EE381K Multiuser Wireless Communications - Fall 2002

Multiuser OFDM with Adaptive Frequency Hopping and Bit Allocation

Term Project Report

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December 9, 2002

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Abstract

This project investigates two new techniques for multiuser orthogonal frequency division multiplexing (OFDM) systems: adaptive frequency hopping and adaptive modulation. The subcarrier blocks are hopped periodically based on the channel conditions. Each user is allocated subcarriers that have the best average SNR ratio for that user. Adaptive bit allocation is implemented using the Levin-Campello rate adaptive solution every time when the subcarriers are reallocated. Simulation results show that with adaptive frequency hopping and bit allocation incorporated, the outage probability increases with the number of users in the system. This indicates the randomness of the hopping scheme with large number of users.

1 Introduction

Orthogonal frequency division multiplexing (OFDM) is one of the most promising solutions to provide broadband transmission over wireless channels. It has been standardized for Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and Wireless Local Area Networks (WLAN). It was selected for these systems primarily because of its high spectral efficiency and multipath tolerance [1].

OFDM allows for a high spectral efficiency as the carrier power, and modulation scheme can be individually controlled for each carrier. Adaptive frequency hopping and adaptive modulation are two important techniques for multiuser OFDM systems. Significant performance improvement can be achieved if adaptive modulation is used with OFDM [2]. The employment of high modulation scheme for subcarriers with large channel gain can increase the spectral efficiency of the overall system [1]. In addition, the subcarriers that appear in deep fading to one user may not be in deep fading for other users. Hence dynamical allocating the subcarriers based on channel conditions can utilize the channel resources more efficiently. Assuming knowledge of the instantaneous channel gains for all users, Wong *et al* [2] proposed a multiuser OFDM subcarrier, bit, and power allocation algorthim to minimize the total transmit power with fixed bit rate for each user. Rhee and Cioffi [3] also proposed a low-complexity adaptive subchannel allocation algorithm to increase the system capacity. Both work proved potential advantages of the adaptive techniques in multiuser OFDM systems.

In this project, we investigate the impact of adaptive frequency hopping and bit allocation technique on the data rates in a multiuser OFDM system. The subcarriers are reassigned to each user based on the channel conditions in a past short period. The Levin-Campello rate adaptive loading algorithm is applied for bit allocation. Simulation results are provided indicating that the randomness of hopping scheme dominates as more users are in the system.

