A Radio Resource Allocation Algorithm for QoS Provision in PMP-based Systems

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***Abstract*—Based on the studies on downlink resource allocation in point to multi-point (PMP) mode in the 802.16e systems, an efficient downlink resource allocation algorithm with low complexity is proposed to maximize the system throughput, which takes the advantage of frequency-selective fading property in orthogonal frequency division multiple (OFDM) networks. The proposed algorithm not only provides the traffic rate as high as possible, but also satisfies the minimum reserved traffic rate for non-real-time services. The simulation shows that the proposed algorithm performs better in terms of assuring individual QoS and offering fairness among users at the cost of slight degradation in throughput.**

***Index Terms*—radio resource management, downlink resource allocation, QoS, PMP, 802.16e**

I. Introduction

It is well known that one of the most challenging technical problems for future wireless systems is to provide various services to meet the requirement of an increasing number of consumers while ensuring individual quality of service (QoS). Owing to the scarce frequency spectrum, resource allocation has been considered as one of the key technologies for increasing utilization rate of the limited power and spectrum in future wireless networks. According to the IEEE 802.16e standard, the medium access control (MAC) layer supports both point to multi-point (PMP) mode and mesh mode [1, 2], between which the former is the primary topology structure. The downlink transmission operates on a PMP basis, and data for MSs need to be transferred by a central BS via a wireless link. The PMP mode provides a comparatively high traffic rate, since network resources can be shared among users. As a result, broadband wireless access systems widely adopted the PMP mode in the last few years.

The MAC layer in IEEE 802.16e network uses the conception of service flow, which provides unidirectional packet transmission [1]. A service flow is characterized by a set of quality of service (QoS) parameters such as latency, jitter, and throughput assurances. Owing to the low traffic rate and high error rate in a wireless link, as well as user's mobility, a QoS-guaranteeing resource allocation algorithm becomes one of the key techniques in broadband wireless network. Consequently, to support various applications under limited radio resources and time-varying channel, a dynamic resource allocation, which can achieve both higher system spectral efficiency and better QoS, has been identified as one of the imperative tasks in wireless communication since a few years ago.

Letaief and Zhang provide an overview of recent research on dynamic resource allocation, especially for MIMO and orthogonal frequency division multiple (OFDM) systems [3]. They propose an algorithm to maximize data rate for a given power budget with a target BER. The proposed scheme in [4] adjusts the power to meet the predefined delay requirement, which is one of the decisive factors to guarantee end-to-end delay. Ref. [5] proposes an efficient subcarrier and power allocation algorithm, which formulates necessary conditions of downlink scheduling for proportional fairness in orthogonal frequency division multiple access (OFDMA) systems. However, since it considers power allocation after subcarriers' allocation for assuring individual QoS and subsequent proportional fairness (PF) allocation, it adds a lot of complexity. As we know, in a scenario with high SNR, the performance of allocating power evenly to each subcarrier is almost equivalent to that of the classic optimal power allocation algorithm, at the same time the complexity is reduced greatly. Ref. [6] utilizes a user and connection based scheme to improve transmission efficiency and guarantee quality of service. It schedules the user with the highest priority first and the allocation starts from the maximum deviation channel, with the result that the QoS requirement of the user with low priority may not be met. The target QoS of resource allocation in [7] corresponds to a minimum user data rate, a target bit-error rate and a maximum BER-outage

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probability. Ref. [8] distributes subcarriers and bits among users based on their different quality of service requirements and traffic type. Though they provide an efficient resource allocation for the users with different traffic class, the system throughput may reduce greatly.

