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Novel Scheme for Future 5G Networks using FBMC Schemes

Meghana J*, VidyaHonguntikar**
**(Department of Telecommunication Engineering, Visvesvaraya Technological University, Dr. Ambedkar Institute of Technology, Bangalore-56*
*** (Department of Telecommunication Engineering, Visvesvaraya Technological University, Dr. Ambedkar Institute of Technology, Bangalore-56*
Corresponding Author : Meghana J

ABSTRACT
Future wireless systems will be characterized by a large range of possible uses cases. This requires a flexible allocation of the available time-frequency resources, which is difficult in conventional Orthogonal Frequency Division Multiplexing (OFDM). Thus, modifications of OFDM, such as windowing or filtering, become necessary. Alternatively, we can employ a different modulation scheme, such as Filter Bank Multi-Carrier (FBMC). In this paper, a unifying framework, discussion and performance evaluation of FBMC is provided and compared it to OFDM based schemes. Our investigations are not only based on simulations, but are substantiated by real-world test-bed measurements and trials, where we show that multiple antennas and channel estimation, two of the main challenges associated with FBMC, can be efficiently dealt with. Additionally, we derive closed-form solutions for the signal-to-interference (SIR) ratio in doubly-selective channels and show that in many practical cases, one-tap equalizers are sufficient.

Keywords-FBMC (Filter Bank Multicarrier Modulation), OFDM (Orthogonal Frequency Division Multiplexing), CP (Cyclic Prefix), Carrier Frequency Offset (CFO), OQAM (Offset Quadrature Amplitude Modulation).

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I. INTRODUCTION

Thedemandofhigherdatarateshavebeenincreasingdrasticallyoverthepastseveralyears.newaytofulfillthisrequirementistousesignalswithwiderbandwidthbutwidebandsignalsaresubjecttofrequencyselectivefadingfromthemultipathchannels.Insuchcasessinglecarriersystemsarenotwellsuited.Forwidebandsignals,multicarriermodulation(MCM)isthemostprominenttechniquethatcanovercomethefadingeffectbydividingthewidebandsignalintoseveralnarrowbandsignalsthatcanhandlefrequencyselectivefadingveryeffectively.TheMCMschemeusedsofarinexistingsystems,suchasWiFibasedontheIEEE802.11standard,WiMax(WorldwideInteroperabilityforMicrowaveAccess)basedontheIEEE802.16 standard,Long Term Evolution(LTE),LTE-advancedetc.areOFDMbasedandalargebodyoftheliteraturefocusesontheuseofOFDMbasedmulticarriersystemsforpracticalapplications.ThelargepopularityofOFDMmainlycomesfromanumberofattractivefeatures suchasitsrobustnesstomultipathfadingeffects,itshighSEduetothecloselyspacedorthogonalsubcarriersanditsabilitytoavoidbothintersymbolinterference(ISI)byusingsufficientguardtimeandintercarrierinterference(ICI) byappendingacyclicprefix(CP)intheguardinterval. Additionally,ifthelengthofCPismorethanthemaximumchanneldelayspread,thesystemcanalsoelegantlyequalizeafrequency selectivechannelwithasinglecomplexcoefficientpersubcarrier.However,despiteitsseveraladvantages,OFDMsuffersfromsusceptibilitytocarrierfrequencyoffset(CFO)resultinginICIandtheuseofCPnotonlyreducestheeffectivethroughputofthetransmissionbutalsoincreasestransmitpower.Moreimportantly,OFDMsuffersfromsignificantspectralleakagedueto theuseofrectangularpulsethathaspoorfrequencylocalizationandthusrequireslargeguardbandstoprotectnearbychannelswhichalsoreducestheSEofthesystem.ThispresentsamajorsourceofproblemthatlimitstheapplicabilityofOFDMinsomepresentandfuturecommunicationsystems.TheaforementionedshortcomingslimittheutilizationofOFDMasasuitablewaveformforfuturewireless networksandmotivatedresearcherstolookforalternativesolutionsandproposeenhancedphysicallayersforfuturewirelessnetworks.Future remote frameworks will be described by an enormous scope of potential uses cases. This requires an adaptable allotment of the accessible time-recurrence assets, which is troublesome in ordinary Orthogonal Frequency Division Multiplexing (OFDM). Hence, adjustments of OFDM, for example, windowing or sifting, become essential. On the other hand, we can utilize an alternate balance plot, for example, Filter Bank Multi-Carrier (FBMC).

