Mobile Multiuser Access with Approximately MAI-free PMU-OFDM Transceiver Design

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***Abstract*— A new multiuser OFDM transceiver with precoding was introduced by Tsai, Lin and Kuo in [8]. The system can reduce multiaccess interference (MAI) due to the carrier frequency offset (CFO) to a negligible amount by the use of even or odd Hadamard-Walsh codewords. The performance of this system in a mobile environment, where the channel response varies within one OFDM symbol due to the Doppler effect, is evaluated in this work. It is shown that the use of even or odd Hadamard-Walsh codewords can greatly reduce the MAI due to the Doppler effect as well. It is also demonstrated by simulations that all Hadamard-Walsh codes except for the all-one code result in considerable suppression of ICI due to the Doppler effect. Finally, we show that the new system with odd Hadamard-Walsh codes outperforms a half-loaded OFDMA system in a mobile channel environment.**

I. Introduction

OFDM (Orthogonal Frequency Division Multiplexing) provides a promising technique for high data rate transmission applications, since an OFDM system can combat the inter-symbol interference (ISI) effect due to frequency selective fading with a simple transceiver structure. The mobile OFDM system has recently attracted a lot of attention for three reasons. First, the next generation of mobile wireless communication systems is expected to provide high quality broadband service in a highly mobile environment. Second, wireless communication systems are implemented in higher frequency bands recently so that they are more sensitive to the physical movement of users and their surroundings. Third, to increase the bandwidth efficiency of OFDM requires a larger number of subchannels, implying the use of a longer symbol length. Thus, the effective channel variation rate over one OFDM block increases.

Generally speaking, there are two families of multiuser OFDM systems, *i.e.* multicarrier (MC-) CDMA [3] and Orthogonal frequency division multiple access (OFDMA) [2]. MC-CDMA inherits the ISI-robustness from OFDM systems. However, its capacity is limited by multiaccess interference (MAI) in frequency selective fading channels. OFDMA is MAI-free when the time and frequency are perfectly synchronized. However, OFDMA is very sensitive to the carrier frequency offset (CFO) and the Doppler spread, which are common phenomena in time-varying channels. Rapid variations of the channel over one OFDM symbol destroy the orthogonality among subcarriers and result in inter-subcarrier interference (ICI) and MAI in multiuser OFDM systems. A lot of research has been done to suppress ICI due to the Doppler effect in MAI-free single-user OFDM systems, e.g. see [1], [5] and [10]. However, there is little work on MAI suppression due to the Doppler spread in multiuser OFDM systems such as OFDMA or MC-CDMA. Without a mechanism to suppress MAI in a mobile environment, one has to resort to a more complicated multiuser detection (MUD) technique for symbol detection, whose computational complexity increases with the number of active users exponentially. Therefore, a multiuser OFDM scheme which is intrinsically robust to the Doppler spread effect is very much desired.

A new multiuser OFDM transceiver with specified orthogonal codes, called the precoded multiuser (PMU-)OFDM system, was introduced in [8]. It was shown in [9] that PMU-OFDM with proper code selection result in an approximately MAI-free system even in the presence of a time-invariant environment that has CFO. However, the performance of this system in a time-varying fading channel has not yet been analyzed in the past, which is the main task of this work. Here, we will show that PMU-OFDM reduces the MAI due to the Doppler spread of a time-varying channel to a negligible amount by the use of even or odd Hadamard-Walsh codewords, which corresponds to a half-loaded OFDM system [9]. It is also shown by simulation that PMU-OFDM with even or odd Hadamard-Walsh codewords has up to 10 dB less MAI than OFDMA in an environment with the Doppler effect. Furthermore, we will show that the PMU-OFDM system can suppress the ICI due to Doppler spread considerably by the use of only odd codes. Finally, we will compare the BEP performance and demonstrate that the half-loaded PMU-OFDM system with odd codewords outperforms the half-loaded OFDMA system in time-varying channels considerably.

The rest of the paper is organized as follows. The PMU-OFDM system and the Rayleigh time-varying channel model are reviewed in Sec. II. We analyze the MAI effect of PMU-OFDM due to the Doppler effect and show how to achieve the approximately MAI-free property in Sec. III, where the ICI effect resulting from the Doppler spread is also discussed. The Monte Carlo simulation results are presented in Sec. IV, which include the performance comparison between PMU-OFDM and OFDMA. Finally, conclusion remarks are given in Sec. V.

