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# Heterogeneous Network Bandwidth Control Scheme for the Hybrid OMA-NOMA System Platform

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**ABSTRACT** The emerging non-orthogonal multiple access (NOMA) has been considered as a promising technology to reach the goals of 5G cellular systems. Due to its superior spectral efficiency, the NOMA has attracted a lot of attention recently, and could play a vital role in improving the capacity of future Heterogeneous networks (HetNets). In this paper, we present a joint bandwidth control scheme, which incorporates both NOMA and orthogonal multiple access (OMA) modes into one unified scheme. For the effective collaboration of different multiple access methods, we adopt the ideas of cooperative bargaining solution concepts. In the proposed scheme, the bandwidth allocation process for base stations and channels follows the OMA mode, and mobile devices within a same channel form a group. The power level selection process for mobile devices in each group follows the NOMA mode. In the OMA mode, traditional Nash bargaining solution is adopted to allocate bandwidth resources. In the NOMA mode, groups of individual devices bargain both within and across groups based on the group bargaining solution. Under the dynamic changing HetNet environments, our joint bargaining approach takes various benefits in a rational way while maximizing the bandwidth efficiency. Comprehensive numerical experiments are provided to show that the performance of our proposed scheme is superior to existing HetNet spectrum control protocols.


**INDEX TERMS** 5G heterogeneous network, non-orthogonal multiple access, orthogonal multiple access, group bargaining solution, bandwidth control.

## I. INTRODUCTION

With the rapid developments of mobile network technologies, wireless communication has become one of the best business opportunities of the future. In particular, the development of various wireless communication models fuels the massive growth in the number of mobile devices (MDs) for emerging applications such as smart logistics & transportation, environmental monitoring, energy control, safety management, and industry automation, just to name a few. While these MDs already support many different types of applications and services, there will be a continual increase in demand for mobile data traffic, such as seamless mobility, ultra-low latency, and high reliability. Therefore, future cellular net-

works will face daunting challenges of spectrum scarcity and massive connectivity. To improve the spectrum utilization and provide more MDs with pervasive services, a new paradigm for network infrastructures is essential. Responding to these challenges, heterogeneous network (HetNet) platform has been main attention in both fifth-generation (5G) and beyond 5G cellular networks [1]–[3].

Recently, the paradigm of HetNets has emerged as an advanced networking architecture comprising a hierarchy of macro cells and small cells. Macro cells can provide cellular network coverage for a large ubiquitous area, and small cells are low-powered cellular radio access nodes that operate in licensed or unlicensed spectrum resources to augment capacity. Two different type cells coexist with various radio access technologies, and they are connected via low-latency high-rate backhaul links for the maximum

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management flexibility. In the HetNet infrastructure, multiple small cells are located in each macro cell area, and they work together in a coordinated manner to unlock substantial gains in network capacity and user connectivity experience. Supported by the recent progress, individual hand-held MDs in cell areas can support multiple radio access technologies; it is becoming a common sight in 5G wireless communications [4].

Due to the coexistence of different type base stations (BSs), bandwidth management poses significant challenges in the HetNet system. Therefore, intelligent bandwidth control mechanisms should be employed to improve the capacity of total network system. In 4G networks, orthogonal multiple access (OMA) is used as the air interface technique and proved its effectiveness against multi-path fading while achieving high system throughput. However, the traditional OMA technique can only be used by at most one MD in each scheduling period in order to avoid interference. Therefore, it does not make full use of the spectral resource as it restricts each MD to use a limited part of the bandwidth. Therefore, a more efficient radio access technology is required to fully and efficiently utilize the limited bandwidth resources [5], [6].

Besides the OMA, non-orthogonal multiple access (NOMA) is another promising technology to enhance the bandwidth reuse and connectivity density. Comparing with the OMA technique, the key idea of NOMA is to serve simultaneously multiple MDs over same bandwidth bands at the expense of minimal inter-MD interference; it not only allows serving individual MDs with higher effective bandwidth but also allows scheduling more MDs than the available resources. Therefore, the NOMA technique superposes the message signals of multiple MDs in power domain by exploiting their respective channel gain differences. Recently, researchers from industry and academia consider an important bridge in both OMA and NOMA techniques, and attempt to find a new control paradigm to solve the bandwidth management problem in 5G HetNets [7], [18].

### A. TECHNICAL CONCEPT OF GAME MODELS

Nowadays, game theory applies to a wide range of control issues, and it is now an umbrella term for intelligent and smart network agents. Throughout the past decade, there has been a significant growth in research activities that use game theory for analyzing HetNet systems. This is mainly due to the need for developing autonomous, distributed, and flexible HetNet systems where the network agents can make independent and rational strategic decisions. As a main branch of game theory, cooperative bargaining game models provide analytical tools to study the behavior of rational game players when they cooperate. Up to now, different bargaining game solutions have made revolutionary impacts on a large number of disciplines ranging from resource management, power control, load balancing, fault tolerance, or even network security in HetNet systems [8].

In 1950, J. Nash introduced the fundamental notion of the Nash Bargaining Solution (NBS) to allocate the resource fairly and optimally [9]. The NBS is a field of cooperative game theory and an effective tool to achieve a mutually desirable solution with a good balance between efficiency and fairness. In 2004, S. Chae and P. Heidhues proposed the novel concept of group bargaining solutions (GBSs) based on the original concept of NBS [10]. They actually regarded bargaining process as taking place simultaneously at two levels, between the individual members of a group, i.e., intra-group bargaining, and between groups, i.e., inter-group bargaining. Intra and inter decision-making groups consist of multiple individuals, and they act cooperatively with each other. According to the traditional NBS, their group bargaining solutions constitute the NBS both in the intra and inter-group bargaining problems [10].

### B. MAIN CONTRIBUTIONS

According to the NBS and GBS, we develop a novel bandwidth control scheme for the HetNet platform. In our proposed scheme, the available bandwidth of macro-cell base stations (MBSs) is divided into its corresponding small-cell base stations (SBSs), and each individual BS also divides its assigned bandwidth resource into multiple channels. Based on the OMA mode, the available bandwidth is orthogonally divided for BSs and channels, respectively. Multiple MDs can be categorized as groups based on their service types, and they contact their corresponding BSs through channels; MDs in the same group share the same channel. According to the NOMA mode, individual MDs in each group decide their power levels. In the combination of NOMA and OMA technologies, we apply two different bargaining solutions, i.e., NBS and GBS, for the HetNet infrastructure. Our jointly control approach can leverage the full synergy of Nash and group bargaining solutions while handling comprehensively some group negotiation issues. In detail, the major contributions of this study are as follows:

- This study considers the bandwidth control problem in the HetNet infrastructure. Based the OMA-NOMA integrated platform, the limited bandwidth resource is effectively distributed between BSs and MDs by using different cooperative bargaining solutions.
- Orthogonal bandwidth portions are allocated for SBSs and channels based on the OMA method. To implement the bandwidth allocation process, the idea of traditional NBS is adopted, and intelligent network entities work together interactively to reach an agreement that gives mutual advantages.
- Within each individual BS, MDs in the same group share the same channel and decide their power levels based on the NOMA method. To implement the MD's power decision process, the concept of GBS is adopted, and MDs can reach a compromise consensus in a cooperative manner to.

- Under hierarchical HetNet environments, we explore the interaction of different bargaining solutions to leverage the synergistic features. The main characteristic of our joint approach lies in its responsiveness to the reciprocal combination of NBS and GBS.
- With respect to different performance criteria, comprehensive numerical experiments are provided to show the superiority of our proposed approach. In comparison with other existing state-of-the-art HetNet bandwidth control protocols, we can enhance the overall system performance.

## II. RELATED WORK

Since the initial concept of NOMA was introduced, several attractive researches have considered the NOMA with other novel technologies to enhance bandwidth efficiency by allowing multiple MDs' simultaneous transmissions. The paper [1] investigates and reveals the ergodic sum-rate gain of NOMA over OMA in uplink cellular communication systems. Furthermore, this research reveals that the large-scale near-far gain increases with the normalized cell size, while the small-scale fading gain is a constant in Rayleigh fading channels. In [2], highlighting relevant coverage across topics such as energy efficiency, user support, and adaptive multimedia services are reviewed. In [3], the main goal is to provide a comprehensive treatment of the ongoing research into and state-of-the-art-techniques for addressing the challenges arising from the design of 5G wireless systems. The paper [17] introduces a holistic framework that dynamically combines multiple access technologies while accounting for risk preferences. The MDs exhibit risk-aware behavior while determining their optimal power investment, owing to the uncertainty of the perceived satisfaction due to the shared nature of the network's resources. Finally, the existence and uniqueness of a pure Nash equilibrium point is proven, and the convergence of the MDs' best response strategies is shown [17]. In [11], the *Two-tier based NOMA Spectrum Resource Control (TNSRC)* scheme investigates the performance of NOMA in a two-tier HetNet with the non-uniform small cell deployment. MDs associated to a particular BS are divided into several groups according to their access methods. And then, the NOMA technique is performed within each group, whereas the OMA technique is deployed across the groups with the aim of intergroup multiple access. Next, the *TNSRC* scheme analyzes the effect of the prescribed distance of MBSs and the effect of the power allocation factor on the sum achievable rate of a NOMA group [11].

