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Re:	802.16-REVd/D4 Sponsor Ballot
Abstract	This contribution introduces a change to the 802.16 OFDM DL preamble which will enable the deployment of low cost Direct Conversion receivers for the subscribers where cost is critical.
Purpose	Adopt into P802.16-REVd/D5 draft.
Notice	
Release	
Patent Policy and Procedures	

OFDM DL preamble enhancement for Zero IF receivers

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1. Introduction

This contribution introduces a change to the 802.16 OFDM DL preamble which will enable the subscriber stations to effectively estimate and compensate I/Q gain and phase imbalances typically introduced by Direct Conversion receivers. This will relax the matching requirements of gain and phase on the DC receiver, hence enabling low cost Direct Conversion receiver implementation for the subscriber stations.

2. The current OFDM preamble

Figure 1 shows the current 802.16 OFDM DL preamble structure.

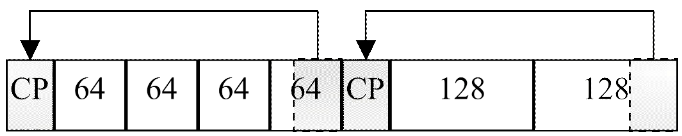


Figure 1: 802.16 OFDM DL preamble structure.

The DL long preamble consists of two consecutive OFDM symbols: a 4 times 64 sequence and a 2 times 128 sequence. In the frequency domain, these symbols are represented by $P_{4\times 64}(k)$ and $P_{EVEN}(k)$ and they are derived from a sequence $P_{ALL}(k)$ of the form:

$$P_{ALL}(-100:100)=\begin{cases}\pm 1 \pm j, & k \neq 0,\\ 0, & k = 0,\end{cases}$$

These sequences are expressed as follows:

$$P_{4\times 64}(k)=\begin{cases}2P^{*}_{ALL}(k), & k_{\mathrm{mod}\,4} = 0,\\ 0, & k_{\mathrm{mod}\,4} \neq 0,\end{cases}$$

and

$$P_{EVEN}(k)=\begin{cases}\sqrt{2}P_{ALL}(k), & k_{\mathrm{mod}\,2} = 0,\\ 0, & k_{\mathrm{mod}\,2} \neq 0.\end{cases}$$

3. Diversity requirement in Direct Conversion Receiver

Direct Conversion Receiver (DCR) is an alternative wireless receiver architecture to the well-established superheterodyne, particularly for highly integrated, low-power, low cost terminals. The fundamental advantage of DCR is that the received signal is amplified and filtered at baseband rather than at a high intermediate frequency. This results in lower current drain in the amplifiers and active filters and eliminates the task of image rejection. Figure 2 shows the architecture of DCR.

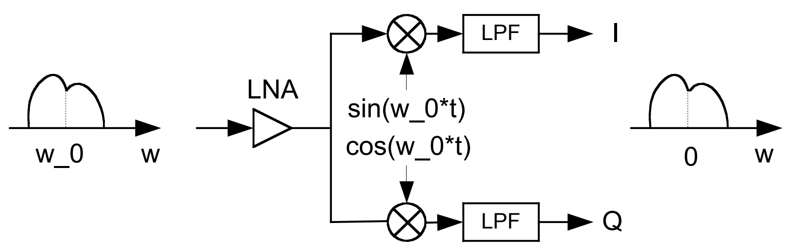


Figure 2: Direct Conversion Receiver architecture.

In a Direct Conversion Receiver, due to the phase/gain imbalances in the I and Q paths, the received frequency domain symbol $R(k)$ can be expressed as

$$R(k) = S(k)C(k) + S^*(-k)C^*(-k)L(k),$$

where:

- $S(k)$ is the transmitted frequency domain symbol,
- $R(k)$ is the received frequency domain symbol,
- $C(k)$ is the channel frequency response,
- $L(k)$ is the image leakage due to the I/Q mismatch,
- k is the sub-carrier index and
- $\{\ \}^*$ is the complex conjugate operator.

For any two symbols $S_1(k)$ and $S_2(k)$, their corresponding received symbols $R_1(k)$ and $R_2(k)$ can be written as (they have been split in positive and negative indices):

$$\begin{bmatrix} R_1(k) & R_2(k) \\ R_1^*(-k) & R_2^*(-k) \end{bmatrix} = \begin{bmatrix} C(k) & C^*(-k)L(k) \\ C(k)L^*(-k) & C^*(-k) \end{bmatrix} \begin{bmatrix} S_1(k) & S_2(k) \\ S_1^*(-k) & S_2^*(-k) \end{bmatrix} \qquad k > 0$$

If we want to recover both the channel and the image leakage from $R_1(k)$ and $R_2(k)$, the following condition must stand:

$$\Delta_S(k) = \det \begin{bmatrix} S_1(k) & S_2(k) \\ S_1^*(-k) & S_2^*(-k) \end{bmatrix} = S_1(k)S_2^*(-k) - S_2(k)S_1^*(-k) \neq 0,\ k = 1..100.$$

