Utility-Based Resource Allocation for Mixed Traffic in Wireless Networks

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Abstract—**In order to solve the problem that the existing resource allocation strategies cannot give integrative consideration to QoS, spectrum efficiency for mixed traffic, this paper proposes a utility-based resource allocation algorithm for mixed traffic in wireless networks. The unified utility function for users with different traffics is studied first. After that, the optimization model for the resource allocation is established based on the unified utility function. A heuristic algorithm based on the solution of the model is proposed in the mixed traffic scenario after analyzing the optimization model. The algorithm which has lower complexity than the existing work can automatically guarantee the QoS requirement for the real-time traffic and make a tradeoff between throughput and fairness for users with best effort traffic due to the unified utility function. Numeric simulation results indicate that the algorithm is very applicable for mixed traffic, and the resource requirements for QoS users can be satisfied preferentially in the mixed traffic scenario.**

I. Introduction

Since radio resource is limited and scarce in wireless networks, resource allocation between users is a crucial issue. The channel quality of each user may vary over time. With the given available resource, there are different criteria or strategies to assign resource to each user, which leads to different benefits, such as system throughput, user fairness, or the Quality of Service (QoS) of user data flow.

When the utility theory in economics is applied to the resource allocation or the cross-layer design between Physical layer and MAC layer, the complexity of resource allocation algorithm can be reduced. Moreover, the tradeoff between throughput and fairness can be made through the cross-layer optimization based on the utility. In this paper, the performance metric for the resource allocation strategy is the user satisfaction, which is described by the utility function of users. The more the resource is allocated to the user, the higher the utility function is, so that the user can be better satisfied.

As wireless networks evolve, the traffic evolves toward mixed one. Different performance requirements for various traffics can be met through different utility functions. Various types of traffic in practical systems can be classified into two categories. One is the best effort (BE) traffic that has no QoS requirement, like some data traffics without delay requirement. The fairness among users should be guaranteed to the best. The other is the traffic with QoS requirement, which needs certain resource to satisfy this requirement, like interactive media, streaming, or IP-based TV.

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The research on resource allocation in wireless networks has obtained a few achievements, including many strategies based on utility function. Distributed resource allocation was studied in [1] under target data rate in multi-cell networks. [2] analyzed the resource allocation for QoS-aware OFDMA. [3, 4] adopted a cross-layer design based on utility function to allocate the resource in OFDM. The utility-based resource allocation in the system with two traffics is studied in [5, 6]. In [7], the utility was assumed as the sigmoid utility function, and the utility-based resource allocation for soft QoS traffic was studied. The sigmoid utility function was discussed for real-time systems in [8]. [9] is one of the first papers introducing a unified utility function (for BE only) into scheduling. Resource management based on unified utility function was studied in [10, 11]. We can see that either the maximum throughput or the minimum power consumption can be used as the objective to explore the resource allocation. We can also establish the model by maximizing the aggregate utility.

In this paper, we study the resource allocation for the mixed traffic scenario. The previous related literatures studied the utility-based resource allocation in certain traffic, or discussed the resource allocation for multiple traffics separately. The solutions in [6] can be recognized as different resource allocation problems with different utility functions, and resource allocation based on unified utility function for single traffic in [10, 11]. [12] studied the dynamic resource allocation for applications with real-time resource requirements according to their utility functions. But hardly any research or simulation of the resource allocation strategy based on unified utility function in the mixed traffic scenario is done. Thus, we focus on studying a unified utility function when the mixed traffic exists in the system. After that, the resource allocation for mixed traffic is studied based on this utility function, which can satisfy both the requirements of BE traffic and QoS traffic.

The rest of this paper is organized as follows: Section II proposes a unified utility function for various traffics. The optimal resource allocation model based on unified utility function and the corresponding solution is analyzed in Section III, and the practical allocation algorithm is also studied in this section. Section IV presents the simulation results for the algorithm. Finally, conclusions are summarized in section V.

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II. Utility Function

In this section, we mainly discuss the utility function in the mixed traffic scenario. Since the performance metrics for users with different traffics are different, we study the unified utility function which is fit for the mixed traffic. Types of users are distinguished by the parameters of the unified utility function. The detailed method to explore the utility function is as follows. First, the characteristics for the unified utility function are extracted from the practical situations and the characteristics of different user traffics. After that, appropriate utility function is constructed based on these characteristics.