Wang *et al.* [12] present the *Locally Cooperative game based NOMA Spectrum Allocation (LCNSA)* scheme for the purpose of downlink interference mitigation in small cell networks. Specifically, authors formulate a locally cooperative game, which is proved to be an exact potential game with the network throughput being the potential function. And then, they design two concurrent distributed algorithms to achieve the Nash equilibrium of the game, corresponding to the globally or locally optimal solution to the distributed

bandwidth resource assignment problem. By opportunistically applying the NOMA technique, the *LCNSA* scheme can more efficiently mitigate the inter-cell interference caused by neighboring SBSs. Finally, simulation results reveal the superiority of *LCNSA* scheme under the trend of ultra-dense networking [12].

The *NOMA based HetNet Spectrum Resource Allocation (NHSRA)* scheme is a novel bandwidth resource allocation protocol for the NOMA embedded HetNet systems [13]. With the aim of maximizing the sum rate of MDs while taking the fairness issue into consideration, a new bandwidth allocation algorithm is formulated. In particular, the bandwidth allocation problem is modeled as a many-to-one matching game model. For solving the matching game, a swap-operation enabled matching algorithms are proposed to match SBSs with bandwidth resources aiming at maximizing MDs' sum rate. Finally, it is proved mathematically that the matching algorithm converges to a two-sided stable state within limited number of iterations [13].

Although a lot of researches have exploited HetNets and NOMA technique extensively, the existing NOMA based protocols are hardly a concern with cooperative bargaining approach among network entities. Therefore, until now, efficient NOMA control algorithms with bargaining solutions have not been fully utilized. In this study, we propose a joint bargaining approach while investigating bandwidth control issues in the NOMA embedded HetNet system. By taking temporal network fluctuations into account, we can make rational decisions to reach an agreement that gives mutual advantage. Different from existing *TNSRC*, *LCNSA* and *NHSRA* protocols, our proposed scheme has more potential benefits in terms of MD's payoff, system throughput and fairness among applications.

## III. THE BANDWIDTH CONTROL ALGORITHM IN 5G HETNET SYSTEM

In this section, we first introduce the two-tier HetNet architecture, which is integrated with OMA and NOMA techniques. Then, we discuss the basic concept of bargaining solutions to design our proposed bandwidth control algorithm. Finally, the main step procedures of our proposed algorithm is delineated based on the cooperative game model.

### A. TWO-TIER HETNET SYSTEM INFRASTRUCTURE WITH SMALL CELLS

We consider a two-tier cellular network platform, which comprises two types of BSs. At the upper tier, MBSs  $\mathbb{M} = \{\mathcal{M}_1, \dots, \mathcal{M}_n\}$  exist, and they provide cellular network coverage for a large area. At the lower tier, SBSs  $\mathbb{S} = \{\mathcal{S}_1, \dots, \mathcal{S}_m\}$  coexist, and they break up a macro-cell site into much smaller areas to increase the macro-cell's edge data capacity and overall network efficiency. One MBS (*or* one SBS) has a coverage area of radius  $r_{\mathcal{M}}$  (*or*  $r_{\mathcal{S}}$ ), and has a static portion of bandwidth resource where  $\mathfrak{M}_{\mathcal{M}_i \in \mathbb{M}}$  for the  $\mathcal{M}_i$  and  $\mathfrak{S}_{\mathcal{S}_j \in \mathbb{S}}$  for the  $\mathcal{S}_j$ . By using  $\mathfrak{M}_{\mathcal{M}}$  and  $\mathfrak{S}_{\mathcal{S}}$ , MBSs and SBSs provide the basic services to their corresponding MDs in their covering

areas. In the cellular area, there are multiple MDs  $\mathbb{D} = \{\mathcal{D}_1, \dots, \mathcal{D}_k\}$ ; they are assumed randomly distributed, and are equipped with an antenna to contact their corresponding BSs through wireless communications [12], [13]. The general two-tier HetNet infrastructure is shown in Figure 1.

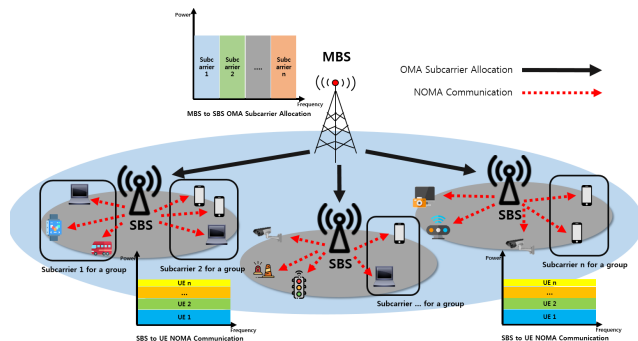


FIGURE 1. Two-tier HetNet platform with OMA and NOMA modes.

Each  $\mathcal{M}$  (or  $\mathcal{S}$ ) divides its own available bandwidth into a set of channels, denoted by  $\mathbb{L} = \{1, \dots, L\}$  (or  $\mathcal{L} = \{1, \dots, l\}$ ). In this study, we adopt the hybrid approach based on the combination NOMA and OMA technologies; it is realistic to effectively reduce the co-channel interference to perform the NOMA technique. The orthogonal bandwidth resources are allocated for different BSs and channels by using the OMA mode. In each MBS and SBS, their corresponding MDs are grouped according to their service types, and each group occupies one channel independently. By using the NOMA mode, MDs in the same group share their corresponding channel with different power levels; we assume that the BS fully understands channel state information, and decides the power levels of individual MDs [14].

In this study, the interactions between BSs and their corresponding MDs are formulated in a cooperative manner. In game theory, a modeling situation is defined as a game to predict the outcome of complex interactions among game players. Formally, we define game entities, i.e.,

$$\mathbb{G} = \left\{ \{\mathbb{M}, \mathbb{S}, \mathbb{D}\}, \{\mathfrak{M}_{\mathcal{M}_i}, \mathfrak{N}_{\mathcal{S}_j}^{\mathcal{M}_i}\}, \{\mathbb{L}, \mathcal{L}\}, \right. \\ \left. \left\{ \mathcal{T}_{\mathcal{W}_{\mathcal{M}_i}}^{\mathcal{M}_i}, \mathcal{T}_{\mathbb{L}}^{\mathcal{M}_i}, \mathcal{T}_{\mathcal{L}}^{\mathcal{S}_j} \right\}, \left\{ \mathbb{P}_{\mathcal{N}_{\mathcal{M}_i}}^{\mathcal{M}_i}, \mathbb{P}_{\mathcal{N}_{\mathcal{S}_j}}^{\mathcal{S}_j} \right\}, \{\mathfrak{X}_{\mathcal{M}_i}, \mathfrak{X}_{\mathcal{S}_j}\}, \right. \\ \left. \left\{ U_{\mathcal{M}_i}, U_{\mathcal{S}_j}^{\mathcal{M}_i}, U_{\mathbb{L}}^{\mathcal{M}_i}, U_{\mathcal{L}}^{\mathcal{S}_j}, U_{\mathcal{D}_k}^l \right\}, T \right\}$$

at each time period of gameplay, and Table 1 lists the notations used in this paper.

- $\{\mathbb{M}, \mathbb{S}, \mathbb{D}\}$  are the finite set of MBSs, SBSs and MDs; they are game players of our joint bargaining games.
- $\mathfrak{M}_{\mathcal{M}_i}$  is the total bandwidth amount for the  $\mathcal{M}_i \in \mathbb{M}$ , and  $\mathfrak{N}_{\mathcal{S}_j}^{\mathcal{M}_i}$  is the allocated bandwidth amount for the  $\mathcal{S}_j \in \mathcal{W}_{\mathcal{M}_i} \subset \mathbb{S}$  where  $\mathcal{W}_{\mathcal{M}_i}$  is the set of SBSs within the  $\mathcal{M}_i$ 's area.
- $\mathbb{L}$  and  $\mathcal{L}$  are the set of channels for MBS and SBS, respectively.

TABLE 1. The notations for abbreviations, symbols and parameters.

