www.czasopisma.pan.pl www.journals.pan.pl
INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2018, VOL. 64, NO. 4, PP. 505–512
Manuscript received August 30, 2018; revised October, 2018. DOI: 10.24425/123552

Sequentially Distributed Coalition Formation Game for Throughput Maximization in C-RANs

Abiodun Gbenga-Ilori, and Olufunmilayo Sanusi

***Abstract*—Cloud radio access network (C-RAN) has been proposed as a solution to reducing the huge cost of network upgrade while providing the spectral and energy efficiency needed for the new generation cellular networks. In order to reduce the interference that occur in C-RAN and maximize throughput, this paper proposes a sequentially distributed coalition formation (SDCF) game in which players, in this case the remote radio heads (RRHs), can sequentially join multiple coalitions to maximize their throughput. Contrary to overlapping coalition formation (OCF) game where players contribute fractions of their limited resources to different coalitions, the SDCF game offers better stability by allowing sequential coalition formation depending on the availability of resources and therefore providing a balance between efficient spectrum use and interference management. An algorithm for the proposed model is developed based on the merge-only method. The performance of the proposed algorithm in terms of stability, complexity and convergence to final coalition structure is also investigated. Simulation results show that the proposed SDCF game did not only maximize the throughput in the C-RAN, but it also shows better performances and larger capabilities to manage interference with increasing number of RRHs compared to existing methods.**

***Keywords*—Coalition game, C-RAN, SDCF, throughput, interference, wireless networks**

I. Introduction

As mobile telecommunication technologies evolve towards 5G, operators are in the quest to meet network demands in terms of coverage, capacity and data rates. Massive deployment of base stations to accomodate these needs will incur huge cost which may not necessarily yield a proportional revenue. Inter-cell interference resulting from massive deployment of base stations can cause significant degradation which may affect the overall system performance, [1]. Besides interference, traffic fluctuation at each base transceiver station (BTS) may lead to underutilization of resources [2].

Cloud radio access network (C-RAN) has been proposed as a solution to these challenges, [3], and it is particularly fitting to industry shift towards network function virtualization and self-organizing network, [4], [5]. The C-RAN architecture splits the base station into two parts; the baseband unit (BBU) which is responsible for the computational processing tasks and the remote radio head (RRH) which is responsible for the basic radio processing functionalities [1]. In contrast with the conventional RAN, splitting the BBU from the RRH allows the BBU to be co-located in a centralized location called the BBU pool. Centralizing baseband processing in a pool, coupled with cooperative radio and real-time cloud computing in C-RAN provides the benefits of cost saving, spectral and energy efficiency, load balancing gains, increased flexibility in the network upgrade and performance, [1], [2]. Furthermore, the RRH separation from the BBU facilitates dense deployment which leads to higher achievable rates and better exploitation of frequency resources among multiple cells [6]. Two types of interference are possible in C-RANs; intra-cell interference and inter-cell interference. Though intra-cell interference in C-RAN can be reduced by adopting the orthogonal frequency division multiple access (OFDMA) technique, inter-cell interference caused by high deployment density of RRHs can significantly disrupt system throughput. If not addressed, this challenge places a barrier on the benefits offered by the C-RAN architecture.

Due to the centralization feature in C-RAN, joint processing and coordination technique such as coordinated multi-point (CoMP) transmission and reception was proposed in [7], [8] as an efficient tool to improve the coverage of high data rates and system throughput. An alternating optimization based compressive sensing recovery algorithm was used at the BBU to achieve interference mitigation and data recovery performance in [9]. The authors in [10] proposed time-reversal communication to alleviate interference in C-RAN, in which an optimal content-aware waveform design is used in the downlink transmission and an optimal recovery design is used in the uplink transmission to alleviate interference in C-RANs. In [11], a joint optimization of user grouping, virtual base station clustering and iterative transmit beamforming was proposed for system utility maximization by mitigating intra-cell and inter-cell interference. Other interference management mechanisms were considered in [12], [13] to maximize system throughput.

Though the above interference mitigation schemes have achieved some level of successes, however, modeling interference situation in wireless networks cannot be completely solved analytically. This is because in real life scenarios, modern network nodes are characterized by distributed and self-organizing features which make them able to independently adapt to necessary changes within the network. Thus, game theory is an ideal tool for modeling interactions among a number of interdependent, selfish decision maker [14], [15]. Lately, there has been a shift in network architecture from the familiar centralized and homogeneous architecture to a decentralized and heterogeneous architecture, which requires network device autonomy and cooperation. Cooperative game theory, in particular the coalition formation (CF) game, provides the framework for modeling and developing self-organizing

A. Gbenga-Ilori is with Department of Electrical and Electronics Engineering, University of Lagos, Lagos, Nigeria (email: gbengailori@unilag.edu.ng).

O. Sanusi is with Computer and Electrical Engineering Department, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria (email: sanusi.olufunmi@oouagoiwoye.edu.ng).

techniques for forming coalition based on the mutual cost and benefit of cooperation [16], [17].

Extensive research on the application of coalition game for interference management has been considered in existing literature. Authors in [18], [19], [20] considered femtocell networks while C-RAN was considered in [21], [22], [23]. In [21], a self-optimal coalition formation algorithm based on a defection order was proposed to reduce intra-coalition interference and improve spectrum efficiency. In the paper, the BBU acts as a central entity to assign the RRHs to different coalitions that ensures that maximum individual and average coalition utility is obtained. A cooperative transmission in the downlink was presented in [22], where a hybrid multiple access mode was introduced in the coalition to improve spectrum efficiency. Authors in [23] designed a distributed local altruistic utility function for the social welfare maximization of each RRHs while CoMP scheme was adopted within the coalition to mitigate interference in a hyper-dense scenario.

