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Quality of Service (QoS) Aware Adaptive Radio Resource Management Algorithm for MIMO-OFDMA System*

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Abstract

A real time QoS aware adaptive radio resource management algorithm for downlink of multi-cell and multi user MIMO-OFDMA system. This purposed scheduling algorithm takes account queue status, transmission rates, channel state information and priority of the user for subcarrier, power and bit allocation in MU-MIMO-OFDMA system. Subcarrier selection is based on the priority of the user and eigenvalue product criterion and "water-filling algorithm" is adapted for bit loading and power allocation problem. Simulation results show that this algorithm can not only increase the data rate of the system, but also QoS of the user. This algorithm can also maintain required QoS for each user.

Keywords: MIMO, OFDMA, Radio resource management, eigenvalue product criterion, "water-filling algorithm", adaptive modulation, packet loss rate and priority of the user.

1. Introduction

Now the customer demands for wireless communication is increasing and the existing networks will not be able to fulfill the high data rate and low latency requirements of future communication services. Therefore, the spectral efficiency of future wireless networks needs to be further improved allowing for increased flexibility to serve a large number of simultaneous users and different services [1] [2].

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Orthogonal Frequency Division Multiple Access (OFDM) can be used in conjunction with "Multiple-Input Multiple-Output" (MIMO) transceiver to increase diversity gain and/or system capacity by exploiting spatial domain. Because the OFDM system effectively provides numerous parallel narrow band channels, MIMO system is considered as a key technology in high data rate and reliable transmission system. MIMO-OFDMA based cellular systems are currently being standardized by 3GPP for LTE and by IEEE for WiMAX [1] [5]. In parallel several research projects e.g. WINNER, MASCOT, FuTURE, SURFACE are investing advanced MIMO_OFDMA transmission scheme [4] [2].

Radio resource management in MIMO-OFDMA system is very interesting research topic since past few years. There are many existing MIMO-OFDMA RRM algorithm [6] [7] [8] [9] [10] [11] [12] [13]. These suboptimal algorithms have good performance even though they can't guarantee the required QoS among the users and high data rate of the system. The cross layer scheduling algorithm [12] can guarantee the QoS among the user by considering the priority of the user but this algorithm can't get the maximum achievable data rate in the system. The adaptive resource allocation algorithm [8] can consider the fairness among the users and gives the optimal data rate of the system but this algorithm can't guarantee the required QoS for each user.

In this paper, we investigate the subcarrier, power and bit allocation mechanism in MIMOOFDMA system with maintaining required QoS for each user. We concentrate on the QoS aware radio resource management technique in MIMO-OFDMA system to maximize the capacity and QoS of the system.

The rest of paper is organized as follows: in section II the multi-cell MIMO-OFDMA system model is considered. Priority calculation, subcarrier allocation, power and bit loading problem is done by using "water-filling algorithm" and these are described in section 3. The evaluation of purposed algorithm is done in section 4 by the help of simulation result. Finally we give the conclusion in section 5.

2. System Model

Consider a multiuser MIMO-OFDMA system with N subcarrier and K users. The base station has N_t transmit antenna and receive antenna has N_r receive antennas. The downlink diagram is shown in Figure 1. Let H_k^n represents the $N_r \times N_t$ channel frequency response matrix of the K_{th} user on the n_{th} subcarrier, and the matrix elements $[H_k^n]_{i,j}$ represents the channel response from the j_{th} transmit antenna to i_{th} receive antennas.

The rank of H_k^n is denoted by

$$L = \mathrm{rank}(H_k^n) = \min(N_t, N_r) \tag{2.1}$$

The base station executes SVD to user's feedback channel information H_k^n:

$$H_k^n = U_k^n D_k^n (V_k^n)^H \tag{2.2}$$

where $(\bullet)^H$ represents the complex conjucate transpose of a matrix U_k^n and V_k^n are $N_r \times L$ and $N_t \times L$ matrices, satisfying $(U_k^n)^H U_k^n = I_L$ and $(V_k^n)^H V_k^n = I_L$ respectively and D_k^n is a $L \times L$ diagonal matrix, whose diagonal elements are singular values of H_k^n.

