minimized for a given QoS requirement and power budget constraints. The joint power allocation problem was modeled as a convex optimization problem and we derived the power allocation solution. A series of numerical analysis were done to evaluate the performance of the proposed joint power allocation method. The results show that the proposed method can effectively allocate the powers to obtain the highest ranging accuracy with satisfying the requirements of both communication and positioning purposes.

Appendix A
Derivation of $\widetilde{P}_{p,m}$

The KKT conditions of OP2 can be written as:

$$\sum_{n\in\mathbb{N}_m} \tilde{\mu}_n \left(I_{th}^{(n)} - \sum_{m=1}^{M} I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right) \right) = 0 \tag{25}$$

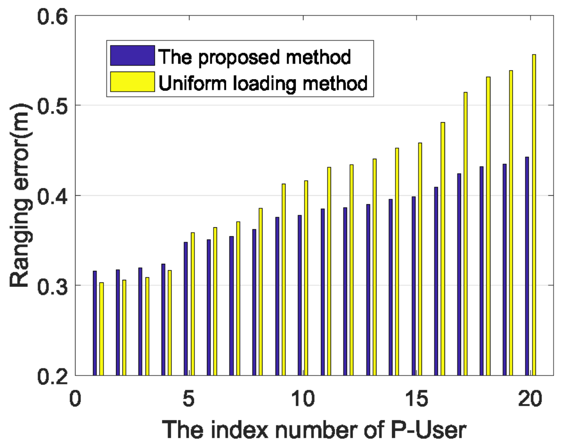
$$\frac{\partial \tilde{\mathcal{L}}}{\partial P_{p,m}} = 0 \tag{26}$$

It is obvious that the optimal solution $\widetilde{P}_{p,m}$ satisfies (26). Thus, from (20), it follows:

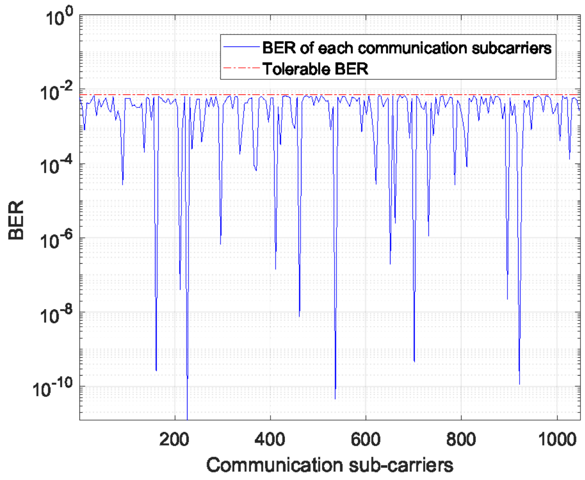
$$\begin{aligned} \frac{\partial \tilde{\mathcal{L}}}{\partial P_{p,m}} &= \frac{\partial - (\sigma_{t,m}^2 + \nu P_{p,m})}{\partial P_{p,m}} + \\ &\frac{\partial \sum_{n\in\mathbb{N}_m} \tilde{\mu}_n \left(I_{th}^{(n)} - \sum_{m=1}^{M} I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right) \right)}{\partial P_{p,m}} \\ &= -\frac{\partial \sigma_{t,m}^2}{\partial P_{p,m}} - \nu - \sum_{n\in\mathbb{N}_m} \tilde{\mu}_n \underbrace{\frac{\partial I_m^{(n)} \left(P_{p,m}, h_c^{(n)} \right)}{\partial P_{p,m}}}_{J_n} \end{aligned} \tag{27}$$

TABLE I: The allocated powers in one simulation run ($B = 15\text{MHz}, P_{th} = 0.8W, \beta_{th} = 7 \times 10^{-3}$)

Index	1	2	3	4	5	6	7	8	9	10
Power (mW)	27.8	28.1	28.4	29.2	33.6	34.2	34.9	36.5	39.3	39.7
distance (m)	35.9	39.6	43.4	52.1	87.1	90.7	95.5	105.4	121.6	124.2
Index	11	12	13	14	15	16	17	18	19	20
Power (mW)	41.3	41.6	42.2	43.6	44.1	46.5	50.1	51.9	52.6	54.5
distance (m)	133.1	134.6	138	145.2	148	160.8	178.3	187	190.5	199.7



(a) Ranging errors of all P-Users



(b) BER after joint power allocation

Fig. 5: Example of a simulation run ($B = 15\text{MHz}, P_{th} = 0.8W, \beta_{th} = 7 \times 10^{-3}$).

where $\frac{\partial \sigma_{t,m}^2}{\partial P_{p,m}}$ is obtained by taking derivative of (5) as:

$$\frac{\partial \sigma_{t,m}^2}{\partial P_{p,m}} = \underbrace{\frac{1}{P_{p,m}^2} \alpha T_p^2 \frac{\kappa P_{c,n}}{B_{fe}} \left(\frac{1}{E_b^{(m)}/N_0} + \frac{B}{B_{fe}} \right)}_{\sigma_{p,m}^2}, n \in \mathbb{N}_m \tag{28}$$

J_n is obtained by taking (2) into (27) as:

$$J_n = |h_c^{(n)}|^2 T_p \text{sinc}^2 \left(m - \frac{n}{G} \right) \tag{29}$$

Then, (27) is set to zero and we have the optimal power allocation strategy as (24) shows.

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