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Energy Efficient Scheduling in Content Distribution Collaborative Mobile Clusters

YUN HU[1], **YANHUI CHEN**[1], **AND ZHENG CHANG**[2], **(Senior Member, IEEE)**
[1]National Demonstration Center for Experimental Electronic Information and Communication Engineering Education, Xidian University, Xi'an 710071, China
[2]Faculty of Information Technology, University of Jyväskylä, 40014 Jyväskylä, Finland

Corresponding author: Yanhui Chen (yhchen@mail.xidian.edu.cn)

ABSTRACT Most of the existing literatures on green communications aimed to improve the energy efficiency at the base station or data server. However, in order to fully experience high rate broadband multimedia services, prolonging the battery life of user equipment is also critical for the mobile terminals, especially for the smartphone users. In this work, we investigate the problem of designing a content distribution mobile platform named collaborative mobile clusters (CMC) via user cooperation to reduce the energy consumption at the terminal side. Specifically, given numbers of users interested in downloading a common content from the operator, both centralized and distributed user grouping and scheduling algorithms are proposed in order to find the proper user to join the CMC in different scheduling time with the objective to obtain energy efficiency as well as user fairness. Through simulation studies, it is shown that a significant energy saving can be achieved by the proposed schemes and user fairness can be maintained as well.

INDEX TERMS Green communications, energy efficiency, collaborative mobile cluster, user cooperation, user scheduling, content distribution.

I. INTRODUCTION

A. BACKGROUND AND MOTIVATION

The main focus of green communication development has been on the improvement of energy efficiency of the Base Station (BS), whereas investigation on the algorithms to reduce energy consumption at the terminal side has not received equal attention. An increasing number of online or multimedia services, such as news download, multimedia multicasting, online games or file distribution are consuming the batteries of mobile devices much faster than before. Meanwhile, the speed of the improvement of battery volume has been relatively low compared to the development of wireless networks. All these factors can deteriorate the user experience and prevent the user from fully enjoying high data-rate services. Therefore, the research on reducing energy consumption of User Equipments (UEs) is of considerable significance in providing satisfactory experience for mobile users about the service.

Today's laptops, smartphones and tablets have large storage capacities, which are rapidly growing and typically under-utilized. The highly developed computing units of these devices are also capable of processing much more complicated tasks, which is often reflected reflected in their energy consumption. Fast development of UEs in the design of an energy- and cost-efficient platform for high data-rate services emerges, consequently, as one of the important trends when evaluating the next generation communication systems. Due to the proliferation of the smartphone technology, offloading cellular network has gained increasing attention during the recent years. Recent approaches to content distribution, sharing and offloading features among the UEs include cooperative content distribution architectures known as collaborative mobile clusters (CMCs) where the UEs can offload from the BS and share content in a cooperative manner [1], [4].

In this platform, the coalition of the UEs can be viewed as a resource pool or computing units in cloud computing paradigm capable of communicating with each other and the outside world. The benefits of CMC can be observed from both social and technological domains. In the social domain, CMC is likely to increase the spread of popular content among a large group of the UEs. In the technological domain, it will be possible to further investigate the potential advances of M2M and D2D communications [2]. In addition to the benefits of content sharing, CMC is also foreseeable to decrease downlink receive energy consumption of UEs and prolong the battery life. Such energy saving features

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of CMC are able to boost the content sharing activities in social networks [1], as energy consumption reduction can stimulate users' willings to broadcast popular content. Therefore, in both technological and social domains, exploring the benefits of CMC is full of research significance.

B. RELATED WORK

Recent literatures on improving the energy efficiency performance of multicasting services over wireless networks focuses on the multicasting grouping techniques. That is, proposing user grouping schemes to reduce the energy consumption when offering multicasting services [5], [6], [24]. However, those research mainly concern energy efficiency design at the transmitter or BS side. Moreover, the design of a content sharing platform over a number of UEs or Device to Device (D2D) communications has also aroused many interests [8]–[23]. The existing literature on such topic focuses on reducing the UEs communication cost [10], increasing the system throughput [12], and reducing energy consumption [11] of the UEs. The authors of [10] and [13] propose different distributed coalition formation algorithms where the UEs can make the decision on group formation by utilizing the local information. In [10], the UEs in the group can randomly download parts of the requested content and exchange it with other UEs. In [13], the UEs are grouped according to the Bluetooth technology, where one UE can join the group if there is enough bandwidth on the short range communications (SR) between the group head and joining UE. In [12] and [14], authors concentrate on the maximization of multicasting rate on long range communications (LR) between BS and the UEs. The authors of [18] and [19] introduce the scheme to further improve the energy efficiency D2D communication.

The authors of [16] and [17] focus on the power saving schemes for wireless distributed computing networks. The authors of [21] and [22] have also investigated the energy efficiency development in different application cases. However, these contributions concentrate more on the power saving performance of computing tasks rather than of communications. We proposed the CMC framework and examined the condition of obtaining energy saving by using CMC. We were able to show that the energy saving gain can be obtained when the the data rate of SR is better than the one of LR in [20]. In [23], [24], we also evaluated different transmission strategies within CMC, such as multicasting and unicasting, in terms of energy efficiency. Previous work on coalition formulation and clustering usually consider from the point-of-view of either BS or UE and does not explore BS-UE interaction. Moreover, social factors and fairness are usually ignored. Therefore, a careful design of grouping and scheduling algorithm from both BS and UE sides is critical.

There has been a lack of attention towards energy-efficient CMC development concerning how we can properly select users, and when and how the user should come to join the cluster. To this end, investigation of efficient and practical algorithms is of particular research importance.

