A Design for OFDMA Receiver

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Abstract—**In this paper, a design for OFDMA receiver is given. Timing synchronization is achieved by ML algorithm with Gold sequence and then multipath delay estimate is achieved by the correlation operation between the local training sequence and the sampled received signal. In order to decrease the overhead for channel estimation, multiple users are combined as a group to share the pilot subcarriers and Walsh codes are used as pilots for different users. For such user group, LS algorithm with the forward estimated delay is adopted to estimate the channels of users. The simulation results show that this receiver can achieve the timing synchroniziton, multipath delay estimate at low SNR and good BER performance with accurate channel estimation.**

Index terms—**OFDMA, TDD, Synchronization, Channel estimation**

I. INTRODUCTION

For Orthogonal Frequency Division Multiple Access (OFDMA) systems, each user occupies different subcarriers and this access scheme could offer dynamic user capacity, and lower interference to adjacent cells [1-2]. It has been adopted in 802.16e and it is an attractive candidate system for Beyond 3G systems [3].

In such system, the task of receiver is to recover the transmitted information as accurately as possible. In order to achieve this target, the synchronization and channel estimation are two key modules as shown in Fig.1. Synchronization, which includes the timing and frequency offset estimate, is the first module at the receiver side. Timing synchronization deals with time instance for the start of received OFDM frame. Frequency synchronization involves the estimate of the frequency offset between the transmitter and receiver local oscillators. Besides, the multipath delay estimate is required for the channel estimation schemes [4]. Channel estimation is tracking the variance of amplitudes and phases of wireless channel. Its accuracy seriously affects the performance of the system. However, the pilot overhead, which is the number of pilots used for channel estimation, and the accuracy is a tradeoff. Therefore, how to use less pilots tracking fast time varying channel is the challenge for system design.

In this paper, timing synchronization is achieved by the correlation operation between Inverse Fast Fourier Transform (IFFT) of the local training sequence and the sampled received signal that involves a given training symbols [5]. The presented multipath delay estimate algorithm based on the training sequence utilizes the peak autocorrelation property of a PN sequence. The combination of m-sequences and Gold sequence is exploited to perform timing and multipath delay estimate at the receiver side.

Furthermore, we also propose to combine some users as a group to share the pilot subcarriers and Walsh codes are used as pilots for different users. Pilot arrangement in each slot is designed and with the estimated multi-path delay, Least Square (LS) algorithm is adopted to estimate the channel with lower overhead. The simulation results show that it supplies the accurate estimation of channel and is robust to Doppler frequency shift. In section II the method for synchronization and multi-path delay estimate is described in detail. In section III the uplink time-frequency channel response is derived for OFDMA system and the proposed channel estimation algorithm is described. In section IV the simulation results and analysis are given and finally the conclusions are achieved.

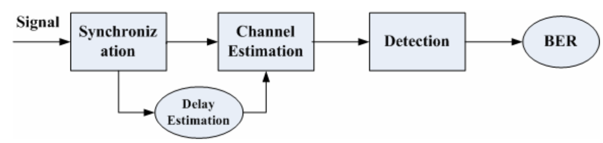

Fig. 1 The OFDMA receiver structure

II. SYNCHRONIZATION AND DELAY ESTIMATION

Consider an OFDMA system with k users. The size of IFFT window is N. Frame is the data transmission unit.. In every frame, two synchronization slots are assigned. The former slot is for downlink synchronization and the latter is for uplink synchronization. Training sequences for timing synchronization are designed as Gold sequences with peak autocorrelation and zero crosscorrelation properties, and training sequences for multipath delay estimate are assigned as m-sequences with peak autocorrelation property. Fig.2 shows the frame structure composed of synchronization and data slots.

