Collaborative Mobile Clouds: An Energy Efficient Paradigm for Content Sharing

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Abstract

On the way towards enabling efficient content distribution, reducing energy consumption and prolonging battery life of mobile equipment, an emerging paradigm, namely mobile cloud that is based on content distribution was proposed. As a mobile platform that is oriented towards content distribution, mobile cloud is also foreseen as an energy-efficient solution for the future wireless networks. The benefits of using collaborative mobile clouds (CMC) for content distribution or distributed computing from social networking aspect have been studied earlier. In this article, we first present the concepts of CMC and then discuss the energy-efficiency benefits from the system level point-of-view as well as open challenges in designing a green CMC. Moreover, we investigate the problem of forming mobile clouds for the purpose of content distribution and energy-efficiency. Specifically, given a group of users interested in downloading the same content from an operator, an energy-aware based user selection and scheduling algorithm is proposed. Simulation examples show that a significant energy-saving performance can be achieved without depleting the battery of any user equipment by the proposed scheme. Moreover, the research potential is discussed in the context of CMC as well.

Index Terms

content distribution; energy efficiency; mobile clouds; social networking; user cooperation; user scheduling; D2D

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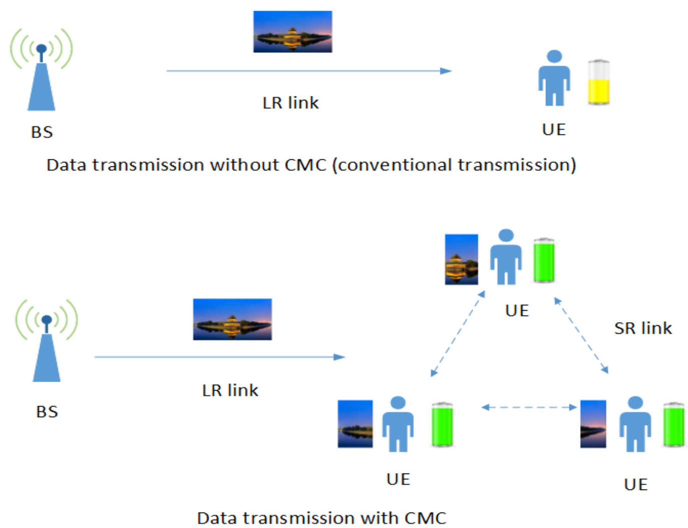

Fig. 1. Data sharing with/without CMC.

I. Introduction

With the birth of smart phones, our life is continually changing through the acceptance of boosted high speed wireless services. The emerging mobile applications including navigation, multimedia events, mobile games, social networking, mobile healthcare and commerce, make the User Equipments (UEs), e.g., smartphone and tablet, an inseparable part of our lives. However, the rise of online services while significantly increasing the frequency of users' online activities, also drown the batteries of user devices much faster than before. Moreover, typical mobile platforms are limited by their characteristics (e.g., speed of processor, size of data storage, and battery life) and communications resources (e.g., bandwidth and connectivity) [1], which hinders the development of future wireless networks as well as deteriorates the end-user experiences. Mobile cloud computing provides one solution to these problems. However, when UEs access cloud provider/server through cellular networks, the link is likely to be overloaded. Thus, a distributed computing and communications platform exploiting the computing capabilities of local devices and device-to-device (D2D) communications can be viewed as an alternative for mobile cloud computing [1][2].

While the researchers have mainly focused on investigating and utilizing the benefits of computing capabilities of the UEs, it is worth noticing that such a distributed computing platform formed by a number of UEs can bring also other benefits, e.g., energy-savings at UEs. Based on the device-based computing platform, the concept has developed into a new paradigm of intelligent content distribution architecture referred as Collaborative Mobile Cloud (CMC), which, among the other, encompasses D2D communications, and other Short-Range (SR) transmission [3].

