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Fourier Transform Based Transmission Systems for Broadband Wireless Communications

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1. Introduction

In recent years, Fourier Transform (FT), as an effective signal processing technology, is more and more popularly applied to wireless communications. By the FT technologies, it can not only reduce the implementation complexity of traditional transmission systems, but also bring in some new features, thus constructing new transmission systems. The current mainstream transmission schemes utilizing DFT technologies include Orthogonal Frequency-Division Multiplexing (OFDM) [1], Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplexing (DFT-S-OFDM) [2] and Filter bank modulation [3]. For OFDM systems, by an IDFT at the transmitter, the whole frequency-selective wideband channel is divided into several flat narrow band sub-channels, which is benefit to overcome the effects of multi-path in wireless channels. For DFT-S-OFDM system, the uplink transmission scheme for 3GPP-Long Term Evolution (3GPP-LTE) standard, besides the IDFT served the same function as in the OFDM systems, additional DFT processing is performed to the transmitted constellation symbols before OFDM modulation. In this way, the whole modulation method can be viewed as a DFT-based interpolation processing, and the modulated signals can be regarded as single carrier signals with low Peak-to-Average Power Ratio (PAPR) property. For filter-bank systems, the FT can be used both to reduce implementation complexity and to construct the cyclic prefix (CP) based block transmission scheme, which has merits of both the filter-bank systems with robustness against to multiple access interference (MAI) and the CP based block transmission systems with simple frequency equalization.

The chapter is organized as follows. Firstly, the implementation structure of OFDM transmitter, time-frequency description of OFDM signals, and effects of timing- and frequency-offset and channel multi-path are discussed detailed. Then, we present DFT-S-OFDM system model, describe time-frequency property of DFT-S-OFDM signals, analyze the effects of carrier frequency-offset (CFO) quantitatively and compare the SIR and PAPR performances with that of OFDM systems. Next, a DFT spread Generalized Multi-Carrier (DFT-S-GMC) system is presented. The time-frequency properties of DFT-S-GMC signal, the DFT-based implementation method and the receive SINR are addressed. Finally, conclusions are collected.
2. OFDM transmission systems

OFDM plays a significant role in modern broadband communication systems. The wireline high-speed access technology, i.e. Asymmetric Digital Subscriber Line (ADSL), was the first widely used application for the FT-based OFDM system. Several other wireless standards, such as the IEEE 802.11a Wireless Local Area Network (WLAN) and IEEE 802.16 (WiMAX) series, have adopted OFDM as a key transmission technology. IEEE 802.20 working group on mobile broadband wireless access uses OFDM as the wireless high speed transmission technology. In the area of cellular mobile communications, OFDM was also adopted as a basic downlink transmission scheme of 3GPP-Long-Term Evolution (3GPP-LTE) standard and the incoming 3GPP-LTE-Advanced standard [6]. OFDM is also widely applied in the areas of audio and video broadcasting. Digital Audio Broadcasting (DAB), initiated as a European research project in 1980s, adopts coded OFDM as the transmission technology. DVB-T based on OFDM in an 8 MHz channel is now a popular technology for terrestrial video broadcast in the world. An additional new application area of OFDM is in Ultra-Wideband (UWB) personal area networks [4].

2.1 OFDM system model

Figure 1 illustrates the principle structure of OFDM transmitter. Assume that the user-specific \( K \) data symbols are \( \{a_k\}, 0 \leq k \leq K-1 \). After the OFDM modulation, the transmit signals can be expressed as

\[
s_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{K-1} a_k \exp\left(j2\pi n\left(k_0 + k\right)/N\right),
\]

where \( N_s \) is the CP length. To simplify the system model, the localized sub-carrier mapping is applied, i.e.,

\[
b_k = \begin{cases} a_k, & k' = k_0 + k \mod N, k' = 0, \ldots, N-1; \\
0, & \text{otherwise}
\end{cases}
\]

\( k_0 \) is the user-specific sub-carrier allocation offset.

Fig. 1. OFDM transmitter
The simulation specification is shown in Table 1. As shown in the Fig. 20, the BER performance of frequency-domain implemented DFT-S-GMC transceiver is almost the same as that of time-domain implemented DFT-S-GMC transceiver.

![Fig. 20. BER performance comparison of FD transceiver with TD transceiver](image)

As presented in the Table 2, the CM performance of frequency-domain implemented DFT-S-GMC transmitter is very close to that of time-domain implemented DFT-S-GMC transmitter. Moreover, the CM of DFT-S-GMC is smaller 1.7 and 1.1dB than that of OFDM for QPSK and 16QAM modulation respectively.

<table>
<thead>
<tr>
<th>Systems</th>
</tr>
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<tbody>
<tr>
<td>Frequency-domain DFT-S-GMC</td>
</tr>
<tr>
<td>Used sub-carriers /sub-band(s)</td>
</tr>
<tr>
<td>16 / 1</td>
</tr>
<tr>
<td>32 / 2</td>
</tr>
<tr>
<td>64 / 4</td>
</tr>
<tr>
<td>256 / 16</td>
</tr>
</tbody>
</table>

Table 2. Cubic Metric (dB) comparison of frequency- and time-domain implemented DFT-S-GMC system with OFDM system

<table>
<thead>
<tr>
<th># of used sub-band(s)</th>
<th>Computation complexity (# of real multiplications)</th>
<th>Percentage of reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD transmitter/ receiver</td>
<td>FD transmitter/ receiver</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>18800/58688</td>
<td>15184/31008</td>
</tr>
<tr>
<td>1</td>
<td>18432/55404</td>
<td>9416/18868</td>
</tr>
</tbody>
</table>

Table 3. Complexity comparison of frequency- and time-domain implemented DFT-S-GMC transceiver
As shown in the Table 3, with frequency-domain implementation structure, the computation complexity of DFT-S-GMC transceiver with equalization can be reduced significantly, compared with that with time-domain implementation structure. For 28 and 1 sub-band(s) transmission, the computational complexity can be reduced about 47% to 66%.

5. Conclusion

In this chapter, the principle, implementation structure, time-frequency property of three Fourier Transform-based transmission systems, namely OFDM, DFT-S-OFDM and DFT-S-GMC, are presented for broadband wireless communications. For OFDM systems, the spectrum of each sub-carrier has a sinc-function shape, spectrums of all sub-carriers are independent each other which cause high PAPR of transmitted signal; For DFT-S-OFDM systems, each sub-carrier contains only a part of spectrum component of transmitted constellation symbols, and the time-domain waveform can be viewed as a DFT-based interpolation of transmitted constellation symbols, which bring in lower PAPR of transmitted signal; For DFT-S-GMC systems, each DFT-S-GMC symbol is formed by cyclically accumulating IFBT symbols with SRRC waveform in the time domain, hence, the spectrum of each sub-band has a Raised Cosine function shape, and due to DFT based spreading among sub-bands, the transmitted signal over all occupied sub-bands can be viewed as single-carrier signal as a whole. Moreover, the effects of time and frequency offset on OFDM and DFT-S-OFDM systems are analyzed quantitatively. Theoretical analysis and simulation results show that except the first symbol, all other demodulated symbols of DFT-S-OFDM system have a better SIR than that of OFDM system under the same CFO condition. Furthermore, the post-processing SINR of DFT-S-OFDM and DFT-S-GMC are addressed for different equalizer. The closed-form expressions of SINR are presented and verified by the simulation results.

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New analytical strategies and techniques are necessary to meet requirements of modern technologies and new materials. In this sense, this book provides a thorough review of current analytical approaches, industrial practices, and strategies in Fourier transform application.

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