Review in FBMC to Enhance the Performance of 5G Networks

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Abstract—The meet on the high demand of wireless communication is the topic of research towards 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 the 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 future promising wireless network that can be used to enhance the capacity and low latency. Some technologies are used with 5G network; one of them is the use of short-range communication using Millimeter waves (mm-wave) frequency bands which gives a 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 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 area of research. The mobility of any wireless networks is also an important issue to deal when designing or evaluating of any wireless system. The high mobility scenario is also one of the essentials of 5G networks; the challenge of meeting the high mobility requirements is the high Doppler shifts. Interference in high mobility and the use of massive MIMO comes from the use of Cyclic Prefix (CP) in building Orthogonal Frequency Division Multiplexing (OFDM). Thus, a new multi-carrier technique to overcome this challenge and make the transmission more reliable, accurate with less time and high packet ratio delivery is introduced and used. Waveform design is an essential component of the air interface and it has been widely studied in researches to satisfy the requirements towards 5G. OFDM can be generated using CP and Fast Fourier Transforms (FFT) to combat severe multipath fading. The use of Filtered-OFDM such as Filter-Bank Multi-Carrier (FBMC) can overcome this drawback. In this review, the use of FBMC to enhance the performance of 5G networks is introduced with mention to some trends topics such as Cognitive Radio (CR) and massive MIMO that FBMC can be used with to enhance the communication.

Index Terms—FBMC, OFDM, massive MIMO, V2V, ICI

I. INTRODUCTION

The growth demand in wireless communication and its application leads to a great effort should be into researcher’s consideration to meet the future requirement of wireless network architecture [1]. The requirements needed in the upcoming years to deal with the huge demand can be summarized in four features. The first one is the high capacity requirement for meeting the high demand of wireless application usage. It’s expected that the traffic will reaches multiple of hundreds than this in nowadays until 2020 and beyond. The second one is the to increase the capacity of the network, a new topology of cell configuration should be deployed which is the use of small cell configuration like Micro and Pico cells. This configuration leads to high data rate network in indoor communication where 70% of the wireless using happens [2]. While the third one is the increasing demand in future is coming from the extra high number of wireless devices connected together or with the network like the use of Internet of Things (IoT) which means that huge number of devices communicate with each other by using Machine-to-Machine (M2M) communications. The last one is the enhancing of the power consumption despite the increasing number of devices used. This means that 5G network should be a green network to reduce its energy consumption [3].

According to the aforementioned requirements, it is known in clearly view that the demand of wireless communication has become the main issue to consider in any modern wireless network like 5G. This requires the capacity provided by 5G networks to be 1000 times higher than in present cellular systems [4]. This is can be performed by using several techniques in PHY layer enhancement such as using new design of the air interface rather than the classical Orthogonal Frequency Division Multiplexing (OFDM) used in fourth generation (4G) to overcome the drawbacks come from the Inter-Channel interference (ICI) especially in high density and mobility networks. The new air interface used in 5G is the use of Filtered-OFDM to overcome the effect of Cyclic Prefix (CP) in OFDM and the use of Non-Orthogonal Multiple Access (NOMA). One of the Filtered-OFDM types is the Filter Bank Multicarrier (FBMC) which is constructed to
remove the CP effect and it is suitable to use with other techniques used to enhance the 5G performance in PHY layer such as Massive Multiple-Input Multiple-Output (M-MIMO) configuration and Millimeter waves (mm-wave) [5]. All these techniques are used to enhance the performance of 5G network as shown in Fig. 1.

When the antenna configuration in MIMO system reaches tens and hundreds of antenna elements, the system is called Massive MIMO system as shown in Fig. 2. This configuration of antennas gives a huge capacity in a given serving area with very efficient use of spectrum with extremely high data rate for each user. Massive MIMO systems suffer from the same constraints as classical MIMO which are the high use of RF frequencies, the cost of establishing, and the inter-cell interference and intra-antenna synchronization [12]. For massive MIMO, some parameters should measure and be into consideration when designing massive MIMO [13]. Some of these parameters are the number of RF channel used to transmit data to avoid interference [14], the positioning of the antenna configuration and the pre-coding techniques used to reduce errors in detection and to make the data more robust during transmission [15] as listed in Fig. 1.

