Rate-and-Power Control Based Energy-Saving Transmissions in OFDMA-Based Multicarrier Base Stations

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***Abstract*—In parallel with the amazing increase in mobile data traffic, the fast-growing requirement and development of the green communication technology have led to many energy-saving designs in mobile networks. Meanwhile, as advanced cellular technologies progress, more than one component carrier (CC) can now be jointly utilized in a base station (BS). As a result, the energy consumption of the BS has become an important concern. In this paper, a novel green rate-and-power control transmission scheme is therefore proposed for the BS transmission to address the problem of energy minimization at BS transceivers subject to certain quality-of-service and fairness requirements for all users. Communication activities in downlink transmissions of the BS with orthogonal frequency-division multiple access-based multi-CCs are considered. Simulation results demonstrate that the energy consumption of the proposed novel energy-saving scheme is much better than that of existing schemes, when all schemes satisfy the same constraints.**

***Index Terms*—Energy saving, green communications, LTE-Advanced, OFDMA, radio resource allocation.**

NOMENCLATURE

B	the CC bandwidth
J	the number of subchannels in each subframe
C_{RT}	the minimum required data rate for the RT session
C_{NRT}	the minimum required data rate for the NRT session
$(m,\ j)_{\mathrm{RB}}$	the RB on the mth time slot and the jth subchannel
N_0	the noise power spectral density
$r_{m,j\_n}^{(k)}$	the ideal transmission rate of the $(m,\ j)_{\mathrm{RB}}$ on CC k for supporting user session n
K	$-1.5/\log(5BER)$, where BER is the desired (constant) bit error rate
$\left\|H_{j\_n}^{(k)}\right\|$	the channel gain between subchannel j and user session n on CC k
$\overline{\left\|H_{n}^{(k)}\right\|}$	the average squared channel gain across all J subchannels for user session n on CC k
$P_{m,j}^{(k)}$	the required transmission power to achieve $r_{m,j\_n}^{(k)}$
β	the bandwidth in Hz for a RB
E_k	the total energy consumption in the subframe on CC k
$E_{\max}$	the maximum available energy in each subframe
t_{sub_frame}	the duration of each subframe in seconds
Ω_k	the set of all RBs in each subframe of CC k
$m_n^{(k)}$	the number of RBs assigned to user session n on CC k
$S_n^{(k)}$	the set of current allocated RBs for user session n on CC k
ρ	the upper marginal factor for the energy check
γ	the lower marginal factor for the energy check
S	the number of maximum sessions allowed in a CC
N_k	the number of user sessions in the system on CC k
α	the period for executing the *CC activation algorithm*
p	the blocking probability of the system, which is defined as the ratio of the number of user sessions being blocked to total arriving user sessions
p_{th}	the blocking probability threshold used to identify when to turn on and turn off the SCC
N_{th1}	the lower threshold of user sessions used to identify when to turn on and turn off the SCC
N_{th2}	the upper threshold of user sessions used to identify when to turn on and turn off the SCC
PreOnFlag	an indicator representing whether the new user session can access the SCC
OnFlag	an indicator representing whether the SCC has been turned off

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I. INTRODUCTION

IT IS WELL known that the fourth generation base station (BS) has been developed to have the promising feature of *carrier aggregation* (*CA*) [1], jointly utilizing its multiple component carriers (CCs) based on respectively corresponding transceivers for transmissions, in order to achieve high total network capacity. The long-term evolution-advanced (LTE-A) BS (refer to [1]–[2] for more details), which has been specified by the third generation partnership project (3GPP), is nowadays a typical representative. Nevertheless, activating a transceiver in such a macrolevel BS will consume large-scale energy consumption [3]. As a result, problems with energy consumption of the access network, especially for those BSs, and the environment impacts on green house gases emissions like the carbon dioxide (CO_2) have become common critical concerns. The role of *green communications* ([see for example [4]–[5]) has therefore become increasingly important. *Green communications* is considered to be a new concept to minimize the total energy consumption in communication activities, while maintaining other certain constraints, different from the traditional idea of the power allocation by setting the objective function to maximize the throughput.

