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Correspondence letter

Traffic balancing over licensed and unlicensed bands in heterogeneous networks

LI Zhen, CUI Qimei, CUI Zhiyan, ZHENG Wei

National Engineering Laboratory for Mobile Network Security, Beijing University of Posts and Telecommunications, Beijing 100876, China

Abstract: The rapid boosting in mobile traffic and the scarcity of available radio spectrum have hindered the improvement of capacity in cellular networks. It is necessary to discover an appropriate coexistence between cellular and other radio access technologies (mainly Wi-Fi) to offload the high traffic on to unlicensed bands. Dealing with joint time and power allocation to devices, a non-convex problem is modeled to maximize the throughput as well as guarantee the desired user satisfaction. A two-step traffic balancing scheme is proposed to derive the solution. We also focus on the inner competition among cellular users instead of traditional competition between cellular and Wi-Fi in the unlicensed bands. Finally, simulation results show the effectiveness of the proposed two-step traffic balancing scheme.

Key words: licensed-assisted access using LTE, traffic balancing, unlicensed band, time allocation

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1 Introduction

Unlike the evolution of traditional cellular penetration based on spectral efficiency, small cells or ultra dense network are proposed by means of network infrastructure densification to deal with boosted mobile data traffic[1,2]. There are abundant Unlicensed National Information Infrastructure (U-NII) bands with frequencies of 5 GHz labeled as U-NII-1, U-NII-2, and U-NII-3[3], which can alleviate the pressure on the licensed bands[4]. However, two types of the most widely used small cells, i.e., femto cell and Wi-Fi hotspot, cannot reach to the maximum spectrum utilization due to the lack of a suitable intelligent coexistence in the unlicensed bands. Many companies (e.g., Qualcomm, HuaWei) in industry have undertaken research and considered advanced strategies in Refs.[5,6] to implement a harmonious coexistence.

The 3GPP (3rd Generation Partnership Project) has designed the specification of LAA (Licensed-Assisted Access) using LTE (Long Term Evolution) for small cells based on carrier aggregation technology[7]. In the literature, numerous methods have been proposed

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for establishing coexistence, such as Listen Before Talk[8], Carrier-Sensing Adaptive Transmission, Dynamic Channel Selection and duty circle model[9-12]. Regardless of the differences and similarities of these methods, a theoretical guide to achieve higher throughput and guarantee user satisfaction is vital. In this paper, we ignore the specific coexistence implementation and focus on the theoretical optimal time allocation in the unlicensed bands.

In particular, time allocation means the time ratio that every device can occupy in the unlicensed bands, and power allocation means the power allocated to every band. Sdevice and wdevice are used to represent the end-user terminal in the LAA and Wi-Fi heterogeneous networks respectively. Sdevices can access both the licensed and unlicensed bands where wdevices can only use the unlicensed bands. Some studies were performed to implement traffic balancing for user satisfaction over the licensed and unlicensed bands under different constraints and scenarios. Bennis, et al. proposed a cross-system learning framework[13] to offload the delay-tolerant data traffic on to the unlicensed bands where no wdevice is assumed in the framework. Elsherif et al. designed a method to maximize the total throughput without guaranteeing the user satisfaction in which multi Wi-Fi, femto and macro users were considered[14]. In Ref.[15] traffic balancing was first presented for user satisfaction, which is achieved by using natural logarithm function, power budget and optimal power allocation. Fang, et al. extended the original single unlicensed band scenario to the multiple unlicensed bands scenario[16] with variable power distribution to the unlicensed bands.

However, all the aforementioned studies mainly focus on the competition between LAA and Wi-Fi and ignore the inner competition among different sdevices in the unlicensed bands. In previous research work, only single-sdevice has been discussed which can certainly access the unlicensed bands as long as the Wi-Fi traffic load is not saturated. However, whether a certain sdevice in the multi-sdevices situation can access the unlicensed bands or not also depends on the conditions of other competitive sdevices, e.g., available licensed bandwidth and channel quality.

The main contribution of this paper is proposing a two-step traffic balancing scheme, and analyzing the optimal power and time allocation in a novel scenario where multi-sdevices and multi-wdevices compete with each other. These multi-sdevices and multi-wdevices coexist in heterogeneous networks, and the inner competitive relationship among sdevices in the unlicensed bands is evaluated.

