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Comparison of 5G Waveform Candidates in High Speed Scenario

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Abstract

This paper focuses on performance evaluation of waveforms in the fifth generation, i.e. universal-filtered multicarrier technique (UFMC), resource block filtered orthogonal frequency-division multiplexing (RB-F-OFDM), filtered-OFDM (F-OFDM), and filter-bank multi-carrier (FBMC) in high speed scenarios. The block error rates (BLERs) of the channel model of tapped-delay-line-D (TDL-D) defined in 3GPP TR 38.900 are evaluated with respect to signal-to-nosie ration (SNR), terminal speed and carrier frequency offset (CFO). Simulation results indicate that RB-F-OFDM is recommended for high speed scenario due to the robustness in terms of high mobility and CFO.

1 Introduction

In recent years, high speed railways (HSRs) have been widely developed worldwide, and high speed scenario has become a hot spot of research in 5G mobile communication. In some countries, the speed of vehicles can be more than 300 km/h, such as Japan Tohoku Shinkansen (320 km/h), German ICE (330 km/h), AGV Italo (400 km/h), and Shanghai Maglev (430 km/h) [1]. Although convenience and time saving, it is more difficult to provide stable, reliable and efficient communication services in such high mobility environments with the present orthogonal frequency division multiplexing (OFDM)-based cellular systems.

OFDM is a multi-carrier modulation (MCM) and all of its subcarriers are orthogonal [2]. A big challenge for OFDM in high speed scenario is serious inter-carrier interference (ICI) due to high Doppler frequency shift, destroying the orthogonality between subcarriers. This will also degrade the accuracy of channel estimation and has a great impact on the overall system performance. Existing works to enhance OFDM performance in high speed scenarios can be divided into two types: anti-Doppler techniques [3] and new channel estimation algorithms.

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Partially aiming to avoid the dramatic performance degradation of losing OFDM subcarrier orthogonality, nonorthogonal MCM waveforms have attracted attention in industry and academia. At present, several nonorthogonal filtering-base waveforms have been proposed to meet the 5G requirements. These waveform candidates can be divided into two types with respect to the filtering granularity: sub-band filtering and subcarrier filtering. For example, universal-filtered multi-carrier Technique (UFMC) [4], resource block filtered orthogonal frequency-division multiplexing (RB-F-OFDM) [5], and filtered-OFDM (F-OFDM) [6] are sub-band filtering waveforms. filter-bank multi-carrier (FBMC) [7] is a subcarrier filtering waveform.

These popular waveform cadidates have been mainly compared with standard OFDM with respect to out-ofband emission (OOBE) and robustness of CFO and ICI [4, 5, 6, 7]. But scenarios, channel models and parameters configuration in the previous studies are not uniform, making it difficult to find out which one is more suitable for high speed scenarios. In this paper, we compare the above 4 waveforms using a uniform channel model and parameters configuration.

The rest of this paper is organiazed as follows. The system model are described in Section 2. The principles of involved 5G waveform candidates are introduced in Section3. Section 4 presents and analyses the simulation results. Section 5 concludes the paper.

2 System Model

2.1 Transceiver Structure

We consider a single-input and single-output (SISO) system. The system model adopted for 4 waveforms introduced in section 2 and standard OFDM is as figure 1, in which the common parts and some unique part for specific waveform are illustrated.

The modules of OQAM pre-processing and post-processing are just for FBMC, which will be instead of N-point FFT/IFFT and CP insertion/removal, and the modules of Q upsampled and downsampled are just for RB-F-OFDM.

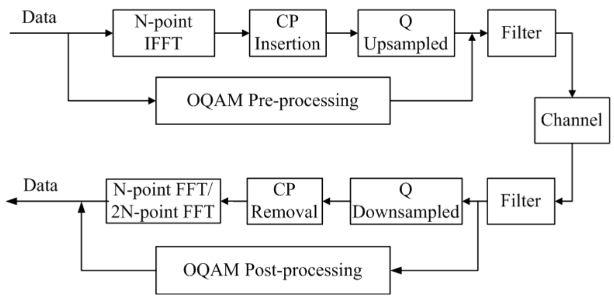

Figure 1. The transceiver structure of the SISO system.

