Opportunistic Feedback Assisted Scheduling and Resource Allocation in OFDMA Systems

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Abstract— **This paper proposes an efficient channel information feedback method to minimize feedback overhead without performance loss for orthogonal frequency division multiple access (OFDMA) frequency division duplexing (FDD) systems in time-varying channel. The proposed best M users' best L subbands feedback method can significantly reduce the feedback overhead. The proposed scheme utilizes the property of the proposed fair (PF) scheduler that most of the subbands are assigned to the users with high average SNR by time selectivity of channel and some high SNR subbands are assigned to the users by frequency selectivity. For adaptive implementation, the threshold assisted feedback method is proposed. In the numerical results, it is showed that the feedback overhead of the proposed scheme is about 12% of the full CSI feedback method with little throughput loss when the number of users is 50.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) divides an entire channel into many orthogonal subcarriers to deal with frequency selective fading and support high data rate. Allocating different subcarriers to different users can achieve multiuser diversity gain (in the frequency domain) [1]-[2]. Even if these schemes can achieve throughput improvement, these need the perfect channel knowledge, which requires the uplink channel state information(CSI) feedback overhead and decreases the data throughput of uplink. To reduce the feedback overhead for CSI, the successive subcarriers within coherence bandwidth are clustered as a subband and it is used as a resource allocation unit [5]. For adaptive modulation and coding, feedback CSI contains channel quality indicator (CQI).

In [4],[5], the opportunistic feedback methods were proposed to reduce feedback overhead. In the [4], active users send a feedback message with some probability if their channel gains are above a threshold and the threshold and the random access probability is statistically determined. In [5], each user feeds back the indices and CSI of the highest L subbands in OFDMA systems. Since the subbands with higher channel gain can be assigned to the user, it makes little performance loss. However, it does not consider fairness or other QoS(Quality of Service) parameters.

In this paper, we propose the feedback method considering scheduling metric in time-frequency selective channel. In OFDMA system, multiple subbands are assigned to a user at a frame. In the PF scheduler for OFDMA systems, due to the time selectivity of wireless channel, more subbands are assigned to high average SNR users. When the number of users is increased, most of subbands are assigned to some users with high average SNR. Using this property, if a set of users with high average SNR sends the CSI of subbands, feedback overhead can be reduced. When the selected users send a set of subbands with high SNR, the feedback overhead can be more reduced. We propose two opportunistic feedback methods. In the first method, BS selects a set of feedback users using average SNR and requests the CSI of subbands of selected users. In the second method, BS sends the threshold and the average rate of each user and each user send the CSI of the subbands which is above the given threshold. The threshold is adaptively determined in BS to minimize performance loss caused by partial feedback.

The organization is as follows. In section II, the system model of a OFDMA system is introduced. In section III and IV, the pre-scheduling method and the threshold assisted method are proposed. In section V, the computer simulation results compare the full CSI feedback and proposed opportunistic feedback in the respect to total throughput and feedback overhead. Finally, the conclusion and further work is described in section VI.

II. SYSTEM MODEL

A downlink OFDM system with K mobile users served by a base station(BS) is considered as shown Fig. 1. Total frequency band is divided as N subbands which are narrow enough to undergo flat fading. The channel process of each user is independent and stationary. The channel gain is not varied in a frame duration T_s, but varied in frame-by-frame. Each user terminal measures signal to noise ratio (SNR) and feedback it to BS. It is assumed that the transmit power is allocated to each subband identically

Denotes $\gamma_{k,n}(t)$ be the instantaneous SNR of the nth subcarrier of user k at the tth frame. The maximum number of bits in a symbol to be transmitted of the nth subband of user k, $r_{k,n}(t)$, is

$$r_{k,n}(t) = \frac{W}{N} \log_2 \left(1 + \frac{\gamma_{k,n}(t)}{\Gamma}\right) \tag{1}$$