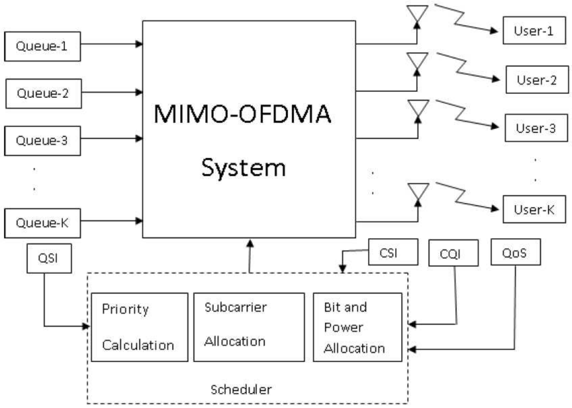

Figure 1: System block diagram of downlink MIMO-OFDMA system

We assume that different users undergoing channel response are independent and identically distributed (i.i.d).So index k can be omitted for simplicity and n_{th} carrier, D^n can be written as:

$$D^n = \mathrm{diag}(\lambda_1^n, \ldots, \lambda_l^n, \ldots, \lambda_L^n). \tag{2.3}$$

Here we do not allow more than one user to share an OFDM subcarrier in order to avoid multiuser interference (MUI) in the system, so we can view the system as a single user system on each subcarrier. Now the transmitted signal vector on the n_{th} subcarrier, x^n is given by,

$$x^n = V^n P^n s^n, \tag{2.4}$$

where s^n is the $L \times 1$ transmitted symbol vector, P^n is the transmit power matrix which is obtained from power control and it is given by

$$P^n = \mathrm{diag}\left(\sqrt{P_1^n}, \ldots, \sqrt{P_l^n}, \ldots, \sqrt{P_L^n}\right). \tag{2.5}$$

By pre-coding the transmitted data symbol with $V^n P^n$ at the transmitter antenna array and decoding its received signal vector with $(U^n)^H$ at the receiver, then the relationship between the input outputs of n_{th} subcarrier can be expressed as:

$$\begin{aligned} y^n &= (U^n)^H (H^n x^n + n^n) \\ &= (U^n)^H (U^n D^n (V^n)^H)(V^n P^n s^n) + (U^n)^H n^n \\ &= D^n P^n s^n + (U^n)^H n^n \end{aligned} \tag{2.6}$$

where x^n, y^n are the $L \times 1$ transmitted and received signal vectors of the n_{th} sub-carrier similarly n^n is $N_r \times 1$ noise vector.

Equation (2.6) revels that on each subcarrier the MIMO channel can be transformed in to L parallel SISO eigen-mode sub-channel with gain $(\lambda_l^n)^2$ and transmit power P_l^n on the l_{th} eigen-mode subchannel $(l = 1, 2, \ldots, L)$. The signal to noise ration on the l_{th} sub channel of the n_{th} subcarrier can be expressed as:

$$SNR_l^n = \frac{P_l^n (\lambda_l^n)^2}{N_0 B}, \tag{2.7}$$

where N_0 is the power spectral density of noise and B is subcarrier bandwidth.

Again signal to noise ratio for subcarrier n can be expressed as:

$$\frac{P_n}{N_n} = \frac{E_{s,n}}{N_{0,n}} = \frac{E_{b,n} \log_2(M_n)}{N_{0,n}}, \tag{2.8}$$

Where P_n denotes allocated transmit power (in W), $E_{s,n}$ and $E_{b,n}$ represent symbol and bit energy for subcarrier n respectively (in J). N_n and $N_{0,n}$ are additive white Gaussian noise power and spectral power density respectively and M_n denotes modulation level on subcarrier n. With that, the bit energy allocated for subcarrier n can be expressed with the help of transmits power as:

$$E_{b,n} = \frac{|H_n|^2 P_n}{\Delta f_c \cdot \log_2(M_n)} \tag{2.9}$$

where Δf_c denotes subcarrier spacing of OFDM transmission, and H_n represents the channel transfer function at the center frequency of subcarrier n. After the transformation above, the modulation level can be determined obviously for each SNR or power level. From equation (2.7) and (2.8) we can determine M_n for the given power, as shown:

$$\frac{P_l^n (\lambda_l^n)^2}{N_0 B} = \frac{E_{b,n} \log_2(M_n)}{N_0}. \tag{2.10}$$

