QoS-Constrained Opportunistic Scheduling for SC-FDMA with Iterative Multiuser Detection

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Abstract—This letter proposes a quality-of-service (QoS) constrained opportunistic scheduling for a single-carrier frequency division multiple access (SC-FDMA) scheme. The SC-FDMA scheme considered in this letter employs an iterative multiuser detection using frequency-domain equalization (IMD-FDE), which allows several users to share a common set of subcarriers. In order to improve spectral efficiency and guarantee QoS of assigned users, the proposed method chooses users by iteratively performing user selection. At each user selection for a set of subcarriers, the scheduler takes into account multiuser interference from previously assigned users of corresponding subcarriers and QoS constraint. Simulation results show that the proposed method provides higher spectral efficiency compared with round-robin and max-SNR.

Index Terms—Iterative multiuser detection, opportunistic scheduling, QoS, SC-FDMA.

I. INTRODUCTION

For next-generation wireless communications, such as 3rd Generation Partnership Project Long Term Evolution (3GPP-LTE), achieving high spectral efficiency is one of the most important issues. 3GPP-LTE has considered single-carrier frequency division multiple access (SC-FDMA) as a multiple access scheme for uplink [1]. SC-FDMA has similar structure and performance as orthogonal frequency division multiple access (OFDMA), while alleviating nonlinear distortion inherent to OFDMA [2], [3]. However, it is shown that only non-orthogonal multiple access schemes can approach the optimal point in capacity region of multiple access channel [4]. As a non-orthogonal scheme, code-division multiple access (CDMA) utilizes multiuser detection (MUD) techniques to reduce multiple access interference (MAI) [5]. Even though they effectively remove MAI, conventional MUD techniques for CDMA have high computational complexity. In [6] and [7], iterative multiuser detection using frequency-domain equalization (IMD-FDE) was proposed. IMD-FDE provides high error performance with considerably low complexity even in frequency-selective fading channels. Moreover, IMD-FDE can be easily incorporated into a SC-FDMA framework, since it is based on single-carrier FDE (SC-FDE). In the framework of SC-FDMA with IMD-FDE, high spectral efficiency can be achieved by assigning more than one user to a common set of subcarriers named by chunk.

In multipath fading environment, all users have different channel conditions due to the frequency-selectivity. Opportunistic scheduling can improve spectral efficiency of SC-FDMA with IMD-FDE by allocating each chunk to users with favorable channel conditions to achieve multiuser diversity. For scheduling of SC-FDMA, a channel dependent scheduling was proposed in [8]. In [9], proportional fairness and inter-cell interference were considered for scheduling algorithm. Due to the non-orthogonal nature of SC-FDMA with IMD-FDE, severe MAI which causes QoS violations can be generated from assigned users in a chunk. Thus, we should consider not only achieving gain of multiuser diversity but also guaranteeing QoS of users sharing a common chunk. To this end, we propose a QoS-constrained opportunistic scheduling method for SC-FDMA with IMD-FDE. The proposed method assigns users to a chunk by iteratively performing user selection for each chunk. When a user is selected for a chunk, the scheduler takes into account MAI from both of this user and previously assigned users of that chunk. Simulation results show that the proposed method achieves higher spectral efficiency than round-robin and max-SNR.

II. SC-FDMA WITH IMD-FDE

System bandwidth of SC-FDMA is divided into M chunks as shown in Fig. 1(a) and each chunk consists of consecutive K subcarriers. Figure 1(b) shows that more than one user can occupy a common chunk in frame structures of SC-FDMA with IMD-FDE. Users who share a common chunk employ distinct interleaver patterns to separate each user’s signal at the receiver [6]. The receiver of SC-FDMA with IMD-FDE performs multiuser detection and channel equalization in the frequency domain for every chunk $m = 0, \ldots, M - 1$.

After multiuser interference cancellation, the received signal vector $Z_{u,m} = [Z_{u,m}(0) \cdots Z_{u,m}(K-1)]^T$ of $u$th user in chunk $m$ can be expressed in the frequency domain as

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is not considered and IMD-FDE, simulations are performed for various chunk sizes from 128 subcarriers. A 1/2-rate convolutional code (CC) with constraint length of 3 is used and the length of information bits is 512. A cyclic prefix (CP) length is set to the maximum channel delay and perfect channel estimation is assumed at the receiver. SC-FDMA utilizes an iterative decoding scheme for fair comparisons and the number of iterations for all cases is 7. Figure 2 shows that the frame error rate (FER) performance of SC-FDMA with IMD-FDE using QPSK for $U_m = 2 (R = 2)$ approaches the FER performance of SC-FDMA using QPSK ($R = 1$). SC-FDMA using QPSK is identical to the SC-FDMA with IMD-FDE using QPSK for $U_m = 1$. With the same overall rate of $R = 2$, the FER performance of SC-FDMA with IMD-FDE using QPSK for $U_m = 2$ is about 3.4 dB better than that of the SC-FDMA using 16QAM at the FER of $10^{-2}$. It means that SC-FDMA with IMD-FDE achieves higher spectral-power efficiency than conventional SC-FDMA. Moreover, by applying opportunistic scheduling to SC-FDMA with IMD-FDE, we can further increase spectral efficiency.

III. OPPORTUNISTIC SCHEDULING

A. Problem Formulation

Problem of maximizing spectral efficiency $\eta$ subject to QoS constraint for every selected user is expressed as

$$\max_{S_u} \eta_S > \eta_S^{th}, \forall u \in S_{sel},$$

where $S_{sel}$ is a set of selected users. In the SC-FDMA with IMD-FDE framework, spectral efficiency $\eta$ can be approximated as follows:

$$\eta \approx \frac{1}{M} \sum_{m=0}^{M-1} \sum_{u=1}^{U_m} R_{u,m} \text{(bit/subcarrier)},$$

where $R_{u,m}$ is a single-user data rate (bit/symbol) at chunk $m$. For simplicity, we assume that all users have the same $R_{u,m}$. From (5), the equivalent problem of (4) can be written as

$$\max_{\bigcup_{m=0}^{M-1} U_m} \text{subject to } \eta_S > \eta_S^{th}, \forall u \in S_{sel}.$$  

In this letter, we consider the bit error rate (BER) performance as the QoS constraint.