The CMC was first proposed as a future paradigm for content distribution and content sharing among the mobile users in the social networks [4]. An example of data transmission with CMC can be found in Fig. 1. As shown in the figure, CMC consists of a number of UEs that 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). Apart from the advantages in sharing, the CMC platform also has its advantages in the reduction of UEs' energy consumption [5]-[6]. A typical CMC application aims at delivering the data to a number of users who have common interests. In the conventional multicasting/unicasting scheme of Fig. 1, the UE has to download the whole content on its own. This leads to a significant energy consumption by UE batteries, especially if the data rates are so low that they significantly increase the receiving time. In contrast, as shown in Fig. 1, several UEs forming a coalition through the concept of CMC can cooperatively receive parts of the required data from the BS, then exchange and share that data with others via SR link. In such a case, each UE only needs to download parts of the data from the BS, and consequently, due to the fact that the data rate on SR link is usually higher, the receiving time of the UEs can be significantly reduced [5], which is able to induce energy-saving gain [5][6]. For other mobile applications, such as mobile games, CMC can also reduce the burden of one UE's processors and memory, as computing tasks can be carried out among a group of UEs [7]. Moreover, CMC can also be used for design of a content distribution vehicular network [8]. However, despite of the numerous CMC's benefits, there are also quite a few issues that need to be investigated when designing CMC. There are a limited number of works on the design of CMC, i.e. [4] and [9]. For the similar content distribution architecture, in [11], the authors have presented a survey and discussed the implementation issues. In addition, the authors of [12] have also investigated the energy aware clustering problem for content distribution among a group of UEs and presented both centralized and distributed schemes. It can be well observed that the platform development of CMC for the content distribution is still in its early stage.

In this article, we wrap up the existing works on this subject and provide some novel insights on the CMC design. Specifically, we first present the concepts of CMC, then we discuss the energy-saving benefits as well as open challenges in designing a green CMC. Moreover, we present an energy-aware user selection and scheduling algorithm. In addition, some future research directions and potentials are pointed out and discussed from both social and technological perspectives.

II. Collaborative Mobile Cloud: Concept, Benefits and Challenges

Let's consider a case where a number of UEs that are geographically close to each other are interested in downloading and sharing some popular content from a BS using LR wireless technology. In a traditional way, the BS can either unicast the content to each UE on a dedicated channel with a customized data rate depending on the individual UE's channel condition or multicast the content once to the UEs with a unified data rate that is limited by the worst channel condition among the UEs. In either case, each UE has to receive all the required data from the BS.

Fig. 2 compares the transmission process of CMC with conventional transmission, e.g., unicasting/multicasting. In Fig. 2, the CMC consists of four UEs. To present the concept of CMC in a simple way, we divide the overall data stream into 4 segments. In a conventional 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 the stand-alone UE has to remain active for the whole reception duration, which depends on the length of the content. Therefore, a long receive time results in high energy consumption due to the required radio frequency (RF) and baseband processing during data reception. In the CMC, the BS can distribute various and exclusive segments of data to different UEs and the UEs can then exchange/share the received parts directly with other members by utilizing SR transmission among themselves [14]. Thus, compared to the conventional transmission, the receive time duration in CMC can be significantly reduced as the data rate of SR is usually higher than that of LR. However, in order to share the received data, new communication overhead, such as UE transmit power, is induced for some of the UEs. As we can see from Fig. 2, only 3 UEs are selected for distributing data while there is only receive energy consumption at the last UE. Consequently, the inherent energy-efficiency (EE) performance calls for an examination and discussion.

Moreover, it is also worth noticing that there are two ways for delivering data between the

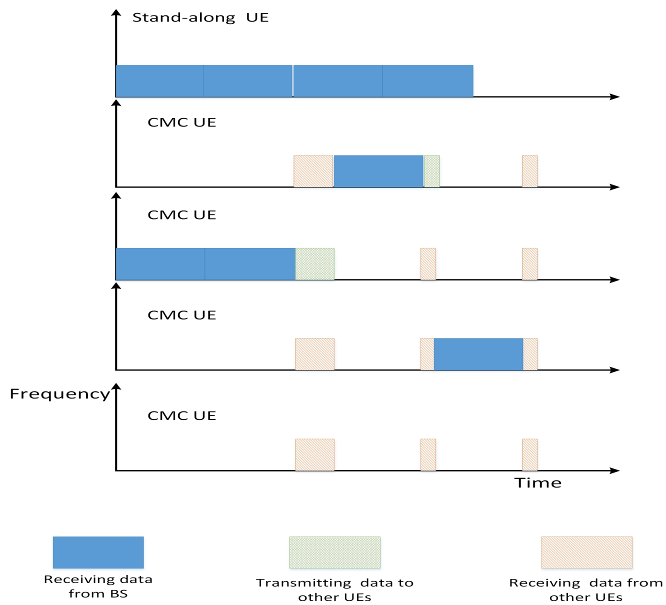

Fig. 2. Collaborative mobile cloud compared with conventional stand-alone user.

