Performance Evaluation of the Use of Filter Bank Multi-carrier waveform in Different mmwave Frequency Bands

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Abstract —The meet of high demand of wireless communication is the topic of research in future wireless networks. This high demand comes from the increase use of mobile devices and sensors in the real environment. Internet of Things (IoT) and machine communication are types of technologies that increase the wireless communication demand. Because of this, there is a need of producing some techniques and technologies that are able to meet this requirement. Fifth Generation (5G) network is the futre promising wireless network that can be used to enhance a lot of performance metrics such as spectral and energy efficiencies, high capacity and low latency. Some technologies are used with 5G network; one of them is the use of short range communication using Millimeter waves (mmwave) frequency bands which gives high data rate and high bandwidth to be used in communication by using small cells of coverage. Massive Multiple-Input Multiple-Output (M-MIMO) is the technology used to meet the high capacity users in the network, It suffers from the high Inter-Carrier-Interference (ICI) due to the use of high number of antennas at the Base Station (BS). To mitigate this, the use of multicarrier waveforms is one of the techniques used in this paper. The use of Filter Bank Multi-Carrier (FBMC) is introduced here in terms of Bit Error Rate (BER) and throughput. The paper simulates the use of FBMC with high order basband QAM modulation (M-QAM) for two different mmwave frequency bands such as 28 GHz and 60 GHz with comparison with 2.6 GHz which is widely used nowadays. The simulation results show that there is less than 0.5 dB and 3 dB SNR difference between 2.6 GHz and 28 GHz and 60 GHz respectively. This indicates that 28 GHz can be used in outdoor communication instead of 2.6 GHz with high bandwidth, and 60 GHz can be used in indoor communication with extremely high bandwidth offering.

Index Terms—mmwave, FBMC, OFDM, 5G, multicarrier waveforms

I. INTRODUCTION

Gigabit data rate transmission is promising to be facilitated in this modern life by using Fifth-Generation (5G) cellular communication which has the capacity to increase the current data rate transmission via Long-Term Evolution (LTE) systems by up to three folds of magnitude [1]. Spectrum in wireless communication networks is allocated and determined by the country communication regulators and to be used in specific applications. Some spectrum bands need to have a license to be used [2]. Each spectrum determined by the regulators has its application which is independent of other spectrum and applications, such as the use of Wireless Local Area Network (WLAN) and the use of LTE [3].

The spectral efficiency of any wireless network is an important issue to deal with when designing or evaluating any wireless system. LTE-A communication network faces more challenges due to the increasing demand for high-speed wireless applications which requires more spectrum; however, Orthogonal Frequency Division Multiplexing (OFDM) does not meet this spectrum efficiency due to its Cyclic Prefix (CP) requirement and its large sidelobes which affects its Peak-to-Average Power ratio (PARP) [4]. This can be a motivation to adopt a new multi-carrier technique that will overcome these problems and make the transmission more reliable and accurate with high spectral efficiency [5]. Waveform configuration is a fundamental segment of the air interface and it has been generally examined in research networks to fulfill the assorted prerequisites towards 5G.

In LTE-A, it is known that the guard band in OFDM construction reserves 10% of the allocated bandwidth to allow a frequency band available to serve the signal attenuation. Unfortunately, this frequency band is considered wasted due to the fact that OOB emission of OFDM is still not very satisfactory [6] which is considered a motivation to use Filter Bank Multi-Carrier (FBMC). Just like OFDM, FBMC is a modulation format in which subcarriers are meant to pass through filters to reduce the signals' sidelobes to ensure that they are restricted to a specific bandwidth. FBMC is mainly used in 5G cellular networks due to its high robustness to frequency mismatches among users compared to OFDM [7].

