Spectrum analysis of OFDM versus FBMC in 5G mobile communications

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ABSTRACT

With the demand for mobile data traffic, multi-carrier transmission techniques are highly attractive for all-new wireless communication systems, which divides data into many components and sends each of these components via a different carrier signal. So far, orthogonal frequency division multiplexing (OFDM) and filter bank multi-carrier (FBMC) techniques are the dominant waveform contenders. A number of studies have been made and failed to give a complete comparison where they did not consider various conditions altogether. Therefore, this paper addresses a complete comparative analysis of OFDM and FBMC, performed based on spectral efficiency, modulation, demodulation, power spectral densities, and peak to average power ratio comparison, all simulated using Matlab and GNU's not unix radio (GNU-radio) software.

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1. INTRODUCTION

In the pursuit to fulfill the need of the new spectral specifications and the increasing data in which long-term evolution (LTE) fails to meet the requirements, a novel generation of systems is developed, Recently, new multi-carrier systems for 5G wireless communications have been discussed to support future wireless access. The new candidate is the orthogonal frequency division multiplexing (OFDM) system which is the most common case of multi-carrier systems that has been proposed to share the various subsets of those subcarriers, with the use of cyclic prefix as an important element to make OFDM signal operate reliably [1], [2]. This new spectral specification comes with several problems, such as the intersymbol interference along with the high vulnerability to carrier frequency offsets and phase noise [3].

However, the cyclic prefix is shown redundant in terms of information along with the noise of the signal as amplitude with a very large dynamic range, which considerably reduces the bandwidth efficiency. We overcome these limitations of OFDM by a new multi-carrier communication system known as filter bank multi-carrier (FBMC) with no cyclic prefix required thereby freeing up more space for real data, by adding generalized pulse shaping filters that produce a well-localized subchannel in each frequency and time domain. Correspondingly, the filter bank systems have more spectral containment signals [4]. The paper is structured as: section 2 is a comparison between OFDM and FBMC. Next, we describe the implementation of OFDM and FBMC using GNU radio, while section 4 discusses the synchronization performance and measurements by GNU not unix radio (GNU radio) and Matlab simulation, then we conclude by remarks and a conclusion.

2. OFDM vs FBMC
2.1. Orthogonal frequency division multiplexing
OFDM is a novel multi-carrier technique that divides all transmitted bit-stream into different substreams [5]. It sends them back into many different subchannels, where each has a much lower bandwidth than the channel coherence bandwidth. Figure 1 shows the basic structure of OFDM; using the serial to parallel data converter (S/P) [6], the incoming data streams are split into parallel data where each data stream is modulated. Through the inverse fast fourier transform (IFFT), the pre OFDM symbols are modulated into N orthogonal sub-carriers, and then we add the cyclic prefix (CP) to increase the symbol duration. Next, to form an OFDM symbol, we multiplex the mapped sub-carriers and transform the symbol representation from frequency into the time domain by the parallel to serial converter. At last, we remove the cyclic prefix. Consequently, the digital signal is produced and converted into an analog form before being transmitted over the channel [7].

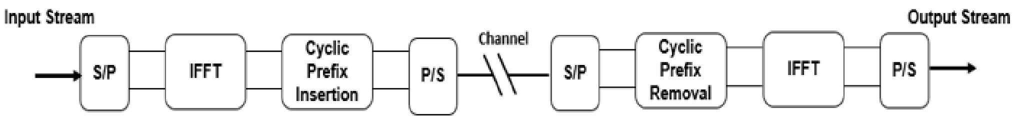

Figure 1. Basic structure of OFDM

2.2. Filter bank multi carrier
FBMC is a multi-carrier technique, an evolved version of OFDM. It is an alternative transmission method used on both the transmitter and the receiver with a network of filters called synthesis and analysis filters [8], along with a fast fourier transform (FFT) as a de-modulator and an IFFT as a modulator, it has resolved cyclic prefix (CP) problems to avoid both ingress and egress noises, by dividing the transmitted signal into various components, each one carrying a single frequency sub-band of the original signal [9]. Figure 2 describes the structure of the FBMC system. There is a major difference between both systems, we first replaced the cyclic prefix input with the synthesis filterbank. Meanwhile, on the receiver side, we replaced the output of the cyclic prefix removal with an analysis filterbank. As shown in Figure 2, in order to proceed the incoming signal to the synthesis filter bank, it must be converted first from serial to parallel form using the S/P converter. Next, using the parallel to serial data converter (P/S), the outgoing data are split back into serial data. The signal passes through the channel, and the serial to parallel converter [10], [11] converts the signal into the parallel form on the receiver side and through the analysis filterbank. Eventually, when the output signal is obtained, it will convert into analog form.