BS and CMC. The first method is that a BS can transmit different packets to different UEs in parallel. In this case, more channel bandwidth is needed as the BS is simultaneously transmitting to different UEs with different data. The other way for the BS to transmit to the UEs is in sequence. For each data segment, one UE is selected as the receiver for the BS and transmitter for other UEs. By such, channel bandwidth can be effectively utilized. Here, we focus on the latter case. However, it is also of interest to explore the theoretical limits of both two mechanisms. In addition, multicasting and unicasting are also two options for transmission within CMC. The energy consumption performance of these two strategies is presented in Fig. 3, which considers the energy consumption parameters in [2]. The energy consumption ratio in Fig. 3 is obtained by the energy consumption of all the UEs when using CMC (either unicasting or multicasting) normalized by the energy consumption of the conventional multicasting scheme. We also assume that in Fig. 3, the data rate of SR is ρ times better than LR. One can observe that with CMC, the UEs can save up to 75% of energy when downloading from the BS, which evidences the energy-saving potential of CMC. Moreover, we can also see that there is an optimal value of SR data rate, i.e., $\rho = 5$. This is mainly due to the fact that when the data rate is too high, higher energy consumption is needed for both transmitting and receiving.

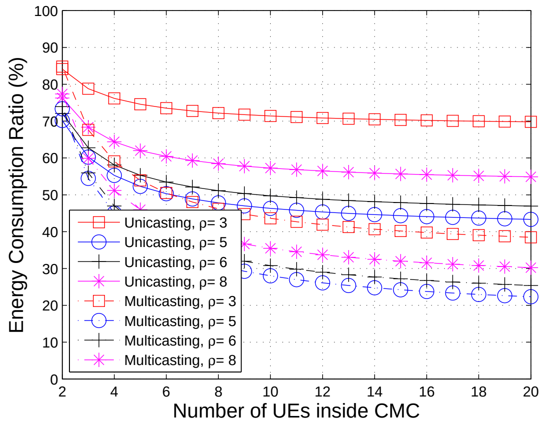

Fig. 3. Energy consumption with multicasting and with unicasting.

As can be seen, CMC brings great energy-saving potential to the mobile devices. However, on designing a green CMC, there are some open problems:

- How can a CMC be formed?
- What performance gain can CMC bring from the EE point-of-view?
- Under what circumstances do the UEs come to join the cloud, and how do we stimulate the users to join?

Typically, scheduling in unicasting or multicasting transmission often involves users' channel conditions or Quality of Service (QoS) requirements [5]. However, scheduling for CMC has some additional difficulties brought by its structure. For example, BS only sends exclusive data segments to a dedicated user in one scheduling time, and the dedicated user might have to sacrifice its own battery for the other CMC members. Thus, for CMC, we first discuss the involved principles and present a novel energy-aware user selection and scheduling algorithm. The impressive energy-saving gain as well as user fairness are presented to illustrate the advantages of CMC and our energy-aware proposals. Moreover, we will also discuss other open research challenges to shed light on future directions.

III. Energy-Aware User Scheduling Principle

One may observe that CMC is a candidate proposal towards energy-efficient wireless network design for content distribution and sharing in which the computation and storage capabilities of

