Energy Efficient User Grouping and Scheduling for Collaborative Mobile Cloud

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Abstract—In order to fully exploit the high speed broadband multimedia services, prolonging the battery life of user equipment is critical especially for the current smartphones. In this work, we investigate the problem of designing a content sharing collaborative mobile cloud via user cooperation to reduce the energy consumption at terminal side. Given a group of users interested in downloading the same content from operator, a grouping and scheduling based algorithm is proposed in order to select the proper user in each scheduling time to obtain energy efficiency as well as user fairness. The proposed scheme takes both base station and terminal aspects into consideration and it is shown that the significant energy saving performance can be achieved without sacrificing and drawn battery of any terminal.

Index Terms—energy consumption; energy efficiency; collaborative mobile cloud; multicast grouping; user cooperation

I. INTRODUCTION

The rapidly-increasing high data rate wireless networks and fast-growing smartphone technique are continually changing our daily behaviors as well as coloring our life. The rise of online services significantly increases the frequency of users’ online activities as well. However, the demand for high data rate services is straining the current network as well as drawing battery of devices much faster than before. One class of these emerging mobile applications is simultaneous common content distribution to a group of User Equipments (UEs) over a broadband wireless network, such as news download (e.g., breaking news), multimedia multicast (e.g., live sport events), or file distribution (e.g., device configuration files/pictures).

To cope with the wireless capacity crunch and embrace emerging high data rate mobile services, novel energy efficient approaches for network design are essential. So called green communications development, including the design of energy efficient communication infrastructures, protocols, devices, and services, becomes inevitable trend in the wireless communication research. One of the proposed approaches to reduce energy consumption of UE is to design cooperative content distribution architectures with Collaborative Mobile Clouds (CMCs) where UEs not only share their personal interests and keep in touch with each other by messaging, but can also share some content and information cooperatively through Device-to-Device (D2D) or Machine-to-Machine (M2M) communications. A CMC consists of numbers of UEs that actively use two wireless interfaces: one to communicate with the Base Station (BS) over a Long-Range (LR) wireless technology (such as UMTS/HSPA, WiMAX, or LTE) and one to cooperate with other UEs over a Short-Range (SR) communication link (such as Bluetooth or WLAN).

In a traditional multicast scenario, each UE has to download the whole content on its own, which leads to significant energy consumption from UE batteries, especially if the LR data rates are low which results in long receiving time. Through the concept of CMC, several UEs that can form a coalition and cooperatively receive parts of required information data from BS, then exchange the received data with others. CMC not only can offer a potential solution for content sharing in social networks, but also is foreseeable to reduce the energy consumption of UEs [10]. In this work, we tackle the problem of optimizing energy efficiency performance of CMC. In particular, we optimize the size of CMC to determine which and when the UE is able to participate in forming the cloud and dedicate to receive data from BS. By introducing user selection and scheduling algorithms, the energy efficient gain and fairness among UEs of using CMC can be achieved.

Recently, design of a content sharing platform for mobile terminals draws increasingly interests. The existing literature on such topic aimed at either reducing energy consumption [1]–[5] of UEs, increasing the system throughput [7], or reducing the UE communication cost [8]. Meanwhile authors of [11] and [12] dedicated the work on the power saving schemes for wireless distributed computing networks. However, these contributions focus more on the power saving performance of computing rather than the one of communication. We have proposed the CMC framework in [13] and examined its potential ability in energy saving. In [14], we also evaluated different transmission strategies, such as multicast and unicast, inside CMC in term of energy efficiency. Previous work usually considered from either BS or UE point-of-view without considering BS-UE interaction. Moreover, social factor and fairness are usually ignored. Therefore, a careful design of grouping and scheduling algorithm from both BS and UE sides is critical.

The main contributions of this work can be summarized as follows. We first present the formulation of CMC and then explore its potential of reducing energy consumption and sharing content among users. The power consumption and energy consumption models are presented accordingly. Second, we introduce the problem of CMC formulation from
the user energy saving point-of-view. A candidate list is first formed according to the minimization of energy consumption on LR and SR. Then, the problem of user selection and scheduling from BS and system aspects is also formulated based on the candidate list. Social factor is introduced when scheduling so that fairness among the group is able to be guaranteed and none of UEs can be drained battery during receiving process. Two proposed algorithms will be executed iteratively in order to obtain energy efficiency and fairness among CMC.

The reminder of this paper is organized as follows. The system model and problem formulation are described in Section II. In Section III, energy consumption model of CMC is presented. The proposed scheme is introduced in IV. In Section V, simulation results are illustrated and we finally conclude our work in Section VI.

