SPECIAL SECTION ON GREEN INTERNET OF THINGS

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NOMA-Enabled CoMP Clustering and Power Control for Green Internet of Things Networks

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ABSTRACT In this paper, we investigate the clustering and power control problem for coordinated multipoint (CoMP) transmission in green non-orthogonal multiple access (NOMA) networks. NOMA is a promising multiple access technique to support massive connectivity in the case of a large number of Internet-of-things (IoT) devices. Recently, CoMP transmission is introduced into NOMA networks to improve network capacity, which enables multiple access points (APs) to simultaneously serve one device while not cutting off the association with other devices. However, non-orthogonal resource sharing brings interference in AP clusters, which further boosts up the transmit-power consumption. To tackle this issue, we propose a scheme to minimize the total transmit power of APs by jointly optimizing AP clustering and power control. Specifically, the AP clustering is modeled as a many-to-one matching problem with externalities. We design an exchange-matching based algorithm to iteratively update the AP clustering and finally achieve the matching with one-sided stability. Furthermore, we show that the power control with a given AP clustering can be solved by linear programming. Simulation results demonstrate that the proposed scheme can release the potential of CoMP in NOMA networks and effectively mitigate interference to save transmit power while meeting rate requirements for all devices.

INDEX TERMS Coordinated multipoint, non-orthogonal multiple access, green communications, user association, Internet of Things.

I. INTRODUCTION

With the advent of the Internet of things (IoT) era, future wireless networks are required to support massive connections for a large number of devices over limited spectrum resources [1]–[3]. To this end, non-orthogonal multiple access (NOMA) is proposed to allow multiple devices to reuse the same spectrum resource by power-domain multiplexing, which has been proved to significantly improve network connectivity and spectrum efficiency [4]. However, massive access for IoT devices aggravates interference as well as puts great pressure on the access points (APs) at the edge of wireless networks [6], [7]. Particularly, when an AP is associated with many devices, it will cause high power consumption and heavy inter-cell interference. Therefore, efficient interference management techniques are important for enhancing spectrum efficiency and energy efficiency in NOMA-based IoT networks.

Recently, coordinated multipoint (CoMP) transmission is introduced into NOMA networks to mitigate potentially severe interference and enhance transmission capacity [8], [9]. CoMP transmission enables multiple APs to simultaneously transmit the desired signal for a single device (called CoMP device), which avoids one AP consuming excessive transmit power to meet the rate requirements for all associated devices [10]. In NOMA-enabled CoMP, the CoMP device can form NOMA groups with non-CoMP devices that are served by the single-transmission [8]. By this way, the AP cluster can provide signal transmissions for multiple devices simultaneously. It is intuitive that NOMA brings interference in AP clusters, which, if not properly handled, could reduce the CoMP transmission rate and bring additional transmit-power consumption. Hence, how to schedule CoMP transmission in NOMA networks is a worthy issue to be investigated.

There has been extensive research on CoMP in NOMA networks [11]–[15]. Choi [11] and Sun *et al.* [12] showed the CoMP transmission can improve the coverage and

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spectrum efficiency of NOMA networks through performance analysis. Tian *et al.* [13] proposed an opportunistic user association algorithm to promote the outage performance of NOMA-enabled CoMP systems. Al-Eryani *et al.* [14] and Ali *et al.* [15] proposed the power allocation algorithm to manage interference and increase spectrum efficiency. However, the blind pursuit of network capacity would significantly increase energy consumption in NOMA-enabled CoMP systems [7], [16]. The increase of transmit power is not friendly to the environment as well as deteriorates the interference among IoT devices. Therefore, it is necessary for CoMP transmission in NOMA networks to take into account transmit-power saving while meeting the requirements of IoT devices.

Due to complicated interference in NOMA groups and among AP clusters, the green scheduling for NOMA-enabled CoMP systems is very challenging. First, the CoMP transmission in NOMA networks suffers both interference in NOMA groups and that from other AP clusters. Hence, AP clustering should consider not only channel conditions between CoMP device and associated APs but also the interference among the CoMP device and non-CoMP devices in the same NOMA group. This means that traditional clustering algorithms in orthogonal multiple access (OMA) [17]–[20] are not applicable for NOMA networks. Second, there exists interference in AP clusters due to the coexistence of NOMA groups and AP clusters. If the transmit power for one non-CoMP device increases, the CoMP device in one NOMA group will suffer more interference and hence require higher transmit power. The increase of transmit power for this CoMP device will further make the devices in other AP clusters require higher transmit power. In this light, the variation of transmit power for one device can lead to the ripple effect to transmit power for other devices. The power control algorithm should be designed carefully to restrain the interference among devices. Furthermore, the interference among devices depends on both the AP clustering and transmit power. Therefore, it is required to jointly design AP clustering and power control scheme to release the potentials of CoMP and NOMA.

In this paper, we investigate the total transmit-power minimization problem for NOMA-based IoT networks. Multiple APs are allowed to perform CoMP transmission to increase the transmission rate of devices. We intend to provide the answers for the following questions: 1) how NOMA influences the AP clustering for CoMP transmission? 2) how to reduce total transmit power in NOMA networks with employing CoMP transmission? The main contributions of this paper can be summarized as follows.