Recently, there has been an extension of the coalition formation game to overlapping coalition formation (OCF) game. Most practical cases involve nodes suffering from multiple interferers simultaneously, or a node interfering with multiple nodes in a network. Overlapping coalition game allows network nodes to participate in multiple coalitions simultaneously and contribute part of their limited resources to these different coalitions, thus providing flexibility for the players to utilize resources which results in outcomes with higher payoffs [24]. A number of papers [25], [26], [27], [28], have utilized the OCF game model in various cellular networks. In [25], a decentralized algorithm was proposed that allows small cell base station to interact and make independent cooperative decision. Authors in [26] developed an OCF game model for collaborative smartphone sensing to improve the quality of smartphone applications. In [27], a distributed multi-hop coalition based on cooperative routing and scheduling algorithm was proposed for cognitive radio networks. Authors in [28] considered interference coordination in Device-to-Device (D2D) under-laying LTE-A network. However, the merge and split rule deployed involves dynamic joining and quitting a coalition as there is no actual concurrent participation of the players in different coalitions. Though OCF game is able to achieve better network throughput compared to CF games, a player in multiple overlapping coalitions may however deviate from some of the coalitions and therefore withdraw the resources contributed. This causes instability and complicates the computation of the total OCF payoff.

In this paper, we consider a sequentially distributed coalition formation (SDCF) game model among RRHs to study downlink interference mitigation in an ultra-dense C-RAN with RRHs serving the UEs within its coverage. Similar to the OCF game, our proposed SCFG game is dynamic in that it allows players to participate in multiple coalitions however the coalition formation is done sequentially. Rather than contributing portion of their resources to different coalitions, players form coalitions sequentially depending on the availability of resources. In contrast with the merge and split method used in OCF games, the merge only method is adopted in this paper to prevents the players from deviating from the coalitions they have formed. This places a limit on the number of coalitions formed and ensure that players maximize their payoffs from the current coalitions they are in. It also discourages frequent deviation of players from their coalitions and foster the stability of the coalition structure.

A number of literature where coalition game is used to study interference in C-RAN adopted a cooperative transmission within the coalition, coordinated by the time division multiple access (TDMA) technique. This method is not likely to yield an optimum system performance in a hyper-dense network since UEs are allotted time slots in the time frame within the coalition. We propose a handover and power control interference mitigation scheme in which an intracell handover is performed in the interfering RRH to curb interference in the victim RRH. Where this is not possible due to the traffic condition in the interfering RRH, a power control mechanism is adopted.

Due to the high deployment density, certain RRHs will be affected by co-channel interference from neighbouring RRHs. In our proposed model, the RRHs in a coalition are classified as seekers or conceders; with the victim RRH becoming the seeker and the interfering RRH becoming the conceder. Coalition formation decision depends on the expected utility of the RRH with the ultimate goal of maximizing the system throughput. RRHs can act cooperatively to form multiple coalitions with each other and perform a handover or adopt power optimization technique to manage the interference. To ensure stability of the final coalition structure, we adopt a merge-only method. The main contribution of the work is summarized as follows:

- proposal of a sequentially distributed coalition formation (SDCF) game based on handover technique for cooperative interference management and system throughput enhancement in C-RANs,
- formulation of an algorithm for the proposed model and proof of convergence to a stable coalition structure, and
- proposal of a power optimization technique to mitigate interference within the coalition in the event that the handover-based SDCF game cannot be implemented.

The rest of the paper is organized as follows. System model is described in Section II. Section III presents the SDCF algorithm, as well as the stability and convergence of the proposed game. Numerical simulation and analysis is demonstrated in Section IV while the concluding remarks are given in Section V.

II. System Model

Consider a downlink transmission scenario in C-RAN with an ultra-dense deployment of RRHs within the coverage of the macrocell base station (MBS). Each RRH is connected to a pool of BBUs through the optical fibre fronthaul link and serves the user equipment (UEs) within its coverage. The UEs served by the same RRH are assigned orthogonal sub-channels so that transmission can take place concurrently without mutual interference. However, there exist co-channel interference generated by neighboring RRHs to the UEs served by other RRHs operating in the same channel. This is particularly severe for UEs located at the edge of a cell, as strong interfering signals from adjacent cells can affect the data rate of the UEs as they move farther away from their serving RRHs.

Let $\mathbf{N} = \{n_a, n_b, \cdots, n_n\}$ denote the set of all RRHs with each RRH $n \in \mathbf{N}$ serving a set of $\mathbf{U} = \{u_1, u_2, \cdots, u_i\}$ UEs that has been assigned $\mathbf{H}$ orthogonal sub-carriers denoted by the set $\mathbf{H}_n = \{h_1, h_2, \cdots, h_H\}$. Let $g_{n,n}$ be channel gain from RRH n to its UE u_i while P_n denote transmit power of RRH n and σ^2 is the variance of the additive white Gaussian noise. I_0 and $I_{n,N}$ are the interference from the MBS and from other RRHs respectively. The received signal-to-interference-plus-noise ratio (SINR) of UE u_i served by RRH $n \in N$ on the sub-channel $h_f \in \mathbf{H}_n$ is given by:

$$SINR_n^{h_f} = \frac{P_n g_{n,n}}{I_0 + I_{n,N} + \sigma^2}, \tag{1}$$

and

where $I_0 = P_0 g_{n,0}$, $I_{n,N} = \sum_{m \in N} P_m g_{n,m}$, and $m \neq n$. The transmit power of RRH $m \in N$ using sub-channel h_f is P_m while $g_{n,m}$ is the channel gain from RRH m to u_i. The transmit power of the MBS is P_m while $g_{n,0}$ is the channel gain from MBS to u_i. The achievable Shannon rate of u_i on sub-channel h_f is given by:

$$R_n^{h_f} = \log_2(1 + \frac{P_n g_{n,n}}{I_0 + I_{n,N} + \sigma^2}). \tag{2}$$

Since the throughput of the RRH is a function of the performance of UEs attached to it, thus, the throughput for RRH $n \in N$ serving $\mathbf{U}$ UEs is defined by:

$$R_n^H = \sum_{h \in \mathbf{H}} \log_2(1 + \frac{P_n g_{n,n}}{I_0 + I_{n,N} + \sigma^2}). \tag{3}$$

From Fig. 1, without loss of generality, we consider three RRHs in the network: n_a, n_b and n_c. Let $\mathbf{U}_a = \{U_{a_1}, U_{a_2}, \cdots, U_{a_e}\}$ be the set of UEs in n_a, $\mathbf{U}_b = \{U_{b_1}, U_{b_2}, \cdots, U_{b_f}\}$ is the set of UEs in n_b and $\mathbf{U}_c = \{U_{c_1}, U_{c_2}, \cdots, U_{c_g}\}$ is the set of UEs in n_c, $u_{a_1}^b$ and $u_{a_2}^c$ are at the cell-edge served by n_a and are being interfered by n_b and n_c respectively. This interference situation can cause significant degradation in the sum throughput of the affected RRH in a non-cooperative scenario. To mitigate interference, n_a can act cooperatively by forming coalitions with n_b and n_c in a distributed manner as shown in Fig. 2, by adopting a handover and power optimization scheme within the coalitions.

