BER Analysis of Multiuser LS MIMO FBMC

Shefin Shoukath, P.A.Haris

Abstract— The Large Scale MIMO system is the leading technology to realize 5G network demanding higher bandwidth, greater capacity, security and lower latency. But the implementation of LS MIMO system is a real challenge. Multicarrier modulation techniques have been deployed to meet the demands of wired and wireless communication, as it can utilize the resources efficiently. In recent networks, Orthogonal Frequnecy Division Multiplexing (OFDM) has been the most implemented multicarrier scheme. New multicarrier schemes are needed to meet the requirements of these technologies as OFDM is not efficient due to high spectral leakage and bandwidth inefficiency. Filter Bank Multicarrier (FBMC) is a multicarrier modulation technique that can address the shortcomings of OFDM, as it offers better bandwidth efficiency and spectral localization in time and frequency with low out of band leakage. Thus LS MIMO FBMC outperforms due to the absence of cyclic prefix, carrier assemblage and ability of self equalization. In this paper OQAM based FBMC with different prototype filters is analysed, in which LS MIMO FBMC with Root Raised Cosine Filter is proposed as it exhibits reduced bit error rate characteristic as close to theoretical value.

Index Terms— BER, FBMC, LS MIMO, OFDM, OQAM, PHYDAS, RRC

1 Introduction

LARGE Scale MIMO FBMC gained the importance as a candidate by improving the spectrum utilization by increasing the multiuser network capacity. In addition to that, due to its ability to separate the multiusers , low sidelobes of its filters and avoiding the requirement of synchronization enhanced its performance. In Large scale MIMO technique, the gain of each multiuser are the channel gains in between the antenna terminal of each users and the antenna terminals of base station. Thus the gain can be enhanced to infinity by implementing with increased number of antennas. The processing gain increases with the number of antennas as discussed by Marzetta while leading to a reduction in noise and multiuser interference effect. Thus an increased channel capacity will be attained in wireless network channel [1],[2].

Frequency spectrum is the scarce resource in wireless systems, which has to be efficiently used. Inorder to improve the efficient utilization of the frequency spectrum, several methods have been developed. The multicarrier modulation technique is one of the most promising method to improve the utilization of spectrum. The multicarrier modulation transforms the serial high data rate bit stream into parallel bit stream over narrow band carrier signals. Thus bandwidth is optimizated and fading effects are reduced and which also lead to achieve immunity towards intersymbol interference [2].

Orthogonal frequency division multiplexing (OFDM) has gained importance among the multicarrier technologies and hence deployed in multipath channels. OFDM offers higher data rates especially in downlink communication. However the OFDM technique have challenges like high out of band leakage as it is implemented with rectangular window, spectral leakage due to intersymbol interference and inter carrier interference, reduction in bandwidth efficiency due to cyclic prefix and difficulty in synchronization requirement [2].

Therefore the OFDM is not an appropriate choice for the emerging technologies. Filter bank multicarrier (FBMC) is an alternative technique that is capable in overcoming the limitations and offering an improved carrier spectral shaping and providing an improved bandwidth efficiency by eliminating cyclic prefix [3].

Filter bank multicarrier (FBMC) scheme gained attention as it attains improved spectral efficiency due to the filter banks included in the transmitter and receiver. The transmultiplexer of FBMC scheme transmits OQAM symbols which provides high capacity and orthogonality, avoiding the interference between neighbouring subchannels. This in turn maintains a system with high bit rate of transmission [4], [5].

FBMC combined with LS MIMO system gains channel flattening by its self-equalisation property [6]. The channel distortions such as intersymbol and intercarrier interferences is comparatively reduced with the increase of antennas in the base station. The pilot contamination can also be resolved with FBMC in LS MIMO networks. So the multiusers effectively utilize the same spectrum in a more efficient manner [6],[7].

2 FBMC Principles

The Filter Bank Multicarrier (FBMC) is a multicarrier modulation enabling higher throughput data rates. The spectrum is divided into multiple orthogonal sub bands and filter applied to each sub bands individually. The side lobes and inter carrier interference (ICI) is less dominating in

- *Shefin Shoukath is currently pursuing PhD program in Electronics & Comunication Engineering in CET, University of Kerala, India. E-mail: shefinshoukath@macev.org*
- *Prof. P.A Haris is currently working as Professor in Govt. Engineering College, Barton Hill, Kerala, India.*

FBMC, compared to the OFDM multicarrier.The input serial bit data streams are preprocessed and transmitted through several parallel data bit stream channels after transmitting it through the pre proessing block.These sub data streams are then shaped for data transmission using the synthesis filter banks. These prototype filters are localized both in time and frequency which leads to the removal of cyclix prefix and thus ensuring the elimination of both intersymbol interference and intercarrier interference [8],[9].

