Utility-Oriented Resource Allocation Scheme in LTE-WLAN Heterogeneous Networks

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Abstract. In this paper, a utility-oriented resource allocation scheme (UORA) is proposed to improve network efficiency for LTE-WLAN heterogeneous networks. Isolated resources such as OFDMA subcarriers and WLAN time slots, which are always ignored in existing schemes, are considered in the proposed UORA scheme to give guidance on engineering practice. Aiming at improving user satisfaction, UORA scheme also considers various traffic characteristics and dynamic transmission rate. To guarantee high overall average level of user QoS, the resource allocation problem is formulated as an constrained optimization problem to maximize the total user utility but not total transmission rate. Based on optimization theory, a heuristic iterative algorithm is constructed to solve the problem. Numerical simulation is also adopted to prove the performance enhancement of our proposed UORA scheme compared with previous ones.

Keywords: LTE-WLAN heterogeneous networks · Utility-Oriented Resource Allocation Scheme (UORA) · Traffic characteristics · Utility maximization

1 Introduction

Heterogeneous wireless networks comprised of different radio access technologies are the inevitable developing trend of next-generation wireless networks [1]. These heterogeneous networks with overlapped coverage respectively have unique complimentary service capabilities, from the perspective of maximum transmission rate, coverage region and network stability. Reasonable integration of these advantages and radio resources which are separated among networks will enhance the overall network performance as well as quality-of-service (QoS) [2-4]. Hence, researching on radio resource management scheme for heterogeneous wireless networks is drawing great attention.

In literature, various works have been done on radio resource management problem in heterogeneous wireless networks. These works mainly focus on optimizing the performance of network selection mechanisms and multi-traffic transmission mechanism. Network selection in a heterogeneous wireless network using the theory of

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evolutionary games is studied in [5]. Authors in [6] studied radio resource allocation for mobile terminals in a heterogeneous wireless access medium considering the simultaneous presence of both single-network and multi-homing services. A distributed joint allocation algorithm to maximize total system capacity for multiple transmissions by multiple RATs in heterogeneous wireless networks is proposed in [7]. [8] introduced a RAT selection algorithm based on fuzzy logic method to realize load balancing, considering voice and data application in the WLAN-3G heterogeneous wireless networks. And since improving user experience is the ultimate aim of communication networks, QoS is frequently chosen as the optimized object. Utility, which is a concept in economics, is often used to measure the QoS with the allocated resources for each user [9]. [10-11] introduces several kinds of utility functions, which consider various scenario characteristics and take the allocated resources as variables. And maximizing the total utility is the goal of these typical schemes. Also, the emergence of multi-mode terminals makes multi-traffic parallel transmission possible and provides huge network cooperation gains [7, 12].

Although these works have made brilliant achievements, three major weaknesses still exist in heterogeneous networks resource management. Firstly, most works focus on resource allocation from higher perspectives, such as access rate value, but not deep down to the detailed resource allocation results, such as which specific resource unit is occupied. We believe a more detailed resource unit model will provide a more effective allocation scheme. Secondly, most works ignore traffic characteristics or consider just one kind of traffic. With the rise of user needs, multiple types of traffic arise, such as voice, http, video and so on. Since different traffics have different characteristics, the data rate that the traffic required to support positive QoS is also different. The resource allocation scheme should take this fact into consideration. Thirdly, previous resource allocation optimization usually aims at maximizing total transmission rate which can be regarded as certain utility, which is not always the best since sometimes total rate maximization will lead to poor QoS of some users.

To deal with the weaknesses mentioned above, a utility-oriented resource allocation scheme (UORA) is proposed to improve network efficiency for LTE-WLAN heterogeneous networks. To make resource allocation problem close to the actual engineering situation, we introduce the OFDMA subcarriers allocation and WLAN time slots model in our proposed UORA scheme to model these isolated resources among heterogeneous networks, which are always ignored in existing schemes, especially in those schemes which maximizing the total system utility. To consider various traffic characteristics and measure QoS with dynamic transmission rate, the traffic characteristics based utility function model is also introduced in our UORA scheme. Based on these models, the UORA scheme model is formulated as a constrained optimization problem to maximize total user utility but not total transmission rate to guarantee that the overall average level of user QoS is high and no user will experience poor QoS. To make the problem tractable, we relax the integer constraints by introducing multi-mode terminals and allowing resource element sharing. Then a heuristic iterative algorithm to solve this optimization problem is constructed based on optimization theory. Numerical simulation is also adopted to verify the performance enhancement of our proposed UORA scheme compared with previous works.