Future portable frameworks will be exceedingly heterogeneous and described by a huge scope of conceivable use cases, going from improved Mobile Broad-Band (eMBB) over upgraded Machine Type Communications (eMTC) to Ultra Reliable Low dormancy Communications (URLLC) in vehicular correspondences. Filter bank multicarrier (FBMC) is an elective transmission strategy that settles the above issues by utilizing top notch channels that maintain a strategic distance from both entrance and departure clamors. Likewise, on account of the extremely low out-of-band outflow of subcarrier channels, use of FBMC in the uplink of multiuser systems is trifling. It very well may be sent without synchronization of versatile client hubs signals. In the use of psychological radios, the channel bank that is utilized for multicarrier information transmission can likewise be utilized for range detecting.

Then again, contrasted with OFDM, FBMC misses the mark in giving various info different yield (MIMO) channels, in spite of the fact that a couple of answers for receive FBMC in MIMO directs have been accounted in the writing; For instance, see. In any case, as our ongoing examination contemplate has appeared, in the rising region of enormous MIMO, FBMC is found as incredible as OFDM and at times better than OFDM.Filter Bank Multi-Carrier (FBMC) with Offset Quadrature Amplitude Modulation (OQAM), in short just FBMC, is an interesting modulation scheme for future wireless systems because it has much lower Out-Of-Band (OOB) emissions than Orthogonal Frequency Division Multiplexing (OFDM).

This improves the performance in asynchronous transmissions and allows an efficient time-frequency allocation for different use cases. Additionally, FBMC typically does not require a Cyclic Prefix (CP), further increasing the throughput. To fulfill the Balian-Low theorem, FBMC replaces the complex orthogonality condition with the less strict real orthogonality condition. This causes intrinsic interference, concentrated on the imaginary part, which makes channel estimation and Multiple-Input and Multiple-Output (MIMO), more challenging.

II. RELATED WORK

Ahmed et al., [1] presented a multicarrier framework utilizing a low computational multifaceted nature change that joins the WHT and the DFT into a solitary quick orthonormal unitary change. The proposed change has been broke down in a T-change based OFDM called T-OFDM, for noteworthy improvement in BER and a sensible decrease in the PAPR.

Ronald Nissel et al., [2] provided an unifying framework, discussion, performance evaluation of FBMC and comparison to OFDM based schemes. In this paper investigations are not only based on simulations, but are substantiated by real-world testbed measurements and trials, where multiple antennas and channel estimation are showed, two of the main challenges associated with FBMC, can be efficiently dealt with. Additionally closed-form solutions for the signal-to-interference ratio in doubly-selective channels are derived and shows that in many practical cases are, one-tap equalizers are sufficient. A downloadable MATLAB code supports reproducibility of results.

Ali,I.,Pollok,A.,LinLuo.And Davis, [3]investigated a T-transform based multicarrier communication system with significant uncoded BER performance improvement over conventional OFDM in a Rayleigh fading channel was proposed. However, due to the involvement of Walsh Hadamard transform (WHT), the T-transform OFDM system does not satisfy the cyclic convolution property and hence fails to diagonalize the channel matrix, resulting in an enormous equalization complexity. In this paper, a new receiver processing mechanism where the T-transform is replaced by two equivalent transforms are proposed and the equalization is carried out in between them. The new approach diagonalizes the channel matrix and single tap equalization is possible without any compromise in the performance. The detailed computational complexity of the proposed approach is also presented and compared with some other schemes.

Chen,Metal., [4] demonstrated an IFFT/FFT size efficient DFT-spread orthogonal frequency-division multiplexing (OFDM) based on complex-valued IFFT/FFT operations without Hermitian symmetry (HS) constraint at the input, for short-reach intensity-modulated and directly-detected (IMDD) optical fiber transmission systems is demonstrated. The only complex-valued IFFT based OFDM has the similar peak-to-average power ratio (PAPR) and bit error rate (BER) performance, but with only half of the IFFT/FFT size as the conventional real IFFT-based OFDM. In this paper, the complex IFFT based OFDM combined with DFT-spread technique is proposed and applied to reduce PAPR and IFFT/FFT size, and improve BER performance at the same time. The experimental results show that, with the help of PAPR reduction enabled by DFT-spread, more than 3-dB improvement in receiver sensitivity has been achieved after 20.62-km of SMF transmission at a BER of 3.8×10-3 (7% hard-decision forward error correction (HD-FEC) threshold). In addition, by using the DFT-spread technique, the BER performance comparison between complex IFFT-based OFDM and real IFFT-based OFDM is also performed. The results show that, the BER performance of the former is slightly worse than the latter, but has lower hardware complexity and less power consumption due to the reduced IFFT/FFT size.

