Dynamic resource management in the fourth generation wireless systems

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Abstract: **In this text, we consider the problem of fair scheduling in the downlink of Orthogonal Frequency Division (OFDM) systems. Based on the proportional fair scheduling algorithm proposed in the CDMA/HDR, we present three schemes to manage the parallel subcarriers in the OFDM system to utilize the time selectivity and frequency selectivity. Subcarriers in a slot are divided into several nonoverlapped subbands, which are the scheduling objects. The first scheme is that every subband is placed a scheduler and the average rates are updated independently; the second scheme is that transfer the two-dimensional channel resource into one-dimension equivalent channel, and then schedule the resource like in HDR systems; the third one is that users contend every subband in a same slot using one scheduler without updating the average rates, after finished a slot, the average rates are updated together. Compared to the first scheme, the third one has the least complexity and its performance degrades little. It is shown that system throughput is improved by 40%~100%, the appropriate number of subbands is 16~32 and scheme 3 is an appropriate choice for practice systems.**

Keywords: dynamic resource management, OFDM, Proportional fair, fair scheduling

I. INTRODUCTION

Next generation wireless communications systems will seek to support a wide range of services, including high-rate data applications such as web browsing, file downloading. In contrast to the voice users, data applications can usually sustain some amount of packet delay, as long as the throughput over a long interval is sufficient. The relative delay tolerance of data applications, together with the bursty traffic characteristics, opens up the potential for scheduling transmissions to optimize the throughput. It is a critical issue to improve the spectrum efficiency and system throughput in the wireless data transmission systems. Dynamic resource management has been becoming a hot area for it improves the system performance greatly.

In the wireless networks, multiple data users share the same wireless channel in the downlink and uplink. One feature of the channel is the fact that the capacity of channel varies with time randomly and asynchronously for different users. The variations of the channel capacity are due to user mobility and fast fading. A good scheduling algorithm should take advantage of the variations by giving some preference to a user whose channel is currently good. Several scheduling algorithms are proposed by many authors, such as exponential rule[1], opportunistic scheduling algorithm[2]. In the CDMA/HDR (high data rate), a proportional fair scheduling algorithm has been proposed for wireless packet data services at high data rates (up to 2Mbps) for CDMA2000 1x evolution[3]. The forward link channel is divided into 1.67ms slots. The access terminal (AT) predicts the SINR, computes the supported rate, and sends it to the access point (AP). A scheduler at the AP determines next terminal to be served based on the reported data rate request from the AT and the amount of data that has been transmitted to each terminal. The HDR scheduler performance is studied by many authors [3][4][5] and it is shown that every data user shares the almost same amount of slots and the optimal throughput is achieved under some idealizing assumptions.

Another feature of the wireless channel is that the received signal consists of a number of time-varying multipath components that introduce the intersymbol interference (ISI) and frequency selectivity. OFDM is an efficient scheme to mitigate the effect of multipath channel since it eliminates the intersymbol interference (ISI) by inserting a cyclic prefix (CP) longer than the delay spread of the channel [6]. Therefore, OFDM is generally known as an effective technique for high data rate service such as DVB-T, DAB, and HIPERLAN/2, and is a candidate technique for the next generation wireless system.

There are few literatures considering fair scheduling in the OFDM systems. AT&T Labs network assisted Dynamic Packet Assignment (DPA)[7] is a combination of DCA and data packet scheduling based on combining EDGE with Wideband OFDM. Eriksson[8] proposed another dynamic single frequency networks scheme to utilize the macro-diversity in the DVB-T to transmit high-speed data.

In this text, we propose three schemes to allocate the subcarrires in the OFDM systems based on the proportional fair scheduling algorithm to utilize the time selectivity and frequency selectivity. The subcarriers are divided into groups, i.e. subbands, and every subband is composed of several successive subcarriers. The first scheme is that every subband is placed a scheduler and the average rates are updated independently; the second scheme is that users contend the subbands one by one using one scheduler and then the average rates are updated immediately; the third one is that users contend every subband using one scheduler without updating the average rates, after a slot is finished, the average rates are updated together.

