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D2D Enabled Cellular Network Spectrum Allocation Scheme Based on the Cooperative Bargaining Solution

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ABSTRACT In 5G cellular networks, device-to-device (D2D) communication has undoubtedly become a general trend to increase spectral efficiency while reducing communication delay. In particular, D2D technology is able to bear more and more services, which help user-centred and personalized services in future wireless networks. However, several technical issues and challenges are associated with the deployment of D2D communications. In this paper, we tackle the spectrum allocation problem of D2D enabled cellular networks. By employing the major ideas of cooperative game theory, we design a novel two-stage resource allocation protocol based on the weighted utilitarian and meta bargaining solutions. The purpose of bargaining solutions is to clarify what could be the best solution when game players share a surplus that they can jointly generate. According to the main advantages of step-by-step interactive bargaining mechanism, our proposed solution takes various benefits in a rational way. Some simulation results and numerical analysis are provided to confirm the effectiveness of our two-stage bargaining approach and validate the accuracy of the proposed spectrum allocation scheme. Finally, we address some challenges and identify research areas for the future study.

INDEX TERMS D2D multicasting, spectrum allocation, meta bargaining solution, weighted utilitarian bargaining solution, cooperative game theory.

I. INTRODUCTION

Recently, it is expected that the number of wireless mobile devices will surpass 50 billion by 2020, and that a 1000-fold increase in data rate is required to accommodate the explosive growth of data traffic in wireless services. In addition, a wide range of emerging services such as virtual training, augmented reality, e-learning and remote surgery will continue to proliferate. These developments will lead to inevitable technical challenges to support the proliferation of different multimedia services. With large-scale mobile traffic requirements and wireless applications in the future network, it will soon become difficult for the traditional infrastructure-centric cellular network system. One reason is that, in traditional cellular networks, all network traffic is forwarded and relayed by the fixed infrastructure even when the sources and destination devices are close to each other [1]–[3].

With the evolution of the fifth-generation (5G) networks, new technical attempts have been employed to enhance the network capacity while improving the qualities of service. One technique that promises an efficient way to increase the network reliability and capacity is a device-to-device (D2D) communication. It has a great potential to bring the significant performance boost to the conventional cellular networks. In fact, D2D communication is defined as the direct communication between two mobile devices in a close range without traversing the core network infrastructure. This new communication technology not only decreases communication delay and energy consumption but also increases the reliability of the networks. In addition, the D2D user devices in cellular networks can communicate by sharing the spectrum resources assigned to mobile user devices. This approach can

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increase the network spectral capability and also improve energy efficiency and user experience [2]–[4].

With the landing of the key technology of D2D communications, D2D content sharing is known to be an effective solution to improve the quality of local services of cellular networking. Fortunately, D2D multicast content sharing can reduce the redundancy transmissions for the same contents, and making it possible to achieve the large-scale parallel implementation in a distributed manner [5]–[7].

In a typical D2D multicast content sharing scenario, the main concern is the spectrum allocation protocol, which can characterize how efficiently the wireless spectrum. Considering that multiple near-located users may request the same service with similar behavior characteristics, and they are formulated into a logical collection, i.e. cluster or community in D2D multicast systems. For the content distribution, cluster head users are selected; they forward the same content to multiple D2D requesters in each cluster. The spectrum resource, which is assigned to the cluster head, is shared within the corresponding cluster to maximize the overall network throughput. This spectrum sharing technology potentially opens new opportunities to ensure a higher spectrum efficiency [3], [5].

Traditional cellular network provides a wide coverage for mobile user devices, but the D2D multicasting system installs a diverse set of clusters. To avoid the co-channel interference, we partition the total spectrum into disjoint portions and allocating one partition for each cluster. To manage an irregular cluster topology, efficient spectrum allocation process is highly desirable to exploit the limited wireless spectrum resource. In the last couple of years, several spectrum allocation methods have been presented for the D2D multicasting network. However, the research about this issue is still in its infancy, and several technical challenges keep haunting both academia and industry. Therefore, a new and novel control paradigm is expected to provide a comprehensive and effective solution [3]–[7].

As a theoretical framework, bargaining theory seems to offer the important advantage of giving insight into how game players behave such as how subsets of players bargain over which actions are played [8]. In this study, we design a new spectrum allocation scheme for the D2D multicasting system. To effectively allocate the spectrum resource, our proposed scheme adopts the main concept of weighted utilitarian and meta bargaining models. The utilitarian solution has been discussed extensively in the social welfare literature. In 1975, it was axiomatized and argued for extensively by Harsanyi; it can be easily used in the bargaining context as well. The meta bargaining idea was originally introduced by van Damme to clarify what could be a reasonable solution if cooperative game players have different notions about the ideal solution concept to be applied. It is characterized by the fact that the players' strategy sets are sets of bargaining solutions, and determines distinguished solutions of the cooperative bargaining game [9].

A. MAIN CONTRIBUTIONS

Based on the features of different cellular network users, we assume that they have different ideas about their utopian solutions. To find the best solution among them, we design a novel resource allocation scheme based on the weighted utilitarian and meta bargaining solutions. At the first phase, utilitarian-based bargaining solution is applied to maximize the system utilitarianism. At the second phase, negotiation-based meta bargaining solution is adopted to share the spectrum resource. According to a two-stage bargaining approach, selfish cellular users adaptably adjust their profits to achieve a mutually desirable solution. Therefore, our proposed approach can leverage the full synergy of self-adaptability from the interdependence among cellular users. Due to these reasons, we can effectively allocate the limited spectrum resource in a fair-efficient manner. In summary, the major contributions of this study are as follows:

- This paper considers the concepts of weighted utilitarian and meta bargaining game solutions. These solutions can effectively handle the situation that game players could support different weights or concepts of fairness and equity. From a strategic point of view, we can jointly reach a mutually acceptable agreement.
- Motivated by the two bargaining solutions, we develop a new two-stage spectrum allocation scheme for the D2D multicasting system. The proposed scheme formulates the spectrum allocation problem as a sequential bargaining model, and makes it practical for real network operations.
- To implement the meta bargaining game, we have focused on traditional bargaining solutions such as Nash, and Kalai-Smorodinsky bargaining solutions. To achieve a compromise result, individual bargaining solutions work together and act cooperatively with each other.
- For the implementation practicality, we develop a step-by-step interactive process. This mechanism can significantly reduce computational complexity. Therefore, it is implemented with polynomial complexity. For realistic system operations, it is an important feature.
- By comparing the existing protocols, we provide a comprehensive simulation analysis. Simulation results show that our approach can strike an appropriate performance fairly and efficiently. In particular, the effectiveness of our proposed approach has been addressed by using the performance metrics such as normalized user payoff, system throughput, and fairness.

