Comparison of ML Carrier Estimation Schemes Based on APSSB and Preamble for OFDMA in Fading Channel

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Abstract—**The paper proposes a novel estimation scheme of carrier frequency offset (CFO) based on Added Preamble Sequence Semi-Blind (APSSB) scheme. The proposed maximum-likelihood (ML) CFO estimator is based on APSSB OFDMA model in which Gold sequence is added to the output of IFFT modulator and exploited for CFO estimation at the receiver. CFO estimators based on APSSB scheme and preamble are compared by both SINR analysis and simulation. We propose that the APPSB scheme should be employed for fine frequency synchronization in OFDMA especially in delay-insensitive service.**

I. Introduction

In recent years, orthogonal frequency division multiplexing access (OFDMA) has been suggested and standardized for high-speed communications. In OFDM, the available bandwidth is sliced into narrow subchannels so that each channel is subject only to flat fading. OFDM is the standard modulation scheme in Europe for Digital Audio Broadcasting (DAB) and Terrestrial Digital Video Broadcasting (DVB). OFDMA forms the basis for the physical layer in upcoming standards for broad-band wireless local Area Networks (Hiperlan/2), IEEE802.11a and Multimedia Mobile Access Communication Systems (MMAC) [1].

In order to attain spectral efficiency when compared to well-known frequency division multiplexing (FDM), OFDM carriers have overlapping spectra. The carrier frequency offset between the transmitter and the receiver local oscillators causes self-interference between the carriers. OFDM is very sensitive to carrier frequency offset. Estimation and correction of carrier frequency offset from noisy data is a difficult but important task, since this enables mitigation of unwanted interchannel interference in OFDM [2].

One of the most available CFO estimation schemes for OFDMA is based on preamble in the front of every frame. However, the accuracy of CFO estimation is limited by preamble symbol number and data rate decreases due to preamble. Many papers have investigated the CFO estimation scheme based on preamble ([3]-[8]). In addition, some blind CFO estimation schemes have been proposed, but most of them are characterized by large complexity ([9]-[11]).

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In this paper, we propose the APSSB OFDMA model in which APSSB sequence is added to the output of IFFT modulator. The APSSB sequence is exploited for CFO estimation by correlation detection with the local APSSB sequence at the receiver. Comparison of SINR is made between CFO estimation schemes based on APSSB and preamble. The APSSB scheme suffers no data rate loss, and is more accurate than preamble scheme when APSSB symbol number for CFO estimation is large enough to excess the threshold. Compared with preamble scheme, the APPSB scheme has the property of better accuracy as well as larger delay. We propose the APPSB scheme should be employed for fine frequency synchronization in delay-insensitive service.

The rest sections of the paper are organized as follows. In Section 2, the proposed APSSB OFDMA system model is described. Based on this model, section 3 presents the ML CFO estimation scheme based on APSSB. A comparison is made in section 4 in terms of SINR of the two schemes in fading channel. Simulation and analysis are presented in section 5. Finally, section 6 concludes the paper.

In this paper, we use the superscripts $(\cdot)^T$, $(\cdot)^H$, $(\cdot)^*$, $|\cdot|$, $\|\cdot\|$ and $Diag\{\ \}$ to denote the operations matrix transpose, Hermitian complex conjugation, the 2-norm and diagonal matrix, respectively. Variables or matrices like the form of *t or *f denote time-domain or frequency-domain variables or matrices respectively.

II. System Description

Fig. 1 shows the APSSB OFDMA model. We consider the uplink of an OFDMA system employing N subcarriers and accommodating a maximum of K simultaneously active users. Each user transmits on a set of L assigned subcarriers. In one symbol duration of the kth user, the output of IFFT modulator can be denoted as follows:

