Abstract

In this paper, a low-complexity integer frequency offset (IFO) estimation scheme is proposed for an orthogonal frequency division multiplexing (OFDM) based digital radio mondiale plus (DRM+) system. In order to reduce the complexity of the IFO estimation, this paper addresses a grouping of time reference cell (TRC) pilot subcarriers in DRM+ system. The grouping method of TRCs is using the characteristics of phase rotation between TRC subcarriers. The performance of the proposed IFO estimator is compared with the conventional IFO estimator. The simulation results show that the proposed scheme can effectively achieve similar estimation errors in the IFO estimation as well as can be implemented with reduced computational complexity.

Keywords: digital radio mondiale plus(DRM+), orthogonal frequency division multiplexing(OFDM), integer frequency offset(IFO)

1. Introduction

DRM is an OFDM based digital radio standard which was designed to fit in with the existing AM broadcast band plan [1]. DRM consortium intended DRM to be used on FM frequency up to 120 MHz, called DRM plus (DRM robustness mode E) [2]. This mode, being designed for the FM bands, will use the same channel width as the current FM transmission. Wider bandwidth channels will be used, which will allow radio stations to use a higher bit rate, thus providing higher audio quality. In combination with better sound quality and more reliable reception as the analogue FM as well as the possibility of additional service information and data services. As DRM requires low transmitter powers, it would cost far less to distribute mobile TV over DRM than via either digital multimedia broadcasting (DMB) or digital video broadcasting-handheld (DVB-H) at UHF frequencies.

Since DRM+ uses OFDM modulation which is sensitive to the frequency synchronization error caused by doppler shift or a difference between the oscillators at the transmitter and receiver, results in significant performance degradation. Therefore, the frequency offset estimation is one of the most important procedures for OFDM-based systems. The carrier frequency offset (CFO) is usually divided into an fractional part and integer part. The integer frequency offset (IFO) results in a shift of the subcarrier indices and fractional frequency
offset (FFO) causes inter-carrier interference (ICI) due to loss of orthogonality at the receiver. Several schemes have been proposed in the literature for the estimation of the FFO [3]-[4] and the IFO [5]-[7].

This paper proposes a low-complexity estimation of the IFO in the OFDM-based DRM+ system. By grouping pilot subcarriers into a number of pilot sub-groups and performing IFO estimation for each pilot sub-group, the proposed IFO estimator is computationally very efficient. Based on the simulation, the low-complexity IFO estimation method is tested and verified within the framework of the OFDM parameter and pilot pattern defined in the DRM+ specification [2].

2. Signal Model

Consider an OFDM system employing N subcarriers and N_g guard interval (GI) samples. An OFDM symbol is comprised of N_trc time reference cells (TRCs) and N – N_trc data symbols. In the DRM system, the TRCs are transmitted at a boosted power level of 2 to detect the position of the start of a transmission frame and IFO estimation. The transmitted discrete-time signal period is created by taking the inverse Fast Fourier transform (IFFT) of the stream of complex values as follows

\[ x(n) = \frac{1}{N} \sum_{k} X(k) e^{j2\pi kn/N}, \]  

with

\[ X(k) = \begin{cases} D(k), & k \in D \\ P(k), & k \in P \end{cases} \]

where D denotes the set of N – N_trc data subcarrier indices and P denotes the set of N_trc TRC indices. Define a TRC as

\[ P(k) = \sqrt{2} \cdot e^{j2\pi \theta(k)/1024}, k \in P, \]

where \( \sqrt{2} \) is pilot boost factor and \( 2\pi \theta(k)/1024 \) denotes a predefined phase rotation of the pilot cell. The exact position and phase rotation of TRCs are depicted in [1].

After passing over frequency selective channels, the received signal is

\[ y(n) = h(n) * x(n - \tau) e^{j2\pi (n-\tau) \Delta / N} + w(n), \]

where \( \Delta \) denotes the CFO normalized to carrier spacing, \( \tau \) is the symbol timing offset (STO) normalized to sample interval, \( w(n) \) is the zero-mean AWGN, and \( h(n) \) is the channel’s impulse response. Generally, the CFO is divided into two parts, i.e., \( \Delta = \Delta_s + \Delta_f \) with \( \Delta_s \in \text{int}(\Delta), |\Delta_f| \leq 0.5 \).