The use of multi-carrier waveforms is simulated in [8]. They simulate the performance of using Frequency Spreading Filter Bank Multi-Carrier (FS-FBMC) waveform in 5G network applications based on mmWaves at 60 GHz compared with traditional OFDM waveform. The simulation results show that FS-FBMC overcomes the performance of OFDM with respect to

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non-linear properties. The FBMC is simulated in [9] considering FBMC as a good technique to have good spectral properties for future transmission technique. They used FBMC transmissions over real-world channels at 60 GHz and demonstrated that Alamouti's space-time block code worked well once the symbols are spread by the system in time. The results proved that the combination of coded FBMC with mmWaves ensured low-latency and high spectral efficiency; the combination also allowed a continuous use of multiple antennas but the Phase Noise (PN) is considered the main challenge in using multicarrier waveforms.

The studies in [10] effect on mmwave-FBMC systems and CP-OFDM by evaluating the degradation in performance due to the imperfection in the coded and uncoded BER. Also [11] compared the FBMC with OFDM by evaluating the performance of both of them in mmwave bands using OQAM baseband modulation schemes only. In this paper, a full comprehensive performance evaluation of using high order baseband modulation with FBMC was compared to OFDM at different mmwave bands to have a full image about the performance of using FBMC with respect to Bit-Error-Rate (BER) and throughput. This study applied different high order baseband modulation to the FBMC to have the BER and throughput for each one with a performance comparison of using them at different mmwave frequency bands. Some of results show the FBMC effect on the mobility of each user according to throughput.

The rest of this paper is organized as follows: Section II discusses, the proposed system model of using FBMC in mmwave bands. The following section, section III, addresses the BER and throughput performance results for the use of the FBMC in different mmwave bands compared with OFDM. Finally, Section IV concludes this paper.

II. System Model and Methodology

Fig. shows the simulation scenario that is used in this paper. The scenario considers two types of multicarrier modulations which are OFDM and FBMC with M-QAM of the baseband modulation for each type. The modulator consists of the general construction of the Multi-Carrier Modulation (MCM) as in OFDM construction. It starts from generating the OFDM symbols using Inverse Discrete Fourier Transform (IDFT) followed by adding the cyclic prefix bits. The channel used is AWGN. The demodulator performs the opposite operation of the modulator; this means that it performs the DFT to regenerate the base band bits after transmission.

As seen in Fig. 1 in case of generating FBMC, the only block should be added is the filtering after the CP block. This block is responsible to eliminate the effect of the CP to avoid high PAPR and high OOB. In the demodulator, at the beginning of the receiver, the filtering block is responsible to remove the CP bits in order to recover the original symbols.

The simulation parameters are shown in Table I The carrier frequencies used are 2.6 GHz, 28 GHz, and 60 GHz which are used in modern wireless communication with the mmwave-FBMC. The reason of using these bands is to satisfy all the scenarios of communication which are:

- Just an indoor communication which satisfies by using 60 GHz only because of the very short range signal used [12].
- The indoor/outdoor communication which is comes from the use of 28 GHz where its signal travels for large distance than the 60 GHz reached to 200 m of transmission. This allows to be used for outdoor communication besides the indoor one.
- The use of 2.6 GHz is for evaluating the use of FBMC with mmwave bands with the results obtained from the LTE where 2.6 GHz represents.

The subcarrier spacing equals 15 kHz to mitigate interference between sub-carriers. This is come from the concept that each symbol in OFDM construction needs this spacing where FBMC also uses it. The Fast Fourier Transform (FFT) size used for is 1024 with available bandwidth 100 MHz for 2.6 GHz and 1 GHz for the mmwave bands.