$$Dt^{(k)} = W \cdot STP^{(k)} \cdot Cf^{(k)} \quad (1)$$

where

$$Cf^{(k)} = \{cf^{(k)}(0), cf^{(k)}(1), \ldots, cf^{(k)}(L-1)\}^T \quad (2)$$

$$Dt^{(k)} = \{dt^{(k)}(0), dt^{(k)}(1), \ldots, dt^{(k)}(N-1)\}^T \quad (3)$$

$$STP^{(k)} = \{STP^{(\mathrm{k})}(m,n)\}_{N\times L}$$

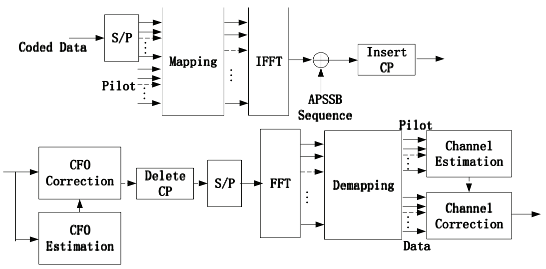

Figure 1. Block diagram of the proposed APSSB OFDMA

$$STP^{(k)}(m,n)=\begin{cases}1, m=d^{(k)}(l), 0\le n=l\le D^{(k)}-1\\ 0, otherwise\end{cases} \quad (4)$$

$$W=\{W(m,n)\}_{N\times N}$$

$$W(m,n)=e^{\frac{j2\pi mn}{N}}/\sqrt{N} \quad (5)$$

where $D^{(k)}$ is the data subcarrier number of the kth user, and $\{d^{(k)}(0),d^{(k)}(1),...,d^{(k)}(D^{(k)}-1)\}$ is the subcarrier index set assigned to the kth user.

User-specific Gold sequence with the same length as the subcarrier number assigned to one user is added to the output of IFFT modulator.

The power ratio of data to APSSB sequence is defined as:

$$DPR=\sigma_D^2/\sigma_P^2 \quad (6)$$

where σ_D^2 and σ_P^2 are the variances of data and APSSB sequence respectively.

We assume that the channel is wide sense stationary uncorrelated scattering (WSSUS). Hence, the time-domain correlation of the channel response can be written as:

$$r_t(\Delta t)=J_0(2\pi f_d \Delta t) \quad (7)$$

where f_d is the maximum Doppler frequency and $J_0(\cdot)$ is the zero-order Bessel function of the first kind [12].

After passing a WSSUS channel, the received signal can be denoted by:

$$Rt=\sum_{k'=1}^{K}\sum_{q=1}^{Q_{k'}}Ht_q^{(k')}W_q^{(k')}(Dt_q^{(k')}+PSt_q^{(k')})+Wt \quad (8)$$

and the receive signal at the *m*th receive antenna b where

$$Rt=\left\{rt(0),rt(1),\dots,rt(N-1)\right\}^T \quad (9)$$

$$Ht_q^{(k)}=\left\{Ht_q^{(k)}(m,n)\right\}_{N\times N}$$

$$Ht_q^{(k)}(m,n)=\begin{cases}ht_q^{(k)}(m)e^{jw^{(k)}(m-n)}, m\ge n=\tau_q^{(k)}\\ 0, otherwise\end{cases} \quad (10)$$

$$W_q^{(k')}=e^{-jw^{(k)}\tau_q^{(k)}}Diag\{1,e^{jw^{(k)}},\dots,e^{jw^{(k)}(N-1)}\} \quad (11)$$

$$Dt_q^{(k')}=\{0,...0,dt^{(k)}(0),\dots,dt^{(k)}(N-1-\tau_q^{(k)})\}^T \quad (12)$$

$$PSt_q^{(k)}=\{0,...0,pst^{(k)}(0),\dots,pst^{(k)}(N-1-\tau_q^{(k)})\}^T \quad (13)$$

$$Wt=\left\{wt(0),wt(1),\dots,wt(N-1)\right\}^T \quad (14)$$

where the delay spread of the kth user is $\tau^{(k)}=\left\{\tau_1^{(k)},\tau_2^{(k)},\dots,\tau_{Q_k}^{(k)}\right\}$, and Q_k is the path number of the kth user. $ht_q^{(k)}(m)$ is the channel impulse at the mth sample of the qth path of the kth user. $w^{(k)}=2\pi\overline{f^{(k)}}/N$, where $\overline{f^{(k)}}$ is the normalized CFO, which could be due to Doppler effects and mismatch between the transmitter and receiver oscillators and. $PSt^{(k)}$ is the APSSB assigned to kth user. Wt denotes zero-mean additive white Gaussian noise (AWGN) [13].