- An unified optimization framework is proposed for the total transmit-power minimization problem by jointly considering the AP clustering and power control. With the aid of this optimization framework, the impact of NOMA user grouping on AP clustering can be characterized. In particular, the interference in NOMA group can affect the CoMP transmission rate. Hence, the AP clustering should consider both channel conditions between CoMP devices and APs as well as interference between CoMP devices and non-CoMP devices.
- We show that the AP clustering can be formulated by a many-to-one matching model with externalities. An exchange-matching based algorithm is proposed to jointly optimize the AP clustering and power control, which updates the association between CoMP devices and APs in an iterative manner. In each exchange matching operation, the total transmit power is calculated by the power control algorithm based on linear programming method. Furthermore, we prove that proposed matching algorithm is convergent.
- We conduct extensive simulations to evaluate the proposed algorithm. The results indicate that the proposed algorithm can efficiently reduce total transmit power while meeting the minimum rate requirements for all devices. Furthermore, the results show that the proposed algorithm can well exploit the advantage of CoMP transmission on network capacity in NOMA networks to reduce transmit-power consumption.

For the remainder of this paper, we first present the system model and problem formulation in Section II. Afterward, we discuss how to design a joint optimization scheme of AP clustering and power control in Section III. Simulation results are then given in Section IV and finally the conclusion are drawn in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

In this section, we introduce the network scenario and model the CoMP transmission in NOMA networks. On this basis, a total transmit-power minimization problem is formulated.

A. NETWORK MODEL

We consider a CoMP system in downlink NOMA networks which consists of multiple APs and multiple IoT devices. All APs share the same spectrum resource. Let $\mathcal{A} = \{1, 2, \ldots, K\}$ denote the set of APs. IoT devices are classified into CoMP devices and non-CoMP devices [15], [20]. CoMP devices receive the desired signal from a cluster of APs, while non-CoMP devices receive the desired signal from one associated AP. Let $\mathcal{N} = \{1, 2, \ldots, N\}$ denote the set of CoMP devices and $\mathcal{M}_k = \{1, 2, \ldots, M_k\}$ denote the set of non-CoMP users associated with AP k. The number of non-CoMP devices is $M = \sum_{k\in\mathcal{A}} M_k$. Fig. 1 illustrates an example of CoMP systems in downlink NOMA networks. The association between non-CoMP devices and APs is determined according to the maximum received signal strength indicator (RSSI) principle [10], [20]. Note that each BS is typically allowed to serve at most one CoMP device in practical systems for maintaining the reasonable amount of the signalling overheads [21], [22].

Let $h_{n,k}$ denote the channel power gain between CoMP device n and AP k. For a non-CoMP user $m \in \mathcal{M}_k$, $h_{m,j}$ denotes the channel power gain between it and AP j. We consider that the channel power gains between AP k and all

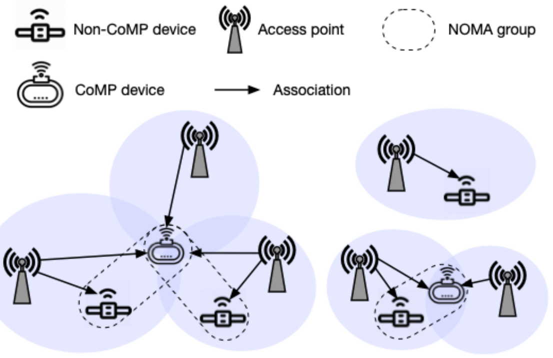

FIGURE 1. An example of multiple APs performing CoMP transmission for IoT devices in NOMA networks.

associated non-CoMP devices $m \in \mathcal{M}_k$ follow

$$h_{1,k} > h_{2,k} > \cdots > h_{m,k} > \cdots > h_{M_k,k}, \quad \forall m \in \mathcal{M}_k. \tag{1}$$

The receiver in NOMA networks adopts the successive interference cancellation (SIC) decoding to detect the signals. The decoding order in downlink NOMA transmission follows the ascending order of the channel power gains between the AP and associated devices [17], [18], [23]. Once the signal is successfully decoded, it would be subtracted from the superposed signal. Hence, the device only suffers the interference from other devices with higher channel power gains in a NOMA group. We consider that each AP can be associated with at most D non-CoMP devices for limiting the size of NOMA group and getting a grip on practical complexity of SIC decoding [24].

B. NOMA-ENABLED CoMP TRANSMISSION

The CoMP device can form NOMA groups with non-CoMP devices associated with coordinated APs in NOMA networks, as illustrated in Fig. 1. As such, the AP cluster simultaneously serves the CoMP device and non-CoMP devices on the same spectrum resource. Consider that the CoMP device has higher decoding order than non-CoMP users in a NOMA group, since the CoMP device is generally located at cell edge and likely to be with worse channel condition than non-CoMP devices [8], [25]. Therefore, the non-CoMP device can decode and subtract the signal of CoMP devices before decoding its own desired signal. The CoMP device directly decodes the desired signal with the interference from the non-CoMP devices. Fig. 2 illustrates an example of NOMA-enabled CoMP transmission.

The signal-to-interference-and-noise-ratio (SINR) of CoMP device n is expressed as

$$\xi^{\mathrm{C}}_n = \frac{\sum\limits_{k\in\mathcal{B}} x_{n,k} p^{\mathrm{C}}_k h_{n,k}}{\sigma^2 + \sum\limits_{k\in\mathcal{B}} \sum\limits_{m\in\mathcal{M}_k} p^{\mathrm{N}}_{m,k} h_{n,k} + \sum\limits_{m\in\mathcal{C}\setminus n} \sum\limits_{k\in\mathcal{B}} x_{m,k} p^{\mathrm{C}}_k h_{n,k}} \tag{2}$$

where p^{C}_k and $p^{\mathrm{N}}_{m,k}$ denote the transmit power of AP k for CoMP transmission and that for its non-CoMP m, respectively. σ^2 is the noise power. Let $x_{n,k}$ denote the indicator of the association between AP k and CoMP n. If CoMP device n is associated with AP k, then $x_{n,k} = 1$. Otherwise, $x_{n,k} = 0$. The transmission rate of CoMP device n is expressed as $R^{\mathrm{C}}_n = \log_2\left(1 + \xi^{\mathrm{C}}_n\right)$.