The rest of this paper is organized as follows: the system model and problem formulation are presented in Section 2. A novel two-step traffic balancing scheme is proposed to solve optimal time and power allocations respectively in Section 3, where the competitive relation among sdevices with different licensed bandwidth is analyzed. Simulation results of the traffic balancing scheme are shown in Section 4. Finally, a conclusion is drawn in Section 5.

2 System model and problem formulation

2.1 System model

Femto cells represented with N_s and one Wi-Fi AP(Access Point) are considered in a scenario where each femto cell is connected with one sdevice and the Wi-Fi AP serves wdevices represented with N_w. Each sdevice can use both the licensed and unlicensed bands while wdevices can only work in the unlicensed band through the Wi-Fi AP, as shown in Fig.1. Assuming that each sdevice can access k different licensed bands and coexists with wdevices in a certain unlicensed band. $K(i)$ denotes the set of specified licensed bands for sdevice i and $G(i)$ denotes the set of available licensed and unlicensed bands for sdevice i. t_s^i is the time ratio of unlicensed band occupied by the sdevice i while t_w is the time ratio for all wdevices. There are two kinds of power allocation, $P_u^{(j)}$ denotes the power allocation for band j when sdeivce i accesses the unlicensed bands while $P_l^{(j)}$denotes the allocation when sdevice i does not.

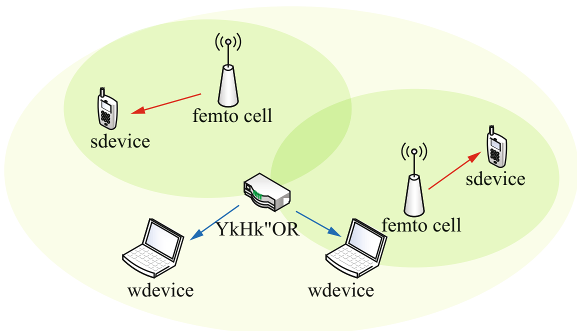

Figure 1 Multi-sdevices and multi-wdevices scenario

For LAA function is physically attached to LAA base station, e.g., the upper limit of the sum of $P_l^{(j)}$ and $P_u^{(j)}$ are both equal to total transmit power.

2.2 Problem formulation

The throughput of a certain nth wdevice $S_{\omega,n}$ can be expressed as

$$S_{\omega,n}=R_{\omega,n}\lambda_n t_\omega , \tag{1}$$

where $R_{\omega,n}$ is the data rate of wdevice n, and λ_n represents the proportion of t_ω that wdevice n occupies in the unlicensed band. $R_{\omega,n}$ and λ_n are constant when all the wdevices are under the same conditions. Similarly, the throughput of ith sdevice represented by $S_{s,i}$ is

$$S_{s,i}=\sum_{j\in K(i)}(1-t_s^i)R_s(P_l^{(j)}\gamma^{(j)})+\sum_{j\in G(i)}t_s^i R_s(P_u^{(j)}\gamma^{(j)}), \tag{2}$$

where $\gamma^{(j)}$ is the path loss of signal in band j. $R_s(\cdot)$ is the data rate of the sdevice, which is formulated by Shannon Capacity theorem for simplicity.

Another problem is finding an accurate function to denote the user satisfaction $U(S)$. Proportional Fairness[17] is an efficient algorithm to balance the traffic by maximizing the whole throughput while all users can accept at least a minimal level of service. This mathematical problem has been solved[18] and can be presented as:

$$f(x) = \ln(x) . \tag{3}$$

Intuitively, the value of natural logarithm increases rapidly when the variable is small and slows down as the variable increases, which is consistent with the requirement of traffic balancing. Therefore $U(S)$ can be formulated by the widely used natural logarithm function to achieve a fairly balanced estimate of all devices' throughput, which is also used in Refs.[15,16].

