Performance Analysis of GFDM System in 5G Cellular Networks

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Abstract*- Orthogonal Frequency Division Multiplexing (OFDM) is employed in the current 4G cellular technologies. Because of its resistance to multipath propagation channels, OFDM is a popular multicarrier modulation technique. Although OFDM is one of the effective approaches for a 4G network, out-of-band radiation, inter-symbol interference (ISI), and inter-carrier interference make this method unsuitable for 5G. (ICI). A new approach or next-generation cellular network, i.e., very high data rate, low latency, greater throughput, more device connectivity, and improved device-to-device communication, should be used to deliver effective and dependable communication. The system introduces generalized frequency division multiplexing (GFDM). In GFDM, a single cyclic prefix is utilized throughout the frame and an adjustable pulse-shaping filter can be used to monitor the transmitted signal's out-of-band emission. Using this ISI, the multipath channel can be controlled. In the proposed system, with large signal constellations, higher-order modulation schemes, and advanced receiver structure, a very high data rate can be achieved. By using various iterative receiver structures the performance of the GFDM system in 5G cellular networks can be analyzed.

***Keywords:*—5G, GFDM, OFDM, FBMC, modem, MF, ZF, MMSE.**

I. INTRODUCTION

In many current communications systems, including wireless ones, OFDM is an effective technology. Although OFDM has several attractive benefits, such as ease of installation and resistance to frequency selective fading, it is unable to realize the needs of 5G network systems. A high Peak to Average Power Ratio (PAPR) and ICI sensitivity are just two of its shortcomings. Furthermore, the CP (Cyclic Prefix) fails when the channel's delay distribution exceeds the CP length and is ineffective in the spectrum, resulting in ISI. Numerous methods have been suggested to mitigate these drawbacks. GFDM, one of them, is distinguished by a decrease in leakage outside the pass band. GFDM, a flexible multicarrier modulation technique, has also been suggested for the air interface of 5G System networks.

The KM sample block structure of the GFDM symbol has K subcarriers that each has M timeslots. This is a generalized version of OFDM. As a result, a GFDM symbol is made up of several OFDM symbols. GFDM has a higher spectrum efficiency than OFDM since it only needs one CP per symbol. On the other side, the introduction of CP makes simple frequency domain equalization possible (FDE). The foundation of GFDM is the modulation of independent blocks, each constituted of several sub-carriers and sub-symbols. A prototype filter that has been circularly shifted in both the time and frequency domains filters the subcarriers. Fewer OOB emissions enable fragmented spectrum and dynamic spectrum assignments without impairing current services or other users.

In general, Filter Bank Multicarrier (FBMC) systems can be used to describe all of these signaling methods. Both those with linear pulse shaping and those with circular pulse shaping can be roughly split into these two categories. In contrast, in FBMC systems with circular pulse shaping, prototype filter transients, also known as tail-biting features, are abolished. The advantages of GFDM come at the expense of a greater Bit Error Rate as compared to OFDM (BER). There is a decline since GFDM is a non-orthogonal waveform. Therefore, the non-orthogonality of the neighboring subcarriers and time slots results in self-interference.

To overcome the self-interference, Matching Filter (MF), Zero Forcing (ZF), or Minimum Mean Square Error (MMSE) receivers were developed. The MF receiver is unable to entirely remove the ICI, so the ZF receiver can be used. Because of its noise enhancement problem, the ZF receiver exhibits some BER performance loss. The MMSE technique can be used to reduce the influence of noise enhancement and boost the signal-to-interference noise ratio (SINR).

The existing methods are used to enhance this study of designing a low-complexity modem structure for GFDM. The modulation matrix's unique structure is used to simplify the transmitter to provide a common framework for the MF, ZF, and MMSE receivers. This unified receiver structure has the advantage that filter coefficients need to be altered to implement various receivers. These coefficients can be stored in memory and used as necessary in various circumstances. For instance, high signal-to-noise ratios allow the use of a ZF receiver rather than an MMSE one SNR. Because our methods are precise and do not account for data channel transient periods. As a result, the receivers can address the wireless channel losses using Frequency Domain Equalization, which also lessens the complexity of the channel equalization.

II. SYSTEM DESCRIPTION

The binary data vector encoder is provided by a source of information. The encoded bits are converted to symbols from a complicated constellation with a value using a mapper, such as QAM which is in Fig. 1. The resulting vector will be split into K subcarriers and subsymbols to represent an N-element data block. The total number of symbols is given by N = KM. The data transferred in the subcarrier and the blocks sub-symbol are divided into individual components.