2 System Model

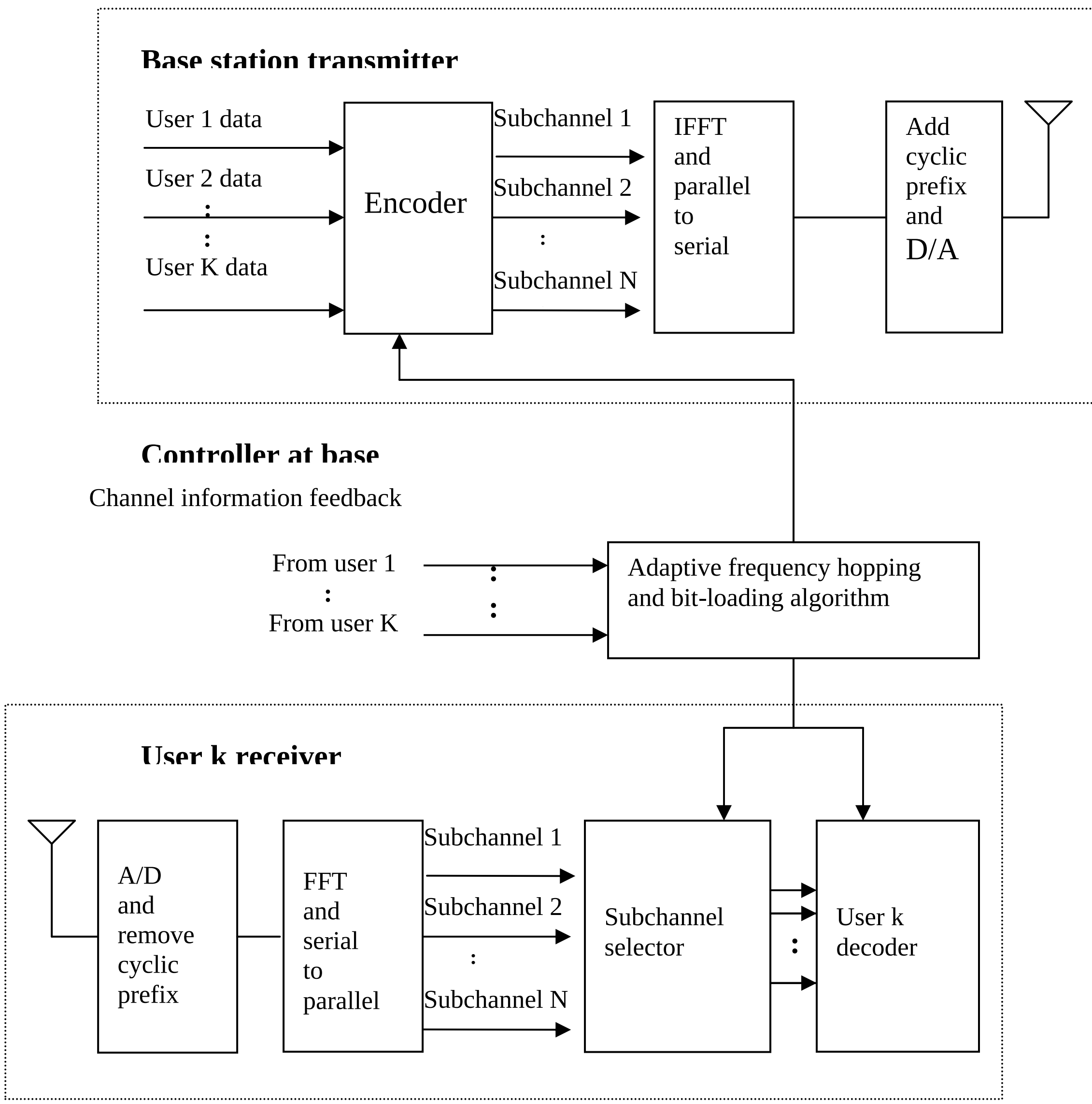

Fig. 1 Multiuser OFDM transmitter and receiver [3].

Fig. 1 illustrates the structure of the multiuser OFDM system that is under consideration. The controller at base station receives the down link channel conditions (average SNR in the last short period) from all users, and controls base station transmitter using the "adaptive frequency hopping and bit-loading algorithm". It is assumed that each subcarrier has a bandwidth much smaller than the coherence bandwidth of the channel and the channel is frequency selective Rayleigh fading for each user. Furthermore, the channels are assumed quasi-static where the channel for each subcarrier is time-invariant during a block period and changes randomly every block.

The objective is to investigate the variations of the data rates of the system with a fixed total power constraint. In the following two sections, the adaptive frequency hopping and the Levin-Campello rate adaptive bit-loading solution will be described.

3 Adaptive frequency hopping

The adaptive frequency hopping algorithm is relatively simple and described as follows:

Initialization:

- Divide the N subcarriers into K groups and assign them to the K users in a random order.

Periodical hopping:

- Update the average SNR over the last period.
- Allocate each subcarrier to the user that has the highest average SNR among other users.

4 Bit loading algorithm

We use the Levin-Campello rate adaptive (LC-RA) solution [3] to implement single user bit allocation. The LC-RA algorithm contains two parts: the Levin-Campello Efficientizing (LC-EF) algorithm and the Levin -Campello E-tightening (ET) algorithm, which are described as follows.

Define a bit distribution vector **b** as

$$\mathbf{b} = [b_1 \quad b_2 \quad \ldots \quad b_N] \tag{1}$$

where b_n is the number of bits allocated to the nth subcarrier.

Since we're using M-QAM modulation scheme, the QAM subcarriers' energies are given by

$$E_n(b_n) = 2\frac{\Gamma}{g_n}(2^{b_n} - 1) \tag{2}$$

and the incremental energy $e_n(b_n)$ for adding each bit on the nth subcarrier that currently has b_n bits is

$$e_n(b_n) = \frac{\Gamma}{g_n} 2^{b_n} \tag{3}$$

where Γ denotes the SNR for specified bit error rate (BER) and g_n the channel gain.

