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IMPROVED CHANNEL ESTIMATION AND MAI-ROBUST SCHEMES FOR WIRELESS OFDMA SYSTEM

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Abstract—This paper presents an investigation into improving the channel estimation scheme and reducing the effects of symbol timing misalignment when OFDMA is used as an access scheme. Under OFDMA uplink channel environments, appropriate symbol length of CAZAC sequences as a preamble could be utilized in accordance with the number of transmitting antenna and channel condition. The effect of the number of CAZAC sequences for channel estimation is also presented in terms of mean square error (MSE). Taking into account the effect of multiple access interference (MAI) introduced by a symbol timing misalignment, the symbol error rate (BER) and throughput performance are investigated for a typical OFDMA uplink scenario.

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is commonly used for high data rate wireless communications due to their effective transmission capability when dealing with various types of channel impairment, such as severe multipath fading and impulsive noise [1–8]. Orthogonal frequency-division multiple access (OFDMA) technology has been seen as one of the reliable solutions in wireless multi-user environments. OFDMA, also referred to as Multiuser-OFDM, is being considered as a modulation and multiple access method for 4-th generation wireless networks. OFDMA is an extension of orthogonal frequency division multiplexing (OFDM), which is currently the modulation of choice for high speed data access systems such as IEEE 802.11a/g wireless LAN (WiFi) and IEEE 802.16a/d/e wireless broadband access systems (WiMAX and WiBro) [9–12].

The evolution of OFDM to OFDMA completely preserves the robustness against multipath propagation and high bandwidth efficiency. However, in case of using multiple antenna for OFDM systems, recovering the transmitted signal is impossible without knowing channel coefficients because the signals from each multipath channel are overlapped. Therefore, channel estimation processing is a major key as recovering the corrupted signal [13–15]. In a typical OFDMA uplink scenario, moreover, multiple access interference (MAI) caused by symbol timing errors destroys the orthogonality among users [16–18]. This paper shows our investigations for improving the performance, the effects of channel estimation and symbol timing misalignment on OFDMA uplink performances are discussed, respectively. At the same time, we provide an algorithm which generates extended-CAZAC (E-CAZAC) sequences to overcome a limitation of the number of transmitting antennas and multipath components to maintain the orthogonality for both uplink and downlink of OFDMA systems. Besides, the bit error rate (BER) and throughput performance of the interactive OFDMA uplink system for symbol timing misalignment are considered.

2. SYSTEM MODEL

2.1. Interactive OFDMA System Model

The OFDMA system consists of a forward interaction path which is used to provide information and any other required communication for the interactive service provision, and a return interaction path conveyed from the user to the service provider. Fig. 1 shows a return path model for OFDM uplink systems. As a consequence, the interactive networks make use of two unidirectional physical layers, implementing a downstream and an upstream. In this paper, we consider an interactive OFDMA network with multiple antenna. To allow access by multiple users, the VHF/UHF return channel is partitioned using a combination of frequency division multiplex (FDM) and time division multiplex (TDM) [9].