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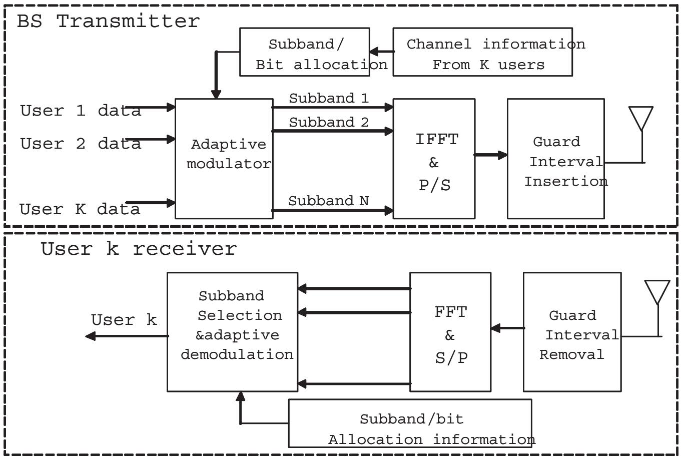

Fig. 1. System model of downlink multiuser OFDM system

where $\Gamma = -\ln(BER)/1.5$[1], BER represents the target BER and W is the total bandwidth.

In the proportional fair(PF) scheduler for time-slotted OFDMA system, the following user at the nth subband and the tth frame is selected[2].

$$k^*(n,t) = \arg\max_{k} \frac{r_{k,n}(t)}{\bar{R}_k(t-1)} \quad \forall \;\; n \tag{2}$$

where $\bar{R}_k(t-1)$ is the average rate of user k at the previous frame and it is updated as

$$\bar{R}_k(t) = \left(1 - \frac{1}{T_c}\right)\bar{R}_k(t-1) + \frac{1}{T_c}\sum_{n\in \boldsymbol{S_k}(t)} r_{k,n}(t) \tag{3}$$

where T_c is the average window size and $\boldsymbol{S_k}(t)$ is the set of subbands which are assigned to user k at the tth frame.

III. PRE-SCHEDULING METHOD

A. The Algorithm Description

In time-varying OFDMA channel, the channel gain of each subband is varied with time due to time and frequency selectivity. The average channel gain of each time is also varied. Denotes $r_k(t) = \sum_{n=1}^{N} r_{k,n}(t)/N$. $r_k(t)$ represents the mean of frequency domain channel gain while $\bar{R}_k(t)$ represents the mean of time and frequency domain channel gain. Since the PF scheduler depends on $\bar{R}_k(t)$, not $r_k(t)$, more subbands can be assigned to the higher $r_k(t)/\bar{R}_k(t)$ users. This property is similar to the max C/I scheduler which more resources are assigned to the high average SNR users. When the number of users is large, all subbands can be assigned to the some of users with high $r_k(t)/\bar{R}_k(t)$ and no subbands can be assigned to the other users. This means the only CSI of some users with high SNR users are required. Using this property, we propose the PF scheduling method with partial channel information. Fig. 2 illustrates the procedure of the proposed pre-scheduling method as follows.

Step 1: BS requests average CSI to each user. Each user feeds back the average CSI, $r_k(t)$.

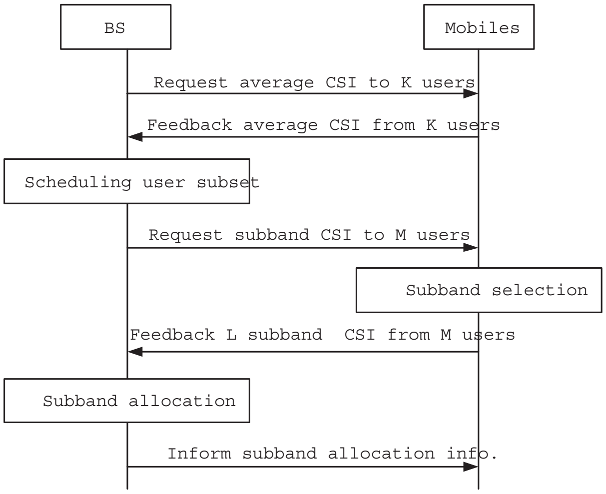

Fig. 2. Procedure of pre-scheduling method

Step 2: BS selects the best M users as follows.

$$\boldsymbol{U}_M(t) = \{k|q_{(1)}(t), q_{(2)}(t), \dots, q_{(M)}(t)\} \tag{4}$$

where $q_k(t) = r_k(t)/\bar{R}_k(t-1)$, $q_{(1)}(t) \geq q_{(2)}(t) \geq \dots q_{(M)}(t) \geq \dots \geq q_{(K)}(t)$.