With the centralization of the BBU in C-RAN, handover events results in performance gain in terms of reduced signaling, simplified procedure and reduced handover delay. Furthermore, there is a decrease in handover failure rate which consequently enhances user experience [29]. For the handover to take place, there must be free sub-channel in the interfering RRH. However, this may not always be possible due to the traffic load and the interference condition in that sub-channel. Thus a power optimization scheme will, in this case, be adopted within the coalition to reduce interference. The list of notations is given in Table I.

III. Sequentially Distributed Coalition Formation Game

The aim of this work is to improve overall system throughput by maximizing the data rate of UEs and hence, the sum throughputs of the RRHs cooperatively. In conventional coalition games, the players are restricted to participating in only one coalition at a time or at best are modeled to dynamically join and quit a coalition. Here, we propose a sequentially distributed coalition formation (SDCF) game model in which the players can belong to multiple coalitions simultaneously to improve the spectral efficiency and performance of the system.

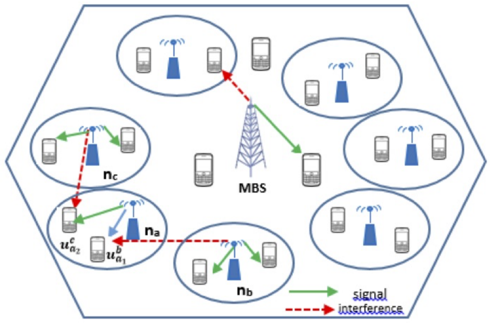

Fig. 1. Model for C-RAN in a Non-Cooperative Scenario

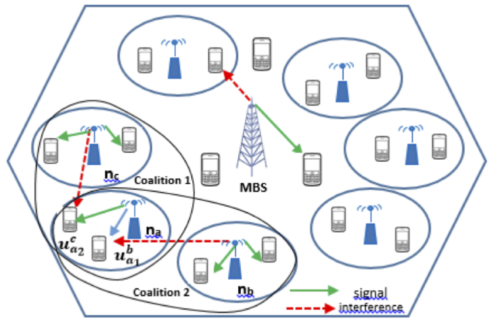

Fig. 2. Model for C-RAN in a Cooperative Scenario

We assume all RRHs are in singleton, meaning a coalition with only one RRH in it. We define two types of RRHs in the network: seekers denoted by n^s and conceders denoted by n^c. The seeker is the RRH that is being interfered and requests a merger with the interfering RRH while the conceder is the interfering RRH that receives a merger request and agrees to merge. With this concept, a RRH can either be a seeker or a conceder depending on whether it is interfering or being interfered. In particular, n^s has an incentive to cooperate because the interference affecting its UEs will be minimized and its throughput will improve. On the other hand, n^c also has an incentive to cooperate because its cooperation will it earn a weight assigned by the central entity, which is the BBU. Moreover, since the overall system throughput will increase, each RRH in the network have strong incentive to cooperate to improve the system utility.

To mitigate interference, each RRH utilize the received signal strength indicator (RSSI) feedback measurement from its UEs to create a list of interferers, ranking them in descending order. Depending on the payoffs, the RRH forms a new coalition partition with the interfering RRH after negotiation and a handover or power optimization is adopted within the coalition. From Fig. 2, u_{a_1} served by n_a, is interfered by a number of interferers with a sequence ($n_b, n_j \ldots n_c$), and sorted from strongest to weakest. We assume n_a is serving u_{a_1} on sub-channel h_B and n_b, serving u_{b_1} on the same sub-channel is interfering with u_{a_1}. Therefore n_a becomes the seeker and n_b, the conceder. Cooperatively, n_a and n_b may decide to merge and form a new coalition. Once a coalition is formed, n_b will offer part of its available free sub-channel, say h_C, with the best channel condition. Then u_{b_1}, currently using channel h_B will be transferred to h_C to release h_B and thus eliminate interference to u_{a_1}. Similarly, n_a will form coalitions with other interferers using the same process in order to reduce the interference in its UEs. However, the number of coalitions formed by n^s is limited by:

$$RSS_i \geq RSS_{min}, \tag{4}$$

where RSS_i is the received signal strength of the interferer and RSS_{min} is the minimum acceptable interfering received signal strength.

This implies that a seeker RRH will only form a coalition with conceders if the RSS of the interferer is greater than a given minimum. The number of coalition formed by n^c is limited by:

$$h_s \in \mathbf{H}_s \leq h_c \in \mathbf{H}_c, \tag{5}$$

where $\mathbf{H}_s$ the set of n^s's sub-channels interfered by n^c, and $\mathbf{H}_c$ is the set of sub-channel available for handover at n^c. This implies that at every request from n^s for a merger, n^c checks if equation (5) is satisfied before forming a coalition. Therefore, the elements of $\mathbf{H}_c$ is decreased as more coalitions are formed by n^c. If there are no free sub-channels from n^c due to the traffic situation, in which case $\mathbf{H}_c = \emptyset$, a power control techniques will be adopted according to equations (6) and (7):

$$\text{minimize} \quad P^c \quad , \tag{6}$$

$$\begin{aligned} \text{subject to} \quad & R^c \geq R^c_{min} \quad \text{and,} \\ & R^s \geq R^s_{min}, \end{aligned} \tag{7}$$

where P^c is the transmit power of n^c, R^c and R^s are the sum throughput of n^c and n^s respectively, R^s_{min} and R^c_{min} are the minimum acceptable rate for the seeker and conceder respectively. If handover or power control is not possible, the request for a merger is rejected.