So far, the issue related to the design of the radio resource management, the packet scheduling algorithm, and the power allocation to improve the system performance in individual aspects has been comprehensively studied in many papers, for example, [6]–[11]. Notice that all of these papers were considered in the multiuser orthogonal frequency division multiplexing (OFDM) system. In [6], a jointly adaptive subcarrier, bit, and power allocation algorithm was proposed to improve the system performance. Paper [7] derived an optimal power allocation procedure, where the proportional fairness (PF) was achieved. From the practical perspective, an efficiently cross-layer packet scheduling and resource management scheme was proposed in [8]. In [9], a class of computationally efficient algorithms was presented for allocating subcarriers and power among users. Recently, paper [10] proposed a quantized water-filling packet scheduling scheme employing *CA* to minimize the packet transmission delay. In [11], fast algorithms were proposed to compute the optimal resource allocation for maximizing the overall system utility. However, these works did not consider the concern about the energy-saving issue. In other words, while they did have significant contributions in respective aspects, their designs were not capable of handling the increasingly critical energy consumption problem.

Recently, some research groups have paid attention to the energy-saving transmission related topics, for example, [3]–[5] and [12]–[14]. References [3]–[5] provided an overview and survey on the power consumption related issues in wired or/and wireless communication networks. Several energy-conserving network architectures were presented by the energy-saving management group in the 3GPP [12]. In [13], an energy-saving algorithm was proposed for the dual-cell high-speed downlink packet access system to exploit variations in network traffics. In [14], a computationally efficient power-saving scheme for downlink transmissions was proposed in orthogonal frequency-division multiple access (OFDMA)-based multi-CC systems, where the frame structure followed that of the LTE-A system, that is, the scheduling process was executed subframe by subframe. Nevertheless, the energy-saving transmission problem for next-generation BS transceivers still has not been fully investigated. Thus, how to minimize the energy consumption of the multiple transceivers in those BSs is still an open issue. While works [13]–[14] concerned on such an issue, the fairness concept was not considered; thus, their energy-saving designs could not reflect the effectiveness of the overall system. Also, one can find in [14] that the data rate could not be efficiently and adaptively adjusted according to network traffic loads.

Due to the above observations, the objective of this paper aims to minimize the total energy consumption in each subframe for the BS transceivers of OFDMA-based multiple CCs, while maintaining certain quality-of-service (QoS) minimum required levels and the fairness among users. Here, the QoS is considered to be the blocking probability and the data rate. This paper focuses on the downlink transmission and supports both the real-time (RT) and the nonreal-time (NRT) traffics simultaneously. Motivated by the practical need to more reasonable energy-saving designs in this area, a novel green scheme based on the rate-and-power control design is therefore proposed for efficiently solving the considered problem. The presented scheme also includes necessary scheduling and call admission control mechanisms. Simulation results demonstrate that the energy consumption performance of the proposed novel energy-saving scheme is much better than that of existing schemes, 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. In Sections III and IV, the green rate-and-power control scheme for this model is described in detail. Simulation results are subsequently demonstrated in Section V. Finally, conclusions are drawn in Section VI.

II. System Model

A. Basic Assumptions

Consider the downlink transmission in a single-cell cellular network. A list of all notations used in this paper for describing the considered model and its analysis is provided in the Nomenclature section. In this model, the BS can jointly utilize two CCs that are classified into primary CC (PCC) and secondary CC (SCC). The PCC is looked upon as the main CC for transmissions, while the SCC is thought of as the supplementary CC when the traffic is relatively heavy. Assume that the two CCs are consecutively located in the same band and each has bandwidth B in Hz. The LTE-A frame structure that the scheduling process is executed subframe by subframe is followed. In each subframe, there are J subchannels and two time slots. The resource block (RB), which consists of seven OFDM symbols in one time slot and 12 subcarriers in one subchannel, is set as the smallest allocation unit.