In the 802.16a OFDM PHY, we can use the two training symbols from the long preamble $P_{4\times 64}(k)$ and $P_{EVEN}(k)$ as $S_1(k)$ and $S_2(k)$, recover the image leakage for every 4th carrier, and use interpolation for the rest of the carriers. This requires that

$$\Delta_P(k) = \det \begin{bmatrix} P_{4\times 64}(k) & P_{EVEN}(k) \\ P_{4\times 64}^*(-k) & P_{EVEN}^*(-k) \end{bmatrix} = P_{4\times 64}(k)P_{EVEN}^*(-k) - P_{EVEN}(k)P_{4\times 64}^*(-k) \neq 0,\ k = 4:4:100.$$

However, for the current preamble we have:

$$\Delta_P(k) = 2P_{ALL}^*(k)\sqrt{2}P_{ALL}^*(-k) - \sqrt{2}P_{ALL}(k)2P_{ALL}(-k) = -4\sqrt{2}\ \mathrm{Im}\{P_{ALL}(k)2P_{ALL}(-k)\} k = 4:4:100,$$

which has some zero values.

4. Proposed change in the OFDM preamble

In order to make $\Delta_P(k)$ non-zero for all $k = 4:4:100$, we propose to change $P_{4x64}(k)$ as

$$P_{4x64}(k) = \begin{cases} \operatorname{sgn}(k) \cdot \sqrt{2} \cdot P_{EVEN}(-k) & k_{\mathrm{mod}\,4} = 0 \\ 0 & k_{\mathrm{mod}\,4} \neq 0 \end{cases}$$

With this changed $P_{4x64}(k)$, we will have:

$$\Delta_P(k) = \sqrt{2} P_{EVEN}(-k) P^*_{EVEN}(-k) - P_{EVEN}(k)\left(-\sqrt{2} P^*_{EVEN}(k)\right) = \sqrt{2}\left(\left|P_{EVEN}(-k)\right|^2 + \left|P_{EVEN}(k)\right|^2\right) = 8\sqrt{2}, \qquad k = 4{:}4{:}100$$

As a result, the I/Q phase/gain imbalances can be estimated and corrected on a frame basis with virtually no SNR loss.

This will greatly relax the requirements for the direct conversion receiver.

To decorrelate P_{4x64} and P_{EVEN}, some of the phases are changed as shown in Section 5.

5. Editorial instructions

Section 8.3.3.6, page 419, lines 55-57, replace:

$$P_{4x64}(k) = \begin{cases} \sqrt{2} \cdot \sqrt{2} \cdot conj\left(P_{ALL}(k)\right) & k_{\mathrm{mod}\,4} = 0 \\ 0 & k_{\mathrm{mod}\,4} \neq 0 \end{cases}$$

with:

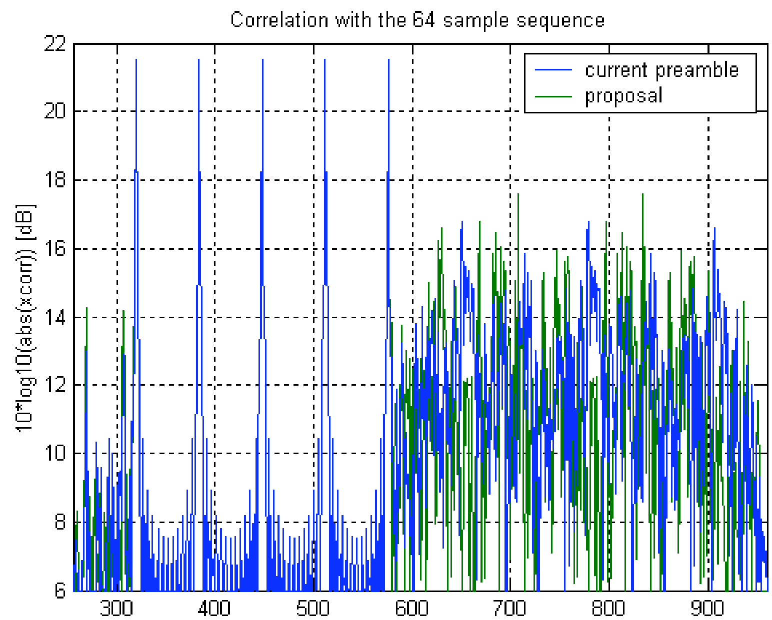
$$P_{4x64}(k) = \begin{cases} \operatorname{sgn}(k) \cdot \sqrt{2} \cdot (-1)^{\mathrm{floor}((|k|-4)/20)} \cdot P_{EVEN}(-k) & k_{\mathrm{mod}\,4} = 0 \\ 0 & k_{\mathrm{mod}\,4} \neq 0 \end{cases}$$

