MULTICARRIER WAVEFORMS FOR ADVANCED WIRELESS COMMUNICATION

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https://doi.org/10.26782/jmcms.2020.07.00020

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is one of the best techniques for improving bandwidth efficiently and combating multipath fading by choosing proper modulation scheme in wireless communications. However, this technique has a major drawback of high Peak-to-Average Power Ratio (PAPR) which makes transmitter section inefficient by leading to power inefficiency in the Radio Frequency section. Therefore OFDM with high PAPR makes the high power amplifier nonlinear and decreases efficiency of power and generates a nonlinear distorted output, and thereby reducing performance of both spectral efficiency and energy efficiency. These drawbacks of OFDM can be mostly reduced by using proposed 5G transmission schemes.

Keywords: PAPR, Radiofrequency, OFDM, Spectral efficiency, 5G

I. Introduction

Nowadays in trending wireless technology the need for high data rate with best quality services is escalating quickly. The structure designer need to regulate process to facilitate growth in the given QOS as well weaken the outcome of delay spread & Doppler shift. Devices like smart phones and tablets are provided with high speed data and large bandwidth in 4G LTE system using OFDM technology. OFDM is a multicarrier modulation used for minimizing multi-path fading [IX, XII, XIII] with low complex structure and also provides a large bandwidth with enhanced data rates. OFDM is also efficient in optimizing channel delays [III, V], but it suffers from a major drawback of Out of Band Emissions (OOBE) and high PAPR. OOBE will effect in reducing spectral efficiency and high PAPR needs high power amplifiers and increases non linear behavior of it [I]. PAPR in OFDM can be reduced by different
methods like Amplitude clipping then filtering, Partial Transmit Sequence and Selective Mapping [VII]. But all these methods are computationally complex. OFDM employs a Cyclic Prefix (CP) to overcome offsets caused by time and frequency, but CP consumes bandwidth and reduces spectral efficiency.

The drawbacks of OFDM can be mostly reduced by using 5G transmission schemes [XIV]. These schemes come with a tremendous advantage of high data rates accommodating large number of users, low latency, spectrally efficient and minimize offset errors caused by frequency and time [XV]. 5G communication waveforms are capable of dealing the needs of advanced technological applications like virtual reality, smart home appliances, 3-D gaming etc.

Filter bank multicarrier (FBMC) is a multicarrier technique which performs filtering of each subcarrier when compared with OFDM, and uses frequency selective filters to reduce side lobes [IV, VIII]. Due to filtering of each subcarrier computational complexity is increased in FBMC and makes it unfavorable in short burst uplink communication.

In Generalized Frequency Division Multiplexing (GFDM) filter tails are avoided by filtering, using a cyclic convolution, and make it suitable for short bursts.

Universal Filtered Multi Carrier (UFMC) is overview of OFDM as well as FBMC modulation method and in this method an assembly of subcarriers (sub bands) is filtered and it shrinks the filter length (when compared with FBMC) and also provides sidelobe attenuation. A special frame structure is employed in UFMC to reduce inter-symbol- interference (ISI) thereby avoiding CP.

II. 5G Candidate Waveforms

This section elucidates the operating principles of 5G candidate waveforms for next generation communications based on different transceiver designs.

UFMC Transceiver

Figure 1 depicts UFMC transmitter and receiver. Filtration of signal is performed on sub-band basis. Each sub-carrier is further divided into \( B \) number sub-bands out of \( N \) sub-carriers [XIV]. MIMO techniques can be employed in UFMC. Prototype filter \( f_i(m) \) named Dolph-Chebyshev is used to filter each sub-band \( i \). This filter is of length \( L_{\text{UFMC}} \) side lobe attenuation \( \alpha \) and modulated frequency is near center frequency of the sub-band. In the first block for \( i^{th} \) sub-band, time–domain signal \( s_i(n) \) is generated from vector of array of QAM symbols \( d_i(l) \) at time \( l \) using IFFT and parallel to serial alteration. For every block of \( N \) QAM symbols all filtered signals are added to generate discrete baseband UFMC signal given by

\[
x(m) = \sum_{l=0}^{B-1} \sum_{n=0}^{L-1} s_i(n) f_i(m - n) \quad (1)
\]