TABLE I: SIMULATION PARAMETERS

Simulation parameter	Values
Bandwidth for mmwave bands	1 GHz
Bandwidth for 2.6 GHz	100 MHz
Carrier frequency	2.6 GHz, 28 GHz, and 60 GHz
Subcarrier spacing	15 kHz
FFT size	1024
Modulation	M-QAM
Cyclic prefix	normal cyclic prefix
Multicarrier waveforms	OFDM, FBMC
SNR	Up to 30 dB

The simulation process starts from initializing the simulation scenario and simulation parameters shown in The simulation parameters are shown in Table I. The carrier frequencies used are 2.6 GHz, 28 GHz, and 60 GHz which are used in modern wireless communication with the mmwave-FBMC. The reason of using these bands is to satisfy all the scenarios of communication which are:

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Table The simulation continues and asks about the mmwave frequency band used. The system up-converted the frequency to the mmwave frequency and asks about the multicarrier modulation used. If the multicarrier modulation is chosen as OFDM, the standard process of generating OFDM symbols is performed, while if the multicarrier modulation is FBMC, the process of generating FBMC is performed. For both types of multicarrier modulations, the BER and throughput of the system are calculated and graphed with respect to different SNR values. The simulation is repeated for different mmwave frequency bands with different order and types of baseband modulation. This is to evaluate most of the parameters that affect mmwave-FBMC performance.

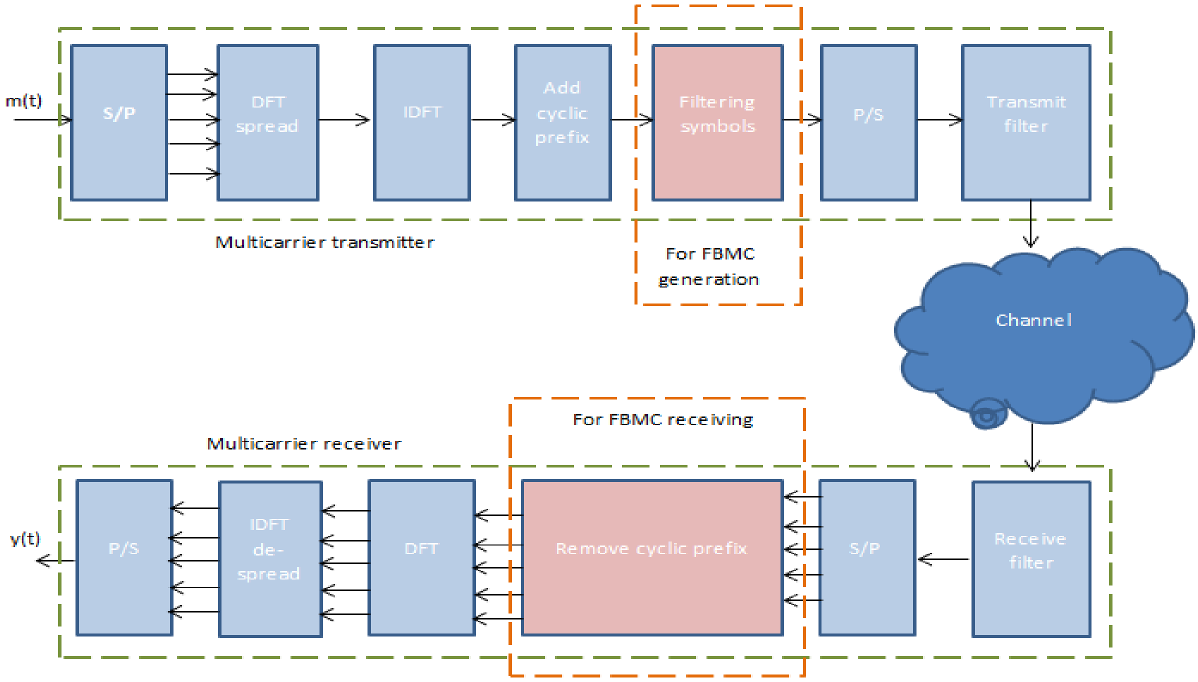

Fig. 1. Simulation scenario.