In order to meet the requirements of non-real-time polling service (nrtPS) in IEEE802.16e network, a downlink resource allocation algorithm is proposed to maximize the system throughput, which takes the advantage of frequency-selective fading property of OFDM networks. What's more, the proposed Delta algorithm combines the key QoS parameters of nrtPS and assures the required minimum data rate for each user. Under the circumstances of using non-real-time polling service in PMP-based OFDM networks, such items as subcarrier/bit allocation statistics, throughput and fairness index are compared and analyzed by using four different resource allocation algorithms. The four algorithms are Delta, MT [3], fixed modulation and code scheme (FMCS) algorithm based on 16 quadrature amplitude modulation (QAM) and maximum throughput confined by minimum traffic rate (MTMR) [9]. The simulation shows that though the proposed Delta algorithm sacrifices few throughput, it comes close to the best MT algorithm in terms of system throughput and the best FMCS algorithm in terms of fairness index. And Delta algorithm meets QoS demand of the minimum reserved traffic rate for all users at the same time. Besides, its complexity is reduced greatly, which makes it appropriate for application in non-real-time business.

The remainder of this paper is organized as follows. Section 2 briefly describes the basic consideration of an adaptive radio resource allocation algorithm based on OFDM system. In view of QoS characteristics of nrtPS defined in 802.16e protocol, a relevant adaptive allocation algorithm in the multi-carrier system is discussed and a downlink resource allocation algorithm to maximize the system throughput is introduced in section 3. Section 4 presents simulation result for the proposed Delta and other three algorithms. Finally, the paper is concluded in section 5.

II. Basic Considerations

Power is one of the important resources in wireless communication system. The system capacity directly depends on BS's transmitting power. In OFDM system, a scheduler needs to provide the power allocation of each subcarrier as well as subcarrier assignment. The classic optimal power allocation algorithm is called Water-filling theorem [10], of which the basic idea is allocating to the channels of good quality as more power as possible, the ones of bad quality relatively less. However, according to information theory, it is easily proved that allocating the power to each subcarrier on average can dramatically reduce the complexity of the resource allocation just at the cost of slight degradation in system capacity.

Assume that there are J independent parallel Gaussian channels, of which noise power are respectively $N_1 \ldots N_J$. According to Shannon's formula, the capacity of J channels is

$$C = \underset{P_i}{Max} \frac{1}{2} \sum_{j=1}^{J} \log_2 (1 + \frac{P_j}{N_j}) \tag{1}$$

where P_j denotes the signal power of channel J, and satisfies the equation of power limitation $\sum_{j=1}^{J} P_j = P$.

By the method of Lagrange multipliers, we can get the power allocation method which can maximize the system capacity:

$$P_j = (\gamma - N_j)^+ \tag{2}$$

where $(x)^+$ represents positive function, γ constant is to be determined by $\sum_{j=1}^{J} (\gamma - N_j)^+ = P$. Thus the whole capacity of parallel Gaussian channels equals to

$$C = \frac{1}{2} \sum_{j=1}^{J} \log_2 (1 + \frac{(\gamma - N_j)^+}{N_j}) \tag{3}$$

From (2), the less the noise power of each channel is, the more power each channel can obtain and vice versa.

In order to simplify the power allocation scheme, we assume that the power is high enough. Hence, $\sum_{j=1}^{J} (\gamma - N_j)^+ = P$ retrogresses to:

$$\sum_{j=1}^{J} (\gamma - N_j) = P \tag{4}$$

Then it is easy to get the equation:

$$\gamma = \frac{1}{J} (P + \sum_{j=1}^{J} N_j) \approx \frac{P}{J} \tag{5}$$

Substituting (5) into (3) yields the channel capacity:

$$C \approx \frac{1}{2} \sum_{j=1}^{J} \log_2 (\frac{P}{J \cdot N_j}) \tag{6}$$

From (6), the channel capacities obtained from average power allocation algorithm and water-filling power allocation algorithm are roughly equivalent at high SNRs. As a result, in order to simplify the algorithm, it is generally regarded that the channel capacity with the average allocation algorithm approximately equals to the best allocation result at high SNRs. In OFDM system, we can allocate the power to each subcarrier on average, and then consider the assignment of carriers and bits together, which can reduce the complexity of adaptive allocation algorithm to a large extent.