B. ORGANIZATION

The rest of this paper is organized as follows. In Section II, we review some of the most relevant research articles that have drawn our attention. In Section III, the D2D multicasting cellular infrastructure is introduced, and we briefly present the basic ideas of different bargaining solutions to implement our spectrum allocation scheme. And then, we provide our bargaining model and the primary steps of the proposed algorithm. Section IV presents the extensive simulation results. Through the performance comparison between our proposed scheme and existing state-of-the-art protocols, numerical results together with their analyses are demonstrated. Finally, some conclusions, key findings of this study, and future research directions are summarized in Section V.

II. RELATED WORK

In 5G networks, D2D multicast platform has become one of the irresistible trends. Over the years, many researches have been devoted to develop a lot of state-of-the-art work on the D2D multicasting system. In [1], authors have investigated the resource allocation problem for D2D communications underlaying cellular network. Reference [2] has considered the spectrum sharing problem between multiple D2D links and a cellular network with multiple operators. Liu *et al.* study the downlink channel allocation in D2D-assisted small cell networks with heterogeneous spectrum bands [3]. The authors in [4] propose a new joint channel and power allocation algorithm to maximize the network achievable throughput, control the interference, and improve the energy efficiency of the user devices. A. Bhardwaj et al study the tradeoff between spectral efficiency and energy efficiency in a single cell D2D integrated cellular network, where multiple D2D multicast groups may share the uplink channel with multiple cellular users [6]. Reference [7] formulates a novel user clustering problem for a D2D multicast content sharing scenario, which aims to maximize the energy efficiency of the whole network. Even though these schemes [1]–[4], [6], [7] have been designed to control the spectrum allocation problem in wireless networks, it is difficult to fairly compare the performance result with the proposed scheme. These schemes are designed for specific network environments, and focus on theoretical analysis.

In [5], the *Stackelberg Game based Resource Allocation* (*SGRA*) scheme is proposed to efficiently allocate the spectrum resource while enhancing the content sharing via D2D multicast. This scheme investigates the resource allocation for D2D video multicast, and formulates the distributed channel and power allocation problem as a multi-leader multi-follower Stackelberg game. Based on the developed Stackelberg game, a multi-agent hierarchical learning algorithm is proposed to optimize the resource allocation of the entire network, which can improve the throughput of the network. Finally, the performance of *SGRA* scheme is validated by comparing to other three existing algorithms through simulation results [5].

The *Revenue Maximizing Resource Allocation* (*RMRA*) scheme [10] considers the problem of revenue maximization of the network operator when users have different data request rates, profit, and channel quality. In this study, D2D multicast users may demand the multicast data at various rates. Therefore, they may have different channel qualities from the BS, which will also affect the data rates. To address the objective of maximizing the operator's profit, the *RMRA* scheme proposes a greedy heuristic and two approximation algorithms. The proposed greedy heuristic algorithm addresses the second objective of maximizing the number of satisfied users, and the proposed two approximation algorithms assign the spectrum resource by considering all possible channel quality combinations to the users. Through simulation analysis, the performance superiority of the *RMRA* scheme is confirmed by comparing to the baseline algorithms [10].

The *Social-Aware Resource Allocation* (*SARA*) scheme [11] is a new social-aware resource allocation framework for 5G D2D multicast communications. The *SARA* scheme mainly consists of two algorithms; i) the D2D cluster formation algorithm, and ii) the power and channel jointly optimization algorithm. In the D2D cluster formation algorithm, members and head in each cluster are selected by taking into account both social attributes and physical factors, such as community, ties, and geographical closeness. In the power and channel jointly optimization algorithm, a two-step process is designed. At the first step, the optimal power allocation is calculated by geometric proximity. At the second step, suitable cellular channels are selected for each D2D multicast cluster by using the Hungarian algorithm [11].

Different from existing work, we mainly focus on the spectrum resource allocation problem for D2D multicast communications. The *SGRA*, *RMRA* and *SARA* schemes have introduced unique challenges to efficiently solve the spectrum allocation problem in the D2D multicast platform. Recently, they have attracted lots of attention due to their various advantages. Compared to these existing *SGRA*, *RMRA* and *SARA* schemes [5], [10], [11], we demonstrate that the proposed scheme attains a better performance during the D2D multicasting operations.

III. THE D2D MULTICASTING SPECTRUM ALLOCATION SCHEME

In this section, we first introduce the D2D multicasting infrastructure layout, and the main ideas of different bargaining solutions are explained concisely. And then, our two-phase bargaining game model is formulated. Finally, we develop a new spectrum allocation scheme, which can improve the effectiveness of D2D multicasting system.

A. THE D2D MULTICASTING SYSTEM INFRASTRUCTURE

This work tackles the spectrum allocation problem for an D2D multicasting enabled cellular network. We consider a classic D2D cellular system which consists of a cellular base station (BS) and multiple cellular users (CUs) labeled as $\mathcal{Q}^{BS} = \{\mathcal{S}_1, \mathcal{S}_2, \ldots, \mathcal{S}_n\}$. CUs opportunistically access the spectrum resource of the cellular network. It is common that a specific hot content is bound to attract the interest of multiple users. To improve the spectral efficiency while easing the burden of the BS, CUs cooperate to form a cluster for the content sharing. Within each cluster, one CU, denoted as the cluster header (CH), caches the target contents from the BS, and then delivers them to other CUs, regarded as the content requesters (CRs), in its corresponding cluster. Simply, we assume that CRs are no overlap between clusters, and will not leave their current cluster until the content sharing is completed. It is not necessary that all the CUs find their favorite clusters. The CUs who are out of the clusters will connect the BS directly in the traditional cellular mode; they are denoted as DCUs [12].

Without loss of generality, there exist clusters labeled as $\mathbb{C} = \{\mathcal{C}_1, \mathcal{C}_2, \ldots, \mathcal{C}_m\}$ where $m \ll n$. In the $\mathcal{C}_{1 \le i \le m}$, one CH and multiple CRs. Fig.1 gives a typical D2D multicast content sharing scenario, where three clusters, i.e., $\mathcal{C}_1, \mathcal{C}_2, \mathcal{C}_3$, are formed, and $\mathcal{S}_3$, $\mathcal{S}_5$ and $\mathcal{S}_8$ are the CHs, respectively. Taking $\mathcal{C}_1$ as an example, $\mathcal{S}_3$ firstly receives the content from the BS via cellular spectrum resource, and then shares it with $\mathcal{S}_1$ and $\mathcal{S}_2$ simultaneously. Since the content sharing is also based on wireless transmissions, the spectrum resource should be assigned to avoid the mutual interference between the two communication types [12].