Based on the system model and problem description, the integrated problem can be formulated as follows:

$$\max_{t_s^i,t_\omega,P_l^{(j)},P_u^{(j)}} U=\sum_{n\in N_\omega}U(R_{\omega,n}\lambda_n t_\omega)+ \sum_{i\in N_s}U\left(\sum_{j\in K(i)}(1-t_s^i)R_s(P_l^{(j)}\gamma^{(j)})+\sum_{j\in G(i)}t_s^i R_s(P_u^{(j)}\gamma^{(j)})\right), \tag{4}$$

$$\begin{aligned}
\text{s.t.}\ \mathrm{I}:&\ P_l^{(j)}\left|h^{(j)}\right|\leqslant I,\ j\in K(i),\\
\mathrm{II}:&\ P_u^{(j)}\left|h^{(j)}\right|\leqslant I,\ j\in K(i),\\
\mathrm{III}:&\ \sum_{j\in K}P_l^{(j)}\leqslant P_{\mathrm{tot}},\\
\mathrm{IV}:&\ \sum_{j\in G}P_u^{(j)}\leqslant P_{\mathrm{tot}},\\
\mathrm{V}:&\ P_u^{(j)}\leqslant P_{\max},\ j=k+1,\\
\mathrm{VI}:&\ t_\omega\leqslant\bar{t}_\omega,\\
\mathrm{VII}:&\ \sum_{i\in N_s}t_s^i+t_\omega\leqslant t_{\max},\\
\mathrm{VIII}:&\ t_s^i\geqslant 0,\ t_\omega\geqslant 0,\\
\mathrm{IX}:&\ P_u^{(k+1)}\geqslant 0,\ P_l^{(j)}\geqslant 0,\ P_u^{(j)}\geqslant 0,\ j\in K.
\end{aligned} \tag{5}$$

Constraints Ⅰ and Ⅱ indicate that the interference power leaked from the femto cell to its neighbors can not surpass the maximum power limit I in one licensed band. Constraints Ⅲ, Ⅳ and Ⅸ show that the limit power allocated by femto cell over the licensed and unlicensed bands can not exceed the maximum transmit power. Constraint Ⅴ provides the upper limit power of the unlicensed band when it is occupied by sdevices. The average traffic load of all the wdevices is denoted as $\bar{t}_\omega$, and the practical trac load of wdevices should be less than the average load in order to maximize the entire throughput, which is achieved by constraint Ⅵ. Constraints Ⅶ and Ⅷ introduces the maximum usage of the available time denoted by $t_{\max}$· t_s^i and t_ω can be regulated to improve $U(S)$ through the optimal time allocation and so do $P_l^{(j)}$ and $P_u^{(j)}$ through optimal power allocation.

The problem is non-convex because of the joint of power allocation and time allocation, thus in this paper the problem is divided into two sub-problems to achieve the calculation, which is known as heuristic algorithm. In the first sub-problem optimal power allocation is solved with the fixation of t_s^i and t_ω where in the second sub-problem optimal time allocation is solved with power allocation obtained in previous sub-problem. A novel two-step traffic balancing scheme is proposed to solve two sub-problems and finally obtain a locally optimal solution. The scheme will be discussed in the next section.

3 Traffic balancing scheme

In this section, the problem is divided into two sub-problems, i.e., optimal power allocation and optimal time allocation, details of each are shown in next two subsections. First optimal power allocations $P_l^{(j)}$ and $P_u^{(j)}$ are calculated while time allocation t_s^i and t_w is fixed. The power allocation is proved to be convex and will be obtained by water-filling algorithm. Second, after getting the optimal power allocations the time allocation concludes an optimal calculation, and numerical results are obtained by adjusting parameters.

3.1 Power allocation

Depending on whether the sdevice accesses the unlicensed bands or not, there are two types of power allocation $P_l^{(j)}$ and $P_u^{(j)}$. $P_u^{(j)}$ denotes the power allocation for any band j when sdeivce i accesses the unlicensed bands while $P_l^{(j)}$ denotes the allocation for only licensed band j when sdevice i does not, and thus they should be solved individually.