Acronym	Explanations
NOMA	non-orthogonal multiple access
OMA	orthogonal multiple access
HetNet	heterogeneous network
MD	mobile device
NBS	Nash bargaining solution
GBS	group bargaining solution
MBS	macro-cell base station
SBS	small-cell base station
TNSRC	Two-tier based NOMA Spectrum Resource Control
LCNSA	Locally Cooperative NOMA Spectrum Allocation
NHSRA	NOMA based HetNet Spectrum Resource Allocation
PE	Pareto efficiency
IAT	invariance with respect to affine transformation
IIA	independence of irrelevant alternatives
SIR	Strong Individual Rationality
AN	Anonymity
SYM	symmetry
RHG	representation of a homogeneous group
r-RHG	r-representation of a homogeneous group
Notations	Explanations
$\mathbb{M}$	the set of MBSs where $\mathbb{M} = \{\mathcal{M}_1, \dots, \mathcal{M}_n\}$
$\mathbb{S}$	the set of SBSs where $\mathbb{S} = \{\mathcal{S}_1, \dots, \mathcal{S}_m\}$
$\mathbb{D}$	the set of MDs
$r_{\mathcal{M}_i}, r_{\mathcal{S}_j}$	MBS and SBS's coverage area radius, respectively
$\mathfrak{M}_{\mathcal{M}_i}$	the total bandwidth amount for the $\mathcal{M}_i \in \mathbb{M}$
$\mathcal{W}_{\mathcal{M}_i}$	the set of SBSs within the $\mathcal{M}_i$ 's area
$\mathfrak{N}_{\mathcal{S}_j}^{\mathcal{M}_i}$	the assigned bandwidth amount for the $\mathcal{S}_j \in \mathcal{W}_{\mathcal{M}_i}$
$\mathbb{L}$	a set of channels in the MBS
$\mathcal{L}$	a set of channels in the SBS
$\mathcal{R}_{\mathcal{M}_i}$	the bandwidth amount allocated for the $\mathcal{M}_i$
$\mathcal{R}_{\mathcal{S}_j}^{\mathcal{M}_i}$	the bandwidth amount allocated for the $\mathcal{S}_j$
$\mathcal{T}_{\mathcal{W}_{\mathcal{M}_i}}^{\mathcal{M}_i}$	the bandwidth allocation vector for the $\{\mathcal{M}_i \cup \mathcal{W}_{\mathcal{M}_i}\}$
$\mathcal{G}_{\mathcal{L}}^{\mathcal{M}_i}$	the bandwidth amount allocated for the $L^{\text{th}}$ channel in $\mathcal{M}_i$
$\mathcal{T}_{\mathbb{L}}^{\mathcal{M}_i}$	the bandwidth allocation vector for $\mathcal{M}_i$
$\mathcal{T}_{\mathcal{L}}^{\mathcal{S}_j}$	the bandwidth allocation vector for the $\mathcal{S}_j$
$f_{\mathcal{L}}^{\mathcal{S}_j}$	the bandwidth amount allocated for the $l^{\text{th}}$ channel in $\mathcal{S}_j$ .
$\mathcal{N}_{\mathcal{M}_i}$	the set of MDs contacting to the $\mathcal{M}_i$
$\mathbb{P}_{\mathcal{N}_{\mathcal{M}_i}}^{\mathcal{M}_i}$	the power level of the $\mathcal{D}_e$ in the $\mathcal{M}_i$
$\mathbb{P}_{\mathcal{N}_{\mathcal{M}_i}^{\mathcal{S}_j}}^{\mathcal{M}_i}$	the power level vector for MDs
$\mathcal{N}_{\mathcal{S}_j}$	the set of MDs within the $\mathcal{S}_j$
$\mathbb{P}_{\mathcal{N}_{\mathcal{S}_j}}^{\mathcal{S}_j}$	the power level of the $\mathcal{D}_k$ in the $\mathcal{S}_j$
$\mathfrak{X}_{\mathcal{M}_i}$	the set of available MBS power levels
$\mathfrak{X}_{\mathcal{S}_j}$	the set of available SBS power levels
$U_{\mathcal{M}_i}, U_{\mathcal{S}_j}^{\mathcal{M}_i}$	utility functions of $\mathcal{M}_i$ and $\mathcal{S}_j$ , respectively
$U_{\mathcal{L}}^{\mathcal{M}_i}$	utility functions of $L^{\text{th}}$ channel in $\mathcal{M}$
$U_{\mathcal{L}}^{\mathcal{S}_j}$	utility functions of $l^{\text{th}}$ channel in $\mathcal{S}$
$U_{\mathcal{D}_k}^l$	utility functions of $\mathcal{D}_k$
$d_{\mathcal{M}_i}$	disagree point of $\mathcal{M}_i$
$d_{\mathcal{S}_j}$	disagree point of $\mathcal{S}_j$
$\Psi_{\mathcal{M}_i}, \Psi_{\mathcal{S}_j}$	profit coefficient factors for $U(\cdot)$
$\varrho, \xi$	control parameters for $U(\cdot)$
$r_{\mathcal{M}_i}^{\text{rc}}$	the total requested bandwidth amounts in the $\mathcal{M}_i$
$r_{\mathcal{S}_j}^{\text{rc}}$	the total requested bandwidth amounts in the $\mathcal{S}_j$
$\eta_l, \alpha$	control parameters for the $U_{\mathcal{L}}^{\mathcal{M}_i}(\cdot)$
$r_l^{\text{rc}}$	the total requested bandwidth amounts in the channel $L$
$\psi, \gamma$	an orthogonality factors for wireless communications
$\omega_{\mathcal{D}_e}$	a path gain from the BS
$\Gamma_{\mathcal{D}_e}$	a background noise to the $\mathcal{D}_e$
$\Theta_{\mathcal{L}}^{\mathcal{M}_i}$	the set of MDs in the channel $L$ of $\mathcal{M}_i$
$\mathbb{P}_{\Theta_{\mathcal{L}}^{\mathcal{M}_i}}^{\mathcal{M}_i}$	the power level vector of MDs in $\Theta_{\mathcal{L}}^{\mathcal{M}_i}$
$\mathcal{E}^{\mathcal{M}_i}$	the maximum power limit of each MBS
$\Theta_{\mathcal{L}}^{\mathcal{S}_j}$	the set of MDs in the channel $l$ of $\mathcal{S}_j$
$\mathbb{P}_{\Theta_{\mathcal{L}}^{\mathcal{S}_j}}^{\mathcal{S}_j}$	the power level vector of MDs in $\Theta_{\mathcal{L}}^{\mathcal{S}_j}$
$\mathcal{E}^{\mathcal{S}_j}$	the maximum power limit of each SBS's channel



- $\mathcal{J}_{\mathcal{W}_{\mathcal{M}_i}}^{\mathcal{M}_i} = \langle \mathcal{R}_{\mathcal{M}_i}, \dots, \mathcal{R}_{\mathcal{S}_j \in \mathcal{W}_{\mathcal{M}_i}}^{\mathcal{M}_i}, \dots \rangle$  is a  $(1 + |\mathcal{W}_{\mathcal{M}_i}|)$ -dimensional bandwidth allocation vector for the  $\{\mathcal{M}_i \cup \mathcal{W}_{\mathcal{M}_i}\}$  where  $\mathcal{R}_{\mathcal{M}_i}$  and  $\mathcal{R}_{\mathcal{S}_j}^{\mathcal{M}_i}$  represent the bandwidth amount allocated for the  $\mathcal{M}_i$  and  $\mathcal{S}_j$ , respectively.
- $\mathcal{J}_L^{\mathcal{M}_i} = \langle \mathcal{C}_1^{\mathcal{M}_i}, \dots, \mathcal{C}_L^{\mathcal{M}_i} \rangle$  is a  $L$ -dimensional bandwidth allocation vector for the  $\mathcal{M}_i$  where  $\mathcal{C}_L^{\mathcal{M}_i}$  represents the bandwidth amount allocated for the  $L^{\text{th}}$  channel in the  $\mathcal{M}_i$ .
- $\mathcal{J}_L^{\mathcal{S}_j} = \langle f_1^{\mathcal{S}_j}, \dots, f_l^{\mathcal{S}_j} \rangle$  is a  $l$ -dimensional bandwidth allocation vector for the  $\mathcal{S}_j$  where  $f_l^{\mathcal{S}_j}$  represents the bandwidth amount allocated for the  $l^{\text{th}}$  channel in the  $\mathcal{S}_j$ .
- $\mathbb{P}_{\mathcal{N}_{\mathcal{M}_i}}^{\mathcal{M}_i} = \langle \dots, \mathbb{P}_{\mathcal{D}_e \in \mathcal{N}_{\mathcal{M}_i}}^{\mathcal{M}_i}, \dots \rangle$  is a  $|\mathcal{N}_{\mathcal{M}_i}|$ -dimensional power level vector for MDs where  $\mathcal{N}_{\mathcal{M}_i}$  is the set of MDs contacting to the  $\mathcal{M}_i$ , and  $\mathbb{P}_{\mathcal{D}_e}^{\mathcal{M}_i}$  represents the power level of the  $\mathcal{D}_e$  in the  $\mathcal{M}_i$ .
- $\mathbb{P}_{\mathcal{N}_{\mathcal{S}_j}}^{\mathcal{S}_j} = \langle \dots, \mathbb{P}_{\mathcal{D}_k \in \mathcal{N}_{\mathcal{S}_j}}^{\mathcal{S}_j}, \dots \rangle$  is a  $|\mathcal{N}_{\mathcal{S}_j}|$ -dimensional power level vector for MDs where  $\mathcal{N}_{\mathcal{S}_j}$  is the set of MDs within the  $\mathcal{S}_j$ , and  $\mathbb{P}_{\mathcal{D}_k}^{\mathcal{S}_j}$  represents the power level of the  $\mathcal{D}_k$  in the  $\mathcal{S}_j$ .
- $\mathfrak{X}_{\mathcal{M}_i} = \{\mathfrak{P}_{\min}^{\mathcal{M}_i}, \dots, \mathfrak{P}_{\max}^{\mathcal{M}_i}\}$  is the set of available MBS power levels where  $\mathbb{P}_{\mathcal{D}_e}^{\mathcal{M}_i} \in \mathfrak{X}_{\mathcal{M}_i}$ , and  $\mathfrak{X}_{\mathcal{S}_j} = \{\mathfrak{P}_{\min}^{\mathcal{S}_j}, \dots, \mathfrak{P}_{\max}^{\mathcal{S}_j}\}$  is the set of available SBS power levels where  $\mathbb{P}_{\mathcal{D}_k}^{\mathcal{S}_j} \in \mathfrak{X}_{\mathcal{S}_j}$ .
- $U_{\mathcal{M}_i} U_{\mathcal{S}_j}^{\mathcal{M}_i} U_L^{\mathcal{M}_i} U_l^{\mathcal{S}_j} U_{\mathcal{D}_k}^l$  are utility functions of  $\mathcal{M}_i$ ,  $\mathcal{S}_j$ ,  $L^{\text{th}}$  channel in  $\mathcal{M}$ ,  $l^{\text{th}}$  channel in  $\mathcal{S}$ , and  $\mathcal{D}_k$ , respectively.
- $T = \{t_1, \dots, t_c, t_{c+1}, \dots\}$  denotes time, which is represented by a sequence of time steps.