Similarly the received data streams at the receiver side are converted into parallel data streams. After its post processing by filter banks the data streams are converted back into orginal serial data streams. FBMC method includes a synthesis and analysis filters at the transmitter and receiver end [10].

By using FBMC techniques, it is possible to increase the spectral efficiency and limit the spectrum, inorder to increase the spectral efficiency. Hence all the available resources related to frequency and time must be enhanced for the available bandwidth to the maximum extent. This can be achieved by either increasing the rate of symbol transmission or reducing the guard band intervals. But this is inturn leading to loss of orthogonality between the successive symbols transmissions. So must ensure to minimize the self interference due to the loss of orthogonality for particular spectrum and maintain the symbol rate equal to Nyquist rate [11],[12].

3 PROTOTYPE FILTERS

Prototype filters are used to enable pulse shaping to meet the desired spectral requirements. The prototype filter for OFDM multicarrier modulation is designed using windowing method [13],[14]. And the most widely rectangular window is used. Prototype filters in Filter bank multicarriers satisfy the Nyquist criteria.

$$h(nT) = \begin{cases} 1 \; ; \; for \; n=0 \\ 0 \; ; \; else \end{cases} \quad (1)$$

Where T is the symbol duration.

According to the Nyquist criterion, it is equivalent to:

$$1/T \sum_{-\infty}^{+\infty} H(f- k/T) =1; \quad (2)$$

Prototype filters mainly PHYDYAS, Raised Cosine and Root Coisine are the some of the filters which satisfies the Nyquist condition.

3.1 PHYDYAS Filter

PHYDYAS filter bank is based on the polyphase structure and analytical formulas for calculating the prototype filter coefficients. The term PHYDYAS reference filter bank refers to the design with the prototype filter length, $Lp = 4M-1$. where M is the number of subchannels [15].

The number of subchannels is typically a power of two so as to provide efficient implementation. The prototype filter lengths are chosen to be Lp= kM-1, Lp=kM and Lp=kM+1, where Lp is a positive integer called as overlapping factor. The prototype filter is designed such that only adjacent subchannel filters are significantly overlapping with each other in the frequency domain. The number of subchannels is twice the upsampling and downsampling factors indicating 2x oversampled filter banks. However, the transmultiplexer input and output signals are purely real or imaginary valued then it is a critically sampled TMUX [16].

3.2 Raised Cosine Filter

Raised Cosine filter response is wider due to the transition band than the ideal low-pass filter. The roll off factor is the parameter which controls the excess frequency bandwidth. The frequency response is plotted for several different roll off factors. The transition band becomes steeper, as the roll off factor gets closer to zero and the filter approaches an ideal low pass filter [8]. By Nyquist it is shown that the frequency characteristics has odd symmetry at the cutoff frequency ,the impulse response will have zeros at uniformly spaced intervals.This can be attained simpler by Raised cosine filters. The effects of jitter can aslo be minimized by using this filter. Impulse response of a raised cosine filter has a sinc term that ensures that it has zero crossings like an ideal low pass filter [17].

$$\frac{\sin \pi t/T}{\pi t/ T} \quad (3)$$

In addition it has another term,

$$\frac{\cos \pi\beta t/T}{1-(4\beta^2 t^2 / T^2)} \quad (4)$$

that decays in time hence reduces the tails reducing the impact of jitter.

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3.3 Root Raised Cosine Filter

Root Raised Cosine filter theoretically has infinite number of taps, so it has infinite attenuation in the stop band. However its length must be reduced to a finite value during its implemenatation. The stop band attenuation of this filter can be reduced by decreasing the number of samples or filter delay. The roll of factor of this filter is the excess bandwidth of the filter, i.e. it is the bandwidth beyond the Nyquist bandwidth of 1/2T. Smaller roll off leads to attain a narrow bandwidth. However attenuation in the stop band is reduced as its side lobes increases. RRC filters are implemented as a digital filter in the base band of transmission. Since implementing narrow filters in the RF bands is difficult. Another issue to consider in pulse shaping of RRC filters is the peak to average power ratio (PAPR). High PAPR reduces the efficiency of the power amplifier snce it has to operate with large back off [18],[19].