III. Simulation Results and Discussion

Fig. 2 shows the comparison of the spectral densities between basic OFDM access and FBMC over the frequency with a considerable reduction in the Out-of-Band (OOB) leakage compared to OFDM because of the use of filter before generating OFDM symbols. The lower OOB leakage enables several new scenarios such as asynchronous transmission without the need of perfect synchronization. In addition, high spectral efficiency is achieved due to the absence of the CP.

All these desired features of FBMC, however, come at the price of the relaxation of the orthogonality condition from the complex field using QAM to the real field using OQAM. Theoretically, OQAM does not show any drawback compared to QAM since they both have the same spectral efficiency.

Furthermore, the use of typically long filters can realize the excellent frequency localization on one hand, but it also leads to long tails in the time domain on the other hand. This leads to a decrease in the overall energy efficiency and an increase in the delay of transmission when using FBMC.

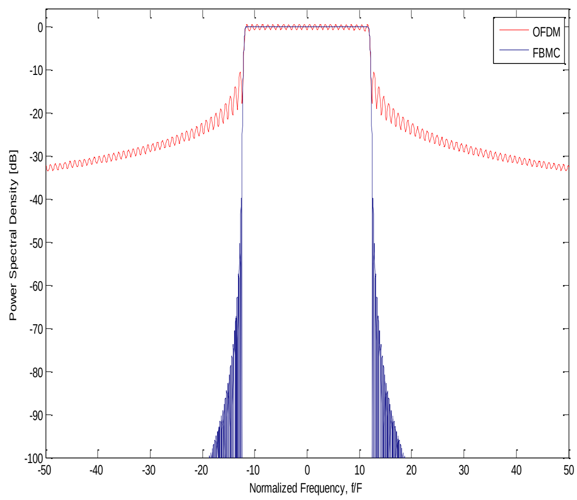

Fig. 2. Spectral density of FBMC compared with OFDM

Fig. 3 shows the 64-QAM BER performance for the mmwave bands used. It can be seen from this figure that all bands do not exceeds below 10-3 BER which means high interference between adjacent symbols due to the high order used. The other notice is that the BER of the 2.6 GHz affected by the adjacent interference higher than the other mmwave bands. This is because of the use of narrow beamwidth of communication with mmwave bands which is not used in 2.6 GHz.

This narrow beamwidth is also one of the beamforming techniques used with mmwave bands in order to cancel the interference comes from the adjacent symbols, interference from adjacent users especially for cellular areas contain high number of users in the coverage area, and interference comes from the adjacent antennas at the base station when using hundreds of antennas at the system which is called massive MIMO configuration.

The simulation results in Fig. 3 also shows that there is less than 0.5 dB and 3 dB SNR difference between 2.6 GHz and 28 GHz and 60 GHz respectively. This indicates that 2.8 GHz can be used in outdoor communication instead of 2.6 GHz with high bandwidth, and 60 GHz can be used in indoor communication with extremely high bandwidth offering.

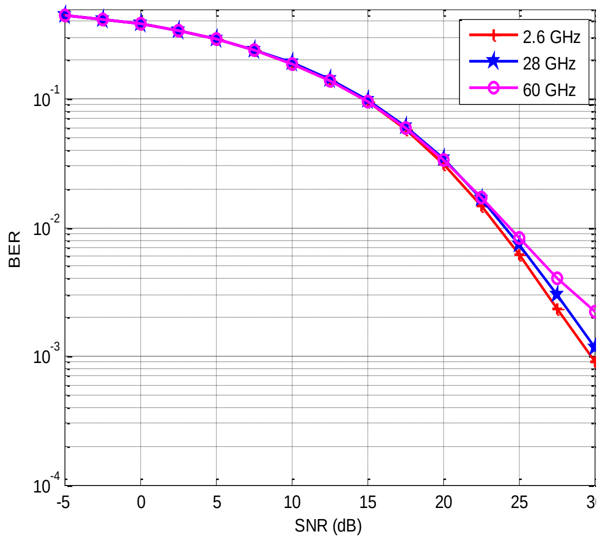

Fig. 3. BER for 64-QAM applied on different frequency bands.