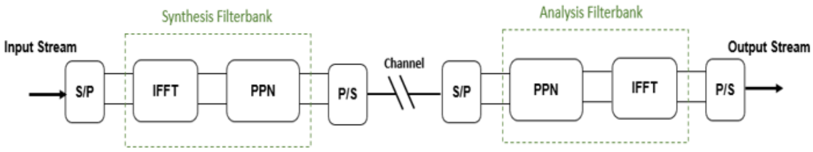

Figure 2. Basic structure of FBMC

2.3. Differences between OFDM and FBMC
One of the major differences between both systems is the replacement of the cyclic prefix on FBMC with the filter banks on both sides. However, the pulse shaping on OFDM and FBMC are applied at each subcarrier, also due to the overhead in overlapping symbols in the filter bank, the implementation of FBMC is more complex than OFDM where the customized FFT and IFFT which are part of the OFDM system block diagram. They are used in their standard form without modifications [12].

In terms of orthogonality, OFDM requires it in subcarriers. However, FBMC needs orthogonality only in adjacent sub-channels for the frequency exploitation polyphase network. On the other hand, the offset quadrature amplitude modulation (OQAM) accomplishes the task of total throughput in FBMC by dividing the given frequency into many sub-channels [13]. In OFDM, the given frequency divides into several subcarriers. In order to re-design a new waveform that meets the requirement of the 5G applications, these logical differences will make us improve the spectral efficiency, the low latency, and the peak-to-average power ratio (PARP) [14] directly demand from the physical layer to validate our research we followed this analysis with our simulations and testing results.

3. GNU RADIO IMPLEMENTATION

This section details the different structures that intervene in building blocks in both OFDM and FBMC and explains the setup of the transmitter and the receiver. Starting with Figure 3 illustrates the generated information using a file source, which will be sent to both transmitters using a socket of the protocol data unit (PDU) that receives data from the file sink and passes them on to the systems. Both examples use a Gaussian noise source to simulate the real signal, with an amplitude up to 6.7 mV.

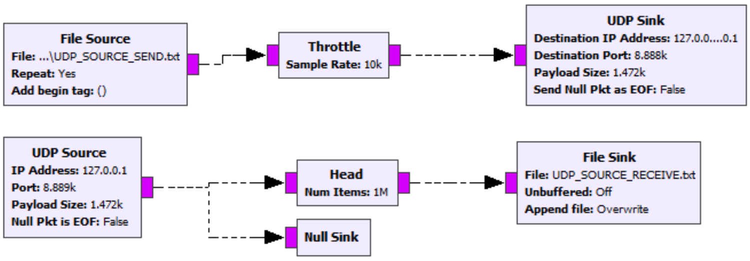

Figure 3. Flowgraph for the information source

3.1. Transmitters

Figure 4 describes the structure of OFDM. First, the socket of the PDU receives data from the file sink and passes them on. Then it converted the protocol data into byte format data through PDU to tagged stream. This byte data is sent at the stream to tagged stream block, which adds tags evenly on spaced intervals. Then we add cyclic redundancy to the data through the cyclic redundancy check (CRC32). The check code is divided into two channels to generate the data header and the data payload part, respectively carry out the binary phase shift keying (BPSK) and quadrature phase-shift keying (QPSK) mapping [12], and assemble them through the tagged stream mux module, both systems are using fast fourier transform (FFT) to transform from frequency to time domain [13].

