Performance analysis of various noise & channel (ICI) cancellation schemes in FBMC systems

Shashi T. J.
Research Scholar, VTU Research Centre,
E&CE Dept., BVBCET, Hubli, Karnataka, India

Dr. Priyatamkumar
Professor, School of Electronics & Communication Engineering,
KLE Technological University, Hubli-580031, Karnataka, India.

Email ids: shashitj050986@gmail.com priyatam@kletech.ac.in

Abstract—In this research paper, the main objective is to study and conduct a brief performance analysis of various ICI cancellation schemes in FBMC systems which is presented with the theoretical background to start with, finally ending up with the presentation of the simulation results & the overall conclusive remarks at the end. Here, we study the best ICI cancellation schemes in the FBMC systems and compare them with the design of a high profile prototype filter. So, we considered, 2 very best ICI cancellation schemes, viz., FBMC auxiliary & FBMC coding process with the incorporation of a suitable high profile digital filter. Considering these 2 - FBMC auxiliary & FBMC codings, we had showed that FBMC auxiliary ICI performance is the best by analyzing various parameters like Signal to noise ratio (SNR) v/s the bit error rate (BER) for both aux & main coding, Time index (TI) v/s the frequency index (FI) for both aux & main coding, Transmitted power (TP) v/s the time for both aux & main coding, Power spectral density (PSD) v/s the frequency for both aux & main coding, etc… The mathematical modelling of the ICI (noise & channel interference cancellation) is also presented in this paper along with the overall wireless communication system model of the 2 types of systems, i.e., FBMC coding & auxiliary considered which is being used in the development of the code. Algorithms are developed in the Matlab environment & the simulated results are presented in the end along with the justification. Quantitative results are also presented for comparison purposes. The performance analysis is carried out for different NR iterations and finally compared for the best performance, solving the first objective, i.e., carrying out a performance analysis of different ICI interference schemes.

Keywords—OFDM, FBMC, 5G, Noise, Interference, Matlab, Simulation, Wireless, Communication, Spectrum, Channel, ICI, OQAM, PAPR, ISI.

I. INTRODUCTION - BRIEF REVIEW ABOUT THE TYPES OF FBMC MODELS

It is a well-known fact that over the last 2 decades, the FBMC modulation has gained a lot of prominence an attracted attention over a large section of the researchers who are doing the research in the wireless communication field and this has finally got a lot of appreciation also from the community over the digital spectrum well-localization concepts. Indeed, FBMC concepts are not only just developed as an option in contrast to symmetrical or orthogonal freq. division multiplexing, it is likewise considered as an engaging contender for the future 5G cellular mobile communication wireless systems. Consequently, the point is to develop the self-optimized high performing low computational algs that can procedure data information streams and limit the channel interference with better execution, performance and lesser complexities with good reliabilities. Ongoing conversations on suitable advancements for 5G wireless communications on the requirement for waveforms with preferable spectral containments with the sub-carrier over the commended OFDM concepts.

![Fig. 1 : OFDM & FBMC T_s](image-url)

The FBMC modulation could be considered as one of the methods of the extensions of the developed OFDM. The channel’s filter banks addresses the various fundamental issues of the OFDM concepts referenced previously. To begin with, their sub-channels could be ideally planned & designed in the FD region in order to have the desired spectral control of the communication process. Next, FBMC frameworks don’t require a redundant CP & in this manner, they are progressively productive and highly...
efficient when the spectral issues are taken into consideration. The high quality filter bank will definitely provide good frequency isolations with enough of out of the band attenuation of the filters in the sub-bands in order to implement the much needed selectivity component & the reception components in the wireless communication process. This will enable us to move all the functions of the signal processing blocks in the communication system after the filter banks to the lowest sampling rate.

When the multi-user settings are taken into consideration, the sub-channels or the sub-groups of sub-channels distributed to the client users are spectrally isolated when a void (empty) sub-channel is available in the middle. In this manner, clients or the users do not required to be perfectly synchronized before they get the access to the transmission framework. This is a significant factor for the up-link in the conventional base station-driven systems or in the near future dynamic spectrum access WC system. In the CRs & in the SDRs, the FBMC gives the possibility of carrying out the spectrum process as well as the transmission functions with the help of the same communication device, thus acting as a bi-functional process (dual in nature). Similar to the multicarrier communication process, the FBMC can profit the multi antenna communication system. MIMO strategies/techniques can likewise be applied in this context. Further examination or research is as yet required here, but as it may be. One case of a research initiative that could be reviewed is the FBMC in 5G applications nowadays which is the developmental stage. Another process, effectively completed, was the Physical Layer for Dynamic Spectrum Access & the Cognitive Radios, which is termed as the PHYDAS. This has investigated the FBMC as another new idea for dynamic access spectrum management & the CR apps.