II. System Model

The PMU-OFDM system proposed in [9] is reviewed in this section. The block diagram of the PMU-OFDM system is

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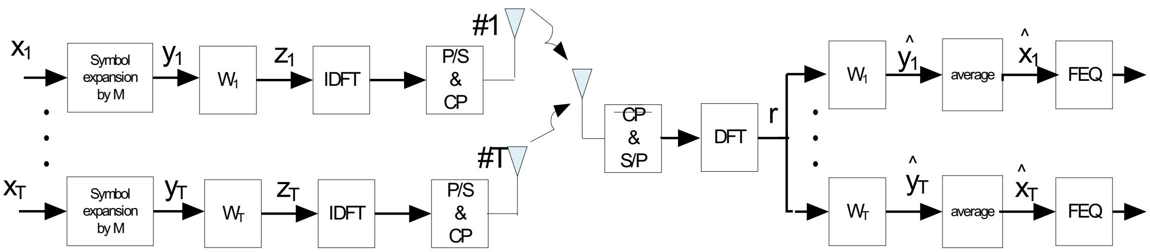

Fig. 1. The block diagram of the PMU-OFDM system.

shown in Fig. 1. Let the input for user j be an $N \times 1$ vector $\mathbf{x}_j$. Each symbol in $\mathbf{x}_j$ is repeated by M times to form an $NM \times 1$ vector $\mathbf{y}_j$ with element

$$y_j[v+kM] = x_j[k], \quad 0 \le k \le N-1, \quad 0 \le v \le M-1. \quad (1)$$

In the next stage, $\mathbf{y}_j$ is multiplied by a diagonal matrix $\mathbf{W}_j$ of size $NM \times NM$ whose diagonal elements are obtained by repeating the jth column of an $M \times M$ real Hadamard matrix $\mathbf{D}$ by N times, *i.e.*,

$$\mathbf{W}_j = \text{diag}(\mathbf{d}_j^t, \mathbf{d}_j^t ... \mathbf{d}_j^t), \quad (2)$$

where $\mathbf{d}_j^t$ is the transpose of the jth column of $\mathbf{D}$. Since $\mathbf{D}$ is a unitary matrix, the following property holds

$$\sum_{v=0}^{M-1} w_i[v+kM] w_j[v+kM] = \begin{cases} M, & i = j \\ 0, & i \neq j \end{cases}, \quad (3)$$

where $w_j[v+kM]$ is the $(v+kM)$th diagonal element of $\mathbf{W}_j$, $0 \le v \le M-1$ and $0 \le k \le N-1$. After passing through the diagonal matrix $\mathbf{W}_j$, the resultant $NM \times 1$ vector $\mathbf{z}_j$ can be written as

$$z_j[l] = w_j[l] y_j[l], \quad 0 \le l \le NM-1, \quad (4)$$

where $l = v+kM$ is the index for frequency. Next, each coded vector is passed through the NM-point inverse DFT (IDFT) matrix. Then, following the parallel to serial conversion, N_p cyclic prefix (CP) are inserted at the beginning of each OFDM symbol. Thus, the jth transmitted signal in the time domain over a block is given by

$$s_j(n) = \frac{1}{NM} \sum_{m=0}^{NM-1} z_j[m] e^{j\frac{2\pi}{NM}nm}, -N_p \le n \le NM. \quad (5)$$

These symbols are fed to the multiple access channel.