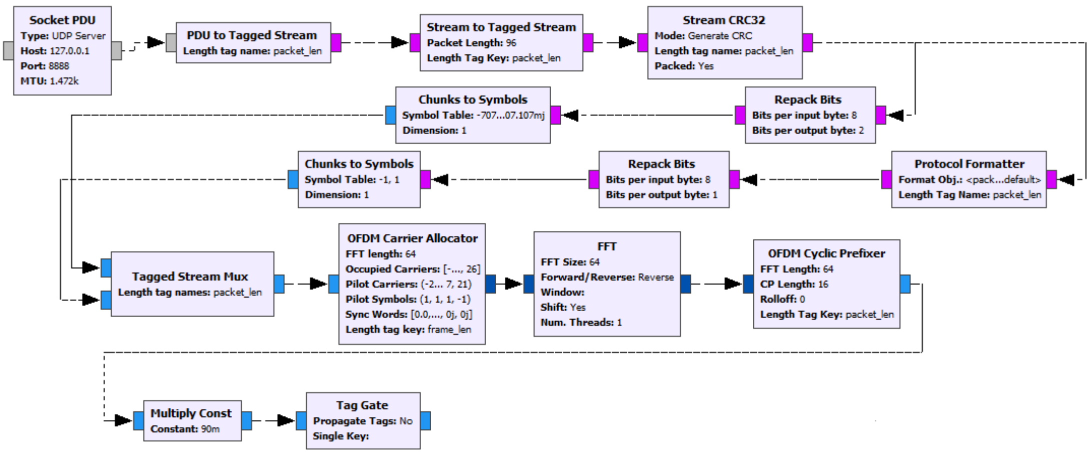

Figure 4. Flowgraph for OFDM transmitter in GNU radio

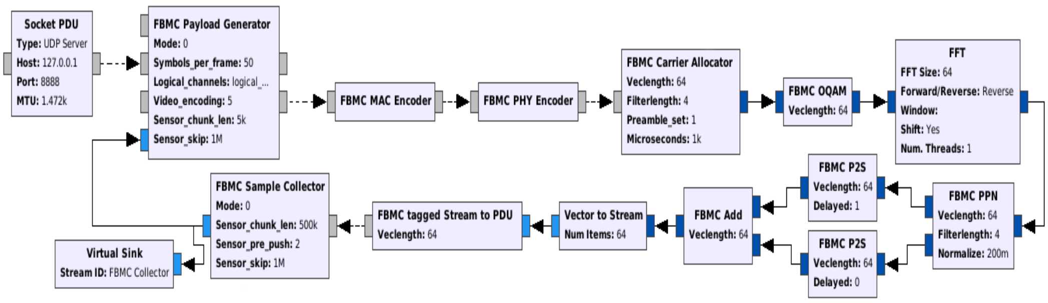

Figure 5. Flowgraph for FBMC transmitter in GNU radio

Figure 5 display the FBMC transmitter, we used almost the same thing with the OFDM. As it can be seen, there is a data source receiving binary messages from the file sink using the socket PDU to be encoded by the mac encoder then into the carrier allocated which transforms byte data into the OQAM symbols. Finally, the symbols are passed through the IFFT and synthesis filters, for which we used a polyphase network (PPN) for shaping the subcarriers into a smoother pulse.

3.2. Receivers

In both receivers, we can visualize three important parts, starting with OFDM receiver in Figure 6. First, the synchronizer uses a Schmidl and Cox synchronizer to realize the frame offset correction for OFDM. Second, the header/payload demuxer (HPD) block ducting the samples, then the trigger signal sent to indicate the beginning of the frame. Third, the IFFT transforms the received signal from time to frequency domain, then through socket PDU to decode and recover the sent data.

