Frame Synchronization Symbols for an OFDM System

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Abstract-
In this paper, the problem of frame synchronization in orthogonal frequency division multiplexing (OFDM) system is considered. For an OFDM system, frame synchronization is achieved by forcing the receiver to start its FFT at the right time. One way in which this may be achieved is to precede the OFDM data with a special synchronization symbol. Two synchronization symbols are proposed to achieve frame synchronization for an OFDM, the wobbulation symbol and the Barker code. These symbols are evaluated in AWGN and two-ray multipath channels, and performances are compared in terms of the probability of correct synchronization

Keywords- OFDM, Frame Synchronization, Synchronization Symbols, communication channels.

I. INTRODUCTION

Data transmission systems depend to a great extent for their efficiency upon correct synchronization. Correct synchronization occurs by organizing the data into reliable synchronized frames [1],[2]. Each frame includes a synchronization symbol followed by data symbols. At the receiver the synchronization symbol indicates the starting position of the frame. In a noisy communication link, the received data are not always correct, so there is no certainty of being able to recognize the synchronization symbol when it is sent or to detect it by chance when it is not sent, so two factors are essential for designing a synchronization system:
1. The synchronization symbol must be sufficiently unlikely to occur by chance in random data symbols.
2. The receiver must be designed to permit a suitable margin of errors.

In OFDM systems the frame synchronization task is to align the FFT window at the correct received sample. If this is not achieved, then the samples from the adjacent OFDM symbol can be included in the FFT block, resulting in ISI. Several techniques have been proposed for OFDM synchronization [3]-[10].

In this paper two synchronization symbols are proposed to achieve frame synchronization for an OFDM system, the wobbulation symbol and the Barker code.

II. OFDM SYSTEM

OFDM is a special case of multi-carrier modulation system [11], based on the discrete Fourier transform in which a high bit rate stream is separated into a large number of low data rate sub-channels each of which modulates a single carrier. Sub-carriers are spaced by the reciprocal of the sub-channel data rate and are thus orthogonal. OFDM has been proposed for digital mobile radio and wireless multimedia communication [12],[13]. The block diagram for an OFDM system is shown in fig. 1.

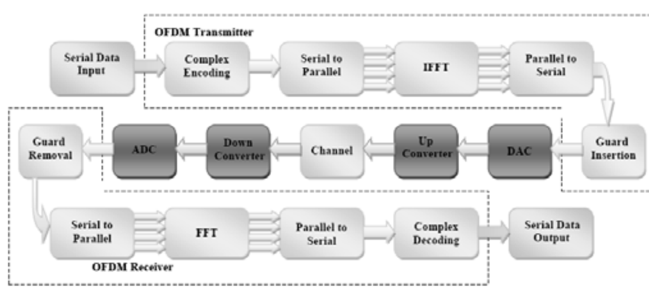


Fig. 1 Block diagram of an OFDM system

The incoming serial data with a high data rate R is first encoded in a complex modulation format. The choice of modulation format may also influence the equalization requirements. Differential decoding requires no Phase equalization.

The encoded data stream is converted from serial to parallel to provide N complex data sub-channels with a data rate R/N for each sub-channel. The sequence of N parallel complex data sub-channels is transferred from frequency domain into time domain by the inverse fast Fourier transform (IFFT) process, to generate an OFDM signal. The OFDM signal is then converted back to serial data for transmission.

The orthogonality between different sub-carriers can be disturbed by intersymbol interference (ISI) caused by multipath propagation in the radio channel, so in order to combat this effect a guard interval is introduced. The discrete symbols are converted to analogue and low-pass filtered for radio frequency (RF) upconversion.

The OFDM receiver is essentially the inverse of the OFDM transmitter as shown in figure 1. The incoming signal is mixed down to base-band, filtered and converted to digital words. The FFT at the receiver extracts the phase and amplitude of each sub-carrier from the block of the received samples. To demodulate the received signal successfully the receiver must start its FFT at the beginning of one of the OFDM data blocks, so frame synchronization is essential for an OFDM system.

III. FRAME SYNCHRONIZATION in OFDM SYSTEMS

There are two types of synchronization that an OFDM receiver must achieve. The first one is the synchronization of the carriers for the receiver and the transmitter. This is important for the orthogonality between subcarriers, which is essential to avoid ICI.

The second synchronization task is to align the FFT window at the correct received sample. If this is not achieved then, the samples from the adjacent OFDM symbol can be included in the FFT block, resulting in ISI.

Here we have concentrated on the second synchronization task "FFT window alignment" in which we have introduced a complex OFDM synchronization marker.

In Fig. 2, a generalized OFDM receiver structure with synchronization block is given. Typically, the frame synchronizer operates on the data in the time domain and its output is used as an alignment point in serial to parallel conversion.

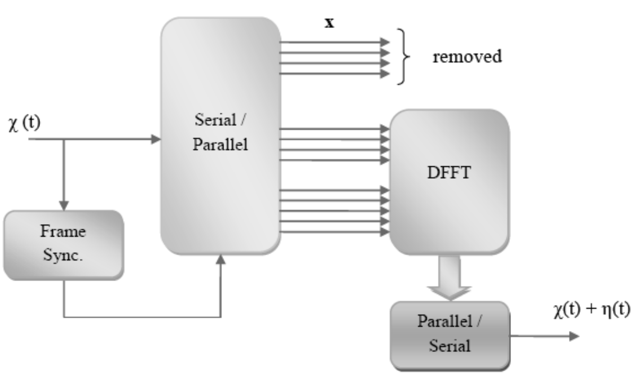


Fig. 2 Generalized OFDM receiver structure with synchronization

IV. SYNCHRONIZATION SYMBOLS

The two proposed synchronization symbols are:

A. *Wobbulation symbol*

The wobbulation symbol is described by the following equation (i is the time-sample):

$$x_i = e^{j\pi i^2 / N} \tag{1}$$

(except in the range $0 \le i < \Delta\mu_{\max}$ and $N - \Delta\mu_{\max} < i \le N-1$, in which x_i is zero)

$\Delta\mu_{\max}$ is the maximum uncertainty of the null symbol search (in samples) from the correct position. N is the number of active carriers.