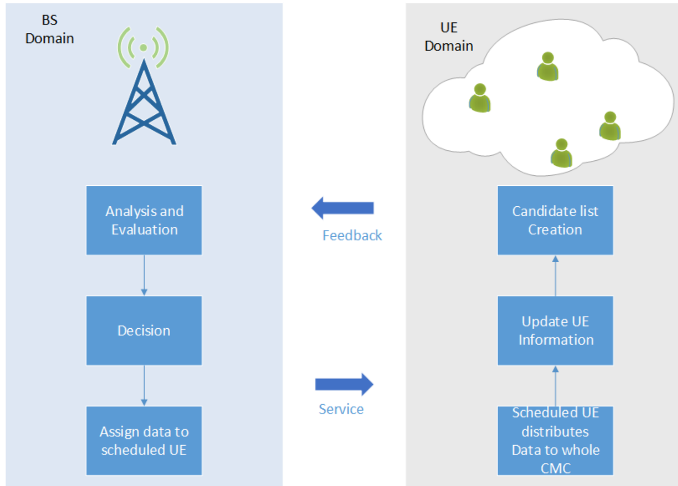

Fig. 4. Algorithm flowchart.

UEs are utilized. Although the discussions and results in Fig. 3 are based on a "perfect" scenario (e.g., practical issues such as channel conditions of different UEs are not considered), the energy-saving potential can still be clearly discerned. One may also notice that the aforementioned EE analysis relies on the willingness of UEs to join the CMC. In addition, energy-saving performance is also affected by SR data rates. Therefore, effective user scheduling for CMC is of considerable interest and importance. In the following, we will present one energy-aware scheduling method to tackle these issues. When forming a mobile cloud, the bottom line should be that none of the network elements can act as a dictator since UEs have to sacrifice for others. Thus both the BS and the UEs should be involved in making decisions on when and which users are able to participate.

In some previous works, game theoretic-based schemes have been applied for the design of content distribution platform. In particular, cooperative game, such as coalition formation, have shown its effectiveness in the user clustering design [8][12] [13]. In this section, a scheduling method based on BS-UE interactions is presented. The flow of the introduced algorithm is summarized in Fig. 4. First, a candidate list containing a selection of UE names/IDs is provided to the BS. The candidate list consists of the numbers of UEs that can minimize energy consumption of SR transmission inside CMC. The BS will then schedule the users of the list for receiving data segments based on its own objective and various energy consumption and fairness constraints.

A. UE Domain: Mobile Could Gathering

In order to minimize the energy consumed by distributing a single data content in a CMC, the distributor should be able to minimize the communication overhead that the CMC brings. Although it is possible to provide an optimal solution for minimizing energy consumption when the best candidate UE is chosen to receive certain data, it may lead to a situation where one user could always be assigned data no matter how low the user's battery may be. In this kind of situation, the UE will be excessively strained and consequently the battery will be drained. Therefore, instead of a single UE, a candidate list containing a number of potential UEs should be created, while the UEs in the list should have available energy for receiving and distributing data. The list should be based on the energy consumption in an ascending order. The list is then fed back to the BS for making further decisions on which user should be assigned to receive the data segment, as shown in the left part of Fig. 4.

In the current standardization, there are no standardized content distribution/sharing protocols that would enable UEs to communicate with each other on the SR link and to collaboratively download content on the LR link. Therefore, generic communications systems are assumed to take the responsibility for these actions. As stated, UEs can download content from BS via standardized UMTS or LTE and share the data among themselves through WiFi or Bluetooth. The created list can be reported as an attachment to the standard feedback mechanism.

B. BS Domain: User Selection and Scheduling

After receiving the candidate list, BS needs to evaluate and then makes a decision on which UE should be selected to deliver a certain amount of data. Apparently a simple decision is not easy to make since different aspects need to be considered. When a UE is willing to join the cloud, it is not a good policy to drain its battery quickly just because that can minimize the energy consumption in multicasting the received data. Thus, the first constraint is to use a fairness indicator to measure the UE's contribution before each scheduling. Another constraint can be the UE's energy level since there should be enough energy left for satisfying the UE's operating cost. Combining the two criteria together, we could obtain the optimal or trade-off selection results. We will present some examples of the discussed constraints to evaluate our proposals in the following section.