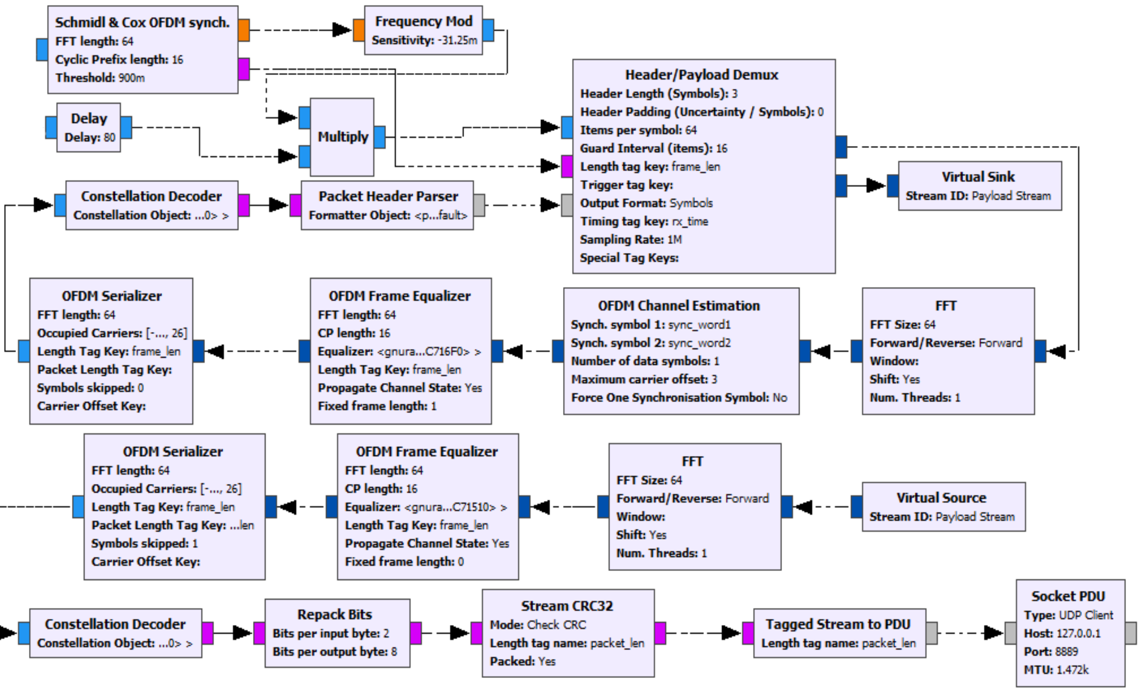

Figure 6. Flowgraph for OFDM receiver in GNU radio

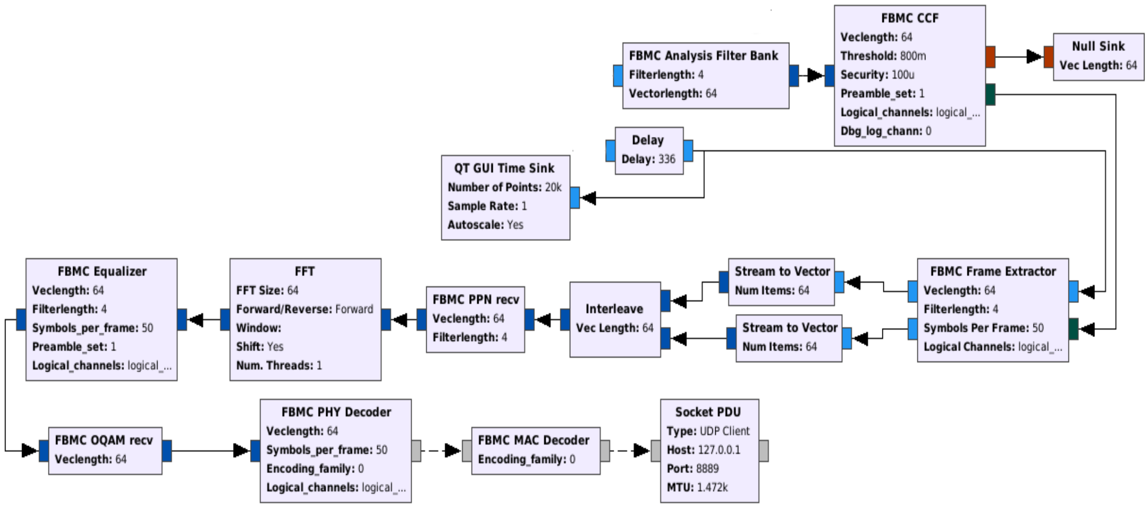

Figure 7. Flowgraph for OFDM receiver in GNU radio

Figure 7 shows the FBMC receiver. We first used the analysis filter bank for synchronization. Next, the cross-correlation function (CCF) to performs and measures the symbol in timing offset and passes them in the frame extractor to extract the frame and go into a second analysis filter bank. Finally, the IFFT transforms the received signal and through socket PDU to recover the data.

4. SIMULATION AND RESULTS

This simulation gives a comparative analysis of OFDM modulation along with FBMC to overcome all known limitations. It offers ways to meet strict synchronization requirements and improves spectral efficiency. In order to choose a better match for the 5G frequency range, we operated on the mmWave spectrum band at 30 GHz. We used an open-source software called GNU radio [15], [16], which provides signal processing blocks to implement software radios and develop new components, and Matlab software to measure the spectral efficiency and the peak-to-average power ratio between the two systems [17].

4.1. Power spectral density comparison

Figure 8 shows the power spectral density difference between an OFDM and FBMC. By comparing these two figures, we can see the difference in relative gain of the two waveforms due to the rectangular windowing. OFDM shows strong sidelobes compared with FBMC, which does not intervene with the adjacent sub-channel lobes. Correspondingly, we noticed that the OFDM subcarriers are suppressed compared with FBMC subcarriers due to the polyphase network, where the energy is focused within the frequency range of a single subcarrier [18].