The considered system model is conceptually shown in Fig. 1. The session-level transmission is assumed in the model. Assume that the maximum number of sessions that each CC can accommodate is constant denoted as S. When a session request arrives, the *classifier* in the system will first classify it into either RT or NRT session, and then it will be forwarded to the *scheduling queue*. Next, the *admission control mechanism* is proposed to be used to determine whether to block the session request in the *scheduling queue* and further which CC should be assigned to the session if it is allowed to access the network. The mechanism is to assure the system not being heavily congested, as elaborated in Section II-B. Those allowed sessions are subsequently through a *resource scheduling algorithm* and a *CC activation algorithm* for transmissions, whose details are elaborated in Sections III and IV, respectively.

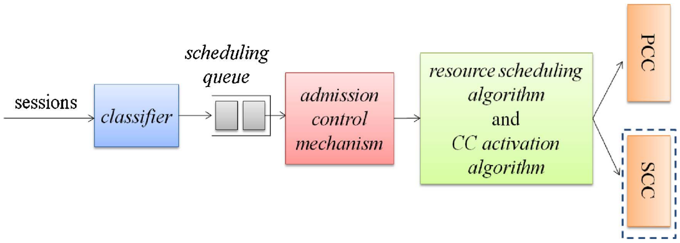

Fig. 1. System model consisted of a *classifier*, a *scheduling queue*, an *admission control mechanism*, a set of *algorithms*, and 2 CCs with $2J$ RBs in each subframe on each CC for downlink transmissions. The dotted line for the SCC means that the SCC can be turn off based on the traffic load.

Moreover, in this model, let C_{RT} and C_{NRT} be the minimum required data rate for the RT and NRT sessions, respectively. For convenience, the PCC and the SCC are indexed as $k = 1$ and 2, respectively, and RT and NRT users are indexed as $z =$ rt and nrt, respectively.

B. Admission Control Mechanism

First define $(m, j)_{\mathrm{RB}}$ as the RB on the mth time slot and the jth subchannel. Then define the ideal transmission rate of the $(m, j)_{\mathrm{RB}}$ on CC k for supporting user session n as $r^{(k)}_{m,j\_n}$. Based on [15], $r^{(k)}_{m,j\_n}$ can be derived via

$$r^{(k)}_{m,j\_n} = \beta \log_2 \left(1 + \frac{K P^{(k)}_{m,j} \left| H^{(k)}_{j\_n} \right|}{\beta N_0} \right). \tag{1}$$

Note in (1) that N_0 is the noise power spectral density, $\left| H^{(k)}_{j\_n} \right|$ is the channel gain between subchannel j and user session n on CC k, $\beta = 12 \cdot 15000$ is the bandwidth in Hz for a RB, since one subchannel includes 12 subcarriers and each subcarrier is defined to have 15 000 Hz, $K = -1.5 / \log(5BER)$, where BER is the desired (constant) bit error rate, and $P^{(k)}_{m,j}$ is the required transmission power to achieve $r^{(k)}_{m,j\_n}$ under the formulation structure in (1).

Based on (1), the transmission power of $(m, j)_{\mathrm{RB}}$ on CC k can thus be expressed as

$$P^{(k)}_{m,j} = \frac{\beta N_0}{K |H^{(k)}_{j\_n}|} (2^{\frac{r^{(k)}_{m,j\_n}}{\beta}} - 1). \tag{2}$$

Accordingly, the total energy consumption herein considered in the subframe on CC k denoted as E_k is given to be

$$E_k = \frac{t_{\mathrm{sub\_frame}}}{2} \sum_{(m,j)_{\mathrm{RB}} \in \Omega_k} P^{(k)}_{m,j} \tag{3}$$

where $t_{\mathrm{sub\_frame}}$ is the duration of each subframe in seconds and Ω_k is the set of all RBs in each subframe of CC k.