B. QoS-constrained Scheduling Method

In order to solve the problem of (6), the QoS-constrained scheduling method assigns users to a chunk by iteratively performing user selection for each chunk. The scheduler chooses only one user with the highest sum of expected SINRs from users satisfying QoS constraint at each selection.

The proposed method performs the following procedures for each chunk $m = 0, \ldots, M - 1$.

**Initialization:** $S_{sel,m} = \emptyset$ and $S_{cand,m} = \{1, \ldots, U_T\}$. $S_{sel,m}$ and $S_{cand,m}$ are a subset of $S_{sel}$ and a candidate user set for chunk $m$, respectively. $U_T$ is the number of total users.

**Step 1**: At the selection of $u$th user of $S_{sel,m}$, compute expected SINRs of a candidate user and previously selected users.

$$\Gamma_{u,m}^0 = \frac{\mu_{u,m}^2}{\mu_{u,m}^2 - \nu_{u,m}^2}, \forall u \in S_{cand,m},$$

where $\tilde{S}_{u}^{a} = S_{sel,m} \cup \{u\}$ for $\forall u \in S_{cand,m}$.
Step 2: Compose a set $S_{QoS,m}^g$ with candidate users satisfying QoS constraint and choose a user $u^*_g$ with the highest sum of expected SINRs as the $g$th user of $S_{sel,m}$ from $S_{QoS,m}^g$.

$$S_{QoS,m}^g = \{ u | BER_{u \in S_{sel,m}^g} < BER_{th}, u \in S_{cand,m} \}.$$  

$$u^*_g = \arg \max_{u \in S_{QoS,m}^g, u \in S_{sel,m}} \{ \sum_{u' \in m} \Gamma_{u',m}^g \}.$$  

Step 3: Delete $u^*_g$ from $S_{cand,m}$. Repeat steps 1~3 for $(g+1)$th selection until $S_{QoS,m}^{g+1}$ becomes an empty set for chunk $m$.

Since the scheduler cannot decode actual data, we should get SINRs and BER performance by using SNR evolution [10] for every selection. BER performance and $\nu_{u,m}$ of $u$th user at chunk $m$ are functions of SINR.

$$BER_{u,m} = q(\Gamma_{u,m}), \quad \nu_{u,m} = f(\Gamma_{u,m}).$$  

Therefore, a new SINR can be obtained by using the following recursion:

$$\Gamma_{u,m,new} = \frac{\mu_{u,m}^2}{\mu_{u,m} - f(\Gamma_{u,m,old}) \mu_{u,m}^2}, \forall u, \forall m.$$  

After a number of iterations, SINR converges and we can estimate the BER performance of each user by using (10).

IV. SIMULATION RESULTS

We compare spectral efficiencies of the proposed scheduling method with those of round-robin and max-SNR over multipath fading channels. Round-robin is a per-flow scheduling algorithm and all users have the same service chances. Max-SNR chooses users with respect to the order of the highest SNR $\Gamma_{u,m} = \frac{1}{M} \sum_{m=0}^{M-1} (\Delta_{u,m}(k))^2 / \sigma^2_k$ without considering MAI for $u=1, \ldots, U_T$, $m=0, \ldots, M - 1$. The channel model is the six-tap TU channel ($L = 25$) and $f_dNT_s = 0.001$. We assume equal power transmissions for all users with SNR = 7 dB and perfect channel estimation at the receiver. Transmission bandwidth is 5 MHz and is divided into 16 chunks with $K = 32$ subcarriers. A 1/2-rate CC with constraint length of 3 is used and the length of information bits is 8192. The CP length is set to the maximum channel delay. The target BER as a QoS constraint is $10^{-3}$ and the number of iterations for SNR evolution is 10.

As shown in Fig. 3, the proposed method provides the highest spectral efficiencies among the three methods for both single-input single-output (SISO) and single-input multiple-output (SIMO) systems. For SISO systems, the performance of proposed method is almost 50% higher than that of max-SNR, while round-robin has about 50% lower spectral efficiency than that of max-SNR, when the number of users is large. As such, it is observed that SC-FDMA with IMD-FDE achieves additional spectral efficiency by opportunistic scheduling, especially using the proposed method. For SIMO systems with two receiver antennas, the gains of proposed method over max-SNR and round-robin are not as large as the cases of SISO systems because the effect of channel-selectivity is decreased. Nevertheless, the performance of proposed method is steadily increased, while the other cases become saturated as the number of users is increased. In this letter, we assume fixed modulation and coding schemes. If an adaptive modulation and coding scheme is applied to SC-FDMA with IMD-FDE, spectral efficiency can be more improved, and is a subject for future research.

V. CONCLUSIONS

This letter presented a QoS-constrained opportunistic scheduling for SC-FDMA combined with IMD-FDE. The SC-FDMA with IMD-FDE achieves high spectral-power efficiency by allowing several users to occupy a common chunk. To further increase spectral efficiency with guaranteeing QoS, the proposed method chose users with the highest sum of expected SINRs by iteratively performing user selection for each chunk. When selecting a user for a chunk, the scheduler took into account MAI from both of this user and previously assigned users of that chunk. Simulation results show that the proposed method provides higher spectral efficiency than round-robin and max-SNR without considering MAI.

REFERENCES