The $2N$-point FFT is just for UFMC instead of the receive filters. The difference between standard OFDM and 5G waveform candidates is the module of filter due to that the proposed waveforms are based on filtering.

2.2 Channel model

The channel model simulation method is called TDL channel model which is greatly significant to describe the time-varying channel under high speed scenario. The CIR of TDL model can be formulated in (5) [11].

$$h(\tau,t) = \sum_{l=0}^{L(t)-1} g_l(t)\delta[\tau - \tau_l(t)] \tag{1}$$

where, l is the index of tap, $g_l(t)$ represents resolve amplitude of the lth tap, and $\tau_l(t)$ is the excess delay of the lth tap.

The channel parameters are referred to 3GPP TR 38.900 [12] which gives the values of tap delays and delay power. The channel model in this document can be applied into the scenario with carrier frequency of from 0.5GHz to 100GHz and terminal speed up to 500 km/h. For our simulation, we adopt the TDL-D channel model parameter proposed in this document which is suitable for high speed scenario in consideration of the existence of LoS (Line of Sight) in most case and the user equipment (UE) mobile speed up to 500 km/h. The first path of TDL-D channel model is Rician distribution, and other paths are Rayleigh distribution.

3 5G Waveform Candidates

3.1 UFMC

UFMC is an MCM technology which divides the whole frequency band of the system into several sub-bands, adopting the appropriate filter to filter per sub-band composed of several subcarriers, such as one physical resource block (PRB) in LTE. The signal of each subband in frequency-domain is transformed into timedomain signal through N-point IFFT. Then each timedomain signal which has a length of N samples is passed through a FIR filter of length L generating an output signal of length $N+L-1$. The transmitted signal in timedomain is the sum of output signal of each sub-band, and can be expressed in (1):

$$y[n] = \sum_{i=1}^{B} x_i[n] * f_i[n] \tag{2}$$

where, i represents the index of different sub-bands, B is the total number of sub-bands, x_i is the signal after N-point IFFT and f_i is the impulse response of the FIR filter used with sub-band i [8].

At receiver, the digital signal is demodulated by $2N$-point FFT with $N-L+1$ zeros padded instead of directly being demodulated by N-point FFT. The received signal can be formulated as in (2) [8],

$$Y[m] = \sum_{n=0}^{2N-1} y[n]\, e^{-\frac{j2\pi nm}{2N}} \tag{3}$$

where, $m \in \{0,2,4,...,2N-2\}$.

3.2 RB-F-OFDM

RB-F-OFDM utilizes non-contiguous spectrum fragment for transmission, which can be divided into several resource blocks (RBs), i.e., chunks of contiguous subcarriers. The signal of each RB is individually generated, filtered and modulated from baseband to corresponding frequency band. The transmitted signal is the sum of all the signals of different RBs. The operations for per RB are the same. Firstly, the signal for per RB is operated with an N-point IFFT and cyclic prefix (CP) insertion as standard OFDM. Then the time-domain signal is upsampled by Q and passed through a lowpass filter $p_T[n]$. Finally, the baseband signal is modulated to frequency f_k of the kth RB according to the RB's central subcarrier index m_k, the transmitted signal can be formulated as in (3) [9].

$$x_k[n] = \left(\sum_m b_k[m]p_T[n-mQ]\right) e^{\frac{j2\pi m_k n}{NQ}} \tag{4}$$

where, k represents the index of different RBs, and b_k represents the signal of the kth RB after IFFT and CP insertion.

At the receiver of RB-F-OFDM, the received signal of per RB is demodulated from f_k to baseband. The receive module is same on each RB, including filtered, downsampled, CP removal and N-point FFT.