The spectral efficiency of a communications channel (in bit/s/Hz) expressed with conditional entropy function can be calculated as:

$$C_{M-QAM} = \log_2 M_n (1 - H(X/Y)_{M-QAM}). \tag{2.11}$$

Again,

$$H(X/Y)_{M-QAM} = -[(1 - P_b) \log_2(1 - P_b) + P_b \cdot \log_2 p_b], \tag{2.12}$$

where p_b is the maximum acceptable probability of bit error and $H(X/Y)_{M-QAM}$ is the conditional entropy function. By using equation (2.11) we can calculate the capacity of the system for the required bit error probability.

3. Purposed Algorithm

The purposed algorithm is executed as shown in Figure 2. The priority of the user is calculated by using the channel quality indicator (CQI) and this is utilized to provide channel state information (CSI) from user terminals to base station scheduler, quality of service (QoS) factor and is based on the packet loss rate (PLR) and packet delay in queue and queuing state information (QSI) observed at the MAC layer [12].

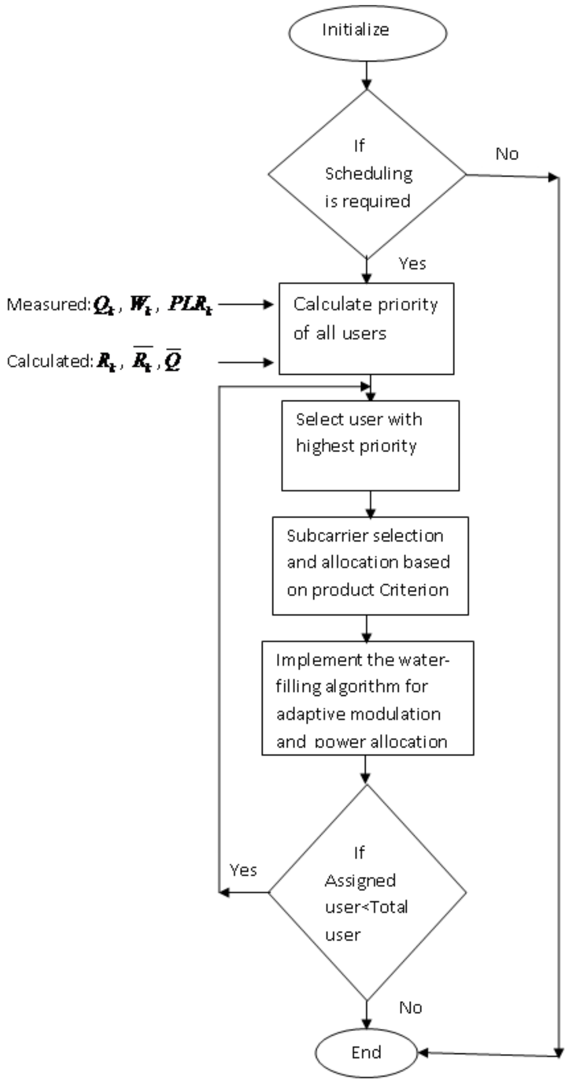

Figure 2: Purposed novel RRM algorithm for downlink MIMO-OFDMA system

The priority of the user is given by $\mu_k(t)$:

$$\begin{aligned}\mu_k(t) &= f(CQI_k(t), QoS_k(t), QSI_k(t)) \\ &= \frac{\min(R_k(t)), Q_k(t)/T_s}{\overline{R}_k(t)} \cdot \frac{PLR_k}{PLR_{req,k}} \cdot \frac{W_k(t)}{W_{max,k}(t)} \cdot \frac{Q_k(t)}{\overline{Q}(t)}\end{aligned} \tag{3.1}$$

