

An efficient power-saving downlink transmission scheme in OFDM-based multiple component carrier systems

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Abstract—Traditional resource allocation studies of wireless access networks almost all focused on the maximization of the network capacity and quality of services (QoS). As the development of the cellular technologies (such as LTE-Advanced) progress, more than one component carrier (CCs) can now be jointly utilized in a base station (BS). However, the use of some CCs may not be necessary at light traffic loads, from the point of view of *green communication*. In this study, we propose a technique for dynamic power adjustment to enable energy-efficient data transmissions. That is, utilize only the necessary transmission power. In our model, the activities in downlink transmissions of a BS with 2 OFDM-based CCs are considered, while simultaneously supporting both real-time and non-real-time users. We employ a computationally efficient scheme according to the fluctuating traffic load to address the problem of power minimization at the BS transceiver, subject to the constraint of minimum rates for all users. Simulation results demonstrate that the energy consumption of our proposed scheme is much better than that of the case in which all CCs are always active, when both schemes maintain the required QoS.

Keywords— Power Saving, Green Communication, OFDM, LTE-Advanced, Radio Resource Allocation

I. INTRODUCTION

In order to enhance the capacity of the current cellular network to deal with the fast-growing data demand, the 4th generation (4G) system (such as LTE-advanced [1-2]) has now been developed. It is well known that for an LTE base station (BS), its multiple component carriers (CCs) can be jointly utilized for transmissions, and it is one of the promising features in a 4G system for achieving high capacity. As a result, the power consumption of wireless access networks, especially in the BS, has also become a crucial issue in the last few years, due to the rising energy cost and the serious environment impacts on green house gases emissions like CO₂.

To solve such a problem, *green communication* ([see for example [3-4]]) seems to be a new possible approach. The main purpose of *green communication* aims to reduce the total energy consumption in the transmission of communications, while maintaining the quality-of-service (QoS) of all users. Therefore, different from the traditional idea of the power allocation by setting the objective function to maximize the

throughput, we herein hope to minimize the total energy consumption subject to that the respective QoS and throughput requirements of all users can be satisfied.

Till now, the issue of designing the radio resource management, the packet scheduling algorithm, and the power allocation to improve the system performance in individual aspects has been fully studied in many papers, for example, [5-10]. Notice that all of these papers were considered in the multiuser orthogonal frequency division multiplexing (OFDM) system. In [5], Wong, *et al.* proposed a jointly adaptive subcarrier, bit, and power allocation algorithm to improve the system performance. Shen, *et al.* derived an optimal power allocation procedure in [6], where the proportional fairness was achieved. From the practical point of view, an efficiently cross-layer packet scheduling and resource management scheme was proposed by Jeong, *et al.* in [7]. In [8], Kivanc, *et al.* presented a class of computationally efficient algorithms for allocating subcarriers and power among users. Recently, Chung and Tsai proposed a quantized water-filling packet scheduling scheme employing carrier aggregation (see [3-4] for more details) to minimize the packet transmission delay in [9]. Madan *et al.* developed a fast algorithm to compute the optimal resource allocation for maximizing the overall system utility in [10]. However, these works did not consider the concern about the power-saving issue. Thus, although these papers had significant contributions in respective aspects, their designs were not tailored to handle the increasingly important power problem.

Based on the previously rich results (like [5-8]), some research groups have turned their attention to the power-saving transmission related topics, for example, [3-4] and [11-12]. Literatures [3-4] provided an overview and survey on the power consumption related issues in wired and wireless communication networks. Several energy-conserving network architectures were presented by the energy-saving management group in 3GPP [11]. In [12], an energy-saving algorithm was proposed for the dual-cell HSDPA system to exploit variations in network traffics. Nevertheless, to the best of our knowledge, the design of power-saving transmission schemes in a multiple-CC system at the cellular BS side still has not fully been investigated yet. In addition, due to the fact that a BS should have the capability of conserving the unnecessary power for its transceiver, as a key feature of *green communication*, efficient

power saving designs in such an environment should become more and more important.

Motivated by the above reasons, an efficient power-saving transmission scheme in the OFDM-based multiple-CC system is proposed. We focus on downlink transmissions that can support both real-time (RT) and non-RT (NRT) traffics simultaneously. Simulations are conducted to show that the performance of the energy consumption of our proposed scheme is much better than that of the case that all CCs are always active, while still maintaining the acceptable level for users' requirements.