The remainder of the paper is organized as follows. In section 2, we introduce the basic system model. In section 3, we present three schemes to allocate subbands to the data users based on the proportional fair scheduling algorithm. The performance of the schemes is studied in section 4 by simulation. We conclude this paper in the section 5.

II. SYSTEM MODEL

We consider the problem of fair scheduling in the downlink of an OFDM wireless system in a single cell scenario. Inter-cell interference is not considered or included in the additive Gaussian noise. We assume a slot has 8 OFDM symbols, an OFDM symbol is composed of M subcarriers, the subcarriers are divided into S nonoverlapped groups, i.e. subbands, and every subband contains $Z = M/S$ subcarriers. N users are placed in the cell according to the uniform distribution. The distance of user i to the basestation is d_i. The access terminal (AT) predicts the SINR of the subbands without error, computes the supported rates, and sends them to the access point (AP) immediately. The number of subbands corresponds to the amount of feedback information. We assume the ATs always have data to receive, i.e. the queues are always full at the AP. As HDR downlink adopts no power control, every subcarrier uses the constant maximal power P_t to transmit data to the ATs.

Path loss, large scale shadowing, and small-scale temporal fading and frequency selectivity are included in the SINR computation. Large scale shadowing is modeled by lognormal shadowing with the standard derivation of 5dB. There are L paths and every path is modeled as Rayleigh fading. Path loss index is 3. Channel is not changed in a slot.

III. THE SCHEDULERS

First, we descript the HDR scheduling algorithm in the CDMA2000-1X. At slot t, AP computes the priority metric of AT i using the data rate $D_i(t)$ reported by the AT i as follows

$$D_i(t)/R_i(t-1) \tag{1}$$

where $R_i(t)$ is the average rate of user i in the past time until slot t. The scheduling rule is

$$j = \arg\max_i D_i(t)/R_i(t-1) \tag{2}$$

i.e., the scheduler select user j to receive the next slot service if user i has the maximal priority metric. After scheduled, the average rate is updated (if user j is selected)

$$R_i(t) = (1-\frac{1}{T_c})R_i(t-1) + \begin{cases} 0 & i \neq j \\ \frac{1}{T_c}D_i(t) & i = j \end{cases} \tag{3}$$

where T_c is the average window. If a user doesn't receive service at slot t, its average rate will become smaller, then its precedence will increase at the next slot. In another word, the serviced user will have less chance to access next slot. Therefore, a user will not starve too long time unless its channel is always very bad. The value of T_c determines how much channel information of past time is included in the average rates. Scheduler will take more advantage from the variation of channels for the bigger value of T_c, at the same time, the users of poor channel may starve longer time to receive services, especially when the channel suddenly change from good to bad, and jitter is also increased.

In the OFDM system, unlike in the HDR, users have to contend S parallel subbands simultaneously. User i supports data rate $D_{i,m}(t)$ on the subband m at slot $t, m = 1, \cdots, S$. Let $X_{i,m}(t) = 1$ indicate that the subband m is allocated to user i, otherwise $X_{i,m}(t) = 0$.

3.1 THE FIRST SCHEME

Every subband is placed a scheduler, and schedulers work independently. Thus, the number of schedulers is equal to the number of subbands. For subband m, the priority metric of AT i is

$$D_{i,m}(t)/R_{i,m}(t-1) \tag{4}$$

where $R_{i,m}(t)$ is the average rate of user i at subband m in the past time until slot t, and the scheduling rule at subband m is

$$j = \arg\max_i D_{i,m}(t)/R_{i,m}(t-1) \tag{5}$$

the average rate is updated as

$$R_{i,m}(t) = (1-\frac{1}{T_c})R_{i,m}(t-1) + \frac{1}{T_c}X_{i,m}(t)D_{i,m}(t) \tag{6}$$

If the channels of users are stationary and independent, and if T_c is big enough and the HDR scheduler is optimal, this scheme is also an optimal one, i.e., this scheme can take advantage as much as possible of the temporal variations and frequency selectivity of channels.