The LV-EF algorithm then translates any bit distribution into an efficient bit distribution as follows:

1 $m \leftarrow \arg\{\min_{1 \le i \le N} [e_i(b_i + \beta)]\}$

2 $n \leftarrow \arg\{\max_{1 \le i \le N} [e_j(b_j)]\}$

3 WHILE $e_m(b_m + \beta) < e_n(b_n)$ DO

- IF $(b_m + \beta > b_{\max}) or (b_n - \beta < 0)$ STOP;
- $b_m \leftarrow b_m + \beta$
- $b_n \leftarrow b_n - \beta$
- $m \leftarrow \arg\{\min_{1 \le i \le N}[e_i(b_i + \beta)]\}$
- $n \leftarrow \arg\{\max_{1 \le i \le N}[e_j(b_j)]\}$

where b_{max} is the maximum num ber of bits that are allowed on each subcarrier. We allow b_{max} = 6.

The LC-ET algorithm is then applied to e-tighten the resultant **b**:

1 SET $S = \sum_{n=1}^{N} E_n(b_n)$

2 WHILE $(N\overline{E}_x - S < 0) or (N\overline{E}_x - S \ge \min_{1 \le i \le N}[e_i(b_i + \beta)]$

IF $N\overline{E}_x - S < 0$ THEN

- $n \leftarrow \arg\{\max_{1 \le i \le N}[e_i(b_i)]\}$
- $S \leftarrow S - e_n(b_n)$
- IF $b_n - \beta < 0$ STOP
- $b_n \leftarrow b_n - \beta$

ELSE

- $m \leftarrow \arg\{\min_{1 \le i \le N}[e_i(b_i + \beta)]\}$
- $S \leftarrow S + e_m(b_m + \beta)$
- IF $b_m + \beta > b_{\max}$ STOP
- $b_m \leftarrow b_m + \beta$

5 Simulation Results

To evaluate the performance of the above-described scheme, five-path frequency selective Rayleigh fading channels with an exponential power delay profile are used to for simulations. In simulations, each set of channels consists of K independent channels, one for each user. We use an OFDM system with 64 subcarriers over a 5 MHz band along with a total variable data rate. The channel gain on each subcarrier for different users depends on the selection of the subcarriers. Hence frequency hopping involves some randomness.

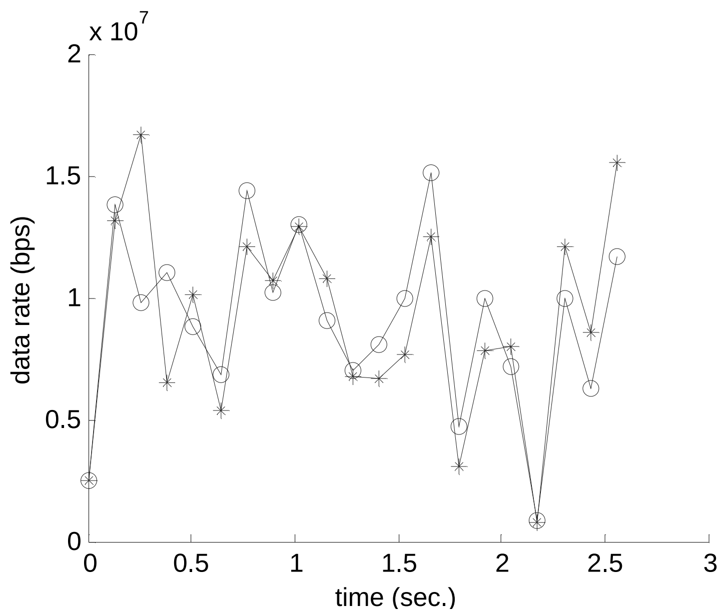

Fig. 2 Data rate versus time for two users. The hopping interval is 128 μs.

Fig. 2 gives the simulation result of a two-user OFDM system with adaptive schemes incorporated. The variation of data rates indicates the change of the channel conditions.