Step 3: The BS requests subbands CSI to the selected users. The selected users select the best L subbands and feed back the CSI of the selected subbands.

$$\boldsymbol{C_k}(t) = \{n|c_{k,(1)}(t), c_{k,(2)}(t), \dots, c_{k,(L)}(t)\}, k \in \boldsymbol{U}(t) \tag{5}$$

where $c_{k,n}(t) = r_{k,n}(t)/r_k(t)$, $c_{k,(1)}(t) \geq c_{k,(2)}(t) \geq \dots c_{k,(L)}(t) \geq \dots \geq c_{k,(N)}(t)$.

Step 4: The BS scheduler assigns subbands to the selected users by the PF scheduling rule.

$$k^*(n,t) = \arg\max_{k\in \boldsymbol{Z_n}(t)} \frac{r_{k,n}(t)}{\bar{R}_k(t-1)} \quad \forall \;\; n \tag{6}$$

where $\boldsymbol{Z_n(t)} = \{k|\rho_{k,n}(t) = 1\}$ $\forall n$, $\rho_{k,n}(t)$ is the subband indicator for the nth subband of the kth user at the tth frame representing which includes CSI or not. If $\boldsymbol{Z_n(t)} = \phi$, the nth subband is randomly allocated.

B. Problem formulation

Denote the longterm average throughput of the optimal PF scheduler with full CSI be R_f and the longterm average throughput by PF scheduler with best-M user feedback is R_M. In the best-M user feedback method, for small M, the average channel gain of selected users is similar. However, for large M, the difference of the average SNR of the selected users is large. When the difference of average channel gain is large, the users with higher average channel gain can have higher priority like max C/I scheduler. Then as M is increased for large M, the total throughput is not increased and saturated. Fig. 3

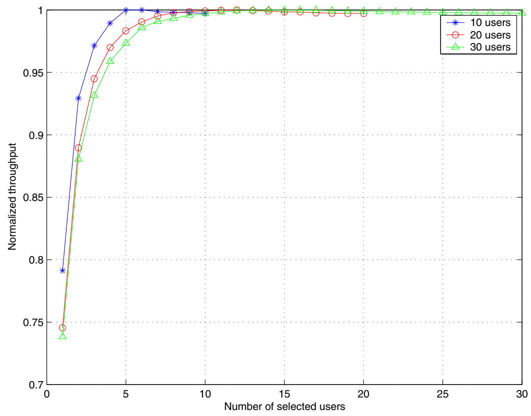

Fig. 3. Number of selected users vs. Normalized throughput

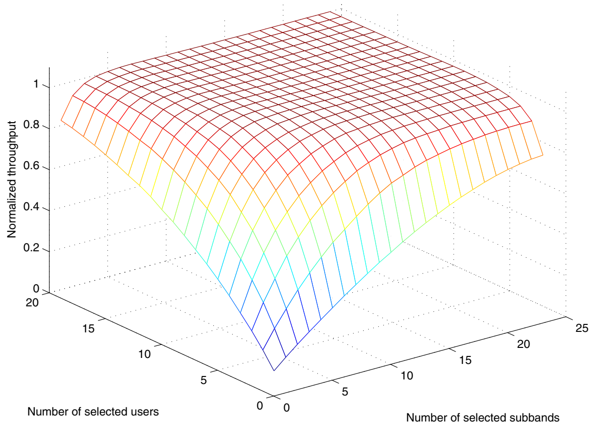

Fig. 4. the number of selected users(M), the number of selected bands(L) vs. Normalized throughput when K=20,N=24