The time-varying channel impulse response for any user can be expressed by

$$h(n;\tau) = \sum_{d=0}^{N_h-1} g(n;d)\delta(\tau - d), \quad (6)$$

where n and τ denote time and delay, respectively, N_h is the maximum length of channel impulse response, $g(n;d)$ is the channel coefficient gain at time n for the dth tap, and $\delta(.)$ is the Kronecker delta function. Coefficient $g(n;d)$ is assumed to be a complex Gaussian random variable with zero mean and unit variance. Also, the typical wide-sense stationary uncorrelated scattering (WSSUS) model is adopted for the channel model [4], [6]. Thus, we have

$$E[g(n;d)g^*(m;q)] = \phi(n-m)\sigma_d^2 \delta(d-q), \quad (7)$$

where σ_d^2 is the variance of the dth tap and $\phi(n-m)$ is the time-autocorrelation function. One classic time-autocorrelation function is the Jakes model [4], which can be written as

$$\phi(n-m) = J_0(2\pi f_D T_s (n-m)), \quad (8)$$

where $J_0(x)$ is the zeroth order Bessel function of the first kind, f_D is the maximum Doppler frequency and T_s is the sampling rate. Throughout this work, the time-correlation function is assumed to be the classical Jakes model.

If the cyclic prefix duration is chosen such that $N_p \ge N_h$, the received signal after removing the cyclic prefix is given by

$$r(n) = \sum_{i=1}^{T} \sum_{d=0}^{N_h-1} g_i(n;d) s_i(n-d) + e(n), \quad (9)$$

where $e(n)$ is the discrete-time additive white Gaussian noise, $g_i(n;d)$ is the channel complex coefficient of user i, and T is the number of multiple access users. Next, each block of size NM is converted from serial to parallel and then passed through the unitary DFT matrix. The output of DFT can be expressed as

$$r[l] = \sum_{n=0}^{NM-1} r(n) e^{-j\frac{2\pi}{NM}nl}, \quad 0 \le l \le NM-1. \quad (10)$$

To detect the symbol transmitted by the jth user, the $NM \times 1$ output vector of DFT is multiplied by $\mathbf{W}_j$ and the symbol average is performed as follow. By denoting the output of $\mathbf{W}_j$ with $\hat{\mathbf{y}}_j$ and the average output with $\hat{\mathbf{x}}_j$, we have

$$\begin{aligned} \hat{x}_j[k] &= \frac{1}{M} \sum_{v=0}^{M-1} \hat{y}_j[v+kM] \\ &= \frac{1}{M} \sum_{v=0}^{M-1} r[v+kM] w_j[v+kM], \end{aligned} \quad (11)$$

where $0 \le k \le N-1$. By substituting Eqs. (5) and (10) into

(11), we have

$$\hat{x}_j[k] = \frac{1}{M}\sum_{v=0}^{M-1} w_j[v+kM]\frac{1}{NM}\sum_{i=1}^{T}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1}\sum_{m=0}^{NM-1} \cdot\left[g_i(n;d)y_i[m]w_i[m]e^{j\frac{2\pi}{NM}(u+fM)(n-d)}e^{-j\frac{2\pi}{NM}n(v+kM)}\right] + \underbrace{\frac{1}{M}\sum_{v=0}^{M-1} e[v+kM]w_j[v+kM]}_{\hat{e}[k]}. \quad (12)$$

By Eqn. (1), we get $y_i[m] = y_i[u+fM] = x_i[f]$, where $m = u+fM$, with $0 \le u \le M-1$ and $0 \le f \le N-1$. Since all symbols of an individual user use the same Hadamard-Walsh code, we have $w_i[u+fM] = w_i[u]$ and $w_j[v+kM] = w_j[v]$. By defining

$$\eta(n) = \frac{1}{M}\sum_{v=0}^{M-1}\sum_{u=0}^{M-1} w_i[u]w_j[v]e^{-j\frac{2\pi}{NM}(v-u)n} \quad (13)$$

and using Eqn. (II), we can rewrite Eqn. (12) as

$$\hat{x}_j[k] = \sum_{i=1}^{T}\sum_{f=0}^{N-1} x_i[f]\frac{1}{NM}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1}\left[g_i(n;d)\,\eta(n)e^{-j\frac{2\pi}{NM}(u+fM)d}e^{-j\frac{2\pi}{N}(k-f)n}\right] + \hat{e}[k]. \quad (14)$$

Finally, to mitigate the fading effect on the received symbols, $\hat{x}_j[k]$ is passed through the frequency equalizer (FEQ).