In the above equation \( m = 0, ..., N - L_{\text{UFMC}} - 1 \) samples. A length \( L_{\text{UFMC}} - 1 \) of guard interval is introduced in each block of UFMC with zero padding. Guard interval is used to compensate the time dispersion produced by filters. Extra guard intervals can be employed to mitigate time dispersion in severe multipath channel. Time dispersion is mitigated by using 1-tap FDE channel.

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AT the receiver UFMC converts the serial data into parallel form and then a FFT operation of 2N-point is performed on every UFMC symbol. All odd sub-carriers contain ICI and due to this data are retrieved from N even sub-carriers and then each symbol undergoes 1-tap FDE to recover final data symbols.

**Fig. 1: UFMC Transceiver**

**FBMC Transceiver**

The operation of FBMC can be explained by using figure-2. The spectral containment problem in OFDM is resolved in FBMC by means of a prototype filter \( h(n) \) of length \( NK \) where \( N \) is the number of subcarriers and \( K \) is overlapping factor which allows overlapping of each symbol with adjacent \( K \) symbols in time domain and avoids ISI using Nyquist criterion [X]. Nyquist filter is planned in frequency domain by using \( 2K-1 \) symmetric samples at the transmitter and receiver.

These are prototype filters in frequency domain with roll-off factor of \( \beta \) equal to unity and the each prototype filter \( h(n) \) is produced by using IFFT of \( KN \)-point. At the transmitter for a \( k^{th} \) subcarrier, initially Quadrature Amplitude modulation (QAM) symbols designated as \( d_k(l) \) are converted into Offset QAM (OQAM) symbols \( s_k(n) \) and this process is given by

\[
\begin{align*}
\text{for } k \text{ even, } & \\
\begin{cases}
  s_k(n) &= \text{Re}[d_k(l)] \\
  s_k(n+1) &= \text{Im}[\text{Re}[d_k(l)]]
\end{cases} \\
\text{for } k \text{ odd, } & \\
\begin{cases}
  s_k(n) &= \text{Im}[\text{Re}[d_k(l)]] \\
  s_k(n+1) &= \text{Re}[d_k(l)]
\end{cases}
\end{align*}
\]
where $n = 2l$ and therefore OQAM symbol rate is double to that of QAM. In the next level OQAM output is upsampled by a factor of $N/2$ and then filtered by a transmission filter $f_k(m)$ given by

$$f_k(m) = h(m)e^{j2\pi km/N}, m = 0, 1, \ldots, KN - 1$$

Thus the transmitter generates FBMC baseband signal $x(m)$ by filtering each subcarrier as

$$x(m) = \sum_{k=0}^{N-1} \sum_{n=-\infty}^{\infty} s_k(n) f_k(m - \frac{nN}{2})$$

FBMC receiver employs a matched filter $g_k(m)$ with the respective transmission filter $f_k(m)$ thereby remove orthogonally among sub-carriers. At transmitter for odd time slot the real part of impulse response crosses zero while for even time slot imaginary part crosses zero. Thus from (2) for any specific sub-carrier, OQAM process generates alternating imaginary and real parts of QAM symbols and restores orthogonality. At the receiver end same throughput is maintained by down-sampling by a factor of $N/2$. At the receiver to compensate multipath interference FIR equalizer is used then OQAM demodulation is performed to generate the estimated QAM symbols. FBMC with OQAM is not suitable for MIMO techniques [VII]. Due to long filter tail this method is also unfavorable for short bursts.