shows that the number of selected users vs. the normalized throughput. As shown Fig. 3, R_M can be represented as

$$R_M = \begin{cases} g(M)R_f, & if\ M < M^* \\ R_f, & if\ M \geq M^* \end{cases} \tag{7}$$

where $g(M)$ is non-decreasing function with $0 \leq g(M) \leq 1$. To more reduce the feedback overhead, the best M-user feedback method can be combined with best L-subband feedback method. In this case, the scheduling outage event [3] can be occurred. The scheduling outage is defined as the event that no users send the channel information at the nth subband, i.e. $\sum_{k \in U_M(t)} \rho_{k,n}(t) = 0$ or $\boldsymbol{Z_n(t)} = \phi$. If the scheduling outage event is occurred, BS scheduler assigns the subband to a randomly selected user. If M is fixed, as L is decreased, the scheduling outage probability is increased. If L is fixed, as M is increased, the scheduling outage probability is decreased. Therefore, the scheduling outage probability can be represented as the function of M,L, i.e. $P_{out}(M,L)$. Then the total throughput is

$$R_p(M,L) = R_M(1 - P_{out}(M,L)) + P_{out}(M,L)R_r \tag{8}$$

where R_r is the throughput of randomly allocated users. Fig. 4 shows the normalized throughput according to the number of selected users M and the number of selected subbands L when the maximum throughput is 1. In this case, the feedback overhead per scheduling interval is

$$F(M,L) = KB + M(LB + N) \tag{9}$$

where B bits are required bits for CQI encoding. Since the throughput and feedback overhead are dependent on M,L, an optimization problem for the trade-off between the throughput and the feedback overhead can be formulated. The optimal M and L is obtained in the sense of minimizing feedback overhead without sacrificing throughput. The objective function to find optimal M and L are

$$\min_{\substack{1 \leq M \leq K \\ 1 \leq L \leq N}} F(M,L) \quad subject\ to \quad R_p(M,L) \geq \lambda R_f \tag{10}$$

where $\lambda (0 \leq \lambda \leq 1)$ a nonnegative number representing a design parameter to consider uplink traffic condition. The optimal M^*, L^* can be obtained by the exhaustive search method.

IV. THRESHOLD ASSISTED METHOD

A. The Algorithm Description

In the pre-scheduling method, it is difficult to implement adaptively and the redundant feedback overhead for average CSI is required. In the threshold assisted method, it is easy to achieve adaptive implementation by adapting threshold. In [3], threshold based opportunistic feedback method is suggested. However, the threshold of [3] is a statistical value, the threshold of the proposed scheme is a variable value to minimize the scheduling outage events while tracking the instantaneous resource allocation condition of all users. Fig. 5 illustrates the procedure of the threshold assisted method for partial CSI feedback as follows.

Step 1: BS calculates the threshold $\beta(t)$ and updates the average rate of each user, $\bar{R}_k(t)$, and informs them to each user.

Step 2: Each user selects the subbands using threshold and the average rate of the kth user as follows.

$$\boldsymbol{C_k}(t) = \left\{ n \middle| \frac{r_{k,n}(t)}{\bar{R}_k(t)} \geq \beta(t) \right\} \quad \forall\ k \tag{11}$$

In the threshold assisted method, the number of selected subbands of each user is different and varied with time according to the determined threshold. The number of selected users is also varied with time. Let $|\boldsymbol{U}(t)| = M(t)$, $|\boldsymbol{C_k}(t)| = L_k(t)$, $\boldsymbol{U}(t) = \{k | \boldsymbol{C_k}(t) \neq \phi\}$, and , where $|\boldsymbol{X}|$ is the cardinality of $\boldsymbol{X}$.

Step 3: The selected users select the best $L_k(t)$ subbands and feed back the CSIs of the selected subbands to BS.

Step 4: The BS scheduler assigns subbands to the selected users by the PF scheduling rule (7).

