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Joint Timing Synchronization and Channel Estimation Using Perfect Sequence in Uplink Time Domain Synchronous OFDMA

M. Lakshmanan, P.S. Mallick and L. Nithyanandan

Abstract—**Time Domain Synchronous Orthogonal Frequency Division Multiple Access (TDS-OFDMA) is used in mobile broadband wireless access scheme in uplink transmission. This leads to multiple user interference due to timing offset and frequency offset. In this paper, the effect of timing offset and channel estimation in mobile broadband system is analysed. Time-space two dimensional structure is used in TDS-OFDMA and perfect sequence is used for guard interval to achieve perfect timing synchronization and channel estimation for each user. Simulations are performed for timing synchronization and channel estimation using perfect sequence under Urban channel, Indoor Office B channel and HIPER LAN-A channel. Simulation results show that the timing synchronization is achieved and channel estimation performance using perfect sequence is better than CAZAC and PN Sequences.**

Keywords— **Timing synchronization, Channel estimation, TDS-OFDMA, Perfect sequence, Guard interval**

I. INTRODUCTION

BROADBAND wireless systems are envisioned for rapid increasing demand in modern society for high data rate with reliable information exchange in future wireless communication technologies [11], [12]. In recent years, orthogonal frequency division multiple access (OFDMA) is a promising physical layer mechanism for broadband wireless technology due to better spectral efficiency than conventional frequency division multiple access (FDMA) [1], [2]. In OFDMA, different group of orthogonal subcarriers assigned to a group of users. Thus, all the users can access air interface simultaneously. There are two subcarrier assignment strategies are used for assigning subcarriers to the users. They are distributed and contiguous subcarrier assignment schemes [4].

In distributed subcarrier assignment strategy, subcarriers are assigned pseudo randomly to the users whereas in contiguous subcarrier assignment strategy, subcarriers are arranged in contiguous set. Multiple access interference is prevented among users due to orthogonality among the subcarriers. The distributed allocation scheme attracts high flexibility in resource management. However, despite such appealing features of OFDMA, there are some issues in mobile environment that can degrade the performance of the system. Synchronization is one of the major issues in OFDMA because each mobile station (MS) needs to communicate synchronously with base station (BS) with perfect timing and frequency. In uplink OFDMA, the received signal at the base station is the combination of signals from each mobile station. Hence timing and frequency synchronization is required in uplink OFDMA.

In this paper, the effect of timing offset and channel estimation in mobile broadband system is analysed. Synchronization is recent hot research trade in uplink OFDMA [14], [15], [16]. In cyclic prefix (CP) based timing synchronization method [18], the guard interval is used to avoid inter symbol interference. CP based method is not accurate. Therefore, 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 timing errors. Hence, there will be a loss in spectral efficiency with long CP. The upper limit length of CP and two way propagation delays are chosen for resulting channel impulse response (CIR) to keep spectral efficiency in a tolerable level [1], [2], [3]. 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 [5], [6] for accurate timing acquisition. This type of repetitive blocks is considered to decrease the transmission efficiency. But, additional pilot symbols are required for channel estimation. A joint timing synchronization and channel estimation using perfect sequence in uplink Time Domain Synchronous Orthogonal Frequency Division Multiple Access is proposed to resolve these issues. Simulation results show that the proposed method works better under Urban channel, Indoor Office B channel and HIPER LAN-A channel.

The rest of the paper is organized as follows. Section 2 gives the system model of OFDMA and its frame structure. The proposed joint timing synchronization and channel estimation using perfect sequence is discussed in section 3. Section 4 analyses the simulation results under Urban channel, Indoor Office B channel and HIPER LAN-A channel followed by conclusion.

II. TDS-OFDMA SYSTEM MODEL

TDS-OFDMA system is shown in fig. 1 with M users. Time–Space two dimensional frame structure is used for the transmission of data frames for M users. Each user frame N_f consist of N point Discrete Fourier Transform (DFT) block and a guard interval (GI) of length N_g. Assume L_s and L_t be the length of symbol frame and transmitted frame respectively.