For the users with BE traffic, the utility function should be monotonically increasing since the system pursues the maximum aggregate utility. Moreover, for the sake of fairness of users, the slope of the utility function, the marginal utility function, should be monotonically decreasing, which prevents assigning too much resource to the users with good channel condition. In summary, the utility function for BE users should be a convex function with respect to the allocated resource.

For the users with QoS traffic, similarly, the utility function should be a monotonically increasing function. Since the QoS requirement needs to be satisfied, when the resource obtained by the user is less than the critical value for the QoS requirement, the priority of the request for the resource of this user is high, and the marginal utility function is monotonically increasing. When the resource obtained by the user is more than the critical value for the QoS requirement, the priority of the request for the resource of this user is low, which prevents assigning too much resource to some certain users, and the marginal utility function is monotonically decreasing. In summary, the utility function for QoS users should be a sigmoid function with respect to the allocated resource.

In the following, we study the specific form of the utility function. Assuming the forms of utility functions for all users are unified, denoted by $U(r)$, where r is the resource assigned to the user. The total resource in the system is R, so the domain of $U(r)$ is $[0, R]$. In order to give integrative consideration to the resource assignment for users with different traffics so that the utility values of users are comparable, we assume the range of the utility function is $[0, 1]$. The marginal utility can be expressed as $u(r) = U'(r)$. From the analysis above, the utility of BE and QoS users are convex and sigmoid functions, respectively. In order to unify the utility functions of users with different traffics, without loss of the generality, we assume the form of the unified utility function is a universal sigmoid function, which has different characteristics with different parameters. It can represent the utility functions for both the BE and QoS users. The sigmoid function can be expressed as:

$$U(r) = \frac{1}{A + B\mathrm{e}^{-C(r-d)}} + D \tag{1}$$

where A, B, C, D, and d are the parameters to be determined. Parameter C affects the slope of the curve. Parameters A, B and D mainly affect the range of the utility function. Through adjusting A, B and D, the utility values of different traffics are comparable, which is helpful to the implementation of the resource allocation in the mixed traffic scenario. d is the inflexion of the utility function, which denotes the resource requirement of users. When the resource allocated to users is smaller than d, the utility function is concave, which represents that the user requires the resource of d strongly. While the resource allocated to users is larger than d, the utility function is convex, which represents that the user requires the resource of d not so strongly. The values and the meanings of these parameters are discussed in the following.

For the users with QoS traffic, the resource requirement is r_0, then we can get the characteristics of the utility function

$$\begin{aligned} 0 < r < r_0, u(r) > 0, u'(r) > 0 \\ r_0 \le r < R, u(r) > 0, u'(r) \le 0 \end{aligned} \tag{2}$$

$$U(0) \approx 0, U(R) \approx 1 \tag{3}$$

where $u'(r)$ is the first derivative of $u(r)$. According to the conditions (2)(3), we get the utility function for QoS users

$$U_1(r) = \frac{1}{1 + \mathrm{e}^{-C_1(r-r_0)}} \tag{4}$$

where the parameter C_1 is used to adjust the slope of the utility curve around r_0. It reflects the demand degree of the user for the resource requirement r_0. The larger C_1 is, the higher the slope of the utility curve around r_0 is, so that the user demands the resource r_0 more strongly, or on the contrary, the demand is weaker. The effect of C_1 on the utility curve is reflected by the solid curves in Fig. 1, where $r_0 = 10$. Today's wireless networks contain heterogeneous traffic like voice, video, FTP etc. which require different levels of QoS treatment. They can be represented by different values of C_1 and r_0.