According to Eq.(4), $P_l^{(j)}$ affects the user satisfaction only through the part $\sum_{j\in K(i)}(1-t_s^i)R_s(P_l^{(j)}\gamma^{(j)})$. Function $U(S)$=ln(S) is strictly increasing with throughput S and t_s^i is fixed in this step, hence this part can optimize Eq.(4) as well. The optimal $P_l^{(j)}$can be described as

$$\max_{P_l^{(j)}}\sum_{j\in K(i)}(1-t_s^i)R_s(P_l^{(j)}\gamma^{(j)}), \tag{6}$$

which is subject to constraints Ⅰ and Ⅲ . $R_s(\cdot)$ is formulated by Shannon Capacity theorem, that is

$$R_s(P_l^{(j)}\gamma^{(j)})= B^{(j)}\log_2(1+P_l^{(j)}\gamma^{(j)}), \tag{7}$$

where $B^{(j)}$ is the bandwidth of licensed band j. Eq.(7) is convex so $P_l^{(j)}$ can be solved using the Karush-Kuhn-Tucker (KKT) conditions[19]:

$$P_l^{*(j)}=\min\left(\left(\frac{B^{(j)}}{v}-\frac{1}{\gamma^{(j)}}\right)^+,\frac{I}{|h(j)|^2}\right), j\in K(i), \tag{8}$$

where $(x)^+$ means max(x, 0) and v is chosen to satisfy constraint Ⅲ with equality.

In the same way optimal $P_u^{(j)}$ is calculated

$$P_l^{*(j)}=\begin{cases}\min\left(\left(\frac{B^{(j)}}{u}-\frac{1}{\gamma^{(j)}}\right)^+,\frac{I}{|h(j)|^2}\right), j\in K(i),\\ \min\left(\left(\frac{B^{(j)}}{\omega}-\frac{1}{\gamma^{(j)}}\right)^+,\frac{I}{P_{\max}}\right), j\notin K(i),\end{cases} \tag{9}$$

where u and ω are chosen to satisfy the constraint Ⅳ with equality and $P_{\max}$ is the maximum power for a unlicensed band.

3.2 Time allocation

The total data rate of the sdevice i is represented as below in order to simplify Eq.(4):

$$\begin{cases} R_l^i = \sum_{j\in K(i)} R_s(P_l^{*(j)}\gamma^{(j)}), \\ R_u^i = \sum_{j\in G(i)} R_s(P_u^{*(j)}\gamma^{(j)}). \end{cases}$$

R_l^i and R_u^i are constants after the optimal power allocation $P_l^{*(j)}$ and $P_u^{*(j)}$ are determined. Thus Eq.(4) can be represented as

$$\max_{t_s^i, t_\omega} U = \sum_{n\in N_\omega} \ln(R_{\omega,n}\lambda_n t_\omega) + \sum_{i\in N_s} \ln((1-t_s^i)R_l^i + t_s^i R_u^i) . \tag{10}$$

Constraint 7 should be achieved with equality to maximize the user satisfaction

$$t_\omega = t_{\max} - \sum_{i\in N_s} t_s^i . \tag{11}$$

Eq.(10) can be simplified further by plugging Eq.(11) into Eq.(10) as shown below:

$$\max_{t_s^i} U = N_\omega \ln(t_{\max} - \sum_{i\in N_s} t_s^i) + \sum_{i\in N_s} \ln((1-t_s^i)R_l^i + t_s^i R_u^i) . \tag{12}$$

Then the derivative of Eq.(11) is taken with respect to t_s^i, and set the derivative to zero, thus obtain

$$N_\omega \left(t_s^{*i} + \frac{R_l^i}{R_u^i - R_l^i} \right) = t_{\max} - \sum_{i\in N_s} t_s^{*i},\ i\in 1,\cdots,N_s . \tag{13}$$

There are N_s derivatives indicating the optimal time allocation of N_s sdevices, and are added together to obtain an equation about $\sum_{i\in N_s} t_s^{*i}$

$$N_\omega \left(\sum_{i\in N_s} t_s^{*i} + \sum_{i\in N_s} \frac{1}{R_u^i / R_l^i - 1} \right) = N_s t_{\max} - N_s \sum_{i\in N_s} t_s^{*i} . \quad i\in 1,\cdots,N_s \tag{14}$$

The sum of t_s^{*i} can be denoted by considering the Ⅵ and Ⅷ constraints as follows:

$$\sum_{i\in N_s} t_s^{*i} = \max(t_{\max} - \overline{t}_\omega), \quad \frac{1}{N_\omega + N_s}(N_s t_{\max} - N_\omega \sum_{i\in N_s} \frac{1}{R_u^i / R_l^i - 1}). \tag{15}$$