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GI is composed of cyclic extension of the symbol with Pseudo Noise (PN) sequence and it is defined in time-space dimension [4] as

$$\begin{cases} P_{m,i+1} = P_{m,i}^{\emptyset N_t} \\ P_{m+1,i} \quad P_{m,i}^{\emptyset N_s} \end{cases} \tag{1}$$

where N_t and N_s are circular shift in time and space domain respectively, with $L_t \leq L_s$ and $ML_s \leq N_f$.

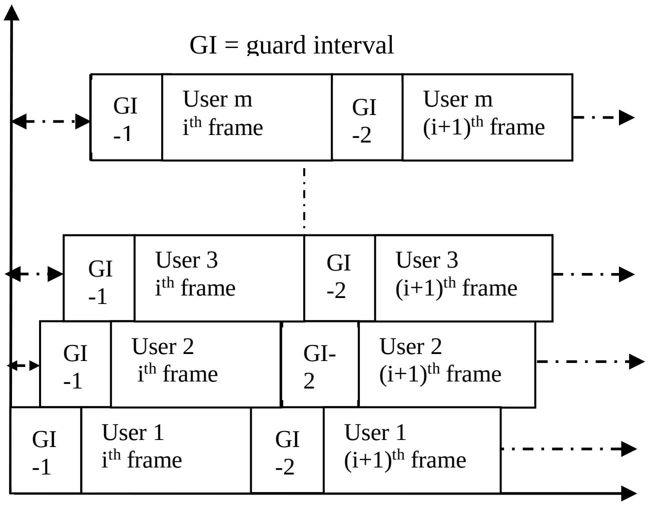


Fig. 1. Time-Space frame structure

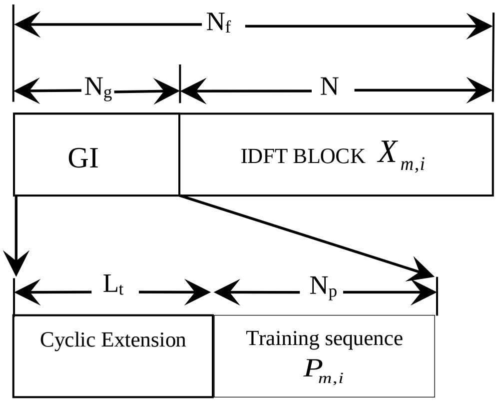


Fig. 2. Frame Structure

At the transmitter, distributed or contiguous subcarrier assignment strategy is used. The data frames of M users are mapped in frequency domain on orthogonal subcarrier set and IDFT is performed. Then, GI is appended with the IDFT block before the transmission of data [4] and its frame structure is shown in fig. 2.

The received IDFT block for ith frame is expressed as

$$r_i = \sum_{m=1}^{M} X_{m_i} * h_{m_i} + v_i \tag{2}$$

h_{m_i} is the multi-path CIR for mth user modelled as L_m order finite impulse (FIR) response filter and is given as $h_{m_i} = \left[h_{m_i}(0), h_{m_i}(1), h_{m_i}(2), \ldots\ldots\ldots\ldots. h_{m_i}(L_m - 1)\right]$. 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 σ^2. At the receiver, each user is separated using the same time-space frame structure.

III. PROPOSED METHOD

The proposed method consists of timing synchronization and channel estimation

A. Timing Synchronization

The process of timing synchronization at BS is described in fig. 3 and each user needs to detect the starting point of each frame perfectly [17]. Fig. 3 shows the synchronization process between MS and BS. When MS wants to access network resources through uplink, it should transmit initial signal. Then BS listens to user signal and request for timing adjustment. MS transmit the signal with new timing after adjustment. MS confirms the same to BS when the timing is adjusted. This process is repeated when BS requires timing adjustment with MS.

