AN EFFICIENT FBMC BASED MODULATION FOR FUTURE WIRELESS COMMUNICATIONS

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ABSTRACT

This paper proposes of implementing a diminished (or pruned) DFT (d-DFT) precoded Filter bank multicarrier (FBMC). We develop an efficient precoding method using d-DFT by combining with one-tap scaling. This technique has advantages of both FBMC-Offset Quadrature amplitude modulation (OQAM) and Single carrier Frequency division multiple accesses (SC-FDMA).Proposed technique has same PAPR as SC-FDMA and has very low out-of-band emissions and does not need cyclic-prefix. This method reduces latency and complex orthogonality is restored at a considerable computational complexity. A comparative performance is also evaluated between d-DFT-FBMC and other multicarrier schemes and we observe that d-DFT is better than other schemes. Simulation is performed by using Matlab.

Keywords: FBMC, OQAM, DFT-s-OFDM, windowed OFDM, 5G.

1. INTRODUCTION

FBMC-OQAM is an efficient modulation scheme for future generation wireless communications due to its low OOB (Out-of-Band) emission than OFDM [1].This system also has high performance in asynchronous transmissions where it implements efficient time-frequency allotment for different users [2].Cyclic prefix is not needed for FBMC and thereby increases throughput. Balian-Low theorem[3] is fulfilled for orthogonality by considering less strict real orthogonal condition instead of complex. This results in cause of intrinsic interference on imaginary part and therefore challenges the implementation of channel estimation[4]and Multiple-Input and Multiple-Output(MIMO) [5], [6].

These challenges are dealt with several methods proposed in [2],[7],[8].As per [2],spreading of symbols in frequency or time domain can restore complex orthogonality in FBMC, thereby all detection methods of OFDM can be directly employed for an approximately flat channel within spreading length. The spreading can be implemented in time, based on DFT [6].For a flat channel [9],[10], Walsh Hadamard spreading is better than DFT spreading [5],[11].Walsh Hadamard spreading has a low computational complexity and also restores complex orthogonality in every block. Nonetheless reducing PAPR by shaping the transmitter signal in time can be achieved by DFT spreading. In FBMC, non-linearities resulting from power amplifier and Digital-to-Analog converter destroy spectral confinement [2],[12]. Thus FBMC has to be used in linear region but in multi-carrier systems poor PAPR makes it difficult. Several techniques to reduce PAPR, like Selective mapping [13] or Partial Transmit Sequence [14] used for OFDM, can also be applied for FBMC [15]-[17] but at a very high computational complexity and side lobes. Due to these drawbacks, above methods are not implemented in reality.

In SC-FDMA (LTE),a DFT precoded uplink is used. This can also be extended for 5G mobile communication, but simple combination of FBMC and DFT performs poorly. As suggested in [14], performance can be improved by precoding a filter bank in place of DFT. Compared to SC-FDMA, this method reduces PAPR but at the cost of increased overhead and computational complexity. As per [6], in DFT spread scheme of FBMC, phase term also influences PAPR performance. Optimized phase term is also giving poor PAPR compared to SC-FDMA. Therefore authors in [6] proposed a new scheme but at the cost of poor latency, high side lobes and high complexity. To reduce all these drawbacks we proposed a new modulation scheme based on diminished DFT with one tap equalizer. Using this method, in FBMC, we restore complex orthogonality. The advantages of our scheme can be illustrated as:

- Low PAPR
- Low OOB emissions when compared with FBMC, Low latency
- Restored Complex orthogonality enabling optimized multi-user transmissions in uplink
- Maximum possible symbol density.
- Compatible to MIMO for flat fading channels.

The possible disadvantages can be listed as:

- Computational complexity is slightly higher than SC-FDMA.
- A small residual interference is produced making the system quasi-orthogonal.
- For Flat channels, only Maximum likelihood low complex detection works.
- Throughput is slightly reduced because of spreading

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2. MULTI CARRIER SYSTEM MODEL

In a multicarrier system data is transmitted on a rectangular frequency-time grid. Frequency and Time spacing determines the shape of pulse. For efficient bandwidth subcarrier spacing should be small, but it increases latency of transmission. Spacing in subcarriers is decided based on the channel conditions. Thus 5G communications will require flexible subcarrier spacing depending on different use cases and different studies reveal that FBMC is a better choice for next generation wireless systems.