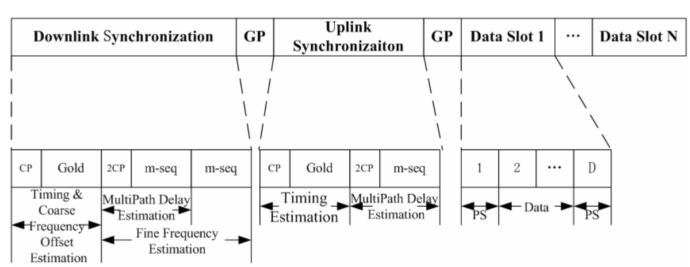

Fig. 2 Frame structure

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A. *Timing Synchronization Scheme*

In this paper, the timing algorithm is implemented both in uplink and downlink. Frame and symbol synchronization can be accomplished by the correlation operation between the local training sequence and the sampled received signal. The principle of the timing synchronization algorithm is:

$$A(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} a(k) \cdot e^{j2\pi kn/N}. \quad (1)$$

$$B(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} b(k) \cdot e^{j2\pi kn/N}. \quad (2)$$

Where, $a(k)$ and $b(k)$ are sequences in the frequency domain. $A(n)$ and $B(n)$ are their corresponding transform in the time domain. So, the equation can be concluded below:

$$\sum_{n=0}^{N-1} A(n)B(m-n) = \sum_{k=0}^{N-1} a(k)b(k)e^{j2\pi km/N}. \quad (3)$$

$$\sum_{n=0}^{N-1} A(n)B(-n) = \sum_{k=0}^{N-1} a(k)b(k) \quad (4)$$

In (4), it is considered that the correlation operation in the frequency domain is equivalent to that in the time domain, and the quantity of the IFFT operations in the receiver is reduced because of that. Consider complex number,

$$\sum_{n=0}^{N-1} A(n-m)B^*(n) = \sum_{k=0}^{N-1} a(k)b^*(k)e^{j2\pi km/N} \quad (5)$$

$$\sum_{n=0}^{N-1} A(n)B^*(n) = \sum_{k=0}^{N-1} a(k)b^*(k) \quad (6)$$

Where * means complex conjugate operation.

It is assumed that $C(n)$ is the IFFT of the local training sequence, which is obviously a sequence in the time domain. $R(n)$ is the received signal. Then the optimum timing acquisition can be given by:

$$\hat{d} = \max_{d} \Lambda(d) = \max_{d} \left| \sum_{n=0}^{N-1} R(n+d) \cdot C^*(n) \right| \quad (7)$$

Absolute value contributes to consider the random phase of different transmit antennas.

B. *Multipath Delay Estimate Algorithm*

It is supposed that there are *n* paths where the correlation value isn't negligible compared to the noise power, namely there are *n* paths' delay can be achieved by detecting. The implementation is as follows:

1) Choose *n* maximums among all the autocorrelation value in a frame.

$$\hat{\tau}_i = \max_{d(i)} \Lambda(d(i)) = \max_{d(i)} \left| \sum_{n=0}^{N-1} R(n+d)M(n) \right| \quad (8)$$

$$i = 0, \cdots, n-1$$

Where, $M(n)$ denotes the local training sequences used to estimate multipath delay, which is different from $C(n)$ used to estimate multi-antenna timing in (7).

2) It is found that multipath delay $\hat{\tau}_i$ ($i = 0, \cdots, n-1$) estimated in every frame will bring some error because of the effect of a multipath fading channel. In this paper, probability statistics for multipath delay of multi-frame is performed to decrease the effect of a fading channel and improve the performance. It is assumed that altogether there are *w* frames attached to the probability statistics. The value of *w* should be adapted to the variety of multipath delay in a fading channel, the birth of new path and the vanishing of old path. *w=10* is acceptable in the simulation presented in this paper. *n* multipath delay can be detected from (8) in a frame. Altogether, $w \times n$ chosen multipath delay is concerned with the probability statistic. *n* multipath delay which appears the most frequently is chosen from that, and is decided as the *i* th ($i = 0, \cdots, n-1$) path delay according to the magnitude order of the autocorrelation value.

III. GROUP LS CHANNEL ESTIMATION

In previous sections we have described a scheme for delay estimation, a channel estimation method with known delay is proposed in this section. For OFDMA systems, the different user will occupy the different subcarriers. In Fig.4, one example is given and the user number of system is K_{multi}. Here we assume that kth user specified subcarrier index belongs to the set $S_k = \{\mu_k + v \cdot d \,|\, v = 0, \cdots, V\}$, $\mu_k, v, d \in \mathrm{Z}$, which means each user has V subcarriers totally. Moreover, μ_k is the start offset and belongs to $\{0, 1, \cdots, d-1\}$. d is the distance between two adjacent subcarriers of one user. We can define channel time-frequency response of user k is:

$$H_k(n, \mu_k + v \cdot d) = \sum_{i=0}^{L-1} \gamma_{k,i}(n) e^{-j\frac{2\pi}{N}\lfloor BW \cdot \tau_{k,i} \rfloor \mu_k} e^{-j\frac{2\pi}{N}\lfloor BW \cdot \tau_{k,i} \rfloor v \cdot d} \quad (9)$$

in which $v = 0, \cdots, V-1$. BW is the system bandwidth, $\tau_{k,i}$ and $\gamma_{k,i}(t)$ are the delay and the time-variant complex amplitude of path i of user k and $H_k(n, \mu_k + v \cdot d)$ is still FFT of time-delay channel impulse response (CIR).