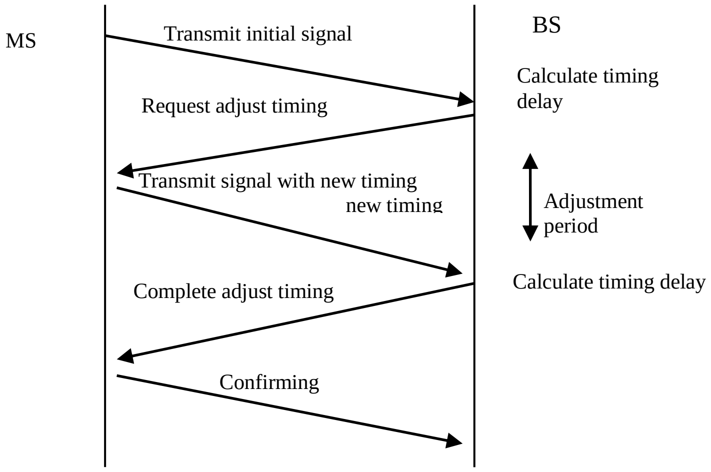


Fig. 3. Timing synchronization process

The signal is received with user specific frequency error ε_m corresponds to the transmitted signal of mth user is given as

$$q_{m,i} = \left|erfc(n)\varepsilon_m r_x\left((i-1)N_f + L_t\right)\right| \sum_{m=1}^{M}\left(\delta(n-(m-1)L_s)\right) \tag{3}$$

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. δ(n) is the kronecker delta function and erfc(.) is a complimentary error function and n is the index of PN sequence.

The correlation peak corresponds to mth user of ith signal frame [10] is given as

$$q_{m,i}((m-1) * L_s = \left|erfc(n)\varepsilon_m r_x\left((i-1)N_f + L_t\right)\right| \tag{4}$$

Similarly, the correlation peak corresponds to mth user of (i+1)th frame [10] is given as

$$q_{m,i+1}((m-1)*L_s = \left|erfc(n)\varepsilon_m r_x\left((i)N_f+L_t\right)\right| \tag{5}$$

B. *Channel Estimation*

The received PN sequence is circularly correlated with the local PN sequence [13]. Thus, GI is protected due to cyclic extension and the channel estimation is performed with perfect sequence as

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

where v_i is additive white Gaussian noise with zero mean and variance σ^2.

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

$$q_i = \sum_{m=1}^{M}P_{m,i}\otimes h_{m,i} = \left(\sum_{m=1}^{M}\widetilde{P_{m,\imath}}\, h_{m,i}+v_i\right) \tag{7}$$

$$q_i = \left[\widetilde{P_{1,\imath}}\ \ \widetilde{P_{2,\imath}}\ \ \widetilde{P_{3,\imath}}\ \ \dots\dots\dots.\ \ \widetilde{P_{m,\imath}}\right]\begin{bmatrix} h_{1,i}\\ h_{2,i}\\ \vdots\\ \cdot\\ \vdots\\ h_{m,i}\end{bmatrix}+v_i \tag{8}$$

$$q_i = P_i h_i + v_i \tag{9}$$

where $\widetilde{P_{m,\imath}}$ is N_pXN_s circular matrix derived from $P_{m,i}$, $P_i = \left[\widetilde{P_{1,\imath}}\ \widetilde{P_{2,\imath}}\ \widetilde{P_{3,\imath}}\ \dots\dots\dots.\ \widetilde{P_{m,\imath}}\right]$ is N_pXMN_s training matrix and h_i is MN_sX1 channel vector.

Then, the performance of channel estimation is measured using the procedure [4].

The vector $\hat{h}_i$ is computed using maximum likelihood method estimation as

$$\hat{h}_i = (P_i^H P_i)^{-1}P_i^H q_i \tag{10}$$

The Means Square Error (MSE) of (10) is obtained as

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

$$(P_i^H P_i) = \frac{1}{N_p}I_{MN_s} \tag{12}$$

The condition in (12) is satisfied to achieve minimum mean square error using perfect sequence.

According to [7], the perfect sequence is given by the following procedure.

The unit ordered perfect sequence set $X = \{X_l\}_{l=0}^{m-1}$ is defined as,

$$x_l(k) = \exp\left(\frac{i2\pi f_l(k)}{sm}\right) \tag{13}$$

with

$$f_l(k) = mc(s)\alpha(l)k^2+\beta(l)k+f_l(0) \tag{14}$$

where,

$$f(x) = \begin{cases}\frac{1}{2}, & sfor\ even\\ 1, & s\ for\ odd\end{cases} \tag{15}$$

is a function with $\alpha(l)\epsilon Z_s,\ \forall l\epsilon Z_m\ and\ \beta(l)\epsilon Z_{sm}$ with gcd of $(\alpha(l),s)=1$ such that $\beta(l)(mod(m))$ is a permutation of the elements of Z_m and $f_l(0),\ \forall l\epsilon Z_m$ are any rational numbers that are periodically uncorrelated and complimentary respectively.