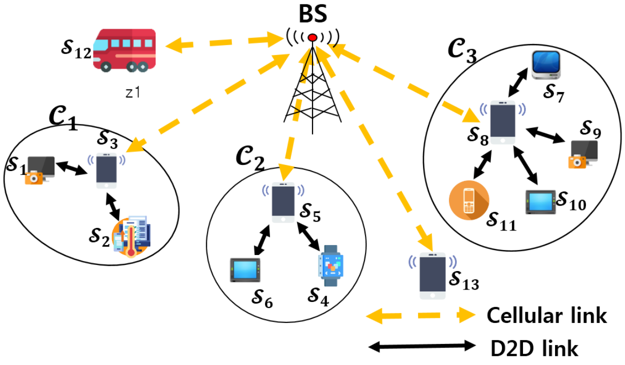


FIGURE 1. **D2D multicasting system infrastructure.**

Within this interference environment, this study aims to properly and accurately allocate the cellular spectrum resource while maximizing the throughput of D2D multicasting system. To satisfy this goal, the main challenge of BS is how to distribute its spectrum resource among CHs and DCUs. From the viewpoint of CHs, the major concern is how to share the allocated spectrum resource for the D2D multicasting service. In this study, we adopt the basic idea of weighted utilitarian bargaining solution for the BS spectrum distribution problem. For the CH resource sharing problem, the meta bargaining solution is applied to split the assigned spectrum into two parts; one is for the direct communication with the BS, and the other is for the D2D multicasting service.

In order to guarantee the advantages of D2D multicast content sharing, the key is to provide a reasonable user clustering method. The clustering method consists of two parts; i) the CH selection and ii) CR grouping. Initially, each individual CU locally broadcasts a *join-request* message notifying its neighboring CUs while checking whether they are interested in one common content to be shared. The nearby CUs within listening range can receive the *join-request* message. If they want to participate in the clustering, they respond to send a *join-acceptance* message back to the sending CU. In an entirely distributed online fashion, each individual CU can monitor the number of available CRs, i.e., $\mathcal{N}^{CR}$, for its own cluster, and reports this information to the BS. At this moment, the BS selects the CU with the highest $\mathcal{N}^{CR}$ number as the CH, and the first cluster is formed. With the remaining CUs, who are not included in the currently generating cluster, this clustering process is repeated sequentially until all the possible clusters are configured.

B. BARGAINING SOLUTIONS FOR COOPERATIVE GAME MODELS

In 1950, J. Nash introduced the axiomatic approach to the analysis of bargaining problems. And then, his approach has been enriched in different ways. Due to the multiplicity of reasonable criteria, there are a number of cooperative bargaining solution concepts such as Nash solution, Kalai-Smordinsky solution, weighted utilitarian solution, etc. Therefore, many diverse bargaining solutions have appeared and been axiomatically analyzed [13]. In this study, we introduce the notation and basic definitions of bargaining solution. Usually, bargaining games $(\boldsymbol{S}, d)$ consist of a set of feasible utility allocations over the set of feasible agreements, $\boldsymbol{S}$, and the outcome which would result in case of disagreement point, d. The points in $\boldsymbol{S}$ represent the feasible utility levels that the individuals can reach if they agree [14]. Otherwise, if agreement is not reached, they obtain the utility levels given by the disagreement point. Simply, a two-person bargaining game is a tuple $(\boldsymbol{S}, d)$ where $\boldsymbol{S} \subseteq \mathbb{R}^2$. Let $\boldsymbol{x}, \boldsymbol{y} \in \mathbb{R}^2$, $\boldsymbol{x} \ge \boldsymbol{y}$ means $x_i \ge y_i$ and $\boldsymbol{x} \ne \boldsymbol{y}$. On the other hand, $\boldsymbol{x} > \boldsymbol{y}$ means $x_i > y_i$ for all $i = 1, 2$. $u(\boldsymbol{S}, d)$ is defined by $u_1(\boldsymbol{S}, d) := \max\left\{x_1 \ge d_1 | \exists_{x_2} \ge d_2 : (x_1, x_2) \in \boldsymbol{S}\right\}$ and $u_2(\boldsymbol{S}, d) := \max\left\{x_2 \ge d_2 | \exists_{x_1} \ge d_1 : (x_1, x_2) \in \boldsymbol{S}\right\}$. Let Σ denote an arbitrary set of games, and a bargaining solution on Σ is a function $f : \Sigma \to \mathbb{R}^2$ such that $f(\boldsymbol{S}, d) \in \boldsymbol{S}$ holds for all $(\boldsymbol{S}, d) \in \Sigma$. $\mathcal{F}$ denotes an arbitrary set of admissible solutions on Σ [14].

Some well-known bargaining solutions contained in F are Nash bargaining solution (*NBS*), Kalai-Smorodinsky bargaining solution (*KSBS*), and weighted utilitarian bargaining solution (*WUBS*). The axiom commonly involved in the characterization of all bargaining solutions is *Pareto Optimal* (***PO***): if $\forall (\boldsymbol{S}, d) \in \Sigma$, then $f(\boldsymbol{S}, d) \in \boldsymbol{PO}(\boldsymbol{S})$ where $\boldsymbol{PO}(\boldsymbol{S}) \equiv \{\boldsymbol{x} \in \boldsymbol{S} | \forall \boldsymbol{x}' \in \mathbb{R}^2, \boldsymbol{x}' \ge \boldsymbol{x} \Rightarrow \boldsymbol{x}' \notin \boldsymbol{S}\}$ [8], [14], [15]. For a simple two-person bargaining model, the *NBS*, *KSBS*, and *WUBS* are mathematically formulated as follows;

- The *NBS* f^{NBS} is defined by [14];

$$f^{NBS}(S, d) = \begin{cases} \arg \mathbf{max}\left\{\prod_{i=1}^{2}(x_i - d_i) \,|x \in \boldsymbol{S}_{\ge d}\right\}, & \text{if } d \notin \boldsymbol{WPO}(\boldsymbol{S}) \\ \bar{x} \in \boldsymbol{PO}\left(\boldsymbol{S}_{\ge d}\right), & \text{otherwise, i.e., } d \in \boldsymbol{WPO}(\boldsymbol{S}) \end{cases} \quad (1)$$

where $\boldsymbol{S}_{\geq d} = \{x \in \boldsymbol{S} | x \geq d\}$. To simplify notation we define $\boldsymbol{S}_{+} = \boldsymbol{S}_{\geq 0}$. Let $\boldsymbol{WPO}(\boldsymbol{S}) = \{x \in A | \{y \in A | y > x\} = \emptyset\}$ denote the set of *weakly Pareto-optimal* allocation.