Doufexi,A.,Armour,S.,Butler,M.,Nix,A.,Bull,D.,McGeehan,J. andKarlsson,P., [5] discussed about the present, WLANs supporting broadband multimedia communication are being developed and standardized around the world. Standards include HIPERLAN/2, defined by ETSI BRAN, 802.11a, defined by the IEEE, and HiSWANa defined by MMAC. These systems provide channel adaptive data rates up to 54 Mb/s (in a 20 MHz channel spacing) in the 5 GHz radio band. In this article an overview of the HIPERLAN/2 and 802.11a standards is presented together with software simulated physical layer performance results for each of the defined transmission modes. Furthermore, the differences between these two standards are highlighted (packet size, upper protocol layers etc.), and the effects of these differences on throughput are analyzed and discussed.

Hui,Y.,Li,B.andTong,Z., [6] reviewed that an optimal order selecting scheme for 4-weighted fractional Fourier transform (4-WFRFT) over doubly selective channels is developed. First, the expression for carrier-to-interference ratio (CIR) is deduced and then through maximising the CIR the optimal order factor is obtained. Through selecting the optimal order factor of 4-WFRFT, this system can match the doubly selective channel characteristics through switching between orthogonal frequency division multiplexing (OFDM) and single carrier (SC) systems according to obtained channel state information. The simulation results show that the optimal order 4-WFRFT scheme can improve the performance over doubly selective channels with respect to the traditional SC or OFDM.

Lee,K.S.,Cho,Y.J.,Woo,J.Y.,No,J.S.andShin,D.J., [7] discussed Partial transmit sequence (PTS), a well-known peak-to-average power ratio (PAPR) reduction scheme for orthogonal frequency division multiplexing (OFDM) systems, has been actively investigated to reduce its high computational complexity. Ku et al. proposed a selection method of dominant time-domain samples and by only using the selected samples, the PAPR of each alternative OFDM signal vector is calculated.This method clearly reduces the computational complexity but it is crucial to select proper time-domain samples to achieve acceptable PAPR reduction performance. In this study, a new selection method of dominant time-domain samples is proposed based on rotating samples of inverse fast Fourier transformed (IFFT) sub-blocks to the local area on which the corresponding sample of the IFFT first sub-block is located. Moreover, pre-exclusion of phase rotating vectors based on the above time-domain sample rotation is proposed to further reduce the computational complexity. Numerical results confirm that the proposed PTS schemes substantially reduce the computational complexity with negligible degradation of PAPR reduction performance.

Li,C.P.,Wang,S.H.andWang,C.L.,[8]

researchedSelected mapping (SLM) schemes which are commonly employed to reduce the peak-to-average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) systems. It has been shown that the computational complexity of the traditional SLM scheme can be substantially reduced by adopting conversion vectors obtained by using the inverse fast Fourier transform (IFFT) of the phase rotation vectors in place of the conventional IFFT operations [C.-L. Wang and Y. Ouyang, “Low-Complexity Selected Mapping Schemes for Peak-to-Average Power Ratio Reduction in OFDM Systems,” IEEE Trans. Signal Process., vol. 53, no. 12, pp. 4652–4660, Dec. 2005]. To ensure that the elements of these phase rotation vectors have an equal magnitude, conversion vectors should have the form of a perfect sequence. This paper presents three novel classes of perfect sequence, each of which comprises certain base vectors and their cyclically shifted versions. Three novel low-complexity SLM schemes are then proposed based upon the unique structures of these perfect sequences. It is shown that while the PAPR reduction performances of the proposed schemes are marginally poorer than that of the traditional SLM scheme, the three schemes.

MarkkuRenfors et al. [9] demonstrate that the previous transmission systems depend on the OFDM technique to achieve the goals. OFDM has many negative points; the big challenges are of the cyclic prefix. Cyclic prefix causes the loss the capacity and bandwidth. It required maintaining the orthogonality among all the subcarriers. Due to the limitations of OFDM, FBMC introduced in the radio communications systems. Filter bank multicarrier can achieve higher channel capacity than OFDM because of the low spectral leakage. The spectral components are interfering to obtain very sharp frequency selectivity and they can be used very effectively. This can be done in very flexible manner.