Fig. 1. Taxonomy of the 5G PHY layer enhancement techniques

“Fig. 1“ shows the technologies used in enhancing the performance of the 5G networks in PHY layer. These technologies have their own goals in 5G, one of them like Massive-MIMO is used in enhancing the capacity of the system while the mm-wave is used to enhance the energy efficiency of the system. The configuration of the Base Station (BS) antennas depend on the number of antennas used to serve the large number of users. The antenna configuration can be classified into three types of configurations; the first one is the planner which is called 2-Dimentional (2D) configuration. The second one is the 3-Dimentional (3D) where the antenna arrays configured as rectangular, circular and cylindrical to satisfy the users capacity needed [6]. The 3D antenna array is considered more attractive to use in modern wireless communication due to its ability to mitigate interference between adjacent antennas [7]. The last configuration of antenna arrays is the network configuration where the antennas distributed along the serving area and connected together by a network. This types can be useful in wide area of coverage [8]. It is good to say that there is no massive MIMO network without the use of beamforming techniques because the massive number of Radio Frequency (RF) links cause severe interference between adjacent channels, because of this, beamforming is a useful technique to use with massive MIMO [9].

In mm-wave technology, the small cells coverage is the key to enhance the throughput performance of 5G. The coverage area is split into several small cells linked together by backhauling techniques. Some cells are microcells and others are Pico-cells depending on several issues like the application of the small cells used and the area of coverage [10]. The air interface techniques are also used to enhance the 5G performance such as NOMA and multicarrier waveforms which are used widely to enhance the spectral efficiency of the system which is considered one of the most important issues in 5G [11].

Most of the antenna types are digital one and it is the device responsible for the increasing capacity of the system because of the increasing use of Radio Frequencies (RF) to communicate with users. The performance of the network depends in the quality of the communication link that means the reducing of multipath in the communication and interference. This can be done by using beamforming which means a concentrated beam on the direction of the communication [17].

The benefits of the beamforming are maximizing the communication link between each antenna and each user in the serving area in order to mitigate interference, enhancing the spectral efficiency and reducing the power needed to perform transmission. The main construction of beamforming is to let each antenna transmit signals by different amplitudes and phases which allows communication via multiple channels through the massive MIMO antennas.

A lot of researches deal with beamforming in massive MIMO, [18] and [19] are two papers studied the beamforming techniques for massive MIMO. In [18], a review of beamforming techniques with addition to pre-
coding algorithms used to enhance the performance of the massive MIMO have been investigated and discussed. They perform the study under different types of network challenges such as complexity, power reduction and capacity enhancement, while [19] discussed the use of beamforming in cognitive network by a technique called cognitive beamforming under the assumption of perfect Channel State Information (CSI) and best Quality-of-Service (QoS). This technique can be used with the help of game theory, genetic algorithms, and neural networks.

[20] and [21] discussed the use of beamforming in mm-wave MIMO communication that is mean that they discussed the use of beamforming in short range indoor/outdoor communication. Both of them use the basic concepts of beamforming such as architectures and approaches with focusing in [21] on the use of mm-wave beamforming to serve high speed users in small cells configuration.

It is known that the spectrum is a limited resource and it is not logical to expand the spectrum of each application if there is a need of extra spectrum. This is considered as a drawback of the spectrum efficiency. Because of this, there are several techniques appear on the surface in wireless communication to enhance the spectrum efficiency such as using the spectrum during the coverage area between the cells, developing a coding/decoding techniques to enhance the usage of the spectrum, using multiple access techniques like Orthogonal Frequency Division Multiplexing (OFDM) and allowing the spectrum sharing concept [22]. All the aforementioned techniques are used in modern wireless communication system to enhance the spectrum efficiency. The sharing process is known as cognitive process performed in cognitive networks where two types of networks makes the sharing of their spectrum available.