4 LS MIMO FBMC SYSTEM

LS MIMO technology includes a very large number of antennas at both endes of transmission inorder to separate the individual channels in a multipath environment over which multiple data streams are transmitted. This enhances the transmission efficiency of a multipath environment. Noise and small scale effects were also found to be reduced in a LS MIMO link.The energy required to transmit each bit can also substanatially reduced by LS MIMO link [20],[21].

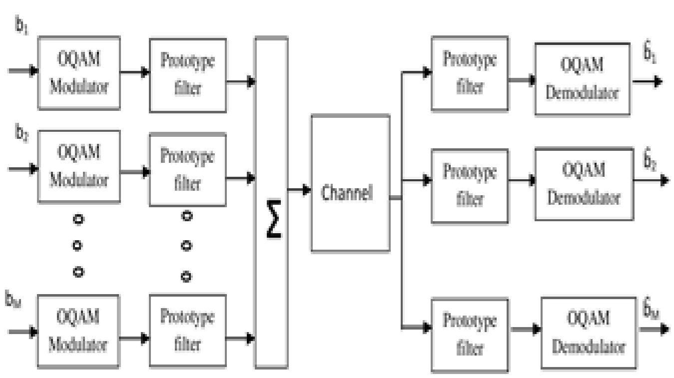


Fig 1: Block Diagram of LS MIMO FBMC

The number of antennas in a LS MIMO link is too large than the number of users, so the available degress of freedom is large which helps in eliminating interference. Thus each of the individual antennas can bring down the power required to transmit the data streams.The type of waveform to be used in LS MIMO system has relevance. Orthogonal frequency division multiplexing is one among them which is based on cyclic prefix. But the better performance is achieved only when orthogonality is maintained between them and proper synchronization is maintained.

Filter bank multicarrier is an alterantive multicarrier waveform, capable of improving the spectral efficiency.This technique avoids the use of cyclic prefix and also reduces the guard band present. It laso shows an advancement in terms of spectrum utilization.

LS MIMO along with FBMC results in a network that can be used efficiently for transmission of data. The property of self-equalisation in the channel is another special feature in a LS MIMO link. The distortion of channels in LS MIMO FBMC is averaged as the signals are linearly combined at the base station receiver [22].

The more the number of antennas at the base station the channel distortions are reduced over each sub carrier. Thus an equal flat gain can be achieved across each subcarrier. The real valued data symbol $b_{m,n}$ are transmitted over the m_{th} subcarrier and the n_{th} symbol time index. LS MIMO FBMC system is illustarted in the Figure 1. In order to maintain the orthogonality among the subcarriers and to minimize the interference between the symbols, phase adjustment must be maintained between the data symbols. These symbols are then pulse shaped using the prototype filters. The discrete time FBMC waveform is represented as:

$$S(l) = \sum_{n=-\infty}^{n=+\infty} \sum_{M=0}^{M-1} b_{m,n} a_{m,n}(l) \qquad (5)$$

.

where, $a_{m,n}(l) = p_m(l - nM/2)e^{j\theta_{m,n}}$

5 SIMULATIONS

LS MIMO FBMC is investigated in terms of Bit Error Rate by simulating the system with different prototype filters. The prototype filters used for the study are namely PHYDAS Filter, Raised Cosine Filter and Root Raised Cosine Filter.

The presence of errors in the frequency synchronization effects the orthogonality between the subcarriers, which results in the degradation of the OFDM system performance.
FBMC technique reduces intersymbol interference and intercell symbol interference by properly choosing the prototype filter [23].[24].