III. Resource Allocation Algorithm Based On Maximum Throughput

A. *Algorithm Description*

Generally speaking, the target of an algorithm in multi-carrier system is maximum throughput, or best fairness index, or tradeoff between them. This paper focuses on maximizing system throughput and guaranteeing the minimum reserved traffic rate of non-real-time polling service, and only downlink OFDM system is considered. Assume that the number of users served by a BS in a cell is K, and the number of subcarriers available is N. At transmitting terminal, data from K users will be mapped to subcarriers and bits, i.e., different subcarriers with corresponding bits will be allocated to different users. An adaptive algorithm can allocate resource for each subcarrier at transmitting terminal on condition that channel state is always given. We define $\rho_{k,n}$ as the occupying identifier of a subcarrier, whose value is 1 when the nth subcarrier is occupied by the kth user, otherwise $\rho_{k,n}$ equals 0. Besides, $c_{k,n}$ signifies the number of bits available for the kth user on the nth subcarrier.

After inverse fast Fourier transform and adding cyclic prefix, signal is transmitted through the downlink. Generally, when the duration of cyclic prefix is larger than maximum multipath delay spread, inter signal interference can be eliminated and then every subcarrier is supposed to be experiencing flat fading in the channel. It is assumed that channel state information is acquired through dedicated control channel. With cyclic prefix removed and fast Fourier transform, users can obtain their own data information from relevant subcarrier, according to subcarrier allocation and modulation information.

When a system has a target bit error rate (BER), there exists a relationship between BER and $c_{k,n}$ as follows:

$$c_{k,n} = f(BER, p_{k,n}, h_{k,n}) \tag{7}$$

where $p_{k,n}$ is the transmitting power needed when allocating the nth subcarrier to the kth user, $h_{k,n}$ is the magnitude of channel gain, and function f indicates a mapping relationship.

For every OFDM subcarrier, there is:

$$T = \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n} c_{k,n} \tag{8}$$

For user k, the number of bits transmitted on this subcarrier is

$$R_k = \sum_{n=1}^{N} \rho_{k,n} c_{k,n} \tag{9}$$

Based on the analysis mentioned above, the problem that the proposed algorithm needs to solve can be concluded as:

$$V = \underset{c_{k,n}, \rho_{k,n}}{Max} \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n} c_{k,n} \tag{10}$$

while it should also submit to the following restraint:

$$\sum_{n=1}^{N} \rho_{k,n} c_{k,n} \geq r_k \quad \forall k \tag{11}$$

$$\text{If } \rho_{k,n} = 1, \text{ then } \rho_{k',n} = 0 \quad \forall k \neq k' \tag{12}$$

$c_{k,n}$ can be obtained from (10), and the minimum traffic rate for every user is confined in (11). From (12), we can see that a subcarrier can be occupied by at most one user. The target of the proposed algorithm is to obtain proper $\rho_{k,n}$ and $c_{k,n}$. Since $c_{k,n}$ is an integer and has non-linear relationship with $\rho_{k,n}$, the resolution of (10) belongs to non-linear problem. Here, $\rho_{k,n}$ is supposed to be the average value of transmitting power, i.e., power is distributed evenly, as a result that calculation complexity is reduced and sub-optimal solution is achieved at the same time.

When $\rho_{k,n}$ is fixed, $c_{k,n}$ can be solved from (7). Firstly, we ignore the restraint of (11), and take only the target of maximum throughput into consideration. According to (10), subcarriers are only allocated to users who can provide maximum throughput to the system. Then, bit allocation is adjusted according to the minimum reserved rate of each user. The subcarriers occupied by QoS satisfied users needs to be allocated to those unsatisfied ones till QoS requirements of all users are satisfied. However, modulation order of some subcarriers must be set lower to satisfy QoS requirements of all users during the re-adjustment processing of subcarriers. What's more, adjustment of subcarriers in this algorithm is supposed to obey the following rule, that is, always choosing the one that least affects the system throughput.

$$Delta_{k,n} = \frac{c_{k_n^*,n} - c_{k,n}}{c_{k,n}} \quad \forall n \tag{13}$$

where $Delta_{k,n}$ is the criteria of judgment when adjusting bits, and $c_{k_n^*,n}$ indicates the traffic rate available when subcarrier n is initially allocated to user k^*. The flow chart of this algorithm is illustrated in figure 1.

