Efficient Use of Multicast and Unicast in Collaborative OFDMA Mobile Cluster

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Abstract—Future wireless services induces higher demands for the circuits of mobile terminals, which will subsequently increase energy usage and hence limit users’ abilities to experience high quality of multimedia services offered by the high data rate wireless systems. In order to address this problem, we advocate a model called collaborative mobile cluster (CMC), that is foreseen as one of the potential solutions to reduce energy consumption per terminal in a network by enabling collaboration within a cluster of mobile terminals. We first compare the energy efficiency performance of unicast and multicast transmission strategies within the CMC. In addition, we propose an algorithm that can dynamically use unicast as an additional support for multicast, ultimately overcoming the inherent drawbacks of sole multicast. Analytical results are derived and illustrated by simulations. The analysis demonstrates that: i) CMC enables a great potential to reduce the per-terminal energy consumption; ii) unicast and multicast transmissions are two optional candidates, but a proper combination of them allows better energy saving gain while still fulfilling the minimum data rate requirement.

Index Terms—OFDMA; energy consumption; energy efficiency; multicast; unicast; collaborative mobile cluster;

I. INTRODUCTION

Due to the tremendous growth of the wireless market, the next-generation wireless communication systems are going toward offering broadband multimedia services. In order to accommodate such high-data traffic services, aggressive wireless techniques will be utilized to the mobile terminals (MTs), which consequently induce high energy consumption [1]. It is essential that MTs can fully exploit the high throughput gains offered by future wireless network whenever possible. However, the high energy consumption limits this due to the capacity limitation of battery and thus, the user experience of high-data rate multimedia services would be seriously impacted. Therefore, alleviating energy consumption of the MTs emerges as a critical issue to prolong the battery life in the future wireless networks.

For energy saving purpose, some research works have been done by improving transmission and receiving mechanism for a single receiver [1][2]. In [2], an overview of discontinuous reception (DRX) which is used in LTE to reduce receiver power consumption is presented. Authors in [1] introduced a resource allocation scheme which can dynamically allocate time and frequency to reduce the receiving energy consumption per single receiver. Meanwhile, [3] dedicated the work on the power saving schemes for wireless distributed computing networks. However, papers focused more on power saving performance of computing tasks rather than the one of wireless communications. In [4], short-range cooperation among MTs was proposed as a key idea to alleviate the transmit energy consumption for the data transfer from MTs to AP. Energy saving gains obtained by using different combination of technologies for short-range communications were also derived. However, they only considered transmit energy consumption excluding the studies on receiver side.

Regarding per-terminal energy consumption, we examined the energy efficiency performance of a collaborative mobile cluster (CMC) [5]. In CMC, several MTs can collaboratively receive the information data from access point (AP), and then exchange the received data with others. The CMC is also known as mobile cloud [6], whose operation mechanisms can ensure the model to has advantages on performing social interactions among numbers of users and improve the local services [7]. Although we assume the transmission scheme within CMC was unicast [5], the question of how to handle the inter-device transmissions is still under research. It is known that multicast transmission is an efficient method for group-data transmission [8]. Through broadcast in radio channels, a multicast transmission increases transmission efficiency due to reduction of transmitted redundant data. However, wireless multicast should be adapted according to the worst channel state user in a multicast group. Hence, the system capacity of multicast transmission is affected both by the number of users and the supportable data rate of MT with worst instantaneous channel condition. On the other hand, unicast transmission utilizes wireless channel variations and obtain the multiuser diversity gain [9]. Meanwhile, the unicast transmission can utilize the channel variation on the expense of introducing transmission overhead for same data. Therefore, unicast transmission is costly from the radio resources point of view.

