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Adaptive Pilot Arrangement for Carrier Frequency Offset Estimation

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***Abstract*—In this paper, we propose a novel method for Carrier Frequency Offset (CFO) estimation in Orthogonal Frequency-Division Multiplexing (OFDM) based on adpative pilot arrangement. Since the OFDM transmission is vulnerable to time and frequency offsets, accurate estimation of these parameters is one of the most important tasks of the OFDM receiver. In this paper, we are interrested in CFO estimation. The idea is to use an iterative system which uses as starting state a spacing between the pilot symbols D = 1, then the receiver estimates CFO caused by mobile's movement and sends its value to the transmitter (feedback). If the CFO is in the interval [-0.5 0.5], the transmitter should not change pilot spacing. If the CFO is beyond the interval [-0.5 0.5], the transmitter must change pilot spacing to D = 4. In this way we will keep lower Mean Square Error (MSE) with wide range of CFO and also we will not always use a small pilot spacing which will decrease the throughput. Training sequences used are CAZAC (Constant Amplitude Zero Auto-Correlation) sequences. Simulation results demonstrates the efficiency of this solution : lower MSE with wide range of CFO.**

***Index Terms*—OFDM, CFO, adaptive pilot spacing, CAZAC sequences, MSE, SNR.**

I. INTRODUCTION

Multicarrier modulations are increasingly used in various telecommunication systems such as in Digital Audio Broadcasting (DAB), Digital Video Broadcasting Terrestrial (DVB-T), digital broadband communications, Long Term Evolution (LTE), WiMAX,...

The principle of OFDM is to divide, on a large number of subcarriers, the digital signal that is to be transmitted. So that the frequencies of the subcarriers are as close as possible and transmit the maximum amount of information on a portion of given frequencies, the subcarriers have to be mutually orthogonal. The spectra of different subcarriers overlap but thanks to orthogonality, the subcarriers do not interfere with each other. This technique is conventionally used in systems where the propagation channel is highly frequency selective. In fact, information can be spread over the whole spectrum. This orthogonality between subcarriers is assured as the propagation channel is constant in time. In case of channel variation caused by movement of the mobile, orthogonality between subcarriers is not maintained, creating the inter-carrier interference (ICI).

Dopler frequency generates Carrier Frequency Offset (CFO). The receiver's role is to correct this offset frequency to hold problems caused by ICI. Various researches had been proposed to estimate this CFO [1], [2], [3], [4], [5]... These techniques use training sequences with fixed spacing. For lower spacing, some techniques give good results in term of MSE but with low range of CFO. Others work with wide range of CFO but they give higher MSE.

In this paper, we are interrested in estimating CFO with wide range and lower MSE. We implement an OFDM Transmiter with CAZAC sequences as pilot sequences with adaptive pilot spacing. In reception, a CFO estimator is implemented with feedback (CFO value).

The remainder of this paper is organized as follows. In section 2, we introduce OFDM signal, effect of CFO. Thereafter, Section 3 shows the proposed method. Therefore, the last one shows the performance of this technique in terms of MSE.

II. OFDM SIGNAL AND CFO

OFDM signal is the sum of many independent signals modulated onto subchannels of equal bandwidth. Let us define N symbols in OFDM as $\{X_n, n = 0, 1, \cdots, N-1\}$. The complex baseband representation of a multicarrier signal consisting of N subcarriers is given by :

$$x_l(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_l(k) e^{j2\pi \Delta f k t}; 0 \leq t < NT \qquad (1)$$

Where $j = \sqrt{-1}$, Δf is the subcarrier spacing, l le l^{th} OFDM symbol and NT denotes the useful data block period. In OFDM systems the subcarriers are assumed to be mutually orthogonal (i.e., $\Delta f = \frac{1}{NT}$).

The baseband transmit signal is converted up to the passband by a carrier modulation and then, converted down to the baseband by using a local carrier signal of (hopefully) the same carrier frequency at the receiver. In general, there are two types of distortion associated with the carrier signal [6]. One is the phase noise due to the instability of carrier signal generators used at the transmitter and receiver, which can be modeled as a zero-mean Wiener random process. The other is the carrier frequency offset (CFO) caused by Doppler frequency

	Received signal	Effect of CFO ε on the received signal
Time-domain signal	$y(n)$	$e^{\frac{j2\pi n\varepsilon}{N}}x(n)$
Frequency-domain signal	$Y(k)$	$X(k-\varepsilon)$

TABLE I
THE EFFECT OF CFO ON THE RECEIVED SIGNAL, [7].

f_d. Furthermore, even if we intend to generate exactly the same carrier frequencies in the transmitter and receiver, there may be an unavoidable difference between them due to the physically inherent nature of the oscillators. Let f_c^t and f_c^r denote the carrier frequencies in the transmitter and receiver, respectively. Let f_{offset} denote their difference (i.e., $f_{offset} = f_c^t - f_c^r$). Meanwhile, Doppler frequency f_d is determined by the carrier frequency f_c^t and the velocity v of the terminal (receiver) as :

$$f_d = \frac{v.f_c^t}{c} \tag{2}$$

Let us define the normalized CFO, ε, as a ratio of the CFO to subcarrier spacing Δf , shown as :

$$\varepsilon = \frac{f_{offset}}{\Delta f}$$

The time-domain received signal, with the presence only of CFO (no Phase Noise), can be written as :

$$y_l(n) = \frac{1}{N}\sum_{k=0}^{N-1} H(k)X_l(k)e^{j2\pi(k+\varepsilon)\frac{n}{N}} + z_l(n) \tag{3}$$

Where $X_l(k)$ and $H_l(k)$ denote the k^{th} subcarrier frequency components of the l^{th} transmitted symbol and channel frequency response in the frequency domain respectively, and $z_l(n)$ noise in the time domain.

