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Equalization methods for Filter Bank Multicarrier OQAM

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Abstract

Filter bank multi-carrier offset-quadrature amplitude modulation (FBMC OQAM) is an important topic in 5G multi-carrier researches. In order to achieve high data rates and reliable wireless communication, receiver channel equalization is required. This is because of the equalizer's excellent spectral efficiency, exceptionally low side-lobe leakage, zero periodic cyclic prefixes (CP), and multiphase filter design. However, a number of degradations, including fading, Doppler shift, and inter-symbol interference (ISI), are added to the transmitted data symbols as they traverse the wireless channel, reducing the network's overall quality. To mitigate the negative effects of channel defects, many channel equalization algorithms have been developed for use in modern telecommunications networks. Six different equalizer approaches have been implemented. Using the Pedestrian A and Vehicular B channels in our simulations, to evaluate the system performance. The system was simulated using MATLAB's Communications Toolbox (an M file). The outcomes were evaluated by means of bit-error-rate (BER) and signal-to-noise ratio (SNR). The Bit error rate was calculated by checking the differences between the sent and received bit sequences. The best value of the bit error ratio using frequency domain equalization and time domain equalization, are $5.4* 10^{-5}$and $4.7* 10^{-5}$, respectively.

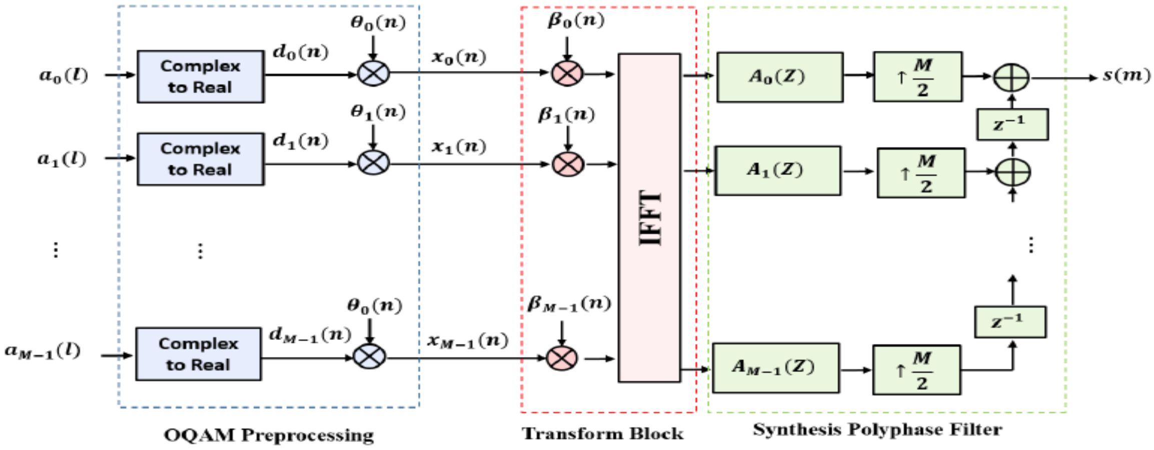
Keywords: FBMC OQAM, Bit Error Rate (BER), Equalizer, Signal to Noise Ratio (SNR)

الخلاصة: يعد تعديل اتساع الإزاحة التربيعية للبنك متعدد الموجات (FBMC OQAM) موضوعًا مهماً في الأبحاث متعددة الموجات الحاملة لشبكات الجيل الخامس. من أجل تحقيق معدلات بيانات عالية واتصالات لاسلكية موثوقة ، يلزم معادلة قناة جهاز الاستقبال. ويرجع ذلك إلى الكفاءة الطيفية الممتازة للمعادل ، وتسرب الفص الجانبي المنخفض بشكل استثنائي ، والبادئات الدورية الصفرية (CP)، وتصميم المرشح متعدد الأطوار. ومع ذلك ، يتم إضافة عدد من التدهورات ، بما في ذلك التوهين ، وتحولات دوبلر ، وتداخل بين الرموز (ISI)، إلى رموز البيانات المرسلة أثناء عبورها القناة اللاسلكية ، مما يقلل من الجودة الكلية للشبكة. للتخفيف من الآثار السلبية لعيوب القناة ، تم تطوير العديد من خوارزميات معادلة القنوات لاستخدامها في شبكات الاتصالات السلكية واللاسلكية الحديثة. تم تنفيذ ستة مناهج مختلفة تعتمد على المعادلة. باستخدام قناة Pedestrian A و Vehicular B في عمليات المحاكاة لدينا ، نفحص مدى جودة عملهم. تمت محاكاة النظام باستخدام MATLAB's Communications Toolbox ملف .M تم استخدام معدل خطأ البت BERونسبة الإشارة إلى الضوضاء SNRلتقييم النتائج. تم حساب معدل خطأ البت عن طريق التحقق من الاختلافات بين تسلسل البتات المرسلة والمستلمة. أفضل قيمة لنسبة خطأ البتات عند معادلة مجال التردد ومعادلة المجال الزمني هي $5.4* 10^{-5}$. و $4.7* 10^{-5}$ على التوالي.