In a multicarrier system orthogonal pulses are used for carrying information. These orthogonal pulses overlap in frequency and time. Generally these pulses require a small bandwidth and converts broadband channels into multiple subchannels which has negligible interference and virtually flat in frequency [10]. In a multicarrier system the transmitted signal is given as

$$s(t) = \sum_{k=1}^{K} \sum_{l=1}^{L} g_{l,k}(t) x_{l,k} \quad (1)$$

$x_{l,k}$,is modulated QAM or PAM, represents symbol transmitted at position k and l^{th} subcarrier. $g_{l,k}$ is the transmitted basis pulse and is given by

$$g_{l,k}(t) = p(t-kT)e^{j2\pi lF(t-kT)}e^{j\pi/2(l+k)} \quad (2)$$

$g_{l,k}$ as shown is a prototype filter $P_{Tx}(t)$ shifted in time and frequency[7] and T & F denotes Time and Frequency spacing respectively. At the receiver symbols are decoded by projecting the received signal r(t) on $q_{l,k}(t)$, where $q_{l,k}(t)$ is basis pulse at receiver

$$y_{l,k}(t) = \langle r(t), q_{l,k}(t) \rangle = \int_{-\alpha}^{\alpha} r(t) q_{l,k}^{*}(t) dt \quad (3)$$

$q_{l,k}(t)$ is defined as a receiver prototype filter $P_{Rx}(t)$

$$q_{l,k}(t) = P_{RX}(t-kT)e^{j2\pi lF(t-kT)}e^{j\theta_{l,k}t} \quad (4)$$

For an AWGN channel SNR is maximized when matched filter is chosen that is
$q_{l,k}(t) = g_{l,k}(t)$ and $P_{Tx}(t) = P_{Rx}(t)$and for a doubly selective channel $P_{Tx}(t)$ is not equal to $P_{Rx}(t)$.Therefore the ambiguity function for the system is defined as

$$A(\tau,\upsilon) = \int_{-\alpha}^{\alpha} P_{TX}(t-\tau/2) P_{RX}^{*}(t+\tau/2) e^{j2\Pi \upsilon t} dt \quad (5)$$

τ,υ are used to designate and time and frequency offsets respectively. To increase the spectral efficiency frequency and time spacing are reduced to half so that TF = 0.5 and it causes intrinsic interference on imaginary part, therefore interference is cancelled by considering real part. Thus time frequency spacing of 0.5 is same as that of TF=1 for complex valued symbols. In general in a complex valued symbol real and imaginary part are matched to first and second time slots respectively and hence it is called as Offset-QAM.

To simplify mathematical calculations we use Matrix based notation for the system. All the basis pulse vectors are stacked in a transmission matrix G, overall Transmission matrix [14] is given as

$$G = \left[G_1, G_2 ......G_k\right] \in C^{N\times LK} \quad (6)$$

Matrix at any time position k is given by

$$G_k = \left[g_{1,k}, g_{2,k} \cdots g_{l,k}\right] \quad (7)$$

where $G_k \in C^{NXL}$

The transmitted signal is represented as

$$S = \sum_{k=1}^{K} G_k x_k = Gx \quad (8)$$

Where
$S \in C^{N\times 1}$, At time position k,
$x_k = [x_{1,k}, x_{2,k} \ldots x_{l,k}]^T \in C^{LX1}$ denotes the transmitted symbols.