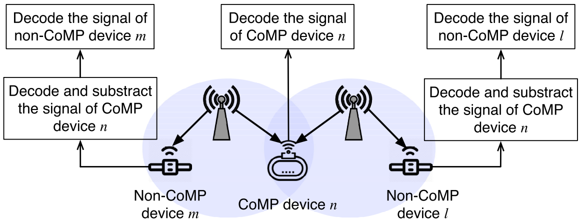

FIGURE 2. An example of NOMA-enabled CoMP transmission.

The SINR of non-CoMP device m associated with AP k, i.e., $\forall m \in \mathcal{M}_k$, is expressed as

$$\xi^{\mathrm{N}}_{m,k} = \frac{p^{\mathrm{N}}_{m,k} h_{m,k}}{\sigma^2 + I^{\mathrm{N}}_{m,k} + \sum\limits_{n\in\mathcal{C}} \left(1 - x_{n,k}\right) \sum\limits_{j\in\mathcal{B}\setminus k} x_{n,j} p^{\mathrm{C}}_j h_{m,j}} \tag{3}$$

where $I^{\mathrm{N}}_{m,k} = \sum\limits_{n<m, n\in\mathcal{M}_k} p^{\mathrm{N}}_{n,k} h_{m,k} + \sum\limits_{j\in\mathcal{B}\setminus k} \sum\limits_{n\in\mathcal{M}_j} p^{\mathrm{N}}_{n,j} h_{m,j}$ denotes the interference from other non-CoMP devices, including interference in the NOMA group and inter-cell interference. Besides $I^{\mathrm{N}}_{m,k}$, non-CoMP device m receives interference from CoMP devices which are not associated with AP k. The transmission rate of non-CoMP device m is expressed as $R^{\mathrm{N}}_{m,k} = \log_2\left(1 + \xi^{\mathrm{N}}_{m,k}\right)$.

C. PROBLEM FORMULATION

Denote $\boldsymbol{X} = \left\{x_{n,k}, \forall n \in \mathcal{C}, \forall k \in \mathcal{A}\right\}$ as the indicator variables for the association between APs and CoMP devices. Denote $\boldsymbol{P}^{\mathrm{C}} = \left\{p^{\mathrm{C}}_n, \forall n \in \mathcal{C}\right\}$ and $\boldsymbol{P}^{\mathrm{N}} = \left\{p^{\mathrm{N}}_{m,k}, \forall m \in \mathcal{M}_k, \forall k \in \mathcal{A}\right\}$ as transmit power variables for CoMP devices and non-CoMP devices, respectively. The total transmit-power minimization (TPM) problem is formulated as follows.

$$\begin{aligned}
(\textbf{TPM}):\ & \min_{\boldsymbol{X},\boldsymbol{P}^{\mathrm{C}},\boldsymbol{P}^{\mathrm{N}}} \sum_{k\in\mathcal{B}} \left(\sum_{m\in\mathcal{M}_k} p^{\mathrm{N}}_{m,k} + p^{\mathrm{C}}_k\right) \\
\text{s.t. } & \mathrm{C1}: \sum_{n\in\mathcal{C}} x_{n,k} \leqslant 1, \quad \forall k \in \mathcal{A} \\
& \mathrm{C2}: \sum_{k\in\mathcal{B}} x_{n,k} \leqslant C, \quad \forall n \in \mathcal{C} \\
& \mathrm{C3}: x_{n,k} \in \{0,1\}, \quad \forall n \in \mathcal{C},\ \forall k \in \mathcal{A} \\
& \mathrm{C4}: \sum_{m\in\mathcal{M}_k} p^{\mathrm{N}}_{m,k} + p^{\mathrm{C}}_k \leqslant P_{\max}, \quad \forall k \in \mathcal{A} \\
& \mathrm{C5}: R^{\mathrm{C}}_n \geqslant R_{\min}, \quad \forall n \in \mathcal{C} \\
& \mathrm{C6}: R^{\mathrm{N}}_{m,k} \geqslant R_{\min}, \quad \forall k \in \mathcal{A},\ \forall m \in \mathcal{M}_k \\
& \mathrm{C7}: p^{\mathrm{N}}_{m,k} h_{n,k} \geqslant \theta I^{\mathrm{N,D}}_{m,n,k}, \\
& \qquad \forall k \in \mathcal{A},\ \forall \{m,n \mid n < m\} \in \mathcal{M}_k
\end{aligned}$$

$$\begin{aligned} \text{C8}: &\sum_{j\in\mathcal{B}} x_{n,j} p_j^{\mathrm{C}} h_{m,j} \geqslant x_{n,k}\theta I_{n,m,k}^{\mathrm{C,D}}, \\ &\quad \forall n\in\mathcal{C},\ \forall k\in\mathcal{A},\ \forall m\in\mathcal{M}_k. \end{aligned}$$