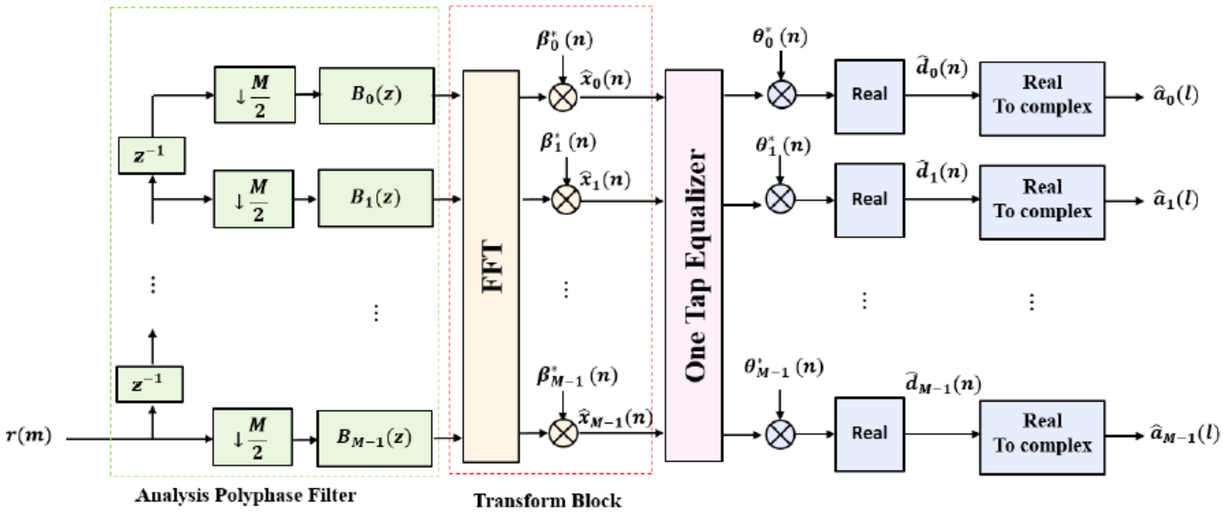
1. INTRODUCTION

One of the potential waveform systems for 4G telecommunications is OFDM stands for "orthogonal frequency division multiplexing." The advantages of OFDM in the frequency domain include straightforward equalization and robustness against difficult channel situations such as frequency selective fading [1]. The orthogonality of the OFDM subcarriers is sustained by the use of cyclic prefixes (CP), which are duplicates of the tailed signals used in OFDM. By separating individual OFDM signals, CP enables block transmission of OFDM; nevertheless, broadcasting the CP always decreases power efficiency and data throughput. An effective system with high-quality signals is also necessary [2]. For 5G wireless communication networks, FBMC has recently emerged as a competitive alternative to (OFDM) [3]. The FBMC approach is helpful in that it allows for more efficient spectrum allocation. Offset quadrature amplitude modulation (OQAM) is a popular kind of modulation used in

FBMC networks [4]. OQAM modulation is used in the FBMC system to lessen the impact of ISI. It is well-known that both noise and intentional interference may affect the FBMC-OQAM system. This might cause transmission quality to decline, resulting in an inferior received signal. To address this problem, an equalizer has to be included in the FBMC infrastructure. Several empirical investigations [5] recommended various approaches. Refer to for more information on relevant prior research. In this research, we will analyse the Equalizer's effect on the FBMC system's Bit Error Rate (BER) and Signal to Noise Ratio (SNR). Using six types of equalizations: single tap, multi-tap, minimum mean squared error (MMSE), Parallel Multi-Stage Equalizer, Frequency Spreading Equalization, and Time-Domain Equalization. Figure 1 shows the wireless communication system of the FBMC. The rest of the paper is arranged such that Section II gives literature survey. the system model is addressed in Section III. Section IV discusses equalizer types. In Section V, the simulation results. In the last part, section VI, the conclusion is given.



a. FBMC transmitter system



b. FBMC receiver system

Figure 1 FBMC communication system [6]

2. LITERATURE SURVEY

In [7] proposed Decision feedback equalizer (DFE) enhancements for an offset quadrature amplitude modulation (OQAM) FBMC system were proposed using the minimum mean squared error (MMSE) criteria. Detected offset quadrature amplitude modulation (OQAM) precursors from neighbouring sub-channels are used to reduce interference between symbols (ISI) and between carriers (ICI) when using channels with multiple paths. This is accomplished with a total of three interference suppressing filters, one for each subcarrier. In a very polluted ICI and ISI setting, their method can greatly beat MMSE-DFE with just modest increases in computing cost. The goal of [8] When the channel's selectivity increases in the time-frequency plane, ICI and ISI introduce distortion to demodulated symbols. It was suggested that a novel parallel equalization structure may restore the performance of a distortion-free system when several AFBs were used at the receiver. In [5] suggested Multicarrier filter banks that can benefit from an equalization structure with multiple equalization taps. They conduct an evaluation of the system's functionality when subjected to selected medium- to high-frequency channels. That's what they're putting forth. It uses a Using a frequency-domain multitap equalizer to make the system more resilient to high-frequency selectivity conditions while reducing computational complexity. In [9] suggested a lattice reduction (LR) strategy for improving the functionality of filter-bank multi-carrier (FBMC) modulated spatially multiplexed (SM) MIMO systems proving that, compared to the state-of-the-art, a Lattice-Reduction-Aided (LRA) equalizer provides a significant performance boost for FBMC-MIMO systems while maintaining a manageable level of complexity. In [2] suggested BER for FBMC-OQAM is better than that of FBMC QAM; interference is still present in this system. Because of this, the transmission process may degrade, leading to a lower-quality received signal. Therefore, this issue requires attention. An equalizer was recently added to the FBMC system's "Bit Error Rate (BER) and Signal to Noise Ratio (SNR)" measurements revealing information about the signal quality system. In some cases, the BER value decreases at a signal-to-noise ratio of 7 dB or less.

3. SYSTEM MODEL

The Filter-Bank Multicarrier (FBMC) modulation method was the first of its kind. Chang created FBMC in 1960. One of the problems of (OFDM) is that it employs a cyclic prefix, hence FBMC was developed to address this issue. As seen in Inverse Fast Fourier Transform / Fast Fourier Transform (IFFT/FFT), digital filters and IFFT/FFT work together to form the foundation of the Filter-Bank system, which acts as both a modulator and demodulator for multiple carriers. Utilizing the spectrum more efficiently is made possible via the use of multicarrier modulation methods.