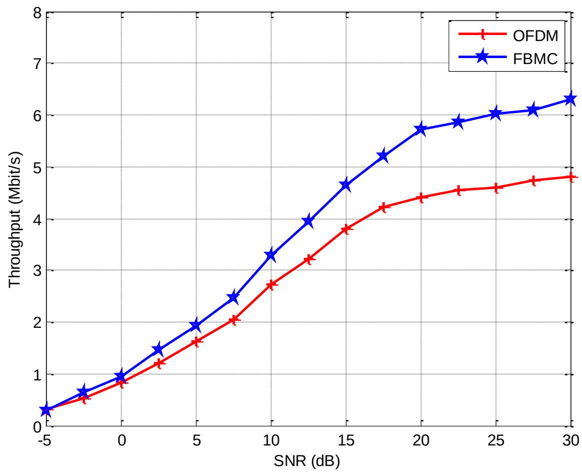

Fig. 4. Throughput of FBMC and OFDM at 28 GHz

It is said before that the OFDM is widely used as a type of MCM but it suffers from high OOB which causes high PAPR especially for high frequencies. It is also known that the 28 GHz band is a promising band to be used in cellular network in indoor/outdoor communication. It seen from Fig. 3 that the 28 GHz band gives a suitable performance to be used, it is near 2.6 GHz in BER and gives high bandwidth as 60 GHz.

Fig. 4 shows the throughput performance of both MCM types. It shows that at 28 GHz, the FBMC gives high throughput better than OFDM. It gives 6 Mbit/s at 25 dB SNR while OFDM gives only 4.5 Mbit/s. This is because there is less OOB in FBMC than OFDM that leads to less PAPR in FBMC.

Fig. 5 shows the throughput performance of different frequency bands. It is clear and logical that 60 GHz gives the high throughput because of the high bandwidth that it used. The drawback here is that this high throughput can only use in indoor communication. The throughput of 60 GHz reaches 7 Mbit/s at 30 dB SNR while it reaches 6.2 Mbit/s for 28 and 4 Mbit/s for 2.6 GHz at static user communication.

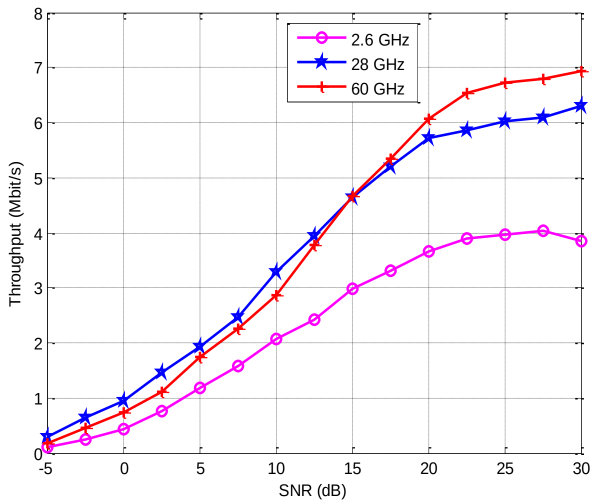

Fig. 5. Throughput of different frequency bands

IV. Conclusion

The use of FBMC as a type of MCM technology is discussed and reviewed. The FBMC in general evolved OFDM because OFDM is the most widely MCM waveform used in wireless communication especially 4G. All results show that FBMC has better performance than OFDM in terms of BER and throughput but with some increase in process complexity. These results comes from the use of FBMC make it as a suitable choice of the MCM in 5G because of its ability to eliminate the ICI that caused from OFDM. It is clearly shown that the FBMC overcomes most of the OFDM drawbacks, the only thing that should be into consideration is the added process when generating FBMC which causes some increase in the latency especially when using FBMC in mobility scenario. It is important to know that OFDM cannot meet efficiently the mobility requirements, but the FBMC can meet using some additional techniques like decreasing the tail of filters used and some coding algorithms. Because of this, FBMC can be used in Vehicle-to-Vehicle (V2V) communication where the mobility satisfaction is the key of communication. Another future trends of using FBMC is to use it in cognitive networks. It can uses to enhance the spectrum sensing process by mitigating the interference between primary user and secondary one because of the low spectral leakage that it gives. The use of FBMC with mmwave massive MIMO with addition to beamforming will allows extremely high spectral density with less errors and high capacity.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