Ari Viholainen et al. [10] give the overview of the physical layer of FBMC. The IFFT (inverse fast Fourier transform) work as the modulator and FFT (fast Fourier transform) work as the demodulator in the FBMC transmitter or receiver side respectively, and the IFFT and FFT are cascaded. Due to the cascade structure of serial to parallel conversion and parallel to serial conversion the one symbol delay has occurred at the FFT output with respect to the IFFT input symbol. When all the FFT symbols are obtained then the bank of filters are also obtained. It gives the idea about the different type of modulations like Multi Pulse Modulation isolation in time etc. In FBMC physical layer two different types of filters are used such as Synthesis Filter Bank (SFB) in OQAM Preprocessing or in modulator part and Analysis Filter Bank (AFB) in OQAM Post Processing or in Demodulator part. SaeedAfrasiabiGorgani depicts a basic idea of OFDM/OQAM with Synthesis and Analysis Filter Bank. In Cosine Modulated Multitone (CMT) real value (0 or 1) are used and in Staggered Modulated Multi-tone (SMT) used only imaginary or complex values.

III. PROPOSED MODEL

FBMC filters each subcarrier modulated signal in a multicarrier system. The prototype filter is the one used for the zero frequency carriers and is the basis for the other subcarrier filters. The filters are characterized by the overlapping factor, K which is the number of multicarrier symbols that overlap in the time domain. The prototype filter order can be chosen as 2*K-1 where K = 2, 3, or 4. The current FBMC implementation uses frequency spreading (FS) which can achieve high equalization and timing offset compensation performance. It uses an N*K length IFFT with symbols overlapped with a delay of N/2, where N is the number of subcarriers. This design choice makes it easy to analyse FBMC and compare with other modulation methods. To achieve full capacity, offset quadrature amplitude modulation (OQAM) processing is employed. The real and imaginary parts of a complex data symbol are not transmitted simultaneously, as the imaginary part is delayed by half the symbol duration. The modulation method used in FBMC is Offset Quadrature Amplitude Modulation (OQAM). The main feature of this OQAM is, imaginary part of the data is delayed by half the value of symbol duration i.e. there is no simultaneous transmission of real and imaginary parts of complex data.

In FS-FBMC (frequency spreading-FBMC), K multicarrier symbols are overlapped in the time domain, where K is defined as the overlapping factor. This parameter also has an impact on the design of the prototype filter used for frequency spreading by defining the number of non-zero samples in the filter frequency domain as 2K − 1. As a consequence of frequency spreading, the IFFT size in FS-FBMC systems is equal to the number of subcarriers (N_c) times the overlapping factor: KN_c. This represents an increased computational complexity compared with PPN-FBMC. However, FS-FBMC simplifies the concept of FBMC and offers the flexibility of changing the number of sub-channels by keeping the IFFT size and simply varying the overlapping factor. Apart from the baseband parameters K and Nc, another important parameter is the number of guard bands on both multicarrier symbol ends.

The symbol mapper's modulation type matches the mapper's modulation; the originally transmitted signal should be matched. OQAM processing has two techniques, one is OQAM pre-processing being performed at the transmitter side and other is OQAM post-processing being performed at the receiver side. In OQAM pre-processing, the first operation is a complex to real conversion for even and odd, where the real and imaginary part of a complex valued symbols are separated to form a new symbol.

As shown in Figure 2 below, at the transmitter side used Inverse fast Fourier transform as a modulator. The figure describes data bits are used as an input. The symbol mapping is used for mapping the symbols. The modulation symbol map is used to generate 16 QAM modulated electrical signals and then the modulation symbol de-mapper demodulates the signals according to that which type of modulation is used. The complex to real conversion increases the sample rate by a factor of 2. The second operation in this OQAM pre-processing is the multiplication by a sequence. After that Serial to Parallel conversion is done. A serial to parallel (S/P) converter is introduced at the output of the OQAM-pre-processing and the samples data appear in the parallel form. In Frequency Spreading gives accurate equalization. Frequency spreading is a type of remote interchanges the recurrence of the transmitted signal is intentionally changed. At the block of data at the Extended IFFT transmitter is recovered at the output of the FFT at the receiver. A parallel-to-serial (P/S) converter is introduced at the output of the IFFT and the samples appear in the serial form. An overlap defined as when two singles are mixed with each other, but in FBMC signals do not overlap with each other.