Fig. 2 shows the detailed flow chart of the *call admission mechanism*. When a new session arrives, the mechanism will first do the energy check by comparing E_k and $\rho E_{\max}$, where $E_{\max}$ means the maximum available energy in each subframe and ρ is the upper marginal factor. If allowed, the mechanism will further check the SCC status to identify if the SCC can be used. Notice that the PreOnFlag is an indicator representing whether the new user session can access the SCC. To be more detail, if PreOnFlag==0, the new session cannot access the SCC even if the SCC is still active and the new session can only use PCC if $N_1 < S$, where N_k represents the number of user sessions in the system on CC k. In the other case, if PreOnFlag==1, CC $k*$ that has the minimum E_k will be selected. Following that, the mechanism will check whether $N_{k*} < S$. If yes, CC $k*$ will be assigned to the new session; otherwise, the mechanism will further check whether $N_k < S$ and $E_k < E_{\max}$ to determine if the new session can access CC k. Notice that the operation and calculation of the mechanism is executed at the beginning of every subframe.

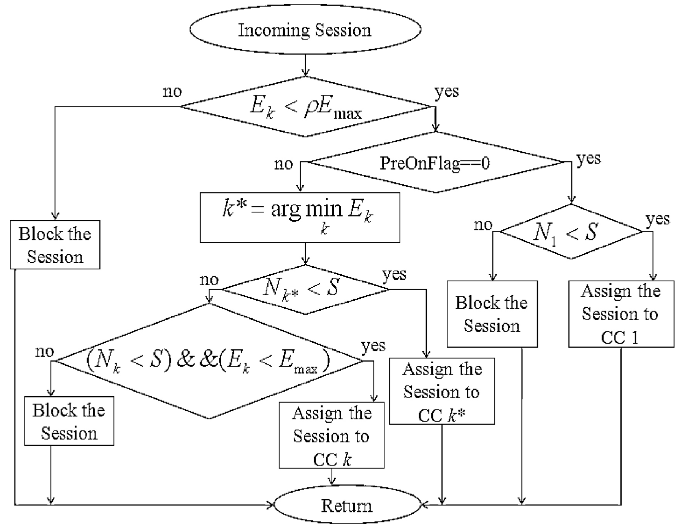

Fig. 2. Flow chart of the *admission control mechanism*.

C. Goal of the Novel Energy-Saving Transmission Scheme

Based on the considered system model, the total energy consumption in each subframe at the BS transceivers is aimed to be minimized, while maintaining the blocking probability of all user sessions, the minimum required data rates for each type of users, and the fairness among all users in an acceptable level. To efficiently and effectively achieve the above goal, a novel energy-saving scheme, which includes a *resource scheduling algorithm* in Section III and a *CC activation algorithm* in Section IV, is proposed.

III. Resource Scheduling Algorithm

The presented *resource scheduling algorithm* includes two algorithms that are separately proposed for the operation as follows: 1) *energy adaptive rate control algorithm (EARCA)* and 2) *radio resource allocation algorithm (RRAA)*. The *RRAA* algorithm is further separated into two subalgorithms named *B.1) bandwidth assignment algorithm (BAA)* and *B.2) resource block allocation algorithm (RBAA)*, respectively.

EARCA is designed to dynamically adjust the NRT user's allocated capacity based on his/her path loss feedback and the current used energy. After the NRT user's data rate is set, *BAA* determines how many RBs should be assigned to each user session, while *RBAA* is used to further determine the set of RBs for those sessions.

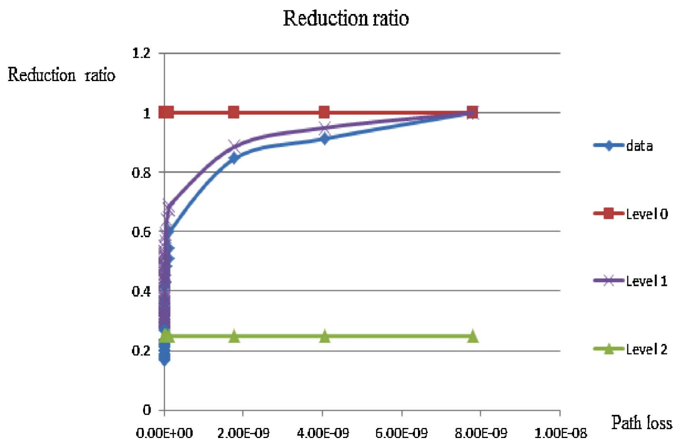

Fig. 3. Illustration of the reduction ratio as a function of the channel gain being used to determine the allocating capacity for the NRT users.