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In MN×1

$$b = [b_0^T \cdots, b_{N-10}^T]$$

Where b is the vector.

$$[b_i = b_i(0), \ldots, b_i(M-1)^T]$$

Where b_i is the data vector

Similarly, $b_i(m)$ refers to the data symbol that will be broadcast during the designated time slot on the i^{th} subcarrier. The data symbols are independent, identically distributed (i. i. d.) processes with a variance of one and zero mean. To create an impulse train the data symbols will be sent on an i^{th} subcarrier in GFDM modulation.

$$s_i(w) = \sum_{m=0}^{M-1} b_i(m)\delta(w - mN), \quad w = 0, \ldots, NM-1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$s_i = [s_i(0), \ldots, s_i(MN-1)]^T$$

Where s_i is up-converted to the matching subcarrier frequency. The resulting signals are added together in each subcarrier to create the GFDM signal x (w). Subsequently performing the same procedure.

$$x(w) = \sum_{i=0}^{N-1}\sum_{m=0}^{M-1} b_i(m) g\{(w - mN) \text{mod} MN\} e^{j\frac{2\pi i w}{N}} \quad \ldots\ldots\ldots\ldots (2)$$

Where g^l is the g^{th} coefficient of the prototype filter

All the transmitter output samples are combined in $MN \times 1$ vector

$$X = [x(0), \ldots, x(MN-1)]^T,$$

Then the GFDM signal is represented as the product of a modulation matrix A and the size MN×MN to the data vector d,

$$x = Ab \ldots\ldots\ldots\ldots (3)$$

$$g = [g0, \ldots., gMN-1]^T$$

Where g holds all the factors of the pulse shaping/prototype filter with the length MN and the element A can be represented as,

$$[A]_{wm} = g\left\{(w - mN) \text{mod} MN e^{j\frac{2\pi w}{N}\left[\frac{m}{M}\right]}\right\} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In GFDM systems, the channel transient time is taken into consideration. At the start, the block with a CP is longer than the channel delay deviation. As a result, the MF and ZF receivers can address the wireless channel impairments using FDE, which also reduces the complexity of the channel compensation. If N_{cp} is the CP length, then the last N_{cp} elements of the vector are attached at the beginning. This will form the transmitted signal vector and the channel impulse response. If the CP length needs to be longer, then the channel length is N_{ch} to receive the signal which has disappeared through the channel, after the CP removal it can be represented as

$$r = Hx + v \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Fig. 1. Block diagram of the transceiver and receiver

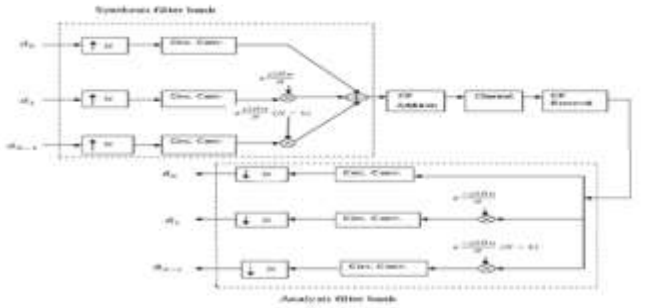

Fig. 2. AWGN Channel Baseband GFDM transceiver system

To decrease or eliminate the ICI transmitted data, three linear GFDM receivers-MF, ZF, and MMSE are taken. As was explained, match filtering enables the recovery of the sent symbols.

$$\hat{b}_{MF} = A^H y \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Therefore, the ZF approach can be used to remove the ICI that was created by the subcarriers' lack of orthogonality The transmitted data vector's ZF estimate and found as

$$\hat{b}_{ZF} = (A^H A)^{-1} A^H y \quad \ldots\ldots\ldots\ldots\ldots (7)$$

As a result, the GFDM transmitter and receiver can be compared to two filter banks for synthesis and analysis, respectively.

III. PROPOSED TECHNIQUES

A. GFDM Transmitter

The design of low complexity GFDM transmitter demonstrated in figure.3 can be made simpler and very low computational load.

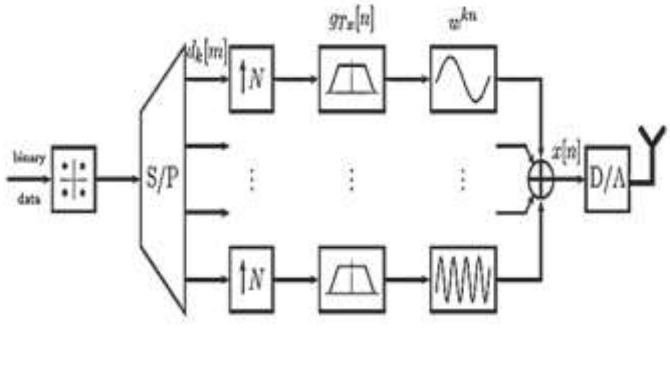

Fig. 3. GFDM baseband transmitter

B. GFDM Transmitter Design

The multiplication of the data vector with the matrix is a complex operation, that necessitates complex multiplications. As a result, complexity will become a problem for systems.