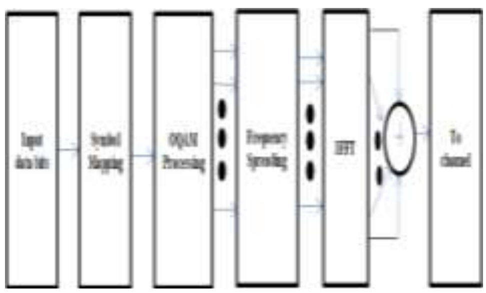

Figure 1: FBMC Transmitter

As shown in the Figure 2, FBMC receiver or demodulator measures the BER for the chosen configuration in the absence of a channel. The processing includes matched filtering followed by OQAM separation to form the received data symbols. These are de-mapped to bits and the resultant bit error rate is determined. In the presence of a channel, linear multi-tap equalizers may be used to mitigate the effects of frequency-selective fading.

The Figure 2 shows that at the receiver side output of the transmitter of FBMC act as an input of receiver FBMC. The data is converted serial to parallel. A serial to parallel (S/P) converter is introduced at the output of the IFFT and the samples data appear in the parallel form. At the receiver side serial to parallel conversion is done, in which data sequences change from serial to parallel. In which analysis filter bank is used. By using this filters the process of decomposition performed by the filter bank. It can be adapted to implement the filter bank, it is just sufficient to extend the IFFT and the FFT. In the modulator part, the Synthesis Filter Bank (SFB) is used. The information sources to the SFB are the offset QAM. The IFFT block basically acting the adjustment to the subcarrier frequencies.

From the equipment perspective, it performs the calculations in a block preparing way. Analysis Filter Bank (AFB) is used in demodulator part. In OQAM post-processing the real to complex conversion decreases the sample rate by a factor 2. The de-mapper modulation type matches the mapper's modulation types, where the originally transmitted signal should be recovered. In the end, at the receiver data bits are recovered.

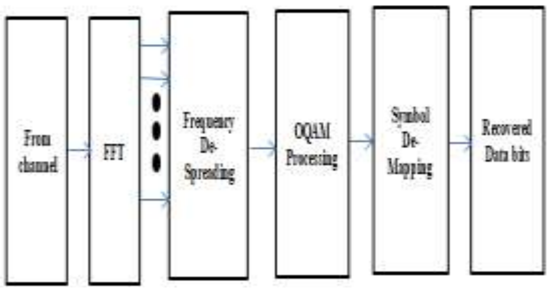

Figure 2: FBMC Receiver

Real-world test-bed measurements in the Figure 3 below shows that MIMO works in FBMC once symbols are spread in time. The spreading process itself has low computational complexity because a fast Walsh-Hadamard transformation can be used. FBMC and OFDM experience both the same BER, but FBMC has lower OOB emissions.

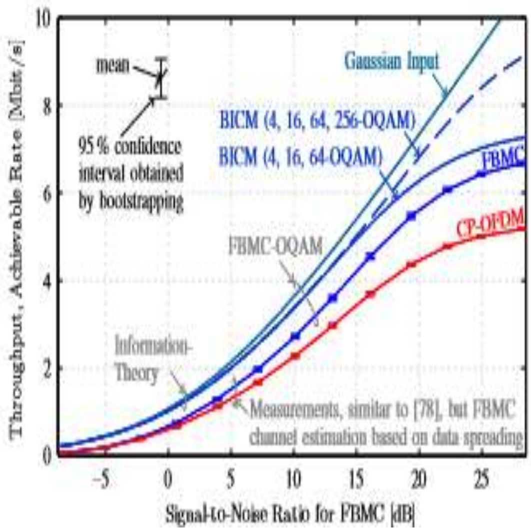

Figure 3: Real world test bed measurements

Test-bed measurements show the measured throughput as well as the theoretical bounds discussed so far (for Rayleigh fading). FBMC has a higher throughput than OFDM due to a higher usable bandwidth and because no CP is used. Employment of data spreading improves the throughput. OFDM and FBMC have the same transmit power which leads to a smaller SNR for FBMC compared to OFDM because the power is spread over a larger bandwidth.

The measured throughput is only 2dB worse than the theoretical BICM bound. Such differences can be explained by an imperfect coder, a limited code length, a limited number of code rates and channel estimation errors.

An important observation here is that the throughput saturates. If we increase the SNR from 0dB to 10dB, that is, by a factor of 10, then the throughput increases by approximately 300%. On the other hand, if we increase the SNR from 20dB to 30dB, also a factor of 10, the throughput only increases by 20%. Even if we consider a symbol alphabet of up to 256-OQAM (BICM), the achievable rate only increases by 40%. Thus, a high SNR provides only a small throughput gain while power and hardware costs are significantly higher. Therefore it often operates in medium SNR ranges.