The rest of this paper is organized as follows. In Section II, the system model is presented. Section III proposes an efficient power-saving downlink transmission scheme for this model. Simulation results are subsequently demonstrated in Section IV. Finally, conclusions and future works are given in Section V.

II. SYSTEM MODEL

In this paper, we consider the downlink transmission from a BS to wireless users in the cellular network. We consider 2 CCs in the same frequency band that can be jointly utilized in the BS for data transmissions. Assume that all the 2 CCs have the same bandwidth B . We call these 2 CCs as primary CC (PCC) and secondary CC (SCC), respectively. The PCC is used as the main CC for data transmissions, while the SCC is the supplementary CC when the traffic is relatively heavy.

The OFDMA radio technology is herein employed as the underlying downlink radio access scheme because of its high spectral efficiency, bandwidth scalability, and robustness against the multi-path fading. In this model, the resource block (RB), which spans 12 sub-carriers and 7 OFDM symbols, is designed to be the smallest allocation unit for the resource scheduling, while the sub-frame which spans J sub-channels and 2 slots, is the smallest transmission unit. Notice that 1 sub-channel includes 12 sub-carriers and 1 slot includes 7 OFDM symbols. Specifically, we define $(m,j)_{RB}$ as the RB in the m th time slot and the j th sub-channel of a given sub-frame, where $m=1,2$, and $j=1,2,\dots,J$. We also let $P_{\max}$ be the maximum transmission power allowed transmitting a sub-frame, and P_{idle} be the basic power consumption of turning on a CC, respectively.

The session arrival process of users is assumed to be a non-stationary Poisson process. The users' data packets are then transmitted in the session level. All user sessions are further classified as RT and NRT in the *classifier*, and if allowed, they are forward to enter the *RT queue* and *NRT queue*, respectively. The data packets of these sessions if allowed are then buffered in the *transmission queue* to wait for transmissions via the proposed scheme, which will be described in detail in Section III. Here, we assume that the RT session indicates a VoIP connection, while the NRT session represents an FTP activity for reasonable simplification. For RT users, their session time is assumed to be exponentially distributed. For NRT users, the

transferred file size is assumed to be with truncated lognormal distribution. Let C_{RT} and C_{NRT} be the minimum requirement data rate for the RT and NRT sessions, respectively. Additionally, we assume that any session of a user is only to connect a single CC for the transmission, regardless of the PCC or the SCC. It is for the reason that, in the physical-layer aspect, the power consumption in this way is less than that in distributing data over 2 CCs simultaneously.

From the system-level point of view, the considered model can be conceptually illustrated in Fig. 1.

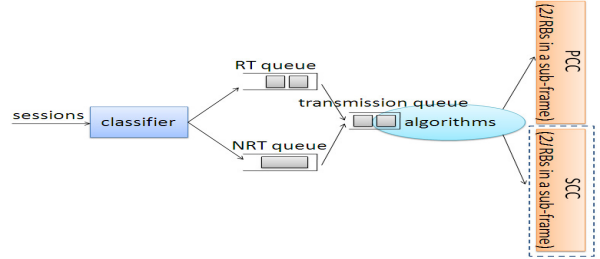


Fig. 1 The system model consisted of a *classifier*, an *RT queue*, an *NRT queue*, a *transmission queue*, a class of algorithms, and 2CCs with $2J$ RBs in each sub-frame of each CC, in a downlink transmission environment. The dotted line for the SCC means that the SCC can be turn off based on the traffic load.

The objective of this work aims to minimize the total power consumption of the BS transceiver, subject to the condition that the QoS of all the users can be satisfied. Nevertheless, this problem is a nonlinear-integer optimization problem, which is in nature difficult to solve. We thus propose an efficient strategy to solve this problem. The description of the proposed scheme is elaborated in Section III.

III. PROPOSED SCHEME

In the proposed scheme, the first step is to determine whether to block an incoming session, and if the session is allowed to enter, we then determine which CC should be assigned to the user. The proposed scheme can thus be logically separated into 2 main algorithms for the operation as follows: A) *the algorithm for the radio resource allocation*, which includes 2 sub-algorithms; and B) *the algorithm for the activity of the SCC*. Moreover, for the convenience of description, PCC and SCC are indexed as $k = 1$ and 2, respectively, and RT and NRT users are indexed as $z = \text{rt}$ and nrt , respectively.