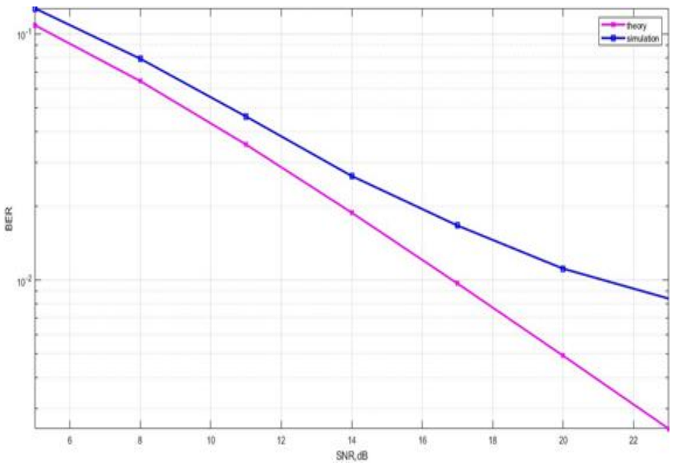


Fig2: BER of LS MIMO FBMC (Raised Cosine Filter)

Figure 2, plots the Bit error rate of LS MIMO FBMC system in which it is implemented with a Raised Cosine prototype filter. With this filter it shows that the simulation results are not approaching the theoretical values. BER values of both theoretical and simulated are initially closer but beyond a BER value of 10^{-2}, it is moving away if the prototype filter used for analysis is a Raised Cosine Filter.

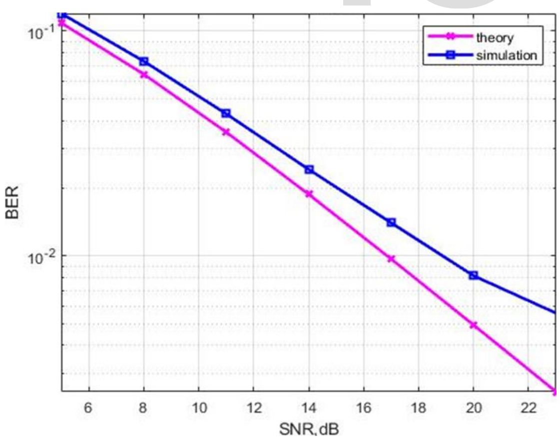


Fig3: BER of LS MIMO FBMC (PHYDYAS Filter)

Figure 3 illustrates the plot of BER of LS MIMO FBMC with a PHYDYAS Filter. It can be observed that at a BER of around 10^{-1}, an average BER value is almost closer to the theoretical value. But as the BER value is varied, it is seen that the closeness of average BER towards theoretical BER is degrading. Around a BER value of 10^{-2} , it is slowing going farther apart.

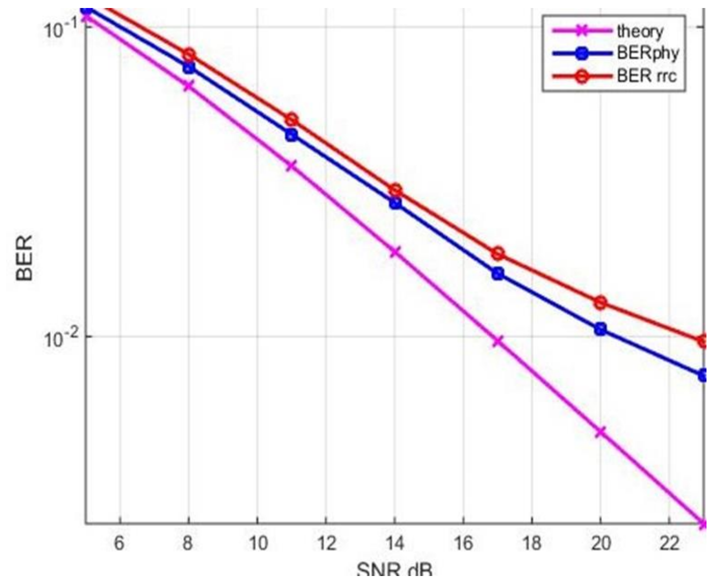


Fig4: BER of LS MIMO FBMC (PHYDAS & RRC Filter)

BER plot in which a comparative study among the prototype filters, PHYDYAS and Root Raised Cosine filters are done and it is shown in figure 4. From the figure it can be understood that PHYDYAS filter outperforms the Root Raised Cosine filter since it has better localization and equalization. But the BER value slowly deviates around 10^{-2} BER .In the same figure it can also observe the BER performance of a PHYDYAS filter. Thus it can understand that BER performance is better for LS MIMO FBMC with PHYDYAS filter.