The rest of this paper is organized as follows. Section 2 describes the system model of the considered LTE-WLAN heterogeneous networks scenario. In Section 3, the proposed utility-oriented resource allocation scheme (UORA) is formulated. An iterative algorithm to solve the UORA optimization problem is constructed in Section 4. Numerical simulation results are offered in Section 5. Finally, Section 6 concludes the paper.

2 System Model

In this section, the LTE-WLAN heterogeneous networks scenario is firstly described. Then the detailed OFDMA subcarriers allocation and WLAN time slots model are introduced. To consider various traffic characteristics and measure user satisfaction with allocated transmission rate, the traffic utility function model is proposed.

2.1 Heterogeneous Wireless Access Networks

Seen in Fig. 1, several WLAN networks are deployed within the coverage of one LTE network. These WLANs are denoted as a set, $\mathcal{N}=\{1,2,...,N\}$, and we assume the index of WLAN network is n, $n\in\mathcal{N}$. Each WLAN network is operated by a unique AP. As shown in Fig. 1, the base station (BS) of LTE and access points (APs) of WLANs are located with overlapped coverage region. It is known that LTE and WLANs are operated on independent frequency bands, hence this heterogeneous networks system has no inter-network interference issues. M users are distributed randomly in this area, we assume user index is m, $m\in\mathcal{M}$, where $\mathcal{M}=\{1,2,...,M\}$ is the users set. Also, each terminal is multi-mode and has the ability to connect LTE and WLANs simultaneously.

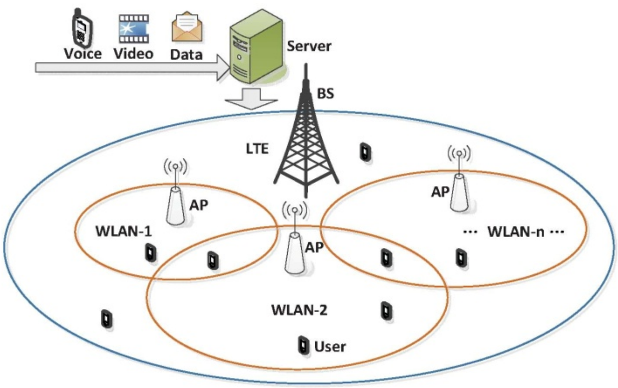

Fig. 1. LTE-WLAN heterogeneous networks scenario

2.2 OFDMA Subcarriers Allocation and WLAN Time Slots Model

To implement radio resource management for the heterogeneous networks shown in Fig. 1, we firstly model the bandwidth occupation rules of LTE and WLANs. There exists a certain time interval, T, and resource allocation scheme is implemented every T time. And then, BS/APs carry out the corresponding resource allocation results to transmit traffic for users during time duration T.

The LTE network is based on OFDMA technology. The total bandwidth of LTE network is divided into S subcarriers, that is, LTE have a set of subcarriers, $\mathcal{S}=\{1,2,...,S\}$. One resource allocation time T corresponds to G OFDM symbol intervals in LTE. From the perspective of resource distribution, each subcarrier, $s\in\mathcal{S}$, have a set of resource elements, $\mathcal{G}=\{1,2,...,G\}$, to be allocated during T, as shown in Fig. 2. Therefore, the set of total allocable resources in LTE during T can be denoted as $\mathcal{K}=\{1,2,...,K\}$, and $K=S\times G$. Generally, each resource element, $k\in\mathcal{K}$, can be utilized by one user traffic, where $k=(g-1)S+s$ ($g\in\mathcal{G},s\in\mathcal{S}$). Under the condition of equal BS power allocation in downlink, $r_{m,k}^{LTE}$ represents the achievable rate of user m at resource element k.