In Problem (TPM), C1 indicates each BS serves at most one CoMP device. C2 indicates that each CoMP device is served by at most C APs. C4 limits the maximum transmit power $P_{\max}$ for all APs. C5 and C6 indicate the minimum rate requirement for all devices. C7 and C8 respectively specify the SIC threshold for non-CoMP devices and CoMP devices, where the interference under SIC is given by

$$\begin{aligned} I_{m,n,k}^{\mathrm{N,D}} = &\sum_{i<m, i\in\mathcal{M}_k} p_{i,k} h_{n,k} + \sum_{j\in\mathcal{B}\backslash k} \sum_{i\in\mathcal{M}_j} p_{i,j}^{\mathrm{N}} h_{n,j} \\ &+ \sum_{i\in\mathcal{C}} \left(1 - x_{i,k}\right) \sum_{j\in\mathcal{B}\backslash k} x_{i,j} p_j^{\mathrm{C}} h_{n,j} + \sigma^2 \end{aligned} \tag{4}$$

$$I_{n,m,k}^{\mathrm{C,D}} = \sum_{j\in\mathcal{B}} \sum_{i\in\mathcal{M}_j} p_{i,j}^{\mathrm{N}} h_{m,j} + \sum_{i\in\mathcal{C}\backslash n} \sum_{j\in\mathcal{B}} x_{i,j} p_j^{\mathrm{C}} h_{m,j} + \sigma^2. \tag{5}$$

Problem (TPM) is not easy to tackle, since it is a mixed-integer non-convex problem [26]. Specifically, binary variables $\boldsymbol{X}$ make Problem (TPM) become a mixed-integer programming problem. Furthermore, the interference among devices results in that this problem is non-convex. Although the optimal solution of Problem (TPM) can be found by the exhaustive search and the branch-and-bound method, it would cause much high computational complexity and is hard to be implemented in practical IoT networks. Hence, we exploit the proper decomposition method and dynamic matching theory to design an effective algorithm with moderate complexity to solve Problem (TPM).

III. PROBLEM SOLUTION AND ALGORITHM DESIGN

In this section, we design a scheme to solve Problem (TPM). We show that Problem (TPM) can be formulated as a many-to-one matching problem. An exchange matching based algorithm is designed which dynamically updates the association between APs and CoMP devices to decrease the total transmit power of all APs. We show that the power control problem is a linear programming problem during the process of exchange matching. Therefore, the power control problem can be solved by the standard convex programming methods [26]. On the basis of above analysis, we propose a scheme to jointly optimize transmit power and the association between APs and CoMP devices.

A. MANY-TO-ONE MATCHING FOR AP CLUSTERING

We exploit the many-to-one matching model to reformulate Problem (TPM) in this subsection. $\mathcal{A}$ and $\mathcal{C}$ are two mutually disjoint sets. In this NOMA-enabled CoMP system, each AP can be associated with at most one CoMP devices simultaneously. Each CoMP device can be associated with at most C APs simultaneously. The AP clustering problem is regarded as how to match APs and CoMP devices for minimizing the total transmit power of this NOMA-enabled CoMP system. Therefore, the many-to-one matching model can be used to formulate the AP clustering problem, which is shown as follows.

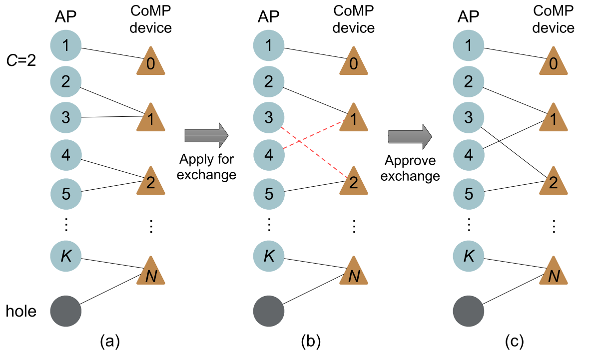

FIGURE 3. An example of many-to-one matching model for AP clustering.

Definition 1: Given $\mathcal{A} = \{1, \ldots, K\}$ and $\mathcal{C} = \{1, \ldots, N\}$, a many-to-one matching Ψ is defined as a mapping function from the set of $\mathcal{A}\cup\mathcal{C}\cup\{0\}$ into the set of all subsets of $\mathcal{A}\cup\mathcal{C}\cup\{0\}$ such that for each $k\in\mathcal{A}$ and $n\in\mathcal{C}\cup\{0\}$

1) $\Omega(k) \subseteq \mathcal{C}\cup\{0\}, \forall k\in\mathcal{A}\cup\mathcal{O};$
2) $\Omega(n) \subseteq \mathcal{A}\cup\mathcal{O}, \forall n\in\mathcal{C}\cup\{0\};$
3) $|\Omega(k)| \leqslant 1, \forall k\in\mathcal{A}\cup\mathcal{O};$
4) $|\Omega(n)| \leqslant C, \forall n\in\mathcal{C};$
5) $n\in\Omega(k) \Leftrightarrow k\in\Omega(n), \forall k\in\mathcal{A}\cup\mathcal{O}, \forall n\in\mathcal{C}\cup\{0\}.$

$\mathcal{A}$ and $\mathcal{C}$ are two mutually disjoint sets. Condition 1 states each AP is matched with a subset of CoMP devices, and the size of this subset is at most one which is limited by Condition 3. Condition 2 states that each CoMP device is matched with a subset of APs, and the size of this subset is at most C which is limited by Condition 4. If one AP is matched with CoMP device 0, this AP is not associated with any CoMP device. The set $\mathcal{O}$ includes the 'holes' which use up all the available vacancies of CoMP devices. The meaning of Ω is different for various parameters. For AP $k \in \mathcal{A}$, $\Omega(k)$ means the CoMP device matched with AP k. For CoMP device $n \in \mathcal{C}$, $\Omega(n)$ means the set of APs matched with CoMP device n. Fig. 3 shows an example of the many-to-one matching model for AP clustering.

Remark 1: The proposed many-to-one matching model for AP clustering subproblem is with the externalities.