In Fig.3 (a), a classic TS of TDD system, which is the detail of data block in Fig.2, is given. In each TS, there is D OFDM symbols totally and 2 of them are used as PS for each user separately in order to track their channels. For each user, their PS occupied the same subcarrier location as data. It is clear that the overhead for estimate is $2/D$ in such arrangement. However, the value of D is decided by the coherence time of channel and for higher mobility (250km/hour), its value decreases obviously. So the overhead in this case increases rapidly and becomes unacceptable.

In this section, a user group is proposed and with such assumption, the TS is designed with the overhead $1/D$. Then LS algorithm is derived for uplink OFDMA system, named as group LS.

A. Principle of User Group

Here we define U_G users to form a group and they occupy the same pilot location P_G. The orthogonal codes with length V are used as pilots to distinguish the different users. In Fig.4, the principle of user group is plotted. Here user 0 and user 1 are combined as group 0 and the overlapped PS could be distributed at $P_{G0} = S_0 \; or \; S_1$. As for the information bits, they are still mapped as the user specific location, that is $S_k = \left\{ \mu_k + v \cdot d \,\middle|\, v = 0, \cdots, V \right\}$. So the multiple-user scheme is still OFDMA.

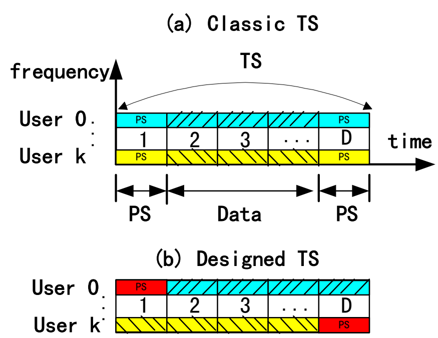

Fig .3 The Structure of TS

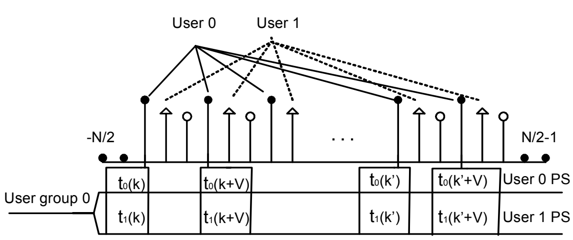

Fig .4 The Principle of User Group

With such group definition, the structure of TS could be designed as Fig.3 (b). At the start of TS, PS of two users are overlapped in subcarrier S_0 and at the end of TS, they are allocated at S_1. With the help of LS algorithm given later, the channel could be estimated for both users in frequency domain firstly. Then linear interpolation in time domain could be utilized to estimate the channel for whole data block.

We define $\mathbf{h}_i = \left(\gamma_{i,0}, \gamma_{i,1}, \cdots, \gamma_{i,L-1}\right)^T$ $i = 0,1$ is the CIR vector of user i and we omitted the time index for we assume ISI is avoided for the length of CP is longer enough. So, at the start of TS, the received signal after FFT demodulator could be expressed in matrix form as:

$$\mathbf{X}_{G0}{}^0 = \mathbf{T}_0{}^0\mathbf{W}_0{}^0\mathbf{h}_1 + \mathbf{T}_1{}^0\mathbf{W}_1{}^0\mathbf{h}_2 + \mathbf{w}^0 \qquad (10)$$

$$\mathbf{X}_{G0}{}^0 = \left\{ X_{G0}{}^0(k) \,\middle|\, k \in S_0 \right\}^T$$