Definition 1: A sequentially distributed coalition formation (SDCF) game $G = (\mathbf{N}, v)$ with non-transferable utility (NTU), where $\mathbf{N}$ a set of players, in this case the RRHs, and v is the function that maps the payoffs to the players in the coaltion. The coalition structure π_N is defined by $\{\phi_1, \phi_2, \cdots, \phi_L\}$. SDCF game has non-transferable utility because the value of the coalition $v(\phi_k)$, cannot be arbitrarily divided amongst its members but instead each member has its own value within the coalition. Since each RRH $n \in \mathbf{N}$ is initialized to be a singleton, the payoff before a merger is sum-rate of the UEs connected to the RRH and defined by:

TABLE I
LIST OF NOTATIONS.

Symbol	*Definition*
$v^s, v^{s\prime}$	Payoff of n^s before and after coalition respectively
$v^c, v^{c\prime}$	Payoff of n^c before and after coalition respectively
ϕ_k	k^{th} coalition
π_N, π'_N	Coalition structure over a set of player N before and after coalition
$R^s, R^{s\prime}$	Sum throughput of n^s before and after coalition
$R^c, R^{c\prime}$	Sum throughput of n^c before and after merging
C^s, C^c	Cost of coalition formation for n^s and n^c respectively
w_j	Additional payoff value for n^c
H_s, H_c	Sets of orthogonal subcarriers allocated to n^s and n^c
$v_E^{s\prime}$	Total payoff of n^s for participating in E coalitions
$v_J^{s\prime}$	Total payoff of n^c for participating in J coalitions
L	Number of coalitions
$\mathbf{N}$	The set of RRHs in the C-RAN
$\mathbf{U}$	The set of user equipment connected to the RRH
R^s, R^c	Sum throughput of n^s and n^c respectively, in all coalitions formed

$$v^s(\phi_k, \pi_N) = R^s(\phi_k, \pi_N) = \sum_{h_s \in \boldsymbol{H_s}} \log_2\Big(1 + \frac{P_n g_{n,n}}{I_0 + \sum_{\substack{m \in \mathbf{N} \\ m \notin n}} P_m g_{n,m} + \sigma^2}\Big) \tag{8}$$

$$v^c(\phi_k, \pi_N) = R^c(\phi_k, \pi_N) = \sum_{h_c \in \boldsymbol{H_c}} \log_2\Big(1 + \frac{P_n g_{n,n}}{I_0 + \sum_{\substack{m \in \mathbf{N} \\ m \notin n}} P_m g_{n,m} + \sigma^2}\Big). \tag{9}$$

The new rates after coalition is formed is defined by:

$$R^{s\prime}(\phi'_k, \pi'_N) = \sum_{h'_s \in \boldsymbol{H_s}} \log_2\Big(1 + \frac{P_n g_{n,n}}{I_0 + \sum_{\substack{m \in \mathbf{N} \setminus \mathbf{K} \\ m \notin n}} P_m g_{n,m} + \sigma^2}\Big), \tag{10}$$

$$R^{c\prime}(\phi'_k, \pi'_N) = \sum_{h'_c \in \boldsymbol{H_c}} \log_2\Big(1 + \frac{P_n g_{n,n}}{I_0 + \sum_{\substack{m \in \mathbf{N} \\ m \notin n}} P_m g_{n,m} + \sigma^2}\Big), \tag{11}$$

where $\mathbf{K}$ is a subset of RRHs that have conceeded to form coalitions with RRH n. After a merger to form a coalition, the cost of information exchange, C^s and C^c for seeker and conceder respectively is taken into account:

$$v^{s\prime}(\phi'_k, \pi'_N) = R^{s\prime}(\phi'_k, \pi'_N) - C^s, \tag{12}$$

$$v^{c\prime}(\phi'_k, \pi'_N) = R^{c\prime}(\phi'_k, \pi'_N) - C^c + w_j. \tag{13}$$

Practically, each RRH exhibit selfish characteristics in that it will only form coalition if its current payoff is increased. A weight function, w_j, is therefore introduced as an additional value to the payoff of the n^c if its payoff will remain constant after a coalition. However no weight function is added if the payoff will increase after the coalition is formed as stated in equation (14). The weight is proportional to the conceder's contribution towards improving the payoff of the seeker. The payoff of n^s will definitely improve after a coalition because interference in its UEs will be reduced, but n^c will only have a strong incentive to form a coalition if its payoff also increases. To increase the overall system throughput, the weight is enforced by the BBU as the central entity.

$$w_j = \begin{cases} 0, & v^{c\prime}(\phi_k', \pi_N') > v^c(\phi_k, \pi_N), \\ \tau\left(\frac{h_g}{h_r}\right), & v^{c\prime}(\phi_k', \pi_N') \leq v^c(\phi_k, \pi_N) \text{ handover}, \\ \mu\left(\frac{R^s_{min}}{R^s_{target}}\right), & v^{c\prime}(\phi_k', \pi_N') \leq v^c(\phi_k, \pi_N) \text{ power control} . \end{cases} \tag{14}$$

h_g is the number of sub-channels granted by conceder while h_r is the amount of sub-channels requested by seeker, and this depends on the number of UEs being interfered by the conceder. τ is a positive constant. Since power optimization is with respect to a rate constraint, the weight for power control can be defined as a function of the rate. R^s_{target} is the target throughput for n^s, R^s_{min} is the minimum rate achieved by n^s after power control by n^c, μ is a positive constant. The total payoff of the seeker and conceder for participating simultaneously in more than one coalition is the sum of its throughput in E and J coalitions respectively and written as:

$$v^s_E{}' = \sum_{e=1}^{E} v^{s\prime}(\phi_k', \pi_N'), \tag{15}$$

$$v^c_J{}' = \sum_{j=1}^{J} v^{c\prime}(\phi_k', \pi_N'). \tag{16}$$

The payoff of the coalition structure is defined as:

$$v(\pi_N') = \sum_{l=1}^{L} v(\phi_k'). \tag{17}$$

The goal of the paper is to maximize the overall system throughput as defined as equations (18) and (19):

$$\text{maximize} \quad R_n(N) = \sum_{n\in\mathbf{N}} \sum_{h\in\mathbf{H}} \log_2\left(1 + \frac{P_n g_{n,n}}{I_0 + I_{n,N} + \sigma^2}\right) \quad , \tag{18}$$

$$\begin{aligned} \text{subject to} \quad R^s(N) &= \sum_{e=1}^{E} R^{s\prime}(\phi_k', \pi_N'), \quad \text{and} \\ R^c(N) &= \sum_{j=1}^{J} R^{c\prime}(\phi_k', \pi_N'). \end{aligned} \tag{19}$$