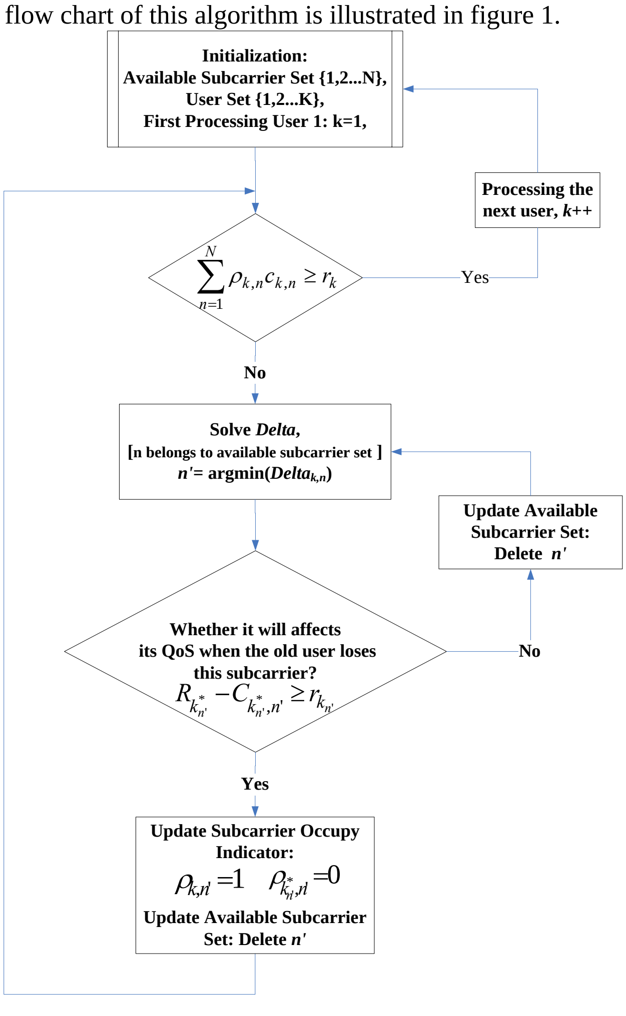

Figure 1. Flow chart of the Delta algorithm

B. Description of Comparison Algorithms

Here the three traditional resource allocation algorithms used for comparison with the proposed algorithm are introduced.

Solution 1: Every subcarrier utilizes fixed modulation mode, that is, 16QAM. Ideally, each subcarrier carries 4 bits, thus an OFDM signal carries $4N$ bits all together. We call this FMCS algorithm.

Solution 2: Adaptive resource allocation targeted at maximum throughput, which has the same result as initial allocation of the proposed algorithm, is reputed as MT algorithm [3].

Solution 3: The allocation algorithm targeted at maximum throughput, token involved and restrained by minimum rate, with precedence judgment criteria is simplified, is called as MTMR algorithm [9]. It can be represented as follows: at time slot t, allocating subcarrier k to user k_n^*.

$$k_n^* = \arg\max_k (T_k^{n-1} \cdot c_{k,n}(t)) \quad n = 1, 2, \ldots N \qquad (14)$$

Every time a subcarrier is allocated, users' demand of minimum rate and the number of tokens should be updated. For example, when subcarrier n is allocated, the number of tokens for user k is updated as follows:

$$T_k(t) = \max\{0, T_k(t-1) + r_k - c_k(t)\} \qquad (15)$$

where $c_k(t) = \sum_{n=1}^{N} c_{k,n}(t)$ represents the number of bits which are already allocated to user k at time slot t, $T_k(t)$ represents the service demand of the user, and $c_{k,n}(t)$ is the real transmission capability of subcarrier n allocated to user k.

