Implementation of OFDM Modulated Digital Communication Using Software Defined Radio Unit For Radar Applications

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Abstract

This paper presents an analysis and synthesis of Orthogonal Frequency Division Multiplexing (OFDM) modulated signal for Radar based applications, using Benchmark’s Software Defined Radio (SDR) unit. OFDM is a trending digital modulation scheme based on multi-carriers. Experimental trials were performed using the SDR setup allowing for analysis of real time data to assess the difficulties involved, in an attempt to make it more suitable for Radar based detection of slow moving targets. This thereby aids in the implementation of small monostatic radar for micro-Doppler based detection of small UAVs, with reduced false alarm probability.

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation or multiplexing technique with the concept of multi-carriers. The origin of parallel data transmission and frequency division multiplexing concepts dates back to the mid-1960s. OFDM seemed to be a suitable modulation choice offering large data rates with robustness, with the focus being on multimedia communications. It is highly spectral efficient and can be implemented effectively using Fast Fourier Transform (FFT).

The usage of OFDM signals in radar systems is not very popular, despite years of such study. However, OFDM has certain features that prove advantageous for Radar systems. One such feature is that it provides high tolerance against Doppler shifts [1]. Also, having its origin from Digital Communication, OFDM signals serve the purpose of information transmission apart from radar sensing. Garmatyuk et al in their paper, discuss the above dual use of OFDM based signals for Radar systems [2]. Moreover, tracking of slow moving targets requires higher range and velocity resolution which leads to wider frequency bandwidth requirement. OFDM, being a multi-carrier modulation technique, serves this aspect well.

This paper throws light on a prospective design of OFDM Radar signal and its implementation using Benchmark’s Software Defined Radio (SDR) units. Also, the challenges in establishing a real time communication setup and information retrieval have been addressed. The construct of OFDM signal is discussed in the following section. The parameterization of the required OFDM signal is discussed in Sec. III, followed by the details on implementation using the SDR unit in Sec. IV. The real time results are discussed in Sec. V and the conclusion in Sec. VI.

2. OFDM SIGNAL CONSTRUCT

OFDM is a multi-carrier modulation technique, with the sub-carriers being orthogonal to each other. Two signals are said to be orthogonal if the integral of the product of the two over a time period is zero. Sinusoidal signals with frequencies being multiples of a common frequency \( f \) satisfy this property:-
The orthogonal property in OFDM is satisfied by choosing the frequency of the sub-carriers to be integral multiple of \( \frac{1}{T} \) i.e.,

\[
\Delta f = \frac{1}{T}
\]

where \( T \) is the OFDM symbol duration and \( \Delta f \) is the sub-carrier frequency spacing. This construction is efficiently met with using the Inverse Fast Fourier Transform (IFFT) algorithm. The time domain OFDM symbol is thereby given by:

\[
y(t) = \sum_{n=-N/2}^{N/2-1} X(n) \cdot e^{j2\pi fnT}, \quad 0 \leq t \leq T
\]

where \( X(n) \) represents set of arbitrary complex symbols obtained through a phase modulation technique say, Phase Shift Keying (PSK). In this paper, QPSK technique is used to generate these symbols. \( N \) denotes the number of sub-carriers with frequency, \( f_c \).

The corresponding OFDM symbol in frequency domain is given by:

\[
Y(f) = \sqrt{T} \sum_{n=-N/2}^{N/2-1} X(n) \cdot \sin(\pi (f - f_c) T)
\]

In simple words, the modulation – demodulation process of the OFDM signal is a combination of IFFT and FFT. Interestingly, IFFT can be performed using FFT by conjugating the input and output of the FFT and dividing it by the FFT size [3]. This reduces hardware complexity and is more cost effective.

An approach to OFDM radar processing and to calculate the radar range profile is discussed by Sturm et al in their paper [4]. According to this approach, the samples of the channel transfer function in frequency domain can be obtained by calculating an element-wise division of the received OFDM de-multiplexed information \( \{R(n)\} \) and the transmitted QPSK symbols \( \{X(n)\} \):

\[
C(n) = \frac{R(n)}{X(n)}
\]

The radar range profile is thus obtained as the Inverse Discrete Fourier Transform of \( \{C(n)\} \).

### 3. CHOICE OF OFDM SIGNAL PARAMETERS

The system is to be designed to operate in the 2.45 GHz ISM band, for a bandwidth of 5MHz. Let us consider a radar application to detect slow moving small UAVs (such as Quad-copters), within a range of 200m and relative velocity of 25 m/s. Here, the Doppler shift is given by:

\[
f_d = \frac{\lambda}{T} = \frac{\text{relative velocity}}{\text{OFDM symbol duration}}
\]

The sub-carrier spacing \( \Delta f \) is chosen such that \( \Delta f > f_d \), to preserve the orthogonal nature between them. The cyclic prefix in OFDM signal is included to handle multi-path effect efficiently. It is usually \( \frac{1}{10} \) times the OFDM symbol duration. In monostatic radar terms, the maximum delay between the transmitted and received signal caused is the round trip delay. Hence, the cyclic prefix duration must be greater than the round trip time, for the given range of 200m. Thus, the calculated OFDM parameters are as below:

\[
f_c = \frac{c}{2d} = \frac{\text{cyclic prefix duration}}{\text{OFDM symbol duration}}
\]
TABLE I