C. CONTRIBUTIONS

On the way towards designing a green mobile cluster, the formulation of CMC to determine which and when the UE is able to participate to receive data from BS so that the total energy consumption can be minimized is of significance. In this work, we first present the formulation of CMC, and explore its potential on energy saving among mobile users correspondingly. The power consumption and energy consumption models of using unicasting and multicasting transmission inside CMC are presented accordingly. Then we introduce user selection and scheduling algorithms for CMC and the energy efficiency gain and fairness among UEs are the prime target. The achievement can be used for the network designers and standardization groups to build up standardized content distribution and sharing mobile cluster protocols in the future. Comparing with the existed works, the main contributions of this work can be summarized as follows:

1) Aiming at reducing the energy consumption at the terminal side, we introduce the problem of CMC formulation from the energy saving point of view. A centralized algorithm is introduced for joint content distribution, cluster formulation and user scheduling. In the centralized scheme, a candidate list is first created, containing the users who have the potential to be selected to minimize energy consumption on LR and SR links. Then, the problem of user selection and scheduling in BS and UEs interaction is also formulated based on the candidate list. Social dimension is introduced during scheduling so that fairness among the group can be guaranteed and none of the UE's batteries can be drained during the transmission process. We also discuss some practical issues such as the way to alleviate the additional transmission overhead that centralized scheme may bring.
2) In addition to the centralized algorithm, we also present a game theoretic distributed scheme, where the decision of cluster formulation can be taken by the UEs themselves through local information exchange and distribution. The Nash Bargaining theory process is brought to solve the formulated problem. A utility function which considers both energy consumption and user contributions is invoked for individual user to evaluate who should be the cluster head.
3) Several remarks are made in order to further explore the system model and the proposed algorithms. Advantages as well as disadvantages are presented and discussed, which helps to point out the future research directions.
4) We analyze the properties of our proposed algorithms with the help of extensive simulations. Various parameters are examined in order to observe their impacts on the presented scheme. Both energy consumption of CMC UEs and fairness among the UEs have been used as performance metrics. The observations are illustrated with proper figures.

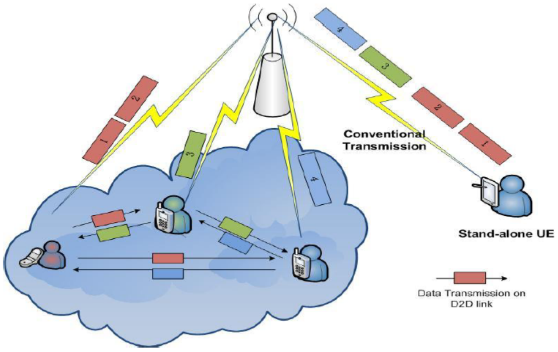

FIGURE 1. Collaborative mobile clusters.

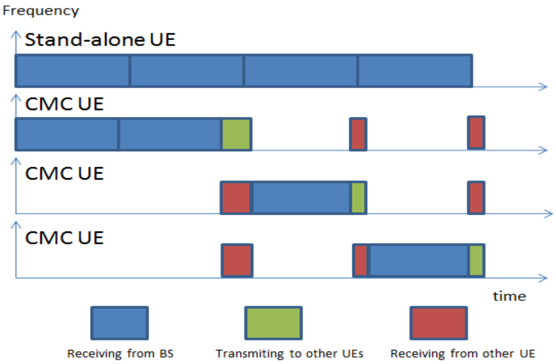

FIGURE 2. CMC transmission vs. conventional transmission.

The reminder of this paper is organized as follows. The system model and energy consumption analysis are described in Section II. In Section III, we formulate the problem and present the proposed centralized and distributed schemes for CMC formulation. In Section IV, simulation results are illustrated. We finally conclude our work in Section V with discussions on the proposed schemes.

II. SYSTEM MODEL AND ENERGY ANALYSIS

A. SYSTEM MODEL AND PROBLEM STATEMENT

In the considered system, CMC is formed by a number of UEs that are close to each other and about to download from a BS. The UEs are able to actively use two wireless interfaces: one to communicate with a BS over a Long-Range (LR) wireless technology (such as UMTS/HSPA, WiMAX, or LTE) and one to cooperate with the other UEs over a SR communication link (such as Bluetooth or WLAN).

Fig. 1 presents an example where CMC is formed by 3 UEs. In a traditional setup, the BS either unicasts the data to each requesting UE on different frequency bands or multicasts once to all requesting UEs (as the "Stand-alone" UE does in Fig. 2). In either case, the communication interface of each UE has to remain active for the whole reception duration, which results in high energy consumption due to the required radio frequency (RF) and baseband processing during data reception.

When all the UEs are willing to participate in the formulation of a CMC, we are able to utilize the SR transmission among UEs to reduce the energy consumption. In the CMC, one UE only needs to offload a part of the required content over the LR link and unicast/multicast it over SR links to other UEs within the CMC, as shown in Fig. 2. Therefore, on the LR link, the receive time will be seriously reduced. The considered transmission process can be depicted as follows,

1) First, BS transmits to the first UE instead of all.
2) The UE receives from BS and shares the received data with the other two UEs.
3) The second UE becomes the scheduled one. So after receving from BS, it can transmit the received parts to other UEs.
4) The third UE is assigned to receive data from BS and share the received parts to other UEs.

As such, the time that communication interface remains active can be seriously shortened and the corresponding energy consumption can be reduced. However, when exchanging information over SR wireless interface, the transmission overhead, such as additional transmit power for multicasting data to other UEs and receive power for receiving from the other UEs have to be considered. Therefore, the scheduled UE also contributes its own transmit power for data sharing within CMC. Ideally, all the UEs participating in the CMC should voluntarily receive assigned data. However, in practice, due to the diversity of channel and battery conditions of individual UE, the cluster formulation and data assignment may be different from ideal case. For example, if one UE has been assigned data several times, it should be selected with a lower probability in the following rounds. Thus, our objective is to minimize the energy consumption of UEs by proposing user selection and scheduling within each scheduling interval for CMC.

B. NOTATIONS

Some key parameters concerning the grouping and scheduling process are given in Table 1. Moreover, in the following, we may also use cluster head stands for the UE which takes the responsibility to receive the assigned data from the BS and transmit it to other UEs in the CMC.