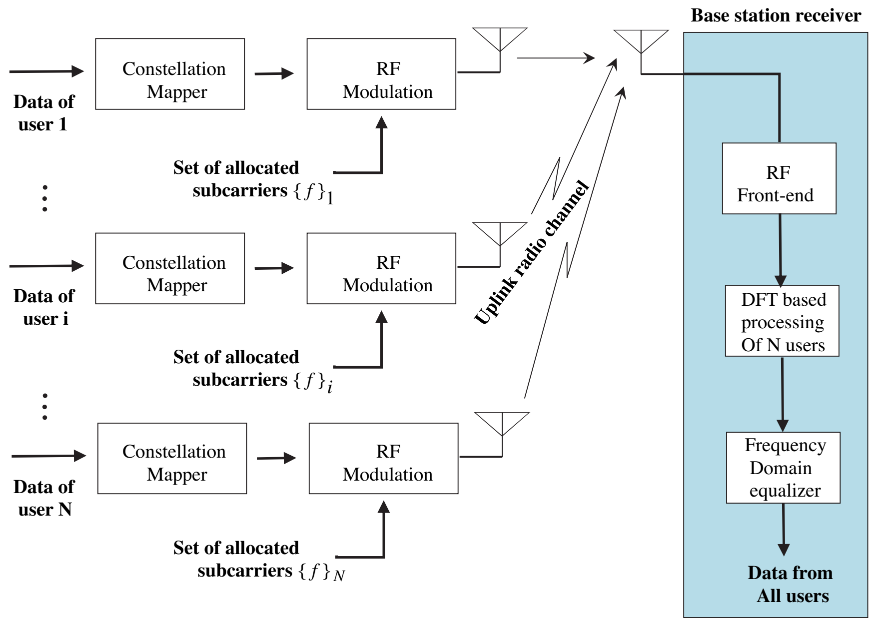

Figure 1. OFDMA system model.

2.2. Symbol Timing Error Model for OFDMA Uplink

In this subsection we are concerned with the evaluation of the uplink subject to symbol timing errors. The subcarrier frequencies from all users form a set of N orthogonal carriers by appropriate choice of the spacing, as it is done in OFDM. As such, each tone in an OFDM symbol is used by a different uplink user. Thus, the users share the same bandwidth at the same time, however orthogonality is achieved by assigning distinct tones to distinct users. These tone assignment schemes consist of *interleaved tone assignment scheme* that the tones of distinct users are regularly interleaved across the overall set of N tones and *block tone assignment scheme* that disjoint blocks of $\mathbf{K}_u$ contiguous tones are assigned to each user, where $\mathbf{K}_u$ is the number of subcarrier per each user. The interleaved scheme yields a worse signal to interference ratio (SIR) compared to the block scheme. The SIR for the block scheme can be further improved by assigning a frequency guard at the beginning and/or end of each block [19]. With the above block scheme in mind, the l-th signal received by the base station can be expressed as

$$s(t) = \sum_{l=0}^{N-1} a_l \exp\left[j2\pi \frac{l(t-\tau_l)}{T}\right] \times \exp\left[j2\pi f_0 t\right] H_l + W_l$$

where W_l is the zero-mean Gaussian noise (AWGN) with two-sided power spectral density of $N_0/2$, τ_l is the timing error for the l-th user, and a_l is a complex quadrature amplitude modulation (QAM) symbol transmitted by the l-th user and f_0 is the carrier frequency as generated by all uplink user's equipment, H_l is the discrete frequency response $H_l = \alpha_l \exp(j\theta_l)$. In the H_l, α_l is the independent identically distributed (i.i.d) Rayleigh random variable and θ_l is uniformly distributed random variable over $[-\pi, \pi]$.

The received signal is down converted to baseband, and then it is applied to FFT block module. So, we can be obtained FFT output. The output of the n-th FFT block is of the form:

$$x_n = \sum_{l=0}^{N-1} \frac{a_l H_l}{T} \times \exp\left[-j2\pi \frac{l\tau_l}{T}\right] \times \int_0^T \exp\left[j2\pi \frac{(l-n)t}{T}\right] dt.$$

Equation (3) gives the desired component of $x_n|_{desired}$ and interference component of $x_n|_{interferer}$ at the output of the FFT block prior to frequency domain equalization as follows:

$$x_n|_{desired} = a_n H_n \times \exp\left[-j2\pi \frac{n\tau_n}{T}\right] \quad (1)$$

$$x_n|_{interferer} = \sum_{l \neq n} \frac{a_l H_l}{T} \times \exp\left[-j2\pi \frac{l\tau_l}{T}\right] \times \int_0^T \exp\left[j2\pi \frac{(1-n)t}{T}\right] dt. \quad (2)$$

As we can see from Equation (4), the n-th desired component symbol is modified by the frequency response of the channel and rotated by an angle which depends on the frequency index n and on the relative delay of the n-th user's signal. In Equation (5), rotation terms experienced by the channel coefficients and relative uplink delays contain the interference component, which destroy the orthogonality among users.