III. ML CFO Estimation Scheme Based on APSSB

Without loss of generality, we suppose that the path with the maximum power is the first path of each user. That is,

$$\left\|ht_1^{(k)}(l)\right\|=\max\left\{\left\|ht_q^{(k)}(l)\right\|\right\}, l=0,...,N-1 \quad (15)$$

In ML APSSB CFO estimation scheme, the CFO of the kth user can be estimated by one symbol as follows:

$$\begin{aligned}\widehat{w}^{(k)}&=\arg\max_w\{\left\|PSt_1^{(k)*}W'Rt\right\|\}\\&=\arg\max_w\{\left\|PSt_1^{(k)*}W'Ht_1^{(k)}W_1^{(k)}PSt_1^{(k)}\right.\\&+PSt_1^{(k)*}W'Ht_1^{(k)}W_1^{(k)}Dt_1^{(k)}\\&+PSt_1^{(k)*}W'\sum_{q=2}^{Q_k}Ht_q^{(k)}W_q^{(k)}(Dt_q^{(k)}+PSt_q^{(k)})\\&+PSt_1^{(k)*}W'\sum_{k'\ne k}\sum_{q=1}^{Q_k}Ht_q^{(k')}W_q^{(k')}(PSt_q^{(k')}+Dt_q^{(k')})\\&\left.+PSt_1^{(k)*}W'Wt\right\|\}\end{aligned} \quad (16)$$

where

$$W'=Diag\{1,e^{-jw},\dots,e^{-jw(N-1)}\} \quad (17)$$

The second part in (16) is the interference of Inter-Path Interference (IPI), which is caused by data. The third and fourth parts in (16) are the Multi-Path Interference (MPI) and Multi-Access Interference (MAI) respectively. Due to the quasi-orthogonality of Gold sequence and the uncorrelation between Gold sequence and user data, we can simplify (16) as:

$$\widehat{w}_k = \arg\max_w \left\{ \left\| PSt_1^{(k)*} W'Ht_1^{(k)} W_1^{(k)} PSt_1^{(k)} \right\| \right\}$$
$$= N \left\| ht_1^{(k)} \right\| \arg\max_w \left\{ \left\| W'W^{(k)} \right\| \right\} \quad (18)$$

It is clear that (18) attains its maximum when $\widehat{w}^{(k)} = w^{(k)}$.

IV. SINR Comparison of CFO Estimation Schemes Based on APSSB and Preamble

For fair comparison, we suppose the power of preamble is equal to the power sum of data and APSSB sequence. In this section, we compare the SINR of APSSB scheme and preamble scheme, in which Gold sequence is also employed for CFO estimation. Based on (16), the SINR when $\widehat{w}^{(k)} = w^{(k)}$ of the two estimation schemes are denoted as:

$$SINR_{APSSB} = \frac{N\sigma_{\gamma_0}^2 \sigma_P^2 N_{APSSB}}{\sigma_{IPI}^2 + \sigma_{MPI}^2 + \sigma_{MAI}^2 + \sigma_N^2} \quad (19)$$

$$SINR_{\Pr} = \frac{N\sigma_{\gamma_0}^2 (\sigma_D^2 + \sigma_P^2) N_{\Pr}}{\sigma_{MPI}^2 + \sigma_{MAI}^2 + \sigma_N^2} \quad (20)$$

where $\sigma_{\gamma_0}^2$, σ_{IPI}^2, σ_{MPI}^2, σ_{MAI}^2 and σ_N^2 denote the channel impulse response (CIR) power of main path, the power of IPI, the power of MPI, the power of MAI and white Gaussian noise power respectively, and $\sigma_{IPI}^2 = \sigma_{\gamma_0}^2 \sigma_D^2$. N_{APSSB} and $N_{\Pr}$ denote the symbol numbers exploited by APSSB scheme and preamble scheme respectively.