C. ENERGY CONSUMPTION FORMULATION

1) ENERGY CONSUMPTION ON LR

Energy consumption minimization is the optimization objective for designing a user scheduling and selection scheme in CMC. As we know, the energy consumption can be modeled as a linear function containing the power consumption and the time duration. Therefore, the energy consumption of UE k when receiving data size S_T from BS can be expressed as

$$E_k^{L_{rx}} = (P_k^{L_{rx}} + P_E)T_k^{L_{rx}} = \frac{(P_{rx} + P_E)S_T}{R_k^L}, \tag{1}$$

where $T_k^{L_{rx}} = \frac{S_T}{R_k^L}$ is the time duration for receiving data S_T on LR. Further, we can assume, for simplicity, the receive RF energy consumptions are the same for both LR and SR links,

TABLE 1. Energy consumption model parameters.

Parameter	Description
$\mathcal{K}$	CMC set,
K	The number of requesting UEs;
S_T	The size of the content to be sent;
R_k^L	Data rate of LR link from BS to UE k;
$R_{k,n}^S$	Data rate of unicasting on the SR links from UE k to UE n;
$R_k^{S,m}$	Data rate of multicasting on the SR links from UE k to other UE n;
P_k^{Lrx}	Receive RF power unit consumed by the UE k during reception on the LR link;
$P_{k,n}^{Stx}$	Transmit RF power unit consumed by the UE k in order to transmit to UE n on the SR unicast transmission;
$P_k^{Stx,m}$	Transmit RF power unit consumed by the UE k on the SR multicasting;
$P_{k,n}^{Srx}$	Receive RF power unit consumed by the UE n during receiving from UE k on the SR transmission;
$P_k^{Srx,m}$	Receive RF power unit consumed by the UE k during reception on the SR multicasting;
P_E	Baseband electric circuit power unit consumed by the UE.

i.e., $P_k^{L_{rx}} = P_k^{S_{rx}} = P_{rx}$ for simplicity. After receiving from the BS, UE k transmits its offloaded data to other required UEs. There are two conventional ways to share data over CMC: unicasting and multicasting. We present the energy consumption analysis on both schemes, respectively.

2) ENERGY CONSUMPTION OF UNICASTING SR

During the unicasting transmission, an UE k has to transmit the data to each UE on different frequency bandwidths. In order to reach UE n, the transmit energy consumption of UE k can be expressed as [20]

$$E_{k,n}^{S_{tx}} = (P_{k,n}^{S_{tx}} + P_E)T_{k,n}^{S_{tx}} = \frac{(P_{k,n}^{S_{tx}} + P_E)S_T}{R_{k,n}^S}. \tag{2}$$

The energy consumption of UE n when receiving from UE k is given as follows,

$$E_{k,n}^{S_{rx}} = (P_{k,n}^{S_{rx}} + P_E)T_{k,n}^{S_{rx}} = (P_{rx} + P_E)T_{k,n}^{S_{tx}}, \tag{3}$$

where it is observed that $T_{k,n}^{S_{rx}} = T_{k,n}^{S_{tx}}$. Therefore, if unicasting is invoked as the transmission strategy, the total energy consumption by using UE k as the data transmitter in a CMC can be expressed as

$$E_k^{uni} = \sum_{n,n\neq k}^{K} \left(E_{k,n}^{S_{tx}} + E_{k,n}^{S_{rx}}\right) + E_k^{L_{rx}}. \tag{4}$$

3) ENERGY CONSUMPTION OF MULTICASTING SR

If multicasting is used as the CMC transmission strategy, UE k only needs to broadcast its data once to the other UEs with a data rate that can reach the UE with the worst channel condition. Thus, the transmit power is given as

$$E_k^{S_{tx},m} = (P_k^{S_{tx},m} + P_E)T_k^{S_{tx},m} = \frac{(P_k^{S_{tx},m} + P_E)S_T}{R_k^{S,m}}, \tag{5}$$

where $R_k^{S,m} = \min_{n\in\mathcal{K}} R_{k,n}^S$ is the data rate of multicasting and $P_k^{S_{tx},m} = \max_{n\in\mathcal{K}} P_{k,n}^{S_{tx}}$ is the transmit RF power consumption on SR multicasting. Therefore, the total energy consumption by using UE k as the transmitter in a CMC can be expressed as

$$E_k^{mul} = E_k^{S_{tx},m} + E_k^{L_{rx}} + \sum_{n,n\neq k}^{K} E_n^{S_{rx},m}, \tag{6}$$

where $E_n^{S_{rx},m} = \frac{P_{rx}S_T}{R_k^{S,m}}$ is the energy consumption of each UE when receiving from the transmitter.

4) ENERGY CONSUMPTION WITHOUT CMC

If there is no cooperation among the UEs, each UE has to download all the content on its own. With the assumption that multicasting is used for LR, the energy consumed by all K UEs is given as

$$E^{no-coop} = \sum_{k}^{K} E_k^{no-coop} = \sum_{k}^{K} \frac{(P_k^{L_{rx}} + P_E)S_T}{R_k^L}. \tag{7}$$

5) POWER CONSUMPTION MODEL

As we can observe from the above energy consumption analysis, the energy consumption model is related to the transmit power consumption and transmit/receive time duration of the involved transmit and receive process. There are some existed power consumption models that have been validated through theoretical and experimental works. We introduced the ones used in [16], [17], [20] and [26].

There are K UEs requiring the same content from BS. For a UE k which will participate in forming CMC, the transmit power and receive power consumptions of RF front-end for delivering message can be expressed as [20],

$$P_{k,n}^{S_{tx}} = \alpha_1\gamma_{min}WL_{k,n} + \alpha_2, \tag{8}$$

$$P_{k,n}^{S_{rx}} = \alpha_2, \tag{9}$$

where α_1 and α_2 depend on the transceiver components and channel characteristics. In particular, α_1 is related to transmitting actions on/after power amplifier (PA), such as antenna and channel gains. α_2 depends on transceiver RF circuit components, e.g., local oscillator and Digital-Analog Converter (DAC)/Analog-Digital Converter (ADC) for processing data on one subcarrier. $L_{k,n}$ is the path loss between UEs k and n, and W is the transmission bandwidth. For multicasting transmission, we also have $P_k^{S_{tx},m} = \max_{n\in\mathcal{K}} P_{k,n}^{S_{tx}}$. γ_{min} is the minimum required Signal-to-Noise Ratio (SNR) at the receiver, which is related to the Bit-Error-Ratio (BER) requirement. Without loss of generality we can take QAM modulation as an example, which would result in [25],

$$\gamma_{min} = \frac{2}{3}(2^b - 1)ln\frac{4(1-2^{-b})}{BER_{req}}, \tag{10}$$

TABLE 2. Tx/Rx power consumption related parameters.

