Adaptive Channel Allocation to Increase Capacity Based on Rate Proportional Constraint in the OFDMA System

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ABSTRACT:
Demands for mobile communications are drastically increasing. Nonetheless, these demands cannot be fulfilled because of the limited frequency resources available for mobile communications. More specifically, channel allocation for different uses of frequency resource has emerged a critical issue. This paper presents an adaptive sub-carrier allocation in an orthogonal frequency division multiple access (OFDMA) downlink transmission system. It also attempts to testify the high performance attitude on capacity compared to the latest available rate in other adaptive OFDMA methods, which maximizes the total system's capacity and the total power in bit error rate (BER) constraints that are subject to proportional rate constraint (PRC). In this study the expectation value statistic scheduling was formed instead of the random numerical ordering during the first time of the sub-carrier allocation. Furthermore, this scheme was developed via rate allocation, based on the PRC scheme to allocate the channel adaptively among users. The rate of the allocation problem was also formulated to enhance the throughput.

KEYWORDS: Adaptive Resource Allocation, OFDMA, Adaptive Modulation, Proportional Rate Constraint.

1. INTRODUCTION

With the increasing demands for wireless internet access, orthogonal frequency division multiplexing (OFDM) has become one of the most appealing communication technologies for future-generation wireless networks [1]. In fact, it has been adopted in systems such as high-speed wireless local area network or WLAN (e.g. IEEE 802.11a) and fixed broadband access systems (e.g. IEEE 802.16a). The OFDM system divides a broadband channel into many narrowband sub-channels. Each sub-channel carries a quadrature amplitude modulation (QAM) signal [2].

In an orthogonal frequency division multiplexing access (OFDMA) network, which is based on the OFDM technology, an enhanced transmission rate is achieved by transmitting data via multiple parallel channels. The system can allocate power and transmission rate adaptively among sub-carriers to achieve a high throughput. Thus, it is a promising multiple access technique for high data rate transmission over wireless radio channels. In addition, it is robust to inter-symbol interference (ISI) and frequency-selective fading [3]. At present, the adaptive resource allocation techniques, which involve adaptive modulation and coding (AMC), adaptive power distribution and hybrid multiple accesses, are recognized as a key approach to enhance the resource utilization efficiency and provide better QoS guarantee [1].

One of the advantages to multiuser diversity and adaptive modulation in the OFDMA system is resource allocation. The problem of assigning sub-carriers and power to different users in the OFDMA system has been an area of active research. Margin adaptive and rate adaptive are two classes of adaptive resource allocation schemes. This idea is to develop an algorithm which can be used to determine which users to schedule, how to allocate sub-carriers to them and decide the appropriate power levels for each user on each sub-carrier.

Rhee [4]considered a scheme by maximizing the minimum user's data rate, which guarantees the minimum quota for each user and partially allows fairness among them. Conversely, Hui [5] minimized the total transmit power from a given set of fixed user data rates and bit error rate (BER) requirements. Shen [6] investigated the rate of the adaptive problem wherein the objective was to maximize the total BER constraints. Kim [7] proposed maximizing the total capacity under the proportional rate constraint (PRC) instead of maximizing the minimum users' capacity as in [4]. However, an accurate numerical solution of the algorithm only exists in a high average sub-channel signal to noise ratio (SNR). Mohanram [8] proposed a sub-optimal algorithm that performed joint sub-channel and power allocation problem formulation, while taking into account the frequency selective nature of the users' channels. However, the rate proportion in this approach has a larger deviation as compared to the pre-determined rate proportionality constraint.

The optimal solution is to schedule users with the best channel at each time. If the users has different rate requirements and needs additional channels, the objective would be to maximize the total achievable rate of users in the system, whereas when the number of available channel is provided, the objective of channel allocation is maximizing the system's capacity. In this paper, a multi-user sub-carrier scheme where all users transmit in all time slots is considered. The objective is to increase the capacity by allocating sub-carriers to the users based on the PRC on each sub-carrier, which is more relevant to the WiMAX system. Thus, this study presents a priority based expectation value statistic instead of the random numerical ordering during the initial sub-carrier allocation and then utilizes the rate adaptive resource allocation scheme approximate rate proportional function. Besides, this scheme has no constraint in term of the number of sub-carriers, so it should be much larger than the number of users which can benefit it in order to suite wider application scenarios.