In addition, we consider the power of the MAI. Let us assume that the data symbols $a_{d,l}$ which is the d-th output signal of the l-th user, on different subcarriers of different users are independent of each other, with a zero mean and the same average power P_a. Without loss of generality, we assume that the channel state is invariant during the observed symbol period.

With the above assumptions in mind, we show that the power of the MAI [18] for k-th output signal of the n-th user is

$$E|MAI|^2 = \frac{1}{\pi^2} \sum_{l \neq n} \sum_{d=0}^{N-1} E|\alpha_{d,l}|^2 P_a \times \frac{1 - \cos 2\pi(k-d)(\tau_{l,n} - T_G)/T}{(k-d)^2} \quad (3)$$

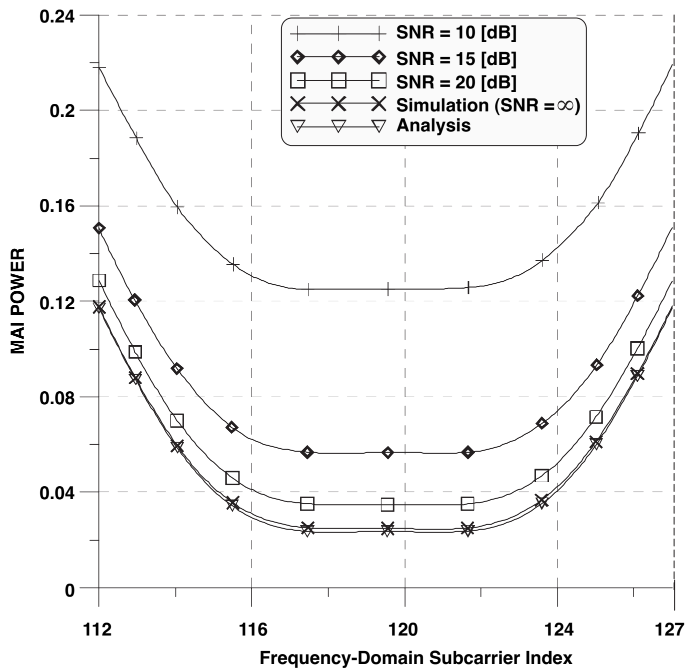

Figure 2. Interference power plus noise versus frequence domain subcarrier index of the 8-th desired user for N=256 and K_u=16 (16QAM and $\tau_{l,n}$=65).

where $\tau_{l,n}$ is the symbol timing misalignment of the l-th user with respect to the n-th user at the receiver, T_G and T are the cyclic prefix and OFDM symbol duration including guard interval, respectively.

Figure 2 shows the MAI power for SNR models versus frequency-domain subcarrier index of desired user (the 8-th user) for N=256 and $K_u = 16$. In this figure, we set to the same symbol timing error ($\tau_{l,8} = 65$) for all users except the eighth user. The Simulation results were obtained by 16QAM signaling and multipath fading channel with respect to various SNR value, also analysis results were obtained through the average channel gain $E|\alpha_{d,l}|^2 = 1$. As we can see from this figure, we confirmed what subcarrier between adjacent subbands has higher MAI power. One popular solution to mitigate the MAI is to insert a guard band (GB) among two adjacent subbands and to use the receiver diversity in the base station. The improving performance of the above methods present the Section 4.

3. IMPROVING CHANNEL ESTIMATION USING E-CAZAC

3.1. CAZAC Sequence

We introduce OFDMA system with multiple antenna using CAZAC preamble as system model. In Section 2, in order to employ simulation, perfect channel estimation on each user is assumed. However, since channel condition has the multipath fading features in practice, we need to estimate the channel coefficients. Also, one of the most dominant factors of the performance degradation is channel estimation error. In order to solve this problem, we achieved the a channel estimation technique using the constant-amplitude zero-autocorrelation (CAZAC) preamble which holds outstanding periodic autocorrelation property [20]. The CAZAC preamble provides good and rapid signal acquisition performances even for low SNR conditions with 4-phase and 16-symbol-length. However, if the CAZAC preamble is adopted in multiple antennas system, its capability of channel estimation is limited by the number of transmit antennas (N_t) and multipath components (P) to maintain the orthogonality as follows [15]

$$1 \leq P \leq \frac{L}{N_t} \tag{4}$$

where L presents the symbol-length of the CAZAC sequence. In order to overcome such problem, we provide an algorithm which generates E-CAZAC.