Define the outage probability in data rate P_{out} as the average of the probability of each user that the data rate is below a threshold R_o, *i.e.*

$$P_{out} = \frac{1}{K}\sum_{k=1}^{K} P[R_k < R_o] \qquad (4)$$

where a reasonable definition of the threshold is

$$R_o = \frac{b_{\max}}{3KT} \qquad (5)$$

Fig.3. shows the outage probability versus the number of users. The outage probability increases with the number of users in the system. This result indicates that as more users are sharing the resources, the randomness in channel conditions increases. Hence adaptive frequency hopping becomes random hopping and is less useful.

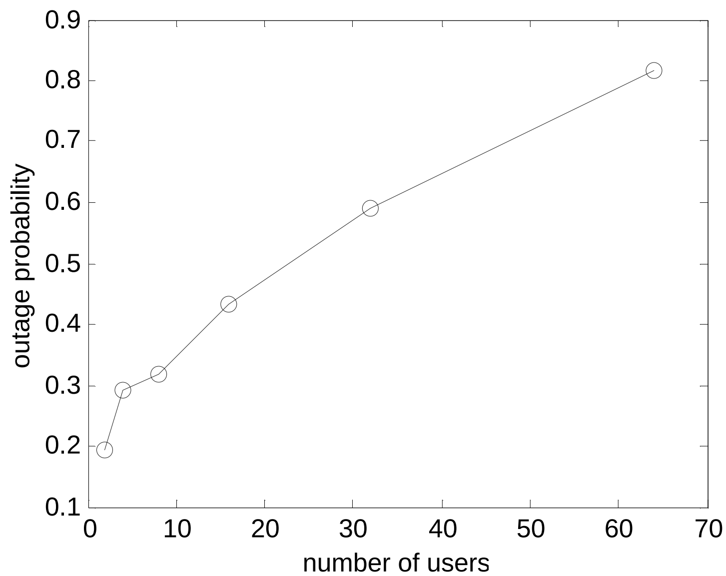

Fig. 3 The outage probability versus the number of users. The hopping interval is 128 μs.

Define the standard deviation of the system as

$$\sigma = \frac{1}{K}\sum_{k=1}^{K} \sigma_k \qquad (6)$$

Fig. 4 shows that the standard deviation def ined as in Eq. 6 decreases with the number of users. This is because as the number of users increases, adaptive hopping approaches random hopping.

So the temporary data rates are not improved or decreased. Simulation results also show that the overall system capacity does not change with the hopping interval.

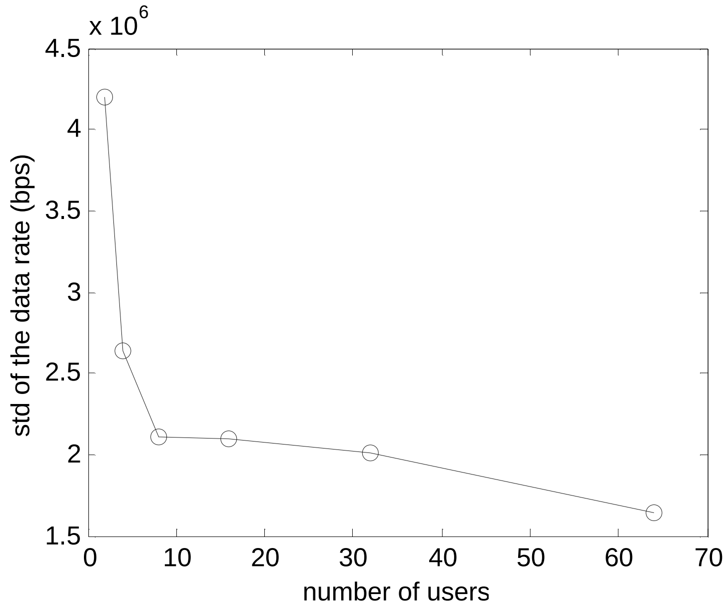

Fig. 4 The standard deviation of each user's data rate versus number of users. The hopping interval is 128 μs.

6 Conclusions

This project investigated the impact of adaptive frequency hopping and bit allocation on the transmission data rate. Simulation results show that the outage probability increases with the number of the users in the system while the overall standard deviation of data rate decreases.

7 References

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