II. SYSTEM MODEL

A. Problem Formulation

In our considered system, it is assumed that a number of UEs that are geographically close to each other are interested in downloading the same content from a server via a BS using a LR wireless technology (e.g., UMTS/HSDPA, WiMAX, or LTE). The BS can unicast the content to each UE on a dedicated channel with a customized rate depending on UEs’ channel conditions, or the BS can multicast the content once to the UEs with a multicasting rate that is limited by the worst channel conditions among them. Within the CMC, UEs communicate with each other through SR transmission. The considered system model and transmission process are described in Figs. 1 and one example of the transmission procedure within CMC can be found in 2 where CMC consists of two UEs.

Remark 1: In this work, we consider our system model as multiple users forming a CMC. 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 neighbors 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.

In a traditional setup, the BS either separately streams the complete content to each requesting UE or multicasts the content once to all requesting UEs. In either case, the communication interface of each UE has to remain active for the whole reception duration depending on the length of the content. This results in high energy consumption due to the required RF and baseband processing during data reception. In the proposed scenario, we are able to utilize the SR transmission among UEs to reduce the energy consumption. Each selected user receives part of the required content over the LR link and multicasts it over SR links to other UEs within the CMC. Therefore, on LR link, the receive time will be seriously reduced. However, being exchanged over an energy efficient SR wireless technology, the transmission overhead will be brought, such as additional transmit power for multicasting data to other UEs and receive power for receiving from other UEs. In this work, we assume the establishment of a D2D network among the UEs over SR wireless links is more energy-efficient than the LR wireless link. We have discussed the condition to achieve energy efficiency of SR in [13] so it will not presented in this work. We only focus on the grouping and scheduling algorithm proposals. Our objective is to jointly determine the optimal set of coalitions among UEs in the network and the optimal user selection within each scheduling interval so as to minimize the overall energy consumption of the UEs when forming the cloud.

B. Notations

Some key parameters concerning the grouping and scheduling process are given in Table I.

III. ENERGY CONSUMPTION ANALYSIS

In this section, we introduce the energy consumption analysis containing both power consumption and energy consumption models.

A. Power Consumption Model

1) RF Front-end Power Consumption: We consider there are $K$ UEs requiring the same content from BS. For a UE $k$ who will participate in forming CMC, the transmit power and receive dissipation of RF front-end for delivering message can be expressed as [13],
Table I
GROUPING AND SCHEDULING RELATED PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>the number of requesting UEs</td>
</tr>
<tr>
<td>$S_T$</td>
<td>the size of the content to be sent</td>
</tr>
<tr>
<td>$N$</td>
<td>the number of parts the content is divided into.</td>
</tr>
<tr>
<td>$R_{S;tx}^k$</td>
<td>transmission rate on the LR links from the BS to UE $k$</td>
</tr>
<tr>
<td>$R_{S;rx}^k$</td>
<td>transmission rate on the SR links from UE $k$ to other UE</td>
</tr>
<tr>
<td>$P_{L,rx}^k$</td>
<td>RF power consumed by the UE $k$ during reception on the LR link</td>
</tr>
<tr>
<td>$P_{L,rx}^k$</td>
<td>RF power consumed by the UE $k$ during reception on the SR links</td>
</tr>
<tr>
<td>$P_{S,tx}^k$</td>
<td>RF power consumed by the UE $k$ during transmission on the SR links</td>
</tr>
<tr>
<td>$P_E$</td>
<td>Baseband circuit power consumed by the UE</td>
</tr>
</tbody>
</table>

The values of parameters are shown in Table II.

result in [15], we can take QAM modulation as an example, which would

$P_{S,tx}^k = \alpha_1 \gamma_{min} WL + \alpha_2$, \hspace{1cm} (1)

$P_{S,rx}^k = \alpha_2$, \hspace{1cm} (2)

where $\alpha_1$ and $\alpha_2$ depend on the transceiver components and channel characteristics. In particular, $\alpha_1$ is related to transmitting actions on/after power amplifier (PA), such as antenna and channel gains. $\alpha_2$ 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. $L$ is the path loss and $W$ is the transmission bandwidth. $\gamma_{min}$ is the minimum required Signal-to-Noise Ratio (SNR) at the receiver, which is related to Bit-Error-Ratio (BER) requirement. Without loss of generality we can take QAM modulation as an example, which would result in [15],

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

where $BER_{req}$ is the BER requirement at receiver and $b$ is the modulation order. Also, $\alpha_1$ and $\alpha_2$ can be expressed as [11],

$\alpha_1 = \eta k_B T_o N F (\sigma_s)^{-Q^{-1}(1 - powr)} (4\pi)^2 LM$, \hspace{1cm} (4)

\[ \alpha_2 = P_{DAC} + P_{RF} + \vartheta \]

where $Q^{-1}$ is inverse Q function. The explanation and possible values of parameters are shown in Table II.