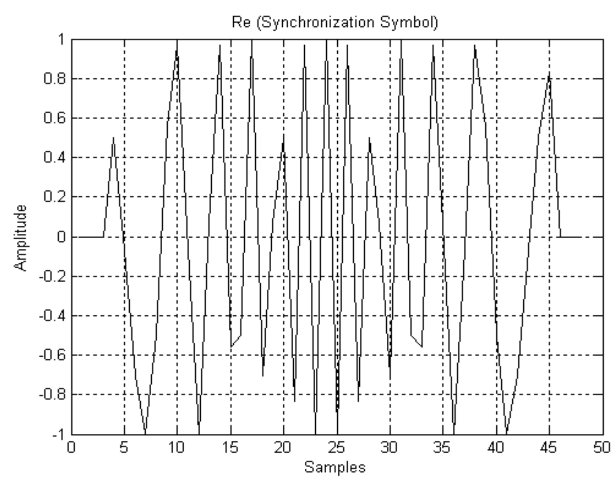
B. *Barker Code*

Barker codes, which are subsets of PN sequences, are commonly used for frame synchronization in digital communication systems. Barker codes have length at most 13 and have low correlation side-lobes. A correlation side-lobe is the correlation of a codeword with a time-shifted version of itself. The correlation side-lobe, Ck, for a k-symbol shift of an N-bit code sequence, {Xj}, is given by:

$$C_k = \sum_{j=1}^{N-k} X_j X_{j+k} \tag{2}$$

where Xj is an individual code symbol taking values +1 or -1, for $1 \le j \le N$, and the adjacent symbols are assumed to be zero.

The characteristics of thirteen-sample Barker code [-1 -1 -1 -1 -1 1 1 -1 -1 1 -1 1 -1], which is used as a reference in this paper to compare with the wobbulation symbol performance. Figures 3 and 4 show the wobbulation symbol and the 13-bit Barker code and their autocorrlation functions, respectively.



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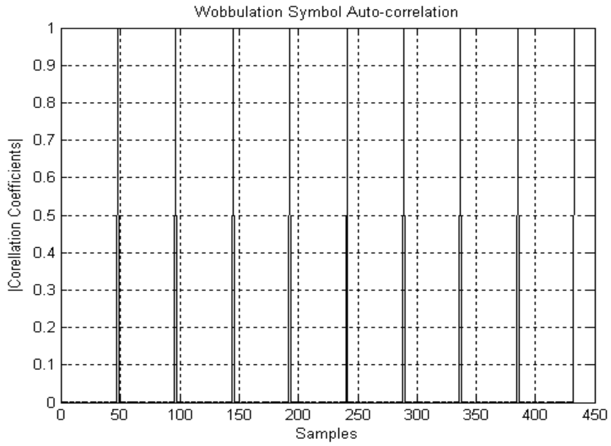
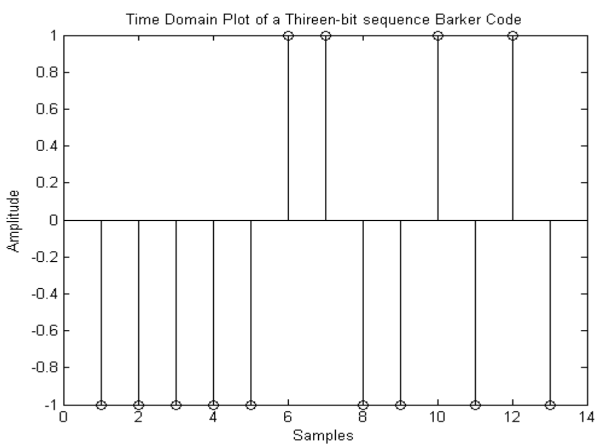


(b)

Fig. 3 (a) The wobbulation symbol and (b) its autocorrelation function



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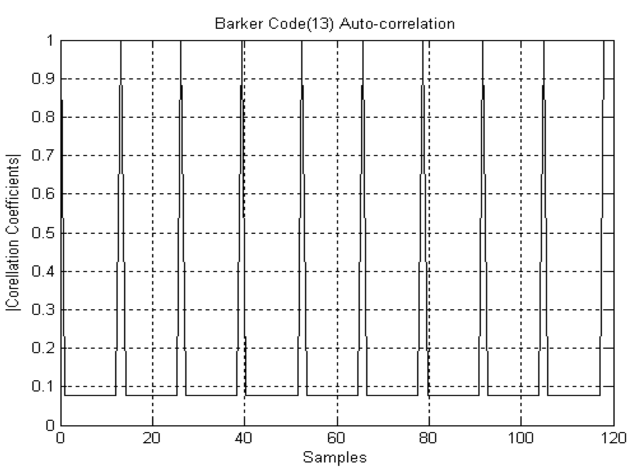


(b)

Fig. 4 (a) 13-bit sequence Barker code and (b) its autocorrelation function

V. WOBBULATION SYMBOL Vs BARKER CODE

We can see from the previous figures that the wobbulation symbol has superios characteristics which make it a good choice for OFDM frame synchronization:

1. Unique shape makes it hard to be confused with arbitrary transmitted bit stream. Figures 5 and 6 show this characteristic clearly.
2. Sharp and clear autocorrelation function.
3. Zero autocorrelation sidelobes.