Given that the specified $\sum_{i\in N_s} t_s^{*i}$ and t_w^* is fixed, Eq.(11) can finally be simplified as follows:

$$\max_{t_s^i} U = \sum_{i\in N_s} \ln((1-t_s^i)R_l^i + t_s^i R_u^i) , \tag{16}$$

$$\sum_{i\in N_s} t_s^i = \sum_{i\in N_s} t_s^{*i} . \tag{17}$$

Eq.(15) can be solved by the water-filling algorithm and KKT conditions. The optimal time allocation of sdevices and all wdevices can be denoted by plugging Eq.(16) into (15) as follows:

$$\begin{cases} t_s^{*i} = (\alpha - \frac{1}{R_u^i / R_l^i - 1})^+, \\ t_\omega^* = t_{\max} - N_s \sum_{i\in N_s} t_s^{*i} = t_{\max} - (\max((t_{\max} - \overline{t}_\omega)^+, \\ \frac{1}{N_\omega + N_s}(N_s t_{\max} - N_\omega \sum_{i\in N_s} \frac{1}{R_u^i / R_l^i - 1}))), \end{cases} \tag{18}$$

where α is chosen to satisfy Eq.(16).

In Algorithm 1, a method is proposed to calculate the optimal time allocation faster, as α improves quickly to make $\sum_{i\in N_s} t_s^i$ approaches $\sum_{i\in N_s} t_s^{*i}$, and then adjusts to achieve the precise calculation.

Algorithm 1 Water-filling algorithm to calculate t_s^{*i}
1: Input data rate R_u^i and R_l^i, α=0 ;
2: while
3: $\sum_{i\in N_s} t_s^i \leqslant \sum_{i\in N_s} t_s^{*i}$
4: do
4: α improves;
5: $t_s^i = \left(\alpha - \frac{1}{R_u^i / R_l^i - 1}\right)^+$;
6: Return $t_s^{*i} = t_s^i$.

The variation of optimal time allocation is observed by adjusting the number of wdevices and the bandwidths of licensed bands while simplified simulation parameters (fixed signal-to-noise(SNR), etc) are adopted, and then the phenomenon is analyzed by previous formulas. Two sdevices are assumed to coexists with wdevices in one unlicensed band, and each sdevice has two licensed bands with the same bandwidth. In addition, the value of $t_{\max}$ is assumed 0.9 and SNR is 10 dB.

Fig.2 shows numerical results of Eq.(18) with N_w =1, 2, 3, 4 and 5 when $\bar{t}_w$ = 0:8. B_l^{tot} is the total bandwidth of licensed bands for a sdevice while Bu is the bandwidth of unlicensed band, which is 20MHz in this case. The bandwidth of a certain licensed band varies from 1~10 MHz.

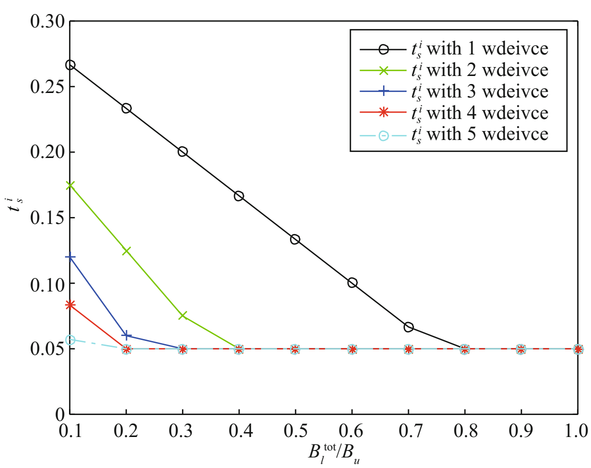

Figure 2 Optimal time allocation with different number of wdevices

As $\frac{B_l^{\text{tot}}}{B_u}$ grows, the optimal value of t_s^{*i} decreases and then tends to be a constant. The constant is equal to $\frac{t_{\max}-\bar{t}_w}{N_s}$.