Saif A. Khudhair has proposed the manuscript title along with collection and preparation of data. The review of the data is supervised by Mandeep Jit Singh. The manuscript is written by the principal author and improvements are suggested by the co-author.

REFERENCES

[1] H. Wang, Y. Cui, W. Du, and L. Xu, "Hybrid PAPR reduction scheme with partial transmit sequence and Tone Reservation for FBMC/OQAM," *Journal of Communications*, vol. 11, no. 5, 2016.

[2] J. Li, K. Kearney, E. Bala, and R. Yang, "A resource block based filtered OFDM scheme and performance comparison," in *Proc. 20th International Conference on Telecommunications (ICT)*, 2013, pp. 1-5.

[3] A. A. A. Boulogeorgos, P. C. Sofotasios, B. Selim, S. Muhaidat, G. K. Karagiannidis, and M. Valkama, "Effects of RF impairments in communications over cascaded fading channels," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 11, pp. 8878-8894, 2016.

[4] X. Zhang, M. Jia, L. Chen, J. Ma, and J. Qiu, "Filtered-OFDM-enabler for flexible waveform in the 5th generation cellular networks," in *Proc. Global Communications Conference (GLOBECOM)*, 2015, pp. 1-6.

[5] P. Banelli, S. Buzzi, G. Colavolpe, A. Modenini, F. Rusek, and A. Ugolini, "Modulation formats and waveforms for 5G networks: Who will be the heir of OFDM? An overview of alternative modulation schemes for improved spectral efficiency," *IEEE Signal Processing Magazine*, vol. 31, no. 6, pp. 80-93, 2014.

[6] J. Bazzi, K. Kusume, P. Weitkemper, K. Saito, A. Benjebbour, and Y. Kishiyama, "Performance of multi-carrier waveforms in vehicle-to-vehicle communications," in *Proc. Vehicular Networking Conference (VNC)*, 2015, pp. 9-16.

[7] C. Y. Liu, *et al.*, "A MMSE joint feedback feed-forward equalizer for FBMC-OQAM baseband receiver in the 60 GHz band," *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, vol. 7, no. 4, pp. 558-568, 2017.

[8] R. Gomes, J. Reis, Z. Al-Daher, A. Hammoudeh, and R. F. Caldeirinha, "5G: Performance and evaluation of FS-FBMC against OFDM for high data rate applications at 60 GHz," *IET Signal Processing*, vol. 12, no. 5, pp. 620-628, 2018.

[9] R. Nissel, E. Zöchmann, M. Lerch, S. Caban, and M. Rupp, "Low-latency MISO FBMC-OQAM: It works for millimeter waves!" in *Proc. IEEE MTT-S International Microwave Symposium (IMS)*, 2017, pp. 673-676.

[10] K. Roth, L. G. Baltar, M. Faerber, and J. A. Nossek, "Performance analysis of FBMC and CP-OFDM in the presence of phase noise," in *Proc. European Conference on Networks and Communications (EuCNC)*, 2017, pp. 1-5.

[11] R. Nissel, S. Schwarz, and M. Rupp, "Filter bank multicarrier modulation schemes for future mobile communications," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 8, pp. 1768-1782, 2017.

[12] A. Majeed, "Investigation the BER characteristics of hexagonal multicarrier modulation in the presence of system impairments," *Journal of Communications*, vol. 14, no. 7, 2019.

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