Ⅳ. SIMULATION AND ANALYSIS

In order to evaluate the performance of the proposed allocation algorithm, the simulation scenario mainly focuses on non-real-time polling service (nrtPS). The proposed Delta algorithm will be compared with other three algorithms (i.e., FMCS, MT and MTMR) in fairness index among users, allocation of subcarriers and bits, and system throughput.

A. Simulation Environment

TABLE I.
PARAMETERS IN SIMULATION

Parameter	Value
The number of users (K)	6 ~ 22 Users
The number of subcarriers (N)	256
Modulation mode allowed	BPSK / QPSK / 16QAM / 64QAM
Target BER (BER)	10e-4
Service model	nrtPS
QoS property: Min traffic rate (bits/symbol)	Uniform distribution over the interval (65, 90)

This simulation scenario contains 256 subcarriers for data transmission and supports four modulation techniques including BPSK, QPSK, 16QAM and 64QAM, where the highest modulation order is six. In simulation, the radius of a cell is 1000m, the maximal transmitting power of a BS is 43dbm and the system target BER is set to 10^{-4}. For the service model, assume that each user has only one nrtPS connection, of whose packet the size ranges from 65bit/symbol to 90bit/symbol. Table 1 shows the parameters in detail.

B. Results and Discussion

At first the fairness index among users of the four algorithms (Delta, MT, FMCS and MTMR) is analyzed. Here the Min/Max fairness index is used to measure the fairness of different algorithms. Its definition is as follows:

$$F = \frac{\min\{s_i\}}{\max\{s_i\}} \qquad (16)$$

where F represents the fairness index, S_i denotes the throughput achieved by user i.

Figure 2 illustrates the relationship between Min/Max fairness index and the number of users by using the four different algorithms.

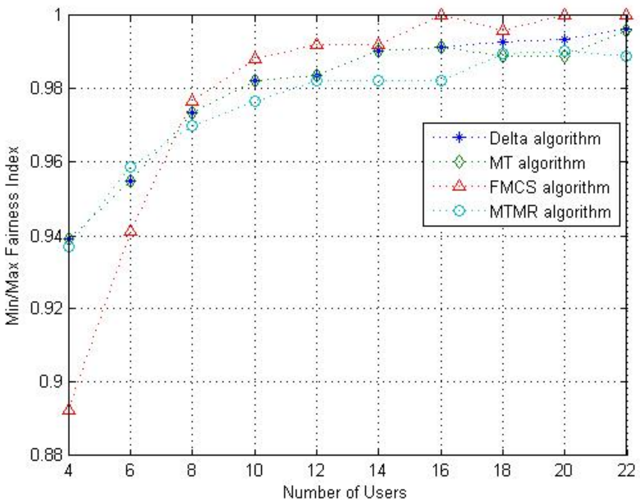

Figure 2. Relationship between Min/Max fairness index and the number of users

In simulation, the number of users changes from 4 to 22. As shown in figure 2, with the number of users in a cell increasing, the Min/Max fairness index of the four algorithms all trends to rising. Especially, for FMCS algorithm, when the user number goes up to a certain value (K=16 in this simulation), the fairness index reaches 1. This is because not only it uses a fixed modulation, but also its resource allocation is similar to the polling of packet scheduling algorithm. Thus the fairness index is supposed to be the highest. The fairness of the other three ascends steadily. Comparatively, the fairness index of MTMR algorithm is slightly lower than Delta and MT algorithms, by 1% under the worst circumstances (K=14-16). The proposed algorithm, Delta algorithm, is rather equivalent to MT algorithm in system fairness, but when the user number is rising (K>=18), Delta algorithm shows superior performance.