As we can see, both of two strategies have their advantages and drawbacks. In light of reducing per-node energy consumption in the downlink while fulfilling the system requirements, we extend our previous research in [5] and provide detailed energy consumption analysis of the CMC using two different transmission strategies. Moreover, we propose a new algorithm, namely Unicast Supported Multicast (USM) scheme for CMC, which can dynamically use unicast as additional support multicast whenever seen advantageous.
from per-terminal energy saving purposes. The proposed USM scheme is designed to overcome the inherent drawback of multicast. By investigating analytical and numerical results, we discuss the benefits of exploiting two different transmission strategies as well as the significant improvements when using USM in CMC.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

We consider an OFDMA network that consists of one AP and several MTs, where K MTs can form a CMC. All the MTs inside CMC are assumed to require the same data from AP, e.g., video. Each MT is assumed to be a dual-mode device, equipped with a short-range (e.g., WLAN) wireless communication technique for performing inter-terminal communications, and also equipped with broadband access technique (e.g., LTE/LTE-A) for receiving from AP. The channel information is assumed to be known for the considered scenario. The system model is as shown in Fig. 1, where \( K = 3 \).

![Figure 1. OFDMA network with Collaborative Mobile Cluster.](image)

B. Problem Formulation

We first invoke the Resource Block Unit (RBU) as the elementary resource unit in our work. A RBU is defined as a certain frequency bandwidth \( W \) in one time slot. We assume that \( P_{AP} \) is the circuit power of MT that is used for receiving data in the bandwidth \( W \) of one RBU from AP. We also assume that there are total \( M \) RBUs that are invoked for transmission from AP to a single MT. Therefore, in case there is no collaboration between the terminals, the total per-terminal energy consumption \( E_{total} \) equals

\[
E_{total} = MP_{AP}T_{AP}. \quad (1)
\]

where \( T_{AP} \) is the duration of a time slot. Similarly, the total energy consumption per terminal in the case of CMC equals

\[
E_{node} = E_{part} + E_{rx, node} + E_{tx, node}, \quad (2)
\]

where \( E_{part} \) is the energy consumption of each MT which is used for receiving its assigned part of data from AP. Without any loss of generality, we assume \( E_{part} = E_{total}/K \) meaning that each \( K \) MTs are assigned equal share of data. \( E_{tx, node} \) and \( E_{rx, node} \) are the transmit and receive energy consumption for data exchange inside the CMC, respectively. Examples of the CMC’s unicast and multicast procedures are shown in Fig. 2 with comparison to traditional AP-MT (point-to-point) transmission. Regarding the terminals in CMC, denote \( I_{tx, node} \) the number of RBUs, \( P_E \) the baseband power consumption and \( P_{rx, node} \) and \( P_{tx, node} \) the transmit and receive RF power consumption for the terminal. The energy consumption per terminal for transmitting can be expressed as

\[
E_{tx, node} = I_{tx, node}(P_{tx, node} + P_E)T_{tx, node}. \quad (3)
\]

With assumption of receive time duration \( T_{rx, node} \) and number of RBUs \( I_{rx, node} \), the energy consumption per terminal for receiving task is given as

\[
E_{rx, node} = I_{rx, node}(P_{rx, node} + P_E)T_{rx, node}. \quad (4)
\]

Similarly, in case of no collaboration between the terminals the \( E_{total} \) is given as

\[
E_{total} = M(P_{rx, AP} + P_E)T_{AP}. \quad (5)
\]

where \( R_{rx, AP} \) is the RF receive power for receiving from AP. The way to obtain RF power consumption can be found e.g. in [5].

III. ENERGY SAVING OF USING UNICAST AND MULTICAST

Since both unicast and multicast have their own advantages and drawbacks, how to choose one as the transmission strategy for the CMC is not obvious. Therefore, in this section, we first present the energy efficiency analysis for both strategies. For the sake of tractable analysis while not loosing any generality, we assume that every node inside CMC is assigned the same amount of resource for transmission. Thus, we have \( I_{tx, node} = I_{rx, node} = I_{node} \), and \( T_{tx, node} = T_{rx, node} = T_{node} \). Regarding unicast, the total energy consumption is as follows,
unicast is called ‘unicast MT’. USM as ‘multicast group’, while the MT that needs additional 3. We further refer the MTs in the CMC which do not require example of considered scenario for USM can be found in Fig. 3. For multicast, in order to obtain better energy efficiency of multicast mode is deteriorated if the cluster of other terminals is not compact but there exists one or more MTs have much worse inter-device channel conditions than the others. Therefore, in this section, we introduce a new transmission scheme, namely Unicast Supported Multicast (USM), which introduces the use of simultaneous unicast, as a support for multicast, in order to obtain better energy efficiency performance while meeting the system QoS requirement. One example of considered scenario for USM can be found in Fig. 3. We further refer the MTs in the CMC which do not require USM as ’multicast group’, while the MT that needs additional unicast is called ’unicast MT’.