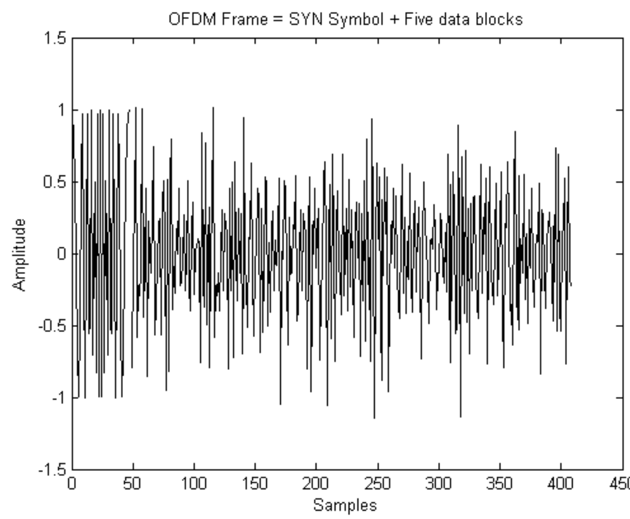


Fig. 5 Transmitted OFDM frame with wobbulation symbol

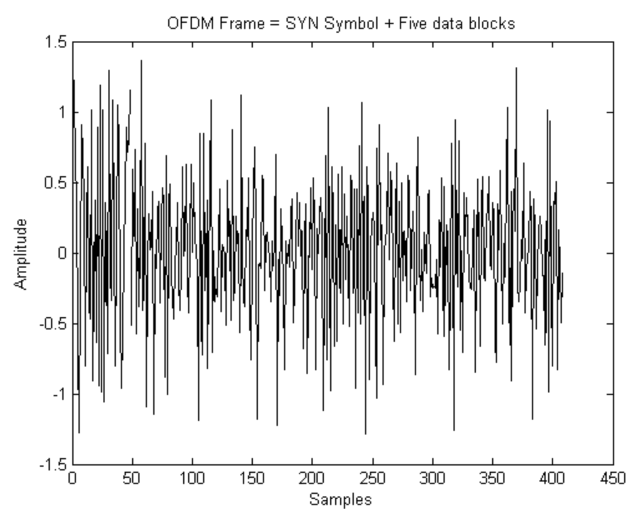


Fig. 6 Received OFDM frame with wobbulation symbol at 6dB SNR

On the contrary, Barker code has non-zero autocorrelation sidelobes and a shape that could be easily occurred through the OFDM data frame leading into erroneous frame detection at the receiver. Figures 7 and 8 show that clearly.

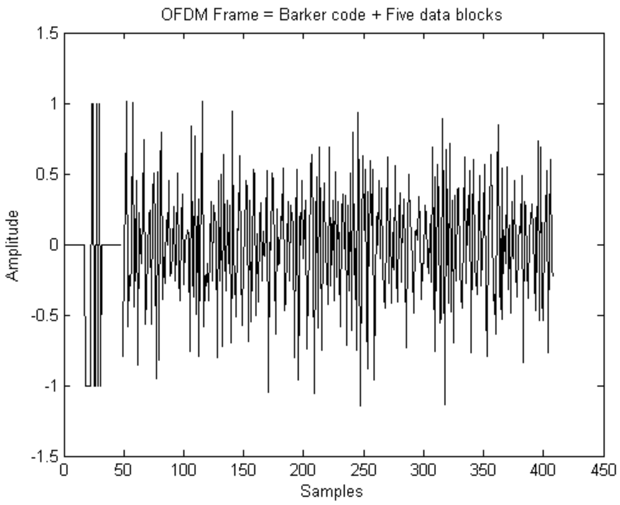


Fig. 7 Transmitted OFDM frame with Barker code

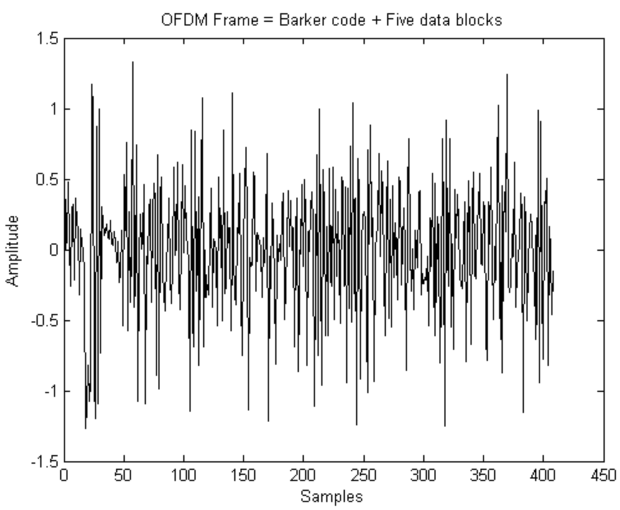


Fig. 8 Received OFDM frame with Barker code at 6dB SNR

VI. OFDM SIGNAL BURST AND MODEL

An OFDM signal comprises a large number of digitally modulated carriers, which are orthogonal to each other within a certain length of the signal period. An OFDM symbol period (*T*OFDM=*TU* + *TG*) consists of an effective OFDM symbol period (*TU*=*NTS*) and a guard interval (*TG*=*PTS*), which is used to mitigate the effect of intersymbol interference (ISI).

