Reducing Energy Consumption via Cooperative OFDMA Mobile Clusters

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***Abstract*—Aggressive techniques induce high energy consumption for the circuits of MTs, which drain the batteries fast and consequently limit mobility. In order to solve such a problem, a scheme called distributed mobile cloud (DMC) is foreseen as one of the potential solutions to reduce energy consumption per node in a network. In this paper we provide a detailed analysis of the energy consumption of a terminal joining the DMC and also analyze the conditions for energy savings opportunities. Numerical results are also provided to illustrate the analysis and show the potential of significant reduction of the per-node energy consumption in the mobile cloud concept.**

***Index Terms*—OFDMA; energy consumption; energy saving; cooperative cluster**

I. Introduction

It is essential that the mobile terminals (MTs) can fully exploit the throughput gains offered by future communication system whenever possible. However, the high energy consumption limits this due to the capacity limitation of battery and the user experience of gigabits transmission would be seriously impacted. Therefore, reducing energy consumption 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. In [1], an overview of discontinuous reception (DRX) which is used in LTE to reduce receiver power consumption was presented. Meanwhile authors of [2] dedicate the work on the power saving schemes for wireless distributed computing networks. However, these contributions focus more on power saving performance of computing rather than the one of communication. [4] introduce Multi-Radio ARQ schemes for hybrid networks combining long-range and short-range communications to improve the throughput. In [5], short range cooperation among MTs was proposed as a key idea to reduce the transmit energy consumption for the transmission from MTs to AP. However, the study considers transmit energy consumption only.

In this work, we consider both transmit and receive energy consumption. Scenario under consideration includes cooperation among MTs. This scenario also known as Distributed Mobile Cloud (DMC) is modelled as a cluster of resource-constrained nodes that can perform receiving and decoding cooperatively and distributively [3]. One DMC contains several MTs that can cooperatively receive the information data from access point (AP), then exchange the received data with others through device-to-device (D2D) links. We provide detailed analysis of the energy consumption of a MT within the DMC and compare it with non-cooperative schemes. Numerical results illustrate the potential of energy saving possibilities in this context compared to the non-cooperative scenario.

The rest of the paper is organized as follows. Section II describes our system model and formulates the problem. In Section III, we analyze the power and energy consumption of using DMC as well as using traditional P2P network. Energy consumption reduction performance analysis and discussion are shown in Section IV. We finally conclude the paper in Section V.

II. System Model and Problem Formulation

A. DMC System Model

We consider there are one AP and Z MTs in the network, where K MTs can form a DMC. All MTs inside DMC require the same data from AP (e.g. a video or television channel). The scenario is depicted in Fig. 1, where $K = 3$.

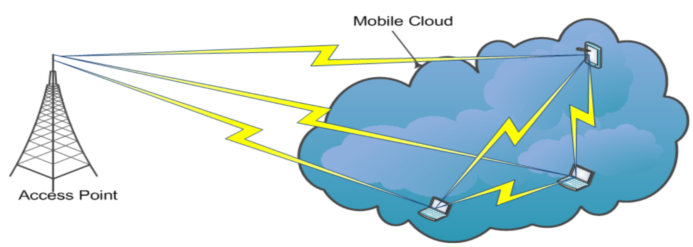

Figure 1. OFDMA network with Distributed Mobile Cloud.

B. Problem Formulation

We first denote a physical resource block unit (PRB) as a certain frequency bandwidth (e.g. 12 subcarriers in LTE) in one time slot T_k for MT k. We assume that P_k is the circuit power of MT k that is used for receiving certain amount of data in one PRB from AP. We also assume there are total M PRBs that are used for transmission from AP to a single MT. Therefore, the total receive energy consumption per node (MT) in the AP-to-MT link equals

$$E_{total} = MP_kT_k. \tag{1}$$

Hence, the total energy consumption per node within the DMC concept can be presented as:

$$E_{node} = E_{rx} + E_{tx} + E_{part}, \tag{2}$$

where E_{part} is the receive energy consumption of single MT that is used for receiving the assigned part of the data from AP. If K MTs are assigned for equal amount of data, we would have $E_{part} = E_{total}/K$. E_{tx} and E_{rx} are the transmit and receive energy consumption for data exchange inside the DMC, respectively. One example of the DMC communication procedure is shown in Fig. 2 with a comparison to traditional point-to-point scheme. Therefore, the objective is to examine the energy saving gain due to DMC, which can be expressed as,