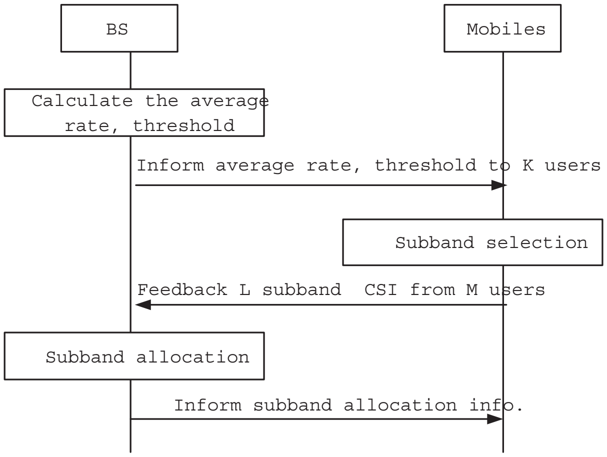

Fig. 5. Procedure of Threshold Assisted Method

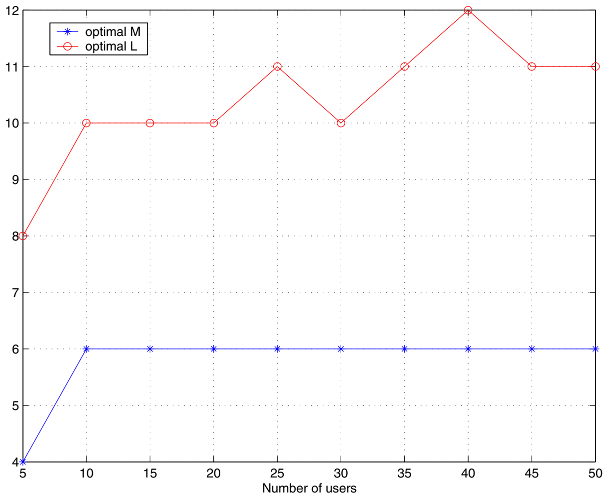

Fig. 6. Optimal M and Optimal L

B. Problem formulation

In the nth subband, the set of the users with CSI, $\boldsymbol{Z_n}(t)$, is represented as

$$\boldsymbol{Z_n}(t) = \left\{k | \frac{r_{k,n}(t)}{\bar{R}_k(t)} \geq \beta(t)\right\} \quad \forall\ n \tag{12}$$

We define the performance metric of PF scheduling with partial CSI , $Y_p(t)$, and the performance metric of PF scheduling with full CSI, $Y_f(t)$,

$$Y_p(t) = \sum_{n=1}^{N} \max_{k \in \boldsymbol{Z_n}(t)} \frac{r_{k,n}(t)}{\bar{R}_k(t)}, Y_f(t) = \sum_{n=1}^{N} \max_{k \in \boldsymbol{Z}} \frac{r_{k,n}(t)}{\bar{R}_k(t)} \tag{13}$$

where $\boldsymbol{Z} = \{1, ..., K\}$. Since

$$Y_p(t) = Y_f(t) - \sum_{n \in D} \max_{k \in \boldsymbol{Z_n}(t)} \frac{r_{k,n}(t)}{\bar{R}_k(t)} \tag{14}$$

Denotes the set of scheduling outage event $\boldsymbol{D}(t) = \{n | \boldsymbol{Z_n}(t) = \phi\}$. If $\boldsymbol{D}(t) = \phi$, $Y_p(t) = Y_f(t)$. In (14), as $\beta(t)$ is increased, the probability that $\boldsymbol{Z_n}(t) = \phi$ is increased. i.e. $Y_p(t)$ is decreased as $\beta(t)$ is increased. Then $Y_p(t)$ is a function of $\beta(t)$, i.e. $Y_p(\beta(t))$. The feedback overhead is

$$F(t) = \sum_{k \in \boldsymbol{U}(t)} (L_k(t) B + N) \tag{15}$$

Since $L_k(t)$ and $M(t)$ is decreased as $\beta(t)$ is increased, we present $F(t)$ can be represented as $F(\beta(t))$. The optimization problem (8) can be represented as

$$\min_{\beta(t)} F(\beta(t)) \quad \mathit{subject\ to} \quad Y_p(\beta(t)) = \lambda Y_f(t) \tag{16}$$