Definition 2: Given a distributed coalition structure defined as $\pi_N = \{\phi_1, \phi_2, \cdots, \phi_L\}$, where L is the number of coalitions. We define a sequential coalition formation game where players can simultaneously participate in different coalitions, such that there exists $\phi_\alpha, \phi_\beta \in \pi_N, \alpha \neq \beta$ such that $\phi_\alpha \cap \phi_\beta = \emptyset$. This means that the performance of the system can be significantly improved instead of players joining and quitting a coalition dynamically.

Definition 3: Given two coalition structures π_i and π_j of a sequentially distributed coalition formation (SDCF) game $G = (N, v)$, we say that the preference order for RRH n is denoted by $\pi_j \succ \pi_i$ if RRH n prefers to switch from π_i to π_j. Therefore, we express it as:

$$v_n(\phi_k^*, \pi_j) \succ v_n(\phi_k, \pi_i), \tag{20}$$

$$v(\pi_j) \succ v(\pi_i). \tag{21}$$

This relations in Definition 3 guarantee the individual payoff of RRH n in the new coalition will increase and the total coalition structure will not decrease.

Definition 4: Consider the initial coalition structure $\pi_N = \{\phi_1, \phi_2, \cdots, \phi_L\}$, where each ϕ_L is a singleton coalition. We define a new coalition structure such that any $\phi_k \subset N$ can agree to merge and form new optimal coalition structure $\pi_N^* = \bigcup_{k=1}^{L} \phi_k$. To maintain stability and ease the convergence of the coalition structure, we adopt a merge-only principle that ensure that once the merging process occurs, players cannot leave the coalition until a period os time during which communication takes place.

Algorithm 1 SDCF Game for Interference Mitigation in an C-RANs

Initialization: The RRH are initialized to be in singletons. The C-RAN with N RRHs are partitioned by $\pi_N = \{\phi_1, \phi_2, \cdots, \phi_L\}$ at time $t = 0$. Each RRH computes its current payoff, $v(\phi_k, \pi_N)$ as in equations (8) and (9).

Phase 1: Interference Detection.

Each RRH detect potential coalition partners by obtaining interference measurements from neighbouring RRHs through received signal strength indicator (RSSI) feedback from the UEs
Interfering RRHs are sorted in descending order from strongest to weakest interferer. The interfering RRHs are considered for cooperation according to equation (4).

Phase 2: Distributed Coalition Formation.
Merge-only rule is adopted
Repeat for each n^s and n^c

Update time index $t = t + 1$
Each RRH $i \in N$computes its payoff for forming a coalition with an interfering RRH
if the payoff is improved according to equation (12) and equation (4) is satisfied **then**
    RRH i sends a proposal to merge
    $i \in N$ becomes n^s
else RRH i remains in present coalition
end if
Each RRH $j \in N$ that receives a merger request, calculates its payoff for merging to form new partition according equation (13)
if the payoff is improved than present payoff and equations (5) is satisfied **then**
    The coalition merging request is granted and a new partition is formed
    $j \in N$ becomes n^c
else Coalition request is rejected
end if
until Convergence to a stable coalition structure

Phase 3: Intra-coalition Interference mitigation.
A handover or power control scheme is adopted within the coalition to mitigate interference

1) The SDCF Game Algorithm: The proposed SDCF algorithm is in three phases; interference detection, the sequentially distributed coalition formation and intra-coalition interference mitigation as shown in Algorithm 1. Initially, at time $t = 0$, the network is partitioned by N singletons and the current payoff of each RRH is computed. The first phase starts with interference detection in which the RSSI from the neighbouring cells is reported to the RRHs through feedback from the UEs. With the RSSI measurement, the RRH identifies potential cooperative partners from the list of interferers according to equation (4) and sorts them in descending order, that is, strongest to weakest. In the second phase, each RRH computes the possible payoff that will result from a merger with an interfering RRH according to equation (12). With an improved payoff, the RRH sends a merging request to interfer RRHs above acceptable limit on the list. The RRH that send the request then becomes n^s. On receiving the proposal, the interfering RRH computes its payoff according to equation (13). If its payoff is improves and equations (5) is satisfied, the merger proposal will be accepted and the interfering RRH becomes n^c. Once the merger takes place, the RRHs are committed to remaining in the coalition. The process is repeated for each n^s and n^c until convergence to a final coalition structure is reached. In the final phase, a handover or power control scheme is adopted within the coalition to mitigate interference.

2) Convergence and Stability: We will proof the convergence and stability for Algorithm 1.

Corollary III.0.1. *The proposed SDCF game algorithm converges to a final coalition structure.*

Proof. n^s will only tend to request a merger if equation (4) is satisfied while n^c will agree to a merger if equation (5) is satisfied. Specifically, n^s will form coalition with potential partners whose interference level is greater than the acceptable minimum and n^c will consider a merger if there is free sub-channel for handover or if there is a possibility of power optimization. Consequently, the number of coalitions formed is finite. In such a case, merge-only method guarantee that the process converges to final stable coalition structure after finite number of steps. □

Corollary III.0.2. *The final coalition structure π_N^* of the SDCF game algorithm is stable.*

Proof. The outcome of SDCF game $G = (N, v)$ is stable if RRH $n \in N$, where $n \in \phi_i$ and $n \in \phi_j$ for $\phi_i, \phi_j \in \pi_N$ has no incentive to leave current coalitions. In the proposed algorithm, each RRH n that agrees to merge remains in the coalition following the merge-only principle. However, they can join other coalitions sequentially provided the necessary criteria is satisfied. If the final coalition structure π_N^* is not stable, then there exist an RRH $n \in N$ that quits its coalition $\phi_i \in \pi_N^*$ to form a new coalition structure $\pi'_N = \pi_N^* \backslash \phi_i \bigcup \pi_N^* \backslash n$. For this to occur, RRH n must perform a preference order switch which contradicts the fact that π_N^* is the final coalition structure resulting from the convergence of the proposed algorithm. Also, a preference order switch contradicts the merge-only rule defined, which ensures that players remain committed to a coalition once it is formed. Hence the final coalition structure π_N^* is stable.