The organization of this paper is as follows: first, the resource allocation in OFDMA is described in section 2, then the allocation optimization objective function of the OFDMA model and sub-carrier is given in section 3, whereas the solution of the mentioned problem and the simulation results are disclosed, respectively, in sections 4 and 5. Finally, the conclusion of this paper is given in section 6

2. RESOURCE ALLOCATION

Resource allocation of an OFDMA system includes time (time slots), bandwidth (sub-carriers), signal space size (number of bits carried by each sub-carrier) and transmission power which are defined by the different available resources for propagation of an OFDMA symbol in a radio environment. In a multi-user environment, a good resource allocation scheme leverages multi-user diversity and channel fading. The optimal solution is to schedule the user with the best channel at each time [9].

In this work, some possible approaches to resource allocation have been considered and the class of techniques that attempt to balance the desire for high throughput with fairness among the users in the system is focused. Four Algorithms for resource allocation are defined in the WiMAX system. In summary, the MSR allocation is the best in terms of total throughput and achieves a low computational complexity but has an extremely unfair distribution of rates. As the MF algorithm sacrifices significant throughput, it can achieve complete fairness. As a result, it is appropriate only for fixed, equal-rate applications.

However The PRC algorithm allows a flexible trade-off between these two extremes, but it may not always be possible to set the desired rate constraints in real time, appropriately. Finally, the popular PF algorithm is simple enough to perform and gain the practical balance between throughput and fairness.

3. THE SYSTEM MODEL

A downlink transmission of the OFDMA system is assumed and its block diagram is illustrated in Fig.1. The system consists of K users and N orthogonal narrowband sub-channels with the overall bandwidth B divided into all channels [5]. Each sub-carrier was assumed to be assigned to only one user to simplify the design. Bits of each user are modulated into m-ary quadrature amplitude modulation (MQAM) symbols. In the base station, the controller gets the channel state information (CSI) feedback from all the K users. Based on these CSI inputs, the proposed adaptive "resource allocation algorithm" was adopted in order to control the sub-carrier block of the OFDMA system [7]. Subsequently, these modulated signals in all the N orthogonal sub-carriers are input to the IFFT module to form an OFDMA symbol. The OFDMA symbol is also considered under time-varying frequency selective Rayleigh fading channels [5].

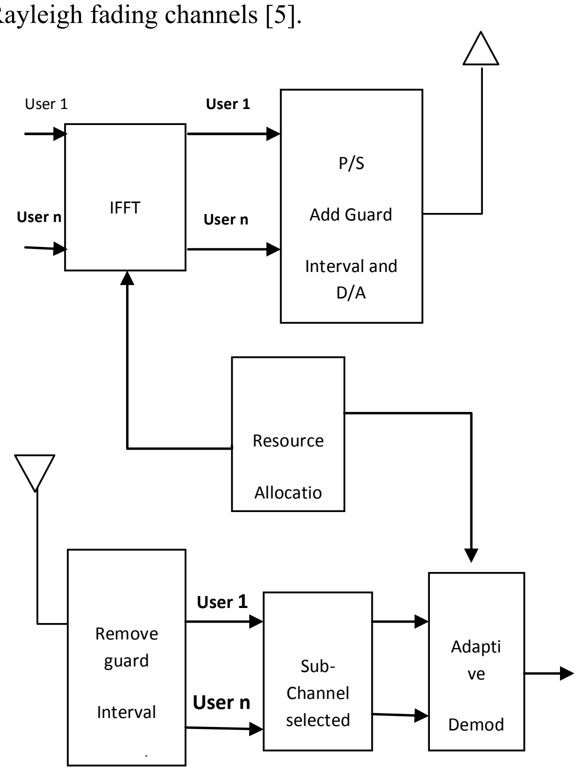

Fig. 1. A block diagram of the OFDMA system

Based on this assumption, the channel estimation problem could then be simplified into such a situation that a perfect CSI is known to the controller at the base station via a dedicated feedback channel such that the resource allocation scheme is adjusted in a timely manner once the channel is changed. In the case of M-QAM, its function, $f_k(c)$, can be represented as:

$$f_k(c) = \frac{N_0}{3}[Q^{-1}(\frac{p_e}{4})]^2(2^c - 1) \quad (1)$$

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2} dt \quad (2)$$

Therefore, the additive white Gaussian noise (AWGN) of variance can be formulated as follows:

$$\eta^2 = N_0 B / N \quad (3)$$

Where N_0 is the noise power spectral density (PSD). The corresponding SNR of the sub-channel is, thus, denoted as:

$$u_{k,n} = g^2{}_{k,n} / \eta^2 \quad (4)$$

where g denotes the gain of users' channel k in the sub-channel n. With adaptive modulation, the number of assigned bit, $c_{k,n}$ for the sub-carrier n of user k can be estimated with the function of SNR in equation $\gamma_{k,n}$ and the target BER.