For a doubly selective channel with a time variant channel matrix H and AWGN noise n, the received signal can be expressed as

$$r = Hs + n = HGx + n \quad (9)$$

At the receiver demodulation is done by G^H matrix and then received symbol is given by

$$\begin{aligned} y &= G^H (Hs+n) = G^H (HG_x + n) \\ &= G^H HG_x + G^H n \\ &\approx diag\{h\} G^H G_x + G^H n \end{aligned} \quad (10)$$

where h represents the one tap channel and OQAM real orthogonality is satisfied as

3. DIMINISHED DFT SPREAD FBMC

Diminished DFT spread FBMC can be explained by its underlying basis pulses. The basis pulses $g_{l,k}$ are precoded by a precoding function C and it transforms the pulses $g_{l,k}(t)$ into $\tilde{g}_i(t)$ described by $\tilde{G}$ as $\tilde{G} = GC = [\tilde{g}_1, \tilde{g}_2, ...]$.

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The size of $\tilde{G}$ depends on precoding method. The following results depict the power of basis pulses and different types of basis pulses from conventional OFDM to our method diminished DFT. Figure-1 represents OFDM basis pulse for N_{FFT} = 512,K=1,L=16. These basis pulses are frequency shifted and rectangular. All basis pulses with data symbols are guassian distributed resulting in poor PAPR of OFDM.

Figure-1. Power of underlying basis pulse in OFDM.

Figure-2 represents the SC-FDMA system obtained from a conventional OFDM [16] by DFT precoding by W_L and this results in emulation of single carrier transmission. The PAPR will be better than OFDM as long as data symbols are chosen from QAM constellation. But in SC-FDMA the pulses at tF = 0 and tF = 1 jumps to zero abruptly and it results in large OOB emissions, only basis pulses at the edges will have this effect

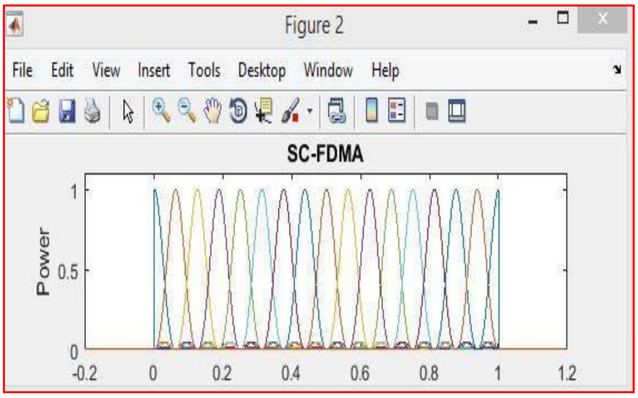

Figure-2. Power of underlying basis pulse in SC-FDMA.

Figure-3 represents idea of diminished DFT where only few edge basis pulses are set to zero and it reduces OOBE and this type of OFDM is called zero- tail DFT spread OFDM [16],[17]. Multipath delays can be avoided by utilizing zero tail in this OFDM similar to cyclic prefix. This results in reduction of spectral efficiency; due to this we implement FBMC instead of OFDM

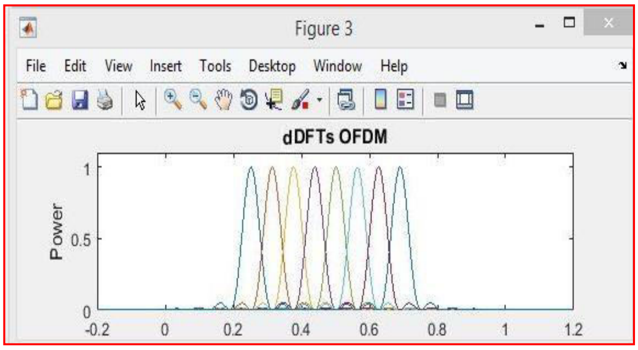

Figure-3. Power of underlying basis pulses in d-DFT OFDM.

As shown in Figure-4, we use a diminished DFT FBMC unscaled. In this system we reduce L basis pulses of W_L matrix into L/2 basis pulses and generate $W_{LxL/2}$ matrix. In this system time spacing is also reduced by half by using OQAM-FBMC and hence it does not impose any overhead. OFDM system is converted into FBMC by multiplying IFFT output with prototype filter P(t).

