Joint Timing Synchronization and Channel Estimation in Uplink of Time Domain Synchronous OFDMA

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Abstract: Multiple users TDS-OFDMA has been proposed based on time domain synchronous orthogonal frequency division multiplexing (TDS-OFDM). This multiple access schemes used mostly in mobile broadband wireless access scheme in uplink transmission due to the multiple user interference in timing offset and frequency offset problems. In this paper we are focusing on timing synchronization and channel estimation. Time-space two dimensional structure is used in TDS-OFDMA and perfect sequence is used for guard interval in it to achieve joint timing synchronization and channel estimation for each user. Simulations are performed for timing synchronization in 0dB SNR value and for channel estimation using perfect sequence in different AWGN-multipath channel.

Keywords: Timing synchronization, Channel estimation, TDS-OFDMA, Perfect sequence.

I. INTRODUCTION

With rapid increasing demand in modern society for high data rate with reliable information exchange anytime and anywhere, broadband wireless systems are envisioned for this in future wireless communication technologies. In recent technologies orthogonal frequency division multiplexing (OFDM) is promising physical layer technology for broadband wireless access which has low complexity modulation and better spectral efficiency than conventional frequency division multiplexing (FDM) [1][2]. Recently, OFDM concept becomes an emerging technology in multiuser scenario. This trade has been implanted as orthogonal frequency division multiple access (OFDMA) technique [2]. In OFDMA, different group of orthogonal subcarriers assigned to different group of users. In this way, more than one user access air interface simultaneously. However, despite such appealing features of OFDMA there are still practical issues, especially in mobile environment that can degrade the performance of such system. Synchronization is one of the major issues in OFDMA because each mobile station (MS) needs to communicate synchronously with base station (BS). In uplink, the received signal at the base station is the combination of signals from different mobile stations. Hence uplink synchronization is multiparameter situation dealing with both timing and frequency synchronzation.

Uplink synchronization is recent hot research trade in OFDMA. In cyclic prefix (CP) based timing synchronization method, the guard interval is used to avoid intersymbol interference. This method is not accurate. So quasi-synchronous model is adopted [3], where long CP is used to encompass physical channel impulse response (CIR) and two way propagation delays of each user to avoid the timing errors. Hence, there
is a loss of spectral efficiency with long CP. For keeping spectral efficiency in a tolerable level the upper limit length of CP is chosen for resulting CIR and two way propagation delays [1],[2],[3]. For more accurate timing acquisition several preamble patterns are proposed such as [A A] used in Schmidl and Cox, [+A +A -A -A] proposed by Minn and [A B A* B*] proposed by Park [6]. These types of repetitive blocks are considered which decreases the transmission efficiency. To solve these problems, we proposed a method for joint timing synchronization and channel estimation using perfect sequences in time domain resulting in less complexity.

The remaining paper is organized as follows. Section 2 discusses the system model of OFDMA followed by frame structure. The joint timing synchronization and channel estimation algorithm have been discussed in section 3. Section 4 analyzes the simulation results. Conclusion is given in section 5.

II. TDS-OFDMA SYSTEM MODEL

TDS-OFDMA system with M users is shown in fig 1. Time-space two dimensional frame structure is used for the transmission of each user frame. Each user frame consists of N point discrete Fourier transform block and a guard interval (GI) of length N_g. GI is composed of cyclic extension of the symbol with PN sequence and it has been defined in time-space dimension [4] as

\[
\begin{align*}
P_{m, i + 1} &= P_{m, i}^{N_f} \\
P_{m + 1, i} &= P_{m, i}^{N_f}
\end{align*}
\]

(1)

Where \( N_f \) and \( N_s \) are circular shift in time and space dimension respectively. With the following conditions \( L_s \leq L_s \) and \( ML_s \leq N_f \).

At the transmitter, any carrier assignment strategy (CAS) is used. All the user specific data are mapped in frequency domain on orthogonal subcarrier set and IDFT is performed. Then GI is appended with the IDFT block before transmission of data [4]. Its frame structure is shown in fig. 2.

The received IDFT block for \( i^{th} \) frame is expressed as

\[
r_i = \sum_{m=1}^{M} X_{m,i} \ast h_{m,i} + v_i
\]

(2)

\( h_{m,i} \) is multi-path CIR for \( m^{th} \) user, \( h_{m,i} = [h_{m,i}(0), h_{m,i}(1), \ldots, h_{m,i}(L_m - 1)] \).