To focus on the estimation of IFO, we assume perfect FFO recovery at the receiver and STO is in the inter-symbol interference region of the cyclic prefix duration. Then, the FFT output \( Y(k) \) at the \( k \)-th subcarrier is given by
\[ Y(k) = H(k - \Delta_i)X(k - \Delta_i)e^{-j2\pi(k - \Delta_i)r/N} + W(k) \]  

(5)

where \( H(k) \) is the channel’s frequency response and \( W(k) \) denotes zero-mean complex AWGN.

3. Conventional IFO Estimation Method

The IFO is typically estimated in the frequency-domain either by exploiting two pilot blocks with differential encoding [5] or by using only one pilot block in [6][7] only one pilot block is used. The IFO estimator in [7] is implemented by maximizing the correlation value between the consecutive reference pilot subcarrier and the consecutive pilot subcarrier in the received OFDM symbol. This conventional estimator uses an algorithm based on the inter-carrier differential correlation (AIDS) as follows

\[
\hat{\Delta}_i = \arg \max_{|d| \leq M} \left\{ \sum_{k \in S_p} \bar{Y}_i(k + d) \bar{P}_i(k) \right\},
\]

(6)

where a notation of \( r \) denotes a trial value of \( \Delta_i \), \( \bar{Y}_i(k) = Y_i(k)Y_i^*(k - 1), \bar{P}_i(k) = P_i(k)P_i^*(k - 1) \), \( P_i(k) \) is the pilot known at the receiver, \( M \) denotes the largest expected value of \( |d| \) depending on the frequency stability of the transmitter and the receiver oscillator, and \( S_p \) is the set of \( N_{trc} \) TRC subcarrier indices.

Assuming the absence of the noise, the likelihood function becomes

\[
\sum_{k \in S_p} \bar{Y}_i(k + d) \bar{P}_i^*(k) = \sum_{k \in S_p} H_i(k - \Delta_i + d) X_i(k - \Delta_i + d)
\]

\[ \cdot H_i^*(k - \Delta_i + d - 1)X_i^*(k - \Delta_i + d - 1)P_i(k)P_i^*(k - 1). \]

(7)

Here, \( d = \Delta_i \) and the channel’s frequency response of two adjacent subcarriers are assumed to be nearly identical, i.e., \( H(k) \approx H(k + 1) \). Then, the in-phase correlation value can be represented as

\[
\left| \sum_{k \in S_p} \bar{Y}_i(k + d) \bar{P}_i^*(k) \right|_{d=\Delta_i} = \left| \sum_{k \in S_p} H_i(k)^2 |P_i(k)|^2 |P_i(k - 1)|^2 \right|.
\]

(8)

which means that (6) fails to estimate the frequency offset correctly with increase in frequency selectivity of the channel and the number of pilot used of estimate IFO. The phase of TRCs in the DRM+ system is non-uniformly or randomly distributed in (3) [1], which increases the complexity of the receiver implementation.
4. Proposed IFO Estimation Method for DRM+ System

In this section, a computationally efficient IFO estimation using TRC grouping scheme for OFDM-based DRM+ systems is proposed. The scheme of TRC grouping is used for reducing the computational complexity.

The concept of the TRC grouping is that the non-uniformly distributed TRC group is divided into a number of pilot sub-group. So that the TRCs in each sub-group have unique phase to each other by only phase difference $0, \pm \pi/2$ and $2\pi/3$. The TRC group denoted by $S_p = \{k_1, k_2, \ldots, k_{N_p}\}$. The $n$-th TRC sub-group $S_n$ needs the following condition.

$$R(k) = \frac{P(k_s)P^*(k)}{2} \in \{\pm 1, \pm j\}, k \in S_p,$$

where $k_s$ is the first subcarrier in each TRC sub-group. $R(k)$ is the parameter which determines the $n$-th TRC sub-group. As a result of the TRC grouping, the phase shifts of the TRC subcarriers in each sub-group are highly correlated.

By a simple TRC grouping scheme, one can quickly find that $N_{re} = 21$ TRCs in DRM+ system are divided into 8 sub-groups. Therefore $N_r = 8$ where $N_r$ is the number of TRC sub-group obtained by the TRC grouping scheme. TRC sub-groups denoted by $S_p = \{-81, -80, -79\}, \{-53, -52, -51\}, \{-32, -31\}, \{12, 13, 14\}, \{21, 22, 23\}, \{40, 41, 42\}, \{67, 68\}, \{80, 81\}$.