□

TABLE II
SIMULATION PARAMETERS, [22].

Parameters	*Values*
Carrier frequency	2 GHz
RRH transmit power	30 dBm
RRH/UE antenna gain	2/0dBi
Number od RRH	7 to 16
Pathloss model (dB)	18.7 x $log_{10}(d[m]) + 46.8 + 20log_{10}(\frac{2.7}{5})$

Corollary III.0.3. *The proposed Algorithm* 1 *yields a stable coalition in $\mathcal{O}(n)$ time.*

Proof. The complexity of our algorithm is dependent on the coalitions formed by the conceder RRH n^c, which is directly related to the number of merge proposals sent by each n^s. Merge proposals from n^s can either be accepted by n^c or rejected. In the case of rejection, n^s remains in the present coalition because no other coalition can reduce the interference from n^c. Therefore, the complexity order of the proposed algorithm is $\mathcal{O}(n)$. □

IV. NUMERICAL ANALYSIS

In order to evaluate the performance of our proposed SDCF game model, we consider a 150 x 150 m^2 macro cell with a single MBS and between 7 to 16 randomly distributed RRHs within the coverage of the mobile base station (MBS). Each RRH has a radius of 20m and serves only four UEs. We set the sum of the interference from the MBS and the noise power equal to -30dBm. The other parameters considered in the simulation are summarized on Table II. MATLAB was used for the simulations.

Fig. 3 shows a snapshot of the final coalition structure resulting from the algorithm with $N = 7$. All RRHs act non-cooperatively initially at $t = 0$. As the iteration process begins, the interfered RRHs identifies cooperative potential partners in order to minimize its interference. Results show that six(6) coalitions are formed. The final coalition structure is described by $\pi_N^* = \{(n_1n_3), (n_1n_2), (n_4n_5), (n_1n_4), (n_6), (n_7)\}$. RRH n_1 forms a multiple coalitions; it acts as n^s in coalitions 1 and 4 and as n^c in coalition 2. RRHs n_2 and n_3 are each in a single coalition while n_6 and n_7 prefers to remain in singleton because of the cost of coalition formation considering their relative distance. From the above we can see that a RRH n can be both n^s and n^c as in the case of n_1 and n_4. Fig. 4 shows the performance of the proposed algorithm in terms of the system throughput as a function of the number of RRHs. Compared with the non-cooperative method, we see an increase in throughput with our proposed model as the number of RRH is increased. However, the difference in performance of both models is not significant when the number of RRH in the C-RAN is low. As n increases, we see a significant increase in the throughput with the proposed model because of the impact of coalition formation on interference mitigation. This

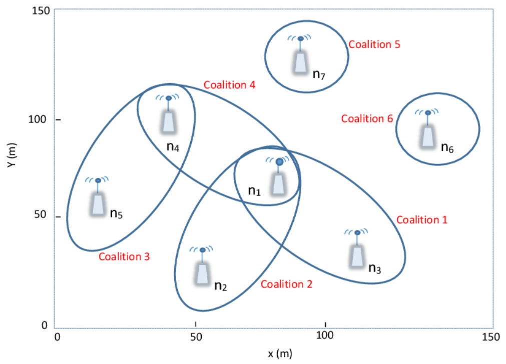

Fig. 3. A stable distributed coalition structure for N = 7

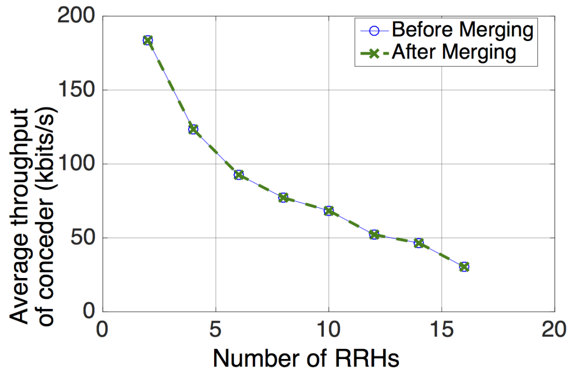

Fig. 5. Average Throughput of n^c Before and After Merger

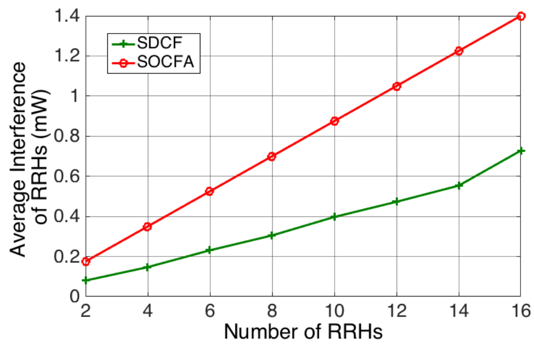

Fig. 6. Average Interference in CRAN: SDCF Game Versus SOCFA

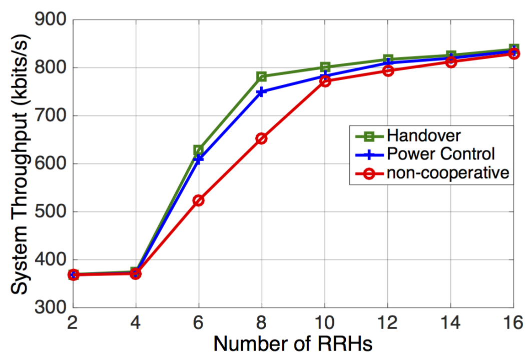

Fig. 7. Average Throughput: Handover Versus Power Control

performance again drops as n increases beyond a certain limit. This is because there is more interference in the CRAN as n increases and there is a constraint on sub-channel needed for the handover scheme. More of the n^c, therefore decide to use power optimization scheme for the coalition which may occasionally impact on the throughput.