$$c_{k,n} = \log_2\left(1 + \frac{-1.6\gamma_{k,n}}{in(5BER)}\right) = \log_2\left(1 + \psi\gamma_{k,n}\right) \quad (5)$$

$$\psi = -1.6 / in(5BER) \quad (6)$$

$$p_{k,n}u_{k,n} = \frac{-1.6\gamma_{k,n}}{in\ (5BER)} \quad (7)$$

where Ψ is a constant related to BER and the effective sub-channel SNR. In order to solve the capacity problem for the user, k which is denoted as Rk, is defined as:

$$R = \sum c_{k,n}\delta = \sum\ \sum \delta \log_2\left(1 + p_{k,n}u_{k,n}\right) \quad (8)$$

The problem involved in the resource allocation of the OFDMA system could be solved using the exp-linear method then would be formulated as follows:

$$\max\ E_\gamma\left(\sum_k \sum_n R\left(p_{k,n}\gamma_{k,n}\right)\right)$$
$$\text{subject to}\quad E_\gamma\left(\sum_k \sum_n p_{k,n}\right) \le \overline{P} \quad (9)$$

where B is the total available bandwidth, N is the total number of users, $\delta_{k,n}$ is the sub-carrier allocation indicator. Meanwhile, $p_{k,n}$ is the power required by the user k on the sub-carrier n, assuming that this is subject to the modulation level of the power allocated to all the sub-carriers. The following subjects are imposed:

C1: $\delta_{k,n} \in \{0,1\}$ for all k, n

C2: $p_{k,n \ge 0}$ for all k, n

C3: $\sum_1^k \delta_{k,n} = 1$ for all k, n

C4: $\sum\sum \delta_{k,n} p_{k,n} \le p_{tot}$ for all n and $1 \le k \le$ K

C5: $R_i : R_j = \Phi_i : \Phi_j$ for all i , j €{1,2,…,K}, i≠j

In C1, $\delta_{k,n}$ is a carrier allocation indicator such that $\delta_{k,n} = 1$, if only sub-carrier n is assigned to user k. C3 imposes a restriction that the sum of the sub-carrier allocation indicators is always equivalent to 1. p_{tot} is the total transmitting power that is allocated for all the users. R_j is the date rate for user j and Φ_j is the constant of proportionality for user, j [5]. In C5, $\Phi_1: \Phi_2: \Phi_3: \ldots: \Phi_k$ are the normalized proportionality constants, where $\sum_1^k \phi_k = 1$ The objective function would be the same as before, i.e. when the maximized system capacity was obtained by maximizing the sum of users' data rate.

4. THE PROPOSED SOLUTION

The sub-channel and power should be allocated to achieve the optimal solution [6]; however, this will cause each of the N sub-carriers to be allocated to one of the K users. This paper extended the work of [5] by developing a sub-carrier allocation scheme while achieving approximate rate proportionality. The solution algorithms were applied to the OFDMA system in order to maximize the capacity by dividing the whole data rate maximization problem under limited power constraint [7, 10]. The exponential statistic approach is applied here. By following all the constraints from C_l to C_5 in the function subjection of (6), the system capacity is further improved by optimizing the resource allocation algorithm.