For the users with BE traffic, the requirement satisfies $r_0 = 0$. The utility function has the following characteristics

$$0 < r < R, u(r) > 0, u'(r) < 0 \tag{5}$$

$$U(0) \approx 0 \tag{6}$$

In a similar way, we can get the utility function for BE users

$$U_2(r) = \frac{1}{1 + B\mathrm{e}^{-C_2 r}} + D \tag{7}$$

To make sure the utility of BE users is lower than that of QoS users when $r > r_0$, we assume $B = 1.5$. From (6), $D = -0.4$. In (7), the parameter C_2 can be used to adjust the slope of the utility curve. It reflects the tradeoff between the spectrum efficiency and the user fairness. The larger C_2 is, the faster the curve rises, which indicates that the utility function tends to better fairness. The smaller C_2 is, the slower the curve rises, which indicates that the utility function tends to higher throughput. The effect of C_2 on the utility curve is reflected by the dotted curves in Fig. 1. We call the parameters C_1 and C_2 as utility parameters.

In order to reflect the demand of QoS users on r_0, C_1 should have a relative large value. For achieving the tradeoff between throughput and fairness for BE users, C_2 should be selected by the practical situation. Thus, in the following simulation, we will select the most appropriate values of C_1 and C_2 after studying how they affect the algorithm performance. From Fig.

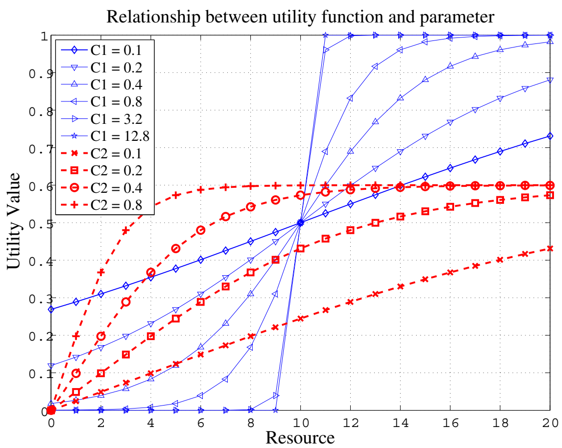

Fig. 1. The effect of the utility parameters on unified utility function

1, we can see that if the rest resource is more than r_0, higher utility can be obtained by assigning the resource to the QoS user, and if the rest resource is less than r_0, higher utility can be obtained by assigning the resource to the BE user.

III. Unified-Utility-Based Resource Allocation

In this section, we study the resource allocation based on the unified utility function. We first establish the optimization model, and then analyze the solution of this model. Finally, the resource allocation algorithm is proposed.

A. System Model and Assumptions

The system being studied consists of one cell and M users, including M_1 QoS users and M_2 BE users. The total resource in the system is R. r_m indicates the resource assigned to the user m. q_m means the channel quality, $0 \leq q_m \leq 1$. The smaller q_m is, the worse the channel quality is. Thus, the effective resource for the user m can be expressed as $r_m q_m$. The utility of the user m is $U_m(\cdot) = U(r_m q_m)$. In practice, the resource could be time-slot, frequency, or other radio resource for data transmission, which is assigned by the controller located at the base station (BS). The channel quality can be indicated by SINR.

The optimization objective of the resource allocation model is to maximize the aggregate utility of users in the entire network. The resource assigned to the users can be dynamically adjusted to improve the network performance, with the total radio resource constraint. Thus, the optimization model for the resource allocation can be expressed as

$$\max O = \sum_{m=1}^{M} U(r_m q_m) = \sum_{m_1=1}^{M_1} U_1(r_{m_1} q_{m_1}) + \sum_{m_2=1}^{M_2} U_2(r_{m_2} q_{m_2})$$
$$\text{s.t.} \quad \sum_{m=1}^{M} r_m \leq R, r_m \geq 0, m = 1, 2, \ldots, M \tag{8}$$

For the QoS users, if the resource is enough, the following constraint should be satisfied, namely the effective resource of the user is no less than the resource requirement:

$$r_{m_1} q_{m_1} \geq r_0, m_1 = 1, 2, \ldots, M_1 \tag{9}$$

B. Solution of the Unified-Utility-Based Resource Allocation

The model in (8) is a constrained non-convex optimization problem. We use Lagrangian method to analyze the optimal solution first. We construct the Lagrangian function as

$$O_2 = \sum_{m=1}^{M} U(r_m q_m) - \lambda \left[\sum_{m=1}^{M} r_m - R \right]. \tag{10}$$

With the Karush-Kuhn-Tucker (KKT) conditions, we have

$$\frac{\partial O_2}{\partial r_m} = \frac{\partial \sum_{m=1}^{M} U(r_m q_m)}{\partial r_m} - \lambda = 0 \tag{11}$$
$$\frac{\partial O_2}{\partial \lambda} = \sum_{m=1}^{M} r_m - R = 0 \tag{12}$$

for $m = 1, 2, \ldots M$, where λ is the assistant constant for the Lagrangian solution and can be obtained from (11) and (12).