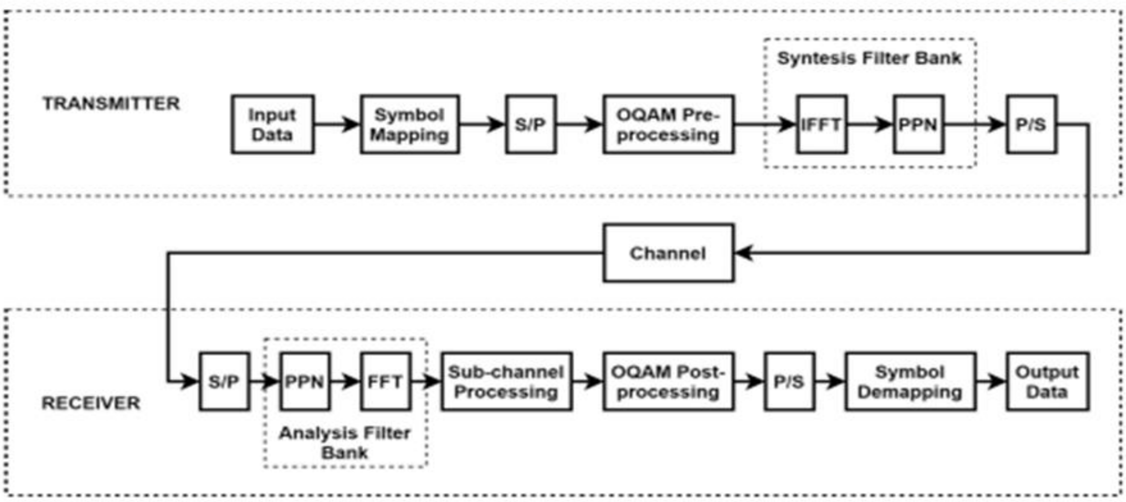


Figure 2 PPN-FFT FBMC Transceiver[2]

3.1 FBMC Transmitter

The signal from the random data generator is modified by the transmitter, which serves as a modulator. Figure 2 depicts the many components that make up the polyphase network- Fast Fourier Transform -FBMC (PPN-FFT FBMC) transmitter system: “symbol mapping, serial-to-parallel conversion, OQAM pre-processing, a synthesis filter bank (including an Inverse Fast Fourier Transform IFFT and a PPN)”. The information signal sent by a transmitter begins as input data that is processed by the transmitter. A random number generator produces the data, which takes the form of a binary code with the values 0 and 1. The M-ary value determines how the signal is altered in the symbol mapping phase when bits are transformed into symbols. The FBMC infrastructure also does a serial-to-parallel conversion of data. The process of modulation results in a parallel stream of data. Parallelization makes it possible to send many data streams at once. Figure 3 shows the OQAM procedure used by the PPN-FFT FBMC transmitter. To implement QAM offset modulation (OQAM), the real and imaginary data of the QAM symbol are sent with a shift of T/2 samples or half the subcarrier interval. Additionally, between neighboring sub-carriers and sub-symbols, a phase rotation of pi/2 (90^0) is performed[2]. In this process, a complex to real conversion is carried out, where the real and imaginary parts of the complex valued symbol are separated to form a new symbol The order of the symbols is based on the sub-channel number, that is the different conversions between even and odd sub-channels. At k with an odd value, the real part is given a delay of 1 symbol, while at k is even, the imaginary part is given a delay of 1 symbol [10]. This process increases the sample rate by 2 times compared to before. Next, multiply by $\boldsymbol{\theta_{k,n}}$ as in equation 1

$$\boldsymbol{\theta_{k,n} = \exp\,(j\pi/2(k+n)) = j^{(k+n)}} \qquad (1)$$

Additionally, the preamble signal is inserted before the symbol array in this method. The receiver uses the preamble signal as a reference to set the parameters or phase for timing recovery.

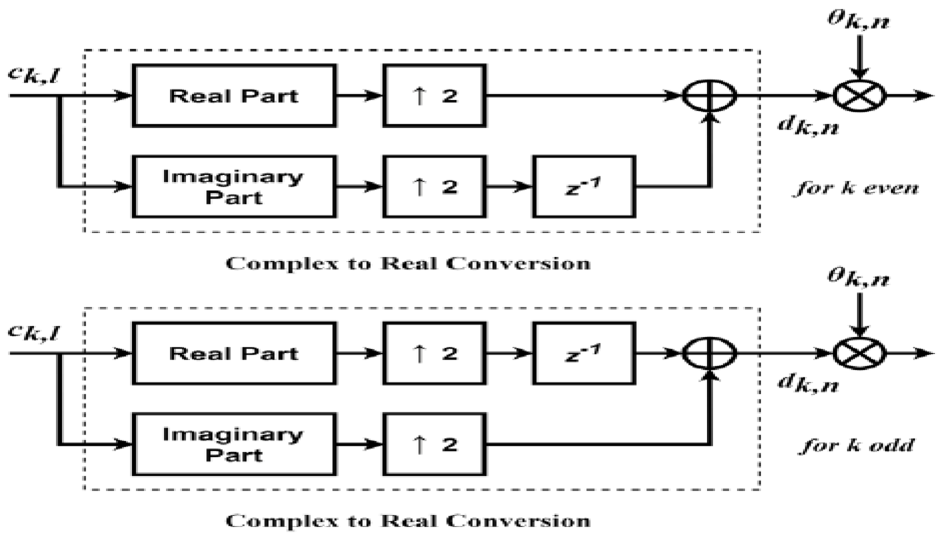


Figure 3 Block Diagram of OQAM Preprocessing[2]

The IFFT components make up the Synthesis Filter-Bank (SFB). Previously, given a filter length of KM-1, the data would be multiplied by the multiplier β on SFB, with a value of as in equation 2

$$\boldsymbol{\beta_{k,n}} = (-\mathbf{1})^{\boldsymbol{kn}}(-\mathbf{1})^{\boldsymbol{kk}} \qquad (2)$$

From the frequency domain, the signal will be converted to the time domain through the (IFFT) procedure. This method employs the filter on the signal in the time domain. Synthesis Filter Bank's up-sampler and delay processing provide the framework for the parallel-to-series data conversion process. Next, the channel is used to send out the modulated signal [2].