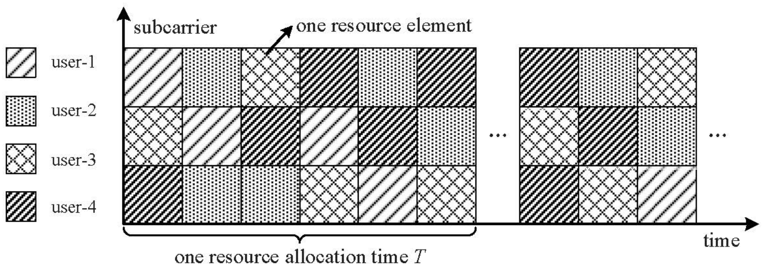

Fig. 2. OFDMA resource element

In our considered WLANs which are based on 802.11 protocol, users can completely avoid collisions when accessing to network. Thus, it's reasonable to consider the ways of users accessing to WLAN as TDMA. Users can monopoly the bandwidth in its allocated time slot during T. $r_{m,n}^{WLAN}$ represents the achievable rate of user m in WLAN-n.

Hence, the data rate of user m in LTE-WLAN heterogeneous networks system can be expressed as following,

$$R_m=\alpha_m^{LTE}\sum_{k=1}^{K}d_{m,k}r_{m,k}^{LTE}+\alpha_{m,n}^{WLAN}\sum_{n=1}^{N}t_{m,n}r_{m,n}^{WLAN} \tag{1}$$

where α_m^{LTE} and $\alpha_{m,n}^{WLAN}\in\{0,1\}$ represent the selection of access network. $d_{m,k}$ $\in[0,1]$ represents the occupation of resource element in LTE. $t_{m,n}\in[0,1]$ represents the time slot allocation in WLAN-n. Thus, this model needs to obtain all information about the occupation of resource units.

2.3 Traffic Characteristics Based Utility Function Model

From perspective of resource constrain issues and fairness issues, the data rate of some users is not always the higher the better. Utility function is more practical, while can reflect user satisfaction with allocated resource and associates the underlying physical resources with higher layer QoS. Also, various traffics rather than a single kind of traffic are requested by user terminals. Traffic type can be typically classified into three categories: voice, data and video. As the sensitivity of each type to transmission rate differs, utility function of each type accordingly differs. Due to the various traffic characteristics, some traffics can obtain high QoS even though their allocated rate is below the required rate, while some traffics have strict requirements regarding the required rate. Utility function can indicate these traffic characteristics.

Voice traffic is a representatively hard realtime traffic. The transmission rate required by voice traffic is constant. Thus, supplying voice traffic with higher transmission than required is not only useless in greatly improving user experience but also resource-wasting. Hence, step function can serve as the utility function of voice traffic.

$$U(R) = w \cdot u(R - R^{\min}) \tag{2}$$

where $R^{\min}$ is the required constant transmission rate, $u(\cdot)$ is unit step function, w represents traffic priority.

Data traffic such as email is a representatively best effort traffic without minimum transmission rate limitation, which means the network will transmit as much data traffic as possible with the allocated rate. By fully utilization of rate, the utility first increases significantly when the obtained transmission rate is at low level. And then its gradient gradually decreases and the utility changes smoothly with allocated rate increasing. Thus, the utility function is expressed as following,

$$U(R) = w \cdot \left[1 - \exp\left(-c_1 R / R^{\max}\right)\right] \tag{3}$$

where non-negative parameter c_1 represents how sensitive utility is to the allocated rate, $R^{\max}$ is the maximum rate that data traffic can achieve based on device capabilities.

Video traffic is a representatively realtime traffic which can adjust transmission rate to ensure the quality of service while network is congesting. Also, it has minimum rate limitation, $R^{\min}$, below which the transmission quality is too poor to accept. Only when the obtained rate exceeds this limitation will the utility raises significantly. Hence, sigmoid curve can approximately express the utility function,

$$U(R) = \begin{cases} w \dfrac{-\exp(-c_2 R^{\min}) + \exp[c_2 (R - R^{\min})]}{2 - \exp(-c_2 R^{\min})}, & R < R^{\min} \\ w \left\{1 - \dfrac{\exp[-c_2 (R - R^{\min})]}{2 - \exp(-c_2 R^{\min})}\right\}, & R \geq R^{\min} \end{cases} \tag{4}$$

where non-negative parameter c_2 represents how sensitive utility is to the allocated rate.

Based on the above analysis, traffics requested by M users can fall into three traffic type sets according to their traffic characteristics: $\mathcal{M}_{voice}$, $\mathcal{M}_{data}$ and $\mathcal{M}_{video}$. These three typical traffic utility functions are shown in Fig. 3.