Through several simulations, the statistics indicate that Delta algorithm and MT algorithm perform approximately the same in scenarios when users are relatively few. This is because every user in this scenario can be met QoS demand of minimum traffic rate, that is to say, there are always enough subcarriers to allocate and thus the adjustment of bits' allocation for QoS provision is unnecessary. However, Delta algorithm reaches a better result for bit allocation when the number of users increases to a certain amount. Figure 3 illustrates the number of bits per symbol allocated to each user in a scenario of 10 users. The results of Delta algorithm and MT algorithm hardly differ from each other. What's more, both of them meet QoS demand of minimum traffic rate. Theoretically, if QoS demand of each user differs, FMCS algorithm, which focuses on fairness index among users, will ignore the restraint of QoS provision. Therefore, when adopting FMCS algorithm, the traffic rates of user 4 to user 9 are a little bit lower than the required minimum traffic rate. The statistics acquired by using MTMR algorithm fluctuate largely. For example, the traffic rates of user 1 and user 4 are comparatively high, while those of user 3 and 10 are too low to satisfy the requirement of minimum traffic rate. The reasons why the result of subcarriers' allocation differs so much are mutual influence during the allocation of adjacent subcarriers, as well as the update of the number of tokens.

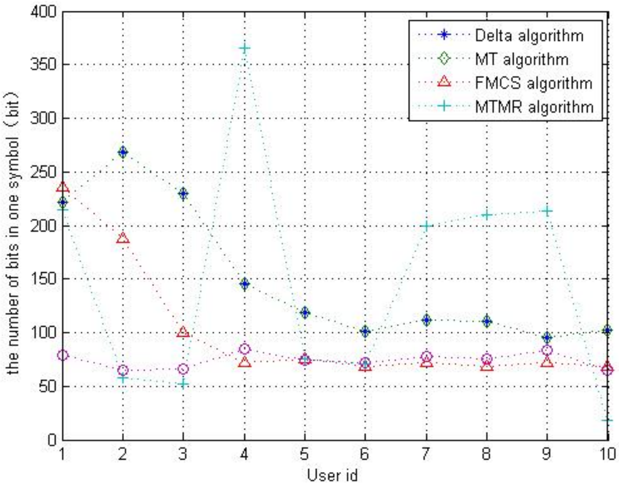

Figure 3. Number of bits per signal allocated to users in 10 users' scenario

Figure 4 shows the number of bits per symbol allocated to each user in 15 users' scenario. The result of MTMR algorithm still fluctuates largely. When the user number is increasing, there are some users experiencing "hungry" by using whether MTMR, FMCS, or MT algorithm, whose target is to maximize the system throughput. While Delta algorithm, an improvement of MT algorithm, allocates fewer bits to certain users than MT algorithm, it satisfies QoS requirements of minimum traffic rate of all users. In addition, Delta algorithm has generally achieved as high traffic rate as possible, this is because Delta algorithm is designed to adjust allocated subcarrier appropriately to meet the requirements of the users who have not obtained the minimum reserved traffic rate on the premise of maximizing the system throughput.