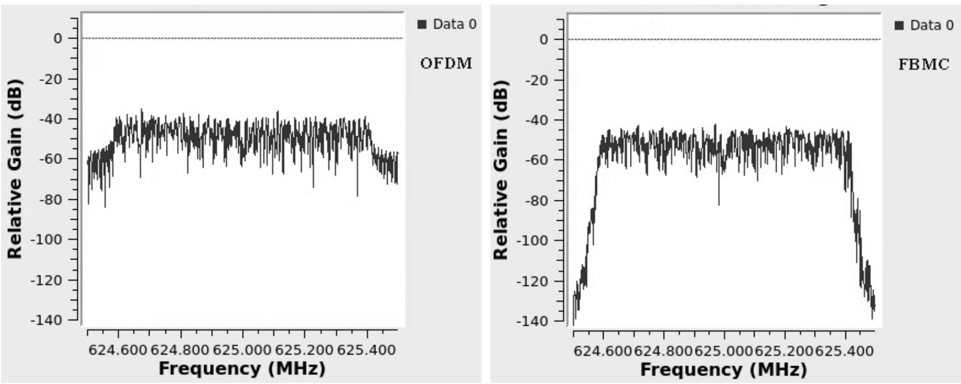

Figure 8. OFDM and FBMC spectrum

4.2. Modulation/demodulation comparison

Figure 9 illustrated the edge power in the time domain signal for both systems. By comparing these two figures, it can be seen that FBMC reduces greatly the dynamics of instantaneous fluctuations of the signal compared to OFDM. Meanwhile, the capacity has been reduced by half due to the imaginary and real part of FBMC being assigned for the OQAM process at the subcarrier [19].

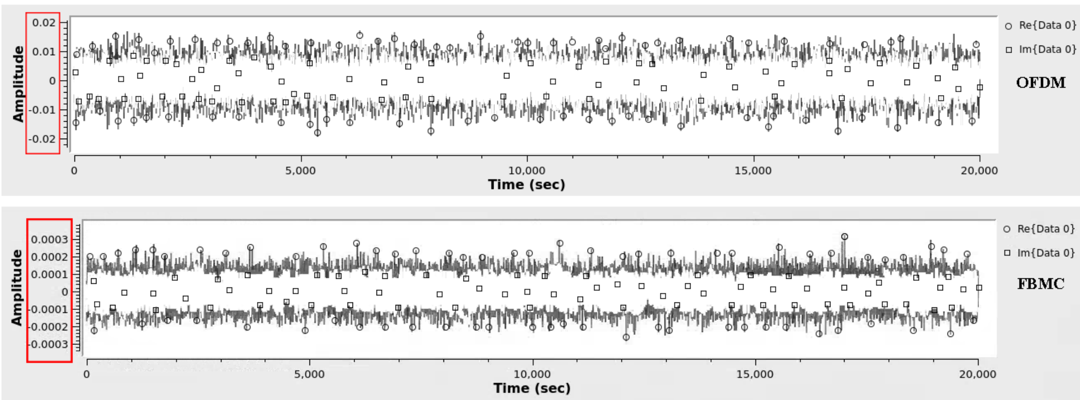

Figure 9. Modulated OFDM and FBMC signals in time domain

Figure 10 shows the spectrum of demodulated OFDM and FBMC signals, respectively, where the demodulated signal is the noise-free useful information, the received impulse responses of the FBMC polyphase filter with the number of subcarriers is almost two times longer than the OFDM rectangular pulse, which demonstrates that FBMC has much power loss of the out-of-band power than OFDM [20]. Regarding these features, OFDM seems to have less frequency delay spreads and offset error than FBMC. Nevertheless, in order to maintain the same spectral efficiency as OFDM, the offset quadrature amplitude modulation (OQAM) of FBMC is normally employed with the symbol time spacing which is reduced by a factor of two, therefore the polyphase filter guarantees only in real fields, which lead to modulate only the real values while the imaginary part is delayed by the half symbol duration [21].