3.2 FBMC Receiver

To demodulate signals, the receiver is used. In order to utilize a modulated signal for communication, the receiver must first demodulate it from the channel it came through. As can be seen in Figure 2, the receiver system building block PPN-FFT FBMC is made up of a few different components[2]. Finally, the serial data signal is transformed back into a parallel one after being received. The serial-to-parallel conversion in the PPN-FFT FBMC system is produced by delay and down-sampler operations based on a Filter Bank Analysis. The filter bank synthesis (SFB) may be thought of as the opposite process for the filter bank (AFB). In cases like these, the AFB has a PPN and an FFT. The PPN process at the receiver, like the PPN process at the transmitter, employs a polyphase filter on the incoming signal. At the transmitter, the IFFT process is reversed into the FFT process. Data may be transformed to the frequency domain from the time domain using FFT. After the FFT has been calculated, the information was multipled by β on AFB .The sub-channel procedure includes the elimination of the preamble that was added during transmission. The result of this procedure is a data signal containing just the desired bits of information, with no extraneous noise. Equalization may be performed here as well if needed. Figure 4 shows that, the real-to-complex-number conversion that constitutes OQAM Post-Processing is performed. The procedure is executed on the basis of the odd and even values of k. The OQAM procedure begins with a multiplication by $\boldsymbol{\theta}^*_{\boldsymbol{k,n}}$ and then moves on to the division itself with a value of as in equation 3 [2].

$$\boldsymbol{\theta}^*_{\boldsymbol{k,n}} = \mathbf{exp}\,(-\boldsymbol{j\pi}/\mathbf{2}(\boldsymbol{k}+\boldsymbol{n})) = (-\boldsymbol{j})^{(\boldsymbol{k}+\boldsymbol{n})} \qquad (3)$$

Next, imaginary numbers are generated by converting real numbers to complex ones. The sampling rate drops by a factor of two when real values are transformed into complex ones. Following the OQAM procedure, the data is serialized from the parallel format. In order for the series format to be used for the demodulated data. Bit sequences are generated from the recovered data by symbol demapping in M-ary. The mapping procedure at the transmitter creates a carrier signal that is then separated. In order to generate a string of bits that accurately represents the sent signal of data. Information data signal that has been demodulated and should be identical to the input signal is what is produced as output. The Figure 5 Waveforms for all stages FBMC(OQAM).

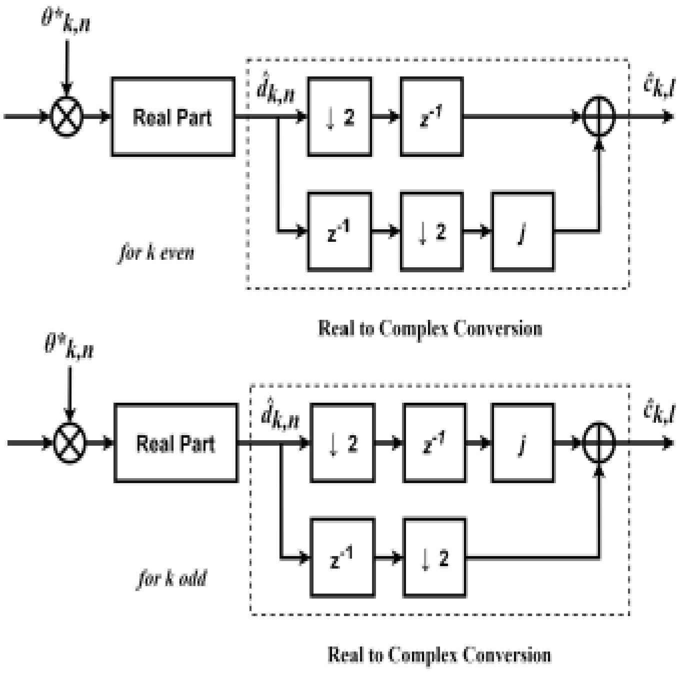


Figure 4 OQAM Post-Processing Block Diagram[2]