II. CONCEPT OF THE FILTER DESIGN PROCESS

- Start
- Add paths
- Define NR repetitions, QAM modulation order
- Create FBMC object – subcarriers, spacing, sampling rate, phase shift
- Design the high profile filter mechanism to reduce ICI
- Start modulation process
- Start the channel estimation process
- Create the Imaginary Interference Cancellation Objects
- Display the results – BER, FI, PSD, PT, SNR
- End

Fig. 3 : Data flow diagram (DFD) for the performance analysis

III. WIRELESS COMMUNICATION SYSTEM MODEL OF THE FBMC SET-UPS (MATHEMATICAL MODEL)

In the process of the FBMC transmissions, the information variables \( x_{l,k} \) at the position of the frequency, \( l \) and \( k \) position are modulated by basic pulse signals \( g_{l,k}(t) \), so that the transmitted signal \( s(t) \) of our framework can be composed as

\[
s(t) = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} g_{l,k}(t) x_{l,k}
\]
with the help of

\[ g_{l,k}(t) = p(t-kT)e^{j2\pi F(t-kT)}e^{\frac{-2\pi^2}{T_0^2}} \]

A time & frequency shifted version of the prototype of the high profile filter \( p(t) \) is actually the basic pulse signal \( g_{l,k}(t) \). The spectral efficiency is determined by the time spacing parameter \( T \) along with the frequency shaping parameter \( F \). Hermite polynomials \( H_n(.) \) is taken as the basis for the design of the high profile prototype filter system \( p(t) \) is modelled as

\[ p(t) = \frac{1}{\sqrt{T_0}} e^{-\frac{2\pi^2}{T_0^2}} \sum_{i=(0,4,8,12,16,20)} a_i H_i \left( \frac{2\sqrt{\pi} t}{T_0} \right) \]

where \( T_0 \) is the fundamental time period, \( a \) & \( H \) are the system parametric values. Using the above equations, the coefficients could be determined using numerical means. The designed high profile prototype filter ensures symmetry/orthogonality of the basic pulses for a period separating of \( T = T_0 \) and a frequency spacing having a value of \( F = \frac{2\pi}{T_0} \).

**IV. PILOT SYMBOL AIDED CHANNEL ESTIMATION**

Here, in this concept, the pilot-image helped channel estimation, uncommon ‘data’ parametric variables, the pilot symbols are known from the earlier at the recipient (apriori in nature). In OFDM, the channel estimation at that point turns into a trivial task - the received parameters at the pilot positions are separated by the comparing data symbols which conveys promptly a gauge of the channel coefficients at the pilot positions and the way that \( D \) is an matrix having identity value (Identity Matrix). The channel estimates at the data positions are then gotten through interpolation process or the extrapolation process. Lamentably, in FBMC process, such straightforward methodology doesn’t work because of imaginary interference, that is, the framework \( D \) which comprises of non-diagonal elements and are imaginary in nature. FBMC depends on taking the realistic part so as to kill the ICI or ISI with the imaginary interference. Be that as it may, this lone works after phase shift equalization which is developed because of the communication channel.

Since we don’t have the phase shift information, this stage moves the preceding channel estimation and we need to utilize the complex domain instead of the real domain. The imaginary interference weights encompassing one pilot (information/data) symbol could be simulated using simulation tools such as the Matlab. Because the interference is absolutely having a pure imaginary value, taking the real part would totally cancel all the ICI & ISI components. In any case, in the complex domain, we acquire a SIR of value of 0 dB which is plainly excessively very low for a precise channel estimation. So, as to utilize pilot-image helped channel estimation process in the FBMC process, we in this manner need to moderate the imaginary interference and has to get it nullified or neutralized.