$\beta(t)$ should be calculated using the partial CSI of the previous frame. If $\lambda = 1$, we can obtain the optimal $\beta(t)$ from (13). In order that $\boldsymbol{Z_n}(t) \neq \phi$

$$\beta(t) \leq \max_{k \in \boldsymbol{Z_n}(t-1)} \frac{r_{k,n}(t-1)}{\bar{R}_k(t-1)} \tag{17}$$

For all n, to satisfy this condition,

$$\beta(t) \leq \min_{n} \max_{k \in \boldsymbol{Z_n}(t-1)} \frac{r_{k,n}(t-1)}{\bar{R}_k(t-1)} \tag{18}$$

then $\boldsymbol{D}(t) = \phi$. When the prediction error can be occurred i.e. $\boldsymbol{D}(t-1) \neq \phi$, $\beta(t-1)$ should be decreased by Δ to decrease the probability that $\boldsymbol{D}(t) \neq \phi$, where Δ is the step size. The step size Δ can be determined by using the moving average of $\beta(t) - \beta(t-1)$. In summary,

$$\beta(t) = \begin{cases} \beta(t-1) - \Delta, & \mathit{if}\ \boldsymbol{D}(t-1) \neq \phi \\ \min_n \max_{k \in \boldsymbol{Z_n}(t-1)} \frac{r_{k,n}(t-1)}{\bar{R}_k(t-1)}, & \mathit{otherwise} \end{cases} \tag{19}$$

Similarly, if $0 \leq \lambda < 1$, $\beta(t)$ can be more increased and feedback overhead is more reduced than the case $\lambda = 1$. Let $|\boldsymbol{D}(t)| = J(t)$, optimal $\beta(t)$ in (19) can be calculated as

$$\beta(t) = \begin{cases} \beta(t-1) - \Delta, & \mathit{if}\ \frac{J(t-1)}{N} < \lambda \\ \min_{n \in \boldsymbol{D^c}(t-1)} \max_{k \in \boldsymbol{Z_n}(t-1)} \frac{r_{k,n}(t-1)}{\bar{R}_k(t-1)}, & \mathit{otherwise} \end{cases} \tag{20}$$

where $\boldsymbol{D^c}(t)$ is the complement set of $\boldsymbol{D}(t)$, that is the set of non-outage subbands.

V. NUMERICAL RESULTS

The channel model is ITU-R pedestrian B model with 6-tap exponential power delay profile and it is combined with Jake's model with Doppler frequency 5.6Hz(3km/h). In a OFDM system, there are 1024 subcarriers in a 10MHz bandwidth and 720 subcarriers are used as data subcarrier. The successive 30 subcarriers are grouped as a subband (24 subbands in a bandwidth). We assume all users have the same target BER 10^{-4} and the channel information is encoded as 5 bits channel quality indicator (CQI). The scheduling interval is 2 ms and the channel is assumed invariant within a scheduling interval. It is assumed that the transmit power is idendically distributed to each subcarrier and continuous adaptive modulation and coding is possible based on SNR.