In this paper, the performance of frame synchronizations using wobbulation symbol and a thirteen-bit sequence parker code is investigated considering an OFDM N- subcarrier baseband transmitted under the influence of:

1) Additive white Gaussian noise channel (AWGN).
2) Dispersive channel: two ray multipath channel.

A block diagram of an OFDM simulation model is shown in fig. 9 and the output of several stages are shown in fig. 10-14 as well.

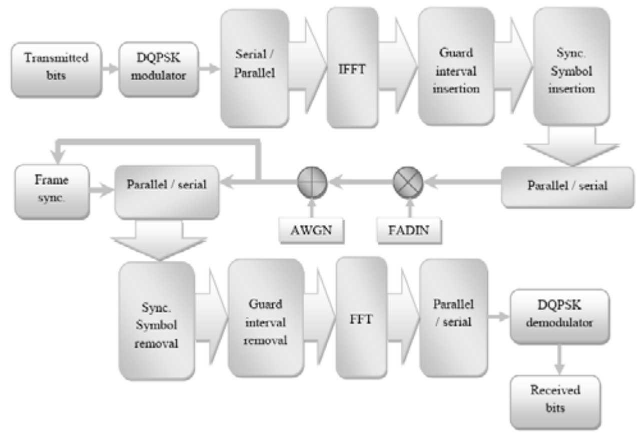
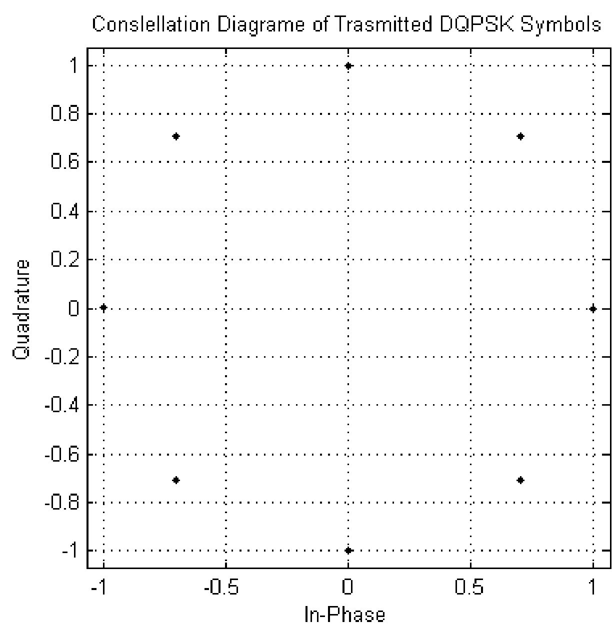
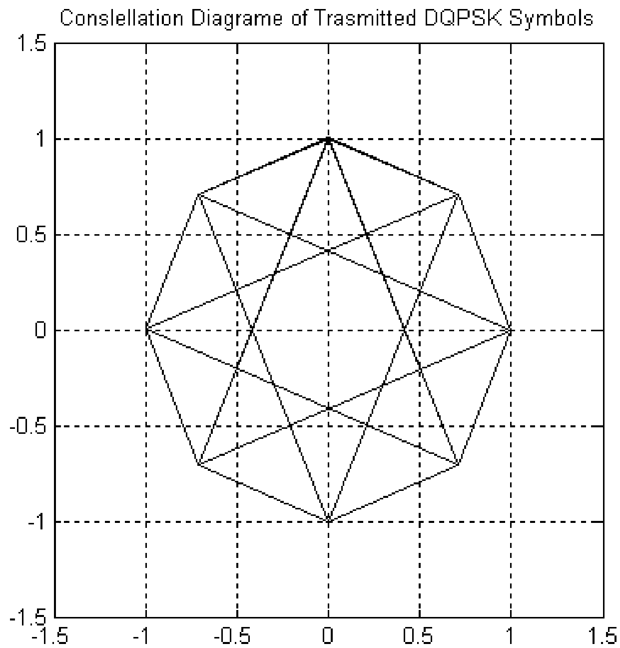


Fig. 9 Simplified OFDM system model with synchronization



(a)



(b)