- The *KSBS* f^{KSBS} is defined by [14];

$$f^{KSBS}(\boldsymbol{S}, d) = \begin{cases} x \in \boldsymbol{PO}(\boldsymbol{S}) \cap \boldsymbol{cvh}(\{d, u(\boldsymbol{S}, d)\}), & \text{if } d \notin \boldsymbol{WPO}(\boldsymbol{S}) \\ x \in \boldsymbol{PO}(\boldsymbol{S}_{\geq d}), & \text{otherwise, i.e., } d \in \boldsymbol{WPO}(\boldsymbol{S}) \end{cases} \quad (2)$$

where $\boldsymbol{cvh}(u(\boldsymbol{S}, d)) := \{x \in \mathbb{R}^2 | x = \lambda a + (1-\lambda) b, \lambda \in [0,1], a, b \in u(\boldsymbol{S}, d)\}$ denotes the convex hull of $u(\boldsymbol{S}, d)$.

- The *WUBS* f^{WUBS} is defined by [15]

$$f^{WUBS}(\boldsymbol{S}, d) = x \in \mathbf{max} \sum_{i=1}^{2} (\omega_i \times x_i), \quad \text{s.t., } (x_1, x_2) \in \boldsymbol{S} \text{ and } x \in \boldsymbol{PO}(\boldsymbol{S}) \quad (3)$$

where $(\omega_1, \omega_2) \in \mathbb{R}_{+}^{2}$ is a pair of weighting factors for two players. It is apparent that the *WUBS* is the one that maximizes the sum of the utility gains and it is *Pareto-optimal* with respect to the reported utilities. However, a weight pair (ω_1, ω_2) should be assigned to the utility scales of the two players, and then we would be maximizing the weighted sum of the utilities [15]. The question of how to determine these weights will be addressed later.

When game players want to adopt the same solution concept, then they obtain the utility levels given by it. However, if they want to apply different bargaining solutions and they do not coincide, problems arise. To resolve such a conflict, a new bargaining solution, called meta bargaining solution (MBS), was proposed. The basic idea of MBS can be understood as modeling a step-by-step bargaining procedure. For players who are involved in a conflict, the MBS selects the midpoint of the line connecting the allocations corresponding to their own bargaining solutions. If the midpoint is in the interior of the set of all possible utility allocations, it will be taken as a new disagreement point [14]. In other words, the iterative procedure of MBS improves the d while satisfying the *Midpoint Domination* property, which requires that all players get at least as much as the average of their preferred allocations. This procedure will be repeated until a *weakly Pareto-optimal* allocation is reached [14]. As the iteration continues, the outcome of MBS converges to a fair-efficient allocation. To sum up, the MBS can be analyzed from a cooperative or non-cooperative point of view. In the cooperative view, properties about fair compromises are formulated and functions, which are compatible with these properties, are developed. In the non-cooperative view, game players can choose bargaining solutions as strategies and the payoff is determined through the outcome of the step-by-step interactive process. In the MBS, the non-cooperative approach is supplemented by cooperative considerations [13]–[17].

In the MBS, each player is assumed to have an intuitive idea about which point to select in every game. This assumption can be formalized as the players always want to apply a certain bargaining solution. In a simple two-player MBS model, it is denoted as $[(\boldsymbol{S}, d); f, g]$ where $(\boldsymbol{S} \subseteq \mathbb{R}^2, d)$ is a game and f and g are bargaining solutions supported by the player 1 and player 2, respectively [14]. Formally, $\Sigma_{\mathcal{F}} := \{[(\boldsymbol{S}, d); f, g] | (\boldsymbol{S}, d) \in \Sigma, f, g \in \mathcal{F}\}$ denotes the class of meta games induced by Σ and $\mathcal{F}$. Given a set $\Sigma_{\mathcal{F}}$ of meta games, a mechanism $\mathfrak{M}$ is a function $\mathfrak{M} : \Sigma_{\mathcal{F}} \rightarrow \mathbb{R}^2$, $[(\boldsymbol{S}, d); f, g] \mapsto \mathfrak{M}[(\boldsymbol{S}, d); f, g] \in \boldsymbol{S}$, which assigns every meta game $[(\boldsymbol{S}, d); f, g]$ to an allocation in $\Sigma_{\mathcal{F}}$. Mathematically, the MBS mechanism $\mathfrak{M}[(\boldsymbol{S}, d); f, g]$, i.e., $\mathfrak{M} : \Sigma_{\mathcal{F}} \rightarrow \mathbb{R}^2$, is defined as follows, and Fig.2 shows the MBS graphically [14], [17];

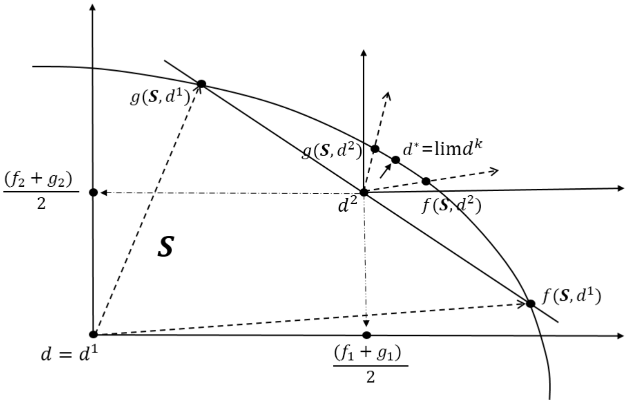


FIGURE 2. **Meta bargaining solution for two-player cooperative game.**

$$\mathfrak{M}[(\boldsymbol{S}, d); f, g] := \lim_{t\rightarrow\infty} d^t \quad \text{s.t.,} \begin{cases} d^1 := d, & \text{if } t = 1 \\ d^t := \frac{1}{2}\left(f\left(\boldsymbol{S}, d^{t-1}\right) + g\left(\boldsymbol{S}, d^{t-1}\right)\right), \\ \quad \text{otherwise } (t > 1) \end{cases} \quad (4)$$

Analogously to bargaining theory, we can formulate some reasonable and desirable properties for the MBS. With some classical properties for bargaining solutions, the MBS has new kind of properties which capture a notion of meta-fairness and meta-equity to treat game players [14]. Given an admissible family of bargaining solutions $\mathcal{F}$, a meta bargaining mechanism on $\mathcal{F}$ is a single valued function $\Phi(f, g) = \Phi_{fg} \in \mathcal{F}$ where $\Phi : \mathcal{F} \times \mathcal{F} \rightarrow \mathcal{F}$ and $f, g \in \mathcal{F}$. MBS $\Phi : \mathcal{F} \times \mathcal{F} \rightarrow \mathcal{F}$ satisfies the axioms of *Pareto Optimal* (***PO***), *Monotonicity* (***Mon***), *Impartiality* (***Im***), *Generalized Midpoint Domination* (***GMD***) and *Step-by-step Bargaining* (***STEP***). In summary, ***Im*** axiom is satisfied if all opinions should be taken into account equally, regardless of whose opinion it is. When a minimal amount of cooperation should enable the agents to reach at least the average of their preferred outcomes, ***GMD*** axiom is satisfied. ***STEP*** axiom is satisfied if the mechanism is invariant under a certain decomposition [13], [14].