**B. THE BASIC CONCEPTS OF COOPERATIVE BARGAINING SOLUTIONS**

The classical NBS can be extended to a more general class of group bargaining problems. GBS is the NBS within each group as well as across groups; groups bargain with each other to determine the feasible set for each group, and the members of each group also bargain with each other to determine their individual payoffs. Conceptually, one can regard bargaining as being done simultaneously at two levels, between groups and between the members of each group. These two processes are interdependent [10]. When bargaining theory is applied to the OMA control problem, orthogonal bandwidth resources can be partitioned fairly and efficiently based on the NBS. When bargaining theory is applied to the NOMA control problem, often at least one of the bargaining parties is a group of MDs using the same bandwidth band. Therefore, the GBS addresses the NOMA control problem by introducing a bargaining model where negotiations occur within as well as across decision-making groups [10]. In the GBS, decision making groups are single agents and groups of individuals bargain with each other based on the generalized classical Nash bargaining model.

In this study, we introduce the notation and basic definitions of bargaining solution. Assuming that there are

non-overlapping groups  $G_1, \dots, G_m$  of individual players. Denote the set of all individuals by  $\mathbb{N} = \{1, \dots, n$ , and the group structure by  $\mathbb{G} = \{G_1, \dots, G_m$ , which is formally a partition of the set  $\mathbb{N}$  where  $n \leq m$ . A payoff vector is an element of the payoff space  $R^{\mathbb{N}}$ , which is the  $n$ -dimensional Euclidean space indexed by the set of individual players. A feasible set  $\mathcal{S}$  is a subset of the payoff space, and a disagreement point  $\mathbf{d}$  is an element of the payoff space. The points in  $\mathcal{S}$  represent the feasible utility levels that the individual players can reach if they agree. Otherwise, if agreement is not reached, they obtain the utility levels given by the disagreement point [10].

A bargaining problem is then specified as triple  $(\mathbb{G}, \mathcal{S}, \mathbf{d})$  consisting of a group structure, feasible set, and disagreement point. The traditional bargaining problem  $(\mathbb{N}, \mathcal{S}, \mathbf{d})$  can be regarded as a special case of the new bargaining problem where each individual forms one group, that is,  $\mathbb{G} = \{\{1\}, \dots, \{n\}\}$ . A bargaining solution is a function  $F$  that associates to each problem  $(\mathbb{G}, \mathcal{S}, \mathbf{d})$  a feasible payoff vector  $F(\mathbb{G}, \mathcal{S}, \mathbf{d})$ . Assume that the group  $G_j$  is replaced by a new group  $\{j^*\}$  that consists of a single representative member  $j^* \in G_j$ . Denote the new set of individuals excluding all members of  $G_j$  but  $j^*$  by  $\mathbb{N}^j \equiv (\mathbb{N} \setminus G_j) \cup \{j^*\}$ , and denote the new group structure by  $\mathbb{G}^j \equiv \{G_1, \dots, G_{j-1}, \{j^*\}, G_{j+1}, \dots, G_m\}$ . To generate the reduced feasible set  $\mathcal{S}^j$  from  $\mathcal{S}$ , we set  $\mathcal{S}^j \equiv \{u \in R^{\mathbb{N}^j} : \text{there exists } v \in \mathcal{S} \text{ such that } v_{j^*} = u_i \text{ for } i \in \mathbb{N} \setminus G_j \text{ and } v_i = u_{j^*} \text{ for all } i \in G_j\}$ . In addition, generate a new disagreement point  $\mathbf{d}^j$  from the original disagreement point  $\mathbf{d}$  by replacing the payoff vector for the group  $(\mathbf{d}_i)_{i \in G_j}$  with the single payoff  $\mathbf{d}_{j^*}$ . Thus we have formally constructed the reduced bargaining problem  $(\mathbb{G}^j, \mathcal{S}^j, \mathbf{d}^j)$  [10].

For the general solution, let  $r(c_j)$  represent the number of rights to talk that a group with  $c_j$  members maintains. As a homogenous group  $G_j$  was reduced to a singleton group  $j^*$ , we can replace group  $G_j$  with  $r(c_j)$  identical singleton groups by replicating a representative member  $j^* \in G_j$ . Denote the new set of individuals by  $\mathbb{N}^{j,r} \equiv (\mathbb{N} \setminus G_j) \cup \{j^1, \dots, j^{r(c_j)}\}$ , the new group structure by  $\mathbb{G}^{j,r} \equiv \{G_1, \dots, G_{j-1}, \{j^1\}, \dots, \{j^{r(c_j)}\}, G_{j+1}, \dots, G_m\}$ , and the new feasible set by  $\mathcal{S}^{j,r} \equiv \{u \in R^{\mathbb{N}^{j,r}} : \text{there exists } v \in \mathcal{S} \text{ such that } v_i = u_i \text{ for } i \in \mathbb{N} \setminus G_j \text{ and } v_i = u_{j^k} \text{ for all } i \in G_j \text{ and } k = 1, \dots, r(c_j)\}$  [10].

Bargaining solutions are characterized by a collection of desirable axioms like as *Pareto efficiency (PE)*, *invariance with respect to affine transformation (IAT)*, *independence of irrelevant alternatives (IIA)*, *Strong Individual Rationality (SIR)*, *Anonymity (AN)*, *symmetry (SYM)*, *representation of a homogeneous group (RHG)*, *r-representation of a homogeneous group (r-RHG)* [10].

- **PE:** There exists no feasible payoff vector  $x$  such that  $x_i > F_i(\mathbb{G}, \mathcal{S}, \mathbf{d})$  for some individual  $i$  and  $x_i \geq F_i(\mathbb{G}, \mathcal{S}, \mathbf{d})$  for all  $i \in \mathbb{N}$ .
- **IAT:** For all  $i \in \mathbb{N}$  and any  $u \in R^{\mathbb{N}}$ , there exist some numbers  $\alpha_1, \dots, \alpha_i, \dots, \alpha_n, \beta_1, \dots, \beta_i, \dots, \beta_n$ ,

where  $\beta_1, \dots, \beta_n > 0$ , such that  $L(u_1, \dots, u_n) = (\alpha_1 + (\beta_1 \cdot u_1), \dots, \alpha_i + (\beta_i \cdot u_i), \dots, \alpha_n + (\beta_n \cdot u_n))$ . If  $L$  is an affine transformation on  $R^{\mathbb{N}}$ , then one has  $F(\mathbb{G}, L(\mathbf{S}), L(\mathbf{d})) = L(F(\mathbb{G}, \mathbf{S}, \mathbf{d}))$ .