There is far reaching understanding that such an eager objective of these systems will be acknowledged through a mix of inventive strategies including diverse system layers. At the physical layer, the OFDM is used as a modulation schemes to enhance the spectral efficiency of the future mobile communication [23]. Synchronism and orthogonality which they occur at the physical layer of today’s Advanced Long Term Evolution (LTE-A) radio access network constitute a major challenge in designing the network architecture in 5G [24]. The process of making the transmit signals to be sent in a common clock means synchronism while the no crosstalk between symbols means orthogonality. Often, both are used in LTE-A OFDM modulation and keep the subcarrier waveforms orthogonal even after the channel, provided the Discrete Fourier Transform (DFT) window which can be properly adjusted by a suitable synchronization mechanism [25].

OFDM in LTE-A systems applies a rectangular model channel, prompting high Out-Of-Band (OOB) discharges which isn’t appropriate for future wireless systems [23]. There are techniques to decrease the OOB emanations in OFDM, for example, windowing or separating, however they all have the weakness of spectral efficiency. Filter Bank Multi-Carrier (FBMC) then again, saves high effectiveness to the detriment of yielding the unpredictable symmetry condition with the less exacting genuine symmetry condition which is considered one of the improvements in physical layer modulation to enhance the spectral efficiency of the future mobile systems where this review studies with addition to the use of mm-wave.

As mentioned above, the spectral efficiency of OFDM is limited by the need of a cyclic prefix (CP) and by its large side-lobes which require some null guard tones at the spectrum edges, which these make OFDM signals may exhibit large peak-to-average-power ratio (PAPR) values [23]. Increasing PAPR makes the impossibility of having strict frequency synchronization among subcarriers which leads to say that OFDM is not really orthogonal technique.

In particular, synchronization is a key issue in the future communication systems and plays an important role in spectral efficiency, because of this, with the notice that the future wireless communication systems need an adaptable time-frequency distribution to productively serve the user requirements, channel attributes and low delay spread at high carrier frequencies as in mm-wave bands with large networks makes the impact of designing a proper modulation scheme more needed.

The aforementioned notice of the FBMC makes it a suitable choice to use in modern wireless communication because the FBMC construction of symbols allows a decent confinement in both, time and frequency, which prompts an effective designation of the accessible time-frequency assets and it gives the low delay spread ensures that straightforward one-tap equalizers are adequate to accomplish near ideal execution.

One of the work on FBMC with combination with mm-wave is in [23]. They provide a performance evaluation of FBMC and compare it to OFDM based schemes in mm-wave bands using for OQAM baseband modulation schemes only.

This review is organized as follows: Section II discusses the literature review of the use of FBMC as a multicarrier waveform example to enhance the 5G performance. After that section III addresses some future trends in using FBMC in modern wireless communication especially in moving communication. Finally, section IV demonstrates the final discussion and conclusion.

II. FILTER BANK MULTICARRIER WAVEFORM (FBMC): REVIEW

Multicarrier Modulation (MCM) is the process of transmitting set of data in robust orthogonal narrow subcarriers in a simultaneous way. Fig. 3 shows the transceiver of the MCM with the use of filtering process which in general consists of the same OFDM transceiver but with addition of filtering on transmitter and receiver [26]. The main advantages of this configuration is that it
can overcome the drawbacks of the OFDM where OFDM suffers from large side lobes that contribute to undesired Out-of-Band (OOB) emission and large Peak-to-Average Power Ratio (PAPR) [27]. The large OOB can increase the Adjacent Channel Interference (ACI), especially in small cell systems such as those proposed for heterogeneous networks. There are some extra advantages of using filtering in construction of MCM, the first one is the ability to perform complex modulation process in order to achieve a good spectral efficiency by means of getting all sub channel filters are frequency shifted versions of the prototype Filter. The second advantage is the uniformly divided if the available bandwidth between all subcarriers because all sub channel filters have the same bandwidth as the filter and they divide the available channel bandwidth equally [28]. The last advantage is the strictly orthogonal signals because of the use of linear-phase filters with addition to exponential modulation schemes that can provide the orthogonality of the MCM symbols.