In order to implement the low-complexity IFO estimation scheme in OFDM-based DRM+ systems, we use the pilot sub-groups designed as in the previous section. Based on (9), the phase-converted signal is expressed as

$$\hat{Y}(k) = H(k)P(k)R(k)e^{-j\pi k_t/N} + \tilde{W}(k), k \in S$$

where $P(k)R(k) = P(k_s)$ and $\tilde{W}(k) = W(k)R(k)$ is statically equivalent to $W(k)$. Based on the above the simple TRC grouping scheme, the proposed IFO estimation method takes expression

$$\hat{\Delta} = \arg \max_{[\hat{\Delta}]} \left\{ \sum_{n=1}^{N_r} \sum_{k \in S_n} \hat{Y}(k+d)\hat{Y}^*(k+d+1) \right\},$$

above the (11) is further derived as

$$\sum_{k \in S_n} \hat{Y}(k+d)\hat{Y}^*(k+d+1) = \sum_{k \in S_n} H(\Delta, X)(k-\Delta, +d)R(k)e^{-j\pi k_t/N}$$

$$\cdot H^*(k-\Delta, +d+1)X^*(k-\Delta, +d+1)R(k+1)e^{-j2\pi(k+1)/N} + \tilde{W}(k).$$

Since each pilot sub-group approximately suffers from flat-fading due to the suitable TRC grouping scheme regardless of the frequency selective of the channel, i.e. $H(k_n) \approx H(k_{n+1})$. 


the sum of correlation when \( k - \Delta_i + d \in S_n \) says that \( d = \Delta_i \) can be rewritten as

\[
\left| \sum_{k \in S_n} \tilde{Y}(k + d)\tilde{Y}^*(k + d + 1) \right|_{d=\Delta_i} = \left| P(k, \Delta_i) \sum_{k \in S_n} |H(k)|^2 e^{-j2\pi i/N} \right|.
\]  

(13)

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<tr>
<th>Table I. System parameters</th>
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<tr>
<td>Duration ( T )</td>
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<td>Carrier spacing ( 1/T )</td>
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<td>Duration of guard interval ( T_g )</td>
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<td>Duration of symbol ( T_s = T + T_g )</td>
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<td>( T_g/T )</td>
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<th>Table II. Channel parameters</th>
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The proposed IFO estimator can be viewed as a low-complexity method of the conventional estimator because the number of complex multiplications use in (10) is reduced by a factor of \( N_{rc}/N_s + 1 \).

5. Simulation Results

In this section, the proposed estimation scheme is evaluate and compared with the conventional method. The system and channel parameters are based n the DRM mode E. We consider five fading environments. Channel models 1-4 are based on EIA channel model, which is widely used in performance analysis of broadcasting system [8]. Channel model 5 is the DAB hilly terrain channel with relatively long echoes [9]. According to the bandwidth of DRM robustness mode E and CM1, CM2 and CM3 are flat-fading channels, while CM4 and CM5 are frequency-selective fading. Details of the system and channel parameters are listed in Table I and Table II. We consider the computational complexity of calculating (6) and (11). The posposed estimator (11) requires \( N_r + 1 \) complex multiplications, while \( N_r \) complex multiplications are needed in (6). The number of complex additions is \( N_{rc} - 1 \) for both approaches.

Figure 1 and Figure 2 present the probability of failure of of IFO estimators, defined by \( \Pr\{\hat{\Delta}_i \neq \Delta_i\} \). Figure 2 shows the probability of failure of estimators when CM1, CM2 and CM3, respectively and used. Figure 4 shows the probability of failure of estimators when CM4 and CM5, respectively. In both examples, the proposed estimators have similar performance with the conventional estimators.
6. Conclusions

This paper proposed a low-complexity IFO estimation scheme for the OFDM-based DRM+ system. To reduce computational complexity, the proposed scheme used grouping method of TRC subcarriers in DRM+ system. The performance of the proposed scheme is compared with the conventional scheme, and it is evaluated computer simulations. The proposed method has very low computational complexity than conventional method and almost similar performance in comparison with the conventional method.

![Figure 1. The Probability of Failure of IFO Estimators versus SNR when CM1, CM2 and CM3](image1)

![Figure 2. The Probability of Failure of IFO Estimators versus SNR when CM4 and CM5](image2)
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References


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