Define the ideal transmission rate of the $(m,j)_{RB}$ on the CC k for the user session n as $r_{m,j-n}^{(k)}$, which is derived to be [13]

$$r_{m,j-n}^{(k)} = \beta \log_2 \left(1 + \frac{K P_{m,j-n}^{(k)} |H_{j-n}^{(k)}|^2}{N_0} \right). \quad (1)$$

Note in (1) that $K = -1.5/\log(5BER)$, where BER is the desired (constant) bit error rate, N_0 is the noise power spectral density,

$|H_{j-n}^{(k)}|$ is the channel gain between the sub-channel j and the user session n on the CC k , and $\beta = 12 \cdot 15000 \cdot 0.0005$ is the bandwidth in Hz for a RB, since 1 sub-channel includes 12 sub-carriers and each sub-carrier is defined to have 15000Hz. Let $\overline{|H_n^{(k)}|}$ be the average squared channel gain across all J sub-channels for the user session n on the CC k , which can be expressed as

$$\overline{|H_n^{(k)}|} = \frac{\sum_{j=1}^J |H_{j-n}^{(k)}|^2}{J}. \quad (2)$$

In addition, denote the average transmission power assigned to each sub-carrier as $\overline{P}$, which is given by

$$\overline{P} = \frac{P_{\max} - P_{\text{idle}}}{12J}. \quad (3)$$

Based on the concept of (1), and with the help of (2)-(3), the minimum requirement data rate for the RT and NRT users can be expressed as

$$C_z = \hat{m}_n^{(k)} \beta \log_2 \left(1 + \frac{K \overline{P} \overline{|H_n^{(k)}|}}{N_0} \right), \quad z = \text{rt or nrt}, \quad (4)$$

respectively. Notice in (4) that $\hat{m}_n^{(k)}$ is the estimated required number of RBs for the user session n on the CC k to meet the minimum requirement C_z of type z user, given that the transmission power assigned to each RB is assumed to be equal.

Next, the decision of determining whether to allow an incoming user session to access the network is described as follows. Specifically, define $\tilde{N}^{(k)}$ as the number of user sessions currently in the system including those being served and intended to be served on the CC k . Also, the remaining number of RBs on the CC k after the RBs are pre-estimated to assign to the $\tilde{N}^{(k)}$ user sessions, denoted as $\hat{m}^{(k)}$, is given by

$$\hat{m}^{(k)} = 2J - \sum_{n=1}^{\tilde{N}^{(k)}} \hat{m}_n^{(k)}, \quad k=1,2, \quad (5)$$

respectively. Upon the arrival of the incoming user session n , it will be checked in 2 steps to determine whether it is allowed to access the network. In the first step, we first calculate $\hat{m}_n^{(k)}$, based on (4), for the user session n , where the CC k is active. (Notice that the algorithm for determining whether the SCC should be active or inactive is described in Section III. B.) Next, we compare $\hat{m}^{(k)}$, via (5), to determine whether to block this session. If either $\hat{m}^{(1)}$ or $\hat{m}^{(2)} < 0$, this session will be blocked; otherwise, the CC k^* that has the largest $\hat{m}^{(k)}$ will be selected and go to the second step. We further compare $N^{(k^*)}$ and S , where $N^{(k^*)}$ means that, given that the first check is allowed, the number of user sessions in the system including those being

served and designated to be served on the CC k^* , and S is the number of maximum sessions allowed in a CC. If $N^{(k^*)} \leq S$, assign the specific CC k^* to this session; otherwise, it is blocked. Fig. 2 gives a detailed flow chart for the above algorithm.

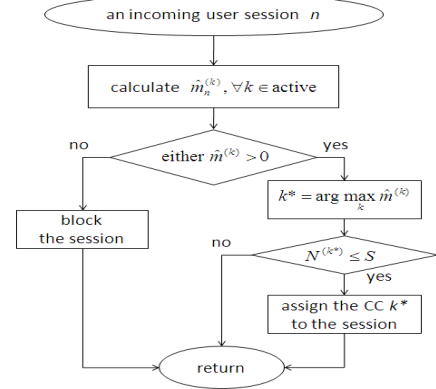


Fig. 2 The flow chart for determining whether to block an incoming user session and to determine which CC should be assigned to it.