Eq.(18) can be used to explain the phenomenon in mathematics only if

$$(t_{\max}-\bar{t}_\omega)^+ < \frac{1}{N_\omega+N_s}\Big(N_s t_{\max} - N_\omega \sum_{i\in N_s}\frac{1}{R_u^i/R_l^i-1}\Big) \quad (19)$$

The bandwidth and data rate of a certain sdeivce have a linear relation in this step, e.g., $R(i) \propto B(i)$, as shown in Eq.(7). Thus $\frac{B_l^{\text{tot}}}{B_u}$ can intuitively replace $\frac{B_l^{\text{tot}}}{B_u}$ to obtain the optimal value of t_s^{*i}· $\sum_{i\in N_s}\frac{1}{R_u^i/R_l^i-1}$ increases with the improvement of $\frac{B_l^{\text{tot}}}{B_u}$, making it easier to obtain the constant value for optimal time allocation. $\bar{t}_w$ is assumed to be less than $t_{\max}$ in most cases, and Eq.(19) can be further written as shown:

$$\sum_{i\in N_s}\frac{1}{R_u^i/R_l^i-1} < \frac{(N_\omega+N_s)\bar{t}_\omega - N_\omega t_{\max}}{N_\omega} \quad (20)$$

The formula holds when $\frac{B_l^{\text{tot}}}{B_u}$ is small, thus t_s^{*i} tends to be fixed value for an increase in the value of $\frac{B_l^{\text{tot}}}{B_u}$.

Fig.3 shows the numerical result of the optimal time allocation when two sdevices compete in unlicensed bands with different licensed bandwidths. Assuming that the average Wi-Fi traffic load $\bar{t}_w$ = 0.8 and the values of the other parameters are the same as those in the previous scenario. B_{L1}^{tot} refers to the total bandwidth of the first sdevice and B_{L2}^{tot} means the total bandwidth of the second sdevice. There are two kinds of variations in this figure, the licensed bandwidths variation of first sdevice and the further variation of second sdevice according to the first one, which are represented as $\frac{B_{L2}^{\text{tot}}}{B_u}$ and $\frac{B_{L2}^{\text{tot}}}{B_{L1}^{\text{tot}}}$respectively. The lower mesh pattern represents optimal time allocation for the first sdevice while the upper one represents allocation for the second sdevice.

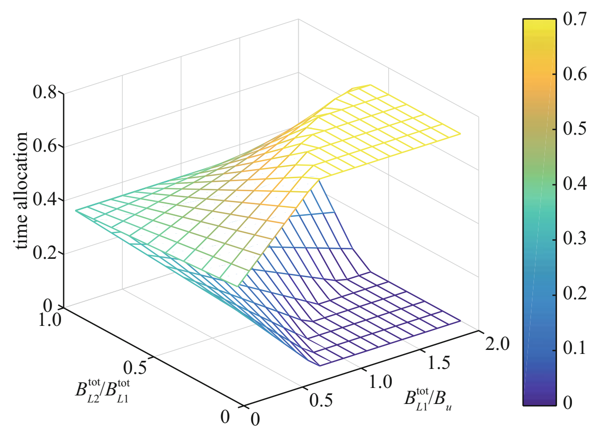

Figure 3 Optimal time usage allocation between 2 sdevices with different licensed bandwidths

When $\frac{B_{L1}^{\text{tot}}}{B_u}$tends to be two and $\frac{B_{L2}^{\text{tot}}}{B_{L1}^{\text{tot}}}$ approaches zero, the first sdevice does not have the opportunity to access the unlicensed band while the t_s^{*i} of the second sdevice is equal to $t_{\max}-\bar{t}_\omega$. The optimal time allocations for two sdevices show an enormous difference from the view of $\frac{B_{L2}^{\text{tot}}}{B_{L1}^{\text{tot}}}$ when the band-width of the second sdevice is much smaller when $\frac{B_{L1}^{\text{tot}}}{B_u}$ is fixed. In addition, the optimal time allocation tends to coincide with the increase of $\frac{B_{L2}^{\text{tot}}}{B_{L1}^{\text{tot}}}$.