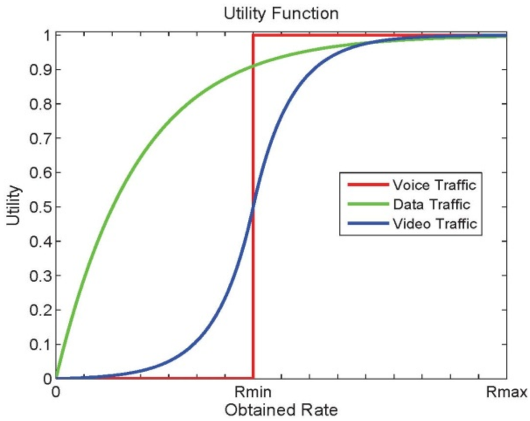

Fig. 3. Traffic characteristics based utility function

3 Problem Formulation

The utility-based resource allocation problem in LTE-WLAN heterogeneous networks can be formulated as following,

$$\max \sum_{m=1}^{M} U\left(R_m\right)$$

$$\text{s.t.} \qquad R_m = \alpha_m^{LTE} \sum_{k=1}^{K} d_{m,k} r_{m,k}^{LTE} + \alpha_{m,n}^{WLAN} \sum_{n=1}^{N} t_{m,n} r_{m,n}^{WLAN} \tag{5a}$$

$$\alpha_m^{LTE} + \sum_{n=1}^{N} \alpha_{m,n}^{WLAN} \leq 1, \ \forall m \in \mathcal{M}; \ \alpha_m^{LTE}, \alpha_{m,n}^{WLAN} \in \{0,1\}, \ \forall m \in \mathcal{M}, n \in \mathcal{N} \tag{5b}$$

$$\sum_{m=1}^{M} d_{m,k} \leq 1, \ \forall k \in \mathcal{K}; \ d_{m,k} \in \{0,1\}, \ \forall m \in \mathcal{M}, k \in \mathcal{K} \tag{5c}$$

$$\sum_{m=1}^{M} t_{m,n} \leq 1, \ \forall n \in \mathcal{N}; \ 0 \leq t_{m,n} \leq 1, \ \forall m \in \mathcal{M}, n \in \mathcal{N} \tag{5d}$$

The optimization goal is to maximize the total utility of user traffics by allocating resources to users. The utility function is in accordance with user traffic type, that is, choosing function (2), (3) or (4) for user $m \in \mathcal{M}_{voice}$, $m \in \mathcal{M}_{data}$ or $m \in \mathcal{M}_{video}$ respectively. Constraint (5b) is in line with the fact that most of user terminals can access only one network simultaneously because of existing technical limitations even they are so-called multi-mode, and the proper multi-mode terminals are rare in practical application. Constraint (5c) guarantees that one resource element in LTE is monopolized by one user.

This optimization problem is a non-polynomial (NP) hard problem with integer constraints. To make this problem solvable, constraints (5b) and (5c) are relaxed by considering user terminals have the real multi-mode capabilities and allowing LTE resource elements sharing among users.

Thus, the NP problem can be transformed into,

$$\max \sum_{m=1}^{M} U\left(R_m\right)$$

$$\text{s.t.} \qquad R_m = \sum_{k=1}^{K} d_{m,k} r_{m,k}^{LTE} + \sum_{n=1}^{N} t_{m,n} r_{m,n}^{WLAN} \tag{6a}$$

$$\sum_{m=1}^{M} d_{m,k} \le 1,\ \forall k \in \mathcal{K};\ 0 \le d_{m,k} \le 1,\ \forall m \in \mathcal{M}, k \in \mathcal{K} \tag{6b}$$

$$\sum_{m=1}^{M} t_{m,n} \le 1,\ \forall n \in \mathcal{N};\ 0 \le t_{m,n} \le 1,\ \forall m \in \mathcal{M}, n \in \mathcal{N} \tag{6c}$$

4 Optimal Solution

Based on convex optimization theory [13], (5) has a unique global optimal solution. The constrained optimization problem (5) can be transformed into an equivalent unconstrained optimization problem, namely a Lagrange function,

$$L(d_{m,k}, t_{m,n}, \lambda_k, \mu_n) = \sum_{m=1}^{M} U(\sum_{k=1}^{K} d_{m,k} r_{m,k}^{LTE} + \sum_{n=1}^{N} t_{m,n} r_{m,n}^{WLAN}) + \sum_{k=1}^{K} \lambda_k (1 - \sum_{m=1}^{M} d_{m,k}) + \sum_{n=1}^{N} \mu_n (1 - \sum_{m=1}^{M} t_{m,n}) \tag{7}$$

where non-negative coefficients λ_k and μ_n are the Lagrange factors.