The filtering process can be used to ensure the orthogonality of the subcarriers, the flexible of the system and reduce the additional latency of the system which is reduces the PAPR of the transmitter. Use of the CP in FBMC which decrease the additional data used which enhance the spectral efficiency of the system. The filtering process can be used to ensure the orthogonality of the subcarriers, the flexible of the system and enhance the energy efficiency. It can also use to reduce the High Power Amplifier (HPA) effect on the system which is reduces the PAPR of the transmitter.

All these networks are discussed in the following subsections.

A. FBMC Meets the 5G Requirements

One of the main advantages of the 5G networks is that it is expected to enable three key of features which are the massive MIMO leads to high capacity, ultra-reliable communication with low latency and high spectral efficiency. It is expected that the latency of the system reduced to less than 1 ms and the spectral efficiency will reaches 10 bit/s/Hz where the capacity can be reached 10 times the nowadays 4G capacity. These applications required different advanced techniques to meet the high data rate required. Table I shows some review of papers discuss the FBMC to meets the 5G requirements.

<table>
<thead>
<tr>
<th>Publications</th>
<th>Topic’s area</th>
<th>Main objective</th>
<th>Scenario</th>
<th>Contribution</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>[33]</td>
<td>The use of air interface in 5G to reduce latency and/or enhance reliability.</td>
<td>Reducing the latency of the 5G network using different air interface.</td>
<td>Different types of MCM used in 5G compared with MAC layer enhancement.</td>
<td>Full comparison between PHY layer and MAC layer enhancement effect on 5G performance.</td>
<td>Considering latency only.</td>
</tr>
<tr>
<td>[34]</td>
<td>MCM usage of air-to-ground communication.</td>
<td>Enhancing the throughput of the unmanned aerial vehicles using MCM.</td>
<td>unmanned aerial vehicles communication</td>
<td>Using MCM in moving propagation.</td>
<td>Not considering ground-to-ground communication (moving vehicles in dense networks with high speed).</td>
</tr>
<tr>
<td>[35]</td>
<td>MCM air interface in 5G</td>
<td>Enhancing the connectivity between things in high throughput.</td>
<td>Different types of MCM used in 5G.</td>
<td>Full overview of the use of different types of MCM to enhance IoT connectivity.</td>
<td>Study for Static objects but dense networks.</td>
</tr>
</tbody>
</table>
In [33], a survey of reducing latency and/or enhancing the throughput of the 5G networks are discussed in PHY layer and MAC layer. One of the techniques used in PHY layer is the use the suitable design of the multicarrier waveforms. This work focuses in reducing latency of the communication between BS and non-moving users. They proposed different types of MCM as an interface. They find that the latency of FBMC is compromised by the need to accommodating long filter tails, and can be decoded quickly by transmitting only a portion of the IFFT output. It also shows that FBMC provides more protection against interference from different numerologies compared to Filtered-OFDM, which results in better Block Error Rate (BLER) performance, higher spectrum efficiency and lower OOB.

Unlike [33], [34] compromises the use of FBMC as an air interface with L-band Digital Aeronautical Communications Systems (LDACS) as a communication between moving objects but without the presence ofICI. The results showed that FBMC has better performance than LDACS, especially in the presence of interference from distance measuring equipment (DME) signals.

The same work is performed in [35] but for dense static networks as in IoT networks where the communication is from static sensors and moving humans. They study the performance of using different types of multicarrier compared with FBMC. The results show that the possibility of operating with relaxed orthogonality without major performance degradation is the main advantage that FBMC brings to IoT scenario.

Some researches such as [36] and [37] compromise the advantages of FBMC with the use of NOMA multiple access. This is logical to perform because FBMC works with less orthogonal subcarriers to overcome the complexity of generating full orthogonal symbols. The non-orthogonal signals cause ICI where FBMC is suitable to use to eliminate this. NOMA in general is more accurate to use than FBMC especially for power distribution between multiple users, but for more complexity computation.

This complexity leads to only 0.1 difference outage probability between orthogonal MCM and NOMA, this means that there is a trade of between complexity and performance and reveals the advantage of increasing the transmission rate at the expense of reduced orthogonality in FBMC.