Fig. 1 Time-space frame structure
This multi-path CIR is modelled as \( L_m \) order finite impulse (FIR) response filter. The length of \( L_m \) is less than the cyclic extension length \( L_t (L_m \leq L_t) \) and \( V_i \) is additive white Gaussian noise with zero mean and variance \( \sigma^2 \). At the receiver side, each user is separated using the same time-space frame structure.

III. PROPOSED METHOD

A. Timing Synchronization

The process of timing synchronization at BS is described in fig. 3 where each user needs to detect the starting point of each frame perfectly. Fig. 3 shows the synchronization sequence between MS and BS. When MS want to access network resource through uplink, it should transmit initial signal first. Then BS listens to user signal and request for timing adjustment. MS transmit the signal with new timing after timing adjustment. MS also confirm the same to BS and the above process repeats whenever BS needs timing adjustment with MS.

The received signal with user specific frequency error \( \varepsilon_m \) corresponding to incoming signal from \( m^{th} \) user is given as

\[
q_{m,i} = \text{erfc}(n) \varepsilon_{m_i} r_x (i - 1)N_f + L_1 \sum_{m=1}^{M} \left( \delta \left( n - (m - 1) L_n \right) \right)
\]  

(3)

The second term in (3) gives the position of each user. The timing adjustment for each user is done based on the position of each user. \( \delta(n) \) is the kronecker delta function and \( \text{erfc} \) is a special complimentary error function and \( n \) is the index of PN sequence. The correlation peak corresponding to the \( m^{th} \) user in \( i^{th} \) signal frame is given as

\[
q_{m,i}(m - 1) \ast L_n = \text{erfc}(n) \varepsilon_{m_i} r_x ((i - 1)N_f + L_1)
\]

(4)

Similarly, the correlation peak in \((i+1)^{th}\) frame is
\[ q_{m, i+1}((m-1) \ast L_x) = \text{erfc}(n) e^{r_x(i)N_f + L_t} \] \hfill (5)

**B. Channel estimation**

The received PN sequence is circularly correlated with the local PN sequence. Then GI is protected by cyclic extension and the channel estimation is performed by applying perfect sequence as

\[
\hat{h} = \frac{1}{N_p} P_{m,i} \otimes q_i = \frac{1}{N_p} P_{m,i} \otimes \left( \sum_{m=1}^{M} P_{m,j} \otimes h_{m,j} + v_i \right)
\] \hfill (6)

where \( v_i \) is additive white Gaussian noise with zero mean and variance \( \sigma^2 \).

The PN sequence in (6) has cyclic property and it is expressed as

\[
q_i = \sum_{m=1}^{M} P_{m,i} \otimes h_{m,j} = \sum_{m=1}^{M} P_{m,j} + v_i
\] \hfill (7)

\[
\begin{bmatrix}
\tilde{P}_{1,i} & \tilde{P}_{2,i} & \ldots & \tilde{P}_{M,i}
\end{bmatrix}
\begin{bmatrix}
h_{1,j} \\
h_{2,j} \\
\vdots \\
h_{M,j}
\end{bmatrix} + v_i
\]

\[
P h_i + v_i
\] \hfill (9)

Where \( \tilde{P}_{m,i} \) is \( N_p \times N_s \) circular matrix derived from \( P_{m,i} \)

\[
P_i = \begin{bmatrix}
\tilde{P}_{1,i} & \tilde{P}_{2,i} & \ldots & \tilde{P}_{M,i}
\end{bmatrix}\]
is \( N_p \times MN_s \) training matrix and \( h_i \) is \( MN_s \times 1 \) channel vector

Then the performance of channel estimation is measured using the procedure [4]. The vector \( \hat{h} \) is computed using maximum likelihood method estimation as

\[
\hat{h}_i = \left( P_i^H P_i \right)^{-1} P_i^H q_i
\] \hfill (10)

The MSE of (10) is obtained as

\[
MSE = \frac{1}{MN_s} E \left[ \left\{ \hat{h}_i - h_i \right\}^H \left\{ \hat{h}_i - h_i \right\} \right]
\] \hfill (11)

\[
\left( P_i^H P_i \right) = \frac{1}{N_p} I_{MN_s}
\] \hfill (12)

The above condition in (12) is satisfied by using perfect sequence for achieving minimum mean square error. According to [7] the perfect sequence is given by the following procedure. The unity ordered perfect sequence set is defined as,

\[
X = \{ x_i \}_{i=0}^{M-1}
\]

\[
x_i(k) = \exp(i2\pi f_i(k)/sm)
\] \hfill (13)

With

\[
f_i(k) = mc(s)\alpha(l)k^2 + \beta(l)k + f_i(0)
\] \hfill (14)
Where,
\[ c(s) = \begin{cases} 
1/2 & \text{S for even} \\
1 & \text{S for odd}
\end{cases} \]

\( \alpha(l) \in \mathbb{Z}, \) is a function with \( \gcd(\alpha(l), s) = 1 \) for every \( \forall l \in \mathbb{Z}_m, \beta(l) \in \mathbb{Z}_m \), and \( \beta(l) \pmod{m} \) with function such that is a permutation of the elements of \( \mathbb{Z}_m \) and \( f_i(0), \forall l \in \mathbb{Z}_m \), are any rational numbers is periodically uncorrelated and complementary.