Fig. 10 (a) and (b) Constellation diagrams of transmitted DQPSK symbols

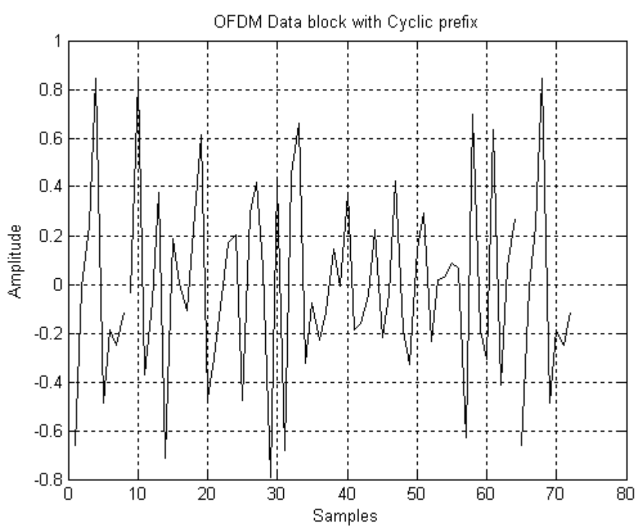


Fig. 11 Transmitted OFDM data block with cyclic prefix

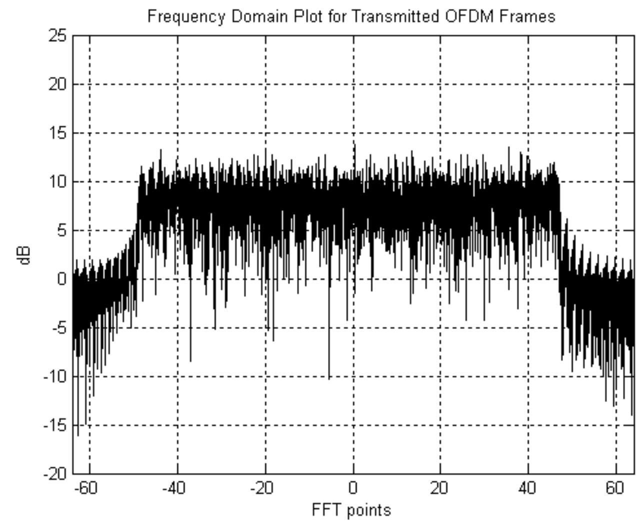


Fig. 12 OFDM signal spectrum

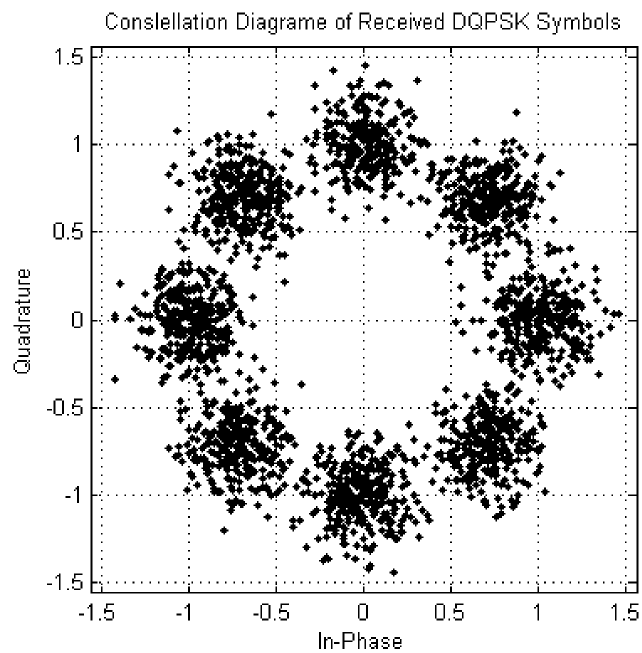


Fig. 13 DQPSK symbols under the influence of AWGN channel, with 12dB SNR

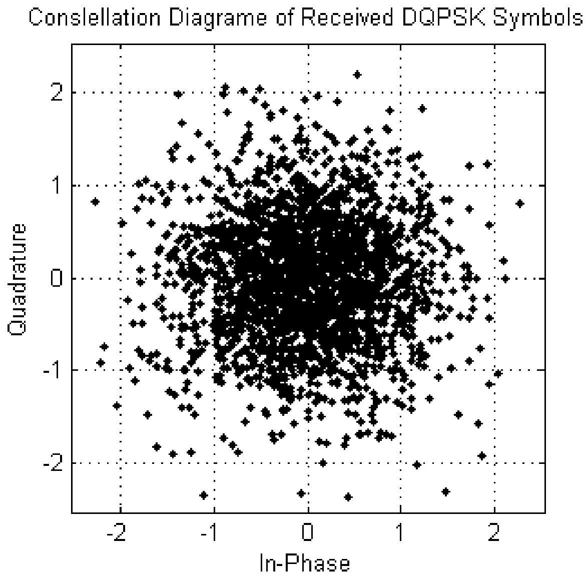


Fig. 14 DQPSK symbols under the influence of dispersive channel, with 12dB SNR

A. Simulation Parameters

Simulation was conducted using DQPSK for the modulation scheme; each burst consists of one reference symbol and six consecutive data symbols. Each of the OFDM symbol uses 48 useful sub-carriers and 64 samples in the time domain (64TS), plus eight additional time sampling durations (8TS) as a guard interval. Thus one OFDM symbol duration (*TOFDM=72TS*=2.88μS).

Table 1 shows the simulation parameters used.

Modulation/detection	DQPSK/differential detection	
Channel spacing	1/T	25MHz
FFT size	N	64
Subcarrier spacing	1/NT	391 KHz
Number of used subcarriers	N_u	48
Total number of virtual subcarriers	V_c	16
guard	T_g	$8T_S$
Doppler frequency	f_d	50Hz

B. Frame synchronization circuit

The frame synchronization circuit structure is shown in fig. 15. The purpose of this circuit is to provide the receiver with the proper frame indices (i.e., the frame starting and ending samples) this circuit has an important roll in aligning the FFT window at the receiver.

As can be seen, this circuit consists of a shift register, correlator circuit, and a comparator. The shift register provides for a sliding correlation window of the reference symbol length (i.e. wobbulation symbol or Barker sequence). The correlator performs the cross-correlation operation between the reference symbol and the incoming data stream. The resulting correlation-coefficients are fed to the comparator which compares its value to a pre specified threshold and decides weather a new frame is presents or not. In other words, it can be said that synchronization circuit's function is to hunt for the SYNC symbol in the received bit stream.

The output of the synchronization circuit for an ideal channel is shown in fig. 16.