- ***PO***: if $\forall (\boldsymbol{S}, d) \in \Sigma$, then $f(\boldsymbol{S}, d) \in \boldsymbol{PO}(\boldsymbol{S})$ where $\boldsymbol{PO}(\boldsymbol{S}) \equiv \{\boldsymbol{x} \in \boldsymbol{S} | \forall \boldsymbol{x}' \in \mathbb{R}^2, \boldsymbol{x}' \geq \boldsymbol{x} \Rightarrow \boldsymbol{x}' \notin \boldsymbol{S}\}$

- ***Mon***: for all f, h bargaining solutions such that $f_1 \geq h_1$, then $\left(\Phi_{fg}\right)_1 \geq \left(\Phi_{hg}\right)_1$ for all g, and symmetrically, for all g, h bargaining solutions such that $g_2 \geq h_2$, then $\left(\Phi_{fg}\right)_2 \geq \left(\Phi_{fh}\right)_2$ for all f
- ***Im***: for each $f, g \in \mathcal{F}$, and all $(\boldsymbol{S}, d) \in \Sigma^2$, then $\Phi_{fg}(\boldsymbol{S}, d) = \Phi_{gf}(\boldsymbol{S}, d)$.
- ***GMD***: for each $f, g \in \mathcal{F}$, and all $(\boldsymbol{S}, d) \in \Sigma^2$, then $\Phi_{fg}(\boldsymbol{S}, d) \geq \left(\left(\frac{1}{2} \times f(\boldsymbol{S}, d)\right) + \left(\frac{1}{2} \times g(\boldsymbol{S}, d)\right)\right)$.
- ***STEP***: for each $f, g \in \mathcal{F}$, and all $(\boldsymbol{S}, d) \in \Sigma^2$, such that there is $\boldsymbol{T} \subseteq \boldsymbol{S}$ satisfying $(\boldsymbol{T}, d) \in \Sigma^2, f(\boldsymbol{S}, d) = f(\boldsymbol{T}, d)$, $g(\boldsymbol{S}, d) = g(\boldsymbol{T}, d)$ and the segment joining $f(\boldsymbol{T}, d)$ and $g(\boldsymbol{T}, d)$, belongs to $\boldsymbol{PO}(\boldsymbol{T})$, $[f(\boldsymbol{T}, d), g(\boldsymbol{T}, d)] \subseteq \boldsymbol{PO}(\boldsymbol{T})$, then $\Phi_{fg}(\boldsymbol{S}, d) = \Phi_{fg}\left(\boldsymbol{S}, \Phi_{fg}(\boldsymbol{T}, d)\right)$.

C. THE PROPOSED D2D MULTICASTING SPECTRUM ALLOCATION SCHEME

In the D2D multicasting system, the BS needs to share its spectrum resource among CUs. The utility payoff obtained by the BS depends on the total traffic services for CUs. Therefore, the BS's payoff is directly proportional to a fraction of the allocated spectrum and the number of CUs. To quantify the BS service satisfaction, the BS's payoff $\left(\mathbb{U}^{BS}(\mathfrak{P})\right)$ with the resource allocation strategy vector $\mathfrak{P} = \left[\ldots, \mathfrak{P}_{S_i}^{BS}, \ldots\right]$ can be derived as follows.

$$\mathbb{U}^{BS}(\mathfrak{P}) = \sum_{\mathcal{S}_i \in \mathcal{Q}^{BS}} \mathcal{U}^{\mathcal{S}_i}\left(\mathfrak{P}_{S_i}^{BS}\right),$$
$$\text{s.t.,} \begin{cases} \mathcal{U}^{\mathcal{S}_i}\left(\mathfrak{P}_{S_i}^{BS}\right) = \alpha \\ \quad \times \log\left(\dfrac{\mathbf{min}\left\{(\mathfrak{N}_M \times \gamma), \mathbf{max}\left\{0, \mathfrak{P}_{S_i}^{BS} - (\mathcal{R}_m \times \mu)\right\}\right\}}{\mathcal{R}_m} + \chi\right) \\ \quad + \eta, \quad \text{if } \mathcal{S}_i \textit{ is } \text{CH} \\ \mathcal{U}^{\mathcal{S}_i}\left(\mathfrak{P}_{\mathcal{S}_i}^{BS}\right) = \\ \log\left(\dfrac{\mathbf{min}\left\{\mathfrak{N}_M, \mathbf{max}\left\{0, \mathfrak{P}_{S_i}^{BS} - \mathcal{R}_m\right\}\right\}}{\mathcal{R}_m} + \chi\right) \\ \quad + \eta, \quad \text{if } \mathcal{S}_i \textit{ is } \text{DCU} \end{cases} \tag{5}$$

where α is the number of CRs of its cluster, and $\boldsymbol{\chi}$, η are control parameter for the $\mathcal{U}^{\mathcal{S}_i}(\cdot)$. γ and μ are spectrum adjustment factors for the D2D multicasting service. $\mathfrak{N}_M$, R_m are the maximum and minimum spectrum requirements, respectively, for the requested service. For the CU spectrum assignment problem, the main concern of BS is the maximization of total system utilitarianism. Due to the characteristics of D2D multicasting, we emphasize the role of CHs. Therefore, the basic idea of *WUBS* is adopted to solve the BS's spectrum assignment problem, and the α value is considered as a weight factor for its corresponding CH. Finally, the *WUBS* for the BS, i.e., $WUBS_{BS}(\mathfrak{P})$, is defined as follows;