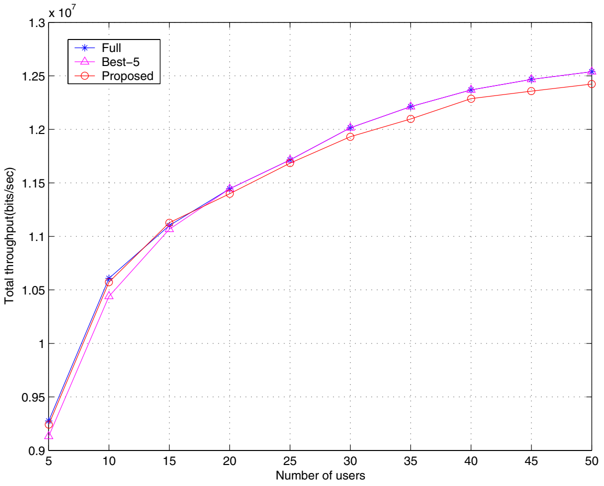

Fig. 7. Total average throughput comparison

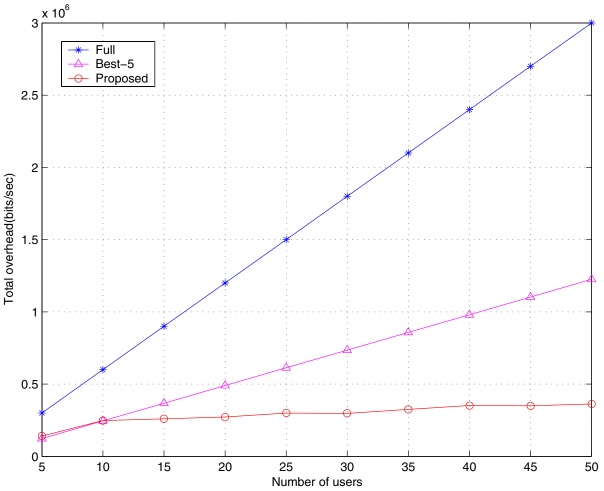

Fig. 8. Total feedback overhead comparison

Simulation is achieved over 2000 scheduling interval. The proportional fair (PF) scheduler with full buffer model is used. The performance of the proposed scheme is compared with Full CQI method and best-5 feedback method [5]. The proposed scheme is the pre-scheduling method when $\lambda = 0.99$ and the pre-scheduling method is used. Fig. 6 shows the optimal value of M and L according to the number of users and it shows that the optimal M and L is hardly increased. Fig 7,8 show the total average throughput and feedback overhead of the proposed scheme, best-5 feedback method and full CQI feedback method, respectively. While the proposed scheme has the almost same throughput with the best-5 feedback method or the full CQI method, the feedback overhead of the proposed scheme is much lower than that of the full CQI feedback method and it is lower than that of the best-5 feedback method. The feedback overhead of the proposed scheme is 12% of the full CQI method at 50 users. While the feedback overhead of the full feedback and best-5 feedback is increased by the number of users, that of the proposed scheme is independent of the number of users.

VI. CONCLUSIONS

This paper deals with proportional fair scheduling in OFDM systems with partial feedback. We propose the pre-scheduling method and threshold assisted method. The proposed scheme achieves the throughput close to the throughput of the full CSI feedback method. The feedback overhead can be considerably reduced and the reduction ratio is increased as the number of users is increased. For realtime service, the proposed scheme can be applied to the modified largest weighted delay first(M-LWDF) scheduler or Exponential scheduler[6] and the proposed scheme can be extended to the MIMO systems.

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REFERENCES

[1] J.Jang and K.B. Lee, ”Transmit power adaptation for mutliuser OFDM systems,”*IEEE J. Select. Areas Commun.* vol. 21, pp. 171-178, Feb. 2003.

[2] H. Kim and Y. Han, ”A proportional fair scheduling for multicarrier transmission systems,” *IEEE Commun. Letters* vol. 9, pp. 210-212, Mar. 2005

[3] D.Gesbert and M. Slim-Alouini, ”How much feedback is multi-user diversity really worth?,” *Proc. Int. Conf. on Commun.* pp. 234-248, June 2004

[4] Taiwen Tang and Robert. W. Heath, ”Opportunistic feedback for downlink multiuser diversity,” *IEEE Commun. Letters* vol. 9, pp. 948-950, Oct. 2005

[5] P. Svedman, et al., ”A simplified opportunistic feedback and scheduling scheme for OFDM,” *in Proc. Vehicular Technology Conf.(VTC 2004)*, pp. 1878 1882, 2004

[6] Matthew Andrew, et al.,”Providing quality of service over a shared wireless link,” *IEEE Commun. Magazine*, pp. 150-154, Feb. 2001