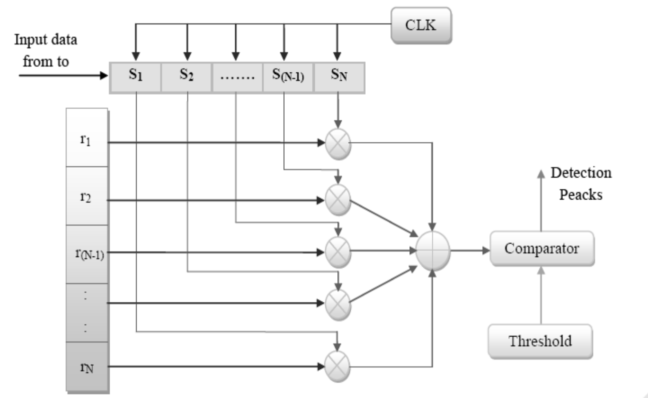


Fig. 15 Synchronization circuit structure

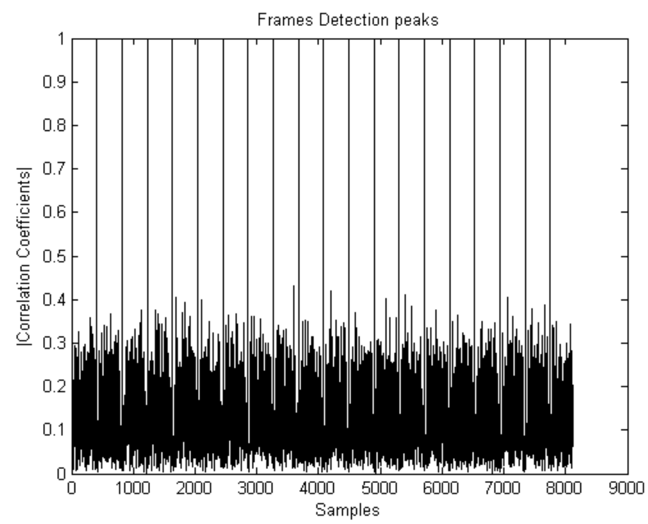
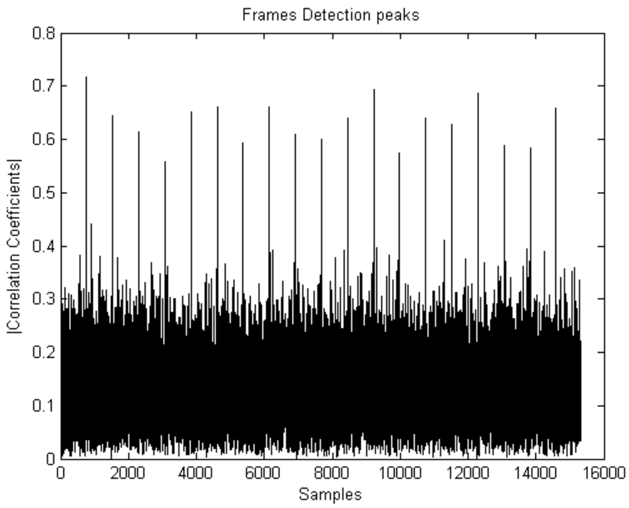


Fig.16 Output of the frame synchronization circuit, for ideal channel

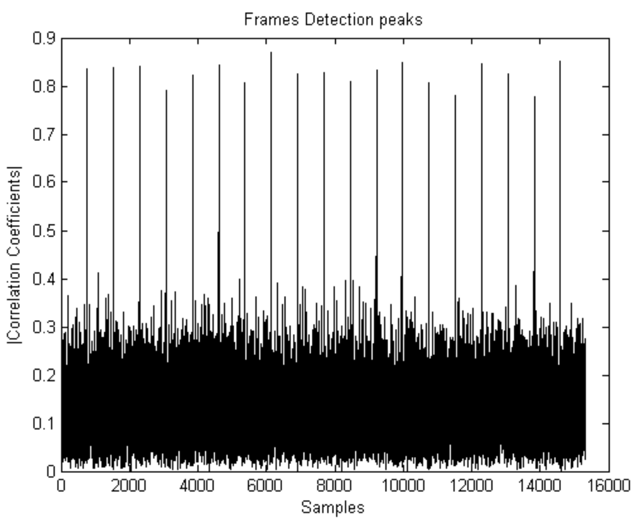
VII. SIMULATION RESULTS

In this paper the performance of frame synchronization for an OFDM system using wobbulation symbol and a thirteen-bit sequence Barker code is investigated under the influence of an AWGN and a dispersive (two-ray multipath) channels.

The output of the frame synchronizer for Barker sequence and Wobbulation symbol @ 0dB SNR under the influence of AWGN channel with a threshold value of 0.8 is shown in fig. 17.



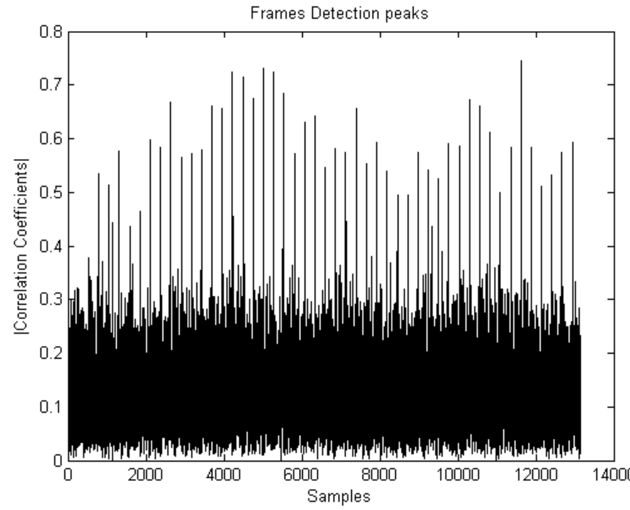
(a)



(b)

Fig. 17 The output of the frame synchronizer for (a) Barker sequence and (b) Wobbulation symbol @ 0dB SNR under the influence of AWGN channel with a threshold value of 0.8

The outputs of the frame synchronizer for Barker sequence and Wobbulation symbol @ 0dB, 6dB and 10dB under the influence of a dispersive channel with a threshold value of 0.8 are shown in fig. 18 and 19.