From (11), for $m = 1, 2, \ldots M$, we have

$$\frac{\partial}{\partial r_m} \left[\sum_{m=1}^{M} U(r_m q_m) \right] = u_m(r_m) = \lambda \tag{13}$$

where the marginal utility function, can be expressed as

$$u_m(r_m) = \frac{dU(r_m q_m)}{dr_m} = q_m U'(r_m) \tag{14}$$

where $U'(r_m)$ is the first derivative of the utility function.

The parameter λ in (13) should be the same for all m in optimal solution. Thus, we can get a necessary condition for the optimal resource allocation:

$$\text{Condition I}: \forall i, j = 1, 2, \ldots, M \qquad u_i(r_i) = u_j(r_j). \tag{15}$$

For users with QoS traffic, to achieve the same marginal utility, the difference in the effective resource allocated to different users is small if the exponential coefficient C_1 is large. Similarly, the difference in the effective resource allocated to BE users is big since the exponential coefficient C_2 is small. This conclusion can be verified by the simulation.

Next, we propose the sufficient condition for the optimal resource allocation problem through the following theorem.

Theorem: The sufficient conditions for the optimal resource allocation $\mathbf{R}^* = r_m, m = 1, 2, \ldots, M$ are that every user m whose resource $r_m > 0$ has an identical marginal utility and the derivative of the marginal utility $u'_m(r_m) < 0$ for all m.

Proof: Consider any other solution for the resource allocation $\mathbf{R}' = r'_m, m = 1, 2, \ldots, M$ where users i and j are allocated an amount of $r_i - \triangle r$ and $r_j + \triangle r$, respectively. $\triangle r$ is a very small real number. The resource allocated to other users in $\mathbf{R}'$ are the same to that in $\mathbf{R}^*$. Thus, the difference in the total utilities of $\mathbf{R}'$ and $\mathbf{R}^*$ can be expressed as

$$\begin{aligned} & U(\mathbf{R}^*) - U(\mathbf{R}') \\ &= [U(r_i) + U(r_j)] - [U(r_i - \triangle r) + U(r_j + \triangle r)] \\ &= [U(r_i) - U(r_i - \triangle r)] - [U(r_j + \triangle r) - U(r_j)] \\ &= \int_{r_i - \triangle r}^{r_i} u_i(r)\, \mathrm{d}r - \int_{r_j}^{r_j + \triangle r} u_j(r)\, \mathrm{d}r. \end{aligned} \tag{16}$$

If $u_m'(r_m) < 0$ for all m, $u_m(r)$ is decreasing. Thus, (16) implies

$$U(\mathbf{R}^*) - U(\mathbf{R}^{'}) \geq u_i(r_i) \triangle r - u_j(r_j) \triangle r. \qquad (17)$$

When all users have an identical marginal utility, $u_i(r_i) = u_j(r_j)$, we get

$$U(\mathbf{R}^*) - U(\mathbf{R}^{'}) \geq 0 \qquad (18)$$

which implies that $\mathbf{R}^*$ is the optimal solution.

Hence, every user m has an identical marginal utility $u_m(r_m)$ and $u_m'(r_m) < 0$ for all m are the sufficient conditions of the optimal resource allocation $\mathbf{R}^*$.

The above analysis is based on the assumption that the amount of resource is enough for M users. If the available resource is limited, the users especially QoS users would be selected to be served. In the scenario with QoS users only, since the user utility is close to zero when the effective resource is smaller than r_0, some users cannot be assigned resource in the solution, while other users whose resource $r_m > 0$ have an identical marginal utility. However, the derivative of the marginal utility $u_m'(r_m)$ for the users with the worst channel condition may be larger than 0, which means their effective resource is smaller than r_0. In the scenario with mixed traffic, if the effective resource for a QoS user is smaller than r_0, the resource would be allocated to BE users for higher aggregate utility since the utility of BE users is higher than that of QoS users when the resource is lower than r_0.