This phenomenon can be explained by the solution of optimal traffic balancing algorithm in Eq.(18). After the sum of the optimal time allocation is calculated in Eq.(14) as $\sum_{i\in N_s} t_s^{*i}$, the allocation for a specific sdevice depends only on the value of $\frac{1}{R_u^i / R_l^i - 1}$. The water in the water-filling algorithm will first fill the lower place, and may not fill the higher lace if the water runs out. It has been proved that R_u^i / R_l^i can be replaced by B_u^i / B_l^i, so the $\frac{1}{R_u^i / R_l^i - 1}$ of first sdevice increases far more than that of the other one when $\frac{B_{L1}^{\text{tot}}}{B_u}$ tends to be two(the ratio is one for every licensed band), and thus the first sdevice will not have any time allocation due to the characteristics of the water-filling algorithm.

Thus it can be concluded from Fig.3 that the bandwidths of sdevices and their competitors is vital to the optimal time allocation. In generally, the optimal time allocation for a certain sdevice improves with the increase in its bandwidth only if it reserves a small part of the whole bandwidth for all sdevices, otherwise the optimal t_s^{*i} reduces as its andwidth increases. The sdevice with small licensed bands always has a better chance to access the unlicensed bands for the demand of proportional fairness. The conclusion of the multi-sdevices scenario is quite different from that of single-sdevice scenario, in which the single sdevice can easily access the unlicensed band unless $\bar{t}_\omega \geqslant t_{\max}$ as well as $t_{\max} \leqslant \frac{N_\omega}{R_u / R_l - 1}$ from Ref.[13].

4 Simulations and analysis

In this section the traffic balancing time allocation scheme is evaluated through Algorithm 1, and will be compared with fixed allocation scheme deployed in practical scenarios. As our propose is to sacrifice the throughput to achieve higher user satisfaction, the performances of these schemes are compared based on user satisfaction and throughput, which are shown in Fig.4 and Fig.5 respectively.

A situation in which there are two sdevices coexisting with two wdevices in the unlicensed band and each sdevice can access two licensed bands is considered. The interference in every licensed band comes from a neighboring sdevice which is connected to another femto cell, and the neighboring sdevice is located randomly within a distance of 300 m from the femto cell. Meanwhile, there is a neighboring AP randomly located at a distance of 200 m from femto cell. Assuming that the maximum data rate is 54 Mbit/s according to 802.11g.

Tab.1 summarizes the parameters used in the subsequent simulations.

Table 1 Simulation paraters

parameters	value
$t_{\max}$	0.9
$\bar{I}$	−100 dBm
transmit power	15 dBm
noise power	−95 dBm (over 20 MHz BW)
path loss: sdevice to femto cell or wdevice to Wi-Fi AP	$38.6 + 20\lg(R) + 0.7R$
path loss: sdevice to nearbysdevice or wdevice to nearbyWi-Fi AP	$15.3 + 37.6\lg(R) + L_{\text{shadow}}$ ($L_{\text{shadow}} = 20$ dB)

Simulation results are used to obtain the average through-put of the sdevices when they have different traffic loads. t_s^{*i} can be adjusted by controlling the access to the interval and transmission duration in Ref. [8] or use the duty circle model, where each sdevice transmits in its own turn and send ABS(Almost Blank Sub-frame) when leaves the unlicensed band.

Fig.4 shows the user satisfaction in a practical situation, where the contrastive schemes have fixed equal time allocations and optimal power allocations. It can be seen that the traffic balancing scheme provides a big improvement to the user satisfaction. The yellow line keeps at a low position because the two sdevices occupy the unlicensed bands for a very long duration and the throughput of the wdevices can not be guaranteed. The cross of green line and cyan-blue line can be solved by the same explanation, as well as the leap of the blue line. The phenomenon presents that the balancing of available bandwidth for every device is vital to the user satisfaction.