C. Algorithm Flowchart

As presented in Fig. 4, which combines the proposed two schemes, a solution for gathering a cloud can be arrived at. At the UE domain, each UE willing to join the CMC will be evaluated to see the transmit energy consumption if selected for transmission. Then a candidate list based on the evaluation is generated and reported to the BS. At the BS domain, after taking the energy fairness and energy consumption of UEs into consideration, the BS makes the decision and schedules one UE from the list. Then the data will be assigned to the scheduled UE and delivered to all the UEs in CMC by the scheduled UE. Based on such energy-aware scheduling algorithm, a CMC can be formed. The scheduled UE will be responsible for receiving data from the BS on the LR link and for transmitting the data to other UEs over the SR link in one time slot. By such, the energy saving gain similar to the one shown in Fig. 3 can be achieved. The complexity of the algorithm is $\mathcal{O}(K)$ where K is the size of list. Therefore, the CMC not only enables the data distribution and sharing features of the UEs but can also improve energy efficiency at the terminal sides.

D. Discovering the Context Information

While the accuracy of the presented scheme relies upon the candidate list creation as well as on its context, the candidate list creation depends on the UE's capabilities of obtaining energy consumption information about data delivery to the fastest UE. To procure such cognitive, sensing-like capability, additional redundancy and modifications to the current devices are required. Therefore, we advocate an alternative for list generation. In this scheme, UEs only send to the BS a list with information about which UE is willing to join the cloud. Then the BS can monitor the energy level of each UE through feedback. At the beginning of scheduling, the Round-Robin method or other well-known methods can be applied so that the BS will get to know the energy consumption of an individual UE when the UE distributes received data. Through such a procedure, the BS is able to estimate how much each UE consumes energy if chosen by the scheduler for a data assignment. It can be noticed that the accuracy of the monitoring and estimation process may affect the decision of the BS. In this scheme, we assume that the information is accurate, and can be obtained by standard feedback scheme. With comprehensive information acquisition, the BS can have information similar to the one obtained through the context of candidate list in the scheme presented previously. Finally, the

BS can evaluate the UEs through its own decision function. Although, due to the monitoring or information collection process, extra energy is consumed in this alternative, it does not require modifications or transmission overheads to the UEs.

IV. Performance Evaluation Example

To illustrate our proposed energy-aware principle, we invoke the energy fairness function

$$f(\varepsilon_k) = (1 - \varepsilon_k)^{1/\beta}, \tag{1}$$

where ε_k is the contribution factor of UE k. It is defined as the data segments assigned to k normalized by total data prior to the scheduling time. When the UEs are willing to participate the formulation of the CMC, from (1), we can see that a bigger value of $f(\varepsilon_k)$ indicates that the UE contributes less for receiving and transmitting data in the CMC, which means that it consumes less energy. We refer to $\beta > 0$ as the fairness index and effectiveness of β is illustrated in the following section. It is worth noticing that (1) is one example of defining fairness among the users. Based on different objectives, such as design of incentive mechanisms for forming the CMC, the definition of fairness can be varied accordingly. The decision function of BS is assumed to be

$$\max U(\varepsilon_k, \gamma_k) = f(\varepsilon_k) \log_2(1 + \gamma_k), \tag{2}$$

where γ_k is the channel Signal-to-Noise Ratio (SNR) from the BS to UE k. In (2), the decision function comprises of two factors: one is the contributions of the UE and the other one is the data rate of the LR link. These two factors can present that the final decision involves both the BS and UE. It is worth noticing that the increase of data rate of LR link can decrease the receive time duration, which reduces the energy consumption of the UE. Therefore, by considering (2), a tradeoff between the energy fairness and EE for data transmission from the BS to the UEs can be achieved. Consequently, based on the maximization of decision function subjected to certain artificial energy constraints, the BS can evaluate each UE in the candidate list. A typical constraint is the assurance of the UE's remaining energy level after the data has been assigned and distributed. The scheduling decision can be made according to the context of the candidate list and the evaluation of the BS. The problem can then be addressed through the presented scheme in the last Section.