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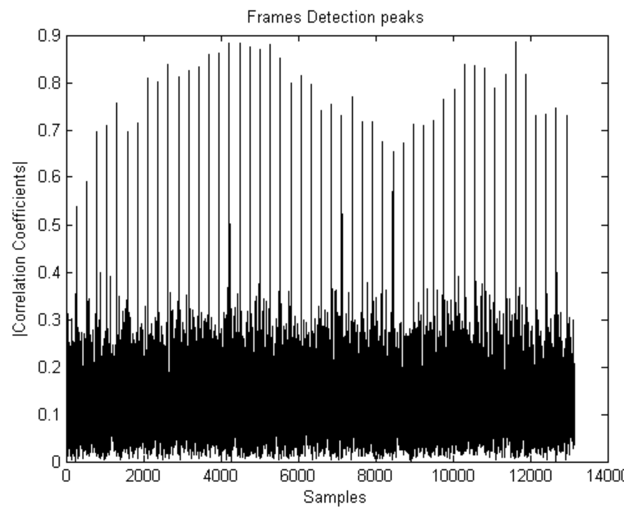

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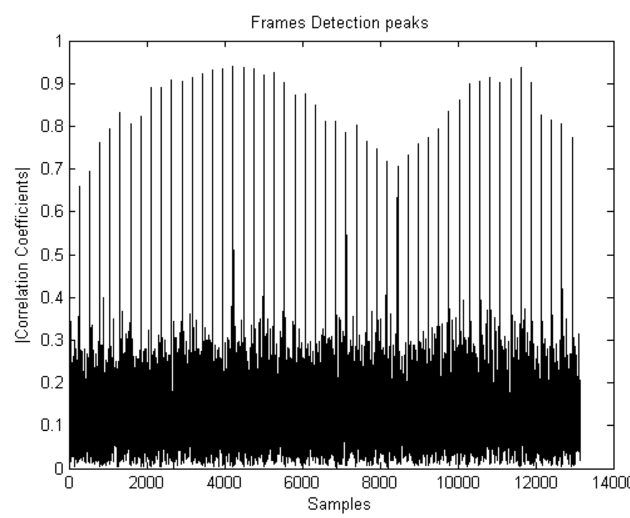

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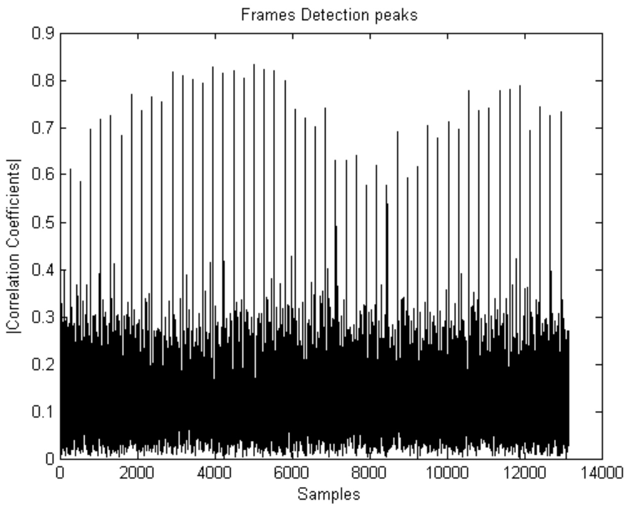
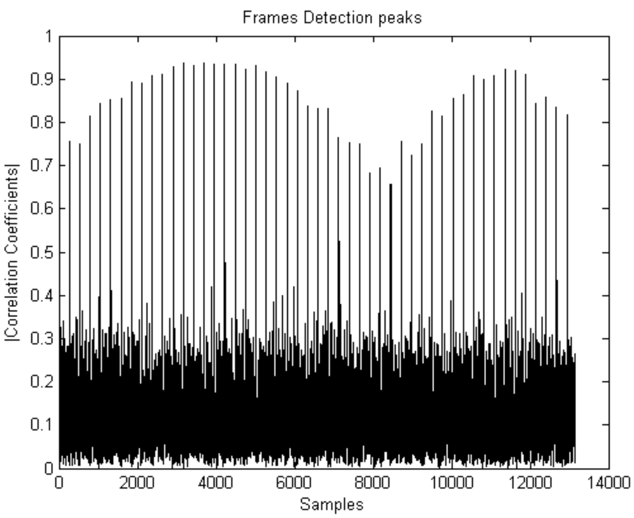
Fig. 18 The outputs of the frame synchronizer for Barker sequence @ 0dB (a), 6dB (b) and 10dB (c) under the influence of a dispersive channel with a threshold value of 0.8



(a)