Parameter	Description	Value
η	PA nonlinearity	0.2
ϑ	PA parameter	174 mW
k_B	Boltzmann Constant	1.3806×10^{-23} J/K
T_o	Temperature	300K
NF	Noise Figure	9 dB
σ_s	Shadow fading standard deviation	12 dB
G_t	TX antenna gain	2 dBi
G_r	RX antenna gain	2 dBi
λ	Signal wavelength	0.15(2GHz)
LM	Link margin	15 dB
W	Transmission Bandwidth	0.2 MHz
d_o	Near field distance	15m
p_{out}	Channel outage probability	1%
P_{DAC}	Power of DAC	15.4mW
P_{RF}	Power of other RF device	131.5 mW

where BER_{req} is the BER requirement at receiver and b is the modulation order. Also, α_1 and α_2 can be expressed as [16],

$$\begin{aligned}\alpha_1 &= \frac{\eta k_B T_o NF(\sigma_s)^{-Q^{-1}(1-p_{out})}(4\pi)^2}{G_t G_r \lambda^2 d_o^{-2}} LM,\\ \alpha_2 &= P_{DAC} + P_{RF} + \vartheta, \end{aligned} \tag{11}$$

where Q^{-1} is the inverse Q function. The explanation and possible values of the parameters are shown in Table 2. The power dissipation for baseband signal processing is presented in [26].

III. GREEN MOBILE CLUSTER SCHEDULING ALGORITHM

A. PROBLEM FORMULATION

Due to the fact that simultaneous transmission to various UEs requires more frequency resource than the conventional multicasting, it is wise to schedule a different UE in each scheduling time on the same bandwidth. In the context of user scheduling, many questions arise. When and which user should be assigned for transmission? How the user should join the cluster? The formulated problem is more complicated than that of simultaneously transmitting different data parts to various UEs.

To start with, we use a binary variable ρ_k as the user scheduling indicator,

$$\rho_k = \begin{cases} 1, & \text{if UE } k \text{ is chosen for data assignment,} \\ 0, & \text{otherwise.} \end{cases} \tag{12}$$

Similarly, we denote another indicator $\upsilon_{k,n}$ as

$$\upsilon_{k,n} = \begin{cases} 1, & \text{if } k \text{ transmits data to } n, n \neq k \\ 0, & \text{otherwise.} \end{cases} \tag{13}$$

Therefore, when unicasting is used for SR, for each data segment with size S_T, the energy consumption objective can be expressed as

$$E_{obj}^{uni} = \sum_k \rho_k E_k^{L_{rx}} + \sum_k \sum_{n,n\neq k} \upsilon_{k,n}(E_{k,n}^{S_{tx}} + E_{k,n}^{S_{rx}}). \tag{14}$$

The problem of user scheduling can be formulated as

$$\min \; E_{obj}^{uni}, \tag{15}$$

$$\begin{aligned} \text{s.t. } C1 &: \sum_k \rho_k = 1; \\ C2 &: \upsilon_{k,n} \leqslant \rho_k; \\ C3 &: \sum_{n,n\neq k} \upsilon_{k,n} + \rho_n = 1; \end{aligned} \tag{16}$$

The first constraint **C1** in (16) guarantees that only one UE k can be selected in each scheduling interval on LR. **C2** ensures an UE k can retransmit to another UE n on SR. **C3** ensures each UE n receives the content either on LR or SR. Similarly, if multicasting is used for SR inside CMC, the energy consumption optimization objective becomes

$$E_{obj}^{mul} = \sum_k \rho_k E_k^{L_{rx}} + \mathbb{1}(\sum_{n,n\neq k} \upsilon_{k,n})(E_k^{S_{tx},m} + E_k^{S_{rx},m}), \tag{17}$$

and the optimization problem becomes

$$\min E_{obj}^{mul}, \tag{18}$$

where

$$\mathbb{1}(\sum_{n,n\neq k} \upsilon_{k,n}) = \begin{cases} 1, & \text{if } \sum_{n,n\neq k} \upsilon_{k,n} \geqslant 1, \\ 0, & \text{otherwise.} \end{cases} \tag{19}$$

and the constraints of (18) are the ones in (16). $\mathbb{1}(\sum_{n,n\neq k} \upsilon_{k,n}) = 1$ means that the chosen UE k transmits to other UEs. The above optimization problems are mixed integer programming problems which aim to find the UE that can minimize the energy consumption for receiving from the BS and delivering data to other UEs. In other words, for both problems (15) and (18), we need to find a user that can provide target data rate for other UEs inside CMC with minimum energy consumption. The complexity of solutions at the BS side could be very high since for each scheduling, the BS needs to evaluate the related information of all K UEs. In practice, such information is not easy to be obtained by the BS. In addition, if only (15) and (18) are invoked as selection criteria, there is a high possibility that some UEs' batteries can be drained due to the frequent data assignments. Therefore, we are going to propose different algorithms to address the problem of gathering UEs to form a CMC.

B. CENTRALIZED SCHEME

To minimize the energy consumed by distributing a single data part of S_T, the selected UE k should satisfy

$$k^* = \arg\min_k E_{obj}^{uni/mul}. \tag{20}$$

Although when k^* is chosen to receive data on LR, optimal solution for minimizing energy consumption is able to be provided, it may lead to a situation that one user can always be selected no matter how much battery it has. Therefore, in our proposed scheme, a candidate list is created based on value of (20) for BS to make further decision on which user should be assigned to receive data.