First, the number of the sub-carriers N_k needed for each user is determined. The approximate allocated rate is then evaluated according to the predetermined required proportion of sub-carriers for each user. The rate ratio vector is approximated by

$r = [r1, r2, \ldots, rk] = [R1 / \Phi 1, \ldots\ldots, Rk\ / \Phi k\ ]$, and the normalized rate ratio vector holds on the value of:

$$r_{\max} = \max[r`_1, \ldots, r`_k] \quad (10)$$

which is subjected to:

$$\sum r`_k = k \quad (11)$$

The value of N_k is determined according to

N_1:N_2: ….: N_k= Φ_1: Φ_2; ….: Φ_k. This is approximated by N_k=ΦN. Here, ΦN stands for the value |ΦN| rounded to the upper integral. The number of those unallocated sub-carriers, N*, is obtained by:

$$N^* = N - \sum N_k \quad (12)$$

which is left for residual sub-carrier allocation. A priority based scheduling criterion is used to allow the user k, with the highest priority to choose its best sub-channel first. The priority is defined as user with a higher level of modulation order and higher priority; this is based on the expected value statistic as:

$$\theta = E\left|\frac{\gamma_{k,n}}{\overline{\gamma}_{k,n}}\right| \quad (13)$$

The channel is given by:

$$n = \arg\max \theta \quad (14)$$

And

The user is given by:

$$k = \arg\min E\left|\frac{\overline{R}_k}{\overline{\varphi}_k}\right| \quad (15)$$

initialization

$set\ \sigma_{k,n} = 0, for\ all\ k \in \{1,...,K\}$ and $n \in \{1,...,N\}$

$set\ R_{k,n} = 0, for\ all\ k \in \{1,...,K\}$ and $p = P_{total}/N$

$\eta = \{1,2,...,k\}; \rho = \{1,2,...,n\};$

$while\ |\eta| \succ 0$

find user with the best priority to choose first subcarrier

$n = \arg\max E\left|\gamma_{k,n} / \overline{\gamma}_{k,n}\right|$

$let\ \sigma_{k,n} = 1;\ N_k = N_k - 1;\ \rho = \rho \setminus \{n\};$

calculate $R_n = R_k + B/\mathrm{N} \log_2(1 + p * u_{k,n});$

$while\ |\rho| \neq 0$

$\eta = \{1,...,K\}, k = \arg\min E\ |\overline{R}_k / \overline{\varphi}_k\ |;$

$find\ \ n = \arg\max E\left|\gamma_{k,n} / \overline{\gamma}_{k,n}\right|;$

$if\ \ N_k \succ o$

$set\ \ \alpha_{k,n} = 1, N_k = N_k - 1; \rho = \rho \setminus \{n\}$

$calculate\ \ R_k = R_k + B/N \log_2(1 + p * u_{k,n})$

$else\ \ \eta = \eta \setminus \{k\}$

Fig. 2. Channel Allocation Algorithm in OFDMA System

Based on the proportional fairness function, a user who more likely needs a sub-carrier repeatedly allocates the best channel from the unallocated sub-carriers. If N >> K, the remaining sub-carriers will be allocated by the best user in order to maximize system capacity.

This step assigns an unallocated subcarrier to each user which has the maximum gain for that user. This provides the user with an inherent advantage of choosing the best available subcarrier.

Other initializations in addition to the whole algorithm are described in Fig.2, and an Exponential statistic value method or sub-carrier allocation flowchart is shown in Fig. 3.

