Adaptive Subband Allocation in FH-OFDMA with Channel Aware Frequency Hopping Algorithm

Ardalan Alizadeh, Seyed Mohammad-Sajad Sadough

Abstract – This paper presents a new subband allocation scheme for multiuser OFDMA systems. Adaptive OFDMA systems have focused on adapting the allocation of subcarriers and power to the instantaneous channel conditions of all users. Using frequency hopping pattern in OFDMA system allow users to minimize intercell and intracell interference, and perform frequency diversity. In contrast to conventional FH-OFDMA, which uses a channel state independent hopping sequence, the transmitter in the channel aware scheme hops to the available frequency subband which has the largest transmission gain. Simulation results demonstrate that in power constraints assumption, using our proposed channel aware frequency hopping (CAFH) along with OFDMA scheme outperforms multiuser OFDMA system with fixed subband assignment.

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I. Introduction

Orthogonal frequency division multiplexing (OFDM) has been presented as a new technology for next generation wireless communication systems. In OFDM systems, high-rate information can be divided into a number of parallel lower-rate streams with the advantage of avoiding the requirements of complex equalization [1]. These systems also provide the multiple access schemes termed as orthogonal frequency division multiple access (OFDMA). In OFDMA, a fraction of available subcarriers is assigned to each user based on the demand for bandwidth. Three advantages of OFDMA include (1) the flexibility in subcarriers' allocation; (2) the absence of multiuser interference due to subcarriers' orthogonality; (3) the simplicity of the receiver design [1].

To improve the system throughput and spectral efficiency, frequency hopping (FH) technique is generally used in OFDMA cellular systems. As mentioned in [2], it is desirable for FH patterns to satisfy the following conditions: (i) minimize intracell interference; (ii) average intercell interference; (iii) avoid ambiguity while identifying users; (iv) exploit frequency diversity by forcing hops to span a large bandwidth. The first aspect is relatively easy to achieve by using orthogonal hopping patterns within a cell. To average intercell interferences, hopping patterns are constructed in a way that two users in different cells interfere with each other only during a small fraction of all hops. The third condition requires base stations to have the capability of distinguishing different user efficiency according to their unique FH signatures. Finally, the last requirement not only ensures the security of the transmission, but also mitigates the effect of fading by exploiting frequency diversity [2].

On the other hand, frequency hopping pattern scheme has achieved considerable attention in both military and commercial communication systems. There has been much research on designing FH-OFDMA systems. For instance in [3], concepts of fast frequency hopping along with OFDM are provided. Orthogonal Latin squares (LSs) are presented as FH patterns in TCM/BICM coded OFDMA in [4]. In LS-aided FH-OFDMA systems, there is wide variability in performance of users within different cells. Therefore, it is not a useful scheme when the fairness consideration is important. Therefore, although users of each cell experiences significant performance improvement, the cell may not occupy all of the available bandwidth to receive full frequency diversity. Other aspects on preventing hostile jamming and pilot-assisted channel estimation in FH-OFDMA are provided in [5], [6].

Nomenclature

$(\cdot)^T$ Transpose operation
$F$ IFFT matrix
$r$ Number of rounds
$N$ Total number of subcarriers
$C_i$ Set of subcarriers assigned to the $i$-th user
$N_i$ Number of subcarriers assigned to the $i$-th user
$n(t)$ AWGN noise
$L$ Number of subbands
$T$ Duration of one OFDM symbol
A channel-aware frequency hopping (CAFH) multiple-access scheme was proposed in [7]. CAFH algorithm monitors the channel status at the base station (BS). The BS then determines the subband gains, for each MS, and uses this knowledge to assign, to each MS, the subband that enjoys the highest gain, while ensuring that no more than one MS is assigned to the same subband. The resulting channel assignment algorithm is iterative in nature and has, in general, \( r \geq 1 \) rounds. The BER of CAFH is analyzed assuming independently Rayleigh faded subbands.