In particular, the externalities mean that the preference of an element not only depends on its matched element but also other elements. Specifically, (2) and (3) show that the SINRs of CoMP devices and non-CoMP devices are affected by the interference. The SINR of each device is determined by both of its transmit power from the associated AP and the transmit power for other devices from other APs. In this light, each AP should not only consider which CoMP device it is matched with, but also the set of APs matching with the same CoMP device. Furthermore, it also should consider the SINR of non-CoMP devices under current matching results. Hence, the proposed many-to-one matching model is with externalities. The exchange matching is an effective method to solve the many-to-one matching problem with externalities [27], [28]. In exchange matching, any two APs could exchange their associated CoMP devices. If the total transmit power is reduced after this exchange operation, this exchange operation is approved. However, different from many other works [29]–[31], the exchange matching can influence the performance of all involved AP and CoMP devices and as well influence the performance of those are not involved. For example, the exchange matching between CoMP device 3 and CoMP device 4 in Fig. 3 involves AP 1, AP 2, CoMP device 3, and CoMP device 4. Although AP 2 and AP 5 are not involved in the exchange matching, the interference received by their associated non-CoMP devices is changed. Hence, the externalities exist among involved elements and also spread to other elements which are not involved.

In order to tackle the complicated externalities among devices, we focus on the one-sided stability in this works. The benefit value of a matching result Ω is denoted by

$$v(\Omega) = \sum_{k\in\mathcal{A}} \left(\sum_{m\in\mathcal{M}_k} p_{m,k}^{\mathrm{N}} + p_k^{\mathrm{C}} \right). \tag{6}$$

The preference relationship for each AP is defined as $\succ_k$, $\forall k \in \mathcal{A}$. For AP k and any two CoMP devices n and n', there are two matching results Ω and Ω' where $\Omega(k) = n$ and $\Omega'(k) = n'$. The following preference relationship

$$(n, \Omega) \succ_k (n', \Omega') \Leftrightarrow v(\Omega) < v(\Omega') \tag{7}$$

indicates that AP k prefers CoMP device n in Ω to CoMP device n' in Ω' because a lower benefit value can be achieved when AP k is matched with CoMP device n than CoMP device n'. Then, we define the exchange matching operation Ω_k^j as

$$\Omega_k^j = \left\{ \Omega \setminus \left\{ (k, n), (j, n') \right\} \cup \left\{ (k, n'), (j, n) \right\} \right\} \tag{8}$$

where $\Omega(k) = n$ and $\Omega(j) = n'$. Ω_k^j means that AP j and AP k exchange the CoMP devices with each other meanwhile the associations between other APs and CoMP devices keep unchanged. It should be noted that one of AP j and AP k is allowed to be a hole. In other words, it is allowed for an AP to move to the vacancies of a CoMP device. Then, we give the definition of blocking pair.

Definition 2: AP k and AP j can form a blocking pair to be approved in a matching Ω if and only if

1) $v(\Omega) > v\left(\Omega_k^j\right), \forall \{j, k\} \in \mathcal{A}$;
2) *In the matching* Ω_k^j, *constraints C4-C8 are satisfied for all APs and devices.*

The blocking pair ensures that total transmit power of all APs decreases, and all constraints are satisfied after each exchange matching operation. Accordingly, we can check each pair of APs (or one AP and one hole) whether they could form a blocking pair. If they form a candidate of blocking pair, the exchange matching operation is executed by exchanging their matched CoMP devices to reduce total transmit power. The matching will converge to one-sided stability through a series of exchange matching operations and achieve a suboptimal solution [32].

Definition 3: A matching is said to be one-sided stability if there is no other matching where some APs are better off and some APs are worse off. In other words, there is not any blocking pair which is found in a matching achieving one-sided stability.

The notations of blocking pair and one-sided stability are similar to that of [32] due to specific externalities but different from the traditional model without externalities.

However, it is required for the exchange matching operation to perform the power control algorithm to determine whether a pair of AP could be a blocking pair. Specifically, we should exploit the power control algorithm to optimize the transmit power of APs for associated devices such that C4-C8 is satisfied after the exchange matching operation. Then, the benefit value after the exchange matching operation is determined.

B. POWER CONTROL

In this subsection, we consider that the association between APs and CoMP devices is fixed, i.e. $\boldsymbol{X} = \boldsymbol{X}^*$. With the fixed AP clustering variables, the power control problem is formulated as

$$\begin{aligned} \min_{\boldsymbol{P}^{\mathrm{C}}, \boldsymbol{P}^{\mathrm{N}}} \quad & \sum_{k\in\mathcal{B}} \left(\sum_{m\in\mathcal{M}_k} p_{m,k}^{\mathrm{N}} + p_k^{\mathrm{C}} \right) \\ & \mathrm{C4, C7, C8} \\ & \mathrm{C5}: \xi_n^{\mathrm{C}} \geqslant \xi_{\min}, \quad \forall n \in \mathcal{C} \\ & \mathrm{C6}: \xi_{m,k}^{\mathrm{N}} \geqslant \xi_{\min}, \quad \forall k \in \mathcal{B}, \ \forall m \in \mathcal{M}_k. \end{aligned} \tag{9}$$

where $\xi_{\min} = 2^{R_{\min}} - 1$ denotes the SINR threshold for all devices. We can observe that the power control problem is a typical linear programming problem, which can be directly solved by standard convex programming methods, such as interior point method [26], [33]. We omit the detailed procedures here.

C. JOINT AP CLUSTERING AND POWER CONTROL SCHEME

We propose the joint AP clustering and power control (JACPC) algorithm according to the designed exchange matching method and the analysis of power control problem. The detailed procedure of proposed JACPC algorithm is presented in Algorithm 1.