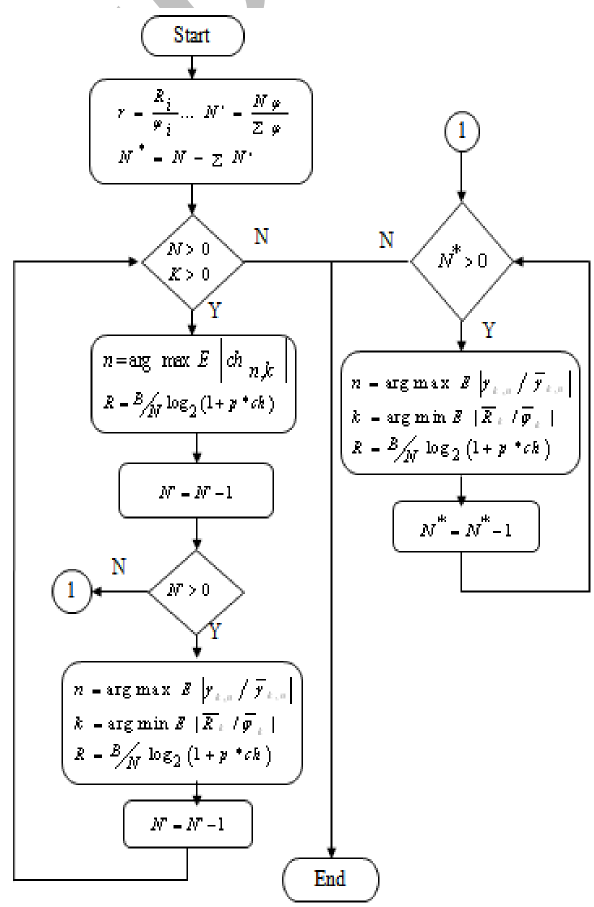

Fig. 3. Channel Allocation Flowchart in the OFDMA System

5. SIMULATION RESULTS

The system under frequency selective fading channel consisting of six independent Rayleigh multi-paths was chosen by an exponentially decaying profile. The maximized delay was 5us and the maximum Doppler frequency shift was 30 Hz. The channel information was sampled every 0.5 ms to update the sub-channel. The total bandwidth assumed was 1 MHz, whereas the average sub-channel SNR was chosen to be 38 dB by the use of M-QAM modulation. The required BER = 10^{-4} gave an SNR gap of 3.3. The number of users for the system varied from 16 to 64, while the number of the sub-carrier varied from 64 to 256. In addition, the model was simulated using the MATLAB simulation tools [11].

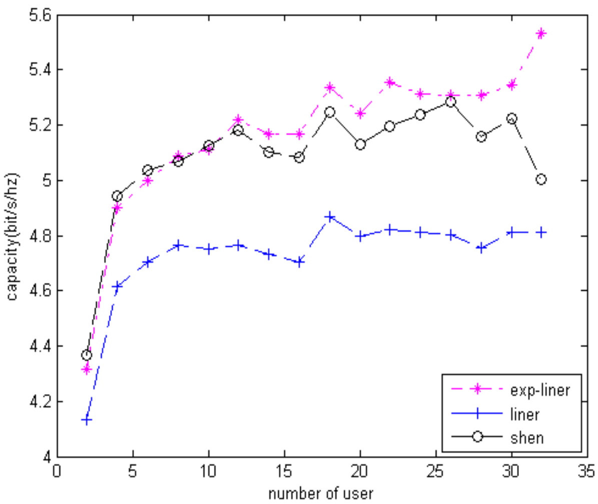

Fig. 4. The total capacity vs. the number of users in the OFDMA system when K = 32, N = 256

In Fig.4, the number of users was set to 32, while the number of carrier was 256. This was done in order to analyze the behavior of the algorithms at various levels of complexity. These simulations were carried out by changing the parameters which include the number of carrier (FFT size) and also the number of users. In this case, both methods were found to yield the similar results until the number of users reached 8. The exp-linear method, however, produced a better Capacity result when the number of users went beyond 8.

Fig.5 shows the graph for capacity vs. the number of users for exp-linear and Wong method where the number of users was set to 32 and the number of carrier was set to 64. The graph shows the capacity for both methods increases as the number of users increases.

Fig.6 and Fig.7 show the capacity gain versus the number of users at different BERs. The number of users was set to 16 with 128 FFT carriers in the OFDM modulation. In addition, the number of samples was adjusted to 500 per second. It was observed that the capacity gain of channel allocation with the optimal power allocation and the equal power allocation increases as the number of users increases. This phenomenon is also known as ‘multiuser diversity’. In a system of 16 users, the proposed power allocation solution was also found to achieve more capacity gain rather than the scheme with equal power. This value was approximately 10% for the graph presented in Fig.4 and about 20% for the graph in Fig.5.