3.3 F-OFDM

F-OFDM is a flexible waveform which can suit the needs of different types of services with configuring suitable subcarrier spacing, length of CP, and transmission time interval (TTI), etc. For F-OFDM system, the assigned bandwidth can be divided into several sub-bands, which are used to transmit different service data. The transceiver structure of F-OFDM is similar to standard OFDM, because the transmit module and receive module of each sub-band is considered as OFDM with filter.

Table 1. Simuation Parametres

Parametre	Value
FFT Size	1024
CP Length	72
Number of Subcarriers	36 (3RB)
Bandwidth of Subcarrier	15 kHz
Carrier Frequency	2.6 GHz
Modulation Scheme	16QAM, R=1/3
Channel Coding Scheme	Turbo Coding
Channel estimation	Ideal
Number of Antennas	SISO
Channel	TDL-D
	(speed of UE up to 500 km/h)

At the transmitter side, the signal $s[n]$ obtained after N-point IFFT and CP insertion is then passed through a designed spectrum shaping filter $f[n]$, i.e., the transmitted signal can be expressed as (4) [10].

$$\widetilde{s}[n] = s[n] * f[n]. \tag{5}$$

The receive module has inverse operations as transmit module. The received signal is firstly passed through the filter $f^*[-n]$ which is matched to the transmitter filter [10]. Then the signal of F-OFDM at reciever is processed as the same as regular OFDM receiver.

3.4 FBMC

FBMC is a multi-carrier modulation based on subcarrier filtering and adopts offset quadrature amplitude modulation (OQAM). The FBMC symbols are mapped into complex domain after quadrature amplitude modulation (QAM) which is the same as OFDM. The differences between FBMC and OFDM can be summarized as follow: i) FBMC adopts OQAM instead of QAM; ii) FBMC adopts filter bank instead of the IFFT and CP insertion at the transmitter and the FFT and CP removal at the receiver.

At the transmitter, the real part and imaginary part of a complex symbol on each subcarrier are extracted and staggered with a time offset $T/2$ which are realized by using a pair of prototype filters denoted by $p(t)$ and $p(t-T/2)$, where T is the symbol space. At the receiver, inverse procedures are operated.

4 Simulaion Results

The parameters for simulation are uniform. The parameters are summarized as table 1.

The BLERs versus SNRs with the terminal speed of 370 km/h and without CFO is illustrated in figure 2. In this case, the maximum Doppler frequency is about 890 Hz which has great effect on system performance. As expected, the standard OFDM achieves the worst performance since the orthogonality of subcarriers is destroyed by the high Doppler

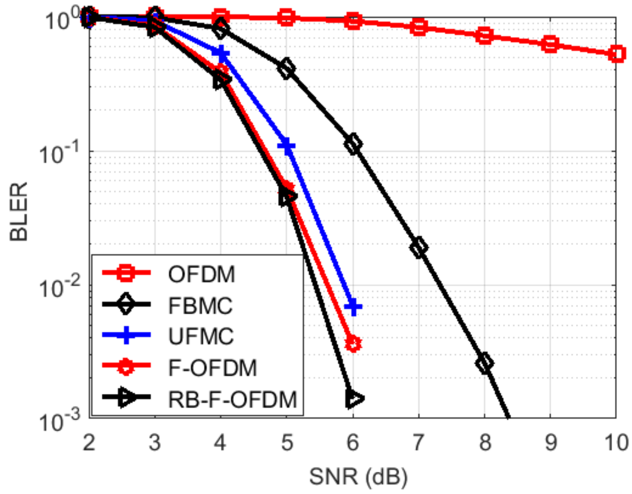

Figure 2. BLERs versus SNRs with the terminal speed of 370 km/h and without CFO.