3.2 THE SECOND SCHEME

All the subbands are allocated to the contending users by only one scheduler. A subband is selected according to some rule and all the users contend simultaneously the subband. After the subband is allocated, the average rates of all users are updated immediately. Then a second subband is picked out and is allocated among all contending users and the average rates are updated immediately. This procedure is going on until all subbands are used up.

For simplicity, users contend subband 1, subband 2, $\cdots$, subband S one by one. The priority metric of user i at subband m is

$$D_{i,m}(t)/R_i(k-1) \tag{7}$$

and the average rate is updated

$$R_i(k) = (1-\frac{1}{T_c})R_i(k-1) + \frac{1}{T_c}X_{i,m}(t)D_{i,m}(t) \tag{8}$$

where $k = t*S+m-1$.

In short, subbands are rearranged according some rule from two dimensions into one dimension, and then a scheduler is used to allocate the resource to users. This scheme is not optimal, for the equivalent one-dimensional channel is not stationary, but cyclostationary. The period is S. The correlation between subbands in the same slot is different from the correlation between subbands among the different slots in the equivalent channel. Therefore, the scheme does not make full use of temporal and frequent selectivity. If T_c is big enough, the equivalent channel can be treated as being approximately stationary. From another point, if the bandwidth of the multipath channel is smaller than the bandwidth of a subband, then the neighbor subbands has strong correlation.

3.3 THE THIRD SCHEME

The above two schemes update the average rates subband by subband, so their complexity is high. The third scheme updates the average rates only after all subbands are finished and its complexity is lower. Like the second scheme, all subbands are allocated by a scheduler. The priority metric of user i at subband m is

$$D_{i,m}(t)/R_i(t-1) \qquad (9)$$

During the allocation of subbands in a same slot, $R_i(t-1)$ keeps constant. After a slot is finished, the average rate is updated as follows

$$R_i(t)=(1-{K_i}/{Tc})R_i(t-1)+Acc\_u/{Tc}$$

$$Acc\_u=\sum_j D_{i,j}(t)X_{i,j}(t),\ K_i=\sum_{j=1}^{S}X_{i,j}(t)$$

From the analysis in the section 3.2, we know that the equivalent channel is cyclostationary of a period S, but after accumulating the equivalent channel in a period, the result is stationary. This scheme is expected to behavior better than the second scheme. Compared with the first scheme, this scheme is not optimal for some information is lost in the rate updation.

IV. SIMULATION RESULTS

In the simulation, M-1225 outdoor channel model shown in table 1 is used. The shadow fading is modeled by lognormal shadowing with the standard derivation of 5dB, the cell radius is 3000m, the reference distance in the pathloss is 500m, and the pathloss index is 3. Subcarrier number $M=1024$, the channel changed slot by slot, the normalized doppler frequecny $f_dT_s=0.1$,where f_d is the maximal doppler rate and T_s is the duration of a slot.The transmission rate is classified into 7 classes listed in table 2. That is,when SINR is in $[-\infty,-2.9)$, no data is transmitted ;when SINR is in $[-2.9,-0.2)$, BPSK and 1/4 turbo code are used .

Fig.1 shows the average throughput of a slot as a function of the nubmer of users when Tc=1000, S=32. We note that the througput of scheme 3 is only little less than the throughput of scheme 1,and they are both better than scheme 1.The throghput of three scheme increases with the number of user number.This is the consequence of multiuser diversity exploited by the schedulers.Compared with no scheduling (normal Time division multipexing), scheme 1 and 3 are able to transmit more data by 40%~100% in a slot, and scheme 2 acquires the additional gain of 40%~80%, especially after the number of user reaches 8.

TABLE 1 M-1225 OUTDOOR CHANNEL MODEL

Tap	**Channel B**		**Doppler spectrum**
	Relative delay (ns)	*Average power (dB)*	
1	0	−2.5	Classic
2	300	0	Classic
3	8.900	−12.8	Classic
4	12 900	−10.0	Classic
5	17 100	−25.2	Classic
6	20 000	−16.0	Classic

TABLE 2 TRANSMISSSION DATA RATE SCHEME

class id	**modulation format**	**code rate**	**bits/symbol**	**SINR (dB)**
1	BPSK	1/4	1/4	-2.9
2	BPSK	1/2	1/2	-0.2
3	QPSK	1/2	1	2.2
4	8PSK	1/2	3/2	5.2
5	8PSK	2/3	2	8.4
6	64QAM	1/2	3	11.8
7	64QAM	2/3	4	15.1