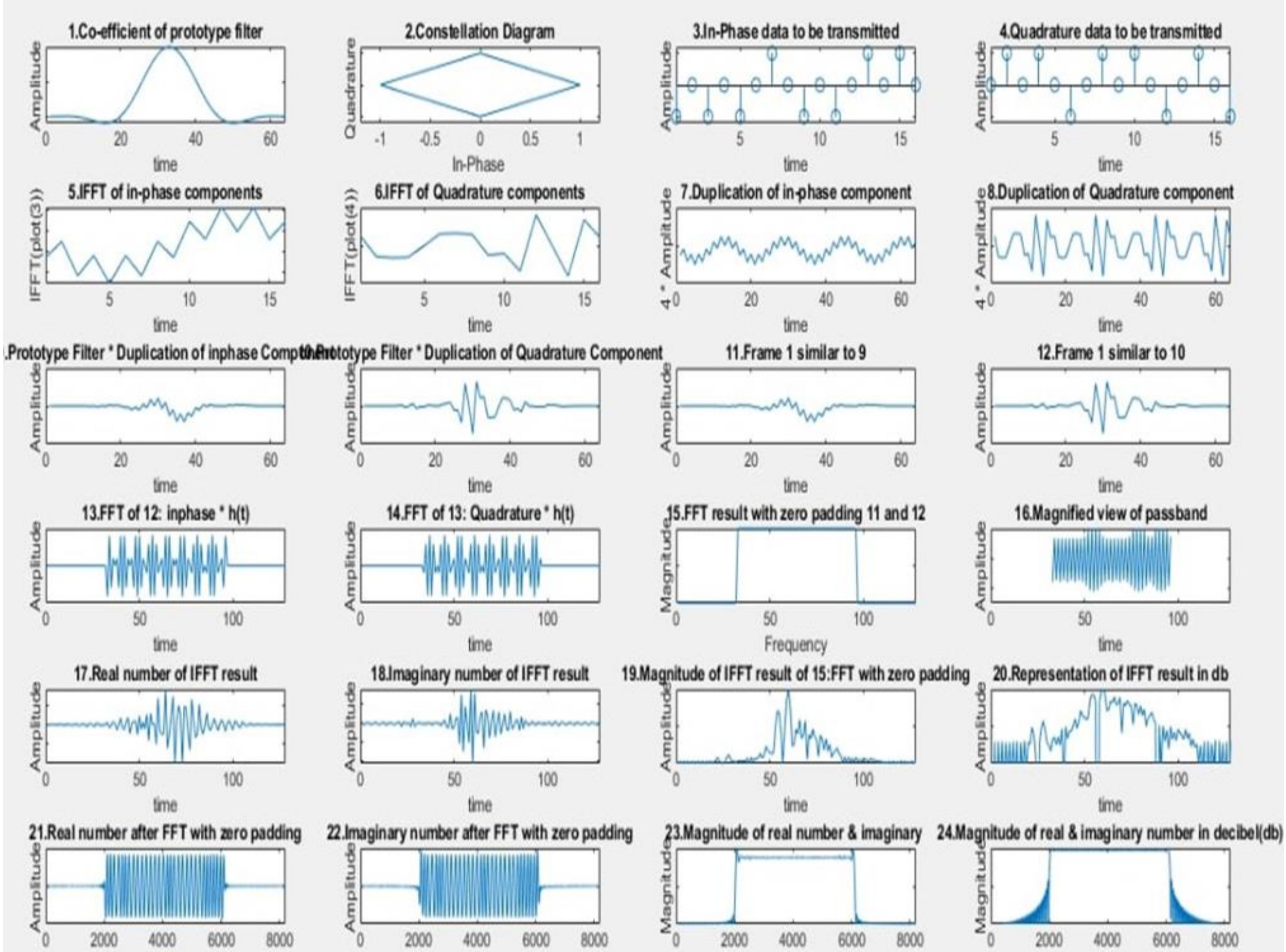


Figure 5 Waveforms for all stages FBMC(OQAM).

4. EQUALIZER TYPES

In this part, we looked at the various equalizers designed to compensate for signal dispersion.

4.1 Single-tap equalizer

Low-complexity single-tap equalization is created using pre-equalization and equalization matrices. The available bandwidth is often split up among numerous individual channels in a multi-carrier system. FBMC - OQAM employs a variable number of subcarriers based on the spread of the channel delays. Under the assumptions of a flat channel and slowly fluctuating phase noise, single tap equalization is carried out at the subcarrier level. For a certain range of frequencies, an equalizer's frequency response (FR) may be calculated using the FIR filter and ZF reconstruction the Zero Forcing Equalizer is a linear equalization method. Using the frequency response is inverted in a zero-forcing equalizer. Of the channel creates a more balanced sound. The Signal has been received and then restored after passing through a channel. In a noiseless environment, Zero Forcing reduces inter-symbol Interference (ISI) to a vanishingly small value whenever ISI is large compared to noise, this will be helpful [2]. The figure 6 shows Single Tap Equalization.

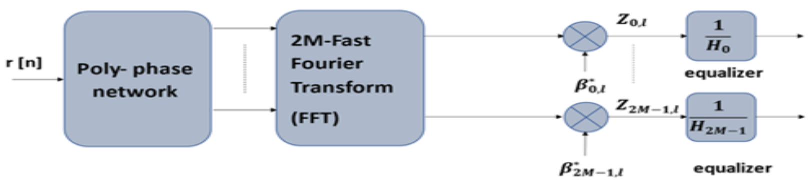


Figure 6 Single Tap Equalization [11].

For a single connection, the equalization coefficient is

$$Ý = \frac{X_{m,n}}{H_m} e^{-j\beta_{m,n}} \tag{4}$$

For the prototype filter, the phase shift is denoted as $\beta_{m,n}$, where m and n are integers

$$\beta_{m,n} = \frac{\pi}{2}(m + n) \tag{5}$$

In this case, $x_{m,n}$ is the transmitted symbol for the mth subcarrier and the nth unequalized symbol, and H_m is the frequency response of the channel.

4.2 Multi Tap Equalizer

For filter bank multi-carrier systems, which might be a waveform for 5G mobile communication networks, this research proposes a multitap equalization structure that is both simple and very effective. They do this by testing how well the system performs in the presence of high- and medium-frequency filtered signals; the goal of this multitap equalization technique is to make the system more resilient to high-frequency selectivity while reducing the computing complexity. Using the time domain coefficients, the Minimum Mean Square Error (MMSE) equalizer is a multitap approach that improves throughput using successive interference cancellation (SIC). The FBMC OQAM system is given a new method of multitap equalization based on frequency sampling [12]. Specifically, as seen in Figure 7. The channel impulse response (CIR) is used to calculate the equalization coefficient for each frequency band in the system.

$$Ý = \left(\sum_{L=1}^{N_{taps}} W_{m,L} X_{m,n}\right) e^{-j\beta_{m,n}} \tag{6}$$

For Zero Forcing (ZF) and MMSE function in frequency sampling techniques, $W_{m,L}$ is the weight of N taps equalization coefficients.

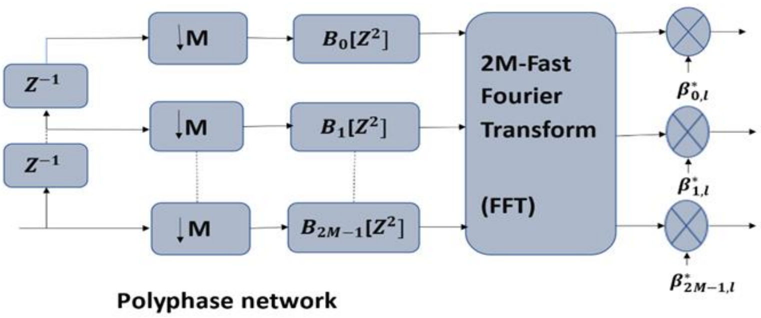


Figure 7 Multi Tap Equalization [11]

4.3 Minimum Mean Square Error (MMSE)

The equalizer coefficients may be optimized to decrease inter-symbol interference and additive noise by using the minimal mean squared error (MMSE) criteria as seen in Figure 8. However, the MMSE equalizer is not as effective when the SNR is low, unlike Zero Forcing. Since MMSE equalizers include both the noise and the signal, they are able to prevent noise amplification even at low signal-to-noise ratio (SNR) [13].