IV. FBMC IMPLEMENTATION

The Figure 4 shown below represents the flow of FBMC operation for future wireless network i.e. 5G (Fifth Generation).

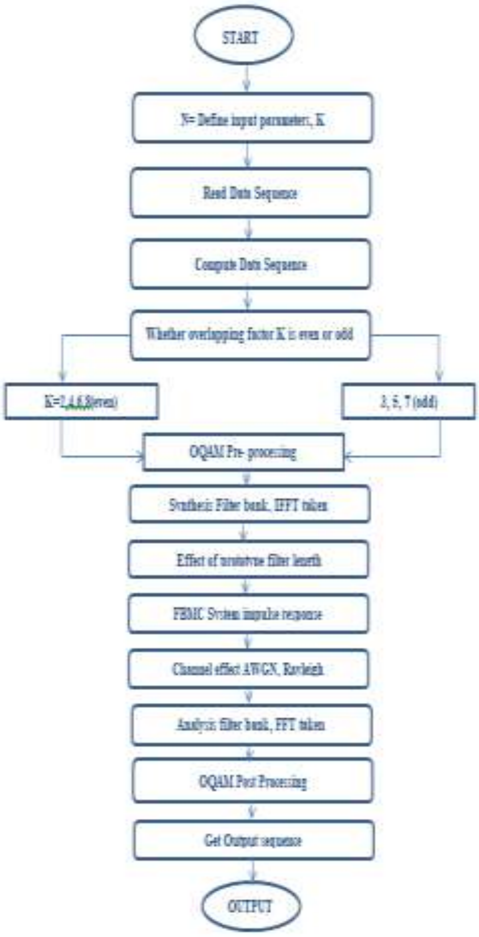

Figure 4: FBMC implementation

The synthesis analysis of filter bank structure is formed by prototype filtering along with IFFT/FFT operation. Here significant ISI suppression is possible by a prototype filter design. In order to guarantee, ISI-free operating additional coefficients are introduced in the frequency domain between FFT coefficients. This additional coefficient number is known as overlapping factor which is represented by K of the filter.To fulfill the demand for high data rate, MIMO is combined with FBMC. MIMO is defined as Multiple Input Multiple Output. In which N no. transmitter signals are transferred through the different channels and received at the receiver side. To reduce fading effect between multiple data streams different MIMO channels are used such as Rayleigh and Additive White Gaussian Noise (AWGN)

The simulations are carried out using MATLAB. It is a multi-paradigm supporting language tool. In this section, the performance of one of the 5G waveforms (FBMC) is examined. The effective spectrum utilization plays an important role to get the popularity of any cellular system.

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V. EXPERIMENTAL RESULTS

Figure 5 shows how the PSD of FBMC depends on the resolution of the DAC (4 bits, 8 bits, 12 bits, 16 bits).

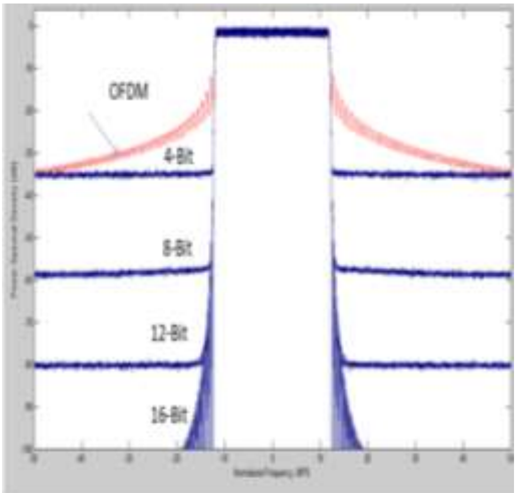

Figure 5: Power spectral density of FBMC and OFDM

CP-OFDM is the most prominent multicarrier scheme and is applied, for example, in Wireless LAN and Long Term Evolution (LTE). CP-OFDM employs rectangular transmit and receive pulses, which greatly reduce the computational complexity. The rectangular pulse is not localized in the frequency domain, leading to high Out-Of-Band (OOB) emissions as shown in both the Figure 5 and 6. This is one of the biggest disadvantages of CP-OFDM.

As shown in the Figure 6. In order to reduce the OOB emissions, 3GPP is currently considering windowing and filtering. The windowed OFDM scheme is called OFDM with Weighted Overlap and Add (WOLA).