- **IIA**: If there exists another bargaining problem  $(\mathbb{G}, \mathbf{S}', \mathbf{d})$  such that  $\mathbf{S}' \subseteq \mathbf{S}$  and  $F(\mathbb{G}, \mathbf{S}, \mathbf{d})$  belongs to  $\mathbf{S}'$ , then  $F(\mathbb{G}, \mathbf{S}', \mathbf{d}) = F(\mathbb{G}, \mathbf{S}, \mathbf{d})$ .
- **SIR**: For all  $i \in \mathbb{N}$ ,  $F_i(\mathbb{G}, \mathbf{S}, \mathbf{d}) > d_i$ .
- **AN**: For any permutation  $\phi : \mathbb{N} \rightarrow \mathbb{N}$ ,  $F(\phi(\mathbb{G}), \phi(\mathbf{S}), \phi(\mathbf{d})) = \phi(F(\mathbb{G}, \mathbf{S}, \mathbf{d}))$ .
- **SYM**: For all  $i \in \mathbb{N}$ , if  $\mathbb{G} = \{\{1\}, \dots, \{n\}\}$  and  $(\mathbf{S}, \mathbf{d})$  is symmetric, then for any two individuals  $i, l$ , one has  $F_i(\mathbb{G}, \mathbf{S}, \mathbf{d}) = F_l(\mathbb{G}, \mathbf{S}, \mathbf{d})$ .
- **RHG**: If a group  $G_j$  is homogeneous in bargaining problem  $(\mathbb{G}, \mathbf{S}, \mathbf{d})$  and  $j^* \in G_j$  then  $F_{j^*}(\mathbb{G}, \mathbf{S}, \mathbf{d}) = F_{j^*}(\mathbb{G}^j, \mathbf{S}^j, \mathbf{d}^j)$ .
- **r-RHG**: If a group  $G_j$  is homogeneous in bargaining problem  $(\mathbb{G}, \mathbf{S}, \mathbf{d})$  and  $j^* \in G_j$ , then  $F_{j^*}(\mathbb{G}, \mathbf{S}, \mathbf{d}) = F_{j^*}(\mathbb{G}^{j,r}, \mathbf{S}^{j,r}, \mathbf{d}^{j,r})$  for an arbitrary  $j^k$  ( $k = 1, \dots, r(c_j)$ ).

It is well known that **SIR** and **IAT** imply **PE**, and **AN** implies **SYM**. **RHG** means that a member of a homogeneous group receives what she would receive if she became a representative member bargaining on behalf of the group. The combination of the **RHG** property with other standard properties led to a solution that allows us to treat a bargaining group as one bargainer even in cases where the bargaining group consists of heterogeneous individual players. For example, **RHG** with **SYM** implies that all groups, rather than individuals, are treated equally in a non-discriminatory manner [10].

For a traditional bargaining problem, J. Nash had shown that there exists a unique solution that satisfies the above four properties, called the NBS, and that it solves the maximization problem as follows [10];

$$\begin{aligned} & \max_{\mathbb{U} \in \mathbf{S}, \mathbb{U} \geq \mathbf{d}} \prod_{i=1}^n (u_i - d_i), \\ & \text{s.t., } \mathbb{U} = [u_1, \dots, u_n] \quad \text{and } i \in \mathbb{N} \end{aligned} \quad (1)$$

The NBS is characterized by a collection of desirable axioms like as **PE**, **IAT**, **IIA**, and **SYM**. Based on the classical NBS, S. Chae and P. Heidhues model a group as a bargaining unit, and introduce a new GBS based on the NBS with the **RHG** property (NBS-R). This solution formulates a situation where a decision making group bargains with outsiders. Therefore, the bargaining problem can be conceptually decomposed into two levels: inter-group and intra-group bargaining. Thus, it expands modeling tools available for the group bargaining. The NBS-R is obtained by solving the maximization problem as follows [10];

$$\begin{aligned} & \max_{\mathbb{U} \in \mathbf{S}, \mathbb{U} \geq \mathbf{d}} \prod_{j=1}^m \left( \prod_{i \in G_j} (u_i - d_i)^{\mathcal{H}(G_j)} \right), \\ & \text{s.t., } \begin{cases} G_j \in \mathbb{G} = \{G_1, \dots, G_m\} \\ \mathcal{H}(G_j) = \frac{1}{|G_j|} \end{cases} \end{aligned} \quad (2)$$

where  $|G_j|$  is the cardinality, i.e., the number of the members, of  $G_j$ . The NBS-R maximizes the weighted product of net utilities, where the weight for each individual is the reciprocal of the size of the group to which she belongs. Therefore, the NBS-R is easy to calculate, and characterized by a collection of desirable axioms like as **PE**, **IAT**, **IIA**, **SYM** and **RHG** [10]. The NBS-R can be generalized to the NBS with the **r-RHG** property (NBS-r). For a general solution, let  $r(G_j)$  represent the number of rights to talk that a group  $G_j$  maintains. Finally, the NBS-r is given by [10];

$$\max_{\mathbb{U} \in \mathbf{S}, \mathbb{U} \geq \mathbf{d}} \prod_{j=1}^m \left( \prod_{i \in G_j} (u_i - d_i)^{\mathcal{H}(G_j)} \right)^{r(G_j)} \quad (3)$$

If  $r(G_j) = 1$ , the members' rights are reduced to a single right. If  $r(G_j) = |G_j|$ , the members of a group maintain their rights to talk. This is equivalent to the standard Nash solution ignoring the group structure. If  $1 < r(G_j) < |G_j|$ , the rights are reduced but not to a single right. If  $r(G_j) > |G_j|$ , the rights actually increase with the formation of a bargaining group. This class of solutions ( $r(G_j) > |G_j|$ ) can provide an independent reason why a group may form even in a pure bargaining situation. The NBS-r can satisfy the axioms - **PE**, **IAT**, **IIA**, **SYM** and **r-RHG** [10].

### C. THE BARGAINING CONTROL SCHEME FOR THE OMA-NOMA SYSTEM

In this study, we concern the appropriate bandwidth control algorithms for the hierarchical HetNet platform. First, each MBS ( $\mathcal{M}$ ) distributes its bandwidth resource ( $\mathcal{M}_M$ ) to the set of SBSs ( $\mathcal{W}_M$ ) within the  $M$ 's area. Therefore, the individual  $\mathcal{M}$  partitions the  $\mathfrak{M}_M$  into disjoint portions, and allocates them for corresponding SBSs. This OMA based bandwidth allocation process can avoid the complex interference management in the wireless network topology. To implement this process for the  $\{\mathcal{M}_i \cup \mathcal{W}_{\mathcal{M}_i}\}$ , we focus on the traditional NBS. As a fair-efficient solution, the  $\mathcal{T}_{\mathcal{W}_{\mathcal{M}_i}}^{\mathcal{M}_i}$  is obtained as follows;

$$\begin{aligned} & \max_{\mathcal{T}_{\mathcal{W}_{\mathcal{M}_i}}^{\mathcal{M}_i}} = \left\{ \mathcal{R}_{\mathcal{M}_i}, \dots, \mathcal{R}_{\mathcal{S}_j \in \mathcal{W}_{\mathcal{M}_i}} \dots \right\} \\ & \left( (U_{\mathcal{M}_i}(\mathcal{R}_{\mathcal{M}_i}) - d_{\mathcal{M}_i}) \prod_{\mathcal{S}_j \in \mathcal{W}_{\mathcal{M}_i}} (U_{\mathcal{S}_j}^{\mathcal{M}_i}(\mathcal{R}_{\mathcal{S}_j}) - d_{\mathcal{S}_j}) \right) \\ & \text{s.t., } \begin{cases} U_{\mathcal{M}_i}(\mathcal{R}_{\mathcal{M}_i}) = \Psi_M \times \log \left( \frac{\min(\mathcal{R}_{\mathcal{M}_i}, r_{\mathcal{M}_i}^{t_c})}{\mathfrak{M}_{\mathcal{M}_i}} + \varrho \right) \\ U_{\mathcal{S}_j}^{\mathcal{M}_i}(\mathcal{R}_{\mathcal{S}_j}) = \Psi_S \times \log \left( \frac{\min(\mathcal{R}_{\mathcal{S}_j}^{\mathcal{M}_i}, r_{\mathcal{S}_j}^{t_c})}{\mathfrak{M}_{\mathcal{M}_i}} + \xi \right) \\ \left( \mathcal{R}_{\mathcal{M}_i} + \sum_{\mathcal{S}_j \in \mathcal{W}_{\mathcal{M}_i}} \mathcal{R}_{\mathcal{S}_j}^{\mathcal{M}_i} \right) \leq \mathfrak{M}_{\mathcal{M}_i} \end{cases} \end{aligned} \quad (4)$$

where  $\Psi_M$  and  $\Psi_S$  are profit coefficient factors, and  $\varrho$  and  $\xi$  are control parameters for the  $U(\cdot)$ . At time  $t_c$ ,  $r_{\mathcal{M}_i}^{t_c}$  and  $r_{\mathcal{S}_j}^{t_c}$  are total requested bandwidth amounts in the  $\mathcal{M}_i$  and  $\mathcal{S}_j$ ,

respectively. And then, each individual  $\mathcal{M}$  splits its assigned bandwidth resource ( $\mathcal{R}_{\mathcal{M}}$ ) to different  $L$  channels. Based on the OMA mode, the bandwidth assignment for each channel is also implemented according to the NBS. Within the  $\mathcal{M}_i$ ,  $\mathcal{J}_{\mathbb{L}}^{\mathcal{M}_i}$  is obtained as follows;