3.2. Proposed Channel Estimation Method

The E-CAZAC sequences are obtained by zero-padded among the CAZAC sequences in order to maintain orthogonality when multiple antenna are used and multipath component are existed. The follow equation shows a structure of the E-CAZAC:

$$e_{m \cdot L/4+n} = \begin{cases} j^{mn} & \text{for } n < 4 \\ 0 & \text{for } n \geq 4 \end{cases} \tag{5}$$

where $m \in 0, 1, 2, 3$, $n \in 0, 1, \cdots, L/4 - 1$. Remark that L must be times of 4.

Since such zero paddings do not provide any additional information about the power spectrum, flat power spectrum of CAZAC sequence is inherited. It shows that we can use the autocorrelation of CAZAC sequences. When E-CAZAC sequence is used, we can have more flexible capability of the channel estimation as L or N_t

is varied. In addition, one may think other CAZAC sequences with higher phase that provide better solution for multiple antennas system because all symbols are used for estimation. However, it provides the additional defect because longer sequences with higher phase cause the transmitter complexity and power consumption for transmission or correlation. Therefore, proposed scheme with conventional 4-phase CAZAC sequences can realize a multiple antennas OFDMA system with low hardware complexity and power consumption.

3.3. Performance Evaluation and Discussions

In this section, several simulation results which show the effect of each scheme are provided. To simulate the OFDMA system performance, a flat Rayleigh fading channel on each subcarrier is used and i.i.d fading among different subcarriers is assumed in the simulations. The entire bandwidth (BW) of 20 MHz is divided into 256 subcarrier. And, the 8-th user is regarded as the desired user. In case of OFDMA uplink channel estimation, we evaluate the performance of proposed E-CAZAC sequnce in terms of MSE. Here, we adopt the least square (LS) estimator simulation.

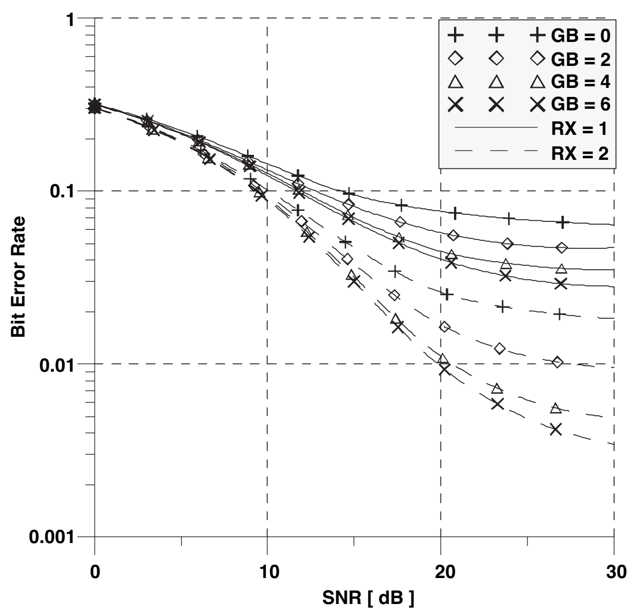

Figure 3. BER performance of OFDMA uplink systems with respect to the number of GB for N=256 and $K_u = 16$ (16QAM and $\tau_{l,n} = 65$).