Based on (19) and (20), we can get the SINR ratio of APSSB scheme to preamble scheme when $\widehat{w}^{(k)} = w^{(k)}$ as follows:

$$\frac{SINR_{\Pr}}{SINR_{APSSB}} = \left(1 + DPR + \frac{DPR}{\frac{1}{SIR} + \frac{1}{SNR}} \right) \frac{N_{\Pr}}{N_{APSSB}} \quad (21)$$

where SNR is the signal-to-noise ratio, and SIR is the signal-to-interference ratio, in which includes MPI and MAI.

From (21), we can see the SINR ratio of APSSB scheme to preamble scheme when $\widehat{w}^{(k)} = w^{(k)}$ is relevant to DPR, SNR, SIR, $N_{\Pr}$ and N_{APSSB}. $SINR_{APSSB} > SINR_{\Pr}$ can be achieved when $N_{APSSB} : N_{\Pr}$ is large enough.

TABLE I.
System Specifications

FFT size	1024
Cyclic prefix	256
Subcarrier number per user	64
Carrier frequency	5GHz
Base bandwidth	20MHz
Modulation scheme	BPSK
Convolution Coding rate	1/2

TABLE II.
Channel Model

Vehicle speed	Dalay (sample)
5km/h	0, 7, 15, 22, 35, 51
120km/h	0, 5, 10, 15

V. Simulation and Analysis

We will compare the performance of CFO estimation schemes based on APSSB and preamble. Main parameters of the OFDMA system are shown in table 1. Two Rayleigh channel models are presented in table 2, in which there are 4 and 6 paths respectively. Scenarios of two active users are simulated in OFDMA system.

Other parameters are listed as follows. Normalized CFOs of the two users are 0.2 and -0.2 respectively. For comparison with APSSB scheme, preamble CFO estimator employs one preamble symbol, and the preamble-to-signal power ratio is 1.

The DPR is an important parameter in APSSB CFO estimation scheme. Smaller DPR leads to more interference of APSSB sequence to data symbols while larger DPR leads to more accurate detection of CFO. There must be a tradeoff in terms of DPR. According to our analysis and simulation, the optimal DPR differs with different channel models. Larger root mean square (rms) delay spread leads to fewer averaging symbols available, which makes the accuracy of channel estimation become the bottleneck. On the other hand, smaller rms delay spread relaxes the requirement for channel estimation, and the accuracy of data symbol detection becomes more important.