At first, we use a contribution factor to measure the individual user's effort (e.g., downloaded volume), that is

$$\varepsilon_i = \frac{\xi_i}{\sum_i^K \xi_i}, \tag{21}$$

where ξ_i is the number of data segments that are sent to UE i. If ε_i is close to one, the UE is the one that has contributed the most in downloading the content in term of the energy cost on LR air-interface. For each user i in the candidate list, we define a social fairness factor of the content download as

$$U(\varepsilon_i) = (1 - \varepsilon_i)^{1/\beta}, \tag{22}$$

which is a decreasing function of ε_i. $U(.)$ is used to capture the social fairness consideration of BS when BS selects the UEs. Therefore, if an UE has contributed more than the others in a CMC, the social factor of this UE will be smaller than the one of the others. We refer to $\beta > 0$ as the fairness index and effectiveness of β is illustrated in the simulations. Therefore, at each scheduling time, BS should select the user as the head according to following rule,

$$\max_i \; U(\varepsilon_i) log(1 + \gamma_i), \tag{23}$$

$$\text{s.t. } E_{i,re} - E_i \geq E_{ma}, \tag{24}$$

where

$$E_i = \begin{cases} E_i^{L_{rx}} + E_i^{S_{tx},m}, & \text{if multicast,} \\ E_i^{L_{rx}} + \sum_{n,n\neq i} E_{i,n}^{S_{tx}}, & \text{if unicast,} \end{cases} \tag{25}$$

and γ_i is the SNR of user i in the LR. $E_{i,re}$ is the remaining energy of user i and E_{ma} is the energy for UE maintenance which must be left after downloading content.

Now, the solution for user scheduling can be arrived. First, the UE who is willing to join to the CMC will be evaluated to see the transmit energy consumption if being selected for transmission. Then a candidate list based on the evaluation is generated and reported to BS. After taking the social fairness factor and energy consumption of UEs into consideration, the BS finally schedules one UE as the receiver in this scheduling duration. One can arrive at the solution as follows,

$$\rho_k^* = \begin{cases} 1, & \text{if } k^* = \arg\max_k U(\varepsilon_k) log(1 + \gamma_k), \\ 0, & \text{otherwise.} \end{cases} \tag{26}$$

The algorithm is summarized in Fig. 3. In a certain schedule interval, a candidate list is created containing the ID/info of UEs and sorted in a ascendant order according to the UEs's capabilities to minimize energy consumption, e.g., (20). Then the list is transmitted to the BS which evaluates the UEs in the list according to (23) and the constraint in (24). The decision is made based on its evaluation and the data is delivered to the chosen one.

C. DISTRIBUTED GAME THEORETIC SCHEME

Here, a distributed solution is presented for the introduced problem, in which the UEs are able to take autonomous decisions on whether or not to join the cluster in order to be the head or not. In the introduced distributed algorithm, instead of waiting for the BS decision, UEs can exchange local information to make the a cooperation decision to elect the cluster head. For the considered system, the UE's individual goal is to align those in the networks and decide which one should be the head to receive the data assignment from the BS. Thus, the UEs perform cooperation, in a way as to benefiting the networks by reducing their overall energy consumption. Essentially, the cluster formulation and user scheduling in a distributed manner can be viewed as a cooperative game [27]–[29].

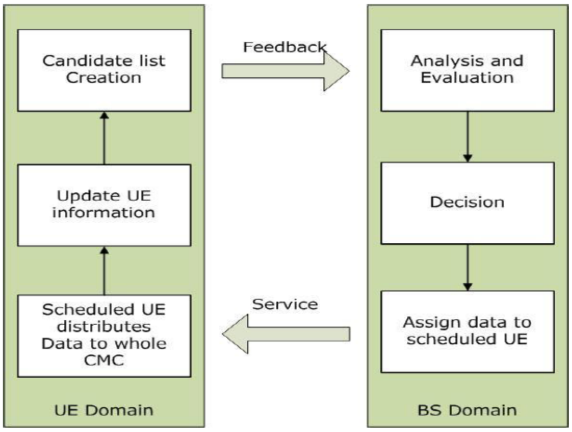

FIGURE 3. Flowchart of centralized algorithm.

1) NASH BARGAINING GAME

In the cooperative game, each UE has a payoff/utility function to evaluate its own benefit and cost when in the role of the head. To ensure fairness among the UEs, we formulate the problem as the Nash Bargaining game. We consider each UE as a player (in this section, both terms UE and player are used interchangeably) who wants to maximize its payoff (considered to be its energy savings), or equivalently, who wants to minimize its energy consumption.

Firstly, we denote $\mathcal{S}$ as the set of all feasible payoffs that the UEs can obtain. We also assume that if no agreement is reached, which means that UEs do not cooperate, they get a utility denoted by $d = (d_1, \ldots, d_K) \in \mathcal{S}$ for each UE where $d_k = (N - n)E_k^{no-coop}$, where N is the total data segment/transmit time interval and n is one certain time. In other words, if there is no agreement in the scheduling interval n, the cluster will be dismissed. Consequently, the loss for UE k as a result of no agreement will be the energy consumption when the traditional unicast/multicasting services are used in the rest of the time. Apparently, obtaining ρ_k in (12) is the solution to this problem. Thus, we denote $\rho = (\rho_1, \ldots, \rho_K)$ as one strategy solution set of the Nash Bargaining problem and $b_k(\rho)$ as the payoff when ρ is used. We have

$$b_k(\rho) = \begin{cases} E_k^{L_{rx}} + E_k^{S_{tx},m/n}, & \text{if } \rho_k = 1, \\ E_k^{S_{rx},m/n}, & \text{otherwise,} \end{cases} \tag{27}$$

where $E_k^{S_{tx},m/n} = \sum_{n,n\neq k} E_{k,n}^{S_{tx},n}$. Here we advocate the generalized Nash Bargaining Solution (NBS), which is

$$\rho = \arg\max_{\rho\in S} \prod_{k}^{K} (d_k - b_k(\rho)), \tag{28}$$

$$\text{s.t. } \rho_k \in \{0, 1\}, \quad \sum_k \rho_k \leq 1, \tag{29}$$

where $\rho_k = 1$ means that the UE will be selected to receive from BS and $\sum_k \rho_k \leq 1$ ensures that for each time only maximum one UE is selected. In this formulated problem, each player's objective is to minimize the energy consumption of the system (corresponds to the problem in (15) or (18), or equivalently maximize the energy saving. In case of no agreement is reached, each player only obtain the data through LR link and the energy consumption of play is d_k and energy saving is then zero.