The simulations of [38] try to use different multicarrier waveforms in mm-wave massive MIMO where hundreds of antennas are used to transmit and/or receive data. The sub-carriers in FBMC are subjected to side-lobe suppression by passing them through a filter bank, which makes them robust to inherent synchronization challenges. It employs features training sequences for synchronization and channel estimation purposes, has flexible resource allocation in the time-frequency domains and is capable of delivering higher spectral efficiency than OFDM. It is not common to use FBMC in massive MIMO because of the increasing latency of the communication due to the huge filtering process required.

### B. FBMC Used with Other Technologies

FBMC can be used with other technologies used in transmitter and receiver of the 5G network to enhance the performance of the network as shown in Table II.

In [39] proposed FBMC system to reduce the effect of High power Amplifier (HPA) by reducing the in-band Non-Linear Distortions (NLD) and their effects on Symbol Error Rate (SER). The simulation results show that the FBMC gives the best Symbol Error Rate (SER) compared with OFDM and other waveforms. The constraint here is the suitability to use for fixed BS and users.

As mentioned above, the configuration of the massive MIMO is considered one of the techniques used to enhance the performance of the 5G networks specially to increase the capacity of the system. The simulation in [40] combines the FBMC with 2D and 3D configuration of the massive MIMO. By this combination, they aim to have high capacity with high spectral efficiency compared with the use of massive MIMO only. They perform this model by using classical OFDM compared with the use of FBMC. The results show that there is a potential to use FBMC with massive MIMO but the constraints here are the cost of establishing the antenna configuration and the determining the suitable configuration of the antennas.
TABLE II: SOME REVIEW OF THE USE OF FBMC WITH OTHER TECHNOLOGIES

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>[39]</td>
<td>MCM used in reducing the effect of HPA.</td>
<td>Enhancing the SER response of 5G system</td>
<td>5G system with HPA effect.</td>
<td>Full comparison between OFDM, f-OFDM, UFMC, FBMC on SER enhancement in 5G.</td>
<td>Not considering for moving scenario.</td>
</tr>
<tr>
<td>[40]</td>
<td>The use of OFDM with changeable MIMO configuration (2D and 3D)</td>
<td>To enhance the SE and to reduce latency of OFDM in 5G.</td>
<td>2D and 3D configuration of antennas.</td>
<td>Enhancing SE without changing the OFDM used in 4G.</td>
<td>Depends only on changing the antenna plane to enhance the SE.</td>
</tr>
<tr>
<td>[42]</td>
<td>Techniques used towards 5G.</td>
<td>Reducing latency and enhancing reliability of 5G</td>
<td>Combination of FBMC and mmwave for static communication.</td>
<td>Full overview about technologies used to enhance spectral efficiency.</td>
<td>Not considering FBMC using for moving scenario.</td>
</tr>
<tr>
<td>[43]</td>
<td>MCM in mm-wave communication.</td>
<td>To improve the throughput and capacity of the mm-wave communication</td>
<td>Heterogeneous network</td>
<td>Full overview and discussion between different types of MCM used in mm-wave.</td>
<td>Static scenario discussion only</td>
</tr>
<tr>
<td>[44]</td>
<td>MCM in WIFI</td>
<td>Enhancing the throughput of the WIFI network</td>
<td>Heterogeneous networks between WIFI and cellular.</td>
<td>Enable the combination between WIFI and cellular.</td>
<td>Moving objects but for WIFI range of frequencies only</td>
</tr>
<tr>
<td>[45]</td>
<td>MCM with spectrum sensing</td>
<td>To enhance the data rate and capacity</td>
<td>Cognitive networks.</td>
<td>Enhancing the MCM performance</td>
<td>Latency issue due to the sensing process required, issue.</td>
</tr>
<tr>
<td>[41]</td>
<td>MCM in 5G.</td>
<td>Enhancing the throughput of the massive MIMO configuration.</td>
<td>Different MCM in massive MIMO.</td>
<td>Full overview and discussion between different types of MCM.</td>
<td>Energy consumption of the massive MIMO</td>
</tr>
</tbody>
</table>

The study in [41] also makes a combination between massive MIMO and FBMC, the constrain appears here is how to optimize the energy consumption of the massive MIMO.