In Fig. 3, consider the baseband system that disperses complex data symbols b(k, m) using k carriers and m symbols. Each sub-carrier is modulated with its center frequency $e^{j2\pi kw/N}$, and is shaped with a transmit pulse, gfx (w).

The MN frequently is chosen for filter gfx (w). This equation can be represented as follows after the data symbols are arranged in a b (k, m) column, an arrow, and the operations of upsampling, circular convolution with pulse shaping, up-conversion, and superposition:

$$x = Ab = AF_d^H F_d \qquad \text{......... (8)}$$

Where A is a modulation matrix with an MN x MN dimension, and x includes transmitted samples in time x(w).

C.GFDM Transmitter implementation

In the designed GFDM transmitter, the modulation can be classified into two stages.

1) M Number of N point DFT operations,

2) N Number of M -point circular convolution operations.

By cascading the block diagrams, all the steps of our GFDM transmitter may be achieved. Every commutator rotates counterclockwise. After one sample collection, both commutators are situated on the right side of the turn.

IV. PROPOSED GFDM RECEIVER

It is important to note that the results are straightforward, which means that these receivers may be made simpler without sacrificing performance because of the unique matrix structure.

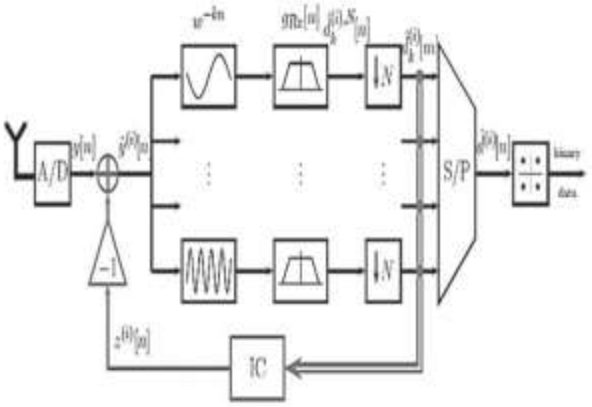

Fig. 4. Matching filter receiver model with interference cancellation for GFDM

The expression generates the time-invariant multipath channel's received signal with impulse response h(w).

ȳ =x*h (w) +n (w) …… (11)

Where n(w) is a vector of Gaussian noise samples with a variance of 2n and a mean of zero, and x is the transmitted signal with the CP. The equation that results once the CP is removed is:

y(w)=x(w)+n(w) …………… (12)

V. COMPUTATIONAL COMPLEXITY

Our suggested GFDM transmitter and receiver structure computational complexity are reviewed, and it is contrasted with that of the ones that are currently in use. Both cases take into account the overall N subcarrier count as well as the M overlapping factor.

A. Transmitter Complexity

The number of complex multiplications (CMs) determines how computationally complex various GFDM transmitter implementations are. There are two steps in our GFDM transmitter proposal. The first includes several N-point FFT operations that require $\frac{M}{N}\log_2 N$ CMs. Circular convolutions with many points are included in the second phase. Since and have actual values, it is obvious that $\frac{M^2}{2}$ CMs are needed for each -point circular convolution.

B. Receiver Complexity

The number of complex multiplications required by various GFDM receivers to process two examples of AWGN and multipath channels. The suggested MMSE receiver is approximately two to three times less sophisticated than the existing ones. Our solutions preserve the best ZF and MMSE performance because they are direct, in addition to having lower computational costs when compared to the current receiver architectures. In contrast to current solutions, their difficulty is independent of the prototype filter selection. The ZF and MMSE receivers are compared to receiver architectures that are over an order of magnitude more sophisticated than OFDM.

VI. SIMULATION RESULTS

The data samples are spread through k-carriers and M subcarrier modulated using QAM modulation and the symbol sampled. The symbol generated by the QAM modulator is,