The table I presents the effect of the carrier frequency offset in time and frequency domain. The frequency shift of $-\varepsilon$ in the frequency-domain signal $X(k)$ subjects to the CFO of ε and leads to an inter-carrier interference (ICI), which means a subcarrier frequency component is affected by other subcarrier frequency components. It is therefore essential to estimate it in order to resolve problmes such as Inter-Carrier Interference.

In this paper, we are interested in estimating CFO in time domain. Let a transmitter sends the training symbols with D repetitive patterns in the time domain, which can be generated by taking the IFFT of a comb-type signal in the frequency domain given as :

$$X_l(k) = \begin{cases} A_m, & \text{if } k = D.i,\ i = 0, ..., (\frac{N}{D} - 1) \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

Where A_m represents an M-ary symbol and N/D is an integer. The receiver make CFO estimation as in [8] :

$$\hat{\varepsilon} = \frac{D}{2\pi} arg\{\sum_{k=0}^{N/D-1} Y_l^*(k)Y_l(k+N/D)\} \tag{5}$$

This CFO estimation is due to that $x_l(n)$ and $x_l(n+N/D)$ are identical, so $y_l^*(n)y_l(n+N/D) = |y_l(n)|^2 e^{j\pi\varepsilon}$.

It is clear that the range of CFO covered by this technique is $|\varepsilon| \leqslant \frac{D}{2}$ but as it is shown in figure 1 that as the estimation range of CFO increases, the MSE performance becomes worse. That is why we try to investigate in this area in order to have a wide range covered by CFO and lower MSE. Our technique will be based on this task : an iterative system using different spacing between pilots.

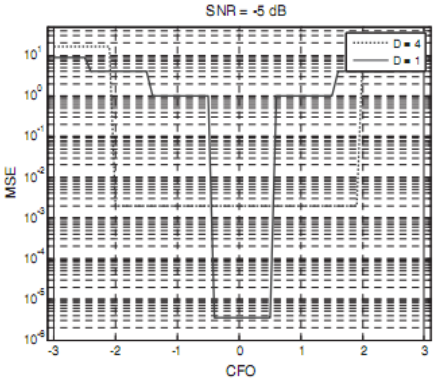

Fig. 1. Estimation range of CFO vs. MSE performance, [7].

III. PROPOSED METHOD

In this section, the proposed method is presented. An iterative OFDM system is used. We use CAZAC sequences as pilot sequences. The pilot sequences are inserted in combo-type model, Fig 3. The Carrier Frequency Offset estimation is done in time domain.