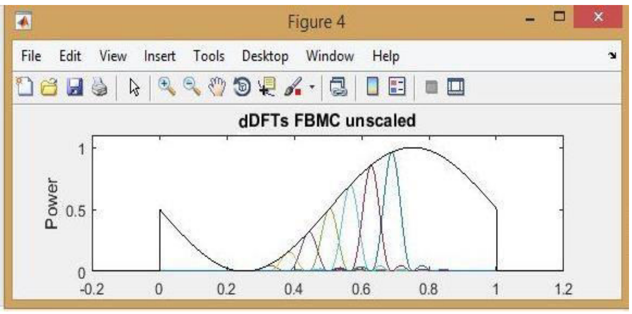

Figure-4. Power of underlying basis pulses of unscaled d-DFT FBMC.

As shown in Figure-5, the transmission power is made constant by scaling individual basis pulses and with this final step diminished DFT spread FBMC is implemented. In this figure we used a root raised cosine in time domain with a roll-off factor 1.

$$p_{tRRC}(t) = \begin{cases} \sqrt{F(\cos(2\pi tF)+1)}, & if -1/2F \le t < 1/2F \\ 0 & otherwise \end{cases} \quad (11)$$

In order to avoid inter-symbol interference in FBMC, overlapping factor should not exceed value of 1.5. Hence we need a truncated Hermite prototype filter. Hermite prototype filter [13] is given by

$$P(t) = 1/\sqrt{T_0} e^{-2\Pi(t/T_0)^2} \sum_{i=0,4,8,12,16,20} a_i H_i 2\sqrt{\Pi} t / T_0 \quad (12)$$

The above filter is defined as truncated Hermite between -0.78T < t < 0.78T and zero elsewhere.

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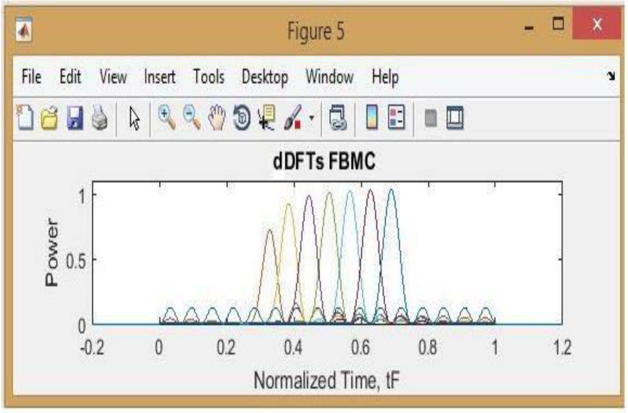

Figure-5. Power of underlying basis pulses of one –tap scaled dDFT FBMC.

The following block diagram represents the basic idea of diminished DFT spread FBMC transmission system. L/2 complex value data symbols are spread over L subcarriers using a precoding matrix or frequency spreading matrix $C_f \in C^{LXL/2}$, so that transmitted symbol at time position k becomes

$$x_k = C_f \tilde{x}_k \tag{13}$$

At the receiver one tap equalization is performed with $e_k \epsilon C^{LX1}$ on received symbols and then dispreading is done to give

$$\tilde{y}_k = C_f^H \, diag\{e_k\}^{-1} y_k \tag{14}$$

Spreading matrix is derived by assuming AWGN channel for which no equalization is needed. Complex orthogonality is restored so that

$$C_f^H G_k^H G_k C_f \approx I_{L/2} \tag{15}$$

The approximation is used here to indicate the presence of small residual interference making the system quasi orthogonal. Matrix C_f consists of diminished DFT matrix W_L with one tap scaling 'b' i.e.,

$$C_f = \tilde{W}_{LXL/2} diag\{\tilde{b}\} \tag{16}$$

An auxiliary vector 'a' is used for assuming spreading and dispreading matrix of W_L and is given by

$$a = diag\{W_L^H G_k^H G_k W_L\} \tag{17}$$

$[a]_i$ corresponds to i-th column of W_L. L/2 largest elements of 'a' of W_L matrix are used for transmission. Therefore diminished DFT matrix and scaling vector for i = 1, 2 …L/2 is given by

