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Spectral Efficiency Evaluation of 5G Waveform Candidates

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***Abstract:** To increase the performance and to meet quality of service (QoS) requirements of future wireless communication and networks, some of these approaches compete for incorporation in future wireless standards such as fifth generation (5G). In this paper comparative study and performance evaluation in terms of spectral efficiency (SE) their PAPR of different 5G waveform candidates. Most multicarrier schemes suffer from high PAPR and are not suitable when high energy efficiency is required.*

***Keywords:** 5G, Spectral efficiency, PAPR, multicarrier schemes*

I. Introduction

Fourth Generation (4G) wireless and mobile communication network has been rolled-out significantly and over a past few years high peak data rates has been increased dramatically[1]. Next generation wireless communication and networks should be improve key performance indicators such as peak data rates, energy and spectral efficiencies, massive connectivity, latency, mobility and power consumption significantly. New wireless network standard should be developed to reaching new services all above under the same networks [2]. The IMT-2020[3] vision defines the fifth generation (5G) mobile communication to herald an era of truly immersive services. The 5G key performance service divided into three main categories such as enhanced mobile broadband (eMBB), massive machine-type communications (mMTC) and ultra-reliable low-latency communications (URLLC) respectively [4]. To meet these requirements a new flexible 5G waveform candidate designed exactly [6].

This paper aims to provide a spectral efficiency analysis of 5G waveform discussions and overviews. The paper is organized as follows: Section II provides a brief discussion of the 5G waveform and waveform definition and requirements. Section III explains spectral efficiency and PAPR analysis of 5G and its comparisons along with the related advantages and disadvantages. Finally, Section IV concludes the paper.

II. 5G Fundamentals waveform

Worldwide there are so many wireless groups working to define 5G needs/expectation, technology and other user requirements. An ideal 5G waveform should be fulfil the requirement of next generation wireless communications and networks such high spectral efficiency (SE), huge amount of peak data rates, low latency, power consumption andout-of-band emission (OOB).Furthermore, to achieve robust against to wireless frequency fading channel.

5G wireless communication & networks addresses various challenges in truly networked society such as the massive connectivity, high traffic and significantly increasing wide range of wireless applications with varying of wireless channel characteristics.

III. Spectral Efficiency and PAPR Comparison of 5G waveforms&RESULTS

In this section, we evaluated the performance comparison of 5G waveform candidates in terms of SE and their PAPR.

A. Spectral Efficiency(SE)

Firstly, compare the 5G waveforms in terms of SE versus the time duration of the burst. In this paper, we consider theLong-Term Evolution (LTE) system channel bandwidth 10 MHz and its related used parameters shown in Table1. In simulations results, considered two users for asynchronous mode multiuser access technique.

The multi carrier modulation schemes [7] such as OFDM, FBMC, SC-FDMA, GFDM and UFMC, the SE does not depend on the burst time and is a function of FFT size, order of the modulation and the modulation parameters.

The OFDM and SC-FDMA have same spectral efficiency defined as

$$\eta_{OFDM} = \eta_{SC-FDMA} = m \times \frac{N_{FFT}}{\left(N_{FFT} + N_{cp}\right)} \qquad (1)$$

where*m* is the modulation order. For UFMC, SE losses because of transient state of the shaping filter.

The SE of UFMC is expressed as

$$\eta_{UFMC} = m \times \frac{N_{FFT}}{\left(N_{FFT} + L - 1\right)} \qquad (2)$$

The rest of the paper, we choose L=N_{cp}+1, in order to have the same SE between UFMC and OFDM.

For GFDM, the CP insertion is done per symbol and the SE is expressed as

$$\eta_{GFDM} = \frac{m \times K \times M}{m \times K + N_{cp}} \qquad (3)$$

The spectral efficiency (SE) of UFMC and OFDM has same, whereas the SE of GFDM depends on FFT size. The SE of FBMC [6]determined by on burst duration, if burst

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duration is always greater than3ms, better SE than UFMC and OFDM [8].

Table 1: Simulation parameters

Overall parameters		
FFT size	N_{FFT}	1024
Bit per Symbol	M	2
Resource block size	N_{RB}	12
No. of RBs	N_{Re}^{1} N_{Re}^{2}	3 for UE 1 9 for UE2
Sampling frequency	F_e	15.36 MHz
OFDM and SC-FDMA		
CP	N_{CP}	72 samples
UFMC		
Length of filter	L	73
Attenuation of Stop band	40 dB	
GFDM		
Sub symbols	P	15
FFT size	M	1024
Roll Off factor	α	0.1
FBMC		
Spreading factor	K	4
Asynchronous access		
Guard carriers	[1,2,4,5]	
Timing Offset	[-0.25 :0.25]	
CFO	0 ; 10%	

If we compare the SE's of GFDM and OFDM:

1. GFDM SE is higher than OFDM SE if the frequency grid is fixed (i,e., same number of data carrier and same FFT size). Each GFDM symbol contains then more modulated complex samples ($M \times N_s$ for GFDM versus N_s for OFDM) and the size of a GFDM sub symbol is equal to the size of an OFDM symbol (without the CP insertion). SE increase for GFDM is due to the use of one CP per M sub symbols.
2. The GFDM SE is identical to the OFDM SE if we consider a constant data block size (i,e., $N_S \times M = N_S^{OFDM}$ and $KM = N_{FFT}$. It means that the frequency grid is modified, and divided by M). In such a case, the GFDM symbol size is the same as the OFDM one (the sub symbol size is thus 1/M compared to OFDM symbol size), and the frequency spacing is M times higher.

In this case, we have fixed the frequency grid, which means that the GFDM SE is thus higher than the OFDM SE.