Once both *EARCA* and *RRAA* are finished in sequence in each transmission run (i.e., subframe), the available RBs for the corresponding user sessions are determined, respectively. Next, the desired data rate is distributed equally over the RBs that the user session obtains and the energy for each RB is then determined according to the required capacity.

A. Energy Adaptive Rate Control Algorithm (EARCA)

In *EARCA*, there are three *Levels* of reduction ratios that can be employed. They are indicated as *Level i*, *i*=0,1,2, respectively. The reduction ratio represents how much reduction in data rate is enforced for an NRT user when compared with the largest allowed data rate. An illustration of the reduction ratios of the three *Levels* are designed to be shown in Fig. 3, respectively.

The natural log function of the *Level* 1 is designed on the basis of the classic PF [16] criterion, in order to maintain the fairness among users in a certain level. The design approach is elaborated as follows. A large number of NRT users are randomly placed in the cell, and they are allocated RBs based on the PF criterion under the assumption of equal power allocation on each RB. After a long-term simulation, the NRT users' averaged data rate as a function of their path loss gains is calculated. Then the natural log function based on the fitting method of minimum mean squared error is used. Notice that the natural log function is normalized so that the reduction ratio of the NRT user having the maximum channel gain equals to 1.

The operation for determining which *Level* should be adopted is shown in Fig. 4, where γ is the lower marginal factor.

B. Radio Resource Allocation Algorithm (RRAA)

RRAA is designed on the basis of the resource allocation approach employed in [9], for its computational complexity advantage. Pseudo codes for the detailed operation are written in Figs. 5 and 6, respectively.

In each decision epoch of every subframe, the *BAA* subalgorithm in Fig. 5 will be executed first. All wireless users will feedback their channel gains to the BS so that averaged squared channel gains can be calculated as input arguments. Also, the number of required RBs for all the user sessions will be set to 0 initially. After initialization, all the user sessions will be allocated 1 RB first, to guarantee minimum data rate requirements. Next, the remaining RBs will be allocated according to the allocation metric. It intends to allocate the RB to the user who can best benefit in term of the energy consumption decrease after getting the RB, and the number of required RBs for the selected user will be added 1 after the allocation.

```
If ((E_k > γE_max) || (E_k < ρE_max))
    If ((E_k > γE_max) & &(Level < 2))
            Level = Level + 1;
    Else if ((E_k < ρE_max) & &(Level > 0))
            Level = Level − 1;
    End
End
∀ NRT users
Set their capacities according to the Level;
End
```

Fig. 4. Pseudo code of *EARCA*.

After the execution of *BAA*, the *RBAA* subalgorithm in Fig. 6 will subsequently be executed. In *RBAA*, channel gains and the number of every user session' required RBs are used as input arguments. For each RB, the subalgorithm intends to find the user who has the largest channel gain among all the users. After finding the user, check whether the number of the current allocated RBs of the user equals to the number of its required RBs. If yes, set the channel gain of the user equal to 0, and find another user whose channel gain is the largest among all the users till the *while loop* is over. After the *while loop*, allocate the RB to the user session picked during this run.

Once the two subalgorithms are finished in sequence, every user session's available RBs are determined. Next, the desired data rate of each user session will be distributed equally over its allocated RBs, and the energy for each RB is subsequently determined.

IV. Component Carrier Activation Algorithm

The *CC activation algorithm* is to determine the practical use of the SCC according to the fluctuating network traffic load to actually conserve the main energy consumption of the BS.