$$[\tilde{b}]_i = \sqrt{1/[a]_i} \tag{18}$$

$$\tilde{W} = W \begin{bmatrix} I_{L/2} \\ O_{L/2} \end{bmatrix} \tag{19}$$

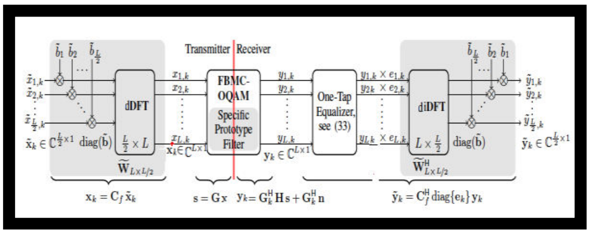

Figure-6. Block diagram of implementation of dDFT spread FBMC-OQAM

As shown in Figure-7, a comparative simulation is performed to measure the transmit power in conventional FBMC and diminished DFT FBMC. In conventional FBMC system, overlapping of symbols in time is very high and transmissions have to go long period because of high ramp-up and ramp-down time. But in diminished DFT precoding matrix will alter the shape of pulse so that symbol overlapping in time is reduced and it also reduces the ramp times of signal. The transmit power for one symbol can be calculated as

$$P_k^{(t)} = diag\{G_k C_f G_k^H C_f^H\} \tag{20}$$

When symbol overlapping factor is reduced we observe that Out-of-band emissions of the system increases. To study the effect of OOB we calculate spectral density of power given as

$$P_k^{(f)} = diag\{W_N G_k C_f G_k^H C_f^H W_N^H\} \tag{21}$$

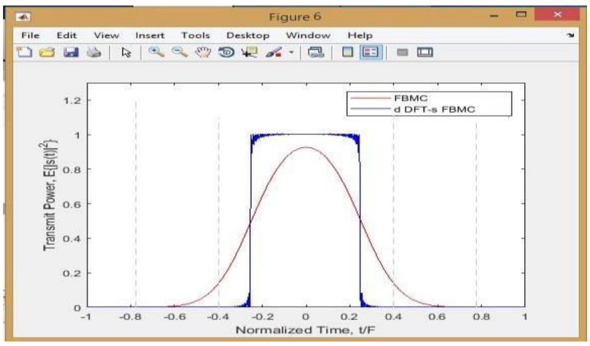

Figure-7. Comparison of average transmit power in FBMC and dDFT FBMC.

From Figure-8 we observe that OOB emission is very low in FBMC based system than OFDM and CP-OFDM. In FBMC, we observe that diminished FBMC performs better. But when overlapping factor is reduced we observe that OOB emissions increases and latency

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reduces. Thus depending on system requirements a proper trade-off must be maintained for choosing overlapping factorso as to maintain optimized latency and OOB emissions.

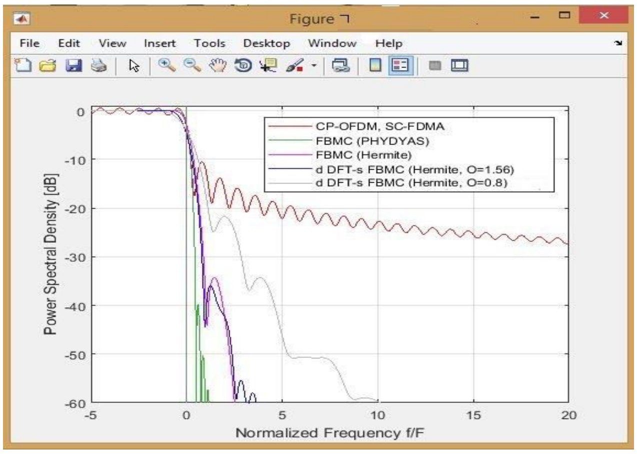

Figure-8. OOB emissions in different systems with different overlapping factor.