For FBMC the SE depends on the frame duration. The SE loss is due to the transient state of the global shaping filter. Thus there is no constant loss per symbol (compared to other waveforms) and the SE increases with the burst duration to reach an asymptotic level equal to the modulation order.

The SE of FBMC is expressed as

$$\eta_{FBMC} = \frac{m \times s \times N_{FFT}}{\frac{(2s-1)N_{FFT}}{2} + N_{FFT}K} = \frac{ms}{s + K - \frac{1}{2}} \qquad (4)$$

where S denotes the number of symbols.

We compute the SE of the different waveform candidates, versus the duration of the burst. Results are depicted in Figure 1 with m=2. It is shown that the same SEs of UFMC andOFDM, the GFDM has a better SE compared to OFDM and UFMC. The SE loss for GFDM is low as the CP is added only once per symbol which means that there is M times less than CP for GFDM compared to OFDM. Besides, FBMC SE depends on the time duration, and is better than OFDM and UFMC if the burst duration is longer than 3.5 ms (when K=4 and m=2).It asymptotically reaches the modulation spectral efficiency and is comparable to GFMD if the burst duration is higher than 18 ms.

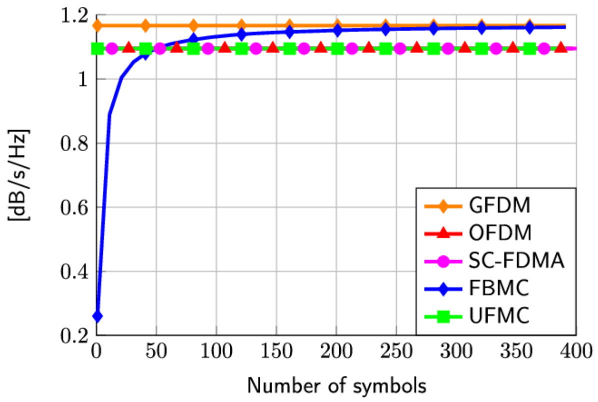

Fig.1: Spectral Efficiency versus number of symbols

B. PAPR Comparison

We compute the CCDF of the PAPR for the considered waveforms, for burst duration of 3ms and with the parameters described in Table-1 with QPSK modulation. The PAPR is defined as

$$PAPR = \frac{\max\left(\left|y[k]\right|^{2}\right)}{E\left[\left|y[k]\right|^{2}\right]} \qquad (5)$$

Figure 2 illustrated that the CCDF of PAPRversus PAPR of multicarrier modulation techniques. The SC-FDMA offers the best performance because of single carrier property and the other modulations have high PAPR.

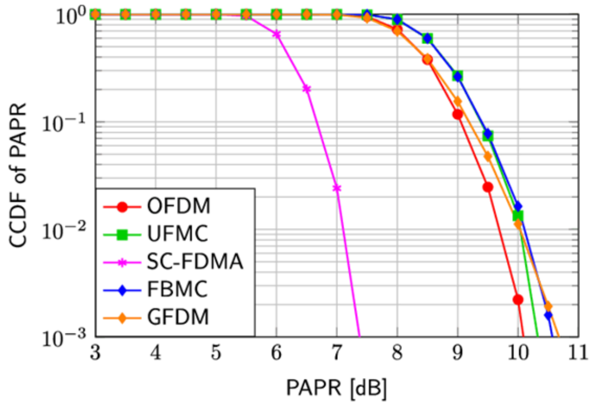

Fig.2: CCDF of PAPR

A summary of the main advantages/disadvantages of these major 5G candidate waveforms is provided in Table II.

Table II: The 5G waveform candidates.

Multicarrier Schemes		
Waveform	**Advantages**	**Disadvantages**
OFDM	✓ Simple FDE ✓ Easy MIMO integration ✓ Flexible frequency assignment ✓ Low implementation complexity	✓ High OOBE and PAPR ✓ Strict synchronization requirement ✓ Poor performance for high mobility applications
GFDM	✓ Flexible design ✓ Good frequency localization ✓ Reduced PAPR	✓ Higher latency due to block processing ✓ Challenging MIMO integration and pilot design ✓ High implementation complexity
UFMC	✓ Good frequency localization ✓ Shorter filter length compared to subcarrier-wise operations (i.e., OQAM-FBMC and GFDM) ✓ Compatible with MIMO	✓ No immunity to ISI due to lack of CP ✓ High receiver complexity due to increased FFT size
FBMC	✓ Best frequency localization (i.e., lowest OOBE) ✓ Good spectral efficiency (no guard band or CP) ✓ Suitable for high-mobility applications ✓ Convenient for asynchronous transmission	✓ Challenging MIMO integration and pilot design ✓ No immunity to ISI due to lack of CP ✓ High implementation complexity ✓ Increased power consumption due to OQAM signaling

IV. CONCLUSIONS

In this paper, discussed all waveforms for 5G provide lower OOBE compared to OFDM and SC-FDMA. The subcarrier-wise filtering operation in FBMC results in the best frequency localization among the candidate waveforms due to the use of longer filter lengths. Although GFDM is another subcarrier-wise filtered waveform, the rectangular window shape in the time domain causes abrupt transitions and increases OOBE. Most multicarrier schemes suffer from high PAPR and are not suitable when high energy efficiency is required. However, GFDM exhibits a reduced PAPR characteristic due to its equivalency to DFT-spread waveforms. The single-carrier schemes are preferable in energy-limited use cases along with the use of flexible guard intervals that provide better spectral confinement and improved PAPR. The spectral efficiency is another critical design criterion that is highly affected by the window/filter duration, the shape of filter, and extra overheads.

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