To solve (7), Karush-Kuhn-Tucker (KKT) conditions should be derived against $d_{m,k}$, $t_{m,n}$, λ_k and μ_n respectively. Thus, the optimal solution of optimization problem (7) needs to meet,

$$\begin{aligned} &\frac{\partial L}{\partial d_{m,k}} \le 0, \qquad d_{m,k} \ge 0, \qquad d_{m,k} \cdot \frac{\partial L}{\partial d_{m,k}} = 0 \\ &\frac{\partial L}{\partial t_{m,n}} \le 0, \qquad t_{m,n} \ge 0, \qquad t_{m,n} \cdot \frac{\partial L}{\partial t_{m,n}} = 0 \end{aligned} \tag{8}$$

Using gradient projection iterative method [14], optimal solution can be obtained by $d_{m,k}^{i+1} = \left[d_{m,k}^{i} + \tau_1 \frac{\partial L}{\partial d_{m,k}} \right]^{+}$ and $t_{m,n}^{i+1} = \left[t_{m,n}^{i} + \tau_2 \frac{\partial L}{\partial t_{m,n}} \right]^{+}$, where $[z]^{+} = \max\{z, 0\}$, τ_1 and τ_2 are non-negative constant iterative step size. When $\left\| d_{m,k}^{i+1} - d_{m,k}^{i} \right\|$ and $\left\| t_{m,n}^{i+1} - t_{m,n}^{i} \right\| \le \varepsilon$ (ε is the iteration accuracy), or upper limit of iterations i^* is reached, $d_{m,k}^{i+1}$ and $t_{m,n}^{i+1}$ are the optimal solution.

To obtain optimal solution $d_{m,k}^{*}$ and $t_{m,n}^{*}$, Lagrange factor λ_k and μ_n also need to be updated simultaneously.

The continuously differentiable dual problem of (7) is,

$$\min_{\lambda_k,\mu_n} D(\lambda_k,\mu_n) \tag{9}$$

where $D(\lambda_k,\mu_n)=\max_{d_{m,k},t_{m,n}} L(d_{m,k},t_{m,n},\lambda_k,\mu_n)$.

Hence, we get the gradient projection,

$$\lambda_k^{i+1}=\left[\lambda_k^i-\sigma_1\frac{\partial D}{\partial \lambda_k}\right]^+=\left[\lambda_k^i+\sigma_1(\sum_{m=1}^{M}d_{m,k}-1)\right]^+$$

$$\mu_n^{i+1}=\left[\mu_n^i-\sigma_2\frac{\partial D}{\partial \mu_n}\right]^+=\left[\mu_n^i+\sigma_2(\sum_{m=1}^{M}t_{m,n}-1)\right]^+ \tag{10}$$

where σ_1 and σ_2 are non-negative constant iterative step size just as τ_1 and τ_2.

The utility-based resource allocation iterative optimization algorithm is described in Algorithm 1.

Algorithm 1. Utility-based resource allocation iterative optimization algorithm

1: **if** $i=0$ **then**

2: Initialize $d_{m,k}^0, t_{m,n}^0, \lambda_k^0, \mu_n^0$;

3: **else**

4: Calculate $d_{m,k}^{i+1}$ and $t_{m,n}^{i+1}$ using gradient projection method:

$$d_{m,k}^{i+1}=\left[d_{m,k}^i+\tau_1\frac{\partial L}{\partial d_{m,k}}\right]^+$$

$$t_{m,n}^{i+1}=\left[t_{m,n}^i+\tau_2\frac{\partial L}{\partial t_{m,n}}\right]^+$$

5: Update λ_k^{i+1} and μ_n^{i+1} using (10):

$$\lambda_k^{i+1}=\left[\lambda_k^i+\sigma_1(\sum_{m=1}^{M}d_{m,k}-1)\right]^+$$

$$\mu_n^{i+1}=\left[\mu_n^i+\sigma_2(\sum_{m=1}^{M}t_{m,n}-1)\right]^+$$

6: **if** $\left\|d_{m,k}^{i+1}-d_{m,k}^i\right\|$ and $\left\|t_{m,n}^{i+1}-t_{m,n}^i\right\|\le\varepsilon$, or i reached the upper limit of iterations **then**

7: $d_{m,k}^{i+1}$ is the optimization result.