IV. SIMULATION RESULTS AND DISCUSSION

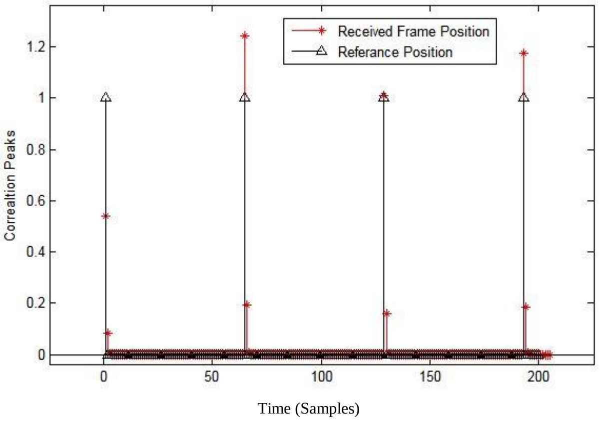
Simulations were performed for joint timing synchronization and channel estimation of TDS-OFDMA under Urban channel, Indoor Office B channel and HIPER LAN-A channel. Four users are considered simulation. Table I shows the parameters considered for the simulation.

Fig. 4 illustrates the performance of timing synchronization under AWGN multipath channel. Fig. 4(a) indicates the correlation peaks of users without timing errors. The starting point of each user frame coincides with its reference position that is known to base station. Fig. 4(b) indicates the correlation peaks of users with timing errors. The timing error is -1 sample, -3 samples, -6 samples, -7 samples for user 1, user 2, user 3 and user 4 respectively.

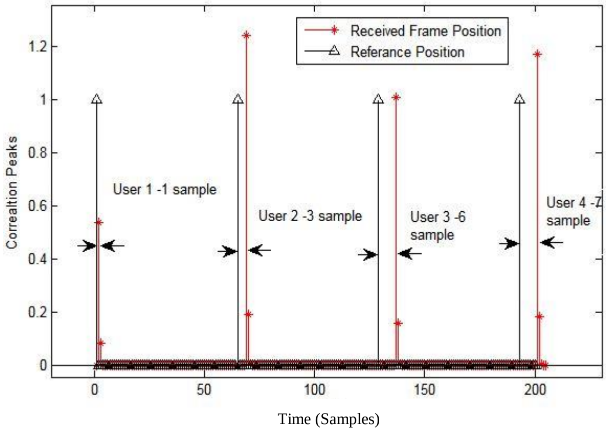
From fig 4(a) and 4 (b), t is seen that the timing synchronization is achieved by counting the position shifts of measured peak with respective reference peak.

TABLE I
SIMULATION PARAMETER

Parameter	Value
Number of Active Users	4
Carrier Allocation Scheme (CAS)	Generalized
System Bandwidth	20MHz
Sub-Carrier Spacing	10.9375kHz
Modulation Scheme	QPSK
Perfect Sequence Length	256
Circular shift in Time Dimension	64
Circular shift in Space Dimension	64