**GFDM Transceiver**

Figure 3 can be used to explain the working of GFDM based multicarrier system. Similar to FBMC, this technique also employs filtration of each subcarrier separately. This technique introduces time and frequency dimensions in data blocks [II]. Each GFDM symbol contains $M$ QAM symbols on each subcarrier and hence GFDM is same like Single carrier system and provides equalization in frequency domain. Unlike FMMC, GFDM uses circular filter to avoid long filter tails. The circular filter of each sub-carrier is given as:

$$\text{GFDM Transceiver}$$
\[ \tilde{f}(m) = f \left( (m + \frac{MN}{2} \mod MN) - \frac{MN}{2} \right) \]  

(5)

In the above equation root-raised-Cosine filter \( \tilde{f}(m) \) is used with a filter length of \( MN \). N symbols are up-sampled in GFDM and then spanning is executed with \( \beta < 1 \) roll-off. Circular filtering or tail biting maintain same signal before and after filtration. Therefore the baseband signal generated at GFDM for a \( k^{th} \) subcarrier is given by:

\[ x(m) = \sum_{l=0}^{M-1} \sum_{k=0}^{N-1} d_k(l) \tilde{f} [m - lN] e^{j2\pi \frac{km}{N}} \]  

(6)

In the above equation \( d_k(l) \) is set of \( M \) QAM symbols and sample index is \( m = 0, ..., NM - 1 \). Single-tap FDE is enabled at the receiver by inserting CP. Zero forcing and minimum mean square error equalization methods are used at the receiver to suppress Inter-Carrier Interference (ICI). In this paper at the receiver matched filter is implemented i.e. \( \tilde{g}(m) = f(m) \), along with interference cancellation algorithm and this selection gives optimized values of BER and computational complexity.

Double-sided serial interference cancellation (DSIC) [XI] method is an iterative scheme employed at the receiver and for each sub-carrier it measures the interference \( z^{(i)}(m) \) and this method is used to suppress the interference due to adjacent sub-carriers and then signal is retrieved at \( y(m) \). At the end of iterations all the subcarriers are free of interference. On every sub-carrier, a sub-iteration process is implemented given by index \( i \). For a \( k^{th} \) sub-carrier and \( i^{th} \) sub-iteration interference is expected as

\[ z^{(i)}(m) = \sum_{k'= \left\{ (k+1) \right\}}^{M-1} \sum_{n=0}^{M-1} \tilde{d}^{(i)}_{k'}(l) \tilde{g}(m - lN) e^{-j2\pi \frac{yn}{N}} \]  

(7)

where \( \tilde{d}^{(i)}_{k'}(l) \) are estimated symbols which are acquired by the process of mapping of symbols received to the constellation grid. Latest estimated data symbols are used to clean, \( (k+1)^{th} \) sub-carrier. For \( J \) equal to 4 full iterations Bit Error Rate of this algorithm will be approximately equal to that of OFDM and gain is also unaltered and hence this scheme becomes unfavorable for MIMO. Due to discontinuities in successive block, Tail biting scheme also reduces spectral efficiency. To avoid this every GFDM block is filtered by MN point RRC filter. To maintain robustness to multi-path channels, receiver drops first and last time slots of every GFDM block and thereby avoids windowing.
III. Results

As shown in figure 5 Bit error rate (BER) performance of various signals with respect to signal-to-noise ratio is compared. The following parameters are used and simulated

Table 1: Parameters of different waveforms

| Name of the waveform | Number of subcarriers | Prototype filter employed |
|----------------------|-----------------------|---------------------------|
| OFDM                 | 128                   | Rectangular               |
| FBMC                 | 128                   | PHYDYAS                   |
| UFMC                 | 12 (10 sub-bands)     | Dolph-Chebyshev          |
| GFDM                 | 128                   | RRC                       |

From the figure 5 we observe that BER of FBMC is minimum (best) and GFDM is maximum (worst) when compared with the other three waveforms and UFMC is superior to OFDM.

Fig. 3: GFDM Transceiver

Fig. 4: BER performance analysis of 5G candidate
IV. Conclusions

This paper provided an overview of 5G waveform contenders and a comparison of BER of these waveforms with existing OFDM technology. We observed that FBMC performs superior in this aspect and then followed by GFDM and we also observe that UFMC is more compatible to MIMO compared to FBMC and GFDM.

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