Combination between mm-wave and FBMC is considered important nowadays because of the need of a tradeoff between spectral efficiency comes from FBMC and Energy efficiency comes from the use of mm-wave by using small cells.

The simulation in [42] and [43] combines the FBMC and mm-wave to reduce latency and enhance the throughput of the system by eliminating the nonlinearity comes from the use of multiple carriers in mm-wave especially in the dense networks. In both of them, the mobility of the network neither is nor considers.

The work in [44] combines the WIFI technology with FBMC. The main reason to do this is to enhance the spectral efficiency or reduce OOB Emissions to enhance the WIFI connection. The constraint here is how FBMC can improve the connection for dense WIFI networks. Combination with Cognitive networks and FBMC is also a promising technique to enhance the spectrum sharing and sensing used. The main objective here is to mitigate interference between users in order to make a suitable sensing to the shared spectrum without any adjacent interference.


This proposed technique uses Wavelet Packet-based Spectrum Sensing (WPSS) to give information about cognitive network and lowering the side-lobes using wavelet-based filter bank multicarrier modulation. The simulation results show that the bit Error Rate (BER) is enhanced when using the proposed filters compared to the Fourier-based spectrum sensing.

C. Enhancing the Performance of FBMC

Although FBMC is used for enhancing the 5G network, there are many challenges appeared in the surface when using FBMC, these challenges makes the use of FBMC is limited in some applications such as massive MIMO and cognitive networks. These challenges are:

- High computational complexity is associated with FBMC implementation when compared to OFDM.
- The time domain overlap of subcarrier symbols in filter bank introduces overhead in tightly time multiplexed operation.
• Analog RF performance is critical for implementing generic RF spectrum sensing with wide bandwidth and high dynamic range.
• The development of MIMO-FBMC system is nontrivial and may be very limited.

Table III illustrates some works that deal with these challenges and propose some modification of the FBMC construction. [46] use Continuous Pilot Sequences (CPS) with FBMC to enhance the FBMC performance.

<table>
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</tr>
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<tbody>
<tr>
<td>1</td>
<td>[46]</td>
<td>FBMC in 5G</td>
<td>To reduce the interference comes from the use of FBMC</td>
<td>Continuous and burst pilot sequences in demodulation of the FBMC</td>
<td>Reducing the outage of the FBMC</td>
<td>Increasing latency especially in moving communication.</td>
</tr>
<tr>
<td>2</td>
<td>[47]</td>
<td>Coded-FBMC</td>
<td>Enhancing the performance of the FBMC using Alamouti coding</td>
<td>Inter-antenna ICI-free Alamouti coding</td>
<td>Reducing PAPR of the system</td>
<td>Not for moving communication</td>
</tr>
<tr>
<td>3</td>
<td>[48]</td>
<td>FS-FBMC in 5G, 60 GHZ</td>
<td>To enhance the SE of the indoor 5G communication and reduce the PA non-linearity effect.</td>
<td>FS-FBMC in 60GHz communication</td>
<td>Enhance the SE of the indoor 60GHz communication</td>
<td>Indoor line-of-sight communication only</td>
</tr>
<tr>
<td>4</td>
<td>[49]</td>
<td>DP-FBMC in 5G</td>
<td>To enhance the SE of the 5G network using FBMC</td>
<td>DP-FBMC</td>
<td>Enhancing the FBMC performance without the use of long-tail filters.</td>
<td>Complexity due to the need for robust orthogonality and the suitable selection of time, frequency and polarization.</td>
</tr>
</tbody>
</table>

The simulation results show that the proposed combination has a better performance in terms of Mean Squared Error (MSE) and SER. The challenge here is the increased of latency when using this combination due to the need of Continuous sequence of transmission.