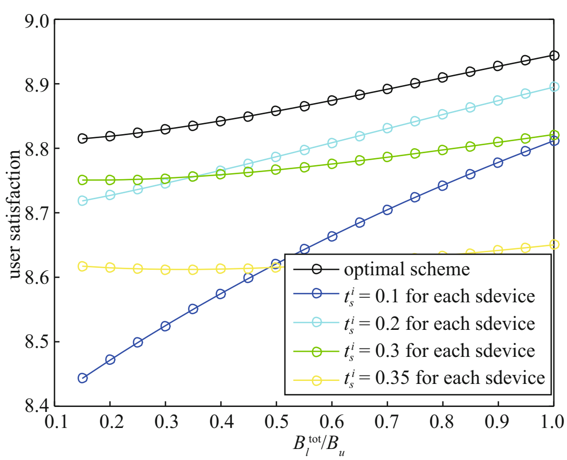

Figure 4 Simulation results of user satisfaction

Fig.5 shows that the price of improving the user satisfaction is sacrificing the throughput. Small cell has better spectral efficiency than Wi-Fi, so the more time unlicensed band is occupied by the sdevices, the more average throughput can the scheme achieves. For this reason the distribution of lines basically appears reversely in Fig.5 The traffic balancing scheme with less bandwidth to sdevices can still approach the green line because the channel condition of sdevices differs and our flexible time allocation can reach better spectral efficiency than fixed allocation.

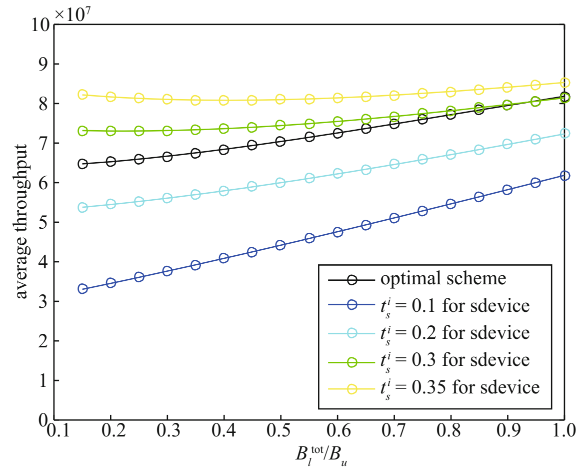

Figure 5 Simulation results of average throughput

5 Conclusion and discussion

In this paper, we have investigated a two-step traffic balancing scheme by proportional fairness and calculated the solution of power allocation and time allocation, which can guide the design of specific coexistence schemes. The competitive relations among sdevices in the unlicensed bands are analyzed using the water-filling algorithm, and simulations indicate that the traffic balancing scheme can improve the whole user satisfaction. We will conduct further research on the coexistence scenario in which multi-sdevices connect to the same femto cell and thus share only one power budget, and the power allocation and time allocation will be discussed together.

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About the authors

LI Zhen received his B.E. from Shandong university, Shandong, China in 2014. Currently he is an M.S. student in Beijing University of Posts and Telecommunication, Beijing, China. His research interests include the co-ordination between LTE and Wi-Fi in wireless communications. (Email: lz2081@bupt.edu.cn)

CUI Zhiyan received her B.E. from Wuhan University of Technology, Wuhan, China in 2014. Currently she is an M.S. student in Beijing University of Posts and Telecommunication, Beijing, China. Her research interests include the energy-efficiency for 5G wireless communications. (Email: cuizhiyan@bupt.edu.cn)

ZHENG Wei received his B.E. from Beijing University of Posts and Telecommunication, Beijing, China in 2014. Currently he is an M.S. student in Beijing University of Posts and Telecommunication, Beijing, China.His research interests include analysis and modeling of heterogeneous network. (Email: heisam@bupt.edu.cn)

CUI Qimei [corresponding author] received her B.E. and M.S. with Honors in Electronic Engineering from Hunan University, Changsha, China, in 2000 and 2003, respectively. Subsequently, she received her Ph.D. degree of Communications and Information Engineering at Beijing University of Posts and Telecommunications (BUPT) in 2006.She is a full professor of School of Information and Communication Engineering (SICE) in BUPT, China. She has been also guest professor in Department of Electronic Engineering of University of Notre Dame since Jan. 2016. Her main research interests focus on transmission theory and networking technology for 4G/5G broadband wireless communications and green communications.She has published more than 100 research articles in high-impact IEEE/IET international journals and conferences of wireless communication fields. She has applied for 37 patents comprising 2 US patents, one European and one Australian. She was once awarded the only Best Paper Award at IEEE ISCIT 2012, Best Paper Award in IEEE WCNC 2014, the Honorable Mention Demo Award at ACM MobiCom 2009, and the Young Scientist Award at URSI GASS 2014 etc. (Email: cuiqimei@bupt.edu.cn)