Adaptive OFDMA Subcarrier Assignment for QoS Guaranteed Services

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***Abstract*—Subcarrier allocation with QoS support in Orthogonal Frequency Division Multiple Access (OFDMA) system is investigated in this work. A novel subcarrier allocation scheme called Power Controlled Dynamic Subcarrier Allocation (PCDSA) is developed to allocate subcarriers according to the QoS requirement based on the appropriate power control and channel condition adaptation. The proposed scheme adjusts the power to guarantee the predefined delay requirement, which is one of the determinants of end-to-end delay. The simulation results conducted in the WSSUS channel show that proposed scheme could reduce the queuing delay and buffer requirements while achieving high utilization.**

Keywords-PCDSA;OFDMA; Subcarrier allocation

I. INTRODUCTION

An Orthogonal Frequency Division Multiplexing (OFDM) system is one of the widely used multicarrier systems, e.g. wireless LAN (802.11a), WiMax (802.16a) and digital video broadcasting (DVB), and OFDM is also a candidate technology for beyond 3G or 4G. The principle of OFDM technique is to split a high-rate data stream into a number of lower rate streams, which are then simultaneously transmitted on a number of orthogonal subcarriers. In an Orthogonal Frequency Division Multiplexing access (OFDMA) system, each user occupies a subset of subcarriers, a subcarrier can be allocated to any user. But one subcarrier can be allocated to only one user. So the system performance differ greatly using different allocation results scheme and radio resources allocation plays a key roll in optimizing the performance of OFDMA systems.

In a multiuser OFDM system, each of the multiple users' signals may undergo independent fading because users may not be in the same locations. An adaptive multiuser subcarrier, bit, and power allocation scheme was proposed in [1-2] based on the instantaneous channel information as a counterpart of multiuser water-filling solution. The Lagrangian relaxation algorithm was introduced in this scheme to minimize the total power consumption with constraints on transmission rate for users require for different classes of services. Despite of its significant gain over the fixed assignment strategy, the algorithm is computational intensive and is difficult to implement.

The authors in [3] proposed a subcarrier allocation in an OFDM system with finite buffer space. They showed that water-filling solutions perform poorly with respects to a long-run throughput criterion due to buffer overflow. The allocation procedure was divided into two steps. The first step is used to decided bandwidth requirement of each user in order to satisfy its outage requirement. And the second step is to maximize the total throughput by selecting the right channel set for each user.

A series of efficient frequency assignment and power allocation algorithms were proposed in [4] to achieve the maximum total utility value. The solutions balance the throughput and fairness between users well when the utility function was selected appropriately based on the channel quality of users.

However, those aforementioned schemes omit important aspects of queuing build-ups and delays, which are required by the upper layer applications. In this paper, a novel scheme, which takes the queuing delay into account as a crucial complement, is proposed. The proposed scheme estimates the delay according to average transmission rates and the queuing build-ups. Then the power allocation is adjusted to speed up or slow down the user data rate. The proposed scheme consists of two control loops. The function of the outer loop is to determine the power allocation according to the QoS requirements and that of inner loop is to control the subcarrier allocation pattern. Through simulation, it is verified that delay is constrained to a certain range and the buffer occupancy is much less than that without QoS control scheme.

The remainder of the paper is organized as follows. In the next section, we describe the system model of the subcarrier allocation scheme. In the section III, the proposed scheme named PCDSA is described. Simulation results are studied in the section IV. Finally, the paper is concluded in the section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

In a downlink transmission of the multiuser OFDMA system, the serial data from all active users is fed into the OFDM subcarrier and power allocation block, which allocates bits from different users to different subcarriers. Using the channel state information feeds back from the user side and the information of buffer build-ups of the transmission buffers, the transmitter applies the combined subcarrier, bits, and power allocation algorithm to assign different subcarriers to different users. The output of the modulators are transformed into the time domain samples by inverse fast Fourier transform (IFFT), Cyclic extension of the time domain samples, known as the guard interval, is then added to ensure orthogonality between

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the subcarriers. Then the transmitted signal is passed through different frequency selective fading channels to different users.

The allocation results are sent to the receiver through a dedicated control channel. At the receiver, the cyclic extension is removed to eliminate the ISI, and the time samples of the user are transformed using FFT at the demodulation block. The allocation results are used to configure the demodulator. The demodulated bits are stored in the receiver buffer.