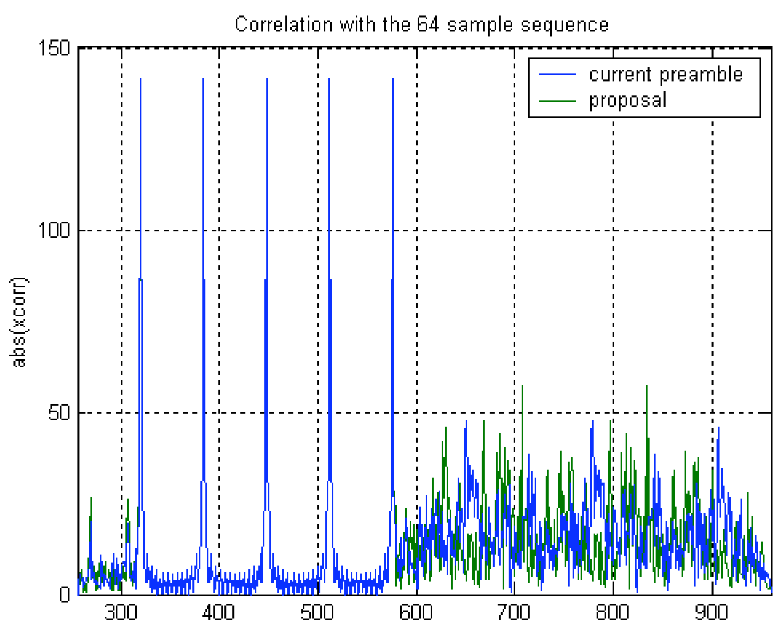
Move P_{4x64} definition after P_{EVEN} definition.

6. Performance

6.1. Cross correlation

The following figures show the correlation between the long preamble and the 64 sample sequence (1/4 of P_{4x64}).





There is 0.8dB loss for the proposed preamble w.r.t. the current preamble.

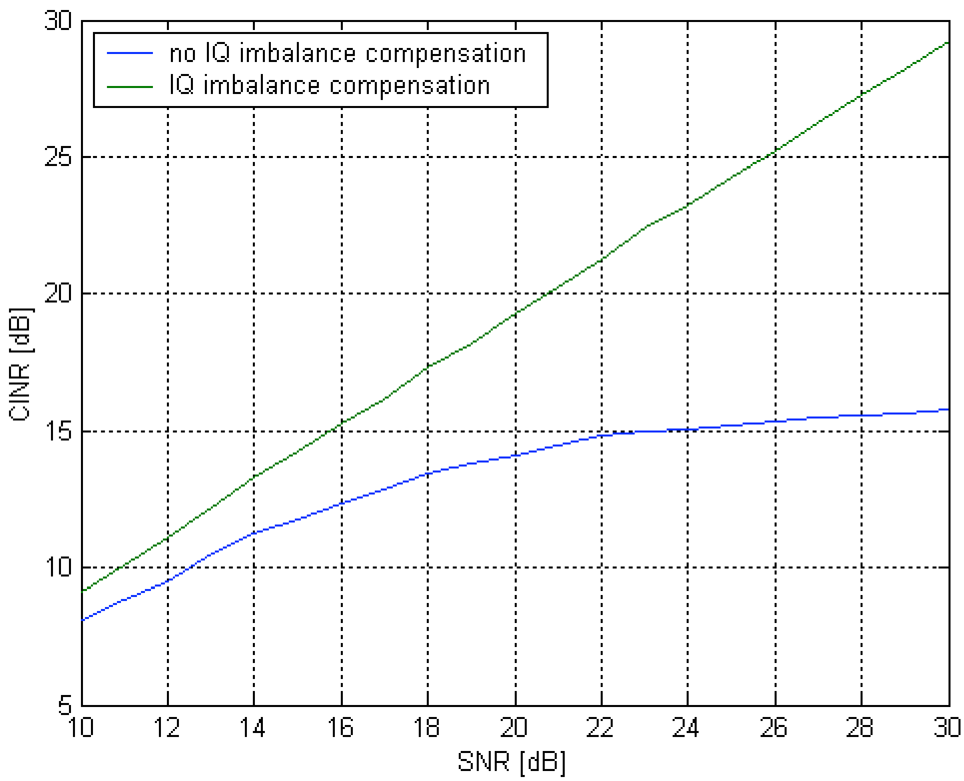
6.2. PAPR

The PAPR of the new sequence is 2.89dB which is slightly better than the current preamble (3.01dB).

6.3. Simulation Results

The following figure shows CINR computed at the slicer output as a function of the receiver SNR.
Both the I/Q imbalance and the channel frequency response are estimated.
Simulation conditions:

- I/Q Phase imbalance = 4deg
- I/Q Gain imbalance = 2dB
- AWGN



As expected, the CINR is upper bounded by the amount of self-interference introduced by the I/Q mismatch. With I/Q imbalance compensation, this effect is fully compensated.