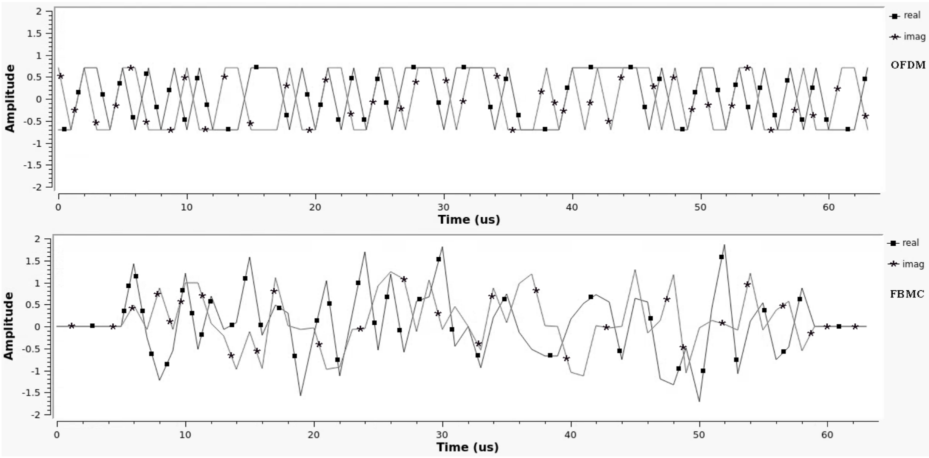

Figure 10. Demodulated OFDM and FBMC signals in time domain

4.3. Spectral efficiency comparison

Figure 11 illustrates how many bits can be transmitted over an OFDM and FBMC bandwidth [22]. The spectral efficiency is generated by varying the duration burst between 0 to 40 ms. As we can see in the figure, OFDM spectral efficiency does not depend on the burst duration. However, it does for FBMC due to the shaping filter’s transient state.

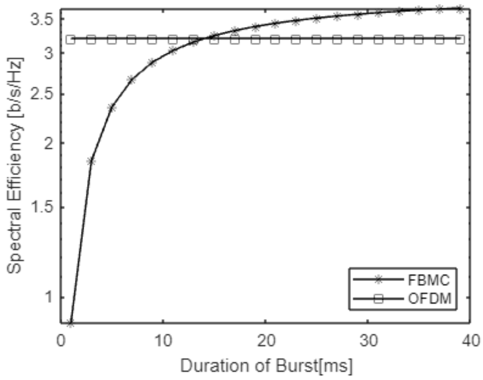

Figure 11. Comparison of OFDM and FBMC spectral efficiency

4.4. PAPR comparison

Figure 12 computes the distribution function of the peak-to-average power ratio (PAPR) for the considered waveforms. OFDM and FBMC are multi-carrier modulations which makes them high inevitably to produce PAPR [23]. To get a closer look at the PAPR behavior, we compare the distribution functions of the PAPR obtained after interpolation of the signal. Compared to conventional OFDM, FBMC has a higher PAPR behavior due to the high-power amplifier used to transform the byte data into OQAM symbols in FBMC systems with a limited linear range [24]. Consequently, causing a severe recession of the bit error rate performance. Therefore, OFDM is considered an ideal candidate for future development for having less PAPR [25].

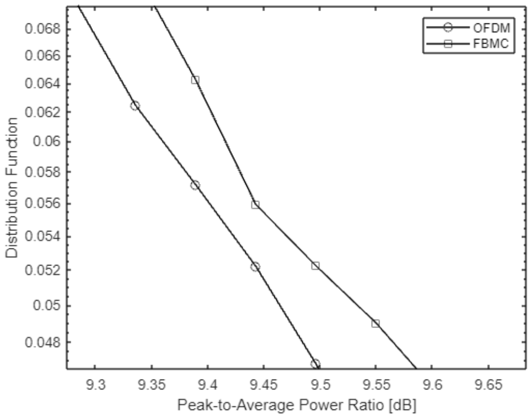

Figure 12. PARP of OFDM and FBMC

5. CONCLUSION

Our goal from this article was to obtain a comparative analysis of different modulation schemes using the GNU's not unix (GNU) platform; the obtaining result shows the efficiency of the modulation techniques considering several parameters. According to the above simulation results, OFDM gives overall performance improvement compared with the FBMC system for all the parameters considered, which confirms our implemented signal processing techniques and validates our testbed, proving that OFDM is the best candidate for the future development in 5G wireless communications. However, the high implementation complexity makes it challenging to realize the large-scale antenna arrays with the conventional OFDM system. Consequently, Extensive research efforts have been made to design and develop a new hybrid precoding architecture that allocates multiple users to different frequencies using the OFDM system.

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