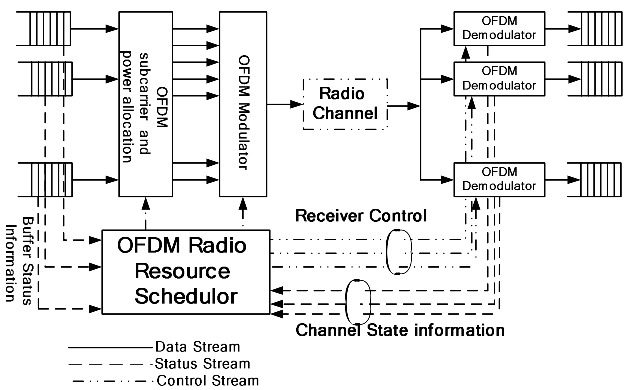


Fig.1 Block diagram of a multiuser OFDMA system

Assuming that M users sharing K subcarriers. Let $D_i, i = 1,2,...,M$ denote the set of subcarriers assigned to the user i . At time t, the power of user i on subcarrier k will be $P_i\ (k,t)$. The power allocated to the user i on any subcarrier allocated to the user is $P_i\ (t)$. Let $H_i(k,t)$ and $N_i(k,t)$ are the channel gain and the noise power of user i on subcarrier k at time t. Define $\gamma_i(k,t) = |H_i(k,t)|^2 / N_i(k,t)$ as channel Signal to Noise Ratio (SNR) of the user i at time t on the subcarrier k. On each subcarrier, an appropriate modulation level is employed according to the channel condition, and power allocation results. At time t, the channel capacity can be expressed as [2] :

$$c_i(k,t) = \log_2(1+\beta P_i(t)\gamma_i(k,t)) \quad k = 1,2,..,K, i = 1,2,...,M \quad (1)$$

where β is a constant related to a targeted Bit Error Rate (BER), which can be expressed as $\beta = -1.5/\ln(5\cdot BER)$. It is worth noting that the transmitting power is user based. That is to say that the power allocated to one user is the same on all subcarriers assigned to the user.

The channel capacity has direct relationship to the channel SNR and transmission power.

After the allocation of all subcarrier, the instantaneous data transmission rate of the user is the sum of the sub-rate on all subcarriers assigned to the user. Assuming the bandwidth of the subcarriers is Δf, the instantaneous data rate of user i at time t is expressed as follows:

$$r_i(t) = \sum_{k\in D_i} c_i(k,t)\Delta f\ ,\ k = 1,2,..,K, i = 1,2,...,M \qquad (2)$$

In fact, the average rate is more practical than instantaneous rate. The rate can be geometrically smoothed as follow:

$$R_i(t) = (1-\rho)R_i(t-1) + \rho r_i(t) \qquad (3)$$

where ρ is a small constant value. The smaller the constant, the more insensitive the average rate to the instantaneous rate.

III. Power Controlled Dynamic Subcarrier Allocation Scheme - PCDSA

For a multimedia communication system, it is not always have data to transmit, so the rate adapts to the incoming data is an important function. Assuming that each user has its own data buffer, the incoming data is queued in the buffer. The objective of PCDSA is to allocate subcarrier according to the user's channel condition as well as buffer build-ups. The scheme is divided into two loops. The inner loop is to allocate subcarrier according to the utility maximum principle. The outer loop is to allocate power to the user who need higher transmitting rate. The structure of our proposed scheme is shown in Fig. 2.

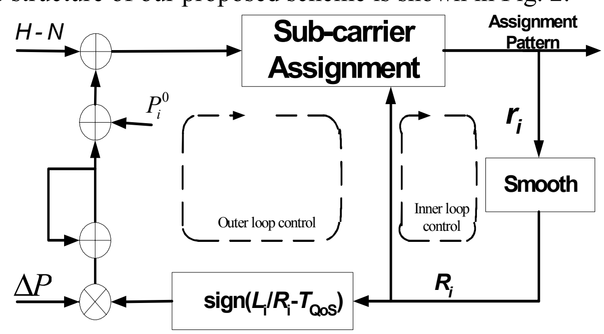


Fig. 2 Structure of PCDSA scheme

A. *Dynamic Subcarrier Allocation for Inner Loop Control*

By the inner loop, the subcarriers are assigned to the users based on the utility maximum principle [4] under the power allocation determined by the outer loop. Assuming the utility function is $U(r) = \log r$. The throughputs of each user are geometrically smoothed. The process of the allocation is per slot based. The determination of the allocation pattern relates to the power allocation, channel state information and current rate of the user.