where $R_k(t)$ is the current data rate that the BS can support, $\overline{R}_k(t)$ is the average rate received by user k over a window of appropriate size, $Q_k(t)$ denotes the number of un-transmitted bits in the queue of user k at time t, T_s is the length of time slots, PLR is packet loss rate, $PLR_{req,k}$ is the maximum allowable packet loss rate, $W_k(t)$ is the head-of-line (HOL) packet delay in the queue of user k, $W_{max,k}(t)$ is the maximum allowable delay and $\overline{Q}(t)$ is average un-transmitted bits. Based on this priority factor of the user we can allocate the resources for each user.

The number of subcarrier for each user is uniformly distributed and the subcarrier allocation for the user is done by considering priority factor of the user and by using "product-criterion" is shown in below [9]:

$$k_n^{(p)} = \arg\max_k \prod_{i=1}^{M_{kn}} \lambda_{kn}^{(i)} \tag{3.2}$$

where subcarrier n is allocated to user k when the product of users k's eigenvalues of subchannels in subcarrier n is greater than that of other subcarriers. For highest prior user the best set of subcarrier (based on product criterion) for that user is allocated. Similarly rest of subcarrier is allocated for other user with decreasing priority factor and so on.

Power and bit allocation among users and subcarriers is done by water-filling algorithm [9]. After the allocation of subcarrier bit and power for each user this process repeats for every scheduling period.

4. Simulation Results

In order to simulate and evaluate the performance of the proposed radio resource algorithm in multi-cell and multiuser (MU) MIMO-OFDMA system is considered. The major parameters that are considered during the simulation are as shown in Table 1.

The users in the cell are uniformly distributed and distance of the user from the BS is randomly distributed and Okumura-Hatta model of different terrain is considered for path loss calculation and channel matrix is based on Gaussian random variable. The system simulation platform is developed by BATLAB, compile and run successfully in the developed environment.

For the calculation of priority measure the number of un-transmitted bits, packet loss rate, queuing length, packet delay, data rate that the BS can support and average transmitted data rate of that user and this is calculated by using equations (3.1). Packet inter-arrival time on the queue and waiting time of the packet in a queue is considered as exponentially distributed. The subcarrier allocation is based on the priority of the user and channel response of the user which is described by eigenvalue “product criterion”. The power and bits are jointly allocated by “water-filling algorithm” for required BER.

Parameters	Value
Number of transmit antenna (N)	4
Number of receive antenna (M)	2
System Band width	5MHz
Sub-channel Band Width	15KHz
Scheduling period	1ms
Target BER for water-filling algorithm	10^{-6}
BS height	30m
Total transmit power	20W
Noise density	3.9811e-21

Table 1: Simulation parameters

Figure 3 shows the average served traffic in the system when priority of the user is considered and power is uniformly distributed. To improve the capacity of the system with maintaining required QoS, we have designed an algorithm with considering priority of the user and eigenvalue product criterion for subcarrier allocation and water-filling algorithm for adaptive bit and power allocation then capacity of the system is increased by 22.33% as shown in Figure 3 and Figure 4. By using priority of the user in subcarrier allocation process this purposed algorithms also increase the QoS of the system by decreasing packet loss in the system by 39as shown in Figure 5 and Figure 6.