(a) No timing errors for all users



(b) With timing errors

Fig. 4. Timing synchronization under AWGN multi-path channel

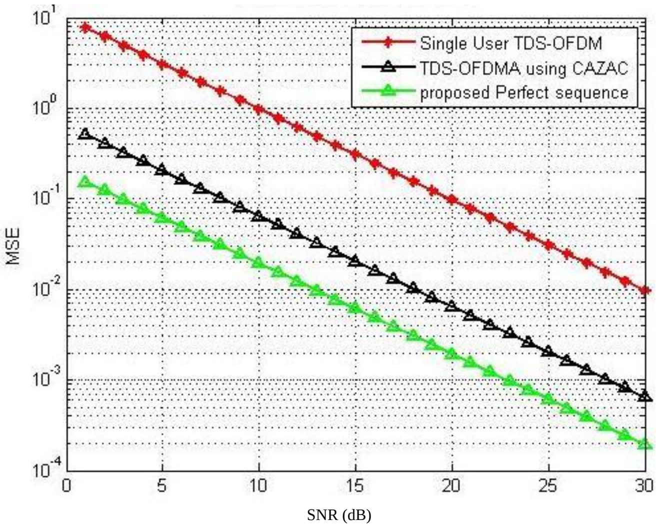


Fig. 5. Channel estimation under 3GPP typical urban channel

Fig. 5 shows the performance of proposed channel estimation using perfect sequence, channel estimation using Constant Amplitude Zero Auto Correlation (CAZAC) sequence in TDS-OFDMA [10] and single user TDS-OFDM [8], [9] using binary PN sequence under 3GPP typical Urban channel. Simulation is performed with CFO of 200Hz. From fig. 5, it is observed that the channel estimation using perfect sequence in TDS-OFDMA outperforms the CAZAC sequence in TDS-OFDMA and binary PN sequence in TDS-OFDM.

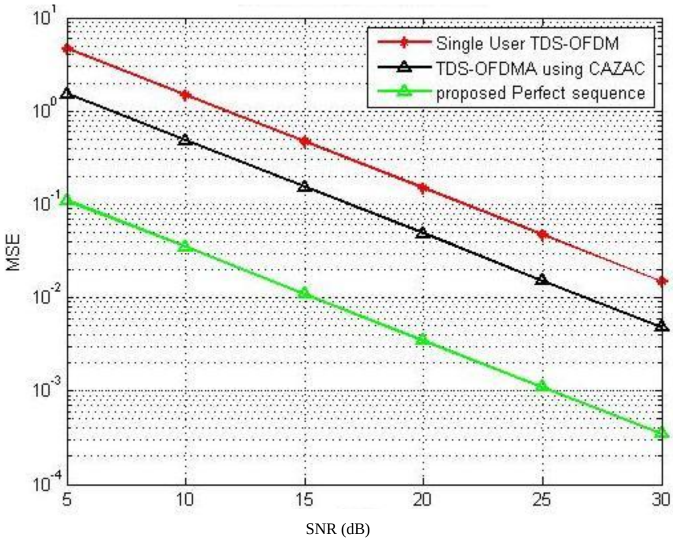


Fig. 6. Channel estimation under Indoor Office B channel

Fig. 6 shows the performance of proposed channel estimation using perfect sequence, channel estimation using CAZAC sequence in TDS-OFDMA and single user TDS-OFDM using binary PN sequence under Indoor Office B channel. Simulation is performed with CFO of 200Hz. From fig. 6, it is observed that the channel estimation using perfect sequence in TDS-OFDMA outperforms the CAZAC sequence in TDS-OFDMA and binary PN sequence in TDS-OFDM.

Fig. 7 shows the performance of proposed channel estimation using perfect sequence, channel estimation using CAZAC sequence in TDS-OFDMA and single user TDS-OFDM using binary PN sequence under HIPERLAN-A channel. Simulation is performed with CFO of 200Hz

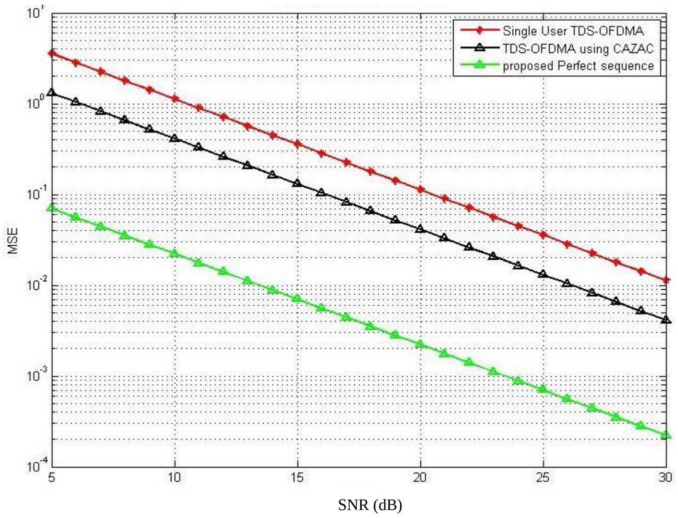


Fig. 7. Channel estimation under HIPER LAN-A channel

From fig. 7, it is observed that the channel estimation using perfect sequence in TDS-OFDMA outperforms the CAZAC sequence in TDS-OFDMA and binary PN sequence in TDS-OFDM.