The BER was plotted to determine the performance among the prototype filters, PHYDYAS and Raised Cosine filters. The BER value of these filters are shown in Figure 5. This figure shows the average BER value of the filters are overlapping initially with the theoretical values.

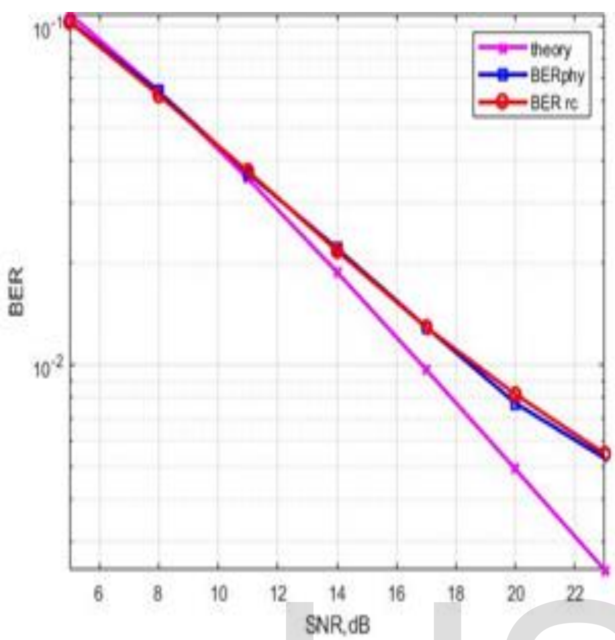


Fig5: BER of LS MIMO FBMC (PHYDYAS & RC Filter)

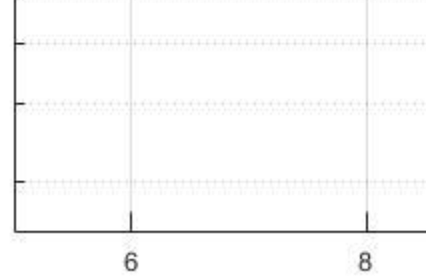
An average BER for LS MIMO FBMC is considered and results are compared with the theoretical values. From the graphs it can be noticed that the simulation results are very nearer to the theoretical results. The proposed LS MIMO FBMC system with PHYDAS filter gives an improved BER when compared with simulation results of BER for the LS MIMO FBMC with Root Raised Cosine filter and Raised Cosine filter.

5 Conclusion

In this paper, Bit error rate (BER) analysis has been analysed for LS MIMO FBMC system using the concepts of FBMC with OQAM and prototype filters. BER simulated for LS MIMO FBMC system with prototype filters namely, PHYDAS, Raised Cosine filter and Root Raised Cosine filter shows an improvement in BER with repect to the SNR..The average BER for these filters and theoretical values were compared and shows that, at BER of 10^{-1} the simulated BER are very nearer to theoretical values. But around a BER of 10^{-2},, from the figure it depicts that simulated BER moves away from the theoretical values. The simulated results depict that the proposed Large Scale MIMO FBMC with PHYDAS filter is appropriate for the 5G technology when compared to the LS MIMO OFDM. Spectrum efficiency can also increased by implementing this system, at the same instant the challenges of complexity due to the prototype filters and high PAPR need to be addressed.