IV. SIMULATION RESULTS AND DISCUSSION

Simulations were performed for joint timing synchronization and channel estimation of TDS-OFDMA. Four users are considered simulation. The AWGN, Rayleigh, 3GPP typical urban, HIPERLAN-A, INDOOR-B were the channels considered for simulation. During entire MATLAB simulation, 4 users were active and they all using generalized carrier assignment scheme. Total system bandwidth and subcarrier spacing was 20MHz and 10.9375KHz respectively. Modulation scheme, PN sequence (perfect sequence) length, circularshift in time and space dimension was QPSK, 256, 64 and 64 used respectively.

Fig.4 illustrated the performance of timing synchronization under AWGN multipath channel at SNR=0dB. Simulation is performed in presence of CFO. Fig.4(a) indicates the correlation peaks of users without timing errors. The starting point of each user frame coincides with its reference position known to base station. Fig.4(b) indicates the correlation peaks of users with timing errors. For user 1, user 2, user 3 and user 4, the timing error is -1 sample, -3 samples, -6 samples, -7 samples respectively. It is obviously by counting the position shifts of corresponding measured peaks with reference peak, we can achieve the timing synchronization. Fig.5 compares MSE performance of circular based channel estimation of proposed perfect sequence with constant amplitude zero autocorrelation (CAZAC) sequence used in TDS-OFDMA and single user TDS-OFDM which uses binary PN sequence in 3GPP Typical Urban channel. Simulation is performed in presence of CFO of 200Hz. Simulation results shows that perfect sequence in TDS-OFDMA outperforms the CAZAC in TDS-OFDMA and binary PN sequence in TDS-OFDM.

Fig.6 compares MSE performance of circular based channel estimation of proposed perfect sequence with constant amplitude zero autocorrelation (CAZAC) sequence used in TDS-OFDMA and single user TDS-OFDM which uses binary PN sequence in Indoor Office B channel. Simulation is performed in presence of CFO of 200Hz. Simulation results shows that perfect sequence in TDS-OFDMA outperforms the CAZAC in TDS-OFDMA and binary PN sequence in TDS-OFDM. Fig.7 compares MSE performance of circular based channel estimation of proposed perfect sequence with constant amplitude zero autocorrelation (CAZAC) sequence used in

![Image of peaks and reference positions](image)

(a) No timing errors for all users

TDS-OFDMA and single user TDS-OFDM which uses binary PN sequence in HIPERLAN-A channel. Simulation is performed in presence of CFO of 200Hz. Simulation results shows that perfect sequence in TDS-OFDMA outperforms the CAZAC in TDS-OFDMA and binary PN sequence in TDS-OFDM. The channel estimation is better in the proposed sequence for TDS-
OFDMA due to perfect autocorrelation of perfect sequence. The other sequences have worst channel estimation performance due to ISI between guard interval and IDFT block. Fig. 8 shows the probability of false detection when perfect sequence is used as PN sequence under AWGN and four different fading channels. From simulation results, it is observed that the PN sequence gives perfect synchronization at SNR of 5dB. The detection probability is very good.

(b) With timing errors

Fig. 4 Timing synchronization under AWGN multi-path channel at Signal to Noise (SNR) = 0dB

Fig. 5 MSE of channel estimation under 3GPP Typical Urban channel model

Fig. 6 MSE of channel estimation under Indoor Office B channel
V. Conclusion

In this paper, we proposed an efficient method for joint timing synchronization and channel estimation in uplink of TDS-OFDMA. From the simulation results it is observed that the timing synchronization has achieved and also the channel estimation performance has improved with perfect sequence under different fading environment. It can be observed that the complexity of the system is reduced using guard sequence instead of cyclic prefix and the channel estimation has been achieved with the same guard sequence. In future, frequency synchronization with minimum MSE can be achieved by perfect sequence and under different fading environment.

Fig. 7 MSE of channel estimation under HIPERLAN-A channel model

Fig. 8 Probability of false detection under AWGN and four different fading channels

References