$$WUBS_{BS}(\mathfrak{P}) = \max_{\mathfrak{P} = [\ldots, \mathfrak{P}_{S_i}^{BS}, \ldots]} \sum_{\mathcal{S}_i \in \mathcal{Q}^{BS}} \mathcal{U}^{\mathcal{S}_i}\left(\mathfrak{P}_{\mathcal{S}_i}^{BS}\right),$$
$$\text{s.t., } \mathbb{C} = \sum_{\mathcal{S}_i \in \mathrm{Q}^{BS}} \mathfrak{P}_{\mathcal{S}_i}^{BS} \tag{6}$$

where $\mathbb{C}$ is the total spectrum capacity of BS. In the viewpoint of CH, the main problem is how to share the assigned spectrum bandwidth $\left(\mathfrak{P}_{\mathcal{S}}^{BS}\right)$ between the direct communication to the BS, i.e., DC, and the multicasting among CRs, i.e., MC. In the proposed scheme, we assume the communication types, i.e., DC and MC, are game players, and they negotiate the spectrum sharing for their services. In the viewpoint of DC, the axiom, *Independence of irrelevant alternatives*, is preferred to share the assigned spectrum resource. It means that a reasonable outcome will be feasible after some payoff sets have been removed. Therefore, the NBS is suitable to get a desirable resource allocation solution for the DC. However, the MC may favor the axiom, *Individual monotonicity*. It means that the increasing of bargaining set size ($\boldsymbol{S}$) in a direction favorable to a specific player always benefits that player. Therefore, the KSBS is preferred by the MC. To solve the conflict arising from their own bargaining solutions, we adopt the MBS to reach a final outcome as follows;

$$\mathfrak{M}[(\boldsymbol{S}, d); f, g]$$
$$:= \lim_{\substack{t \to \infty \\ if\, |d^t - d^{t-1}| > \Delta}} d^t$$
$$\text{s.t.,} \begin{cases} d^t := \dfrac{1}{2}\left(f^{NBS}\left(\boldsymbol{S}, d^{t-1}\right) + f^{KSBS}\left(\boldsymbol{S}, d^{t-1}\right)\right), \\ \quad \text{if } t > 1 \\ d^1 := (0, 0), \quad \text{otherwise } (t = 1) \end{cases} \tag{7}$$

To obtain the $f^{NBS}\left(\boldsymbol{S}, d^{t-1}\right)$ and $f^{KSBS}\left(\boldsymbol{S}, d^{t-1}\right)$, we should define $x = (x_1, x_2)$ for game players. For the DC in the $\mathcal{S}_i$, who is the CH, the payoff value x_1 with the resource allocation strategy $\mathfrak{M}_{\mathcal{S}_i}^{DC}$ is defined through the following utility function;

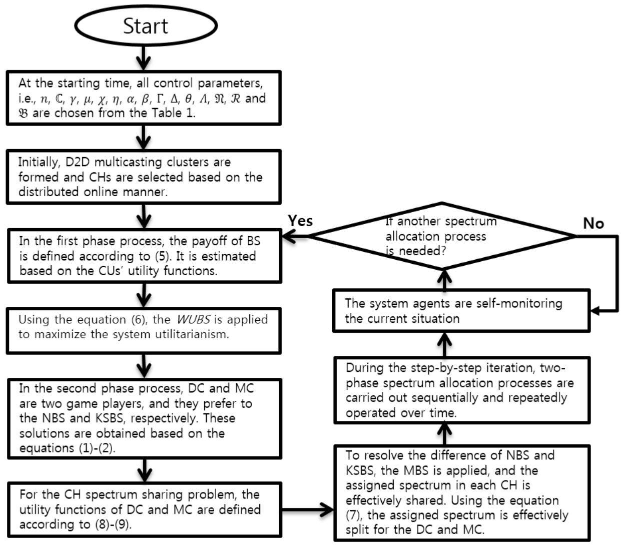
$$x_1 = U_{DC}\left(\mathfrak{M}_{\mathcal{S}_i}^{DC}\right)$$
$$= \left(\frac{1}{1 + exp\left(-\left(\mathbf{min}\left\{\mathfrak{N}_M, \mathfrak{M}_{\mathcal{S}_i}^{DC}\right\} \times \frac{\beta}{\mathcal{R}_m}\right)\right)}\right) + \Gamma,$$
$$\text{s.t., } \mathfrak{M}_{\mathcal{S}_i}^{DC} \leq \mathfrak{P}_{\mathcal{S}_i}^{BS} \tag{8}$$

where β, Γ are control parameters for the DC's payoff. For the MC in the $\mathcal{S}_i$, the payoff value x_2 with the resource allocation strategy $\mathfrak{M}_{\mathcal{S}_i}^{MC}$ is defined as follows;

$$x_2 = U_{MC}\left(\mathfrak{M}_{\mathcal{S}_i}^{MC}\right)$$
$$= \left(\frac{1}{1 + exp\left(-\left(\mathcal{T}^{MC} \times \frac{\beta}{\mathcal{R}_m} \times \Theta\left(\mathfrak{B}_{\mathcal{S}_i}^{C}, \mathfrak{B}_{\mathcal{S}_i}^{E}\right)\right)\right)}\right) + \Gamma,$$
$$\text{s.t.,} \begin{cases} \mathcal{T}^{MC} = \mathbf{min}\left\{(\mathfrak{N}_M \times \mu), \mathfrak{M}_{\mathcal{S}_i}^{MC}\right\} \\ \Theta\left(\mathfrak{B}_{\mathcal{S}_i}^{C}, \mathfrak{B}_{\mathcal{S}_i}^{E}\right) = \theta - \left(\dfrac{\mathfrak{B}_{\mathcal{S}_i}^{C} - \mathfrak{B}_{\mathcal{S}_i}^{E}}{\mathfrak{B}_{\mathcal{S}_i}^{E}}\right) \\ \mathfrak{M}_{\mathcal{S}_i}^{MC} = \mathfrak{P}_{\mathcal{S}_i}^{BS} - \mathfrak{M}_{\mathcal{S}_i}^{DC} \end{cases} \tag{9}$$

where $\mathfrak{B}^{C}_{\mathcal{S}_i}$, $\mathfrak{B}^{E}_{\mathcal{S}_i}$ are current buffering, and desirable buffering amounts, respectively. θ is a calibrating constant for buffering.

The proposed two-phase bargaining game process is hierarchically repeated to approximate a fine solution through a step-by-step approach. Every time period, the BS and CHs periodically re-evaluate the current strategy in a distributed online fashion. Therefore, they have a chance to reconsider their current solution and adaptively react to maximize the expected payoff. The main steps of the proposed scheme can be described as follows, and they are described by the following flowchart:



Flowchart 1. Flowchart of the proposed algorithm.