frequency shift. From the figure, we can see RB-F-OFDM outperforms other non-orthogonal waveforms. For RB-F-OFDM and F-OFDM, the performance of them is better than UFMC and FBMC due to that UFMC and FBMC have no CP limiting the tail caused by the filter and the time-varying channel in order to avoid ISI.WhatâĂŹs more, the performance of system is degraded by the inherent interference introduced by the loss of orthogonality in complex filed for FBMC. The BLERs versus terminal speeds with SNR of 5dB and without CFO is illustrated in figure 3. We can see that the performance of standard OFDM is degrading by increasing the terminal speed. Because the maximum Doppler frequency increases with increasing the terminal speed which results in performance degradation for standard OFDM. The performance of filter-based waveforms outperforms that of standard OFDM. The performance of sub-band filter-based waveforms is gradually enhanced by the speed increasing due to the adoption of ideal channel estimation which captures more Doppler diversity with higher speed at receiver. The performance of FBMC is essentially unchanged due to its long tail caused by the prototype filter which makes it difficult to obtain Doppler diversity gains.

The BLERs versus CFOs with SNR of 5dB and the terminal speed of 370 km/h is illustrated in figure 4. From this figure, we can see that the performance will generally degrade with the increasing of CFO. Abviously, the performance of standard OFDM is the worst due to the ICI resulting from CFO and high Doppler frequency shift. RB-F-OFDM achieves the best performance compared to other waveforms. From the figure, we can see the performance of F-OFDM and UFMC approaches to RB-F-OFDM at medium CFO due to the filter acting on each sub-band. But for FBMC, theoretically the characteristic of frequency-localization resulted from the long length prototype filter can make it more robustness to CFO, it is difficult to design a prototype filter to minimize ISI and ICI with low OOBE.

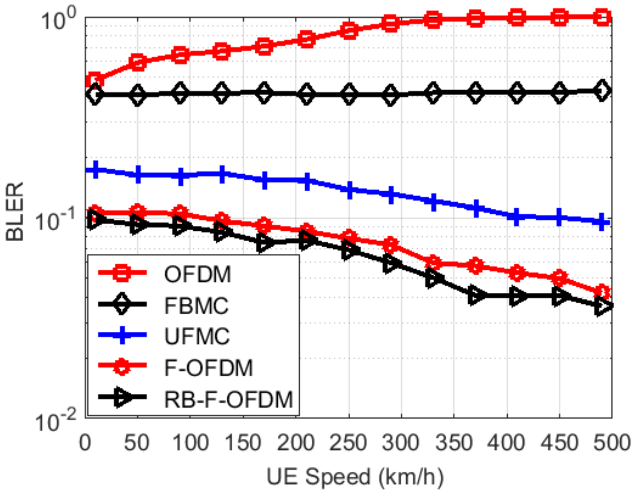

Figure 3. BLERs versus terminal speeds with SNR of 5dB and without CFO.

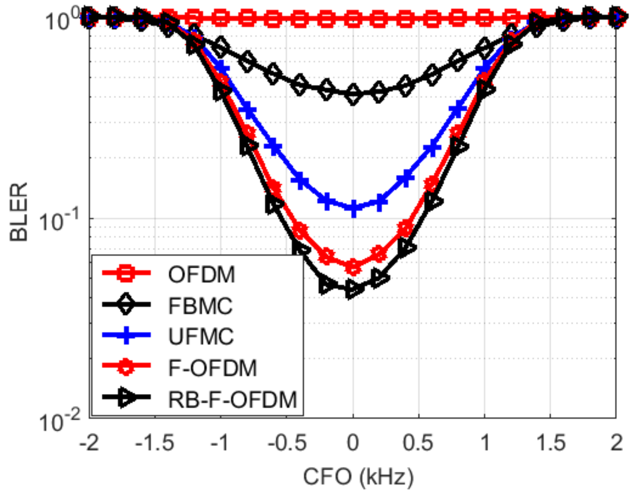

Figure 4. BLERs versus CFOs with SNR of 5dB and with the terminal speed of 370 km/h.

5 Conclusion

In this paper, we introduce the principle of filtering-based waveforms proposed for future 5G and compare their performance in high speed scenario, using the TDL-D channel model in 3GPP TR 38.900. Simulation results shows that RB-F-OFDM outperforms other waveforms in terms of high mobility and robustness against ISI and CFO. Future works will deal with design of new waveform by the performance comparison of 5G waveform candidates and their principle characteristics.

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