For MMSE-based equalization, W is defined as

$$W_m = D_w^{-1}\, E_{mmse} \tag{7}$$

in which the MMSE equalization matrix E_{mmse} is defined as follows

$$E_{mmse} = (R_m^H R_m + \frac{\sigma_n^2}{\sigma_a^2}\, I_{Nt})^{-1}\ \ R_m^H \tag{8}$$

where, $\frac{\sigma_n^2}{\sigma_a^2}$ is the inverse of SNR

When calculating the convergence of transmit and receive filters, interference from neighboring subcarriers must be taken into account. The phrase "frequency sampling" refers to an extra technique that uses equalization coefficient values chosen in such a way that subchannel-specific frequency points must be reached by the equalizer's frequency response. Using either the ZF or MMSE, the optimal frequencies may be chosen. For channels with poor frequency selectivity, an equalization response that closely matches the frequency response of ZF or MMSE is ideal. It's easier to calculate equalizer coefficients with this arrangement [13].

Figure 8 MMSE equalizer [14]

4.4 Parallel Multi-stage Equalizer

In order to simplify the traditional multi tap equalization of FBMC OQAM, a parallel multi tap equalizer is presented in [15]. Figure 9 shows a graphical illustration of this equalizer

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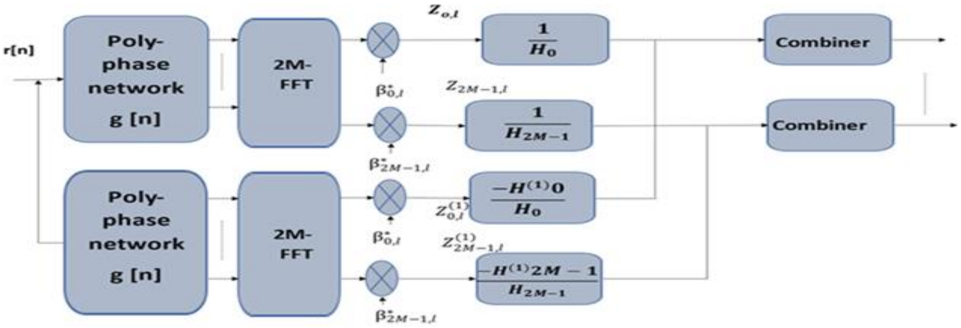

Figure 9 Parallel AFB equalizer [16]

4.5 Frequency Spreading Equalizer

A new equalization technique tailored to multi-carrier systems was described in [17]. Figure 10 depicts this equalizer for FBMC OQAM in graphical form. After a signal is received, its spectral properties are normalized. The primary benefit of this FS FBMC is that it does not need any additional time delay for calculation.

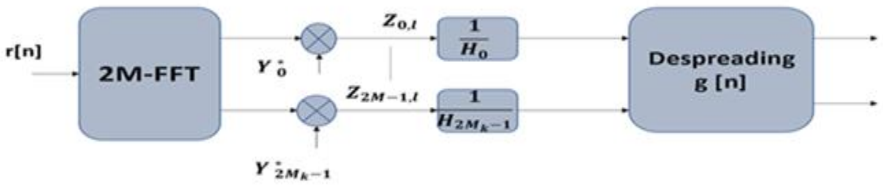

Figure 10 Frequency Spreading equalizer [16]

4.6 Time-Domain Equalizer

The Time domain equalization technique employs a window function to standardize the IFFT-obtained time domain information. A window function of [1-exp (j2n/N] is proposed for use in preventing ICI as seen in figure11. Spectrum efficiency is improved and BER is lowered because to the window feature. If the suggested window function is able to reduce ICI, then [18].

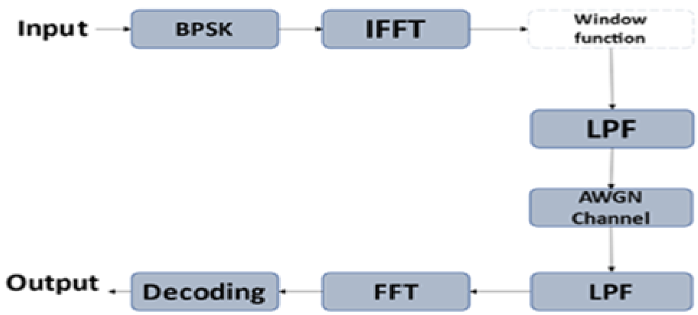

Figure 11 Proposed correlative coding scheme's Time-domain equivalent realization form [18].

5. SIMULATION RESULTS

In this section, we provide the main findings from our simulations and our analysis of the experiment performed on the FBMC system equipped with a channel equalization using the Wireless multipath communications channel models, the AWGN channel, and the Rayleigh channel. This section presents the results of a performance research on the channel equalizer for FBMC using the channel type described above, including a comparison of the bit error rate (BER) with signal-to-noise ratios achieved using the equalization techniques described above and the values of the parameters listed below. To carry out the whole FBMC simulation with the adjustment plan, a "code" in the MATLAB program was run using the MATLAB Communications Toolbox (M file). Table 1 shows the main parameters of the simulation. The channel Model parameters are listed in Table 2.

$$BER=\frac{\textit{Number of bits received in error}}{\textit{Number of total transmitted bits}} \quad (9)$$

Table 1 Simulation parameters of FBMC systems for BER calculation.

parameter	Value
No. of subcarrier	64,128
Modulation order	4,16 QAM
Velocity km/h	120
Channel Type	Veh B, Ped A
SNR	0-8 dB
Type of equalizer	Single tap equalizer, Multi tap equalizer, MMSE equalizer, Parallel equalizer, Frequency spreading equalizer, Time domain equalizer (overlap and save).
Doppler frequency	278 HZ

Table 2 Channel model parameters Vehicular B [19]

Path number	Relative delay (ns)	Average power (dB)
1	0	-2.5
2	300	0
3	8900	-12.8
4	12900	-10
5	17100	-25.2
6	20000	-16

5.1 First Vehicular Channel Scenario

Bit error rate vs Signal-to-Noise Ratio for FBMC systems using the Vehicular B channel and Modulation order 4 OQAM at a speed of 120 km/h and 64 subcarriers is seen in Figure 12. At a Doppler frequency of 278 Hz, an increase in SNR will degrade the BER of the systems. The best value of the bit error rate for an equalizer in the time domain (overlap and save) is $2.7*10^{-7}$ at SNR 8dB. Slight increases in the number of taps lead to steadily better BER performance.