2) Baseband Processing Power Consumption: The power dissipation for baseband signal processing can be modeled as [16]:

$P_E = (C_E + C_R R_{S,\text{max}}/R_S) R_S$, \hspace{1cm} (5)

where $R_S$ is the symbol rate of the transmission, $R_{S,\text{max}}$ is the maximum symbol rate of the transmitter, $C_E$ and $C_R$ are related to system voltage level. More detailed explanations of baseband parameters are introduced in [13].

B. Energy Consumption Model

Given the power consumption analysis, the energy consumption of receiving $S_T$ from BS can be expressed as

$E_{k,rx} = (P_{k,rx}^L + P_E)T_{k,rx}^L = \frac{(P_{k,rx}^L + P_E)S_T}{NR_{k}}$ \hspace{1cm} (6)

Further we can assume the receive RF energy consumptions are the same for both LR and SR link, i.e., $P_{k,rx}^L = P_{k,rx}^S$. After receiving from BS, UE $k$ is going to transmit its received data to other required UEs. We use multicast as the transmission strategy inside CMC since it is more bandwidth and energy efficient [13]. The transmit energy consumption is

$E_{k,tx} = (P_{k,tx}^S + P_E)T_{k,tx}^S = \frac{(P_{k,tx}^S + P_E)S_T}{NR_{k}}$. \hspace{1cm} (7)

Similarly, the energy consumption of UE $m$ receiving from UE $k$ is given as follows,

$E_{m,rx} = (P_{m,rx}^S + P_E)T_{m,rx}^S = (P_{m,rx}^S + P_E)T_{k,tx}^S$ \hspace{1cm} (8)

where we know that $T_{m,rx}^S = T_{k,tx}^S$. Therefore, the total energy consumption of UE $k$ in a CMC can be expressed as

$E_k = E_{k,tx} + E_{k,rx} + (K - 1) E_{m,rx}$. \hspace{1cm} (9)

and if the CMC consists of $K$ UEs, the energy consumption is

$E_{\text{total}} = \sum_k E_k$. \hspace{1cm} (10)

In this section, the energy consumption analysis for the proposed scheme is provided. The simulation results based on the analysis is presented in the performance evaluation section.

IV. ENERGY EFFICIENT USER GROUPING AND SCHEDULING

In order to form a mobile cloud, both BS and users are involved to make the decision on when and which user should participate in our proposed algorithm. In this scheme, at first a candidate list will be provided to the BS and BS will schedule the user from the list for receiving packages based on defined selection criteria.
A. CMC Grouping

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

$$k^* = \arg\min_{k} E_k^{S,tx} + E_k^{L,rx} + (K - 1)E_m^{S,rx}. \quad (11)$$

Although when $k^*$ is chosen to receive certain data optimal solution for minimizing energy consumption is able to be provided, it may lead to a situation that one user will be always selected no matter how much battery it has. Therefore, a candidate list could be created based on value of (9) in an ascendant order for BS to make further decision on which user should be assigned to receive data.

B. User Selection and Scheduling

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

$$\varepsilon_i = \frac{\xi_i}{\sum_{i=1}^{K} \xi_i}. \quad (12)$$

where $\xi_i$ is the number of data parts that sent to UE $i$. If $\varepsilon_i$ is close to one, then the UE is the one that has contributed the most in downloading the content in terms of the cost of using the cellular air-interface. For each user in the candidate list, we define a social fairness factor of the content download is closely related to $\varepsilon_i$. We define a social fairness function, $U(\varepsilon_i) = (1 - \varepsilon_i)^{1/\beta}$ which is a decreasing function of $\varepsilon_i$. Therefore, at each scheduling time, BS should select the user as the content receiver according to following rule,

$$\arg\max_i U(\varepsilon_i)\log(1 + \gamma_i), \quad (13)$$

s.t.

$$E_{i,rx} - E_{i,tx}^S - E_{i,rx}^L \geq E_{ma} \quad (14)$$

where $\gamma_i$ is the SNR of user $i$ in the LR. $E_{i,rx}$ is the remained energy of user $i$ and $E_{ma}$ is the energy for UE maintenance which must be left after downloading content.

C. Solution Description

Combining the proposed two scheme, the solution for user grouping and scheduling can be arrived. First, each UE who is willing to join in the CMC will be evaluated to see the transmit power consumption if being selected for transmission. Then a candidate list is generated based on the evaluation and reported to BS. After taking social factor and energy consumption of UEs into consideration, BS finally schedules one UE as receiver. The algorithm is summarized in as follows,

Algorithm 1 Description of EE Solution

1: Evaluating energy consumption of CMC users.
2: the candidate list is created according to (11)
3: for each $k$ in candidate list do
4: BS evaluates the candidate $k$ according to (13).
5: end for
6: BS selects the candidate receiver according to its evaluation that can maximize (13).