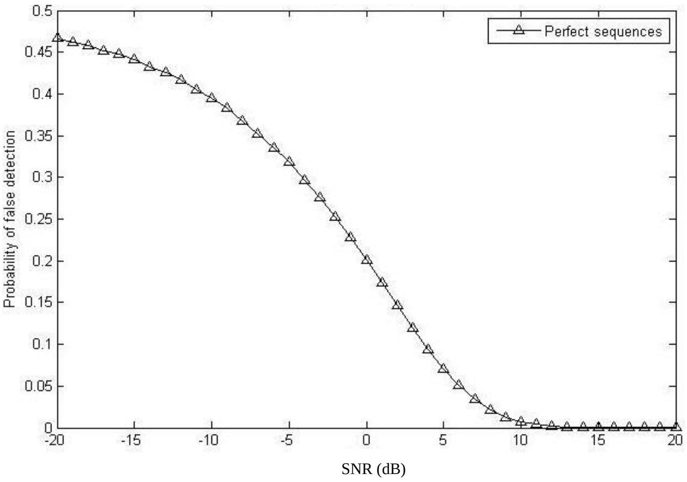


Fig. 8. Probability of false detection under AWGN Channel

The proposed channel estimation using perfect sequence in TDS-OFDMA is better due to accurate autocorrelation of perfect sequence. The channel estimation is not good using CAZAC and PN sequences due to inter symbol interference (ISI) between guard interval and IDFT block.

Fig. 8 and fig. 9 shows the probability of false detection under AWGN and multipath Rayleigh channel when perfect sequence is used for channel estimation. From fig. 8 and fig. 9, it is observed that synchronization is achieved at signal to noise ratio (SNR) of 5dB using perfect sequence. At SNR=5dB, the detection probability is good.

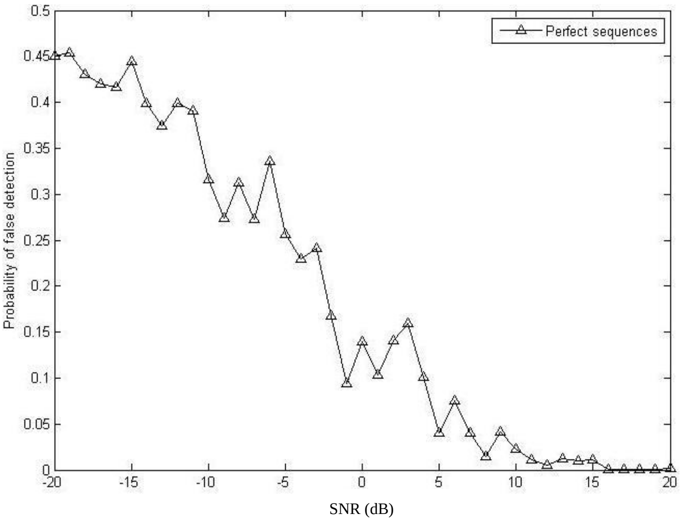


Fig. 9. Probability of false detection under Rayleigh multipath channel

V. CONCLUSION

In this paper, an efficient method for joint timing synchronization and channel estimation in uplink TDS-OFDMA is proposed using perfect sequence. From the simulation results, it is observed that the timing synchronization is achieved and channel estimation performance using perfect sequence is better than CAZAC and PN Sequences under Urban channel, Indoor Office B channel and HIPER LAN-A channel due to accurate auto correlation of perfect sequence. The complexity of uplink TDS-OFDMA is reduced by perfect sequence used as guard sequence instead of cyclic prefix and channel estimation is achieved with same guard sequence. From the simulation results, it is seen that the detection probability is good at low SNR. In future, frequency synchronization can be achieved with minimum MSE using perfect sequence under different fading environment.

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