$$\mathcal{J}_{\mathbb{L}}^{\mathcal{M}_i} = \left\{ \begin{array}{l} \max_{\mathbf{c}_1^{\mathcal{M}_i}, \dots, \mathbf{c}_L^{\mathcal{M}_i}} \prod_{L \in \mathbb{L} = \{1, \dots, L\}} \left( U_L^{\mathcal{M}_i}(\mathbf{c}_L^{\mathcal{M}_i}) - d_L^{\mathcal{M}_i} \right) \\ \text{s.t., } \left\{ \begin{array}{l} U_L^{\mathcal{M}_i}(\mathbf{c}_L^{\mathcal{M}_i}) = \eta_L \times \log \left( \frac{\min(\mathbf{c}_L^{\mathcal{M}_i}, r_L^{tc})}{\mathcal{R}_{\mathcal{M}_i}} + \alpha \right) \\ \sum_{b \in \mathbb{L}} \mathbf{c}_b^{\mathcal{M}_i} \leq \mathcal{R}_{\mathcal{M}_i} \end{array} \right. \end{array} \right. \quad (5)$$

where  $\eta_L$  and  $\alpha$  are control parameters for the  $U_L^{\mathcal{M}}(\cdot)$ , and  $r_L^{tc}$  is the total requested bandwidth amount in the channel  $L$  of  $\mathcal{M}_i$  at time  $t_c$ . Recursively, each  $S$  in  $\mathcal{W}_{\mathcal{M}_i}$  splits its assigned resource ( $\mathcal{R}_S^{\mathcal{M}_i}$ ) to different  $l$  channels by using the OMA mode. Therefore,  $\mathcal{J}_{\mathcal{L}}^{\mathcal{S}_j} = \langle f_1^{\mathcal{S}_j}, \dots, f_l^{\mathcal{S}_j} \rangle$  is obtained as the same manner as the equation (5).

Finally, each BS decides power levels for its corresponding MDs by using the NOMA mode. Usually, 5G cellular networks are expected to support multimedia services. In this study, we assume that different multimedia services over MDs can be categorized into four types according to their characteristics, i.e., type I, II, III and IV applications. Based on the type, multiple applications are grouped, and each group is treated as a unit under diverse traffic environments. For each group, we assign an orthogonal bandwidth portion, i.e., channel, separately. In the proposed scheme, each individual MBS and SBS adopt the NOMA technique to share the channel for same group applications. Due to its high bandwidth efficiency nature, this approach is necessary to achieve the strategic advantage within a cell area. For the NOMA operation in the MBS, we concern the number of MDs in each channel while emphasizing the characteristic of **RHG** axiom. Therefore, the NBS-R is applied to decide each MD's power level in the MBS, and  $\mathbb{P}_{N_{\mathcal{M}_i}}^{\mathcal{M}_i} = \langle \dots, \mathcal{P}_{\mathcal{D}_e \in N_{\mathcal{M}_i}}^{\mathcal{M}_i} \dots \rangle$  is obtained as follows;

$$\mathbb{P}_{N_{\mathcal{M}_i}}^{\mathcal{M}_i} = \left\{ \begin{array}{l} \max_{\mathbf{P}_{\mathcal{D}_e \in N_{\mathcal{M}_i}}^{\mathcal{M}_i}} \prod_{L \in \mathbb{L}} \left( \prod_{\mathcal{D}_e \in \Theta_{\mathcal{M}_i}^L} \left( U_{\mathcal{D}_e}^L(\mathcal{P}_{\mathcal{D}_e}^{\mathcal{M}_i}, \mathbb{P}_{\Theta_{\mathcal{M}_i}^L}^{\mathcal{M}_i}) - d_{\mathcal{D}_e}^L \right)^{\frac{1}{|\Theta_{\mathcal{M}_i}^L|}} \right) \\ \text{s.t., } \left\{ \begin{array}{l} U_{\mathcal{D}_e}^L(\mathcal{P}_{\mathcal{D}_e}^{\mathcal{M}_i}, \mathbb{P}_{\Theta_{\mathcal{M}_i}^L}^{\mathcal{M}_i}) = \frac{(\omega_{\mathcal{D}_e} \times \mathcal{P}_{\mathcal{D}_e}^{\mathcal{M}_i})}{\left( \left( \Upsilon \times \left( \left( \sum_{\mathcal{D}_d \in \Theta_{\mathcal{M}_i}^L} \mathcal{P}_{\mathcal{D}_d}^{\mathcal{M}_i} \right) - \mathcal{P}_{\mathcal{D}_e}^{\mathcal{M}_i} \right) \right) + \Gamma_{\mathcal{D}_e} \right)} \\ \omega_{\mathcal{D}_e} = r_L^{tc}, \Gamma_{\mathcal{D}_e} = |\Theta_{\mathcal{M}_i}^L| \text{ and } \sum_{\mathcal{D}_e \in \Theta_{\mathcal{M}_i}^L} \mathcal{P}_{\mathcal{D}_e}^{\mathcal{M}_i} \leq \mathcal{E}^{\mathcal{M}_i} \end{array} \right. \end{array} \right. \quad (6)$$

where  $\Upsilon$  is an orthogonality factor for wireless communications.  $\omega_{\mathcal{D}_e}$ ,  $\Gamma_{\mathcal{D}_e}$  are a path gain from the BS, and a background noise to the  $\mathcal{D}_e$ , respectively.  $\Theta_{\mathcal{M}_i}^L$  is the set of MDs in the channel  $L$  of  $\mathcal{M}_i$ .  $\mathbb{P}_{\Theta_{\mathcal{M}_i}^L}^{\mathcal{M}_i}$  is a  $|\Theta_{\mathcal{M}_i}^L|$ -dimensional vector to represent power levels of MDs in  $\Theta_{\mathcal{M}_i}^L$ .  $\mathcal{E}^{\mathcal{M}_i}$  is the maximum power limit of each MBS; it allocates power to each MD within the power limit. Therefore, the sum of powers allocated to all MDs in the channel  $L$  cannot exceed the power limit. Each MD has its own utility function that represents the degree of MD's satisfaction of the generic signal quality for a MD. According to (6), the  $\mathcal{D}_e$ 's utility function  $U_{\mathcal{D}_e}^L(\cdot)$  depends not only on its own power level, but also on the power levels of all the other MDs in the same channel [15]. In the case of SBS, we consider the relative power of different channel groups while paying attention to the **r-RHG** axiom. Therefore, the NOMA operation in the  $S_j$  is implemented by using the NBS-r, and  $\mathbb{P}_{N_{S_j}}^{\mathcal{S}_j} = \langle \dots, P_{\mathcal{D}_k \in N_{S_j}}^{\mathcal{S}_j} \dots \rangle$  is obtained as follows;

$$\mathbb{P}_{N_{S_j}}^{\mathcal{S}_j} = \left\{ \begin{array}{l} \max_{\mathbf{P}_{\mathcal{D}_k \in N_{S_j}}^{\mathcal{S}_j}} \prod_{l \in \mathcal{L}} \left( \prod_{\mathcal{D}_k \in \Theta_{S_j}^l} \left( U_{\mathcal{D}_k}^l(\mathcal{P}_{\mathcal{D}_k}^{\mathcal{S}_j}, \mathbb{P}_{\Theta_{S_j}^l}^{\mathcal{S}_j}) - d_{\mathcal{D}_k}^l \right)^{r(\Theta_{S_j}^l)} \right) \\ \text{s.t., } \left\{ \begin{array}{l} U_{\mathcal{D}_k}^l(\mathcal{P}_{\mathcal{D}_k}^{\mathcal{S}_j}, \mathbb{P}_{\Theta_{S_j}^l}^{\mathcal{S}_j}) = \frac{(\omega_{\mathcal{D}_k} \times P_{\mathcal{D}_k}^{\mathcal{S}_j})}{\left( \left( \psi \times \left( \left( \sum_{\mathcal{D}_d \in \Theta_{S_j}^l} P_{\mathcal{D}_d}^{\mathcal{S}_j} \right) - P_{\mathcal{D}_e}^{\mathcal{S}_j} \right) \right) + \Gamma_{\mathcal{D}_e} \right)} \\ r(\Theta_{S_j}^l) = \chi(l), \omega_{\mathcal{D}_e} = r_l^{tc}, \\ \Gamma_{\mathcal{D}_e} = |\Theta_{S_j}^l| \text{ and } \sum_{\mathcal{D}_k \in \Theta_{S_j}^l} P_{\mathcal{D}_k}^{\mathcal{S}_j} \leq \mathcal{E}^{\mathcal{S}_j} \end{array} \right. \end{array} \right. \quad (7)$$

where  $\psi$  is an orthogonality factor for wireless communications.  $\Theta_{S_j}^l$  is the set of MDs in the channel  $l$  of  $S_j$ .  $\mathbb{P}_{\Theta_{S_j}^l}^{\mathcal{S}_j}$  is a  $|\Theta_{S_j}^l|$ -dimensional vector to represent power levels of MDs in  $\Theta_{S_j}^l$ .  $r(\Theta_{S_j}^l)$  is the function of application types; it is dependent on channels.  $\mathcal{E}^{\mathcal{S}_j}$  is the maximum power limit of each SBS's channel. Each MD in SBSs has same characteristics as the MDs in MBSs. Therefore,  $U_{\mathcal{D}_k}^l(\cdot)$  is designed as the same manner as the  $U_{\mathcal{D}_e}^L(\cdot)$ .