8: **else**

9: $i=i+1$

Go to step 4 to continue the iteration.

10: **end if**

11: **end if**

5 Simulation Results

In this section, numerical simulation is executed to evaluate the performance of proposed UORA scheme.

5.1 Parameter Settings

The simulation scenario depicted in Fig. 1 is with one LTE and two WLANs ($N = 2$). Note that our UORA scheme can also apply to the scenario with more WLANs. For LTE network, the detailed physical layer parameters are listed in Table 1 [15]. Table 2 shows the mapping between the SINR (in dB) and the efficiency (in bits/symbol) for the modulation and coding schemes (MCS) of LTE [16]. As for WLAN, the achievable data rates provided by each WLAN are different according to link adaption schemes. Hence, we choose typical traffic rates as illustrated in [17] ($R_{\text{WLAN-1}} = 12\text{Mbit/s}$, $R_{\text{WLAN-2}} = 24\text{Mbit/s}$).

Table 1. Simulation Parameters for LTE Network

Parameter	Value
Bandwidth	3MHz
Number of Subcarriers	180
Macro BS Power	46dBm
Path Loss	128.1 + 37.6 log10(d) d:km
Shadowing	Log-normal, 8dB standard deviation
Noise Power	-174dBm/Hz
User Noise Figure	9dB

Table 2. Mapping Between SINR and Efficiency for MCS of LTE

SINR (dB)	-6.5	-4	-2.6	-1	1	3	6.6	10	11.4	13	15.6	17.6
Efficiency (bits/symbol)	0.15	0.23	0.38	0.60	0.88	1.18	1.48	1.91	2.41	3.32	4.52	5.55

Assuming that there are five users ($M = 5$) within the heterogeneous networks coverage requesting to transmit traffics, while they all have the capacity of accessing three networks simultaneously. Specific traffic characteristics are shown in Table 3. The corresponding utility function of each user traffic is constructed based on what we have proposed in Section2.3, according to which traffic type set ($\mathcal{M}_{voice}$, $\mathcal{M}_{data}$ and $\mathcal{M}_{video}$) it belongs to.

Table 3. Detail Information About Traffic Characteristics

User	Traffic Type	Transmission Requirements
user-1	voice-1 ($\mathcal{M}_{voice}$)	$R_{\min} = 3\text{Mbit/s}$
user-2	data-1 ($\mathcal{M}_{data}$)	$R_{\max} = 8\text{Mbit/s}$
user-3	data-2 ($\mathcal{M}_{data}$)	$R_{\max} = 15\text{Mbit/s}$
user-4	video-1 ($\mathcal{M}_{video}$)	$R_{\min} = 2\text{Mbit/s}$, $R_{\max} = 18\text{Mbit/s}$
user-5	video-2 ($\mathcal{M}_{video}$)	$R_{\min} = 5\text{Mbit/s}$, $R_{\max} = 20\text{Mbit/s}$

In previous work, three conventional resource allocation schemes, i.e., LTE-only, best-network-first selection and load-balancing schemes, are usually adopted to manage resource. Hence, we compared our proposed UORA scheme with these three schemes to evaluate the performance enhancement of UORA scheme. LTE-only scheme means all users can only access the LTE network. Best-network-first selection scheme means users make it a priority to access the network which can provide the highest data rate. In the selected networks, resource allocation scheme is also executed for users. When resource in the selected network is not adequate, users will also access to the next-best network to meet the data rate requirement. Load-balancing scheme means users access available networks with proportional data rate, for example, users access LTE by the ratio of $\dfrac{r^{LTE}}{r^{LTE} + \sum_{n=1}^{N} r_n^{WLAN}}$.

5.2 Simulation Results

To verify the convergence of the iterative optimization algorithm of proposed UORA scheme, the resource allocation iterative process of user-2 (data-1) is depicted in Fig. 4. The three lower curves represent the allocated transmission rate from each available network for user-2 (data-1), while the top curve represent the obtained utility of user-2 (data-1). It is shown that the allocated rate from each network tends to stable after 80000 iterations, which verifies the convergence of our proposed UORA scheme algorithm. Also, more accurate resource allocation results are obtained in our UORA scheme by considering the occupation of specific resource units.