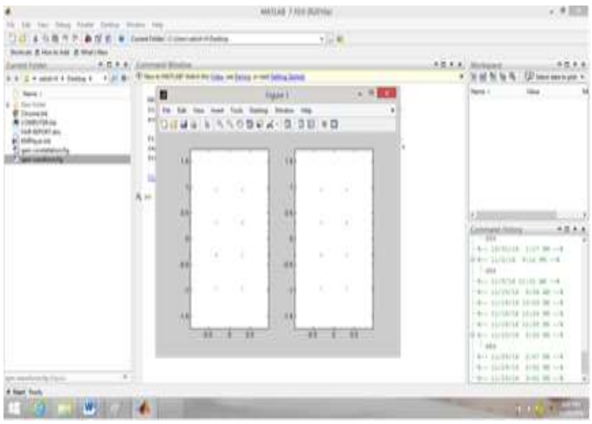

Fig. 5. Constellation diagram of QAM symbol

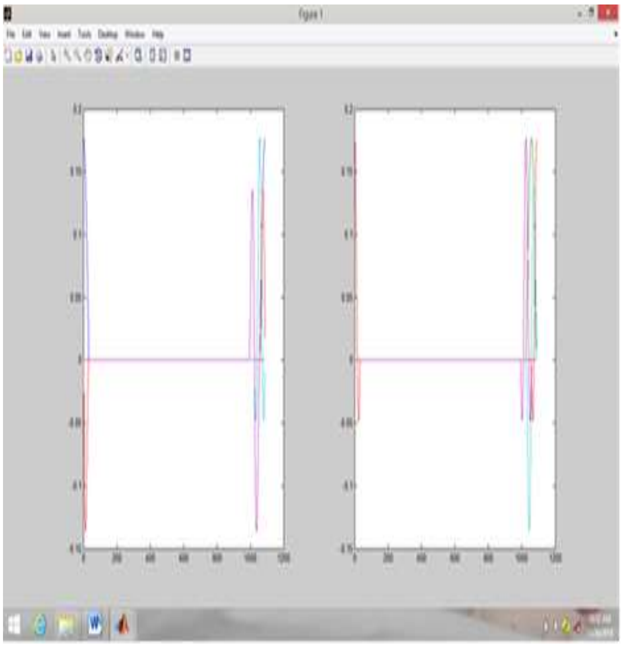

Fig. 6. 16-QAM waveform

The spectrum of GFDM is compared with the spectrum of OFDM given below,

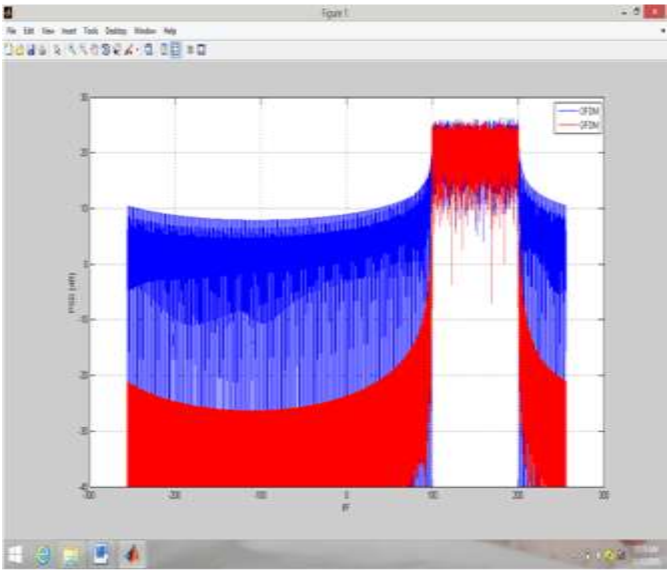

Fig. 7. Spectrum Comparison between GFDM and OFDM Systems

Thus the GFDM spectrum is compared to the OFDM spectrum with 256 subcarriers.

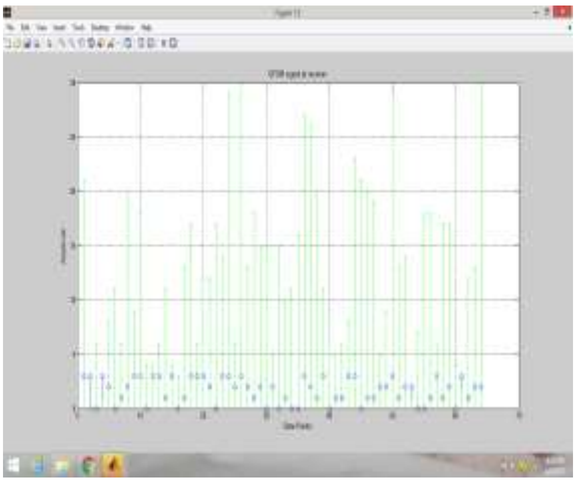

Fig. 8. 16-QAM waveform

At the receiver process, the GFDM signals are maintained. Signal Reconstructed and demodulation process can be done. Finally, the data can be decoded as amplitude levels concerning sampled datapoints. On the receive side, the GFDM signal is obtained with some noisy signals, and that noisesignals are removed by using various receiver structures.

VII. CONCLUSION

The GFDM-based spectrum is better than OFDM. Using an RRC pulse, improved the spectrum gain compared to OFDM. In addition, channel losses also improved because of AWGN for different SNRs. Finally, the signal passes through a Rayleigh channel. In the AWGN and Rayleigh channels, GFDM gives better results compared to OFDM. The receiver structures such as MF, ZF, and MMSE are used to reduce the interference of the system and the MMSE receiver structure provides better performance analysis.

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