$$\xi = E_{total} - E_{node}. \tag{3}$$

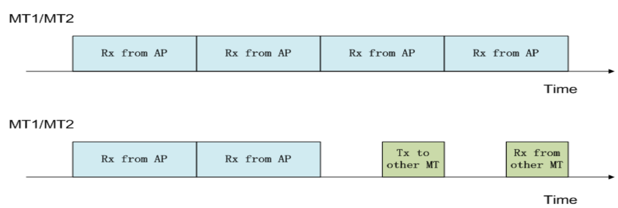

Figure 2. Traditional P2P vs. DMC

III. Analysis of Power and Energy Consumption

A. RF Front-end Power Consumption

For D2D communication inside DMC, the transmit power dissipation of RF front-end for single PRB is expressed as [2]

$$P_{tx} = \beta_1 \gamma_{min} W L + \beta_2, \tag{4}$$

where β_1 and β_2 depend on the transceiver components and channel characteristics. In particular, β_1 is related to transmitting action on/after power amplifier (PA), such as antenna and channel gain. β_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 frequency bandwidth of one PRB. γ_{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 [6],

$$\gamma_{min} = \frac{2}{3}(2^b - 1) ln \frac{4(1-2^{-b})}{BER_{req}} \tag{5}$$

where BER_{req} is the BER requirement at receiver. Also, β_1 and β_2 can be expressed as:

$$\begin{aligned} \beta_1 &= \frac{\eta k_B T_o NF (\sigma_s)^{-Q^{-1}(1-p_{out})} (4\pi)^2}{G_t G_r \lambda^2 d_o^{-2}} LM, \\ \beta_2 &= P_{DAC} + P_{RF} + \vartheta \end{aligned} \tag{6}$$

Table I
Tx/Rx power consumption related parameters

Parameter	Description	Value
η	Power amplifier Parameter	0.2
ϑ	Power amplifier 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	Bandwidth of PRB	0.2 MHz
d_o	Near field distance	15m
p_{out}	Channl outage probability	1%
P_{DAC}	Power of DAC	15.4mW
P_{RF}	Power of other RF device	131.5 mW

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

B. Baseband Processing Power Consumption

The power dissipation for baseband signal processing can be modeled as [7]:

$$P_E = (C_E + C_R \frac{R_{S,max}}{R_S}) R_S, \tag{7}$$

where R_S is the symbol rate, $R_{S,max}$ is the maximum symbol rate, C_E and C_R are related to system voltage level.

C. Total Energy Consumption

Denoting T_{tx} the time for transmitting one PRB, and the number of PRBs that are used for transmitting and receiving by I_{tx} and I_{rx}, respectively, the energy consumption can be expressed as

$$\begin{aligned} E_{tx} &= I_{tx}(P_{tx} + P_E) T_{tx} \\ &= I_{tx}[(\beta_1 \gamma_{min} LW \\ &+ \beta_2) + (C_E + C_R \frac{R_{S,max}}{R_{S,node}}) R_{S,node}] T_{tx}. \end{aligned} \tag{8}$$

Similarly, the energy consumption for receiving can be expressed as

$$\begin{aligned} E_{rx} &= I_{rx}(P_{rx} + P_E) T_{rx} \\ &= I_{rx}[\beta_2 + (C_E + C_R \frac{R_{S,max}}{R_{S,node}}) R_{S,node}] T_{rx}, \end{aligned} \tag{9}$$

where $P_{rx} = \beta_2$ is the receiving power consumption and $R_{S,node}$ is the transmission symbol rate for the nodes inside DMC. As we also have

$$P_k = \beta_2 + (C_E + C_R) R_{S,AP}, \tag{10}$$

we finally result in

$$E_{total} = M P_k T_k = M[\beta_2 + (C_E + C_R \frac{R_{S,max}}{R_{S,AP}}) R_{S,AP}] T_k, \tag{11}$$

where $R_{S,AP}$ is the symbol rate used by AP-MTs transmission.