First, JACPC algorithm exploits Algorithm 2 to initial the association between APs and CoMP devices. In the initialization, CoMP device n^* with maximum $\xi_{\min} - \xi_n^{\mathrm{C}}$ is preferentially picked and then AP k^* which can provide maximum SINR for CoMP device n^* is selected. CoMP device n^* is associated with AP k^* which both will be removed from $\mathcal{C}$ and $\mathcal{A}$, respectively. The initial matching Ω_0 is finished until $\mathcal{C}$ or $\mathcal{A}$ is empty. The total transmit power under Ω_0 can be calculated by solving Problem (9). Second, JACPC algorithm enables the exchange matching operation between

TABLE 1. Default simulation parameters.

Parameters	Values
Network area	300 m × 300 m
Size of AP cluster, C	3
Spectrum bandwidth	180 kHz
Max transmit power, $P_{\max}$	33 dBm
Rate threshold, $R_{\min}$	$\log_2(1+5\text{dB})$
SIC threshold, θ	0 dB [15], [34]
Noise power, σ^2	-174 dBm/Hz × 180 kHz
Path loss model	$37.6\log_{10}(d[\text{km}])+128.1$
Multiple-path fading	Exponential distribution with unit mean
Shadowing	Log-normal distribution with standard deviation of 8 dB

APs. Each AP keeps searching for all other APs and tries to form the blocking pair such that the total transmit power is reduced iteratively. We can calculate the benefit value $v\left(\Omega_k^j\right)$ by solving Problem (9) for an exchange matching Ω_k^j. If a pair of APs can form a blocking pair, the benefit value and many-to-one matching are updated. The exchange matching operation stops until the algorithm does not find any blocking pair in current matching Ω.

Lemma 1: The final matching Ω achieves the one-sided stability when JACPC algorithm converges.

Proof: Assume that there exists a blocking pair, AP k and AP j, in the final matching Ω. We can get that $v\left(\Omega_k^j\right) < v(\Omega)$ while all constraints for APs and devices can be satisfied in Ω_k^j. According to the procedure of Algorithm 1, the algorithm would not stop until all of blocking pairs are found and handled. In this light, Ω is not the final matching of Algorithm 1, which conflicts the original assumption. Therefore, we cannot find any blocking pair in the final matching of Algorithm 1 so that the final matching achieves one-sided stability. Now, we finish the proof of Lemma 1. ■

Proposition 1: JACPC algorithm converges with a limited number of iterations.

Proof: First, the number of APs is limited and each CoMP device can be associated with in most C APs at our proposed many-to-one matching model. Thus, the number of potential exchange matching operations is finite. Second, it is known from Definition 2 that the total transmit power decreases after each exchange matching operation. Since the total transmit power is lower bounded by the optimal value, the exchange matching operations would stop as the total transmit power is gradually close to the lower bound. Therefore, the matching can converge with a limited number of iterations. ■

IV. SIMULATION RESULTS

We investigate the performance of the proposed AP clustering and power control algorithm through the simulation in this section. The simulation scenario is considered as a 300 m × 300 m area where APs and IoT devices are uniformly distributed. The classification of CoMP devices and non-CoMP devices is conducted by RSSI information, and the association between non-CoMP devices and APs is determined by maximum RSSI principle [15], [20]. The default simulation parameters are summarized in Table 1. The performance of proposed JACPC algorithm is compared with the following algorithms.

Algorithm 1 Joint AP Clustering and Power Control (JACPC) Algorithm

```
Perform Algorithm 0 to obtain initial matching $\Omega = \Omega_0$.
Solve Problem (9) to obtain the initial benefit value $v^* = v_0$.
$flag = 1$.
while $flag = 1$ do
    $flag = 0$.
    for each $k \in \mathcal{A}$ do
        for each $j \in \mathcal{A} \cup \mathcal{O} \setminus k$ do
            Calculate the benefit value $v\left(\Omega_k^j\right)$ by solving Problem (9) in matching $\Omega_k^j$.
            if AP $k$ and $j$ form a blocking pair then
                $flag = 1$, $v^* = v\left(\Omega_k^j\right)$, and $\Omega = \Omega_k^j$.
                break
            end if
        end for
        if $flag = 1$ then
            break
        end if
    end for
end while
return a one-sided stable matching $\Omega$ and $v^*$.
```

Algorithm 2 AP Clustering Initialization

```
Set $\mathcal{A}_n = \emptyset, \forall n \in \mathcal{C}$ as the set of AP associated with CoMP device $n$. Initialize $\boldsymbol{X} = \boldsymbol{0}$.
$p_k^{\mathrm{C}} = p_{m,k}^{\mathrm{N}} = \frac{P_{\max}}{(M_k+1)}, \forall k \in \mathcal{A}, \forall m \in \mathcal{M}_k$.
repeat
    Calculate $\xi_n^{\mathrm{C}}, \forall n \in \mathcal{C}$ and $\xi_{m,k}^{\mathrm{N}}, \forall k \in \mathcal{A}, \forall m \in \mathcal{M}_k$ under current $\boldsymbol{X}$.
    Select CoMP device $n^* = \arg\max_{n \in \mathcal{C}} \xi_{\min} - \xi_n^{\mathrm{C}}$
    for all $k \in \mathcal{A}$ do
        Calculate $\zeta_{n,k}^{\mathrm{C}} = \xi_n^{\mathrm{C}}$ supposing AP $k$ is in $\mathcal{A}_n$.
    end for
    Select AP $k^* = \arg\max_{k \in \mathcal{A}} \zeta_{n,k}^{\mathrm{C}}$.
    $x_{n^*,k^*} = 1$, $\mathcal{A}_n = \mathcal{A} \cup k^*$.
    Remove $n^*$ from $\mathcal{C}$ and $k^*$ from $\mathcal{A}$.
until $\mathcal{A} = \emptyset$ or $\mathcal{C} = \emptyset$
return $\boldsymbol{X}$.
```