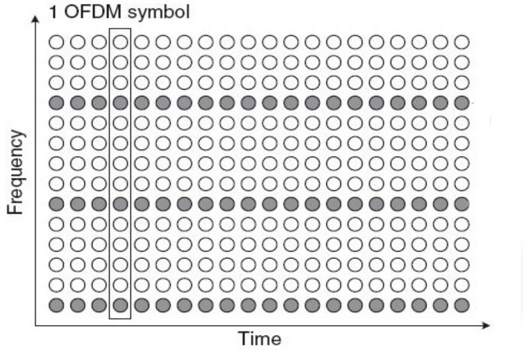

Fig. 2. Comb-Type pilot arrangement

The algorithm is described as follows. First, The transmitter sends pilots with spacing $D = 1$, the receiver estimates the CFO and sends its value value to transmitter. If this CFO is in the range [-0.5 0.5], the transmitter must keep pilot spacing as $D = 1$. If the CFO is beyond the interval [-0.5 0.5], the transmitter must change pilot spacing to $D = 4$.

```
Intial state D =1
    for $OFDM_{symbole} = 1 : T_c : N_{Symbole}$
    receiver estimates CFO sends value to transmitter
        If CFO $\in [-0.5, 0.5]$
            then D=1
            else D=4
        end
    end
Where $T_c$ is coherence time, $N_{Symbole}$ is Total number of OFDM Symbol.
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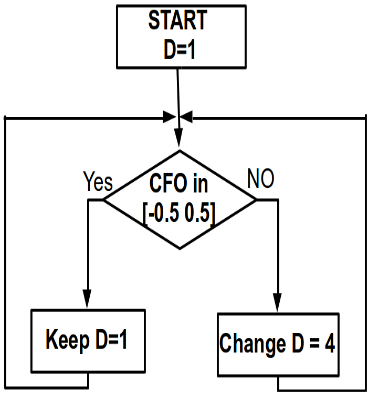

Fig. 3. Algorithm of adaptive pilot spacing

The proposed method synoptic schema is given by figure 4:

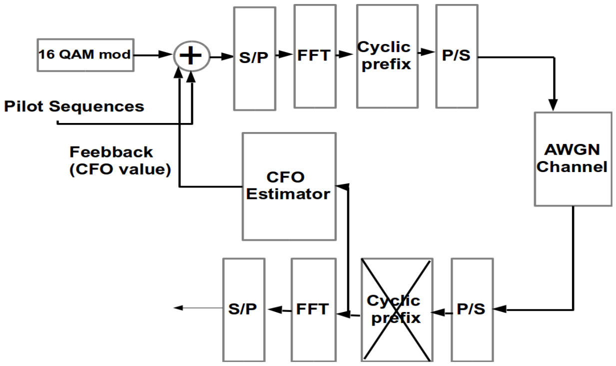

Fig. 4. Block diagram of the proposed method

We will use CFO estimation in time domain with iterative system and CAZAC sequences.

IV. SIMULATION RESULTS AND DISCUSSIONS

To evaluate the performance of the proposed methods, computer simulations are established. Parameters of this simulation are listed in Table II.

Modulation	16 QAM
Number of sub-carrier	128
Cyclic Prefix Length (Ng)	32
Pilot sequences	CAZAC sequences
Number of Bits per Symbol	4
Pilot Spacing (Nps)	1 and 4
Normalized Frequency offset (CFO)	[-3,3]
Signal to Noise Ratio (SNR) range	0:30

TABLE II
THE PARAMETERS FOR SIMULATION.

Figure 5 shows the Mean Square Error (MSE) of the Carrier Frequency Offset (CFO) of the iterative OFDM system using two different pilot spacing and CAZAC sequences for a fixed SNR, such as 15 dB.

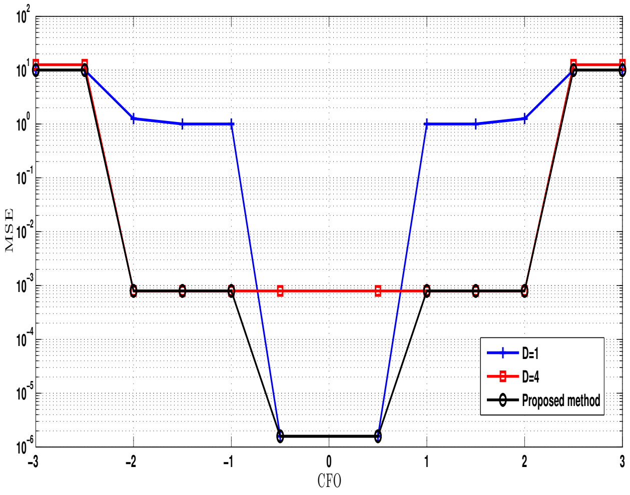

Fig. 5. Estimation range of CFO vs. MSE performance for different pilot spacing and the proposed method.

It is clearly shown in fig 5 that using only pilot spacing as $D = 1$, CFO estimation gives good results but in low range [-0.5 0.5] and also in spite of usuful throughput. Using pliot spacing as $D = 4$ gives a wide range of CFO but higher MSE. The proposed method have the advantage of using each time pilot spacing depending on previous estimated CFO.

Using iterative system covers wide range [-2 2] of CFO with lower MSE. This MSE can reach 10^{-6}. Also, the proposed method doesn't decrease the usuful throughput because it doesn't use only pilot spacing as $D = 1$.

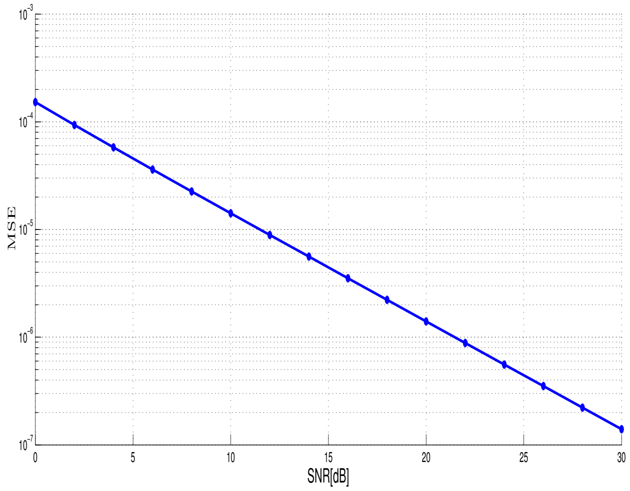

Fig. 6. MSE measure vs SNR with fixed pilot spacing.

Figure 6 gives results for MSE with fixed pilot spacing and CFO = 0.5.

V. CONCLUSION

This paper proposes a new Carrier Frequency Offset (CFO) estimation that uses CAZAC sequences as training sequences with iterative system. The main design criteria of this method is to exploit the advantage of using pilot spacing $D = 1$ (Lower MSE) and $D = 4$ (wide range) with the well-known efficiency of CAZAC sequences in reducing MSE of CFO of the designed system. The system we designed shows attractive performance and stands useful for mobile fading channels.

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