**D. COMPLEXITY ANALYSIS AND SCALABILITY OF THE PROPOSED ALGORITHM**

This study has been initiated to properly combine the OMA and NOMA technologies. For future HetNets,

we develop a novel bandwidth control algorithm for the hybrid OMA-NOMA system. To allocate the bandwidth resource for SBSs and channels, the OMA mode is applied, and the classical NBS models the bargaining process to assign the orthogonal bandwidth portions. Usually, optimal solutions have exponential time complexity. Therefore, they are impractical in real-time process. In this study, we do not focus on trying to get an optimal solution based on the traditional approach. Instead, our solution concept is designed based on the NBS model. In addition, to reduce computation complexity, the expected bandwidth amount is specified in terms of basic bandwidth units. Therefore, the values of NBS in the equation (4) and (5) are obtained using the iterative water-filling method with polynomial complexity.

In BSs, the same type applications share the same channel band, and their power levels are decided using the NOMA mode. To adaptively decide their power levels, we assume the same type applications as a group; it can be a bargaining agent. When groups bargain with each other, they anticipate the final payoffs that the members of the groups will receive in the end. To treat this group bargaining problem, the idea of GBS is well defined. Therefore, we model the group bargaining process to decide the power levels of individual MDs in each BS. To reduce computation complexity, MBS and SBS have the discrete power level set, and the values of GBS in the equation (6) and (7) are also obtained with polynomial complexity.

Usually, cellular network architecture can be simply extended by employing BSs. If we would apply our proposed bandwidth control scheme in the situation with hundreds or thousands of MBSs, each MBS is clustered with its corresponding SBSs in a distributed manner, and our game model is operated in a distributed self-regarding fashion. In other words, through a step-by-step process, our scheme can be extended iteratively. Therefore, scalability is another important novelty of our proposed scheme; it is a desirable property for large scale cellular networks.

### E. MAIN STEPS OF PROPOSED BANDWIDTH CONTROL SCHEME

In the proposed scheme, the NBS and GBS can be mutually dependent on each other to strike the appropriate performance balance. The main steps of the proposed scheme can be described as follows: The main steps of the proposed scheme can be explained as follows, and they are described by the following flowchart:

**Step 1:** For our simulation model, the values of system parameters and control factors can be discovered in Table 2, and the simulation scenario is given in Section IV.

**Step 2:** In each time period, individual MDs generate their application services, and contact their corresponding BSs. According applications' types, they can be categorized as four groups, and members in the same group use the same channel by using the OMA mode.

TABLE 2. System parameters used in the simulation experiments.

Parameter	Value	Description
$n$	16	the number of MBSs in the HetNet system
$m$	64	the number of SBSs in the HetNet system
$k$	100	the number of MDs
$L, l$	5, 5	the number of channels in SBS and MBS, respectively
$\mathfrak{M}_{\mathcal{M}}$	10 Giga bps	the total bandwidth capacity of each MBS
$r_{\mathcal{M}}$	3 km	the radius of MBS's coverage area
$r_{\mathcal{S}}$	1.5 km	the radius of SBS's coverage area
$\Psi_{\mathcal{M}}, \Psi_{\mathcal{S}}$	2.5, 3	profit coefficient factors for $U_{\mathcal{M}}$ and $U_{\mathcal{S}}^{\mathcal{M}}$
$ \mathbb{L} $	4	the number of MBS channels
$ \mathcal{L} $	4	the number of SBS channels
$\varrho, \xi$	1, 1	control parameters for $U_{\mathcal{M}}$ and $U_{\mathcal{S}}^{\mathcal{M}}$ , respectively
$\eta_{l \in \mathcal{L}}$	1.5	the control parameters for the $U_l^{\mathcal{S}}(\cdot)$
$\eta_{L \in \mathcal{L}}$	2.5	the control parameters for the $U_L^{\mathcal{M}}(\cdot)$
$\alpha$	1	a control parameter for $U_L^{\mathcal{M}}$
$\Upsilon, \psi$	2, 1.5	orthogonality factors for wireless communications
$\mathfrak{X}_{\mathcal{M}}$	{1.5, 1.8, 2, 2.5, 3}	the set of available MBS power levels
$\mathfrak{X}_{\mathcal{S}}$	{1, 1.2, 1.4, 1.6, 2}	the set of available SBS power levels
$\mathcal{E}^{\mathcal{S}}$	100	the maximum power limit of each SBS
$\mathcal{E}^{\mathcal{M}}$	150	the maximum power limit of each MBS
$\chi(l)$	$\chi(1) = 1.1$	the function of channel 1 for application group I
	$\chi(2) = 1.15$	the function of channel 2 for application group II
	$\chi(3) = 1.2$	the function of channel 3 for application group III
	$\chi(4) = 1.25$	the function of channel 4 for application group IV
Type	Bandwidth Requirement	Connection Duration
Type I	10 Mbps	180 $t$ -unit
Type II	7.5 Mbps	90 $t$ -unit
Type III	5 Mbps	30 $t$ -unit
Type IV	2.5 Mbps	60 $t$ -unit

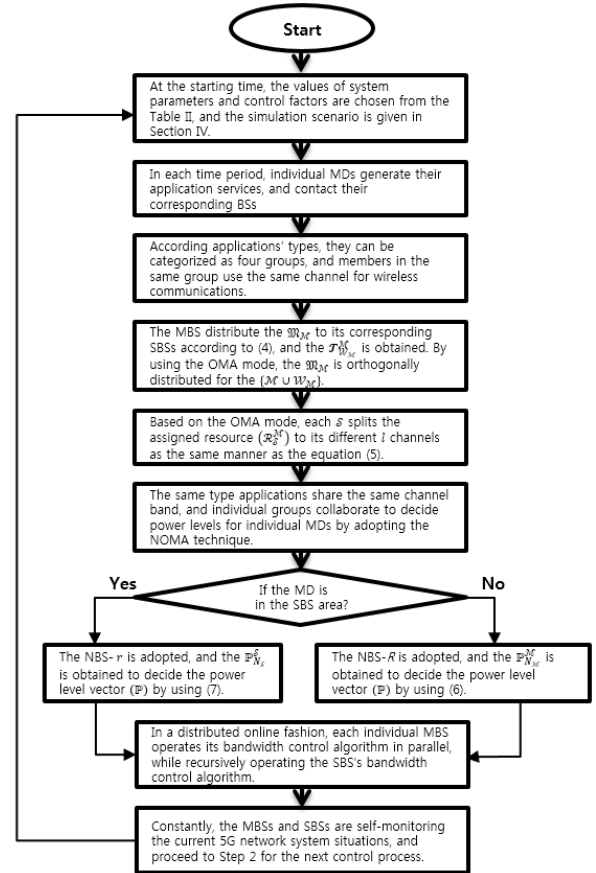
**Step 3:** The MBS distribute the  $M_{\mathcal{M}}$  to its corresponding SBSs based on the classical NBS. By considering the current SBS's traffic situations ( $r_{\mathcal{S}}^{t_c}$ ), the  $\mathfrak{M}_{\mathcal{M}}$  is orthogonally distributed for the  $\{\mathcal{M} \cup \mathcal{W}_{\mathcal{M}}\}$  by using the OMA mode. Finally, the NBS for the  $\mathfrak{J}_{\mathcal{W}_{\mathcal{M}}}^{\mathcal{M}}$  is obtained according to (4).

**Step 4:** Each individual  $\mathcal{M}$  splits its assigned resource ( $\mathcal{R}_{\mathcal{M}}$ ) to its different  $L$  channels. Based on the OMA mode, the bandwidth assignment for each channel



$(\mathcal{C}_{L \in \mathbb{L}}^{\mathcal{M}})$  is also implemented according to the NBS. Finally, the NBS for the  $\mathcal{T}_{\mathbb{L}}^{\mathcal{M}}$  is obtained according to (5).

- Step 5:** As the same manner as the equation (5), each  $S$  splits the assigned resource  $(\mathcal{R}_S^{\mathcal{M}})$  to its different  $l$  channels. Based on the OMA mode, the NBS is applied to obtain the  $\mathcal{T}_{\mathcal{L}}^S$ .
- Step 6:** In BSs, each group members share the same channel band, and individual groups collaborate to decide power levels for individual MDs based on the NOMA mode.
- Step 7:** Each individual MBSs and SBSs adaptively decide MDs' power levels. To treat this power decision problem, we adopt the concept of GBS, and model the group bargaining process to decide the power level vector  $(\mathbb{P})$  in each BS.
- Step 8:** For the NOMA operation in the MBS, the NBS- $R$  is applied, and the  $\mathbb{P}_{N_{\mathcal{M}}}^{\mathcal{M}}$  is obtained according to (6). For the NOMA operation in the SBS, the NBS- $r$  is adopted, and the  $\mathbb{P}_{N_S}^S$  is obtained by using (7).
- Step 9:** In a distributed online fashion, each individual MBS operates its bandwidth control algorithm in parallel, while recursively operating the SBS's bandwidth control algorithm. They act cooperatively and collaborate with each other in a sophisticated manner
- Step 10:** Constantly, the MBSs and SBSs are self-monitoring the current 5G HetNet system situations, and proceed to Step 2 for the next bandwidth control process.