C. Resource Allocation Algorithm

The previous optimization model is a non-convex optimization problem. It is hard to get the precise theoretical solution of the model through analytical method. We propose a heuristic algorithm based on the theorem and analysis in subsection B to solve the resource allocation. First of all, we consider the situation with QoS users only. To make the algorithm converge fast, the maximum number of QoS users supported by the limited resource is estimated at the beginning of the algorithm, and the resource is initialized among these users. In the theoretical solution, all users have an identical marginal utility. Thus, the resource of the users who have smaller marginal utility and $u_m'(r_m) < 0$ should be allocated to the users who have greater marginal utility or $u_m'(r_m) > 0$, which means that the resource of the users with higher effective resource should be allocated to the users with lower effective resource. The algorithm is described in the following.

Algorithm I Resource allocation algorithm for QoS users

1) Prophase preparation: The BS estimates the maximum number of QoS users supported by the system according to the channel quality of each user and the amount of available resource. $M_1 = \underset{N_i}{\operatorname{argmax}} \left\{ \sum_{m=1}^{N_i} r_m q_m \right\} \leq R$
2) Initialization: Initialize the resource for M_1 QoS users, $r_m = R/M_1$. Due to the different channel quality of users, the effective resource obtained by each user $r_m q_m$ is not equal.
3) Resource allocation: Adjust the initial resource of each user. If the effective resource of the user is more than the requirement r_0, the marginal utility function decreases rapidly. Thus, the criterion of the adjustment is to assign the resource of users with more effective resource to the users with less effective resource. The specific process is: Adjust the resource with the step length β. If the aggregate utility of all users after adjusting can improve, then execute the adjusting and go on. Otherwise, reduce the step length β to the next attempt.
4) Iteration: Assign the resource from the user with the most effective resource to the one with the least effective resource, and then go on the next iteration.
5) End: If the aggregate utility cannot be improved in one iteration, end the iteration.

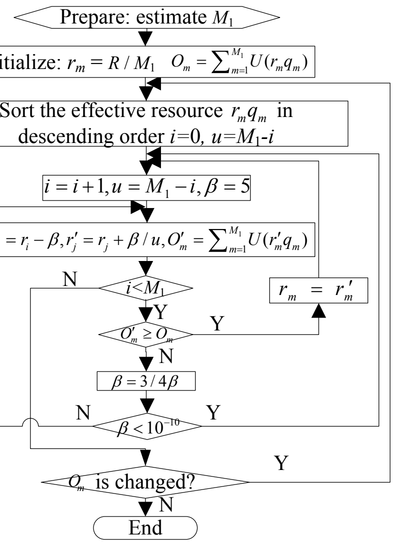

Fig. 2. Flow chart of the resource allocation algorithm for QoS users

The flow chart of this algorithm is shown in Fig. 2.

This algorithm is fit for the heterogeneous network with different levels of QoS. The ones with strong demand for QoS would be serviced preferentially according to our algorithm.

Next, we consider the system with BE users only. The process of the algorithm is as follows. It is similar to that of Algorithm I. The flow chart is similar to Fig. 2.

Algorithm II Resource allocation algorithm for BE users

1) Initialization: Initialize the resource allocation for M_2 BE users, $r_m = R/M_2$.
2) Resource allocation: Adjust the initial resource of each BE user. The process is similar to that of QoS users.

If the system has the mixed traffic, the iteration algorithm is the integration of the previous two algorithms. We first initialize the allocation by assigning the resource to QoS users according to Algorithm I, and then adjust the resource of QoS users and allocate to BE users, which should lead to the improvement of the aggregate utility. The process and the flow chart are similar to the previous ones. The difference is just that the aggregate utility in the process here is the sum of the utility of two kinds of users. From the algorithm flow in Fig. 2, we can see that every loop in all users has

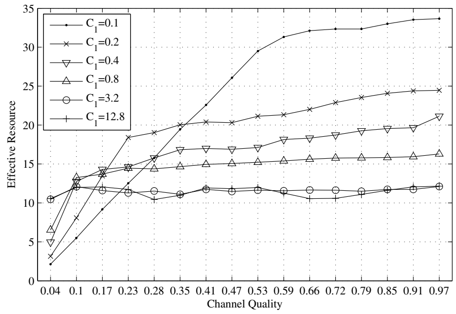

Fig. 3. Resource allocation for QoS users under different values of C_1

polynomial complexity. Thus, the algorithm has complexity of several polynomial times.