Specifically, let p be the blocking probability of the system, which is defined as the ratio of the number of user sessions being blocked to total arriving user sessions. Also, define p_{th}, N_{th1}, and N_{th2} as thresholds used to identify when to turn on and turn off the SCC, respectively. The OnFlag is an indicator representing whether the SCC has been turned off. Notice that the period for executing this algorithm is set to be α subframes, where α is a positive integer. The pseudo code for this algorithm is included in Fig. 7.

```
/m_n^(k) : the number of RBs assigned to user session n on CC k/
/|H_n^(k)| (overlined): the average squared channel gain across all J sub-channels for user session n on CC k, which is expressed as
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$$/\overline{\left|H_n^{(k)}\right|} : \text{the average squared channel gain across all } J \text{ sub-channels for user session } n \text{ on CC } k, \text{ which is expressed as } \overline{\left|H_n^{(k)}\right|} = \frac{1}{J}\sum_{j=1}^{J}\left|H_{j\_n}^{(k)}\right| /$$

$\forall$ *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 the allocation metric expressed as

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

End

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

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

End

Fig. 5. Pseudo code of *BAA*.

/$S_n^{(k)}$ *: the set of current allocated RBs for user session n on CC k/*

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

$n^* = \arg\max_n \left|H_{j\_n}^{(k)}\right|^2$;

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

$\left|H_{j\_n}^{(k)}\right|^2 = 0$;

$n^* = \arg\max_n \left|H_{j\_n}^{(k)}\right|^2$;

End

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

End

Fig. 6. Pseudo code of *RBAA*.

If $((p > p_{th})\,\&\&(\text{OnFlag} == 0))$

OnFlag=1;

PreOnFlag=1;

End

If $((\text{OnFlag} == 1)\,\&\&(N_1 + N_2 < N_{th1}))$

PreOnFlag=0;

End

If $((\text{OnFlag} == 1)\,\&\&(N_1 + N_2 > N_{th2}))$

PreOnFlag=1;

End

If $((\text{OnFlag} == 1)\,\&\&(\text{PreOnFlag} == 0)\,\&\&(N_2 == 0))$

OnFlag=0;

End

Fig. 7. Pseudo code of the *CC activation algorithm*.

V. Simulation Results

In this section, the effectiveness and the efficiency of the proposed energy-saving scheme are examined with MATLAB coded simulations. Consider an urban macrocell environment with the radius equal to 1 km, where two adjacent OFDMA-based CCs in the 2 GHz frequency band are utilized in the BS for downlink data transmissions. The considered time-varying traffic load of the arrival rate (in users/min) versus time is shown in Fig. 8.

A. Parameter Settings

In the considered cell environment, it is assumed that all users are generated with a spatially uniform distribution. The moving speed of every user is assumed slow and set equal to 3 km/h 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 arrival-session process of users of each type is assumed to be a nonstationary Poisson process. For RT users, their session times are assumed exponentially distributed. For NRT users, the transferred file size is assumed with truncated lognormal distribution. The mean of the session time for RT sessions is set to 2 min. The NRT sessions have a fixed file size of 50 MB. Moreover, set the maximum transmission power allowed for transmitting a subframe and the basic power consumption for activating a CC in a subframe equal to 10 W and 10 W, respectively. Additionally, set B=5 MHz, $t_{\text{sub\_frame}}$ = 1 ms, C_{RT} = 64 kbps, C_{NRT} = 500 kbps, N_0 = −130 dBm, J=25, S=40, p_{th} = 1%, N_{th1} = 25, N_{th2} = 35, and α = 240. The International Telecommunication Union (ITU) Extended Pedestrian A (EPA) channel model is adopted.[1] The simulation time is set equal to 3 h. Notice that most of the parameter settings follow the 3GPP.