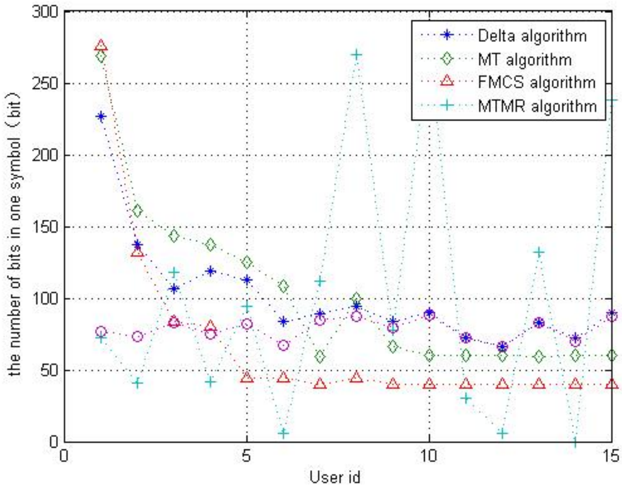

Figure 4. Number of bits per signal allocated to users in 15 users' scenario

Figure 5 shows system throughput in scenario of 10 users. As FMCS algorithm requires special modulation mode, it gets a relatively small throughput, approximately 1020 bit/symbol. Figure 5 also proves the conclusion mentioned before, that the performances of Delta algorithm and MT algorithm are quite the same when the number of users in the scenario is small. However, the throughput of MTMR is slightly smaller than that of Delta algorithm.

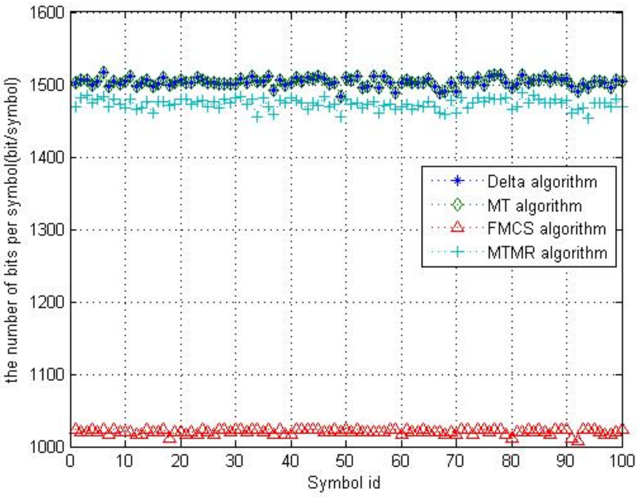

Figure 5. System throughput in 10 users' scenario

Figure 6 indicates system throughput in scenario of 15 users. The tendency is nearly the same as that of 10 users' scenario. Note that the performances of Delta algorithm and MT algorithm are both better than that of MTMR algorithm.

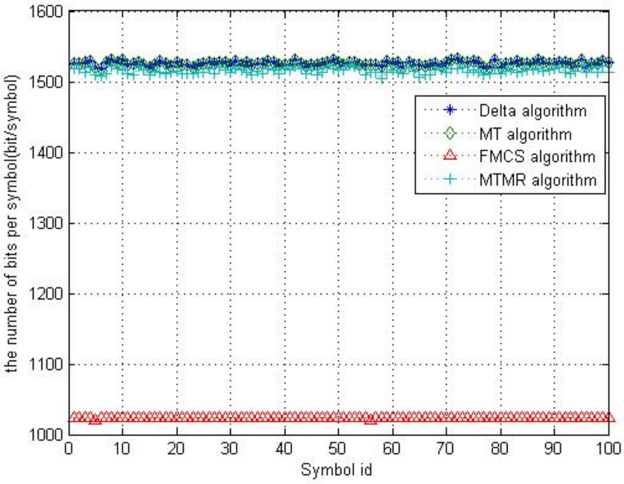

Figure 6. System throughput in 15 users' scenario

V. CONCLUSION

Based on MT algorithm, this paper proposes a new resource allocation algorithm with low complexity, which not only provides the maximum traffic rate as much as possible, but also guarantees the minimum reserved traffic rate for non-real-time services. Through simulation, the proposed Delta algorithm is compared with MT, FMCS and MTMR algorithms in fairness index among users, allocation of subcarriers and bits, and system throughput. The simulation indicates that Delta algorithm, as a promotion of MT algorithm, achieves QoS provision at the cost of slight degradation in throughput, at the same time does well in fairness index among users too. Particularly, in scenario with a relatively large number of users (above 10 in this simulation), Delta algorithm exceeds over the other three in comparison.

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