In the game theory, when analyzing the K-person bargaining problem, the cooperative solution should satisfy five axioms, i.e., invariance, individual rationality, pareto efficiency, independence of irrelevant alternatives, and symmetry. The uniqueness and existence of NBS can then be proved through game theory [30]. Thus, we can obtain the optimal UE at each scheduling time. The problem of (28) can be solved easily through some well known schemes, e.g., proportional fairness (PF) resource allocation method [31] when the logarithm is taken for (28).

2) PRACTICAL NEGOTIATION PROCESS

Since the payoff in our work needs to be updated at each game stage, information exchange among the UEs is necessary. Typically, the signalling or negotiation can be performed over a control channel (e.g., the ad-hoc temporary control channel [32]). In order to mitigate the transmission overhead induced by sharing and updating, we advocate a new method of the information exchange process. That is, only the cluster head who is transmitting the data multicasts its updated payoff. Simply, the message containing updated payoff can be attached to the data transmission and multicast/unicast to others. The UEs in the coalition compare the head's payoff with their own. If one UE finds its payoff is better than the received one, the UE will broadcast a message that it will take the responsibility to be the one receiving from BS. If there are more than one UE whose payoff is bigger than that of the head, they can compare the received message and finally the one with the best payoff can be self-elected.

D. REMARKS

There are several remarks on the proposed schemes.

1) In this work, CMC is formed by multiple UEs. However, the application of CMC should not be limited by user cooperation. It is also reasonable to form a CMC with different devices, such as femtocell/HeNB etc, when neighbours like to download same multimedia contents. Although HeNB is usually empowered by electricity supply, it is worth investigating how to save energy consumption of HeNB.
2) The first selection criteria indicates that the UEs which can minimize the energy consumption on SR will be selected to form the candidate list. Thus, the UE at the first position of the list is the one who can induce the smallest energy consumption when distributing data. The second selection criteria (23) is able to take the LR transmission rate into consideration, which can even reduce energy consumption on the BS side.
3) Criteria (23) can ensure the fairness among UEs as well. For example, if on the candidate list the second UE contributes nothing compared to the first one, the least contributing terminal could be chosen due to the use of social fairness $U(\varepsilon_i)$. The constraint (24) implies that the algorithm selects the terminal whose energy level is sufficient enough to distribute the received data on LR. In addition, the life-time of each UE is guaranteed by E_{ma}.
4) One may notice that in the centralized algorithm, the candidate list creation depends on the UEs' capabilities of obtaining the energy consumption information related to reaching the other UEs. To procure such cognitive sensing-like capability, additional redundancy and modifications to the current devices are required. To alleviate the induced transmission overhead, some other methods can be used instead of that of creating a list. For example, UEs only report to the BS a list with information about UE willing to join the cluster. Then BS can monitor the energy level of each UE through feedbacks. At the beginning of scheduling, Round-Robin or other well-known schedulers can be applied so that the BS gets the information about the energy consumption of individual UE when UE distributes the received data. After obtaining the information of all CMC UEs' energy consumption, the BS has the similar knowledge as the one can be obtained through the context of candidate list in the previously presented scheme. Although in this method, energy consumed is expected to be higher than in our proposed scheme due to the scheduling at the beginning phrase, it does not require modifications or transmission overhead to the UEs.
5) It is worth noticing that the distributed scheme requires local information exchange among UEs. Thus, additional signalling transmission and overhead may be involved. Another disadvantage is that compared to conventional multicasting algorithm, the cluster head need to first receive data and then multicast it due to hardware limitation, which could induce time delay. Therefore, the algorithm is designed for delay-incentive applications.

IV. PERFORMANCE EVALUATION

A. SIMULATION SETTING

The performance evaluations are illustrated in this section. To evaluate the performance of our proposed schemes, following scenario setups are considered. We consider the UEs

TABLE 3. **Simulation parameters.**

Parameter	Assumption
distance between BS and UEs	0.5 km
Path loss model of LR	$2.7 + 42.8log(d)$
central frequency	2 GHz
Bandwidth	15 kHz
Path loss model of SR	$9.95 + 35log(d)$
P_u^{max}	20 dBm
BER_{req}	1 bps/Hz