A) Algorithm A:

The Algorithm for the Radio Resource Allocation

To efficiently allocate the radio resource to all allowed users, we herein appropriately modify the class of 2 radio resource allocation algorithms proposed in [8], to be re-designed to fit our model with the 2 CCs case, for its computational complexity advantage. Also, let $m_n^{(k)}$ be the number of CCs assigned to the user session n on the CC k . The algorithm contains 2 sub-algorithms named 1) *bandwidth assignment algorithm (BAA)* and 2) *resource block allocation algorithm (RBAA)*, respectively, which are given as follows. Notice that the operation and calculation of these algorithms are executed at the beginning of every sub-frame.

1) Bandwidth Assignment Algorithm (BAA)

$\forall$ users $\in$ CC k

allocate each user session 1 RB;

While ($\sum_{n=1}^{N^{(k)}} m_n^{(k)} < 2J$)

For $n=1:N^{(k)}$

calculate

$$G_n^{(k)} = \frac{N_0}{K \overline{|H_n^{(k)}|}} \left(2^{\frac{r_n^{(k)}}{\beta(m_n^{(k)}+1)}} - 2^{\frac{r_n^{(k)}}{\beta m_n^{(k)}}} \right);$$

End

$$n^* = \arg \min_n G_n^{(k)};$$

$$m_{n^*}^{(k)} = m_{n^*}^{(k)} + 1;$$

End

2) Resource Block Allocation Algorithm (RBAA)

$/S_n^{(k)}$: the set of current distributed RBs/

For each $(m,j)_{RB}$

$$n^* = \arg \max_n |H_{m,j-n}^{(k)}|^2;$$

$$\text{While } (|S_n^{(k)}| = m_{n^*}^{(k)})$$

$$|H_{m,j-n}^{(k)}|^2 = 0;$$

$$n^* = \arg \max_n |H_{m,j-n}^{(k)}|^2;$$

End

$$S_{n^*}^{(k)} = S_{n^*}^{(k)} \cup \{(m,j)_{RB^*}\};$$

End

BAA is to determine how many RBs should be assigned to each user session, while RBAA is to further determine the set of RBs for those sessions. Once the Algorithm A (BAA and RBAA) is finished in each transmission run, the respectively available RBs for the corresponding user sessions are determined. Next, in order to meet the minimum required data rate C_z of a given type z user, the data rate is in average distributed over the RBs that the user session obtains, to determine the values that the power should be assigned to these RBs, respectively.

B) Algorithm B:

The Algorithm for the Activity of the SCC

In order to actually conserve the unnecessary power consumption, in this algorithm, we intend to determine when to turn on and turn off the SCC. Specifically, define $p_{th,1}$ and $p_{th,2}$ as the threshold used to identify when to turn on and turn off the SCC, respectively. Note that $p_{th,2} < p_{th,1}$. Moreover, let p be the blocking probability of the system, which is defined as, in the execution period, the ratio of the number of user sessions being blocked of total arriving user sessions. Also, we assume that the users on the SCC are able to be migrated to the PCC immediately if the SCC is determined to be turn-off. Notice that the period for executing this algorithm is set to α times the duration of a sub-frame, where $\alpha \in$ positive integer values. The pseudo code for this algorithm is included as follows.

If $(p > p_{th,1})$

turn on the SCC;

If $((\sum_{n=1}^{N^{(2)}} \hat{m}_n^{(2)} < \hat{m}^{(2)}) \text{ and } (p < p_{th,2}))$

turn off the SCC;

IV. SIMULATION RESULTS

Here, an urban macro-cell environment with the radius equal to 1 km is assumed, where 2 adjacent OFDM-based CCs

in the 2GHz frequency band are utilized in the BS for data transmissions. We then examine the performance of the energy consumption of the proposed scheme in such a system at the BS side under a slow time-varying traffic load environment. The considered time-varying traffic load of the arrival rate (in users/minute) versus time is shown in Fig. 3.

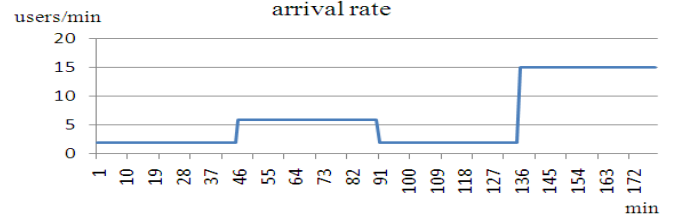


Fig. 3 Slow time-varying traffic loads versus time.