Assigning subcarrier k to user $\hat{m}(k)$ can be expressed as follows:

$$\hat{m}(k) = \arg\max_{i\in M}\left\{\frac{c_i(k,t)}{R_i(t)}\right\} \qquad (4)$$

Where $R_i(t)$ is the geometrically smoothed rate of user i .

The subcarrier allocation scheme described by (4) is channel capacity based fairness. The achieved data rate is proportional to the channel capacity at the current power allocation and channel state. The scheme eliminates the possibility of user whose channel condition is the best will monopolize all radio resource, while the users of bad channel can't achieve resources.

B. *Power Allocation for Outer Loop Control*

Multiuser Water-filling power allocation algorithm is the optimum strategy for maximizing throughput of the system when all users in the system have enough data to be transmitted. But in a multi-service environment, multiple services maybe coexist in the same system. The higher speed user can be allocated more power to compensate the channel fading or raise the modulation level. On the other hand, the higher speed user may queuing more data bits in the buffer than that of the low speed user if the transmission rate is the same. Accordingly, a relationship between buffer build-ups and subcarriers assignment can be established by the allocation of the power. The outer loop control function consist two steps. The first step is to estimate the delay according to the bits in the buffer and current average rate. The second step is to allocate power based on the delay obtained by the first step.

Let $L_i(t)$ denotes the bits queuing in the buffer of user i at time t. A target delay threshold T^{QoS} can be set to determine the tolerable delay for user i. The average transmission rate is determined according to (3), the delay estimation, $\Delta T_i(t)$, can be estimated as follows:

$$\Delta T_i(t) = \frac{L_i(t)}{R_i(t)} - T_i^{QoS} \tag{5}$$

The predefined delay requirement, T_i^{QoS}, is an important parameter. A delay sensitive service needs a lower delay requirement value. A service with higher delay requirement value may tolerate more time delay.

If the delay exceeds the predefined QoS requirements, i.e. the allocated resources to the user are less than that of needed. The user data rate should be speed up to reduce the delay. On the contrary, if the delay lower than the requirements, i.e. the user is assigned more resources than that of needed. The rate can slow down to save resources for other user who need speed up its rate.

From (1), it can be found that the channel capacity has logarithm relationship to the transmitting power at certain channel condition. So, if the transmitting rate should be speed up, more power should be allocated to the user to compensate the channel fading or raise the level of modulation when adaptive modulation is used. That is to say, when the estimated delay is higher than the requirement, the user should be allocated more power; on the other hand, when estimated delay is lower than the requirement. The user should be allocated little power to decrease the user data rate.

A two directions power adjust scheme is used to determine the current power allocation for the user. If the delay estimation is positive, more power should be allocated to boost the data rate. And if the delay estimation is negative, less power should be allocated to slow the data rate. In order to avoid the occurrence of the infinite power increasing, a limit value of power is set.

The power is adjusted as follows:

$$P_i(t) = \begin{cases} P_i(t-1) + \Delta P \cdot sign(\Delta T_i) & P_i(t) < P_{\max} \\ P_{\max} & P_i(t) \geq P_{\max} \end{cases} \tag{6}$$

where ΔP is the power-adjusting step, and $P_{\max}$ is the maximum power, which defines the upper limit of power adjusting.

The dynamic subcarrier allocation of the inner loop control takes the advantage of fairness of channel capacity. While the outer loop control power allocation take the QoS requirement into account. So the power allocation links the inner loop and outer loop control and the scheme is QoS oriented strategy while keeping the fairness of the resources allocation.

IV. Simulation Results

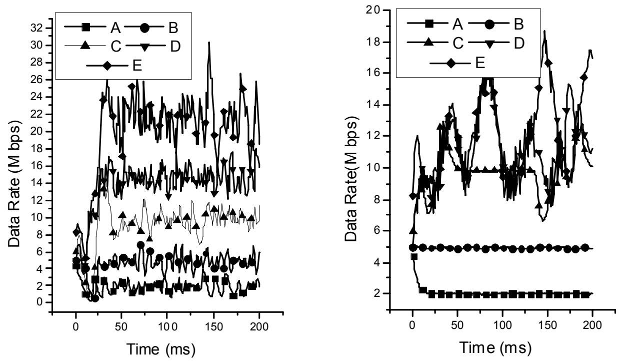
In this section, we compare the performance of the PCDSA scheme with fix power utility dynamic subcarrier allocation (FPDSA) scheme, which does not take the QoS requirements into account. FPDSA is used as a reference because the fairness of the scheme is much better than that of throughput maximum schemes, such as multiuser water-filling algorithm. In our simulation, channel is assumed to be WSSUS model. The average power of the two schemes is the same. Moreover, the performances of total 5 users with different rates are analyzed. The average data arrival rates of 5 users named from 'A' to 'E' are 2,5,10,15 and 22 Mbps respectively according to Poisson distribution. All users have the same utility function $U(r) = \log r$. The buffer depths of all users are 2M bits. For the reason of clarity, the curves are plotted in two figures with 20ms for PCDSA scheme and 200ms for FPDSA scheme ordinate scales.