Step 1: The values of main parameters and system factors can be discovered in Table 1, and the simulation scenario is given in Section IV. Initially, D2D multicasting clusters are formed and CHs are selected based on the distributed online manner.

Step 2: To solve the spectrum allocation problem for the D2D multicasting system, two-phase bargaining process is triggered at each time period. At the first phase, the spectrum allocation process is performed by the BS.

Step 3: According to (5), the payoff of BS is defined based on the CUs' utility functions. The BS's payoff is adjusted by its spectrum allocation strategies, i.e., $\mathfrak{P} = \left[\ldots, \mathfrak{P}^{BS}_{\mathcal{S}_i}, \ldots\right]$.

Step 4: To maximize the system utilitarianism, the *WUBS* is applied to find the strategies $\mathfrak{P}^{BS}_{\mathcal{S}_{1\leq i\leq n}}$. Using the equation (6), strategies are selected adaptively.

Step 5: At the second phase, each individual CH has two game players; DC and MC. The utility functions of DC and MC are defined according to (8)-(9), and their payoffs are adjusted by the spectrum assignment strategies, i.e., $(\mathfrak{M}^{DC}_{\mathcal{S}}, \mathfrak{M}^{MC}_{\mathcal{S}})$.

TABLE 1. System parameters used in the simulation experiments.

Parameter	Value	Description
n	500	the number of CUs
$\mathbb{C}$	100 Gigabyte	total spectrum capacity in each BS
γ, μ	3 , 2	spectrum adjustment factors for the D2D multicasting service
χ, η	1 , 1	control parameters for the $\mathcal{U}^{\mathcal{S}_i}(\cdot)$
α	$1 \leq \alpha \leq \lvert \mathcal{Q}^{BS} \rvert$	the number of CRs of its cluster
β, Γ	5, 0.5	control parameters for the DC's payoff
Δ	(0.05 , 0.05)	pre-defined minimum bound for the MBS negotiation
θ	1	a calibrating constant for buffering
BSU	512 Kbps	one basic spectrum unit for spectrum allocation process
Λ	2 sec	service delay for the CH's D2D multicasting

Service Type	Spectrum Requirement	Minimum Requirement	Desirable Buffering Size	Connection Duration (average/s)
Class I	$\mathfrak{N}_M = 25$ Mbps	$\mathcal{R}_m = 12$ Mbps	$\mathfrak{B}^{\mathcal{E}}_{\mathcal{S}} = 36$ MB	180 sec (3 min)
Class II	$\mathfrak{N}_M = 20$ Mbps	$\mathcal{R}_m = 10$ Mbps	$\mathfrak{B}^{\mathcal{E}}_{\mathcal{S}} = 30$ MB	90 sec (1.5 min)
Class III	$\mathfrak{N}_M = 15$ Mbps	$\mathcal{R}_m = 8$ Mbps	$\mathfrak{B}^{\mathcal{E}}_{\mathcal{S}} = 24$ MB	30 sec (0.5 min)
Class IV	$\mathfrak{N}_M = 10$ Mbps	$\mathcal{R}_m = 5$ Mbps	$\mathfrak{B}^{\mathcal{E}}_{\mathcal{S}} = 15$ MB	60 sec (1 min)
Class V	$\mathfrak{N}_M = 35$ Mbps	$\mathcal{R}_m = 18$ Mbps	$\mathfrak{B}^{\mathcal{E}}_{\mathcal{S}} = 54$ MB	120 sec (2 min)
Class VI	$\mathfrak{N}_M = 30$ Mbps	$\mathcal{R}_m = 15$ Mbps	$\mathfrak{B}^{\mathcal{E}}_{\mathcal{S}} = 45$ MB	15 sec (0.25 min)

Step 6: For the CH spectrum sharing problem, the DC and MC prefer to the NBS and KSBS, respectively. These solutions are obtained based on the equations (1)-(2).

Step 7: To resolve the difference of NBS and KSBS, the MBS is applied. Finally, the assigned spectrum in each CH is effectively shared. Using the equation (7), the assigned spectrum is effectively split for the DC and MC.

Step 8: During the step-by-step iteration, two-phase spectrum allocation processes are carried out sequentially and repeatedly operated over time. This interactive mechanism can effectively adapt the current D2D multicasting system conditions.

Step 9: Constantly, the system agents are self-monitoring the current situation, and proceed to Step 2 for the next two-phase spectrum allocation process.

IV. PERFORMANCE EVALUATION

In this section, the performance of our proposed spectrum allocation scheme is evaluated by simulations, and it is compared with other existing protocols to confirm the superiority of our approach.

A. SIMULATION ANALYSIS

To develop our simulation model, we have used the simulation language 'MATLAB'. MATLAB's high-level syntax and dynamic types are ideal for model prototyping, and it is widely used in academic and research institutions as well as industrial enterprises. As mentioned in the Section II, we select the *SGRA*, *RMRA* and *SARA* schemes [5], [10], [11]; these existing protocols are recently published novel spectrum allocation schemes for the D2D multicasting platform. The assumptions of our simulation environment are as follows:

- The simulated D2D multicasting system consists of sixteen BSs and five hundred CUs.
- Based on the dedicated spectrum resource, we assume the overlay mode for D2D communications.
- The 500 CUs are distributed randomly over an area of 1000 × 1000 meter square area, and 16 BSs are regularly positioned as a grid in the cellular area.
- Each BS can cover its corresponding CUs over its area of 250 × 250 meter square area, and the diameter of each individual CH's coverage area is 90 meter.
- The process for service request generations is Poisson with rate λ (services/s), and the range of offered service load was varied from 0 to 3.0.
- Six different service types are assumed. They are selected randomly, and CUs with the same service type can form a cluster for the D2D multicasting.
- Each CH starts its D2D multicasting service with the service delay (Λ). During this delay, CHs can buffer its service contents.
- The total spectrum capacity ($\mathbb{C}$) in each BC is 100 Gigabyte. To reduce computation complexity, the amount of spectrum allocation is specified in terms of basic spectrum units (BSUs), where one BSU is the minimum amount (e.g., 512 Kbps in our system) of spectrum adjustment.
- System performance measures obtained on the basis of 100 simulation runs are plotted as a function of the offered service request load.
- Performance measures obtained are system throughput, normalized CU's payoff, and fairness among users in the D2D multicasting system.

Fig.3 shows the performance comparison of each scheme in terms of the normalized cellular user's payoff. From the viewpoint of end users, the user's payoff is the most important performance criterion; usually, the user's payoff and satisfaction are strongly related. In Fig.3, we can see that the user's payoff increases as the offered number of service request rate increases. It is intuitively correct. Under the higher service requirement situations, our two-phase bargaining approach can effectively share the limited spectrum resource. It can lead to greater user's satisfaction, resulting in greater user's payoff, while adapting the current D2D multicasting system environment.