B. Various Performance Results of the Proposed Scheme

Energy consumptions of the proposed scheme with different rate control *Levels* against a baseline design with no energy-saving are shown in Figs. 9 and 10, respectively. Note that the energy consumption is calculated every α period. The baseline scheme is to exclude the *CC activation algorithm* regardless of the dynamically fluctuating traffic load. In Figs. 9 and 10, the energy consumption by the BS employing the proposed scheme can be significantly reduced, saving almost 50%.

Also, the fairness index of data rates for all users under the proposed scheme evaluated by the fairness index formula in [19] is able to be maintained at least larger than 0.8, as

[1] Objective of this paper is to gain the main insight of optimizing the number of CCs for energy-saving transmissions by activating/deactivating them. The moving speed of every user considered being slow and set equal to 3 km/h in the parameter setting is given simply as an example. The multiple CCs are able to be aggregated in the BS to become much higher bandwidth for transmissions, to achieve high total network capacity. Since the ITU EPA channel model is intentionally applied in a much wider bandwidth transmission network environment and represents a user speed of 3 km/h [17] as well as is more energy-efficient than that of other ITU extended-form ones [18], we suggest employing the EPA in the physical layer in the considered system.

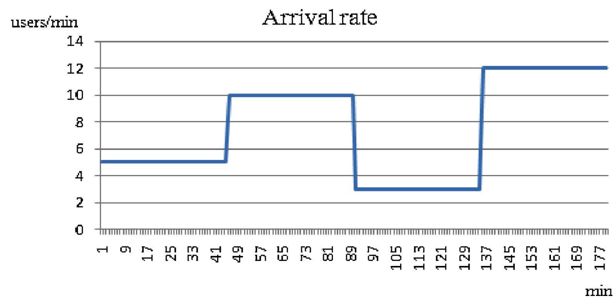

Fig. 8. Slow time-varying traffic loads versus time.

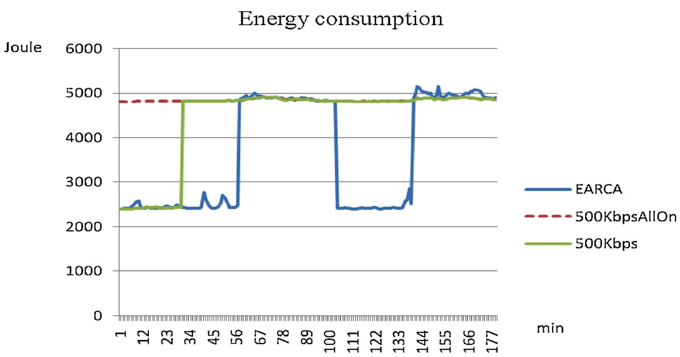

Fig. 9. Comparison of the energy consumption between the proposed scheme with *EARCA*, *Level* 2, and the comparison scheme.

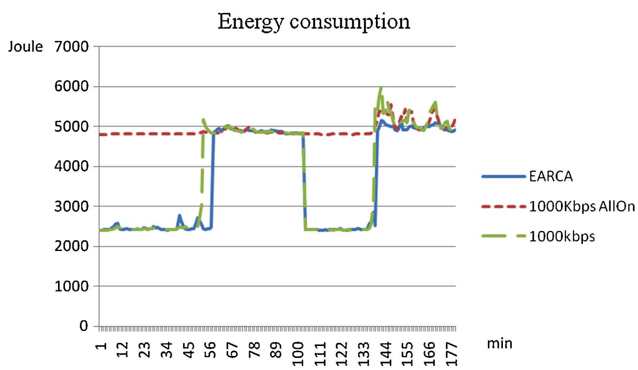

Fig. 10. Comparison of the energy consumption between the proposed scheme with *EARCA*, *Level* 0, and the comparison scheme.

shown in Fig. 11. Moreover, the blocking probability is always guaranteed to be below 1%, due to the effective design of the *CC activation algorithm*. Note that both the two metrics of the fairness index and the blocking probability are examined via simulations every 10 min. Based on the above observations, it thus implies that, disabling the use of the SCC in the light traffic-load situation can significantly reduce the unnecessary energy consumption, while reasonably maintaining the desired blocking probability and fairness at an acceptable level.

Next, one can find in Fig. 9 that, if only *Level* 2 (with fixed date rate set to 500 kbps for NRT users) is adopted, the SCC will be turned on early even if the traffic load is light, because the transmission date rate is low. Moreover, as seen in Fig. 10, if one only adopts *Level* 0 (with fixed date rate set to 1000 kbps for NRT users), it will lead to peak energy when the traffic is relatively heavy, because the bandwidth granted to each user is much less. For both the cases, the

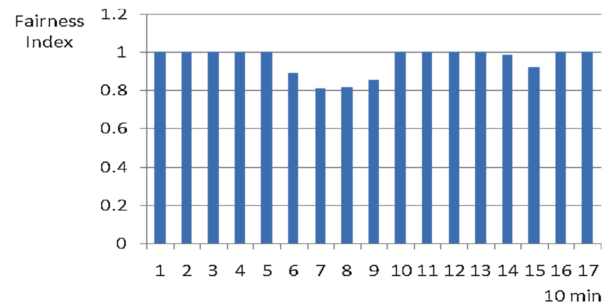

Fig. 11. Fairness index of the proposed scheme.

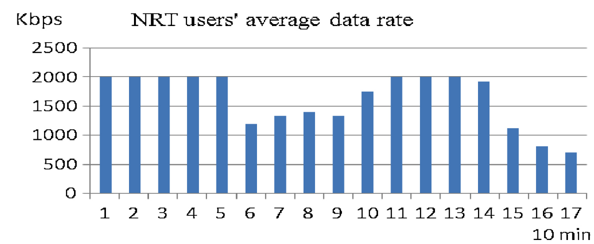

Fig. 12. NRT users' average data rate every 10 minutes of the proposed scheme with *EARCA*.

TABLE I
A COMPARISON OF PERFORMANCE RESULTS IN VARIOUS ASPECTS BETWEEN THE PROPOSED SCHEME AND THE SCHEME IN [14]