Fig. 5 shows the average throughput of the conceder, n^c, before and after a merger to form a coalition. It can be seen that there is no drop in throughput as the rate remain the same as it was before the coalition. This is because n^c will rather not consider a merger than join a coalition that will reduce the rate in its cell.

The performance of our proposed SDCF game is also validated by comparing the average interference that results in a C-RAN with our algorithm with an existing one known as self optimal coalition formation algorithm (SOCFA), [22], which is also applied to C-RANs to mitigate interference. This is shown in Fig. 6. It can be seen that the average interference in both models increase as n increases. However, compared with (SOCFA), there is reduction in the average interference in the C-RAN with our proposed model. Therefore, our algorithm shows better performance.

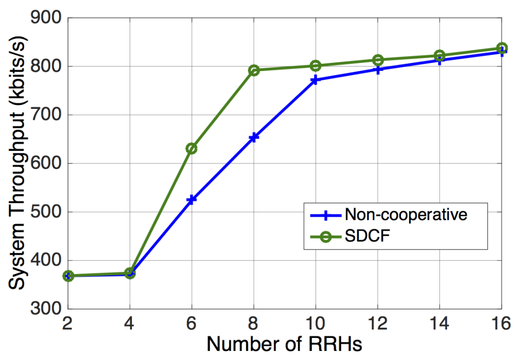

Fig. 4. System Throughput versus number of RRH in the C-RAN

Fig. 7 shows a comparison of the system throughput when handover or power control technique is used with respect to the number of RRHs in the network. The results from these two are also compared with a non-cooperative scenario where the RRHs do not form any coalitions. As seen from the figure, handover technique gave the best throughput results. However, with the limited frequency resource available in C-RANs, power control could still be used to reduce interference and increase throughput in the network as the throughput achieved can be seen to be quite close to that of the handover technique. In general, the cooperative techniques achieved better result than the non-cooperative method.

From Fig. 8, it is observed that the average weight function for n^c decreases as the number of RRH increases. As n^c form more coalitions, the number of frequency resource available decreases and n^c can no longer grant all channel requests from n^s. Similarly, for power control, enforcing a power control mechanism gets more stringent as multiple coalition formation could degrade the QoS of n^c.

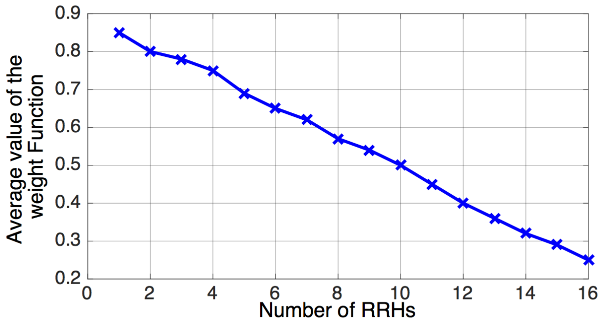

Fig. 8. Average Weight Function for n^c

V. Conclusion

In this paper, a sequentially distributed coalition formation (SDCF) game is proposed for maximizing the throughput in C-RANs. This is necessary in order to reduce interference in these networks and meet the high data rate requirements of new generation cellular networks. The proposed algorithm is based on a merge-only method that incorporates a handover or power control interference schemes. The proposed cooperative model is compared with a non-cooperative model and an existing cooperative model known as SOCFA. Of all the three models, results show that our proposed algorithm produced the best throughput in the C-RAN. Compared with SOCFA, the proposed algorithm shows a better average interference per number of RRH in the C-RAN.

References

[1] A. Checko, H. Christiansen, Y. Yan, L. Scolari, G. Kardaras, M. Berger, and L. Dittmann, "Cloud ran for mobile networks - a technology overview," *IEEE Communications Surveys and Tutorials*, vol. 17, no. 1, pp. 405–426, 2015. DOI: 10.1109/COMST.2014.2355255.

[2] J. Wu, Z. Zhifeng, H. Yu, and W. Yonggang, "Cloud radio access network (c-ran): A primer," *IEEE Network*, vol. 29, pp. 35–41, 2015. DOI: 10.4316/AECE.2014.01001.

[3] Y. Luo, K. Yang, Q. Tang, J. Zhang, P. Li, and S. Qiu, "An optimal data service providing framework in cloud radio access network," *EURASIP Journal on Wireless Communications and Networking*, vol. 23, no. 1, pp. 1–11, 2016. DOI: 10.1186/s13638-015-0503-2.

[4] M. Zorzi, A. Zanella, M. Testolin A De Filippo De Grazia, and M. Zorzi, "Cognition-based networks: A new perspective on network optimization using learning and distributed intelligence," *IEEE Access*, vol. 3, pp. 1512–1529, 2015. DOI: 10.1109/ACCESS.2015.2471178.

[5] E. Mohamed, "Cloud cooperated heterogeneous cellular networks for delayed offloading using millimeter wave gate," *Intl. Journal of Electronics and Telecommunications*, vol. 63, no. 1, pp. 51–64, 2017. DOI: 10.1515/eletel-2017-0008.

[6] P. Rost, C. J. Bernados, A. De Domenico, M. Di Girolamo, M. Lalam, D. S. Maeder, and D. Wbben, "Cloud technologies for flexible 5g radio access networks," *IEEE Communications Magazine*, vol. 52, no. 5, pp. 68–76, 2014.

[7] A. Beylerian and T. Ohtsuki, "Multi-point fairness in resource allocation for c-ran downlink comp transmission," *EURASIP Journal on Wireless Communications and Networking*, vol. 12, no. 1, pp. 1–10, 2014.