In [47]; the concept of Alamouti coding and extend it to be used with FBMC as ICI-free Alamouti-coded FBMC has been used. This proposed technique allows good arrangement and sub-block partitioning of the FBMC symbols. The simulation results show that reduction in PAPR than OFDM and lower BER performance compared with classical FBMC. According to these results, this proposed combination can be generalized to use with different types of MCM. In [48]; a Frequency Spreading Filter Bank Multi-Carrier (FS-FBMC) waveform as a potential candidate for the 5G network applications at mm-waves as an advanced configuration of the classical FBMC to be used for indoor 60 GHz applications has been simulated. The effects of non-linearity of HPS at 60 GHz for both OFDM and FBMC are presented and mitigated using FS-FBMC. The results show that the proposed algorithm is suitable to use in downlink communication due to the HPA high sensitivity to non-linearity.

The simulation of [49] proposes Dual-Polarization FBMC (DP-FBMC) as a new FBMC generation based on using two orthogonal polarizations for wireless communication systems. The proposed system according to simulation results is considered more robust in highly dispersive channels, and also to receiver carrier frequency offset (CFO) and timing offset (TO) and it is considered as one of the techniques used in future wireless communication.

III. FUTURE CONSIDERATION TO USE FBMC IN MODERN COMMUNICATION

There are several trends of modern wireless communication that is capable to use FBMC with them to enhance the spectral efficiency, throughput, packet delivery ratio, and to reduce the latency of the system. Two of the major modern wireless communication trends are discussed in the following subsections, the first one is the Vehicle-to-Vehicle (V2V) communication and the second one is the cognitive networks.

A. Vehicle-to-Vehicle Communication

Vehicle to Vehicle (V2V), vehicle to Infrastructure (V2I) and Vehicle to Roadside (V2R) communication systems research has grown tremendously in recent years [50]. The primary context for this is Vehicle-to-Everything (V2X) as part of intelligent transportation systems (ITS) as shown in Fig. 4. Motivations for ITS include increased system efficiency towards green transportation, reduced transportation delays, economic growth, passenger entertainment, and most importantly, safety [51].

The V2V channel is distinct from that of many typical communication system channels. The closest comparison may be to the cellular channel, and the main distinguishing features of the V2V channel in comparison
to that channel are that in V2V channels where antenna heights of both transmitter (Tx) and receiver (Rx) are low while both Tx and Rx are mobile [52]. As a consequence of these differences, V2V channels can have the LOS between Tx and Rx obstructed more frequently, and scattering is often non-isotropic. With both Tx and Rx moving, channel variation rates can also be larger than in cellular, or in other words, the V2V channel is statistically stationary for a shorter time period than in cellular. In addition, due to multiple scattering or rapid time variation, in some cases amplitude fading may be more severe than in the most common Rayleigh cellular fading model [53].

In any complicated propagation environment, for digital communications purposes, there are several channel parameters that are most important to quantify for their effect on system performance. These include path loss, delay dispersion, and Doppler spread. Path loss is also known as transmission loss or attenuation, and represents the power loss between the Tx and Rx antennas. For a given value of transmit power, path loss determines link range. Delay dispersion quantifies the extent of the V2V Channel Impulse Response (CIR) and the Delay Spread is reciprocally related to frequency selectivity, quantified as the coherence bandwidth, hence for wideband signals these parameters can be used to select equalizer structure for single-carrier signals or subcarrier bandwidth and cyclic prefix in multicarrier systems [54]. The Doppler spread quantifies the channel’s spreading effect upon a transmitted frequency in the frequency domain due to motion; this is reciprocally related to the channel’s coherence.

Communication between vehicles which is means as Cooperative vehicular communication systems is considered one of the ITS advanced system and it considered one of the most important system in research due to the need of transferring data from one vehicle to another in high speed and low latency with efficient use of spectrum available. These requirement are important because exchanging data from vehicles will improve the ITS monitoring of traffic load and accidents, browsing Internet, and allow communication between vehicles and Road Sides and sensors along the road [56]. In addition, the exchanging data between vehicles makes the channel of communication more clear which leads to process the CSI better than the unknown channel. But, there are a lot of challenges face the V2V communication, one of these challenges is the fast mobility changing of the network configuration because of the travelling of users along the coverage area. Because of this changing, V2V suffers from the time-frequency selective fading nature where this selective fading affects the propagation of signals between vehicles, which required a solution to overcome this challenge. Selective fading also affects the system by severe Doppler shift which can be solved by using narrowband measurement systems to identify the channel gain and enhance Doppler shift experienced.