Aspect / Method	Total energy consumption (kJ) in 3 h	Blocking probability	Utilized time of the SCC (min)	Average data rates of RT users / NRT users (kbps)
Proposed scheme	667	0.76%	88	64 / 1506
Scheme in [14]	709	0.79%	97	64 / 500

BS will thus squander the energy. However, it is observed in both Figs. 9 and 10 that if *EARCA* is employed, the above drawbacks can be effectively overcome. It is for the reason that *EARCA* has the ability to adaptively adjust a user's data rate according to the dynamic traffic loads.

The NRT users' average data rate of the proposed scheme with *EARCA* is further examined every 10 min, as shown in Fig. 12. By observing Figs. 8 and 12, one can find that when the traffic load is relatively light/heavy, the data rate obtained by the NRT users will be much higher/lower. It confirms the fact that when the traffic loads dynamically fluctuate, *EARCA* is able to appropriately adjust the NRT users' data rates.

In addition to the above advantages, the computational complexity of the proposed scheme is also small, due to the fact that its design is modified on the basis of [9].

C. Comparisons Between the Proposed Scheme and the Scheme in [14]

For completeness, various performance results are compared between the proposed scheme and the scheme in [14] to further verify the improvement design of the proposed scheme. Table I lists a comparison of performance results in various aspects between the two schemes.

It can be found that the proposed one can save about 6% of the energy consumption compared with that in [14]. Moreover, for the proposed one, the utilized time of the SCC is less than that in [14] and the blocking probability is maintained below 1%. Also, the average data rate of NRT users of the proposed scheme outperforms than that in [14], due to the *EARCA* design, which can dynamically adjust the NRT users' data rates for expediting their transmissions. Joining together the above observations, it implies that the proposed one is far better capable of making the accurate decision for effectively activating/deactivating the SCC to avoid the unnecessary energy consumption than the comparison scheme, mainly due to the PreOnFlag and OnFlag identification indicators.

One thus believes that the proposed transmission scheme is an effective and efficient energy-saving design that should be an excellent candidate to be employed in the further multi-CC cellular system at the BS side.

VI. Conclusion

In this paper, a novel energy-saving downlink transmission scheme in OFDMA-based multi-CC network systems was successfully proposed. The proposed scheme could allocate the radio resource with an adaptively rate-and-power control to users and support an acceptable level of the QoS and the fairness at the same time. Compared with the currently existing works, the proposed one had the great advantage of flexibility to activate/deactivate the SCC according to the dynamically fluctuating traffic load to effectively avoid unnecessary energy consumption.

It was shown from simulation results in Section V that when the *CC activation algorithm* was employed, the energy consumption could significantly be reduced when the traffic load was relatively light. In addition, thanks to the assistance of the *resource scheduling algorithm*, the energy could be efficiently utilized. It was thus believed that the presented energy-saving scheme was an excellent approach to be employed in the future multi-CC cellular system at the BS side for transmissions to overcome the increasingly crucial problem of the rising energy cost and the CO_2 emission concern.

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