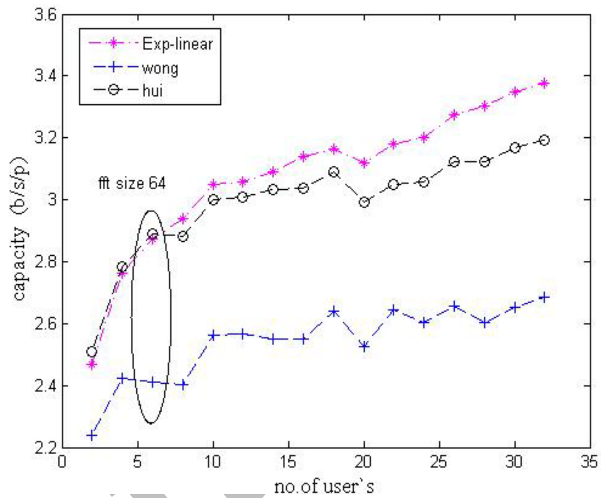

Fig. 5. The total capacity vs. user number in OFDMA system when M = 32, K = 64

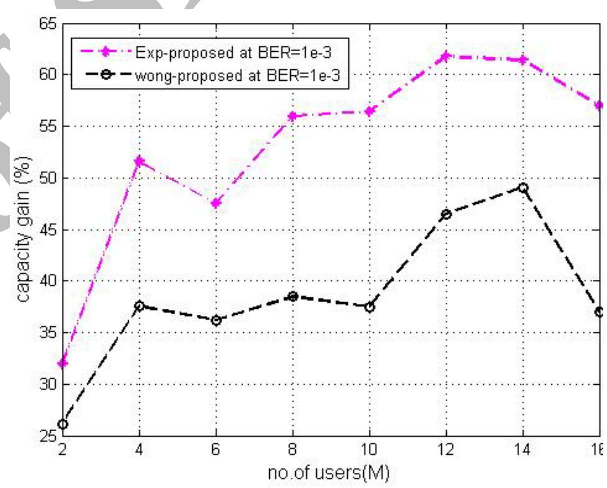

Fig. 6. Capacity gain vs. the number of users at different BER ;Simulation at BER=10^{-3}

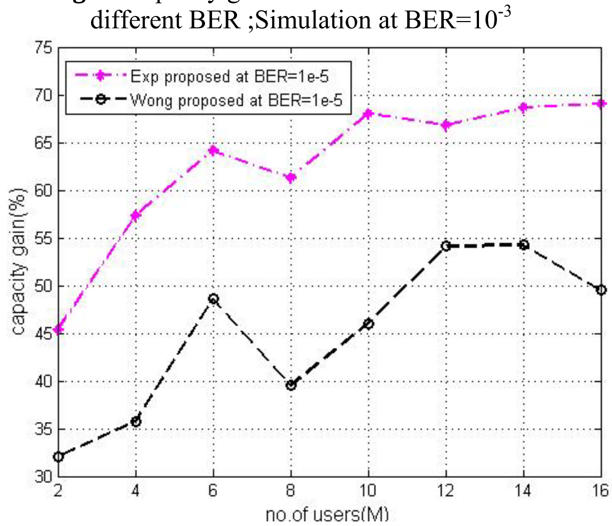

Fig. 7. Capacity gain vs. the number of users at different BER ; Simulation at BER=10^{-5}

Fig.8 shows the comparison of the computational complexity of the Exp-linear and Wong Method. It can be indicated from this figure that the Exp-linear Algorithm has an order of magnitude, approximately 10^2 times, faster in execution time than the method that Wong proposed. Also we notice that computational complexity remains constant with an increase in number of users.

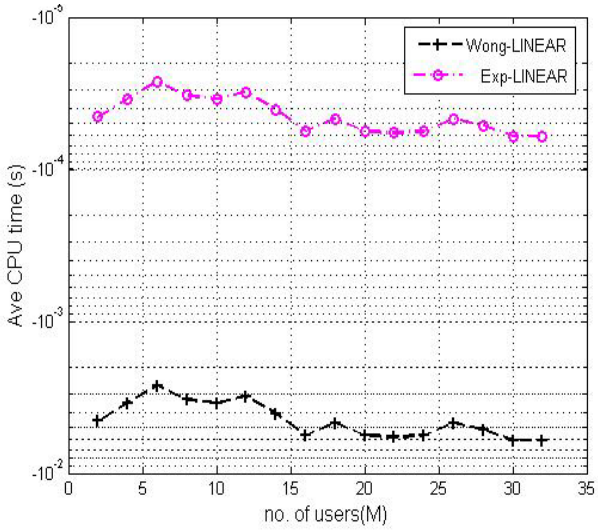

Fig. 8. Computational complexity comparison of Exp-linear algorithm and Wong-linear method vs. number of users. $M = 32$, SNR Gap= 3.3 dB

6. CONCLUSIONS

This paper proposes an optimized rate adaptive resource allocation scheme for the downlink OFDMA system. Introducing the initial priority scheduling in the rate of the proportion allocation method and thus obtained a much higher system capacity by exploiting more multiuser and spectral diversities. The exp-linear allocation method solving the Expectation value statistic equation to allocate channel for the users considers level modulation and the number of bit loading. It is suggested that future next researches on the power allocation problem can consider adaptive modulation in this algorithm and extend the same method in the OFDMA uplink system.

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