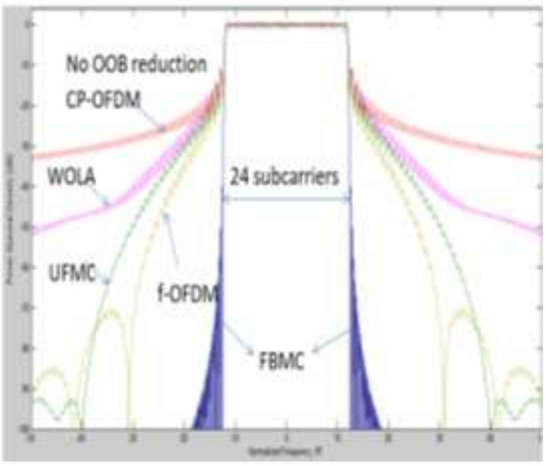

Figure 6: Power spectral density of different modulation techniques

At the transmitter, the edges of the rectangular pulse are replaced by a smoother function (windowing) and neighboring WOLA symbols overlap in time. The receiver also applies windowing but the overlapping and add operation is performed within the same WOLA symbol, reducing the inter-band interference. Note that the CP must be long enough to account for both, windowing at the transmitter and at the receiver. For the filtered OFDM scheme, two methods are proposed.

Firstly, Universal Filtered Multi-Carrier (UFMC) which applies sub-band wise filtering based on a Dolph-Chebyshev window. Orthogonality is guaranteed by either Zero Padding (ZP) or a conventional CP. The performance differences between CP and ZP are rather small, so that we will consider only the CP version here to be consistent with the other proposed schemes. The filter parameters are chosen similarly. This leads to 12 subcarriers per sub-band and, if no receive filter is employed, to orthogonal time-frequency spacing.

The second filter-based OFDM scheme considered within 3GPP is filtered-OFDM (f-OFDM). Here, the number of subcarriers for one sub-band is usually much higher than in UFMC and often includes all subcarriers belonging to a specific use case. The filter itself is based on a sinc pulse (perfect rectangular filter) which is multiplied by a Hann window.

For the FBMC, the prototype filter (PF) is not a constant pulse but a modified cosine shape and it lasts for several symbol duration. In this paper, PHYDYAS prototype filter is adopted for the FBMC implementation. The PF is characterized by two parameters: filter's length L and oversampling factor K = L /N. It was pointed out that the factor K = 4 is optimum for high-speed transmission in terms of the trade-off between performance and complexity.

The Figure 7 below shows the prototype filters initial shapes with FBMC in time domain. The performance evaluation is carried out by varying the different parameters. Firstly, initial shapes of four prototypes are examined. Case 1 uses PHYDYAS prototype whereas case 2 use RRC prototype and Hermite in case 3. However, case 4 use rectangular as shown in time domain (Figure 7) and frequency domain (Figure 8). It is noticeable that rectangular shape has sharpest edge unlike another shape and its power in frequency domain has highest value compared to others. However lowest value has been reached through using PHYDYAS prototype as shown in frequency domain.

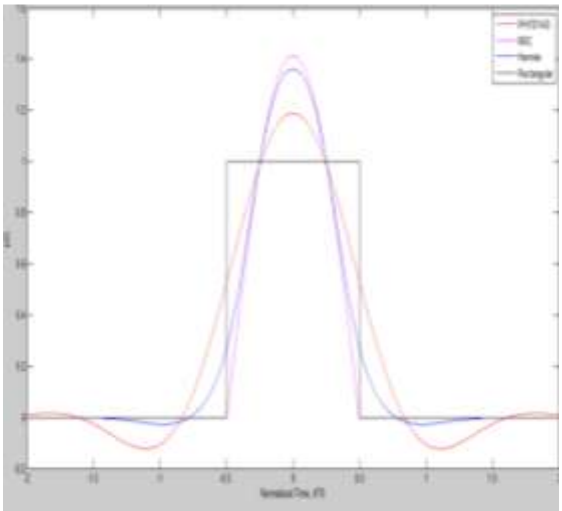

Figure 7: IMPULSE RESPONSE

The PFs impulse and frequency responses comparisons of the OFDM (the rectangular pulse) and FBMC (the PHYDYAS pulse) with the number of subcarriers of 24 (N = 24) and the overlapping factor of 4 (K = 4) are shown in both Figure 7 and 8. Clearly, the impulse response duration of FBMC is K times, i.e. 4 times, longer than OFDMs and the out-of-band power leakage of FBMC is much lower than that of OFDM. These features will make FBMC more robust than OFDM regarding the timing problems, delay spreads and frequency offset error as well. Nevertheless, the PHYDYAS PF only guarantees the orthogonality in real fields. Therefore, only real values are modulated in FBMC. The real and the imaginary parts of a complex data symbol are not modulated simultaneously but the imaginary part is delayed by the half symbol duration.