**V. FBMC AUXILIARY CODING CONCEPTS**

Considering the Auxiliary Pilot Symbols, sacrificing one extra data symbol, the so called aux pilot symbol, permits to destroy or nullify or cancel out the imaginary interference at one pilot position. The framework portrayal created previously could be utilized, so as to communicate this crossing out conditions in an increasingly broad manner that catches likewise the interdependency of firmly divided pilot data symbols and a arbitrary number of auxiliary pilot symbols. The imaginary interference at this pilot positions can be totally wiped out if the aux. pilot symbols are picked so that:

\[ x_p = [D_{p,p} \ D_{p,D} \ D_{p,A}] \begin{bmatrix} x_p \\ x_D \\ x_A \end{bmatrix} x^P \in R|P| \times 1 \]

which is obtained from the wireless communication’s transmission model of the system.
VI. MODELLING OF THE CHANNEL ICI PROCESSES

In this section, the modelling of the channel ICI processes is presented in greater depth & these models also are going to be used in our developed code for simulating the performance of the channel ICI interference schemes in our proposed works. The potential ICI turns from the contiguous sub-channel \((K - 1)\) & \((K + 1)\) for the sub-channel \(K\) of the region of interest, finally, we can write

\[
\begin{align*}
 f_{k-1}[n] \cdot h_k[n] &= \sum_{l=0}^{b} h^e_{k}[t] f_{k-1}^e[n-l] + \sum_{l=0}^{b} h^o_{k}[t] f_{k-1}^o[n-l] \\
 &+ j \left( \sum_{l=0}^{b} h^e_{k}[t] f_{k-1}^e[n-l] - \sum_{l=0}^{b} h^o_{k}[t] f_{k-1}^o[n-l] \right) \\
 &= v_k[n] + j v_k^o[n] \\
 &= v_k[n] \\
 f_{k+1}[n] \cdot h_k[n] &= \sum_{l=0}^{b} h^e_{k}[t] f_{k+1}^e[n-l] + \sum_{l=0}^{b} h^o_{k}[t] f_{k+1}^o[n-l] \\
 &+ j \left( \sum_{l=0}^{b} h^e_{k}[t] f_{k+1}^e[n-l] - \sum_{l=0}^{b} h^o_{k}[t] f_{k+1}^o[n-l] \right) \\
 &= u_k[n] + j u_k^o[n] \\
 &= \text{Real Part+Imaginary part} \\
 &= u_k[n]
\end{align*}
\]

…. (Eqn-I)

…. (Eqn-II)

VII. SIMULATION RESULTS

Codes are developed in the Matlab environment for the proposed two types of systems, viz., FBMC coding & FBMC auxiliary using various sub-routines, function calls, commands, tool-boxes such as the signal processing tool box, optimization tool box, communication tool box, etc. A sample of the Matlab coding shown in the command window is displayed in the Fig. 4. The developed code is run for a specific amount of time, say 30 secs & the results are observed. All the mathematical models described so far in the previous sections are made use of in the code development of the Matlab program. The different simulation parameters such as - Number of Monte Carlo repetition (different channel realizations), the QAM Modulation Order = 16 (may be 4, 16, 256, 1024, ...), FBMC Object creation parameters, Number subcarriers, Number FBMC symbols, Subcarrier spacing (Hz), Sampling rate (Samples/s), Intermediate frequency first subcarrier (Hz), Transmitted real valued signal, Prototype filter (Hermite, PHYDYAS, RRC) and OQAM or QAM, Overlapping factor (corresponding to the prototype filter length), Initial phase shift, Polyphase implementation, ….. are specified at the start of the simulation parameters in the Matlab developed code.

VIII. DISCUSSIONS & JUSTIFICATIONS ON THE WORK DONE

Here, we need to study, the best ICI cancellation schemes in the FBMC systems. So, we consider, 2 very best ICI cancellations techniques / schemes, viz.,

1. FBMC auxiliary &
2. FBMC coding

Considering these 2 FBMC auxiliary & FBMC codings, we should show that FBMC auxilliary ICI performance is the best by analyzing various parameters like

- Signal to noise ratio (SNR) v/s the bit error rate (BER) for both aux & main coding
- Time index (TI) for both aux & main coding
- Frequency index (FI) for both aux & main coding
- Transmitted power (TP) v/s the time for both aux & main coding
- Power spectral density (PSD) v/s the frequency for both aux & main coding

:

Volume XII, Issue VIII, August/ 2020
& so on and so forth. To prove ICI cancellation, the FMBC auxiliary is supposed to be the best as compared to ICI cancellation & to achieve this, the following process is proposed. Our new objective proposed – we analyzed the above 4 parameters (SNR TI FI TP PSD) & many others and took the best performing parameters and placed all these parameters in one Matlab code to prove our aim. Matlab codes were written comparing with different parameters which is some of the new concepts proposed by us. From the simulated results, the following conclusions are arrived upon with.