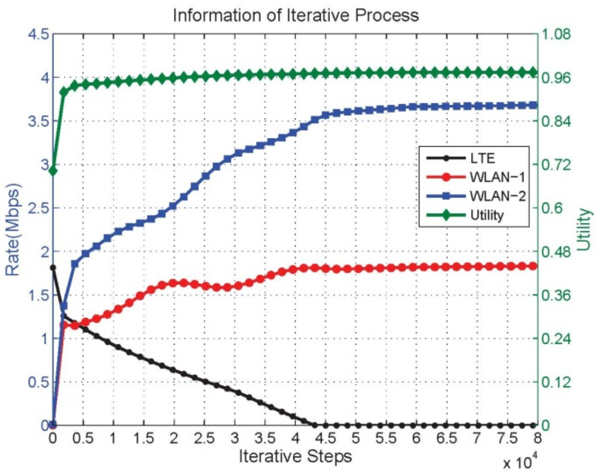

Fig. 4. Iterative optimization process for user-2 (data-1 traffic)

Fig. 5 shows the specific rate allocation results and corresponding utility of our proposed UORA scheme and three comparison schemes. Allocated rate from each of the three networks for each user traffic is completely different in these four schemes, on account of different resource allocation concerns. It is obvious that LTE-only scheme provide the lowest transmission rate and utility, which indicates cooperative transmission among heterogeneous networks can bring huge network gains. Furthermore, owing to the full coordination of heterogeneous resources, our proposed UORA scheme not only achieves network cooperation gains but also obtains the highest utility gains than the other two cooperative transmission schemes.

Based on the results from Fig. 6 and Fig. 7, it is proved that our proposed UORA scheme perform best in terms of obtained utility of user traffic. In Fig. 6, UORA scheme can provide user traffics with the highest utility, which means user satisfaction achieves the highest level and QoS is best guaranteed. This is because UORA scheme considers various traffic characteristics to control rate allocation, so that available resource can be reasonably assigned without wasting of resources to ensure user utility. It can also be found that although the total rate of system achieved through Best-network-first scheme and UORA scheme respectively are close, the total utility achieved through UORA scheme is much higher than that achieved through Best-network-first scheme. The reason for this finding is that the fundamental aim of Best-network-first scheme is rate maximization, which is sometimes at the cost of providing some users poor QoS. UORA scheme can avoid this shortcoming by aiming at utility maximization.

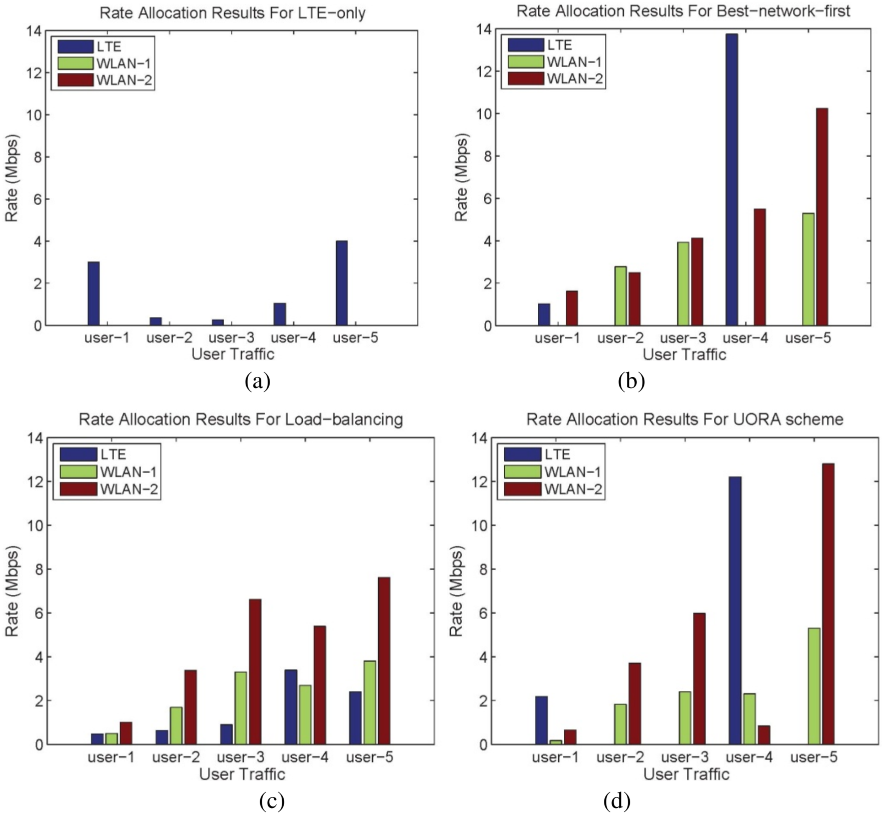

Fig. 5. Rate allocation results of UORA scheme and three comparison schemes: (a) LTE-only scheme, total utility = 1.3090; (b) Best-network-first scheme, total utility =3.7943; (c) Load-balancing scheme, total utility = 3.3980; (d) UORA scheme, total utility = 4.8797