In Fig. 5, we compare our proposed scheme with some other classical non-fair schedulers and with the presented information acquisition scheme. "Maximization Scheduler type 1" means that the BS can select a user to maximize the BS to the UE data rate and transmit data to the selected user until it has no charge left. "Type 2" scheduler allows the BS to select the user at the first position of the list until that UE is drained of charge, which should provide the lowest energy consumption for the considered system. The simulation parameters are according to the ones in [2], where the impacts of RF, circuit and computing are all considered. In Fig. 5, we also present the results of using the presented information collection scheme. In particular, to obtain the knowledge of energy consumption of the UEs, Round-Robin scheduling algorithm is applied at the BS. Once the comprehensive knowledge of energy consumption of the UEs is obtained, the BS can use (2) as the decision function to select UE to assign the data to. Fig. 5 shows that when our selection criteria is more fair (β is small), the energy consumption is higher than with the "Maximization Scheduler type 1". When β is getting higher, the presented scheme can have lower energy consumption. However, due to the energy level protection mechanism, a performance to the level of "type 2" scheduler can never be reached. We can also observe that the proposed context information collection scheme has a similar performance as the one we proposed in terms of curve shape. When β is small, the performance is almost the same since fairness is the main consideration. Also, when β is small, the proposed context information collection scheme has a higher energy consumption due to the collection process.

Finally, Fig. 6 compares the use of CMC with the conventional multicasting scheme via energy consumption snapshots. The CMC consists of 30 UEs: 4 of them are selected to illustrate the energy consumption performance. The stand-alone UE uses a conventional multicasting scheme to receive from the BS. Fig. 6a shows the energy consumption of the stand-alone UE and some of the CMC UEs with a single data segment transmission. UE $\#10$ is the scheduled UE in this case. For a single data segment transmission, due to the transmit energy consumption inside CMC, the energy consumption of the scheduled UE is higher than for the stand-alone UE which is not part of CMC. In Fig. 6b, the energy consumption of UEs for receiving 10 assigned data segment is presented.We can see that in case of the assigned data segments, several UEs are being scheduled. Therefore, the energy consumption of the CMC UEs is lower than that of

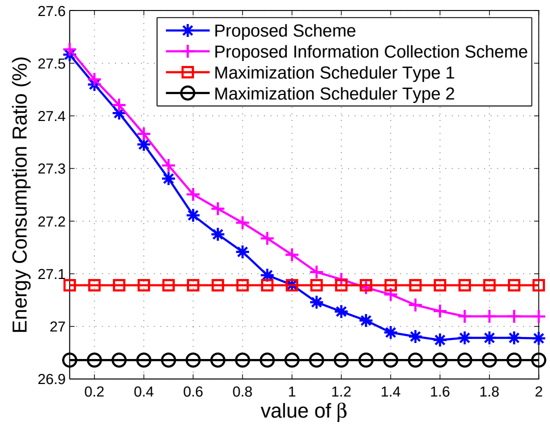

Fig. 5. Total power consumption, where the CMC consists of 20 UEs.

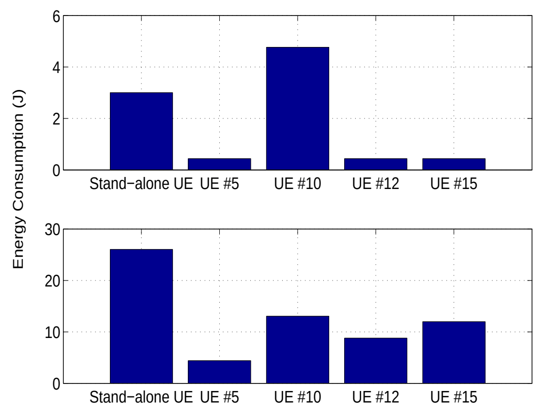

Fig. 6. Snapshot of the proposed algorithm, where the CMC consists of 30 UEs.

the stand-alone UE, which confirms the advantages of the CMC model and of the presented schemes.

V. Open Issues and Future Challenges

A. Use case of CMC

In this work, we consider our system model as a CMC formed by multiple users. However, the application of CMC should not be limited solely by user cooperation. It is also reasonable to consider CMC in different applications, e.g., vehicular networks [**?**] [10] or Femtocell/HeNB, when neighbors like to download the same multimedia contents. It is worth noticing that, in vehicular networks, due to fast speeds and deep fading, some data packets might be lost during the vehicular networks broadcasting stage. To support reliable transmissions, proper approaches should be investigated to complement the missing data among the users [10] or to inform the BS to retransmit the data.