[8] D. Boviz, N. Abbas, G. Aravinthan, C. S. Chen, and M. A. Dridi, "Multi-cell coordination in cloud ran: Architecture and optimization," in *International Conference on Wireless Networks and Mobile Communications (WINCOM 2016), October 2016, Morocco*, 2016, pp. 1–8.

[9] J. Liu, A. Liu, V. Lau, C. S. Chen, and M. A. Dridi, "Joint interference mitigation and data recovery in c-ran with distributed fronthaul compression," in *Proceedings of the International Conference on Communications Systems (ICCS 2016), December 2016, Shenzhen, China*, 2016, pp. 1–6.

[10] M. Hang, B. Wang, Y. Chen, and K. J. Liu, "Interference alleviation for time-reversal cloud radio access network," in *Proceedings of the International Conference on Global Communications (GLOBECOM), December 2016, Washington, DC*, 2016, pp. 1–6.

[11] H. Xiaoyan, G. Xue, R. Yu, and S. Leng, "Joint scheduling and beamforming coordination in cloud radio access networks with qos guarantees." ." *IEEE Transactions on Vehicular Technology*, vol. 65, no. 7, pp. 5449–5460, 2016.

[12] D. Zhu and M. Lei, "Traffic and interference-aware dynamic bbu-rru mapping in c-ran tdd with cross-subframe coordinated scheduling/beamforming," in *Proceedings of the IEEE International Conference on Communications Workshops (ICC), June 2013, Budapest, Hungary*, 2013, pp. 884–889. DOI: 10.1109/ICCW.2013.6 649 359.

[13] S. S. Hashmi, S. A. Sattar, and K. Soundararajan, "Optimal spectrum utilization and flow controlling in heterogeneous network with reconfigurable devices," *Intl. Journal of Electronics and Telecommunications*, vol. 63, no. 3, pp. 269–277, 2017. DOI: 10.1515/eletel-2017-0036.

[14] S. Mehta and K. S. Kwak, "Application of game theory to wireless networks," in *Convergence and Hybrid Information Technologies*, M. Crisan, Ed. InTech, 2010. DOI: 10.5772/9642.

[15] S. Vivek, A. B. Neel, A. B. Mackenzie, R. Menon, L. A. DaSilva, J. E. Hicks, J. H. Reeds, and R. P. Gilles, "Using game theory to analyze wireless ad hoc networks," *IEEE Communications Surveys and Tutorials*, vol. 7, no. 1, pp. 46–56, 2005. DOI: 10.1109/COMST.2005.1593279.

[16] H. Zhu, *Game Theory in Wireless and Communication Networks: Theory, Models, and Applications*. New York: Cambridge Univ. Press, 2012.

[17] W. Saad, H. Zhu, D. Mrouane, H. Are, and B. Tamer, "Coalitional game theory for communication networks," *IEEE Signal Processing Magazine*, vol. 26, no. 5, pp. 77–97, 2009.

[18] Z. Zhang, S. Lingyang, H. Zhu, and W. Saad, "Coalitional games with overlapping coalitions for interference management in small cell networks," *IEEE Transactions on Wireless Communications*, vol. 13, no. 5, pp. 2659–2669, 2014. DOI: 10.1109/TWC.2014.032514.130942.

[19] Y. Shi, G. Zhu, S. Lin, and S. Xu, "Rssi-based dynamic coalition formation for cooperative interference management in femtocell networks," in *Proceedings of the Wireless Communications and Mobile Computing Conference (IWCMC 2015)*, 2015, pp. 1400–1405.

[20] F. Pantisano, B. Mehdi, W. Saad, R. Verdone, and M. Latva-Aho, "Coalition formation games for femtocell interference management: A recursive core approach," in *Proceedings of the Wireless Communications and Networking Conference (WCNC), 2011*, 2011, pp. 1161–1166.

[21] C. Sun, M. Peng, B. Zhang, Y. Sun, Y. Li, and W. Chonggang, "A coalitional game scheme for cooperative interference management in cloud radio access networks," *Transactions on Emerging Telecommunications Technologies*, vol. 25, no. 9, pp. 954–964, 2014.

[22] Z. Zhou, J. Peng, X. Zhang, K. Liu, and F. Jiang, "A coalitional game scheme for cooperative interference management in cloud radio access networks," *Transactions on Emerging Telecommunications Technologies*, vol. 25, no. 9, pp. 954–964, 2014.

[23] Y. Sun, J. Wang, F. Sun, and Z. Zhang, "Local altruistic coalition formation game for spectrum sharing and interference management in hyper-dense cloud-rans," *IET Communications*, vol. 10, no. 15, pp. 1914–1921, 2016. DOI: 10.1049/iet-com.2016.0094.

[24] T. Wang, S. Lingyang, H. Zhu, and W. Saad, "Overlapping coalition formation games for emerging communication networks," *IEEE Network*, vol. 30, no. 5, pp. 46–53, 2016.

[25] Z. Zhang, S. Lingyang, H. Zhu, and W. Saad, "Coalitional games with overlapping coalitions for interference management in small cell networks," *IEEE Transactions on Wireless Communications*, vol. 13, no. 5, pp. 2659–2669, 2014. DOI: 10.1109/TWC.2014.032514.130942.

[26] B. Di, T. Wang, L. Song, and H. Zhu, "Collaborative smartphone sensing using overlapping coalition formation games," *IEEE Transactions on Mobile Computing*, vol. 16, no. 1, pp. 30–43, 2017.

[27] C. S. Hyder and X. Li, "Cooperative routing via overlapping coalition formation game in cognitive radio networks," in *Proceedings of the 25th International Conference on Computer Communication and Networks (ICCCN), 2016*, 2016, pp. 1–6.

[28] S. Xu, C. Xia, and K. S. Kwak, "Overlapping coalition formation games based interference coordination for d2d underlaying lte-a networks," *AEU-International Journal of Electronics and Communications*, vol. 70, no. 2, pp. 204–209, 2016. DOI: 10.1016/j.aeue.2015.10.007.

[29] D. Lpez-Prez, V. Alvaro, L. kos, G. De La Roche, and J. Zhang, "Intracell handover for interference and handover mitigation in ofdma two-tier macrocell-femtocell networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 142629, pp. 1–10, 2010.