The optimal solution for QoS users can be obtained at the convex part of the sigmoid function since the maximum number of QoS users supported by the system is estimated first. The utility function of BE users is convex, so the optimal solution is obtained at the convex part. In summary, the optimal solution for single traffic or mixed traffic is obtained at the convex part, and the convex optimization problem with constraint has a unique optimal solution. Hence, the solution from the heuristic algorithm here is close to the optimal one.

IV. Numerical Simulation and Analysis

In this section, we evaluate the performance of the resource allocation based on unified utility function through numerical simulation. We assume all users adopt the utility function proposed above. The channel quality of each user is normalized and generated randomly from the range of $[0, 1]$ [5].

We first evaluate the performance of the resource allocation algorithm when the system contains only QoS users, and vary the slope of utility function by tuning the parameter C_1 so as to observe how the QoS requirement degree affects the results. We assume the total resource R is 800, the user number is 16, the requirement r_0 is 10. Simulation results are plotted in Fig. 3, where the effective resource for QoS users with different channel qualities is shown under different values of C_1.

From the results, we observe that different values of C_1 result in different performances. The larger C_1 is, the faster the marginal utility saturate with the increase of the allocated resource. The system tends to assigning more resource to the users with worse channel quality, and the effective resource of each user is much closer to its requirement, so that better user fairness can be obtained. The smaller C_1 is, the more slowly the marginal utility saturate with the increase of the allocated resource. Thus, C_1 is set to 12.8 in the following simulation. To achieve the maximum aggregate utility, the system allocates more effective resource to the users with better channel quality.

When the system contains BE users only, we vary C_2 to observe the effects on the performance of the user fairness. We assume the total resource R is 80, the user number is 5. The fairness indexes of users, indicated by F, under different values of C_2 are shown in Table I. The fairness index F based on the effective resource is extended from the fairness index based on the throughput in [13]. It can be defined as

TABLE I
FAIRNESS INDEX FOR DIFFERENT UTILITY PARAMETER

Utility Parameter C_2	0.1	0.2	0.4	0.8
Fairness Index F	0.747	0.775	0.793	0.813

$$F = \left(\sum_{m=1}^{M_2} r_m q_m \right)^2 / M_2 \sum_{m=1}^{M_2} (r_m q_m)^2 \qquad (19)$$

The conclusion we can draw from Table I is the same as that in the analysis. Larger value of C_2 leads to better user fairness, which means that BS allocates more resource to the users with worse channel quality, but at the cost of the system throughput decrease. Thus, C_2 should be selected to balance the tradeoff between the system throughput and user fairness according to the actual situation. In the following, $C_2 = 0.2$, which can give higher priority to QoS users with $C_1 = 12.8$.

Next, we evaluate the performance of the proposed algorithm when the system contains both QoS users and BE users. We vary the proportion of these two categories of users to observe how the algorithm performance varies in the mixed traffic scenario. Total resource R is set to 800, the requirement of QoS users r_0 is 10. We assume there are 20 users in the system. The performance comparison of the resource allocation based on unified utility function under different user proportions is shown in Fig. 4. The last several users (higher user number) are BE users in every proportion case. The smaller user number reflects the worse channel quality.

From the results, we can see that if the total resource is sufficient, the resource requirement of QoS users can be always satisfied. When both QoS users and BE users exist in the system, in order to guarantee the aggregate utility of system, the effective resource allocated to QoS users is a little higher than the requirement r_0. The reason is that the utility is most to the system's profit when the effective resource of QoS users is a little higher than r_0 from Fig. 1, namely the least resource achieves the most utility increase. The rest resource is allocated among BE users. Since the resource is limited, if the QoS users exceed the maximum number that the system can support (e.g. 18QoS : 2BE), the first QoS user with the worst channel quality cannot be serviced. Then two BE users utilize the rest resource to obtain higher aggregate utility.