Fig. 4: The developed algorithm of the objective in the Matlab environment shown in the command prompt

Fig. 5: Plot of the SNR (dB) v/s BER for FBMC Auxiliary and FBMC Coding

Fig. 6: Plot of Time Index v/s Frequency Index for FBMC Coding

Fig. 7: Plot of Time Index v/s Frequency Index for FBMC Auxilliary
The Fig. 5 gives a comparative plot of the Frequency v/s Power Spectral Density for ICI Cancellation w.r.t. both FBMC Auxiliary and FBMC Coding processes. The power spectral density according to the frequency is one major factor and the FBMC auxiliary process prove the best results. In the simulation results presented here, we have shown only for NR = 1000 number of repetitions for the sake of convenience.

TABLE I: Quantitative results of the comparison of the FBMC auxiliary & coding methodologies for a 1024 bit QAM modulation order & 1000 no. of Monte Carlo repetitions

<table>
<thead>
<tr>
<th>No.</th>
<th>SNR (dB)</th>
<th>Bit Error Rate (BER) FBMC Auxiliary QAM 1024 bit, NR =1000</th>
<th>Bit Error Rate (BER) FBMC Coding QAM 1024 bit, NR =1000</th>
<th>Computational time (secs) to observe results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.06</td>
<td>0.05</td>
<td>44 s</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>0.07</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>0.08</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>0.11</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>0.15</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>0.18</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>0.25</td>
<td>0.27</td>
<td></td>
</tr>
</tbody>
</table>

TABLE III: Quantitative results of the comparison of the FBMC auxiliary & coding methodologies for a 1024 bit QAM modulation order & 2000 no. of Monte Carlo repetitions showing the increase in computational time, but with high accuracy of channel noise interference reductions

<table>
<thead>
<tr>
<th>No.</th>
<th>SNR (dB)</th>
<th>Bit Error Rate (BER) FBMC Auxiliary QAM 1024 bit, NR =2000</th>
<th>Bit Error Rate (BER) FBMC Coding QAM 1024 bit, NR = 2000</th>
<th>Computational time (secs) to observe results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.0061</td>
<td>0.0053</td>
<td>2 min, 32 s</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>0.0073</td>
<td>0.0062</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>0.0082</td>
<td>0.0075</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>0.0114</td>
<td>0.1123</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>0.0155</td>
<td>0.0174</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>0.0186</td>
<td>0.0202</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>0.0258</td>
<td>0.0278</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 8: Plot of the Time Index v/s Frequency Index for FBMC Coding & FBMC auxiliary codings

Fig. 9: Plot of Frequency v/s Power Spectral Density for ICI Cancellation in FBMC Auxiliary and FBMC Coding
IX. CONCLUSIONS

Research was carried out on the study of the performance analysis of various ICI cancellation schemes in FBMC systems in this paper, which was our 1st objective. Two methodologies were proposed in this paper, viz., FBMC coding & the FBMC auxiliary. Comparisons were done & it was proved beyond doubt that FBMC auxiliary method is better compared to the FBMC coding. Mathematical models of the cancellation schemes were also taken care off. Software tool 'Matlab' was used to solve the identified problem by developing sophisticated fast computing algorithms & running the same to observe the simulation results and arrive at the expected output results (goals). The simulation results showed the efficacy of the developed ICI noise interference cancellation algorithm which was used to get a very good noise free output at the receiving end of the wireless communication system. To conclude, it is proved that with the use of a high profile designed filter, the auxiliary method utilizing the pilot data based gives less interference cancellations (reduced) much and is found to be much better compared to the coding approach in terms of the bit error rate, power spectral density, frequency index & the power transmitted.

X. ACKNOWLEDGEMENTS

This work was supported by Dept. of E&CE, BVBCET, Hubli and VTU, Belagavi.

REFERENCES


[7]. https://patents.google.com/patent/US8630230