B. Resource Allocation

For a CMC formed by a number of elements in wireless networks, the design of the resource allocation algorithm is quite critical as far as its EE performance and efficient and effective exploitation of its potential are concerned. Moreover, the resource allocation scheme should also consider the service stability and throughput requirement. The problem here concerns how to allocate radio resources, such as frequency subchannels in the context of OFDMA network, and transmit power, etc. Moreover, the scheduled UE may require the other UEs to act as relay to deliver the data to all the CMC members. For the relaying transmission, the protocol should be carefully designed as additional transmit power is involved. The objective of resource allocation methods is to maximize EE while the service stability and throughput requirement can be guaranteed.

C. Incentive Consideration

Building up a CMC platform creates the conditions to increase the potential of cooperation among users driven by selfish considerations. The platform can also be used for social networking development, as the delivery of interesting social content can be speeded up among CMC members. Given the self-interested nature of users, it is also crucial to design appropriate incentives that encourage the user to form the CMC. Leveraging the coalitional game theory and utilizing the potential energy-saving benefits of CMC as individual profits can be the starting point for finding a way to stimulate selfish mobile users to share popular content [8], [10], [13]. In addition, utilizing some of the advanced technologies, such as wireless power transfer, to bring energy to the UEs which join the CMC is also a potential incentive mechanism to gather UEs [5].

Moreover, network operators can also generate some revenue if the multimedia content is completely distributed on the LR (generally, communication on the SR is free, e.g., via Bluetooth or WiFi Direct), since more users will download the content from the operator's network. On the other hand, SR collaboration frees more LR resources, which leads to reduced user blocking rates and allows the utilization of the freed resources to accommodate more content distribution requests (thus leading to more revenue). Consequently, the economic frameworks that consider how to maximize the operators' profits and whether it is possible to refund the UEs which download content for others are of particular interests.

D. *Content/Context-based Mechanism*

Most of the discussions of this article deal with scheduling issues. We only consider constraints of radio resources, such as energy consumption, without exploring the effects of data content and context. However, as the future network is expected to provide various mobile data applications with different content and each type of content is associated with a particular desired QoS, a content- or context-based distribution method for data offloading and/or resource allocation is necessary. Moreover, it is apparent that due to the heterogeneous nature of mobile users, the users also have different QoS requirements and different positions within CMC. Those features, of either UE or data, should not deteriorate the energy-saving performance of CMC. Nevertheless, they still bring new obstacles to the development of an energy-efficient CMC. Therefore, there is a need to design algorithms to facilitate the diversity and utilize the advantages of data content or context to improve system performance.

E. *Signaling Overhead*

CMC in general forms the bases for the effectiveness of D2D communications. Thus, the signaling between UEs and the BS and signaling among UEs can affect the EE performance. Indeed, we need to quantify the tradeoff in the exchanged signaling information on energy consumption performance. The level of required signaling highly depends on the protocol implementation, whether distributed, centralized or hybrid. The overhead due to signaling should not have much impact on the energy savings benefits or lead to additional delays affecting the overall performance gains or the target QoS requirements. Hence, the signaling overhead for cooperative content distribution architectures needs to be quantified and assessed and efficient practical D2D communications protocols with a minimal signaling overhead should be developed.

F. Delay and Throughput Considerations

In this work, we focus on the EE aspect of the CMC. It is worth noticing that there are some other factors which may inflounce the performance of the CMC, such as delay and throughput. The current algorithm is primarily designed for delay-insensitive applications. Although, for packet-switching networks, the delay problem is not as serious as for circuit-switching systems, research on overcoming the CMC delay problem is still worthwhile. The research within this area can focus on the trade-off between EE, throughput and delay. Another topic of interest is how to design a pricing strategy to compensate for the induced time delay, which leads to game theoretic approaches.

VI. Conclusion

In this article, we first explored the energy saving potential of collaborative mobile cloud. The benefits as well as open challenges of CMC were also elaborated. Moreover, with an example of forming a CMC, a principle based on energy-aware user grouping was introduced to investigate when and how the users should participate in forming the cloud. The proposed scheme took both the BS and UE aspects into consideration and tried to find a trade-off between energy consumption reduction and fairness. Moreover, in addition to introducing the idea of the gathering of a cloud, some future research directions were pointed out and discussed from both social and technological perspectives.

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