At the end of TS, the received signal is:

$$\mathbf{X}_{G0}{}^1 = \mathbf{T}_0{}^1\mathbf{W}_0{}^1\mathbf{h}_1 + \mathbf{T}_1{}^1\mathbf{W}_1{}^1\mathbf{h}_2 + \mathbf{w}^1 \qquad (11)$$

$$\mathbf{X}_{G0}{}^1 = \left\{ X_{G0}{}^1(k) \,\middle|\, k \in S_1 \right\}^T$$

Where $X_{G0}{}^0(k)$ represents the received signal of subcarrier k at user 0's subcarrier index. $\mathbf{W}_k$ is $V \times L$ Fourier transform matrix and it is given in equation (12).

$$\mathbf{W}_k = \begin{bmatrix} e^{-j\frac{2\pi}{N}S_k(0)M_{k,0}} & \cdots & e^{-j\frac{2\pi}{N}S_k(0)M_{k,L-1}} \\ e^{-j\frac{2\pi}{N}S_k(1)M_{k,0}} & \cdots & e^{-j\frac{2\pi}{N}S_k(1)M_{k,L-1}} \\ \vdots & \cdots & \vdots \\ \vdots & \cdots & \vdots \\ e^{-j\frac{2\pi}{N}S_k(V-1)M_{k,0}} & \cdots & e^{-j\frac{2\pi}{N}S_k(V-1)M_{k,L-1}} \end{bmatrix}$$

(12)

$\mathbf{T}_i$ is a $V \times V$ diagonal matrix with element $t_i(k)$ is the PS at k subcarrier of user i.

Likewise,

$$\mathbf{T}_i^0 = \begin{bmatrix} t_i(S_0(0)) & 0 & \cdots & 0 \\ 0 & t_i(S_0(1)) & & 0 \\ \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & t_i(S_0(V-1)) \end{bmatrix} \quad i = 0,1$$

(13)

and

$$\mathbf{T}_i^1 = \begin{bmatrix} t_i(S_1(0)) & 0 & \cdots & 0 \\ 0 & t_i(S_1(1)) & & 0 \\ \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & t_i(S_1(V-1)) \end{bmatrix} \quad i = 0,1$$

(14)

$\mathbf{w}^i = \left\{ w(k) \,\middle|\, k \in S_i \right\}^T$ is the additive White Gaussian noise vector with zero mean and variance matrix $\sigma^2\mathbf{I}$. $\mathbf{W}_k^i$

is $V \times L$ Fourier transform matrix with subcarrier index S_i of user k.

Equation (10) can be simplified to:

$$\mathbf{X}^i = \mathbf{T}^i \tilde{\mathbf{W}}^i \mathbf{h} + \mathbf{w}^i \quad (15)$$

Where $\mathbf{T}^i = [\mathbf{T}_0{}^i, \mathbf{T}_1{}^i]$ and $\tilde{\mathbf{W}}^i = \begin{pmatrix} \mathbf{W}_0{}^i & 0 \\ 0 & \mathbf{W}_1^i \end{pmatrix}$, $\mathbf{h} = \begin{bmatrix} \mathbf{h}_0 \\ \mathbf{h}_1 \end{bmatrix}$. Here we define $\mathbf{A}^i = \mathbf{T}^i \tilde{\mathbf{W}}^i$ in order to express the matrix simply.

B. Group LS

LS is originally proposed for mutli-antenna scenario and the principle and performance has been studied in [6-8]. We propose to form the user group and each user is similar to one antenna. Then LS is used to estimate the overlapped channel CIR and we called it as group LS. It is:

$$\hat{\mathbf{h}}_{LS} = \mathbf{A}^{\dagger}\mathbf{X} \quad (16)$$

Where $(\bullet)^{\dagger}$ represents the pseudo inverse operation. If such operation stands, then $U_G \cdot L \le V$ should be satisfied firstly. Here equation (16) can also be expressed as:

$$\begin{aligned} \hat{\mathbf{h}}_{\text{LS}} &= \mathbf{A}^{\dagger}(\mathbf{A}\mathbf{h} + \mathbf{w}) = \mathbf{h} + \mathbf{A}^{\dagger}\mathbf{w} \\ &= [\hat{\mathbf{h}}_0; \hat{\mathbf{h}}_1] \end{aligned} \quad (17)$$

After getting $\hat{\mathbf{h}}_{LS}$, we can have the estimated channel frequency response for each user separately as:

$$\hat{\mathbf{H}}_0 = \mathbf{W}_0 \hat{\mathbf{h}}_0 \quad (18)$$

$$\hat{\mathbf{H}}_1 = \mathbf{W}_1 \hat{\mathbf{h}}_1 \quad (19)$$

With the help of LS, the channel in frequency domain is gotten firstly. Then the interpolation in time-domain is used to estimate the channel for whole data block.