III. Doppler Effect Analysis

In a Doppler environment, the overall Doppler effect can be divided into two parts. One is the interference from other users' symbols due to the time-varying channel, called Doppler MAI. The other is the self-Doppler effect, which consists of the the interference from neighboring subcarriers (*i.e.* Doppler ICI) and the symbol distortions due to this user's own Doppler effect. In this section, we analyze these effects for PMU-OFDM and derive expressions for the average MAI and ICI.

A. Analyis of Doppler MAI

From Eqn. (14), the MAI from the kth symbol of user j due to user i, denoted by $MAI_{j\leftarrow i}[k]$, is given by

$$MAI_{j\leftarrow i}[k] = \sum_{f=0}^{N-1} x_i[f]\frac{1}{NM}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1} g_i(n;d) \cdot\eta(n)e^{-j\frac{2\pi}{NM}(u+fM)d}e^{-j\frac{2\pi}{N}(k-f)n}. \quad (15)$$

It is assumed that $x_i[f]$ is uncorrelated with respect to different symbols; *i.e.*, $E\{x_i[f]x_i[f']\} = \sigma_{x_i}^2\delta(f-f')$, and that $x_i[f]$ and $g_i(n;d)$ are uncorrelated. Under these assumptions and using Eqs. (7) and (8), the averaged power of $MAI_{j\leftarrow i}[k]$ can be found to be

$$E\left\{|MAI_{j\leftarrow i}[k]|^2\right\} = N_h\left(\frac{\sigma_d\sigma_{x_i}}{NM}\right)^2\sum_{f=0}^{N-1}\sum_{n=0}^{NM-1}\sum_{m=0}^{NM-1} \cdot\left[J_0\left(2\pi f_D T_s(n-m)\right)\eta(n)\eta^*(m)e^{-j\frac{2\pi}{N}(k-f)(n-m)}\right]. \quad (16)$$

Let $f = k$ and the resulting MAI be denoted by $MAI_{j\leftarrow i}^{(0)}[k]$. Then, from Eq. (16), the average power of $MAI_{j\leftarrow i}^{(0)}[k]$ is given by

$$E\left\{\left|MAI_{j\leftarrow i}^{(0)}[k]\right|^2\right\} = N_h\left(\frac{\sigma_d\sigma_{x_i}}{NM}\right)^2\sum_{n=0}^{NM-1}\sum_{m=0}^{NM-1} \cdot\left[J_0\left(2\pi f_D T_s(n-m)\right)\eta(n)\eta^*(m)\right]. \quad (17)$$

If only the $M/2$ even or the $M/2$ odd codewords of the M Hadamard-Walsh codes are used, we can show that $MAI_{j\leftarrow i}^{(0)}[k]$ is reduced to a negligible amount. That is, we have

$$E\left\{\left|MAI_{j\leftarrow i}^{(0)}[k]\right|^2\right\} \approx 0, \quad f_D T_s < \frac{1}{2\pi NM}. \quad (18)$$

Eqn. (18) demonstrates that the PMU-OFDM system is approximately MAI-free in a Doppler environment. For example, when $N = 64$ and $M = 16$, PMU-OFDM is approximately MAI-free when the normalized maximum Doppler frequency is less than 1.5×10^{-4}. The detailed mathematical proof of the approximately MAI-free property will be given in [7]. Here, we will show by simulation in Sec. IV that the total MAI can be suppressed greatly in a Doppler environment by suppressing $MAI_{j\leftarrow i}^{(0)}[k]$ via using odd or even Hadamard-Walsh codes.

B. Analyis of Doppler ICI and Symbol Distortion

In this subsection, we investigate the impairment caused by user's own Doppler effect. Let $i = j$ in (14). The kth detected symbol of user j with no other active user is given by

$$\hat{x}_j[k] = \sum_{f=0}^{N-1} x_j[f]\frac{1}{NM}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1}\left\{g_j(n;d)\eta(n)\, e^{-j\frac{2\pi}{NM}(u+fM)d}e^{-j\frac{2\pi}{N}(k-f)n}\right\} + \hat{e}[k]. \quad (19)$$