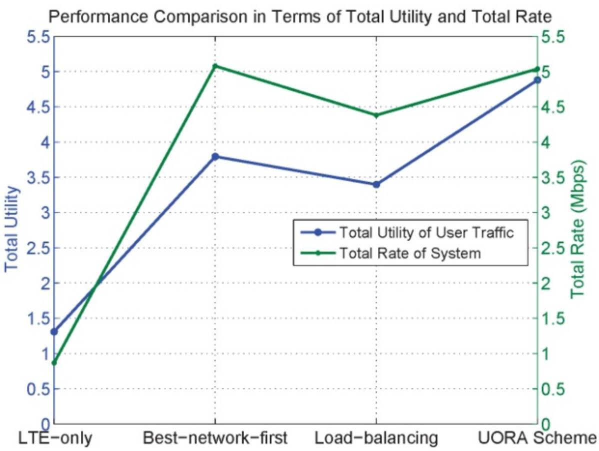

Fig. 6. Performance comparison in terms of total utility of user traffic and total rate of system

In Fig. 7, performance of these four schemes is compared in terms of utility of each user traffic. It can be observed that the utility of each user is close and high enough in UORA scheme, which indicates that user fairness is guaranteed. This is because in UORA scheme, user satisfaction is measured with allocated transmission rate by utility function, which reflects that some users need not completely achieve required maximum rate and sometimes lower rate can also ensure well QoS. Thus, UORA scheme not only offers highest total utility but also guarantees the utility of each user and user fairness.

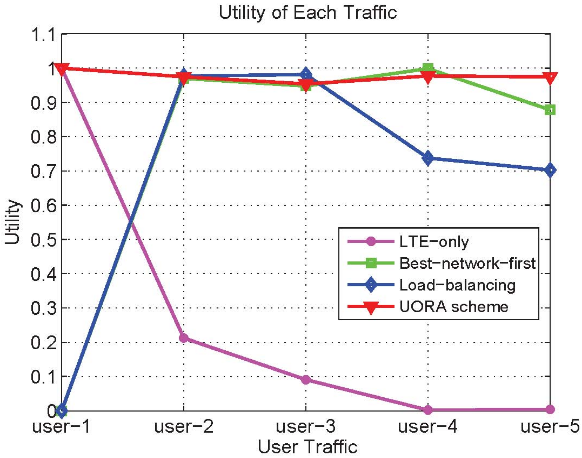

Fig. 7. Performance comparison in terms of utility of each user traffic

Moreover, from the simulation results we can also see that our proposed UORA scheme may have a little high complexity in solving algorithm, especially when the heterogeneous networks are large-scale. This is because our iterative algorithm needs certain central controller to implement information collection and strategy decision. Also, this complexity can be reduced by distributed algorithm which is our study emphasis in further research.

6 Conclusion

In this paper, we have proposed a utility-oriented resource allocation scheme (UORA) to improve network efficiency for LTE-WLAN heterogeneous networks. In UORA scheme, OFDMA subcarriers allocation and WLAN time slots model, considering specific resource units, is introduced to model isolated resources among heterogeneous networks which are always ignored in existing schemes, so that the resource allocation problem is close to the actual engineering situation. Utility function model considering various traffic characteristics is also introduced in UORA scheme to improve user satisfaction. By formulating the UORA scheme as total user utility maximization problem, a heuristic iterative algorithm to solve this optimization problem is constructed based on optimization theory. Through numerical simulation, the performance enhancement of our proposed UORA scheme over previous works is verified in terms of resource utilization and user satisfaction. The main contribution of our proposed UORA scheme is to consider specific resource units and traffic characteristics as key factors of rate allocation problem. The proposed UORA scheme will provide useful insights on how to effectively manage resources in heterogeneous networks, especially when available resources are extremely insufficient. Our future work will mainly focus on constructing a distributed algorithm with low complexity for our UORA scheme.

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