References

[1] T. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," IEEE Transactions on Wireless Communications, vol. 9, no. 11, pp. 3590–3600, 2010.
[2] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," IEEE Transactions on Communications, vol. 61, no. 4, pp. 1436–1449, 2013.
[3] M. Iwamura, K. Etemad, M.-H. Fong, R. Nory, and R. Love, "Carrier aggregation framework in 3GPP LTE-advanced [WiMAX/LTE update]," IEEE Communications Magazine, vol. 48, no. 8, pp. 60–67, 2010.
[4] P. Banelli, S. Buzzi, G. Colavolpe, A. Modenini, F. Rusek, and A. Ugolini, "Modulation formats and waveforms for 5G networks: Who will be the heir of OFDM?: An overview of alternative modulation schemes for improved spectral efficiency," IEEE Signal Processing Magazine, vol. 31, no. 6, pp. 80–93, 2014.
[5] F. Schaich and T. Wild, "Waveform contenders for 5G - OFDM vs. FBMC vs. UFMC," in IEEE ISCCSP 2014.
[6] A. Farhang, N. Marchetti, F. Figueiredo, and J. P. Miranda, "Massive MIMO and waveform design for 5th generation wireless communication systems," in IEEE 5GU, 2014.
[7] B. Farhang-Boroujeny, "OFDM versus filter bank multicarrier," IEEE Signal Processing Magazine, vol. 28, no. 3, pp. 92–112, 2011.
[8] L. Zhang, P. Xiao, A. Zafar, A. ul Quddus, and R. Tafazolli, "FBMC system: An insight into doubly dispersive channel impact," IEEE Transactions on Vehicular Technology, vol. PP, no. 99, pp. 1–14, 2016.
[9] B. Farhang-Boroujeny, "OFDM versus filter bank multicarrier," IEEE SIGNAL PROCESSING MAGAZINE, vol. 92, 2011.
[10] G. L. David, D. S. V.S, J. Chunkath and M. K.R, "Performance Analysis of Fast Convolution Based FBMC-OQAM System," in International Conference on Communication Systems and Networks (ComNet), Trivandrum, 2016.
[11] P. Kansal and A. Shankhwar, "FBMC vs OFDM Waveforms Contenders for 5G Wireless Communication System," Wireless Engineering and Technology, vol. 8, no. 17, pp. 59-70, 2017.
[12] S. Kaur, K. Lavish, G. S. Gaba and N. Sarafov, "Survey of Filter Bank Multicarrier (FBMC) as an efficient waveform for 5G," International Journal of Pure and Applied Mathematics, vol. 118, p. 7, 2018 L. Hubert and P. Arabie, "Comparing Partitions," *J. Classification,* vol. 2, no. 4, pp. 193-218, Apr. 1985. (Journal or magazine citation)
[13] S. A and A. H, "A Comparative Study of FBMC prototype Filters in Doubly Dispersive Channels," in The 8th Broadband Wireless Access Workshop, 2012.
[14] A. Bedoui and M. Et-tolba, "A Comparative Analysis of Filter Bank Multicarrier (FBMC) as 5G Multiplexing Technique," 2017.
[15] A. J. Ramadhan, "Implementation of 5G FBMC PHYDYAS Prototype Filter," International Journal of Applied Engineering Research, vol. 12, no. 23, pp. 13476-13481, 2017.
[16] M. Bellanger, D. Le Ruyet, D. Roviras, M. Terr´e, J. Nossek, L. Baltar, Q. Bai, D. Waldhauser, M. Renfors, T. Ihalainen et al., "FBMC physical layer: a primer," PHYDYAS, January, 201
[17] M.G. Bellanger, "Specification and design of a prototype filter for filter bank based multicarrier transmission," in Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing, 2001, vol. 4, pp. 2417 – 2420.
[18] Joseph Kweku Arthur, Thierry Blaise Taih Coffi Aka, Amevi Acakpovi, "Comparative Analysis of Orthogonal Frequency Division Modulation and Filter Bank-based Multicarrier Modulation", IEEE International Conference on Communications, Signal Processing And Networks (ICCSPN) 2019.
[19] Adnan Zafar, Lei Zhang, Pei Xiao, Muhammed Ali Imran, "Spectrum Efficient MIMO FBMC SYSTEM USING FILTER Output Truncation", IEEE Transactions on Vehicular Technology 2018.



[20] A. Farhang, N. Marchetti, L. E. Doyle, and B. Farhang-Boroujeny, “Filter bank multicarrier for massive MIMO,” in 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall), 2014, pp. 1–7.
[21] A. Aminjavaheri, A. Farhang, N. Marchetti, L. E. Doyle, and B. Farhang Boroujeny, “Frequency spreading equalization in multicarrier massive MIMO,” in IEEE ICC, 2015.
[22] B. Farhang-Boroujeny, “Filter bank multicarrier modulation: A waveform candidate for 5G and beyond,” Advances in Electrical Engineering, 2014.
[23] Wang Yongxue, Song Rong, Wang Sunan, Wu Weiqiang, “Study of the Prototype Filter and Bit Error Rate for the Filter Bank Multi-carrier System”, 5 th IEEE International Conference on Computer and Communication system 2020.
[24] Thierry Blaise Taih Coffi Aka, Amevi Acakpovi, Kester Quist- Aphetsi, “Performance Evaluation of FBMC Compared to OFDM by Simulation with MATLAB”, IEEE International Conference on Computing, Computational Modelling and Applications 2019.