Flowchart 1. Flowchart of the proposed algorithm.

#### IV. PERFORMANCE EVALUATION

In this section, the performance of our proposed bandwidth control scheme is evaluated by simulations, and it is compared with other existing protocols to confirm the superiority of our jointly bargaining approach. As mentioned in the Section II, we select the *TNSRC*, *LCNSA* and *NHSRA* schemes [11]-[13]; these existing protocols are recently published novel NOMA embedded bandwidth control protocols for the HetNet system platform. The assumptions of our simulation environment are as follows:

- The simulated HetNet system platform consists of two-tiers where 16 MBSs in the upper tier and 64 SBSs in the lower tier.
- Multiple BSs are regularly positioned in an area of  $10 \times 10$  kilometer square area; MBS's radius  $r_{\mathcal{M}}$  and SBS' radius  $r_{\mathcal{S}}$  of their coverage areas are 3 and 1.5 kilometers, respectively.
- There are one hundred MDs  $\mathbb{D} = \{\mathcal{D}_1, \dots, \mathcal{D}_{100}\}$ , and they are distributed randomly over the 5G cellular area.
- The process for service request generations is Poisson with rate  $\Lambda$  (services/s), and the range of offered service load was varied from 0 to 3.0.
- The set of MBS power levels  $\mathcal{X}_{\mathcal{M}} = \{\mathfrak{P}_{min}^{\mathcal{M}}, \dots, \mathfrak{P}_{max}^{\mathcal{M}}\}$  is defined as  $\mathfrak{P}_{min=1}^{\mathcal{M}} = 1.5$ ,  $\mathfrak{P}_2^{\mathcal{M}} = 1.8$ ,  $\mathfrak{P}_3^{\mathcal{M}} = 2$ ,  $\mathfrak{P}_4^{\mathcal{M}} = 2.5$ , and  $\mathfrak{P}_{max=5}^{\mathcal{M}} = 3$ .

- The set of SBS power levels  $\mathcal{X}_{\mathcal{S}} = \{\mathfrak{P}_{min}^{\mathcal{S}}, \dots, \mathfrak{P}_{max}^{\mathcal{S}}\}$  is defined where  $\mathfrak{P}_{min=1}^{\mathcal{S}} = 1$ ,  $\mathfrak{P}_2^{\mathcal{S}} = 1.2$ ,  $\mathfrak{P}_3^{\mathcal{S}} = 1.4$ ,  $\mathfrak{P}_4^{\mathcal{S}} = 1.6$ , and  $\mathfrak{P}_{max=5}^{\mathcal{S}} = 2$ .
- The disagreement points  $d_{\mathcal{M}}$ ,  $d_{\mathcal{S}}$  and  $d_{\mathcal{D}}$  are set to zero, respectively.
- Four different service types are assumed, and application services are selected randomly by each MD.
- System performance measures obtained on the basis of 100 simulation runs are plotted as a function of the offered service request load.
- Performance measures are normalized payoff of individual MDs, throughput of HetNet system, and fairness among application services.

In Fig.2, the normalized payoffs of individual MD's are provided. In contrast with the *TNSRC*, *LCNSA* and *NHSRA* schemes, network entities in our proposed scheme work together based on the cooperative bargaining game model, and they attempt to enhance the impact of OMA-NOMA integrated platform. It can lead to higher individual MDs' payoffs under the 5G HetNet system. Fig. 3 shows the comparison results about the system throughput of HetNet infrastructure. Under different service load intensities, our bandwidth control scheme can ensure desirable characteristics in the resource bargaining process. Therefore, we can find that our

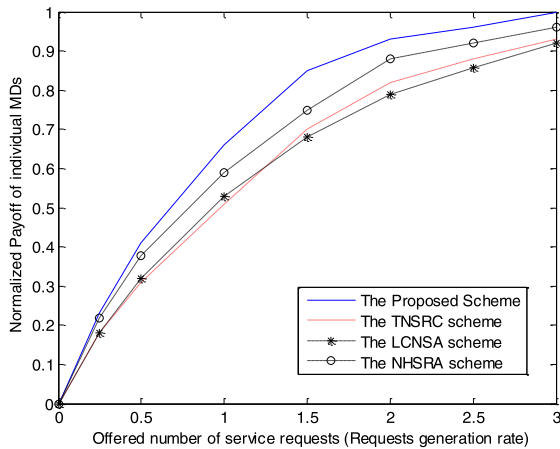


FIGURE 2. Normalized payoff of individual MDs.

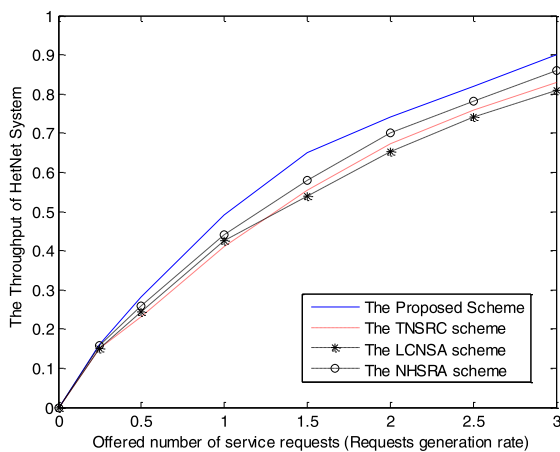


FIGURE 3. Throughput of HetNet System.

jointly bargaining approach is useful in the two-tier HetNet architecture, and also can maintain a stable and higher system throughput performance than other existing schemes.

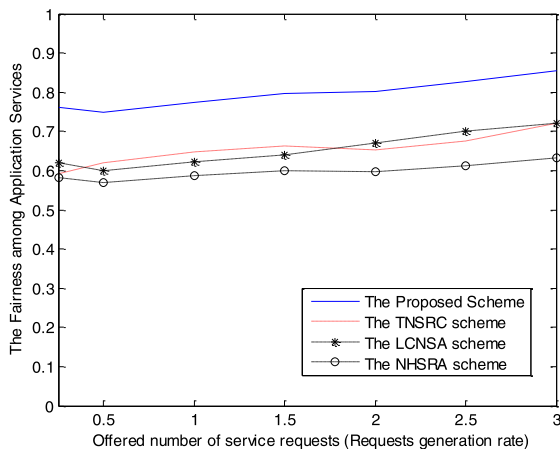


FIGURE 4. The fairness among application services.

Fig.4 is plotted to assess the fairness among application services. In this study, we use the Jain's fairness index to compare the fairness performance [16]. One of major characteristics of NBS and GBS is to guarantee the fairness.

As expected, we observe that our jointly bargaining approach can maintain a higher fairness index than the existing state-of-the-art protocols. From the simulation results shown in Fig.2 to Fig.4, we confirm that our proposed scheme can attain an appropriate performance balance in the hybrid OMA-NOMA system infrastructure.

## V. SUMMARY AND CONCLUSION

This paper studies the 5G HetNet bandwidth control algorithm for different type applications. In our proposed algorithm, the ideas of NBS and GBS are adopted by taking into account the hybrid OMA-NOMA system platform. In the OMA-enabled bandwidth control process, the NBS can adaptively allocate the orthogonal bandwidth resources for different SBSs and channels, respectively. In the NOMA-enabled bandwidth control process, two GBSs are used to decide MDs' power levels; NBS- $R$  for MBSs and NBS- $r$  for SBSs. Under dynamically changing HetNet environments, different bargaining solutions are sophisticatedly combined into the holistic scheme and work together in a coordinated manner to strike the appropriate performance balance between contradictory requirements. At each time period, the limited bandwidth resource is managed in a distributed manner to adapt effectively the current network changes while striking a well-balanced system performance. Simulation results prove that our proposed scheme achieves significant performance gains over other existing *TNSRC*, *LCNSA* and *NHSRA* schemes when the NOMA and OMA coexist in the HetNet system. Therefore, we can confirm the effectiveness of our jointly bargaining approach through the numerical analysis.

For the future work, our current study can be extended in a number of ways. One future direction is to investigate the bandwidth resource and power allocation problem for the tradeoff between maximizing the sum rate and minimum rate requirements of MDs in the NOMA system. In addition, we will separate the joint resource problem into two sub-problems such as a user-channel assignment problem, and a power allocation problem, and develop a joint alternating optimization algorithm with low complexity.

## COMPETING OF INTERESTS

The author declares that there are no competing interests regarding the publication of this paper.

## AUTHOR' CONTRIBUTION

The author is a sole author of this work and ES (i.e., participated in the design of the study and performed the statistical analysis).

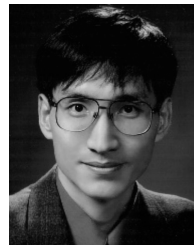
## AVAILABILITY OF DATA AND MATERIAL

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