We can rewrite the above equation as

$$\hat{x}_j[k] = x_j[k]H_j[u;k] + ICI_j^{(0)}[k] + ICI_j^{(1)}[k] + \hat{e}[k], \quad (20)$$

where $H_j(u;k)$, $ICI_j^{(0)}[k]$ and $ICI_j^{(1)}[k]$ are detailed below. The distortion factor, $H_j(u;k)$, is obtained by putting $f = k$ and $u = v$ in $\eta(n)$ in Eqn. (19), *i.e.*

$$H_j[u;k] = \frac{1}{NM}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1} g_j(n;d)e^{-j\frac{2\pi}{NM}(u+Mk)d}. \quad (21)$$

The term $ICI_j^{(0)}[k]$ denotes the interference from subcarriers $u \ne v$ to the desired subcarrier k; namely,

$$ICI_j^{(0)}[k] = x_j[k]\frac{1}{NM}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1} g_j(n;d)\{\eta(n)|_{u\ne v}\} \cdot e^{-j\frac{2\pi}{NM}(u+kM)d}. \quad (22)$$

Finally, the term $ICI_j^{(1)}[k]$ is the sum of all interferences from subcarriers $f \ne k$, *i.e.*,

$$ICI_j^{(1)}[k] = \sum_{f=0,f\ne k}^{N-1} x_j[f]\frac{1}{NM}\sum_{n=0}^{NM-1}\sum_{d=0}^{N_h-1} g_j(n;d)\eta(n) \cdot e^{-j\frac{2\pi}{NM}(u+fM)d}e^{-j\frac{2\pi}{N}(k-f)n}. \quad (23)$$

It can be shown that $E\left\{\left|ICI_j^{(0)}[k]\right|^2\right\}$ is negligible as compared to $E\left\{\left|ICI_j^{(1)}[k]\right|^2\right\}$ when the Doppler frequency is less than $\frac{1}{2\pi NM}$. The proof will be given in [7]. In other words, we only need to consider $ICI_j^{(1)}[k]$ when the Doppler spread is less than $\frac{1}{2\pi NM}$. The average power of $ICI_j^{(1)}[k]$ is given by

$$E\left\{\left|ICI_j^{(1)}[k]\right|^2\right\} = N_h\left(\frac{\sigma_d\sigma_{x_j}}{NM}\right)^2 \sum_{f=0, f\neq k}^{N-1}\sum_{n=0}^{NM-1}\sum_{m=0}^{NM-1} \cdot J_0\left(2\pi f_D T_s(n-m)\right)\eta(n)\eta^*(m)e^{-j\frac{2\pi}{N}(k-f)(n-m)}. \quad (24)$$

IV. Simulation Results

In this section, we compare the MAI performance of the PMU-OFDM and the OFDMA systems by computer simulation. In the simulation, we choose the carrier frequency f_c to be 4 GHz and the sampling frequency $F_s = \frac{1}{T_s}$ to be 2 MHz. The maximum Doppler frequency is related to the mobile speed via $f_d = f_c\frac{V}{c}$, where c is the speed of light and V is the mobile speed. The modulation symbols are BPSK. The Monte Carlo method was used to simulate the result. For fair comparison, we keep the size of IDFT/DFT of the two systems to be the same, *i.e.* NM. We consider both fully-loaded and half-loaded situations. To simulate the half-loaded PMU-OFDM system, the odd Hadamard-Walsh codewords are used. For the half-loaded OFDMA system, the jth user is assigned subchannels with indices $2(j-1)+kM$, $0 \le k \le N-1$, and $1 \le j \le M/2$. The left subchannels are used as the guard band.