In the considered cell, we assume that all users are generated with a spatial uniform distribution. Moreover, the moving speed of every user is assumed slow and set equal to 3 km/hr of uniform distribution in a random direction. The ratio of the number of RT users to the number of NRT users is set to 1:1. The mean of the session time for RT sessions is set to 3 minutes. The mean of the file size with truncated lognormal distribution is set to 2Mbytes for 50% NRT sessions, while the other 50% NRT sessions have a fixed file size of 100Mbytes. Moreover, other main settings of the simulation parameters are referred to [1-4], as summarized in Table 1.

TABLE 1

SIMULATION SETTINGS

B	5MHz
C_{RT}	64kbps
C_{NRT}	512kbps
J	25
S	40
$p_{th,1}$	1%
$p_{th,2}$	0.5%
N_0	-130dBm
P_{max}	10watt
P_{idle}	10watt
α	600000
channel model	ITU-T Extended PedA (EPA)
simulation time	3 hrs

In order to illustrate the advantage of the proposed scheme for transmitting data in a 2 CCs environments, we examine the number of user sessions allowed to access the network versus time of the proposed scheme and compare its corresponding energy consumption performance against a baseline design, as shown in Figs. 4 and 5, respectively. The difference between

these 2 schemes is that the comparison scheme is to exclude the mechanism for activating/deactivating the SCC regardless of the fluctuating traffic load. That is to say, the *Algorithm B* is not executed in the comparison scheme. We can find that, during the interval when the traffic load is light, the energy consumption by the BS employing the proposed scheme can be significantly reduced (saving almost 50%). It implies that, to deactivate the SCC in the light traffic-load situation can significantly conserve the unnecessary power consumption, while still maintaining the blocking probability performance at an acceptable level. Also, due to the fact that the design of the presented scheme is modified on the basis of [8], the computational complexity of our scheme is low. It is consequently concluded that the proposed scheme should be an effective power-saving design to be employed in the cellular system at the BS side.

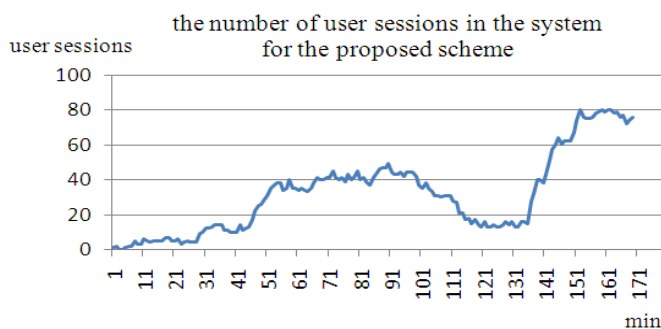


Fig. 4 The number of user sessions in the system for the proposed scheme.

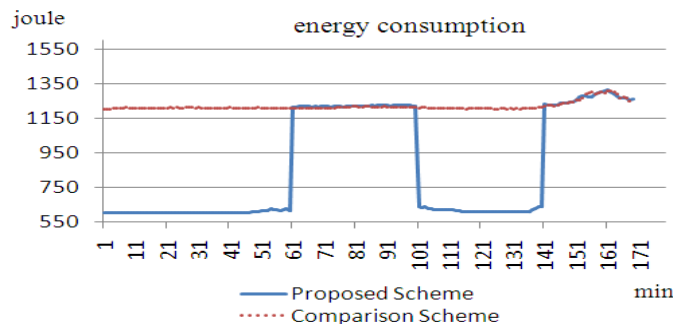


Fig. 5 A comparison of energy consumption between the proposed scheme and the comparison scheme.

V. CONCLUSIONS AND FUTURE WORKS

In this work, an efficient power-saving scheme for downlink transmission in OFDM-based multiple-CC systems has been successfully proposed. The proposed scheme consists of several algorithms that can joint allocate the radio resource to users with a low computational complexity and actually conserve the unnecessary power consumption. Comparing to the currently

existing scheme, the proposed scheme has the flexibility to determine the SCC to be active or inactive on the basis of the fluctuating traffic load.

Simulation results show that, when the active/inactive mechanism is employed in the SCC, the power consumption can be significantly reduced when the traffic load is relatively light. We thus believe that the presented power-saving scheme should be an excellent approach to be employed in the cellular system at the BS side for data transmissions to overcome the problem that the rising energy cost and the huge CO₂ emissions.

Furthermore, we suggest extending the presented system model and scheme to the one that the BS can employ arbitrary number of CCs for data transmissions as a future work.

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