\[
E_{\text{node, unicast}} = (K - 1) (P_{\text{tx, node}} + P_{\text{tx, node}} + 2P_{\text{E}}) I_{\text{node}} T_{\text{node}} + E_{\text{total}} / K
\]

\[
= \frac{MT_{\text{AP}}}{K} \left( P_{\text{AP}} + (K - 1) (P_{\text{tx, node}} + P_{\text{tx, node}} + K P_{\text{E}}) \right)
\]

Regarding multicast, the energy consumption is given as

\[
E_{\text{node, multicast}} = (K - 1) (P_{\text{tx, node}} + P_{\text{tx, dist}} + K P_{\text{E}}) I_{\text{node}} T_{\text{node}} + E_{\text{total}} / K
\]

\[
= \frac{MT_{\text{AP}}}{K} \left( P_{\text{AP}} + (K - 1) (P_{\text{tx, node}} + P_{\text{tx, dist}} + K P_{\text{E}}) \right)
\]

where \( P_{\text{tx, dist}} \) is the RF transmit power to the receiver with worst channel quality and \( I_{\text{node}} T_{\text{node}} = \frac{MT_{\text{AP}}}{K} \). Here \( \rho \) is defined as the modulation ratio, which depends on the amount of data that a subcarrier can carry, and in general, is decided by modulation and coding schemes (MCS). For example, if BPSK is used as modulation scheme from AP to MT and QPSK is used for inter-device communication inside MC, we have \( \rho = 2 \). Therefore, the energy saving \( \xi \) can be defined as

\[
\xi = \begin{cases} 
E_{\text{total}} - E_{\text{node, unicast}}, & \text{if unicast} \\
E_{\text{total}} - E_{\text{node, multicast}}, & \text{if multicast.}
\end{cases}
\]

IV. Unicast Supported Multicast (USM)

In case of multicast transmission, the MT with worst inter-device channel quality requires higher transmit power in order to obtain the same data rate as others. Hence, the energy efficiency of multicast mode is deteriorated if the cluster of terminals is not compact but there exists one or more MTs having much worse inter-device channel conditions than the others. Therefore, in this section, we introduce a new transmission scheme, namely Unicast Supported Multicast (USM), which introduces the use of simultaneous unicast, as a support for multicast, in order to obtain better energy efficiency performance while meeting the system QoS requirement. One example of considered scenario for USM can be found in Fig. 3. We further refer the MTs in the CMC which do not require USM as ‘multicast group’, while the MT that needs additional unicast is called ’unicast MT’.

![Figure 3. Considered Scenario with USM](image)

The idea of the USM scheme is to allocate additional unicast channel to the specified MTs that can not obtain satisfied data rate as others when a fixed transmit power for multicast is used. How to perform USM is depicted in Algorithm 1.

**Algorithm 1 Description of USM**

1. Regarding the terminal who received data from AP, evaluate channel gains \( G_k \) between the other terminals \( k \) in CMC
2. Predefine channel gain \( G_T \)
3. Perform multicast transmission with power \( P_m \), adjusted to worst \( G_k \) for which \( \{G_k | G_k \geq G_T\} \)
4. if \( G_k < G_T \) then
5. perform USM using additional unicast transmit power \( P_u \).
6. end if

A. Energy Efficiency of USM

USM aims to obtain better energy efficiency performance comparing with pure multicast transmission. From the previous description of USM, one may notice that the algorithm performance depends on the selection of \( P_m \) and \( P_u \), i.e. the power of multicast group and additional power for unicast user. Hence, in this part, we will formulate the problem of power selection as well as examining the energy efficiency of the proposed USM scheme. In order to ensure the QoS, the inter-device transmission throughput for each MT in the CMC should fulfill the rate requirement of \( R_T \).