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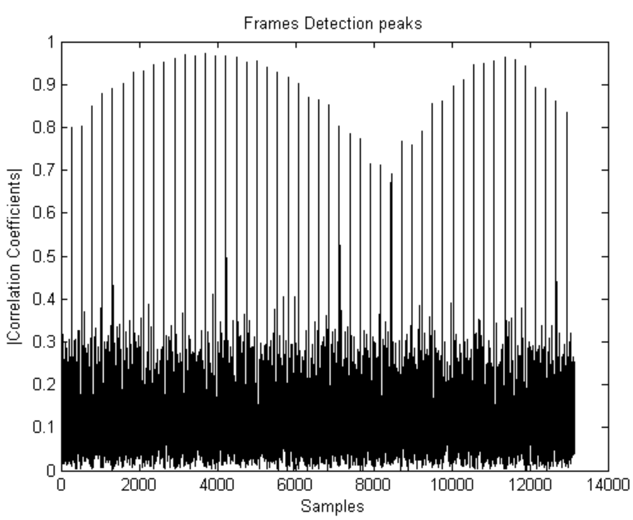

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Fig. 19 The outputs of the frame synchronizer for Wobbulation symbol @ 0dB (a), 6dB (b) and 10dB (c) under the influence of a dispersive channel with a threshold value of 0.8

Random data were transmitted over the same channel for both synchronization symbols, and the probability of correct synchronization (*Pcs*) was calculated. Table 2 shows *Pcs* under the influence of AWGN channel for two different threshold values h=0.80 and 0.65.

Table 2 Probability of correct synchronization under AWGN channel

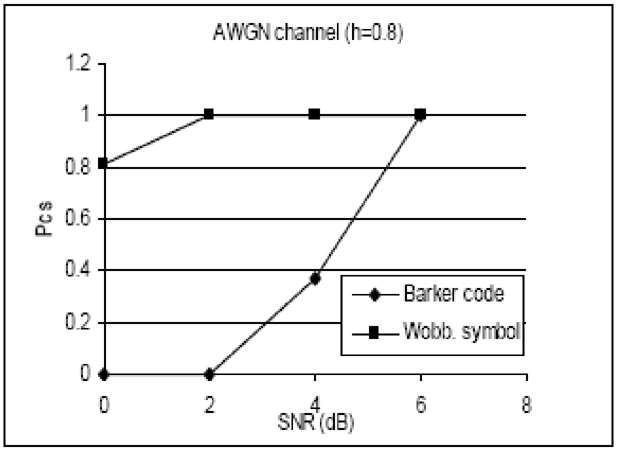
Pcorr (AWGN, 0.79 threshold)				
SNR	0dB	2dB	4dB	6dB
Barker Code	**0.0**	**0.0**	**0.375**	**1**
Wobb. Symbol	**0.81**	**1**	**1**	**1**
Pcorr (AWGN, 0.65 threshold)				
SNR	0dB	2dB	4dB	6dB
Barker Code	**0.3**	**1**	**1**	**1**
Wobb. Symbol	**1**	**1**	**1**	**1**

Table 3 shows *Pcs* under the influence of a dispersive channel for two different threshold values h=0.80 and 0.70.

Table 3 Probability of correct synchronization under dispersive channel

Pcorr (AWGN, 0.79 threshold)										
SNR	0dB	2dB	4dB	6dB	8dB	10dB	12dB	14dB	16dB	20dB
Barker Code	**0.0**	**0.02**	**0.2068**	**0.4416**	**0.5184**	**0.7104**	**0.7644**	**0.8036**	**0.8036**	**0.8036**
Wobb. Symbol	**0.24**	**0.4608**	**0.6912**	**0.7448**	**0.7448**	**0.8232**	**0.8624**	**0.8624**	**0.8624**	**0.8624**
Pcorr (AWGN, 0.70 threshold)										
SNR	0dB	2dB	4dB	6dB	8dB	10dB	12dB	14dB	16dB	20dB
Barker Code	**0.096**	**0.27**	**0.5336**	**0.8064**	**0.9016**	**0.9216**	**0.9408**	**0.98**	**0.98**	**0.98**
Wobb. Symbol	**0.594**	**0.7488**	**0.8832**	**0.9212**	**0.9604**	**0.9604**	**0.98**	**0.98**	**0.98**	**0.98**

Figure 20 shows the probability of correct synchronization *Psc* for different values of SNR for the two synchronization symbols under the influence of AWGN and dispersive channels.



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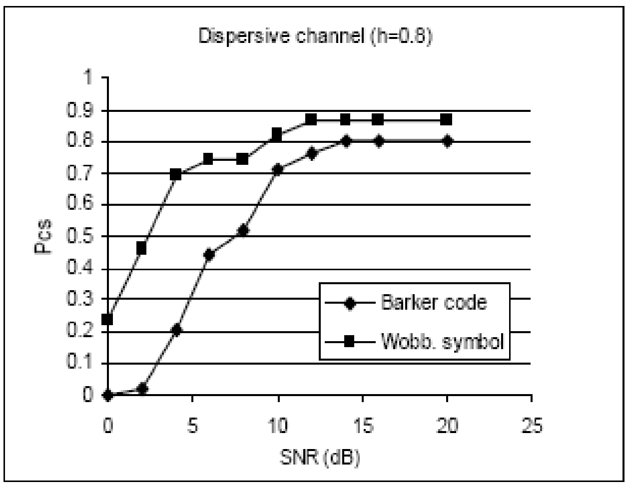

(b)

Fig. 20 *Psc* for the two synchronization symbols under the influence of (a) AWGN and (b) dispersive channels

VIII. CONCLUSION

Frame synchronization for an OFDM system has been presented. Two different synchronization symbols, the wobbulation symbol and the Barker code, were used. The performance of the system has been analyzed under the influence of an AWGN and dispersive channels. The probability of correct synchronization for both symbols was found and the simulation results presented here provide some indication of the improvements available by using the wobbulation as a synchronization symbol for frame synchronization.

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