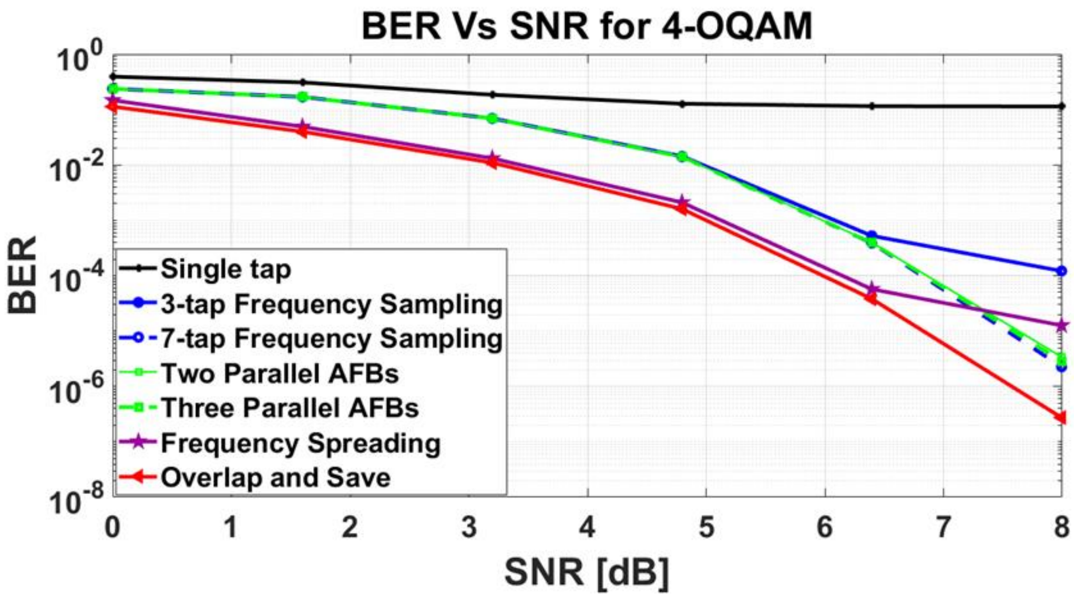

Figure 12 shows BER vs SNR with 64 subcarriers and 4OQAM

5.2 Second Vehicular Channel Scenario

The bit error rate vs signal-to-noise ratio for FBMC system at 120 km/h in Vehicular Channel B and 4 OQAM is shown in Figure 13. We observe that when the number of subcarriers is 128, BER performance improves gradually as more taps are added. results show " in comparison with the case of 64 sub-carriers of figure 12, that the improvement in BER decreased as the number of subcarriers increased".

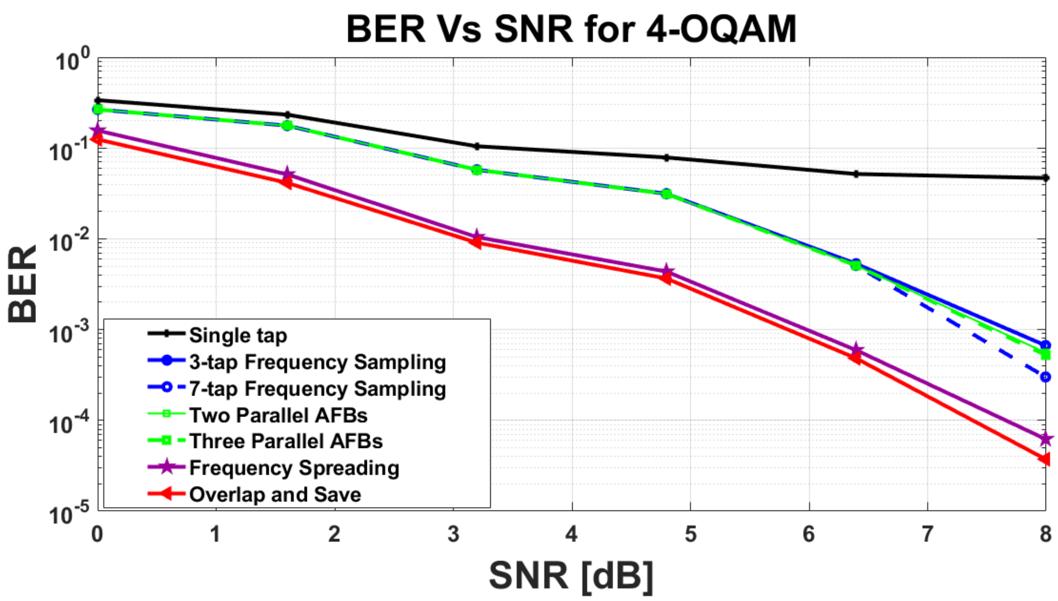

Figure 13 shows BER vs SNR with 128 subcarriers and 4OQAM

5.3 Third Vehicular Channel Scenario

Figure 14 shows the BER performance vs SNR for the FBMC system for 16OQAM at 120 km/h velocity and Vehicular channel type B with 64 subcarriers. The numbers indicate that the BER performance of the system will decline with increasing QAM order.