\[
R_T = log(1 + \gamma_T)
\]

where \( \gamma_T \) is the received Signal-to-Noise Ratio (SNR) of using multicast for all nodes and can provide data rate of \( R_T \). Since inter-device distance is short, so it is reasonable to assume that channel gain is stable in a time slot and varying slowly. Due to the features of multicast transmission, if there exists a MT that has very bad channel condition, e.g., MT is far away from others, it requires higher power consumption for other inter-device source. So if there is a MT \( j \) that has very bad channel, the multicast data rate from MT \( i \) to MT \( j \) can be formulated as

\[
R_{i,j} = log(1 + \gamma_{i,j})
\]

where \( \gamma_{i,j} \) is the received SNR of from MT \( i \) to MT \( j \) adopting multicast transmission. Meanwhile, we assume the SNR of unicast channel is as same as the one of multicast channel as well. Therefore, when a particular MT \( j \) needs additional unicast support, the needed additional data rate of it is given by

\[
R_T - R_{i,j} = log\left(\frac{1 + \gamma_T}{1 + \gamma_{i,j}}\right)
\]

Therefore, when using USM, MT \( j \) should has a unicast SNR \( \gamma_u \)

\[
\gamma_u = \frac{\gamma_T - \gamma_{i,j}}{1 + \gamma_{i,j}}
\]
Thus, we can see that the power saving obtained by using USM over multicast transmission depends on \( P_u, \gamma_{i,j}, \) and \( \gamma_T \). Obviously, we have

\[
\begin{cases}
P_T = \gamma_T / G_{i,j}, \\
F_m = \gamma_{i,j} / G_{i,j}.
\end{cases}
\]

Hence, the power saving \( P_s \) obtained by using USM can be expressed as,

\[
P_s = P_T - P_m - P_u = \frac{\gamma_T - \gamma_{i,j}}{G_{i,j}} - \frac{\gamma_T - \gamma_{i,j}}{G_{i,j}} (1 + \gamma_{i,j}) G_{i,j} = \frac{\gamma_{i,j} (\gamma_T - \gamma_{i,j})}{G_{i,j} (1 + \gamma_{i,j})} = \frac{P_T - P_m}{|\alpha_{i,j} P_m| + 1}.
\]

Since \( P_T \) and \( G_{i,j} \) are fixed if we predefine the required QoS data rate and channel condition, our objective is to decide the value of \( P_m \), which can maximize our power saving objective,

\[
\max P_s.
\]

subject to

\[
\log(1 + P_m G_m) \geq R_T
\]

where \( G_m \) is the worst channel gain within the multicast group. We can notice that (13) is a convex optimization problem. Therefore, we can simply obtain the optimal value of \( P_m \) by applying the KKT conditions. Therefore, we could obtain the energy consumption for the MT that is close to others when using USM as follows,

\[
E_{\text{node,usm}} = (K - 2) P_{rx,m} + P_{tx,m} + (K - 1) P_E) I_{\text{node}} T_{\text{node}} \\
\]

\[
+ E_{\text{total}} / (K - 1) + (P_{rx,u} + P_{tx,u} + 2 P_E) I_{\text{node}} T_{\text{node}}.
\]

\[
(15)
\]

V. NUMERICAL RESULTS AND ANALYSIS

A. Unicast vs. Multicast

Results about impact of unicast and multicast transmission in a CMC are illustrated. Energy saving metric is defined as \( \frac{E_{\text{total}}}{E_{\text{total}}} \times 100\% \). Parameters that are used here are the same as in [5]. The inter-device channel is defined in IEEE 802.11ac [10] with the assumption of indoor environment. The AP-MT channel is according to [11] with assumption around 1000m distance. Energy efficiency (EE) performance when considering different numbers of MTs inside MC and different values of \( \rho \) can be found in Fig. 4(a), where inter-device distance is assumed to be 20m. From Fig. 4(a), we can see that as the number of MTs increases, energy saving gain obtained by using CMC arise as well. The energy saving percentage reach “almost” saturation when there are 20 MTs forming a CMC. It means that without any radio resource (e.g. RBUs) constraints, forming CMC can help MTs that are close to each other saving energy if proper MCS is used no matter which strategies are used. The performance of multicast is generally better than unicast when same scenario is assumed.