<table>
<thead>
<tr>
<th>OFDM Signal Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency (f₀)</td>
<td>2.45 GHz</td>
</tr>
<tr>
<td>Total Design Bandwidth (B)</td>
<td>5 MHz</td>
</tr>
<tr>
<td>No. of Sub-carriers</td>
<td>1024</td>
</tr>
<tr>
<td>Sub-carrier spacing (Δf)</td>
<td>4.8 kHz</td>
</tr>
<tr>
<td>OFDM symbol duration (T)</td>
<td>208.3 μs</td>
</tr>
<tr>
<td>Cyclic prefix duration (Tₚ)</td>
<td>26.04 μs</td>
</tr>
<tr>
<td>Total OFDM symbol duration (T')</td>
<td>234.375 μs</td>
</tr>
<tr>
<td>Total OFDM samples</td>
<td>1024+128</td>
</tr>
<tr>
<td>Radar range resolution</td>
<td>30 m</td>
</tr>
</tbody>
</table>

Preamble samples are generated for the above OFDM signal, in accordance with IEEE 802.16d/e standard. This also serves as a known training sequence, making the retrieval easier. For the case of 1024 sub-carriers, only the carriers from 299 to 727 are non-zero sub-carriers while the rest are zero padded. This is done to reduce the energy levels at the edges and to generate a bandwidth specific OFDM signal. Also, the amplitude of the preamble samples is maintained such that its average power is 3dB more than the OFDM signal’s symbols. Finally, the OFDM frame is formed by prefixing the preamble to the OFDM signal.

4. IMPLEMENTATION OF OFDM SIGNAL USING SDR SETUP

The Software Defined Radio setup used is Benchmark’s WiCOMM-T units. It is a wireless digital communication system with pluggable 70 MHz IF or 2.4 GHz RF modules. The system has a transmitter and receiver. Also, the setup can be interfaced with MATLAB, using the PC’s USB port. All baseband level signal definition and processing algorithms were defined using MATLAB.

The testing and implementation was carried out at three different stages:

A. Baseband loopback
B. IF (70MHz) loopback
C. RF (2.4 GHz) level real time communication

At the transmitting end, random data bits were generated, which are then QPSK modulated. IFFT was performed on the above QPSK symbols, cyclic prefix added accordingly and the signal was up-sampled to generate the final OFDM signal to be transmitted, as shown in Fig. 4.
Fig. 1  70MHz IF module

Fig. 2  2.4 GHz RF module

Fig. 3  WiCOMM-T RF setup

Fig. 4  WiCOMM-T transmitting end (loopback) block diagram in MATLAB
At the receiving end, it is very essential that our code implements algorithm to down-sample, identify & correct frequency offset errors and perform a symbol timing recovery, in order to retrieve the information transmitted, as shown in Fig. 5.

All of the above mentioned procedures were coded in MATLAB, before feeding it to the real time communication setup. Schmidl Cox algorithm [5], as shown in Fig. 6, was used at the receiving end to correct the frequency offset error and to identify the start of OFDM frame.

![WiCOMM-T receiving end (loopback) block diagram in MATLAB](image)

**Fig. 5 WiCOMM-T receiving end (loopback) block diagram in MATLAB**

![Schmidl Cox algorithm](image)

**Fig. 6 Schmidl Cox algorithm**

**5. RESULTS & DISCUSSIONS**

The above generated OFDM signal was tested by transmitting from one WiCOMM-T to another, in loop-back as well as through air in RF-mode (separated by few meters). The plots of the real time transmitted signal, received demodulated signal and other associated parameters, in IF mode are shown in Fig. 7 to 10.

![Generated random input data (IF-mode)](image)

**Fig. 7 Generated random input data (IF-mode)**
It is observed from Fig. 9 that we were able to retrieve the transmitted random data, corrupted with simulated channel noise. Also, the bit error rate was less than 0.1, without any equalizer applied to undo the channel effects.

Fig. 10 shows the auto correlation results, as a part of Schmidl Cox algorithm, to find the start of the frame. It indicates that in the received signal, the OFDM frame starts from 160th sample index and is thereby synchronised accordingly with the transmitter.

The corresponding results in the RF mode are shown below in Fig. 11 to 16.
Fig. 11 Generated random input data (RF-mode)

Fig. 12 Transmitted OFDM signal (RF-mode)

Fig. 13 Auto correlation result to find preamble (RF-mode)
Fig. 13 shows that the OFDM frame starts from sample number 1950 in the received signal. The synchronization of the receiver with the transmitter is done accordingly. Since OFDM demodulation is FFT-based, it is sensitive to frequency offset errors. Fig. 14 & 15 show the estimated frequency offsets, using Schmidl Cox algorithm, which is corrected before demodulation of the signal. The received demodulated & decoded plot of the corresponding transmitted random data (Fig.11) is thus presented in Fig.16. The signal was retrieved with a bit error rate close to 0.3, with no equalizer applied.

5. CONCLUSIONS

In this paper, an approach to model OFDM signal as a radar signal has been presented. Also, the modelled OFDM signal has been implemented using Benchmark’s Wireless Digital Communication
setup (WiCOMM-T). Several challenges in the real time signal processing including dynamic channel conditions have been encountered and some of them have been addressed for enhanced retrieval of the OFDM signal. A bandwidth specific signal modelling has been adapted, with the dual role of preamble. Future scope of this work would be to implement the WiCOMM-T setup as a short range radar system, to detect small, slow-moving UAVs, using the modelled OFDM radar signals. Also, the bit error rate of the communication setup could be reduced significantly by the design of an appropriate equalizer to undo channel effects.

ACKNOWLEDGMENT

First of all, the authors would like to thank the management of VIT University for the facilities and opportunities provided, during the progress of this work. The authors extend their heartfelt thanks to Dr. Ramachandra Reddy (Senior Professor, VIT) for his valuable and extensive guidance throughout this work. They extend their special thanks to Prof. Rajesh A, Mr. Sridhar V (Communication Engineering Lab, VIT) and Mr. Anish (Research, VIT) for their valuable support in carrying out the hardware implementation.

REFERENCES