IV. Analysis of DMC Energy Saving

For simplicity we assume that each node within DMC is assigned the same resource for transmission. Thus, we have $I_{tx} = I_{rx} = I_{node}$, and $T_{tx} = T_{rx} = T_{node}$. Thus we have,

$$E_{node} = (K-1)(P_{rx} + P_{tx})I_{node}T_{node} + E_{total}/K. \quad (12)$$

Therefore, the energy saving gain for our study can be represented as,

$$\begin{aligned} \xi =& \frac{K-1}{K} M P_k T_k - (P_{tx} + P_{rx}) I_{node} T_{node} \\ =& \frac{K-1}{K} M T_k \big(P_k - \frac{P_{tx} + P_{rx}}{\rho}\big) \end{aligned} \quad (13)$$

where we assume that and $I_{node}T_{rx} = \frac{MT_k}{K\rho}, \forall \rho > 0$. Here ρ depends on the amount of data that the subcarrier can carry, which in general, is decided by modulation and coding schemes. For example, if BPSK and code rate (CR) 1/2 is used as modulation scheme from AP to MT and QPSK CR 1/2 is used for D2D communication inside MC, we have $\rho = 2$.

A. Numerical Results and Analysis

The energy efficiency metric for examining the usage of DMC is energy saving percentage, which is defined as $\frac{\xi}{E_{total}} \times 100$. For baseband energy consumption, we have $R_{S,max} = 1MHz$ and $R_{S,node} = R_{S,AP} = 250MHz$. We also assume that $C_E = 8 \times 10^{-8}$, $C_R = 10^{-7}$, and $BER_{req} = 10^{-5}$. The D2D channel is defined according to IEEE 802.11ac , where D2D distance is assumed to be 20m.

From Fig. 3, we can see that as the number of MTs increases, the energy saving gain obtained by using DMC arises as well. The energy saving percentage reaches the saturation level when there are 20 MTs forming a DMC. It means that without any radio resource (e.g. PRBs) constraints, forming DMC can help nearby MTs to save energy if proper modulation and coding schemes (MCS) are used. We also notice that when $\rho = 5$, we reach the maximal energy saving gain for all cases in this setting. The increase of the energy saving as a function of modulation order is expected due to shorter transmit times. However, there's also a need for higher transmit powers with higher modulation order so a trade-off clearly exists.

If we fix the number of MTs inside MC to be 20, we could obtain the impact of D2D distance and value of ρ in Fig. 4. We can observe that when the D2D distance is shorter than $d_o = 15m$, the energy efficiency performance remains at the same level for same values of ρ in Fig. 4. Generally, we can see that lower order MCS should be used when D2D distance is getting larger in order to achieve energy saving. For example, when D2D distance is $20m$, we can obtain 55% when $\rho = 6$, which is the maximum energy saving percentage for that D2D distance. However, $\rho = 5$ is the best choice when distance is $25m$. For the current channel model, forming DMC does not result in energy saving gains if the D2D distance is longer than $45m$.

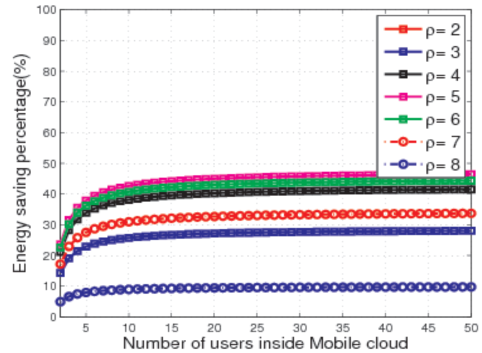

Figure 3. Number of MTs vs. energy efficiency gain with fixed D2D distance of 25m.

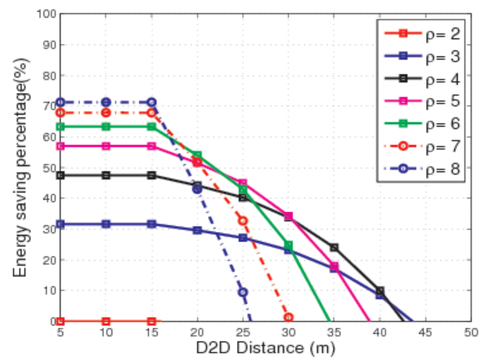

Figure 4. D2D distance vs. energy efficiency with fixed number of MTs.

V. Conclusion

In this work, we exploited the energy saving benefits of using distributed mobile cloud in an OFDMA networks. Targeting to decrease the total energy consumption of single MTs, we studied a distributed mobile cloud model, which is formed by a number of collaborating MTs. We presented a theoretical analysis on the energy consumption of MTs within the cloud. The analysis in this work serves as the foundation for our future distributed mobile cloud algorithm and protocol design.

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