In this paper, we propose a novel strategy based on frequency hopping pattern by channel aware frequency hopping algorithm for practical OFDMA cellular systems. Several channel allocation schemes are currently offering appropriate performance in considerations of power and bit constraints. Our simulation results show that CAFH-OFDMA system can offer significant performance improvement over fixed subband assignment.

II. System Model

In this section, first we describe the FH-OFDMA transmitter for each individual user. Then, we introduce the channel aware frequency hopping scheme under one subband per user assumption.

II.1. FH-OFDMA System

The block diagram of a simple FH-OFDMA system with FEC is shown in Fig. 1. In this model, data bits of every user are channel coded and then mapped to complex constellation points.

Fig. 1. FH-OFDMA system with FEC [2]

We assume that there are \( M \) users in the system, utilizing a total of \( N \) OFDM subcarriers. Each user is assigned a specific set of subcarriers out of the total available subcarriers according to his/her data rates. Let \( N_i \) be the number of subcarriers allocated to user \( i \). Then, user \( i \) transmits the information symbols \( x_i = (x_1, x_2, \ldots, x_K) \) on the assigned \( K \) subcarriers where \( (\cdot)^T \) represents the transpose operation. Therefore, the baseband transmitted signal of user \( i \) can be expressed as:

\[
S^i(t) = \sum_{k=1}^{K} x_{ik} e^{j2\pi(k/T)t}, \quad 0 \leq t < T
\]

where \( s^i(t) \) represents the time-domain signal, and \( T \) denotes one OFDM symbol duration. In OFDMA systems, different set of subcarriers is assigned to every user. This subband allocation is dynamic in the case of frequency hopping OFDMA. In this scheme, the frequency assignment follows a predetermined FH pattern by the IFFT module. If subcarriers are not assigned to users, zeros are transmitted.

For convenience, we note \( C_i \) as the subcarrier that is assigned to user \( i \). Hence, \( N \times 1 \) information symbols vector of user \( i \) can be written as:

\[
x^i(k) = \begin{cases} 0, & k \notin C_i \\ x_{ik}, & k \in C_i 
\end{cases}
\]

The discrete form of the transmitted signal \( s^i(t) \) is then given as:

\[
s^i = Fx^i
\]

where \( F \) is the IFFT matrix defined as:

\[
F = \frac{1}{\sqrt{N}} \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\
\vdots & \ddots & \vdots \\
W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix}
\]

where \( W_N^{pq} = e^{j2\pi pq/N} \).

II.2. Channel Aware Frequency Hopping

System Description: We adopt the slowly time-varying, frequency-selective Rayleigh fading channel model which is commonly used for wideband systems [8]. The instantaneous signal-to noise ratio (SNR), \( \Gamma \) in each subband is exponentially distributed according to:

\[
P_\Gamma(\gamma) = \frac{1}{\gamma_0} e^{-\frac{\gamma}{\gamma_0}}
\]

where \( \gamma_0 \) is the average value of \( \Gamma \). The slowly varying nature of the channel implies that it can be treated as time-invariant over the duration of a frame or an OFDM symbol.

Consider the uplink of a cellular system in which \( K \) MSs transmit over \( L \), \( L \geq K \), subbands to the BS. The signal received (at the BS) during the \( i \)-th signaling interval at the BS is:

\[
r(i) = \sum_{k=1}^{K} g^k_S (i - \tau_k) + n(i)
\]
where $t_k$ is the time delay of MS $k$, $n(t)$ represents additive white Gaussian noise (AWGN) with two-sided power spectral density (PSD) $N_0=2$, and $g^i_k$ is the subband gain of MS $k$ during the $i$-th signaling interval. The subband gain $g^i_k$ depends on the scheme that is used to assign subbands to MSs.

**CAFH Scheme:** In the CAFH scheme with $r$ rounds, the BS assigns subbands to active MSs as follows. The round number is initially set to 1.

In round $j$, $j=1, 2; \ldots; r$ for each MS, $k$, which has not yet received its subband assignment, the subband $t^i_j \in \{1, \ldots, L\}$, with the $j$-th best subband gain, $g^i_j$, out of $L$ subbands is determined. If a given subband has the $j$-th best gain for exactly one MS, the subband is assigned to that MS and the scheme enters round $j+1$. If an ‘available’ subband has the $j$-th best gain for several MSs, the subband is assigned to the MS with the largest gain and the scheme enters round $j+1$.