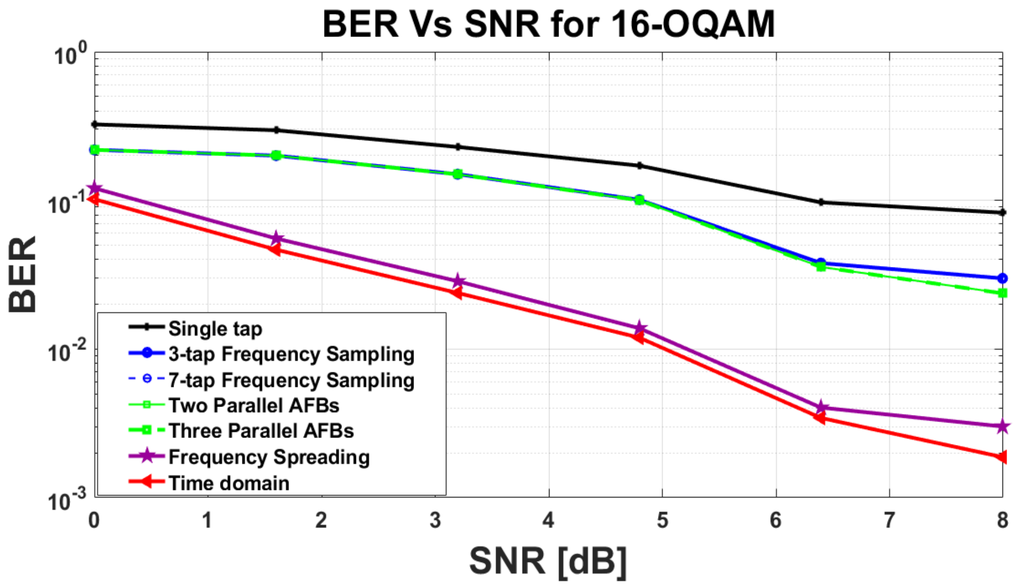

Figure 14 shows BER vs SNR with 64 subcarriers and 16OQAM

Table 3 Channel model parameters Pedestrian A [19]

Path number	Relative delay (ns)	Average power (dB)
1	0	0
2	110	-9.7
3	190	-19.2
4	410	-22.8

5.4 Fourth Pedestrian Channel Scenario

Performance comparisons in terms of bit error rate (BER) are shown in Figure 15 for the Pedestrian A channel operating at 120 km/h with 64 subcarriers and 4 OQAM modulation order. Channel model for pedestrians based on root-mean-square (RMS) delay spread. This suggests that channel models with a relatively small delay spread may be more suitable for describing the current and future systems for mobile communication than those with a much bigger delay spread. Nonetheless, the Vehicular A model of the channel with a large root-mean-square (RMS) delay is affected by a significant delay spread. The pedestrian B channel is better than the vehicular A channel.

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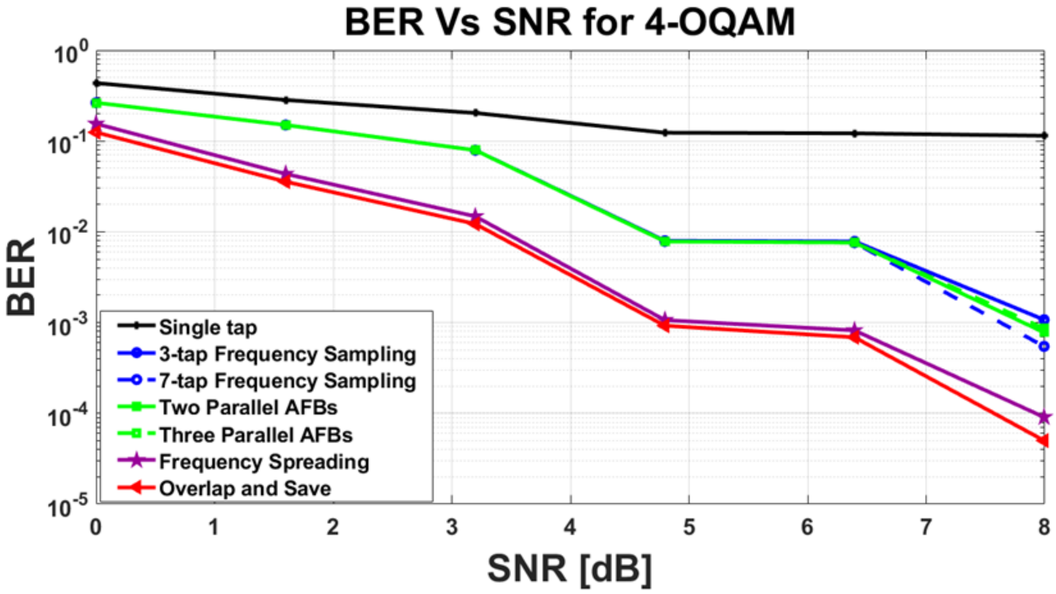

Figure 15 shows the Bit error rate versus SNR for FBMC systems in pedestrian A channel and velocity is 120 km/h

6. CONCLUSIONS

Many equalizers find their first use in wireless communication. Our work here employs the idea of such equalizers inside the framework of FBMC OQAM. BER performance analysis is used to make the comparisons. The two channels, Pedestrian-A and Vehicular-B, are used to test out various situations and settings. The effectiveness of various equalization schemes in terms of bit error rate (BER) is studied in this research for the FBMC-OQAM system. Test data analysis have shown that fewer subcarriers in the FBMC system's equalizer for the Pedestrian-A channel result in lower BER values the pedestrian channel performs better than the vehicular channel because the vehicular channel is in the case of the Doppler effect. The equalization works quite well with FBMC configurations. Subcarrier index 64 experiences a decrease in BER, With the case of 128 sub-carriers the improvement in BER decreased as the number of subcarriers increased demonstrating the usefulness of the equalization in the FBMC system. The system was simulated using MATLAB's Communications Toolbox (an M file). It is proposed to implement the FBMC_OQAM system in the form of hardware by using a GNU RADIO.

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