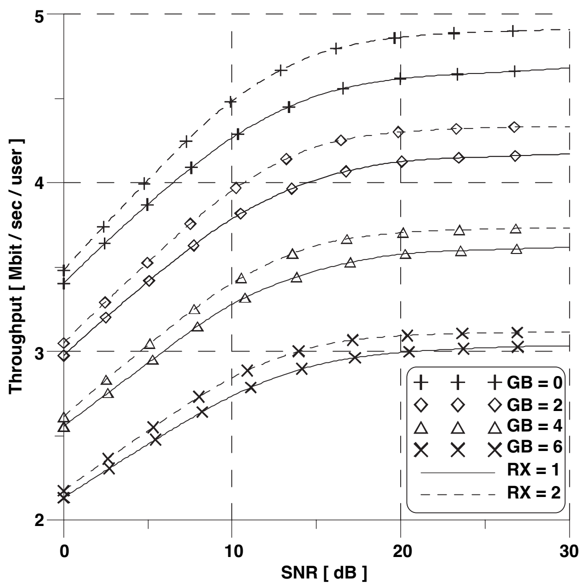

Figure 4. Throughput performance of OFDMA uplink systems with respect to the number of GB for $N = 256$ and $K_u = 16$ (16QAM, $\tau_{l,n} = 65$ and 20 MHz bandwidth).

3.4. MAI Performance

Figure 3 presents BER performances of OFDMA uplink systems with respect to the number of guard band. A performance enhancement can be observed with increase of the number of GB regardless of the number of receiver antennas. As expected, the BER for the existing MAI give a performance degradation since they destroy the orthogonality among users. However, as the number of guard band increases, throughput is decreased as shown in Fig. 4.

3.5. MSE Performance Using E-CAZAC

Figure 5 displays the MSE performances of 32-symbol-length E-CAZAC sequence when 7 paths are presence. In the simulation, we can see that E-CAZAC sequence performs completely when up to 4 transmit antennas are used as Equation (7). In the other case, MSE performaces are very poor because the orthogonality of E-CAZAC sequence is broken. Therefore, we should notice this point. Also, if we want to use 8 transmit antennas, they will estimate the channel condition nicely as E-CAZAC sequence length increases. As

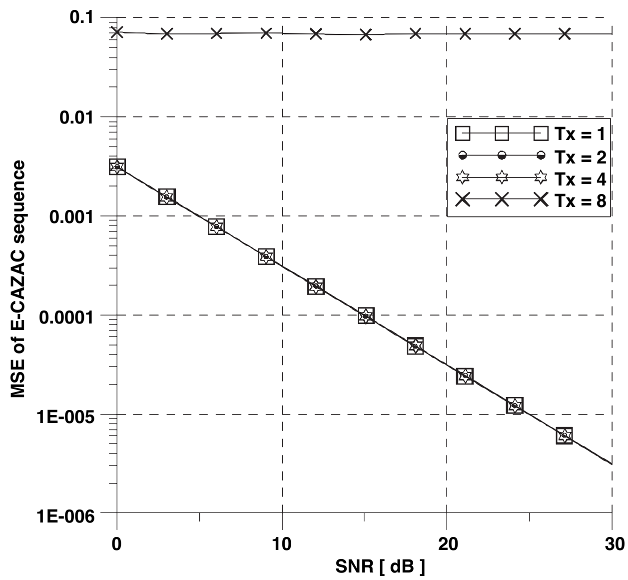

Figure 5. The MSE performance of OFDMA uplink channel estimation using the E-CAZAC for 1, 2, 4 and 8 transmit antennas over 7-path Rayleigh faing channel.

expect, the MSE of CAZAC sequence gives the better performance by increasing the number of CAZAC sequence. However, we should use properly the symbol-length and number of CAZAC sequences restricted in conformity with the system and channel conditions.

4. CONCLUSIONS

OFDMA is a very appealing technique for providing a feasible solution to multiple user access in wireless channels. However, the both MAI problems and channel estimation problems in case of using the multiple antennas based on OFDMA system cause serious performance degradations. In this paper, we described the MAI reduction schemes in the OFDMA-based interactive wireless system. From the results presented above, we confirmed MAI reduction by using the GB and received diversity. At the same time, by the considering system and channel conditions E-CAZAC preamble sequences can provide solutions of the more flexible channel estimation. The presented results are valid for OFDMA systems with reverse link.

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