IV. SIMULATION RESULTS AND DISCUSSIONS

In order to evaluate the algorithm proposed, the simulation will be given in the section. The main parameters of the simulation are listed in Table 1. The fading channel is the ITU-R channel model A-Vehicular situation, of which path number L is equal to 6.

Table 1 The simulation parameters

Carrier frequency	2GHz
Bandwidth	16MHz
FFT length	1024
Used carriers	832
CRC bits	20
Channel Coding	Convolutionary R=1/2, m=7
Modulation scheme	QPSK

With the proposed synchronization method, timing delay can be detected totally while SNR is larger than -5dB. Fig.5 shows the detection probability of multipath delay estimate, which was obtained with varying SNR from -4 dB to 8 dB. The proposed multipath delay estimate method is practical even at low SNR. The simulation result shows the detection probability of 98% for the path which fading coefficient is -20dB is obtained at SNR of 0 dB.

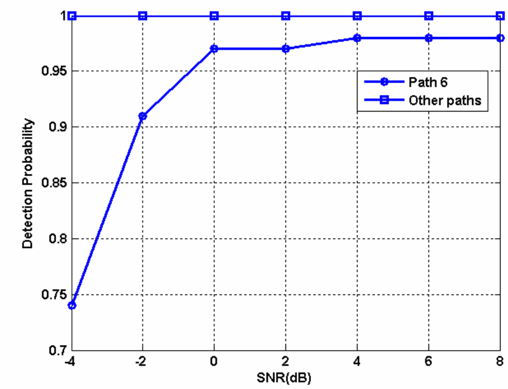

Fig .5 Detection probability of the multipath delay estimate

In Fig.6 the performance of the simulation link with the different known paths is given. The performance of five known path delay has the better performance compared to that of six known at low SNR. The reason comes from the sixth path has the weak power (-20dB) and this path are affected by noise greatly at low SNR. The performance of four known is degraded obviously compared to that of six known. The reason comes from the fifth path has the strong power (-15dB and cant be ignored anymore). So if the delay of strong paths could be estimated, then the proposed channel estimation algorithm could still be used. In fact, with the help of Multipath Delay Estimate Algorithm proposed in section II, strong paths (higher than -15dB) could be estimated accurately.

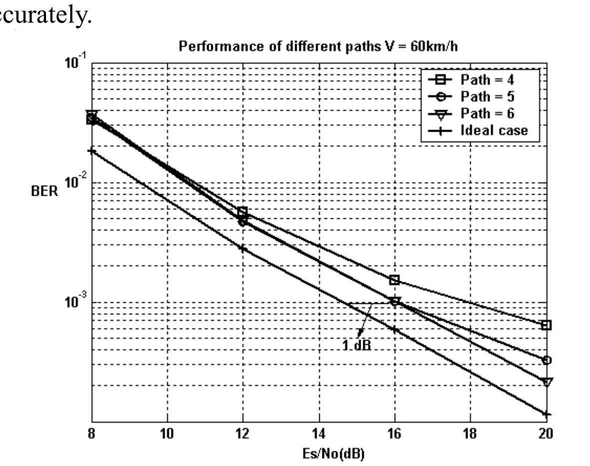

Fig.6 Performance of Uplink with the different estimated paths

V. CONCLUSIONS

In this paper, timing synchronization, multipath delay estimate scheme and Group LS channel estimation for

OFDMA system are presented. Timing synchronization is achieved by ML algorithm with Gold sequence and then multipath delay estimation is achieved by the correlation operation between the local training sequence and the sampled received signal. Probability statistics for multipath delay of multi-frame are introduced to improve the multipath delay estimate performance. Then several users are combined as a group to share the pilot subcarriers in OFDMA systems and Walsh codes are used as pilots for different users. Pilot arrangement in each slot is designed and overhead could be decreased to half for TDD TS. For such user group, LS algorithm is adopted to estimate the channel. The simulation results show that it supplies the accurate estimation of channel (lower than 120km/hour) with decreased overhead.

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