D. Remarks of Proposed Solution

1) The first selection criteria indicates that the UEs who can minimize the energy consumption on SR will be selected to form candidate list. Thus, the UE at the first position of list is the one who can induce the smallest energy consumption when distributing data.
2) The second selection criteria (13) is able to take the LR transmission rate into consideration which can even reduce energy consumption on BS side since we know that multicasting to group of UEs costs more energy than unicasting to the UE has the best channel condition among the group.
3) Criteria (13) 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 $U(\varepsilon_i)$.
4) The constraint (14) implies that the algorithm selects the terminal whose energy level is sufficient enough to
5) One disadvantage could be noticed is that compared to conventional multicasting algorithm, each coalition member consumes its energy to share its own fractional content through the D2D, which could induce delay. Therefore, the current algorithm is primarily designed for delay-incentive applications.

V. PERFORMANCE EVALUATION

The performance evaluations are illustrated in this section. We use both energy consumption of CMC as well as the fairness index as the evaluation criteria to present the performance of the proposed scheme. Simulation parameters of channel model are summarized in Table III.

In Fig 3, the energy efficiency gain of using CMC is shown with different values of $\beta$. The energy consumption ratio is defined as the energy consumption at UEs by using CMC normalized by the energy consumption of traditional multicasting networks. In this figure, we vary the number of UEs inside a $50m \times 50m$ area but the position of UEs are fixed when the size of a CMC is determined. Several observations can be made based on Fig 3. First, we see that as the number of UEs inside CMC increases, the energy saving gain arises. In the considered system model, energy consumption ratio is up to around 25%, which means 75% energy is saved comparing with the conventional P2P networks. Second, as the number of UEs increases, the energy saving gain becomes relatively stable. In other words, hosting more users would not lead to significant energy saving performance when number of users is around or higher than 20 – 25. This is mainly due to the transmission overhead inside a CMC. Third, although different values of $\beta$ result in different performance when the number of UEs is small, the performance gap is almost invisible when there are more UEs forming a CMC. Therefore, different combination of parameters can be selected based on the services or practical situations when performing user grouping and scheduling.

The fairness performance is presented as well. From (12) and (13), we see that when smaller $\beta$ is used, all terminals are forced to download the content more equally due to the social fairness consideration in (13). The scheduler with larger $\beta$, 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; e.g., in a group of family or close friends. When $\beta = 1$, mathematically we can see that the scheduling algorithm becomes insensitive to $\epsilon_i$ and whether the UE should be allocated for packet only depending on its channel quality to BS.

We can evaluate the above observation by simulations accordingly. The scenario in Fig .4 is that the positions of UEs inside CMC are varied from time to time. That is, the channel gains among UEs and from BS to UEs are changed after each scheduling time, which can be also viewed as a mobility scenario. Due to this reason, the candidate list is always recreated. In Fig .4, the fairness is examined in terms of allocated times of each UE where there are 20 UEs inside CMC and the performance is presented in terms of CDF. As we explained, one can see that when $\beta = 1$, the fairness among UEs only slightly worse that the one when $\beta = 0.1$. In addition, the performance of different $\beta$ would not differ too much and energy consumption ratios of different $\beta$ are almost remain the same as shown in the top figure of Fig. 6.

However, from Fig. 5, we can see that when the locations of UEs are fixed, which means that the UE positions in candidate list are unchanged, bigger value of $\beta$ results in unfairness.
due to its insensitivity to $\varepsilon_1$, and the selection criteria mainly relies on the UEs’ locations and their positions in candidate list. Although the fairness can not be guaranteed, the energy consumption can be reduced when bigger $\beta$ is used, which is as shown in the bottom figure of Fig. 6.

![CDF of Data Allocated Times per UE, UE location fixed, 20 UEs](image1)

Figure 5. CDF of Data Allocated Times per UE, UE location fixed, 20 UEs

![Total Power Consumption, UE location fixed/changed, 20 UEs](image2)

Figure 6. Total Power Consumption, UE location fixed/changed, 20 UEs

VI. CONCLUSION

In this work, we first exploited the energy saving benefits of using the collaborative mobile cloud. Targeting to decrease the total energy consumption of UEs, we studied a collaborative mobile cloud model, which is formed by a number of collaborating UEs. We presented a theoretical analysis on the energy consumption of UEs within the cloud. Moreover, user grouping and scheduling based scheme was introduced in order to investigate when and how the users should participate forming the cloud. The proposed scheme took both BS and UE aspects into consideration and tried to find the trade-off among energy consumption reduction and fairness. The simulation results presented the energy saving benefits of using CMC and illustrated our proposed schemes from user fairness aspects as well.

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