The solution of these challenges is the use of MCM. OFDM is one of the solutions that overcome the frequency selective fading in wireless communication, but in V2V systems, OFDM with the use of CP does not work because of the highly non-stationary property which could have a significant impact on performance with less spectral efficiency [57]. Because of this, in V2V, it’s good to enhance the waveform of the communication to overcome the problem of non-orthogonality with the use of filter bank before generation of the OFDM symbols [57]. There are several researches use FBMC as a multiple access in modern wireless communication, most of them use the FBMC in static communication which could have a significant impact on performance with less spectral efficiency [57]. Because of this, in V2V, it’s good to enhance the waveform of the communication to overcome the problem of non-orthogonality with the use of filter bank before generation of the OFDM symbols [57]. There are several researches use FBMC as a multiple access in modern wireless communication, most of them use the FBMC in static communication which could have a significant impact on performance with less spectral efficiency [57]. Because of this, in V2V, it’s good to enhance the waveform of the communication to overcome the problem of non-orthogonality with the use of filter bank before generation of the OFDM symbols [57].

**B. Cognitive Radio Networks with FBMC**

Cognitive Radio Networks (CRN) are considered one of the advanced technologies used in 5G to satisfy the high demand of wireless communication which means high capacity of users where all of these users require more spectrum to serve data. The spectrum is a limited resource, so cognitive networks is responsible to share non-used spectrum between wireless networks using Dynamic Spectrum Access (DSA) and Cognitive Radio (CR) Network [58]. These two technologies allow targeting to have better throughput of wireless networks with low latency. In addition to higher carrier frequencies and wider bandwidths in the band spectrum that allows reducing the energy consumption and establishing cost of implementing new networks. [59]. To meet these, OFDM may not be suitable for the 5G system due to its strict orthogonality. Compared with OFDM, FBMC has lower OOB and higher spectrum efficiency. Moreover, FBMC does not require CP extension or orthogonality among subcarriers, so it is very suitable for CR system.

In CR networks, FBMC can be used due to its flexibility to fill the spectrum holes as in OFDM but without the sensitive to fast time variations of the radio channel and to timing offset due to imperfect synchronization as in OFDM [60]. In addition, FBMC does not require CP extension and shows higher robustness to residual frequency offsets than OFDM by
taking advantage of the low spectral leakage of its modulation prototype filters. Because of all of this, FBMC can be used as an air interface of the spectrum sensing process because of its high performance and low cost [59]. The use of FBMC with CR networks can gives a powerful impact on the Inter-Cell Interference (ICI) resulting from timing offset, can maximizes the total information rates of the system and mitigate the interference constraint between Primary User (PU) and Secondary User (SU) because of the low spectral leakage of its prototype filter.

IV. CONCLUSION

In this paper, 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 in the review show that FBMC has better performance than OFDM in terms of spectral efficiency, latency, and energy consumption but with some increase in process complexity. These advantages of 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. FBMC as a type of multicarrier waveforms also meets the NOMA performance with simple configuration which makes it suitable to use instead of using the complex NOMA air interface. It also suitable to use when the efficiency of the network is required. It can be combined with other advanced techniques such as massive MIMO and mm-wave in order to enhance capacity and energy efficiency in addition to spectral efficiency. This review also mentioned some related works on the use of FBMC in meeting the 5G requirements. In the literature review, some researches deal with FBMC as an air interface used with other 5G technologies in order to enhance the response of the channel and to enhance the performance by decreasing the interference comes from the use of classical OFDM. Some researches discuss the FBMC itself to improve its performance as a key feature of 5G air interface. They discuss as an example adding coding schemes to the FBMC like using Alamouti coding process, using frequency spreading techniques to avoid the nonlinearity of the HPA used in FBMC or using dual-polarization to have robust signals in highly dispersive channels. It is important to know that OFDM can’t 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 V2V communication where the mobility satisfaction is the key of communication. Another future trend of using FBMC is to use it in cognitive networks. It can use 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.

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.

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