Example 1. The approximately MAI-free property of the PMU-OFDM system is demonstrated in Fig. 2, where the averaged total MAI power is shown as a function of maximum normalized Doppler spread $f_d T_s$ for the two systems in fully-loaded and half-loaded situations. The averaged total MAI power for user j from all other users, denoted by $\overline{MAI}_j$, is calculated by the formula $\frac{1}{N}\sum_{k=0}^{N-1}\left|\sum_{i=1,i\neq j}^{T} MAI_{j\leftarrow i}[k]\right|^2$. That is, for any target user, we accumulate the MAI contributed from all symbols of other users, and the MAI power is then averaged for $0 \le k \le N-1$. Here, the parameters are chosen to be $N = 64$, $M = 16$ and $N_h = 4$, and the average MAI power is the average value of 16 or 8 MAI values, *i.e.* $\frac{1}{T}\sum_{j=1}^{T}\overline{MAI}_j$ for the fully- and the half-loaded cases, respectively. For the fully-loaded case, we see that PMU-OFDM performs worse than OFDMA in a low Doppler spread value up to $f_d T_s = 5\times 10^{-5}$, which corresponds to a mobile speed of 27 km/hr. This result is not a surprise since OFDMA is MAI-free with negligible time or frequency asynchronism. For the half-loaded case, the performance of PMU-OFDM is comparable to that of OFDMA when the Doppler frequency is less than 5×10^{-5}. The reason is that PMU-OFDM is approximately MAI-free when only the $M/2$ even or the $M/2$ odd codewords of M Hadamard-Walsh codes are used [8]. The performance of the fully-loaded OFDMA and PMU-OFDM are approximately the same when the mobile speed is greater than 27 km/hr. However, when the number of users decreases from 16 to 8, the MAI of PMU-OFDM with the proposed code selection scheme is greatly reduced by 20-25 dB. Consequently, PMU-OFDM with code selection outperforms OFDMA by 10 dB when the mobile speed is higher than 2 km/hr.

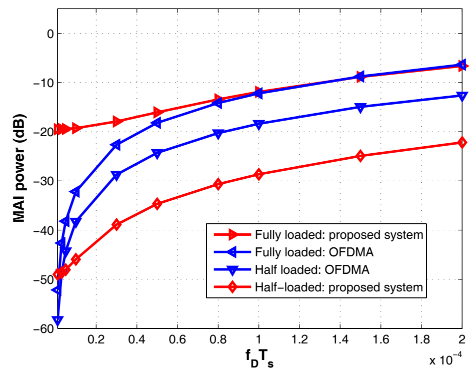

Fig. 2. Comparison of the MAI power as a function of the normalized Doppler frequency for fully- and half-loaded PMU-OFDM and OFDMA systems.

Example 2. In this example, we consider the ICI effect due to the Doppler spread. As mentioned before, we focus on $ICI_j^{(1)}$ for user j, whose average power is calculated as follows. For the kth symbol of the target user, we accumulate the ICI from all other symbols $f \neq k$ of the same user. The average ICI power, denoted by $\overline{ICI}_j^{(1)}$, is then averaged for $0 \le k \le N-1$. That is, $\frac{1}{N}\sum_{k=0}^{N-1}\left|ICI_j^{(1)}[k]\right|^2$. Fig. 3 shows the average ICI power for each individual Hadamard-Walsh codeword used in PMU-OFDM when $N = 64$, $M = 16$ and $N_h = 4$. The maximum Doppler frequency was chosen to be 1×10^{-4}. We see that different users experience a different amount of ICI. Especially, the first user that employs the all-one code suffers more ICI than all other users by 15-40 dB. Intuitively, if a codeword has more sign changes (*i.e.* ± 1), the main lobes of interfering subcarriers may cancel each other so that the ICI power is decreased. This is similar to the self-ICI cancellation technique used to mitigate ICI in OFDM systems [10]. Since the all-one code belongs to the set of even Hadamard-Walsh codes, we suggest to choose the set of odd Hadamard-Walsh codes, since this set is able to exploit the approximately MAI-free property of the PMU-OFDM system and have a relatively low average ICI power at the same time.

Example 3. In this example, we compare the performance of odd and even Hadamard-Walsh codewords for the PMU-OFDM system. In this system, we choose $N = 32$, $M = 8$ and $N_h = 2$. The ICI power and the MAI power for OFDMA and PMU-OFDM systems are plotted as functions of $f_D T_s$ in Fig. 4, where the average ICI power is the average $\overline{ICI}_j^{(1)}$ values of 4 multiple access users (*i.e.* $T = 4$). From the figure, we see that the largest amount of interference is the ICI of the PMU-OFDM system with only even codes. The reason is that the all-one code that belongs to the set of even codes has a high ICI value as compared to the ICI or the MAI value of all other