- Not using CoMP (NoCoMP) algorithm: The scheme does not use CoMP transmission in this NOMA downlink networks, i.e., $C = 1$. The other procedure is similar to the proposed JACPC algorithm.
- OMA-based CoMP (OMA) algorithm: The scheme does not perform NOMA-enabled CoMP transmission such

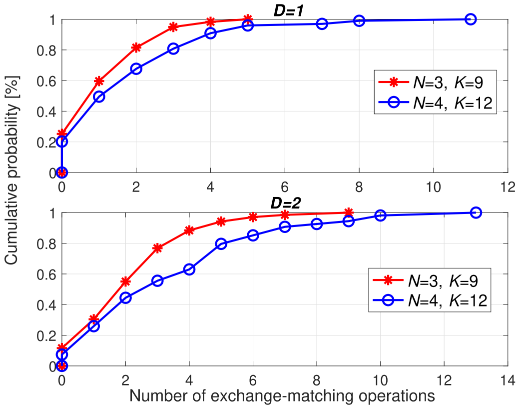

FIGURE 4. CDF of the number of exchange matching operations ($M = 3$).

that the AP cannot simultaneously serve the CoMP device and non-CoMP devices. The other procedure is similar to the proposed JACPC algorithm.

- Greedy AP clustering (GAC) algorithm: The scheme exploits the best channel gain criterion proposed in [19] to complete AP clustering in a greedy way and then use the power control method proposed in our paper.

A. CONVERGENCE OF PROPOSED ALGORITHM

Fig. 4 shows the cumulative probability of the number of swap operations for JACPC algorithm to converge. It can be seen that the proposed JACPC algorithm converges with in a limited number of exchange matching operations, which validates Proposition 1. Furthermore, We can see that the number of exchange matching operations increases with the growth of N and K. This is because that the growth of N and K increases the potential existence of blocking pairs. Furthermore, the growth of D also increases the number of exchange matching operations, because the interference would becomes more complicated.

B. PERFORMANCE COMPARISON

Fig. 5 shows a result of the association between APs and devices obtained by the proposed algorithm and other compared algorithms. It is seen that the JACPC algorithm can achieve lower total transmit power consumption than other algorithms. In the result of NoCoMP algorithm, CoMP device 1 and 2 are only associated with AP 5 and 1, respectively, and cannot acquire the benefit of CoMP transmission. Hence, the associated APs need to consume more transmit power to satisfy the minimum rate requirement than that in JACPC algorithm. In the result of OMA algorithm, the CoMP devices is not allowed to be associated with AP 3 and 5 serving non-CoMP devices. It results in that the CoMP devices cannot be associated with the APs providing better transmission performance, such as that CoMP device 1 cannot be associated with AP 5. Hence, the total transmit power increases. Due to applying NOMA-enabled CoMP transmission, the performance of GAC algorithm is very close to that of JACPC algorithm. However, the performance of GAC algorithm obviously deteriorates when the number of APs and the number of devices increase, which is presented later.

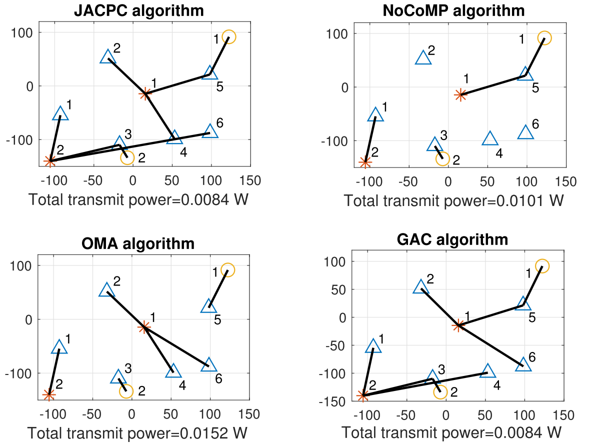

FIGURE 5. The association between APs and devices obtained by the proposed algorithm and other compared algorithms, where '△' represents an AP, '⋆' represents a CoMP device, and '∘' represents a non-CoMP device.

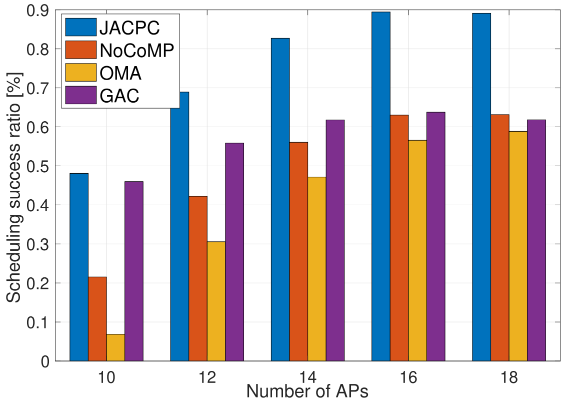

FIGURE 6. Scheduling success ratio versus the number of APs K ($M = 3$, $N = 4$, and $D = 1$).