In the following, we evaluate the performance of the resource allocation strategy by setting different total resource in the mixed traffic scenario. We assume the user proportion is 16QoS : 4BE. The simulation results for the resource allocation under different total resource are shown in Fig. 5.

From the results, we can see that when there is not so much resource ($R = 600$), system would satisfy the requirement of QoS users with better channel quality preferentially. The rest resource that is not enough for QoS users to reach effective resource of r_0 is allocated to BE users. With the increasing of the total resource, QoS users with worse channel quality are satisfied in turn. When the total resource rises from 600 to 800, the effective resource for BE users decreases instead. The

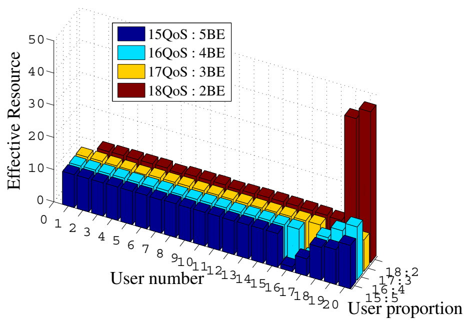

Fig. 4. Resource allocation under different user proportions

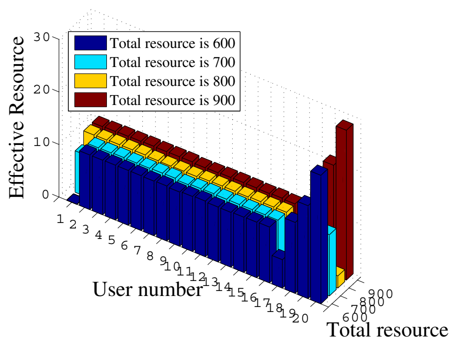

Fig. 5. Resource allocation in mixed traffic under different total resource

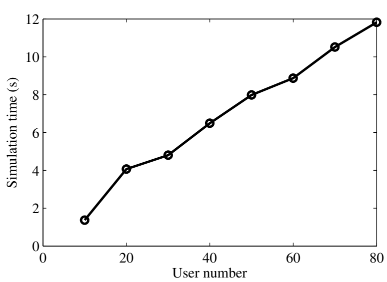

Fig. 6. Simulation time under different user number

reason is that the increased resource is used for the resource requirement of QoS users, so that the aggregate utility achieves maximum. After all QoS users have enough effective resource ($R = 800$ or 900), the total resource continues to increase, the effective resource for BE users would upturn.

The proposed resource allocation strategy can guarantee the requirement of QoS users preferentially in the mixed traffic scenario (Fig. 5) and the fairness of BE users (Table I). These advantages come from the algorithm based on the unified utility function. The marginal utility for QoS users is largest at r_0. When the resource is a little larger than r_0, the utility of QoS users is twice more than that of BE users, so that the resource allocation based on this unified utility function can satisfy the resource requirement of QoS users preferentially. Moreover, the utility function for BE users is convex, which prevents assigning too much resource to the users with good channel condition, so that the user fairness can be guaranteed.

Finally, we evaluate the computation complexity of the proposed algorithm by observing the simulation time under different users. R is set to 800, the user proportion is assumed to be 16QoS : 4BE. The simulation time under different user numbers is shown in Fig. 6. We can see that the simulation time is nearly linear proportional with the user number, which verifies that the complexity of this algorithm is polynomial.

V. CONCLUSION

The resource allocation in wireless networks is the hotspot of the recent research. We analyze the resource allocation in the mixed traffic scenario under the existing research. We first study the unified utility function for mixed traffic, and then establish the optimization model for resource allocation based on the unified utility function. The model is analyzed theoretically. The heuristic algorithm implementations for the resource allocation strategy under different traffic deployments are proposed subsequently. Finally, the numeric simulation is performed to evaluate the performance of the algorithm. The results imply that the proposed resource allocation strategy is fit for the heterogeneous networks with different levels of QoS requirement. The results can automatically satisfy the resource requirement of QoS users preferentially, and the fairness of BE users can be guaranteed automatically to a certain degree.

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