In Fig. 2 and Fig. 3, the performance of APSSB CFO

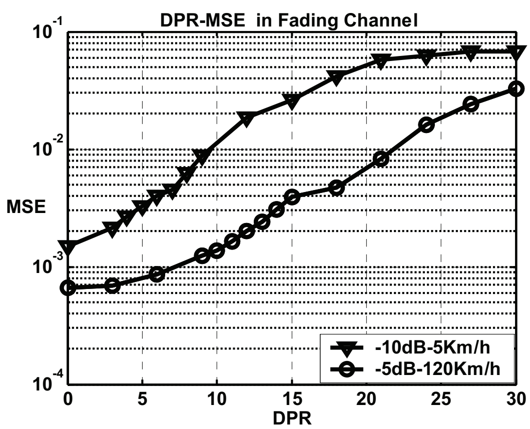

Figure 2. DPR versus MSE

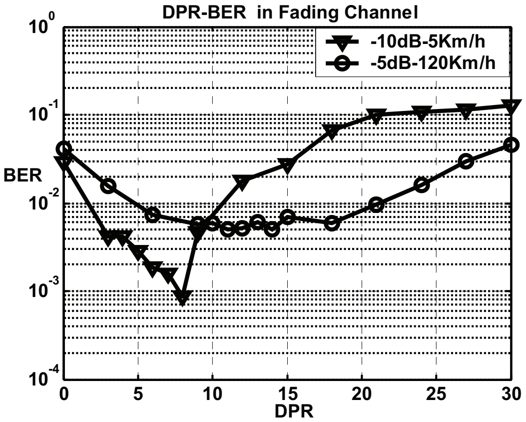

Figure 3. DPR versus BER

estimation is presented when SNR=-10dB for 5km/h scenario and SNR=-5dB for 120km/h scenario. In Fig. 2, the MSE of CFO estimation increases with DPR. In Fig. 3, BER gets its minimum when DPR=8dB for 5km/h and DPR=11dB for 120km/h, which is in good agreement with our analysis above.

We simulate 120km/h scenario to investigate the performance of APSSB and preamble scheme. In Fig. 4, we compare the MSE of CFO estimation schemes based on APSSB and preamble when N_{APSSB} = 8, 10, 15, 20 and $N_{\Pr}$ =1. We can see that the MSE ratio of APSSB scheme to preamble scheme decreases with N_{APSSB}. According to Fig. 4, $N_{APSSB} : N_{\Pr}$ should be nearly equal to 11:1 to achieve the same MSE. We call 11:1 the threshold N_{Th} in this case. Fig. 5 shows the corresponding BER performance. The BER ratio of APSSB scheme to FPFA scheme is a little larger than the MSE ratio because of the interference of APPSB sequence to data.

The comparison of the CFO estimators based on APSSB and preamble can be summarized as follows. APSSB scheme consumes no system bandwidth. Furthermore, CFO can be estimated at the end of any APSSB symbol rather than only in the front of every frame in preamble scheme. APSSB scheme is superior to preamble scheme in terms of accuracy when $N_{APSSB} : N_{\Pr}$ is larger than the threshold N_{Th}. However, the benefits of APSSB scheme are at the cost of a little higher computational complexity as well as larger delay.

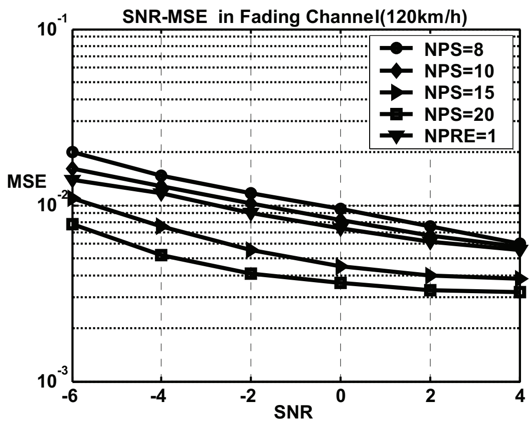

Figure 4. MSE versus APSSB symbol number

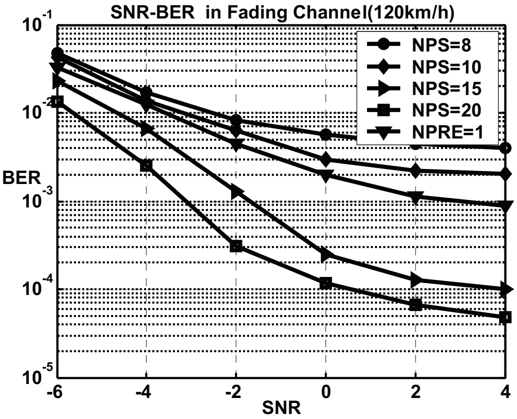

Figure 5. BER versus APSSB symbol number

VI. CONCLUSION

This paper proposes a novel estimation scheme of carrier frequency offset based on APSSB and makes a comparison between CFO estimation schemes based on APSSB and preamble in OFDMA system.

Based on the comparison, we propose a frequency synchronization scheme with the combination of the two schemes. That is, preamble CFO estimation scheme is only employed in the first frame of a new packet for coarse frequency synchronization. The following frames in the packet aren't preceded by preamble, and APSSB scheme is employed for fine frequency synchronization. The proposed synchronization scheme is especially applicable in delay-insensitive services.

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