Fig.3 gives a data rate comparison of PCDSA and FPDSA. The data rate of PCDSA is well adaptive to the incoming data rate while the FPDSA scheme could not show this feature.

Fig.4 shows the delay comparison between PCDSA scheme and FPDSA scheme. The abscissas of them are all time. The results show that the queue delay of the PCDSA is constrained to a certain range less than 20ms when the system enters into steady state, while the delay of the FPDSA varies greatly and could not enter into stable state. The delay increases with time for the FPDSA scheme. When the buffer overflows, the delay decreases because of no more data could be buffered.

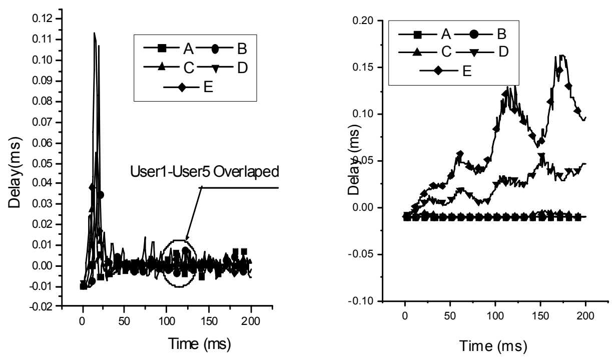
Fig.5 shows the comparison of buffer occupancy between PCDSA scheme and the FPDSA scheme. To be clear, we plot the curve in two figures since the great buffer occupancy difference between the two schemes. The results show that the buffers depth needed by PCDSA scheme is much less than that of FPDSA scheme. For the PCDSA system, the buffer occupancy is constrained at certain level without accumulation and overflow. The buffer occupancies are proportional to the rates, i.e. more buffer occupancy needed for higher transmitting rates. While for the FPDSA scheme, the buffer occupancies could not enter into steady state for higher data rates transmitting. When the data in the buffer exceeds the limit of the buffer, overflow occurs, which cause much more packets losses.

The reason of the difference is the rates can be adjusted according to the buffer depth and current transmitting rates. More power will be allocated to the user who needs higher data rate. As the transmitting rate increase, the delay is reduced with the fixed data arrival rate. The buffer occupancy is reduced accordingly.



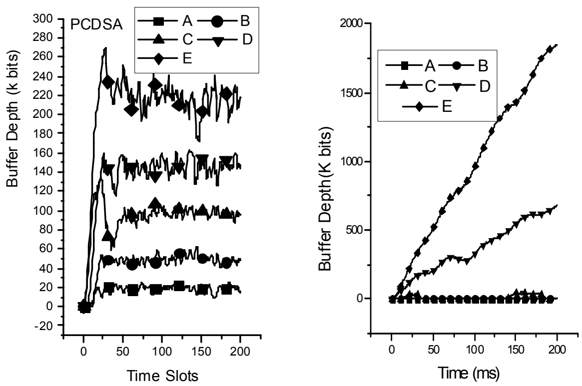
PCDSA FPDSA

Fig.3 Data Rate Comparison



PCDSA FPDSA

Fig.4 Queuing delay comparison



PCDSA FPDSA

Fig.5 Buffer occupancy comparison

V. CONCLUSION

In this paper, we proposed a novel power-controlled dynamic subcarrier assignment scheme for OFDMA system. The power allocation is dynamically adjusted according to the user queuing delay. And the subcarriers are assigned to the user according to the utility maximum principle. Simulation results show that the proposed scheme outperforms the fixed power control utility maximum scheme. The subcarrier assignment scheme doesn't need the iterative procedure, thus the complexity is very low. So the proposed scheme suits to the high-speed wireless communication systems.

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