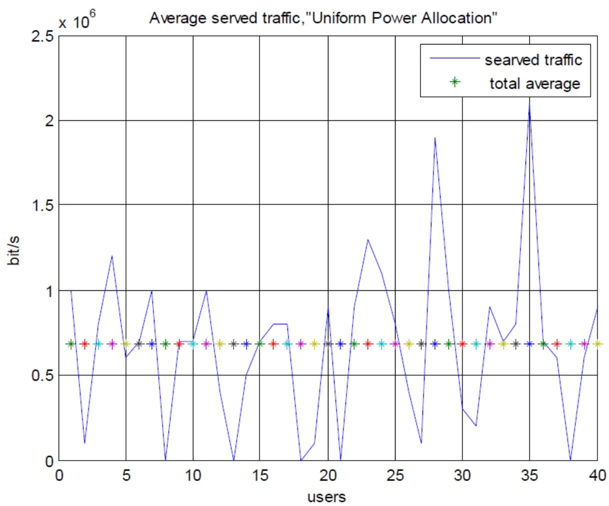

Figure 3: Average served traffic of the user when power is uniformly distributed

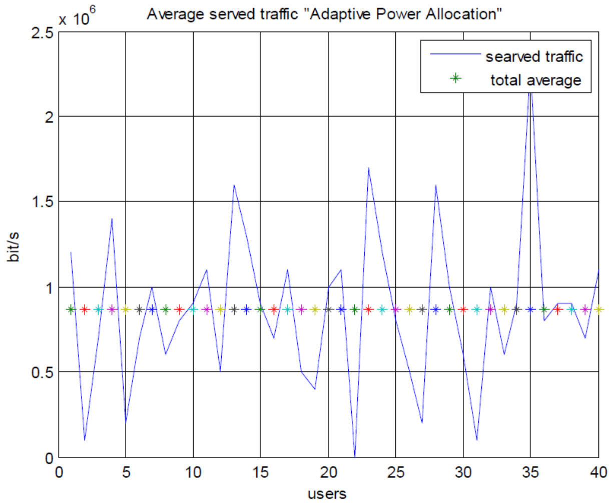

Figure 4: Average served traffic when power is adaptively controlled

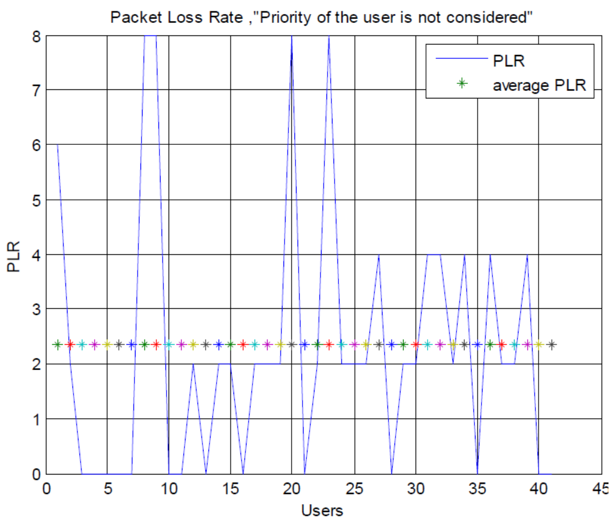

Figure 5: Packet loss rate when priority of user is not considered during subcarrier allocation mechanism

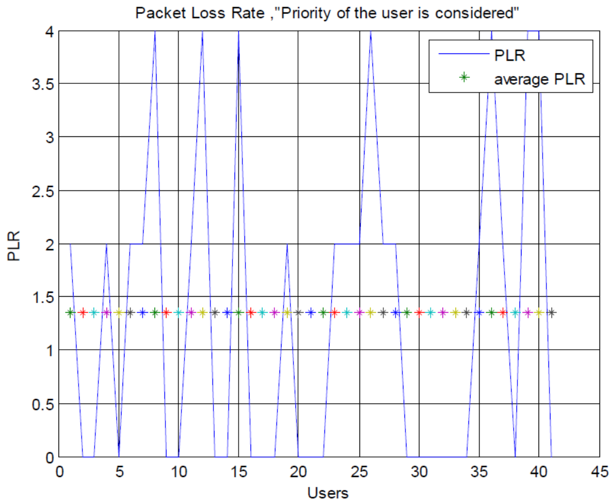

Figure 6: Packet loss rate when priority of user is considered during subcarrier allocation mechanism

5. Conclusion

We have proposed a QoS aware dynamic resource allocation scheme for downlink multiuser MIMO-OFDMA system to improve the QoS and data rate with considering queuing state information of the user in the queue, channel state information, channel quality information, required BER, required transmission rate, required QoS for each user and available maximum power. Simulation result shows that purposed scheme achieves better QoS and data rate than other purposed radio resource management algorithm.

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