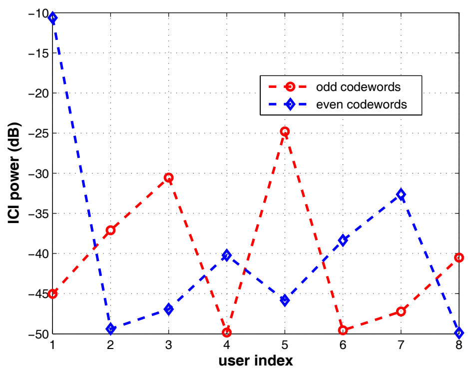

Fig. 3. The ICI power as a function of user index for even and odd codewords with $f_D = 1 \times 10^{-4}$.

users. However, PMU-OFDM with the set of odd Hadamard-Walsh codes has nearly the same amount of ICI as OFDMA. Note that subcarriers assigned to a particular user in OFDMA are spread uniformly across the available bandwidth. Hence, ICI leads to less impairment in OFDMA than in a single-user OFDM. However, for OFDMA, the MAI power is significantly higher than that of PMU-OFDM. We also observe from Fig. 4 that PMU-OFDM with either even or odd Hadamard-Walsh codes experiences about 10 dB less MAI than OFDMA.

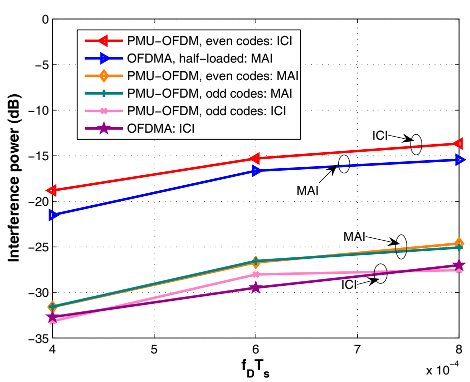

Fig. 4. Comparison of the MAI power and the ICI power as a function of the normalized Doppler frequency.

From this figure, we can conjecture that the PMU-OFDM system with only odd codes outperforms OFDMA in the bit error probability (BEP) performance. With $N = 32$, $M = 8$, $N_h = 2$ and $\frac{E_b}{N_0} = 30$ dB, the simulation results given in Fig. 5 confirm our conjecture, where the BER performance is plotted as a function of the Doppler frequency for PMU-OFDM and OFDMA. With perfect knowledge of channel conditions, a frequency equalizer can be used to compensate the symbol distortion effect, *i.e.* the detected symbol $\hat{x}_j[k]$ is multiplied by $H_j^{-1}[u;k]$. Thus, both systems only suffer from MAI and ICI. Although PMU-OFDM with only even codewords yields more BEP than OFDMA due to high ICI of the user with the all-one code, we see that the PMU-OFDM system with odd codewords outperforms OFDMA in the Doppler environment with a maximum normalized Doppler frequency ranging from 2×10^{-4} to 1×10^{-3}.

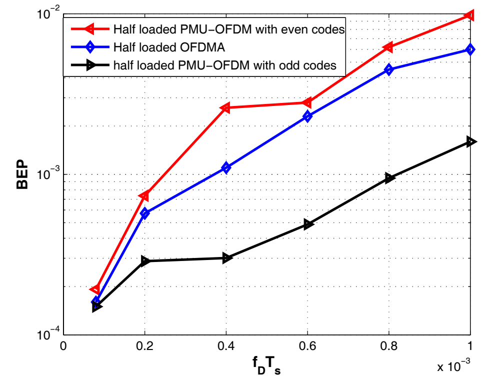

Fig. 5. The BEP comparison for PMU-OFDM and OFDMA as a function of the normalized Doppler frequency.

V. Conclusion

The performance of an approximately MAI-free multiaccess OFDM transceiver, called the PMU-OFDM system in a mobile environment was studied in this work. We showed that the MAI effect due to the Doppler spread can be greatly reduced using either $M/2$ even or odd codewords of M Hadamard-Walsh codes. We also investigated the ICI performance of PMU-OFDM in the Doppler environment and showed by simulations that, excluding the all-one code, PMU-OFDM has an average ICI power comparable to that of OFDMA. Also, the BEP performance of PMU-OFDM and OFDMA was compared. It was observed that the half-loaded PMU-OFDM with the set of odd Hadamard-Walsh codes outperforms OFDMA in a mobile environment.

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