Fig.2 shows the average throughput as a function of T_c when the user number is 16 and $S=32$. The schedulers of scheme 1 and 3 take more advantage from the variations of the channels for a bigger window size ,while the additonal gain of scheme 2 is almost saturated when T_c is no less than 1000. Althoug for the throughput,bigger T_c is better, bigger T_c also incurs a bigger jitter in the data transmission. In Fig.3, the jitter of 16 users increases with T_c, because the users maybe wait a longer time to receive service for bigger T_c when their channels become bad. The jitter and delay bound is a important factor during the choice of T_c.

Fig.4 shows the average throughput of three schemes as a function of the number of subbands. The throughput of scheme 1 and 3 becomes better with the number of subbands, while the throughput of scheme 2 decreases after it reachs a peak. The reason is that when the number of subband is bigger than 16, the bandwidth of a subband is less than the correlative bandwidth of channel, and the neighbour subbands would not share the same priority to be selected for the punishment in the average rate updation of scheme 3. To tradeoff between the throughput and the amount of feedback information, 16 or 32 subbands is a good choice.

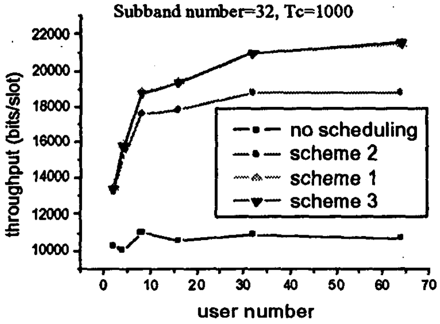

Fig. 1 Average throughput as a function of the number of users

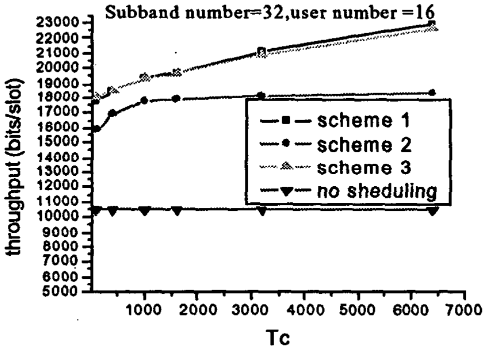

Fig.2 Average throughput as a function of Tc

V. CONCLUSION

We propose three schemes to fair schedule the subbands of an OFDM system to users. It is shown that scheme 3 performs as well as scheme 2, and its complexity is lowest in three schemes. After scheduling, the average throughput can improve by 40%~100%. The appropriate number of subbands is 16 or 32, and scheme 3 is an appropriate choice for practice systems.

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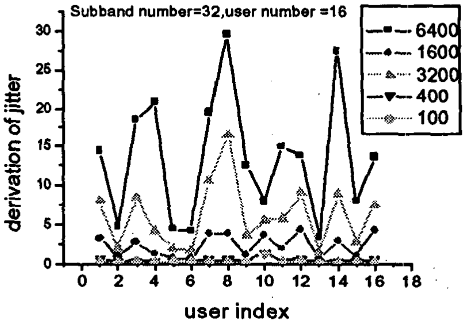

Fig.3 data packet jitter as a function of Tc

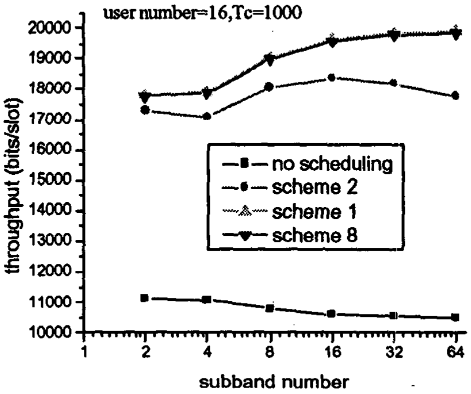

Fig. 4 Average throughput as a function of the number of subbands