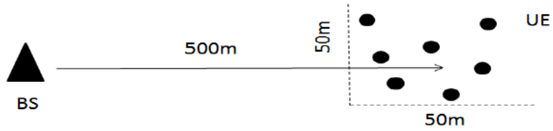

FIGURE 4. **Simulation scenario.**

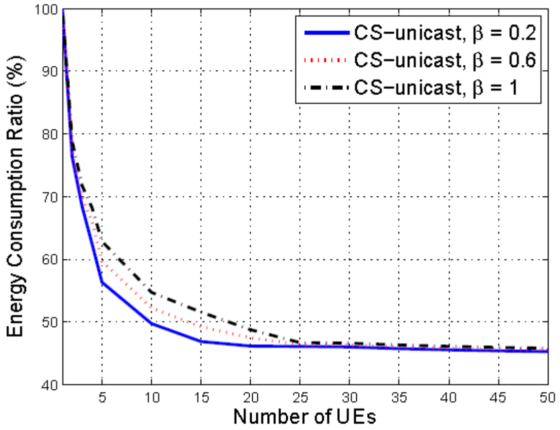

FIGURE 5. **Energy consumption ratio of CS using unicasting.**

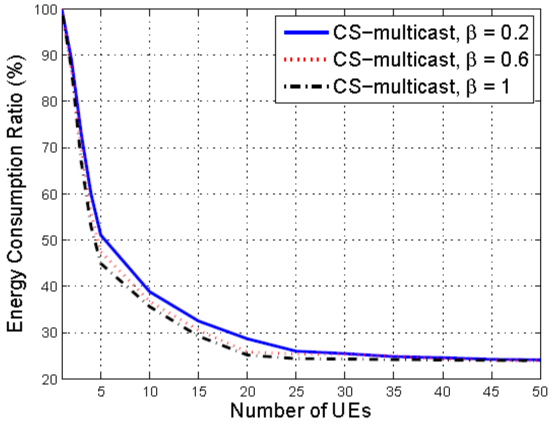

FIGURE 6. **Energy consumption ratio of CS using multicasting.**

are randomly located in a $50m \times 50m$ square. The BS is located about $500m$ from the UEs. The simulation scenario is shown in Fig. 4. The node in the simulations is considered to be static. Monte Carlo method is used for running the simulation and obtaining the simulation results. We invoke both energy consumption of the CMC as well as the fairness index as the evaluation criteria to present the performance of the proposed schemes. Besides the parameters depicted in Table 2, simulation parameters of channel model are summarized in Table 3. We consider $S_T = 1$ for simplicity. Three proposed schemes, which are Centralized Scheme (CS), Centralized Scheme with Practical Consideration (CS-PC) and Distributed Game Theoretic Scheme (DGTS), are demonstrated together with different parameters.

B. SIMULATION RESULTS

Without loss of generality, we capture the energy consumption performance with an energy consumption ratio (ECR) obtained by comparing the energy consumption of all UEs that use CMC to receive data to the energy consumption of all UEs that receive data individually via traditional multicasting. that is

$$\mathrm{ECR} = \frac{\text{Energy consumption using CMC}}{\text{Energy consumption of traditional multicast}} \times 100\%. \tag{30}$$

By such comparison, energy saving gain can be easily observed. In Figs 5 and 6, the energy consumption performance of CS is shown with a different value of β. As we can see, when there is only one UE, the energy consumption ratio is 100%, which means that there is no energy saving in such a scenario. It can also be observed when there are more UEs in the cluster, the CMC can achieve energy saving gain for the UEs. For example, when there are about 5 UEs, the energy consumption ratio is about 45%, which means that 55% energy can be saved. Meanwhile, the change of β has less impact when there are less than 5 UEs in the CMC, since there are less choices for UE selection. When CMC consists of more UEs, the difference of using different β can be observed. However, when there are too many UEs, e.g., more than 30 UEs, the UE selection will be more fair among all UEs. Therefore, the impact of β on the UE selection becomes smaller. It can be also found that the energy consumption ratio is up to around 25%, which means that 75% energy is saved comparing with the conventional multicasting. Meanwhile, as the number of UEs increases, the energy saving gain becomes relatively stable. In other words, when there are more than $20 - 25$ UEs forming a CMC, hosting more users would not result in a significant improvement in energy saving. One reason is that due to the transmission overhead, i.e., transmit and receive energy consumption inside a CMC, the energy consumption performance will be stable. Another reason is that as there are more UEs, there are more options for user scheduling and the scheduling will be fairer among all UEs. Third, although different values of β result in different performance when the number of UEs is small, the performance gap is quite minor when there are more UEs (e.g. 50) forming a CMC. Therefore, a different combination of parameters can be selected, based on the services or practical situations, when performing user grouping and scheduling.

In Fig. 7, we change the value of β as well as the number of UEs and compare the CS with CS-PC. Basically, β in (22) captures the fairness consideration of BS when

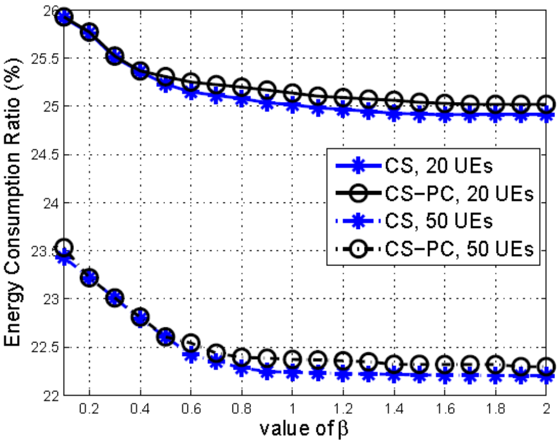

FIGURE 7. Energy consumption ratio of CS vs CS-PC, different value of β.

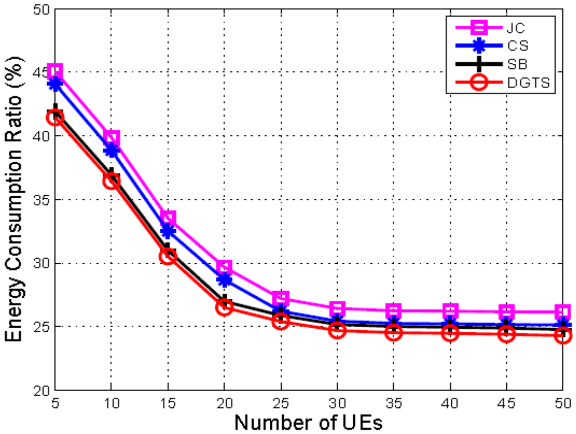

FIGURE 8. Energy consumption ratio of different schemes, different number of UEs.

selecting UEs for data delivery. From (21) and (23), one can also see that when smaller β is used, all terminals are forced to download the content more equally due to the social fairness consideration in (23). The scheduler with larger β, e.g., $\beta = 0.5$ has an unequal situation, which means that each CMC member is required to sacrifice itself for the other members in terms of the cost of airtime or the energy. In this case, the CMC can be considered as a group of family or close friends. When $\beta = 1$, we can see, mathematically that the scheduling algorithm becomes insensitive to ε_i and whether the UE should be allocated for packet only depends on its channel quality to BS. It can be observed that CS-PC and CS have similar performance in term of energy saving. Due to the fact that the CS-PC requires some additional time for BS to obtain the energy consumption status of each UE, the CS has slightly superior performance. Moreover, the performance of DGTS and CS are also presented in Fig. 8 when multicasting is used as both LR and SR. In this figure, we also compare our proposed schemes with the algorithms in [33] and [34]. The algorithm named "JC" is presented in [33], where a user selection algorithm is proposed with the joint consideration of user's energy, LR data rate, distance to other users, and mobility. Each of these factors is assigned with a fixed weight and they are jointly considered together as the selection criteria. We assume their weights are equal in this figure. The Select Best (SB) is modified from the proposed scheme in [34], the target of which is to select the user with best channel qualities of both LR and SR. Both JC and SB are considered to be centralized schemes, where extra information exchange between BS and UEs is needed. It can be found that the distributed algorithm has superior energy saving performance over the centralized one and JC has the worst energy saving gain. It can also be observed that SB has the similar performance to that of DGTS. This is mainly due to the reason that in the SB and DGTS, user fairness is considered less. Therefore, before making any decision, the UE only measures the benefits, i.e., the energy saving gain, without exploring the fairness inside CMC.