4. CONCLUSIONS

The proposed model of FBMC with OQAM modulation is efficient in reducing the PAPR and Latency. Complex orthogonality is also restored with a superior spectral confinement. OOB emissions are reduced in a doubly selective channel without using CP .Latency of the system can be reduced by reducing overlapping factor. This model can further modified by using a linear processed FBMC and thereby reduces residual intrinsic interference.

REFERENCES

[1] T. Strohmer and Feichtinge H.G. 2012. Gabor analysis and algorithms: Theory and applications Springer Science & Business Media.

[2] Rontogiannis D., Katselis E., Kofidis Theodoridis. 2010. Preamble- based channel estimation for CP-OFDM and OFDM/OQAM systems: A comparative study. IEEE Trans. Signal Process. 58(5): 2911-2916.

[3] P. Siohan, C. Lele and Legouable. 2010. The Alamoutischeme with CDMA-OFDM/OQAMEURASIP Journal on Advances in Signal Processing. 2010 (ArticleID703513):1-13.

[4] D. LeRuyet and R. Zakaria. 2012. A novel filter-bank multicarrier scheme to mitigate the intrinsic interference: application to MIMO systems. IEEE Transactions on Wireless Communications. 11(3): 1112- 1123.

[5] K. Mahender, T. Anilkumar, K. S. Ramesh. 2017. An Efficient OFDM system with reduced PAPR for combating multipath fading. Journal of advanced research in dynamical and control systems.9: 1939-1948.

[6] Caus. M and A. Perez Neira. 2013. SDMA for filter bank with Tomlinson Harashima precoding. IEEE International Conference on Communications (ICC). pp. 4571-4575.

[7] Sahin, Guvenc. I, Arslan. H. 202. A survey on multicarrier communications: Prototype filters, latticestructures, and implementation aspects. IEEE Communications Surveys Tutorials. 16(3): 1312-1338.

[8] K. Mahender, T. Anilkumar, K. S. Ramesh. 2018. Analysis of Multipath Channel Fading Techniques in Wireless Communication systems. American Institute of Physics, AIP Conference Proceedings1952, 020050; doi: 10.1063/1.5032012.

[9] H. Muller and J. Huber. 1997. OFDM with reduced peak-to-average power ratio by optimum combination of partial transmitsequences. Electronics letters. 33(5): 368-369.

[10] C. Ye, Z. Li, C. Ni, T. Jiang, Q.Qi. 2014. PAPR reduction of OQAM- OFDM signals using segmental PTS scheme with low complexity. IEEE TransactionsonBroadcasting.60(1):141-147.

[11] K.Mahender, T. Anilkumar, K.S.Ramesh. 2017. Performance study of OFDM over Multipath Fading channels for next Wireless communications. International journal of applied engineering research(IJAER), ISSN 0973-4562, 12(20): 10205-10210.

[12] S.Sesia, Bake. Mand Toufik.I. 2011. LTE-the UMTS long term evolution: from theory to practice. John Wiley & Sons.

[13] Ihalainen.T, T. Stitz, Viholainen, Renfors. M and M. Bellanger. 2009. Filter bank based multi-mode multiple access scheme for wireless uplink. IEEE European Signal Processing Conference (EUSIPCO). pp.1354-1358.

[14] D.Na & K.Choi. 2018. Low PAPR FBMC.IEEE TransactionsonWireless Communications. 17(1): 182-193.

[15] K. Mahender, T. Anilkumar, K. S. Ramesh. Simple Transmit Diversity Techniques for Wireless

Communications. Smart Innovations in Communication and Computational Sciences, Advances in Intelligent Systems and Computing 669, https://doi.org/10.1007/978-981-10-8968-8_28, pp. 329-342.

[16] M. Renfors, E. Kofidis, X. Mestre, F. Bader. 2017. Orthogonal Waveforms and Filter Banks for Future Communication Systems. Academic Press.

[17] K. Mahender, T. Anilkumar, K. S. Ramesh. 2017. SER and BER Performance analysis of digital modulation scheme over multipath fading channel. International journal of control theory and applications (IJCTA) ISSN 0974-5572, 10(22): 81-91.