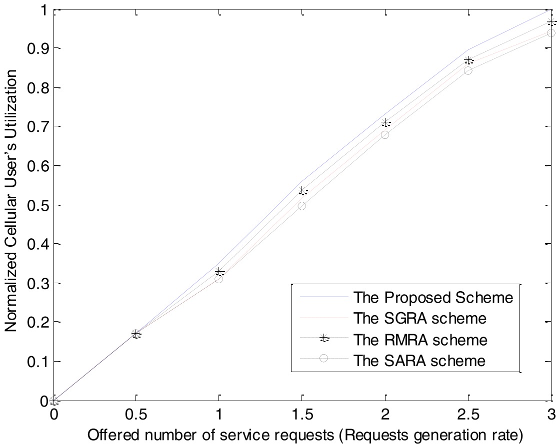


Figure 3. **Normalized cellular user's payoff.**

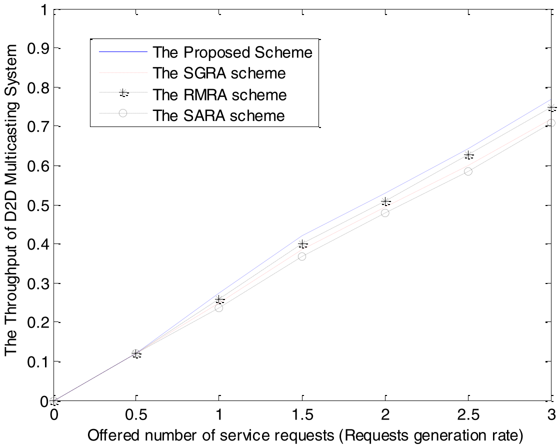


Figure 4. **Throughput of D2D multicasting system.**

Fig.4 represents the throughput of D2D multicasting system of our scheme and the existing *SGRA*, *RMRA* and *SARA* schemes. In this study, the throughput is a measure of how many services are successfully completed. The performance trend showing in Fig.4 are very similar to the curves in Fig.3. In general, the higher system throughput can be obtained based on the higher user's payoff. Under different service request intensities, our proposed scheme is comparatively better than the existing protocols. This is due to the adaptability and flexibility of our protocol, which can effectively handle the spectrum allocation problem while adaptively responding to the current system situations.

Fig.5 plots the fairness among CUs in the D2D multicasting system. When the service request rate is low (below 0.25), the fairness indexes of the four schemes are identical. This is because all four schemes have enough spectrum resource to accept the all requests. Therefore, there is no noticeable difference. As the service requests increases, our proposed scheme is comparatively better than the existing protocols. For the D2D multicasting, our meta bargaining approach effectively compromises the contrasting viewpoints of CHs and CRs. According to the step-by-step sequential decision

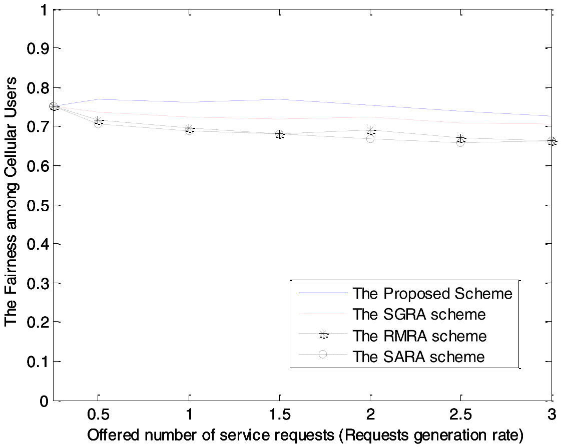


Figure 5. **The fairness among cellular users.**

making mechanism, we can provide the most proper combination of the different fair issues between NBS and KSBS, and efficiently share the limited spectrum resource. Therefore, our proposed scheme can maintain a higher fairness among CUs than the existing schemes.

B. RESULTS DISCUSSION

The simulation analysis shown in Figs.3 to 5 illustrates that our two-phase bargaining based scheme can attain an appropriate performance balance. The *SGRA*, *RMRA* and *SARA* schemes [5], [10], [11] have attracted a lot of attention and introduce unique challenges as a state-of-the-art work. However, even though these existing schemes address spectrum allocation problems for the efficient cellular network management, there are several disadvantages. First, these existing schemes rely on the slightly impractical assumption for real operations. Control algorithms based on the inapplicable presumption can cause potential erroneous decisions. Second, these schemes can not adaptively estimate the current network conditions. In addition, they cause the extra control overhead. The increased overhead can exhaust the network resources and need intractable computation. Third, these schemes operate the network system by some fixed system parameters. Under dynamic network environments, it is an inappropriate approach to operate real world network systems. In contrast, all of the earlier existing schemes in [5], [10], [11] cannot offer such an attractive outcome under widely different service request intensities in the D2D multicasting system.

V. SUMMARY AND CONCLUSION

D2D communication has been identified as one of the technology components for future cellular systems, although this requires the development of effective spectrum resource allocation protocols. In this paper, we design a novel two-phase bargaining game model for the D2D multicasting system. Firstly, we implement the weighted utilitarian bargaining solution to effectively allocate the spectrum resource for multiple CUs. Considering the total system utilization, it is the best way for the BS. Secondly, we apply the meta bargaining approach for the spectrum sharing problem between the CH and CRs. Usually, the CH and CRs have different ideas for the fairness issue in the spectrum sharing problem. Therefore, our meta bargaining approach can strike an appropriate performance balance between conflicting requirements. These two bargaining processes are executed sequentially and individually in a step-by-step manner to find the most profitable solution. Finally, we conduct extensive simulations to evaluate the performance of our proposed method. Numerical results demonstrate that we can improve the performance of D2D multicasting system compared to other existing schemes. Specifically, the performance criteria such as system throughput, CU's payoff, and fairness among users are improved by about 5% - 10% than the existing schemes.

Our work in this paper also opens multiple future directions. One future direction of our research is to study the effect of the imperfect channel state information on the optimal spectrum resource allocation. Another potential direction for the future research is to investigate the mobility-aware resource allocation issues that incorporate dynamic settings such as dynamic traffic and high user mobility. In addition, we will extend this work by incorporating the wireless interference problem to find the optimal communication solution while including the power control methods.

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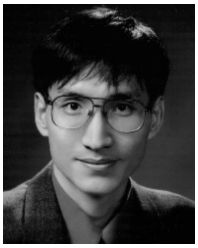

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