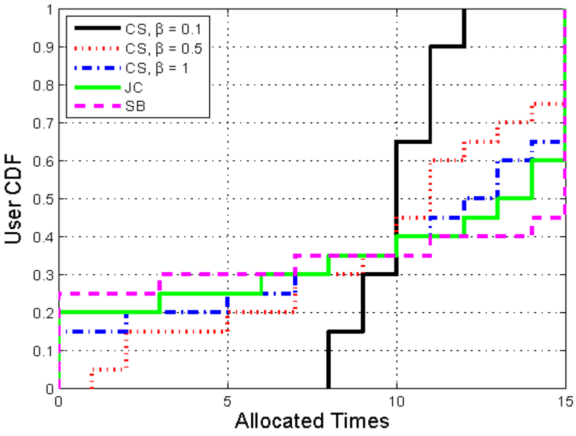

FIGURE 9. CDF of data allocated times per UE, 50 UEs.

In Fig.9, on x-axis we present the times of data allocation and on y-axis, we have the CDF of UE. The CS performance is illustrated in Fig.9 together with the performance of JC and SB: the bigger value of β results in unfairness due to its insensitivity to ε_i and the selection criteria mainly relies on the UEs' locations and their positions in candidate list. For example, when $\beta = 0.1$, almost all the UEs are assigned data equally, around 10 times. It can be observed that SB has the worst fairness performance. Due to the consideration of UE's energy, JB obtains better performance than SB. Because more assigned data implies more energy consumption at UE, our proposed CS scheme can obtain user fairness in term of energy consumption.

V. CONCLUSION

In this work, we first exploit the energy saving benefits of collaborative mobile clusters (CMC). Aiming to decrease the total energy consumption of UEs, we study the CMC model, which is formed by a number of collaborating UEs. A theoretical analysis on the energy consumption of UEs within the cluster is presented as well. Moreover, both centralized and distributed user scheduling schemes are introduced in order to investigate when and how the users should participate forming the cluster and receiving the assigned data. The proposed centralized scheme takes both the BS and UE aspects into consideration and tries to find the trade-off between energy consumption reduction and fairness. The distributed scheme allows the UEs to take autonomous decisions on forming the cluster. The simulation results present the energy saving benefits of using CMC and illustrate our proposed schemes from user fairness aspects as well.

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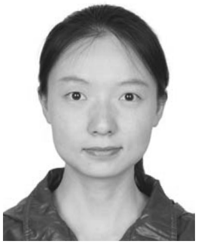

YUN HU received the B.S. degree in communications engineering, the M.S. degree in electronics and communications engineering, and the Ph.D. degree in military communications engineering from Xidian University, Xi'an, China, in 2010, 2013, and 2017, respectively. She is currently a Lecturer at the National Demonstration Center for Experimental Electronic Information and Communication Engineering Education, Xidian University, Xi'an. From October 2014 to April 2016, she was also with the University of Houston, Houston, TX, USA, as a Visiting Scholar, funded by China Scholarship Council (CSC). Her current research interests include high-speed train networks, vehicular ad hoc networks, stochastic network calculus, and martingale theory analysis.

YANHUI CHEN received the B.S., M.S., and Ph.D. degrees in electronic engineering from Xidian University, in 1994, 1997, and 2000, respectively. From 2000 to 2006, he was an Associate Professor with the School of Telecommunication Engineering, Xidian University. In 2007, he was a Visiting Scholar with the Chalmers University of Technology, Sweden. Since 2008, he has been a Professor and the Dean of the National Demonstration Center for Experimental Electronic Information and Communication Engineering Education, Xidian University. His research interests include wireless communications and networking, embedded communication system on chip, and brain-like communication networks. He is a member of special committee on embedded system in China Computer Federation.

ZHENG CHANG (Senior Member, IEEE) received the B.Eng. degree from Jilin University, Changchun, China, in 2007, the M.Sc. (Tech.) degree from the Helsinki University of Technology (currently Aalto University), Espoo, Finland, in 2009, and the Ph.D. degree from the University of Jyväskylä, Jyväskylä, Finland, in 2013.

He was a Visiting Researcher at Tsinghua University, China, and a Visiting Researcher at the University of Houston, TX, USA. He has participated in organizing workshop and special session in Globecom' 19, WCNC'18 and '19, SPAWC'19, and ISWCS'18. He received the best paper awards from the IEEE TCGCC and APCC, in 2017, the reward from the Ulla Tuominen Foundation, the Nokia Foundation, and the Riitta and Jorma J. Takanen Foundation for his research excellence. He also received the 2018 IEEE Best Young Researcher for EMEA. He has been serving as a Technical Program Committee (TPC) Member of the IEEE flagship conferences, such as INFOCOM, ICC, and Globecom. He is also a Secretary of Finland Section. He is an Editor of Springer *Wireless Networks*, *International Journal of Distributed Sensor Networks*, and IEEE ACCESS, and a regular reviewer for many IEEE journals. He was an Exemplary Reviewer of the IEEE WIRELESS COMMUNICATIONS LETTERS, in 2018. He also acts as a Guest Editor of the *IEEE Communications Magazine*, the IEEE WIRELESS COMMUNICATIONS, the IEEE NETWORK, the IEEE INTERNET OF THINGS JOURNAL, *Wireless Communications and Mobile Computing*, *Physical Communication*, *International Journal of Distributed Sensor Networks*, and *EURASIP Journal on Wireless Communications and Networking*.

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