Hence, windowing and filtering can reduce the high OOB emissions of CP-OFDM. However, this comes at the price of reduced spectral efficiency, as indicated by the product of TF, and lower robustness in frequency selective channels. Furthermore, filtering and windowing still do not provide as low OOB emissions as FBMC which can additionally achieve a maximum symbol density.

The Figure 8 below shows the prototype filters initial shapes in frequency domain. The well localization of PHYDYAS filter in both time and frequency domain enables them to avoid ISI and ICI in FBMC system without the use of cyclic prefix. Rectangular prototype filter corresponds to sinc functions in frequency domain. Therefore, OFDM has high side-lobes as given in Figure 7 and Figure 8.

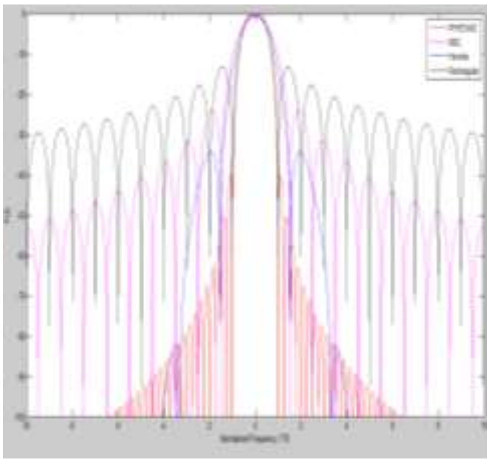

Figure 8: FREQUENCY RESPONSE

It is possible to suppress the side-lobes of OFDM by applying additional windowing period. On the other hand, side-lobes are naturally suppressed in FBMC approaches without sacrificing the spectral efficiency. However, FBMC approaches might be more robust to higher frequency dispersion depending on the filter used, such as Hermite, RRC, Rectangular and PHYDYAS filters.

As opposed to rectangular filter, RRC are theoretically band-limited in frequency domain. However, in practical conditions, the power spectrum of FBMC with these filters will deviate from ideal frequency localization as in Figure and Figure because of the filter truncation in time domain. Additionally, using small α (e.g., half sinc) apparently increases the side-lobes of FBMC. When throughput and side-lobes are considered, Hermite filter has the best characteristic because of two fundamental reasons: 1) very good joint time-frequency localization and 2) being an orthogonal filter. Both of them provide very high time frequency dispersion immunity as well as CFO and timing misalignment.

Hence, FBMC is considered advantageous in comparison to all the schemes by offering higher spectral efficiency. Comparing the plots of the spectral densities for OFDM, WOLA, UFMC, f-OFDM and FBMC schemes, FBMC has lower side lobes. This allows a higher utilization of the allocated spectrum, leading to increased spectral efficiency. FBMC gives a better bandwidth efficiency compared to OFDM because FBMC does not use the CP extension; hence it has to attenuate the interferences within and close to the used frequency band efficiently.

The TABLE 1 shows the important parameters such as resolution of DAC, clipping factor, number of FBMC and OFDM symbols, number of subcarriers and overlapping factor used in this implementation.

TABLE 1.IMPORTANT PARAMETERS

PARAMETERS	VALUE
DAC resolution	4,8,12,16 bits
Clipping factor	8 9 11 12
FBMC symbols	105
OFDM symbols	10
Subcarriers	24
Overlapping Factor	4

VI. CONCLUSION

OFDM based methods such as WOLA, UFMC and f-OFDM has higher spectral efficiency when the number of subcarriers is high. However, not in all the cases meant for future wireless systems will employ large number of subcarriers. For small number of subcarriers, FBMC becomes most efficient than OFDM, in particular if the transmission band is shared between different cases. Many shortcomings associated with FBMC, such as channel estimation and MIMO, can be efficiently dealt with, as validated by real-world test-bed measurements. Additionally, one-tap equalizers in many cases are sufficient once subcarrier spacing is matched (pulse shape) to the channel statistics. In highly doubly selective channels, it can switch from an FBMC-OQAM transmission to an FBMC-QAM transmission, thus sacrificing spectral efficiency but gaining robustness. This leads to an even higher SIR (Signal to interference rtio) than in CP-OFDM. While it is true that the computational complexity of FBMC is higher than in windowed OFDM, both methods require the same basic operations, allowing to reuse many hardware components.

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