If we fix the number of MTs inside MC to be 20, we could obtain the impact of inter-device distance and value of \( \rho \) in Fig. 4(b). We can observe that when the inter-device distance is shorter than \( d_\rho = 15m \), the EE performance remains the same for same values of \( \rho \) in Fig. 4(b). Generally, we can see that lower order MCS should be used when inter-device distance is getting larger in order to achieve energy saving. For example, when inter-device distance is 20m, we can obtain 55\% when \( \rho = 6 \), which is the maximum energy saving percentage for that inter-device distance. However, \( \rho = 5 \) is the best choice when distance is 25m. In this particular example, forming CMC will not result in any energy savings if the inter-device distance is longer than 45m.

B. Performance of USM

From the previous subsection we can observe that if the distance among MTs inside CMC keeps the same, the EE of multicast transmission is superior to the one of unicast transmission. In this part, we analyze the energy efficiency of the proposed USM algorithm compared with sole multicast when there is a distant MT existing in the CMC as illustrated in Fig. 3.

First, we use the channel quality indicator that presents the difference of channel quality between unicast MT and multicast group, which is defined as \( \chi = \frac{G_{\text{rx}} - G_{\text{tx}}}{G_{\text{tx}}} \). The multicast group contains 20 MTs and has around 20m inter-device distance. \( \chi \) is varied by changing the value of \( G_{i,j} \), which by altering the position of unicast MT in practice. \( R_T \) is assumed to be 1 without loss of generality. The performance is measured by power saving, which is calculated as \( P_s / P_T \). It is worth noticing that E can be different for different \( G_{i,j} \) so that QoS can be achieved. As we can observe from the Fig 5, our proposed USM scheme can achieve up to more than 50% power saving compared to the pure multicast transmission. It also worthy to remark that power saving gain obtained by USM arrives its maximum value when \( \chi = 0.75 \), which means

![Figure 4. Multicast vs. Unicast](image-url)
that the use of USM is beneficial when one node has much worse channel quality than the others.

The energy saving gain is illustrated in Fig. 6. One can observe that with USM, we can obtain range extension with same energy efficiency percentage. In other words, the CMC is able to host MTs that are further away from the others without any loss in energy savings. With the same channel quality, the USM can save more energy (e.g. 20% as we mark in the figure) than multicast. Therefore, the energy efficiency of USM over multicast for CMC can be easily noticed.

The EE in Fig. 7 is evaluated by \( \frac{\text{bits}}{\text{Hz}} \times J \), which is defined as the offered data rate divided by energy consumption. Here, EE is obtained by comparing to the traditional AP-MT network. It can be noticed that the EE of USM can be compared with the traditional networks when \( \chi \approx 0.75 \) when \( R_T = 1 \ \text{bps/Hz} \). As the \( \chi \) increases, the value of EE is increased. We can also observe that when the QoS data rate is getting higher, our proposed USM can achieve better EE performance comparing with multicast, especially when channel quality of the unicast user is worse. For example, we can see that USM can achieve 2 times better performance than multicast in light of \( R_T = 2 \ \text{bps/Hz} \) while the performance gain is about 1.5 times when \( R_T = 1 \ \text{bps/Hz} \) at \( \chi = 0.4 \). When \( \chi = 0.7 \), the performance gain is up tp 30 times when considering \( R_T = 2 \ \text{bps/Hz} \). However, when \( R_T = 1 \ \text{bps/Hz} \), we only obtain 2 times energy efficiency when using USM over multicast at \( \chi = 0.7 \). Therefore, we can see that USM can achieve better EE performance than multicast scheme when higher data rate is required and bad channel quality is considered.

VI. Conclusion

In this work, we first exploited the energy efficiency benefits of using CMC in OFDMA networks. Moreover, we presented theoretical analysis on the energy consumption of MTs when multicast or unicast is used. Based on the analysis, we discussed the benefits of using multicast and unicast as transmission strategies for CMC. Furthermore, we proposed USM algorithm, that can compensate the inherent drawbacks of multicast transmission. Through simulation studies, we first observed that CMC shows great potential for obtaining energy saving for MTs. We also illustrated that the energy efficiency performance could be achieved by optionally choosing multicast and unicast as transmission scheme for CMC. With USM scheme, the energy efficiency performance can be improved compared to the case where only multicast is used for CMC.

REFERENCES