Fig. 6 shows the scheduling success ratio versus the number of APs K. The scheduling success ratio denotes the ratio of the number of simulations which meet all constraints to the total number of simulations. The results show that the proposed JACPC algorithm outperforms other algorithm on the scheduling success ratio. This is because that JACPC algorithm exploits NOMA-enabled CoMP transmission to improve the transmission capacity and meanwhile effectively mitigate interference between devices by optimizing AP clustering and transmit power. Furthermore, we can see that the scheduling success ratio increases with the growth of K, since the increase of AP diversity makes the CoMP device acquire more suitable AP cluster.

Fig. 7 shows the total transmit power versus K. It can be seen that the proposed JACPC algorithm efficiently reduces the total transmit-power consumption compared with other algorithms. This is because the proposed algorithm takes into account both interference management and the

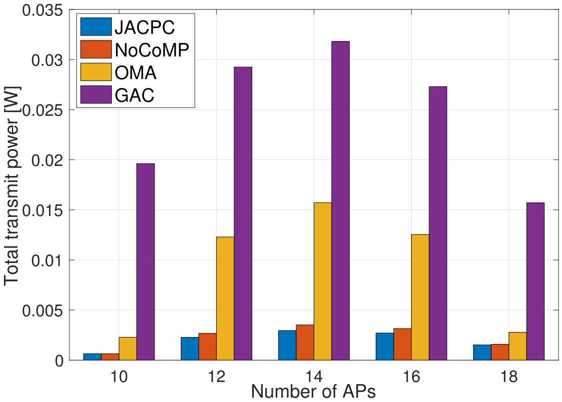

FIGURE 7. **Total transmit power versus the number of APs K ($M = 3$, $N = 4$, and $D = 1$).**

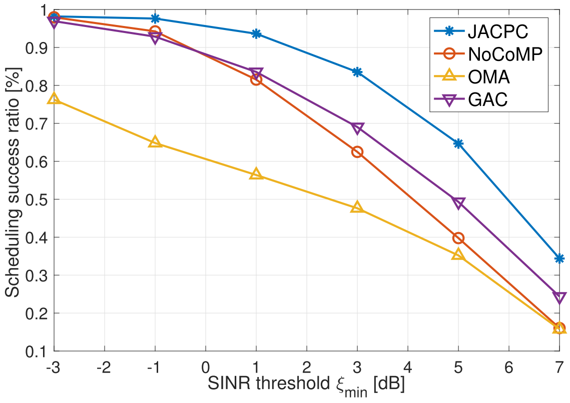

FIGURE 8. **Scheduling success ratio versus SINR threshold $\xi_{\min}$ ($M = 3$, $N = 4$, $K = 12$, and $D = 1$).**

AP clustering, while NoCoMP algorithm and OMA algorithm cannot effectively restrain interference, and GAC algorithm mainly emphasizes the AP clustering. In particular, GAC algorithm only considers the channel power gain between the CoMP device and associated APs and ignores interference in the AP cluster and inter-cell interference. Therefore, GAC algorithm consumes much higher total transmit power under relatively large K and N. Furthermore, the total transmit power first increases and then decreases with the growth of K. This is because the algorithms cannot provide a good AP cluster for each CoMP device, when K is relatively small. In this case, increasing transmit power is the only way to meet minimum rate requirement and SIC threshold for all devices. When K is relatively large, the algorithms can construct the AP cluster with good channel condition for more CoMP devices such that the total transmit power decreases. Hence, the dense deployment of APs is an efficient way for improving the quality of service for IoT devices.

Fig. 8 and 9 show the scheduling success ratio and total transmit power versus SINR threshold $\xi_{\min}$, respectively. The results show that the proposed JACPC algorithm greatly improves the scheduling success ratio and reduces the total transmit power compared with other algorithms.

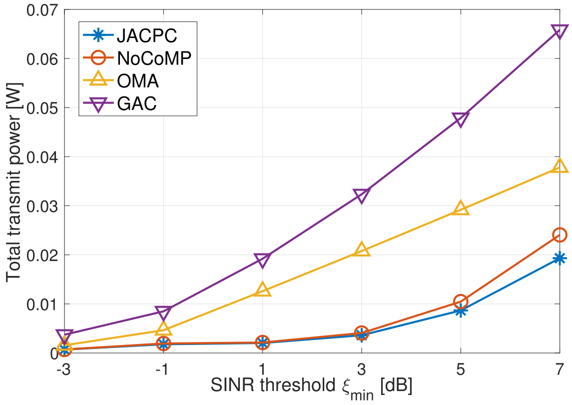

FIGURE 9. **Total transmit power versus SINR threshold $\xi_{\min}$ ($M = 3$, $N = 4$, $K = 12$, and $D = 1$).**

Furthermore, the performance gaps between the proposed algorithm and other algorithms are enlarged with the increase of $\xi_{\min}$. This is because the JACPC algorithm optimizes the AP clustering by exploiting the exchange matching method to effectively alleviate the interference and releases the potential of NOMA and CoMP on spectrum efficiency and transmission capacity.

V. CONCLUSION

This paper has investigated the total transmit-power minimization problem for CoMP transmission in downlink NOMA-based IoT networks by jointly considering AP clustering and power control. We have first formulated the AP clustering problem as a many-to-one matching problem with externalities. Then, an exchange-matching based algorithm has been designed which can achieve one-sided stable matching between APs and CoMP devices. Furthermore, we have shown that the power control can be solved by linear programming method to ensure that the total transmit power decreases after each exchange matching operation. Finally, simulation results have shown the effectiveness of proposed algorithm and demonstrated the potential benefits of NOMA and CoMP for IoT networks.

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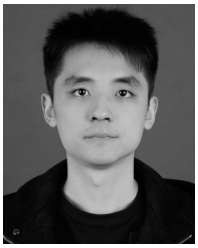

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