Once a subband is assigned to a MS, it is not available in subsequent rounds.

The subband assignment procedure continues until all $K$ MSs have been assigned subbands or round $r+1$ is reached.

In the latter event, i.e. there are still unassigned MSs after round $r$, the BS chooses each such MS in turn, in a random order, and assigns to it the unoccupied subband for which its gain is highest.

A flowchart describing the CAFH scheme is provided in Fig. 2. It is noted that the number of rounds required is at most $min\{r, K\}$.

**Fig. 2. Channel aware frequency hopping flowchart [7]**

### II.3. CAFH-OFDMA Model

In the presented channel model, subband gains are assumed distributed exponentially where the average value ($\gamma_0$) is changed in each OFDM symbol interval. This random channel environment increases multiuser interference and bit error rate of each OFDM symbol.

CAFH algorithm selects high gain subbands and improves fixed subband allocation schemes. In the next section CAFH-OFDMA model is simulated and system performance of CAFH-OFMA and fixed subband assignment method is compared.

### III. Simulation Results

We assume that the instantaneous channel gains of user $k$ and its subcarrier are described by exponential random variables. This random variable is changed in each OFDM symbol intervals and sets to new random value.

Before transmission of signal, BS estimates subbands gain of each user as independent exponential random variable.

For example the gain matrix of three users and four available subcarrier scheme ($\gamma_0 = 1$) is written as:

$$
g = \begin{bmatrix}
0.9693 & 0.8685 & 0.8977 & 0.6697 \\
0.5107 & 0.8806 & 0.8334 & 0.7461 \\
0.2018 & 0.3271 & 0.2652 & 1.1987
\end{bmatrix}
$$

Then CAFH algorithm is applicable to allocate channels with high value gain to users.

After that, each user can transmit modulated (BPSK) signal through IFFT block in order to its selected subband.

To prevent intersymbol interference (ISI) effect of OFDM symbols, the guard intervals (GI) are added in each interval. We assume that GI length is 1/4 of IFFT length.

When OFDM signal is sent, channel imposes additive white Gaussian noise (AWGN) to OFDM symbol. Also each subband multiplies by its random gain value. At the receiver, guard intervals are removed and user’s modulated data is detected.

Choosing random gain model for OFDMA subband channels presents higher bit error rate.

Fig. 3 shows that random gain selection affects the multiuser interference of system, also increases BER undesirably.

In random channel environment, the major approach of OFDM system (i.e. absence of multiuser interference) will be different.

However CAFH scheme can improve the total bit and symbol error rate of overall system.

CAFH-OFDMA scheme requires 3dB lower power in comparison with fixed scheme and for higher iterations this different will be increased.

As shown in Fig. 4, higher MS numbers results in more multiuser interference and average BER is reduced.

Also for higher iteration numbers (or rounds), BER values are not changed reasonably. Also at same conditions, CAFH-OFDMA provides more effective performance over fixed assignment.
The effect of higher iteration value is illustrated in Fig. 5. Under constant SNR value assumption, total bit error rate of users is reduced and converged. For $r > 2$, Fig. 5 shows that the average BER of system will be low where CAFH algorithm requires more processing time and calculations. Therefore our simulation results acquired by $r=1$ and $r=2$.

IV. Conclusion

In this paper, we considered multiuser OFDMA transmission in a random channel gain environment and CAFH scheme is offered to reduce bit error rate under power constraint condition. Applying CAFH-OFDMA scheme, the overall required transmit power can be reduced by more than 3dB from the conventional OFDMA scheme without adaptive modulation. Our simulation results showed that in high iterations, the BER does not change reasonably. Current results acquired under simply assumption that only one subcarrier is assigned to each user. In practice, adaptive subband allocation selects best condition of subbands separately. Also major resource allocation methods that optimize bit and power allocation in OFDMA system can be merge with CAFH-OFDMA and provide high performance and optimal schemes.

References


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