Low Complexity FBMC OQAM Method for Double Selective Channel

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ABSTRACT:- *Filter Bank Multi-Carrier provides ultimate spectral properties compared to Orthogonal Frequency Division Multiplexing (OFDM), due to the imaginary interference, which makes the application of Multiple-Input and Multiple- Output (MIMO) greater challenging. By spreading symbols in time (or frequency), we can totally do away with the imaginary interference, so that all MIMO techniques known OFDM can be straightforwardly applied in FBMC. The technique of spreading itself has low complexity because it is based totally on Hadamard matrices. Although spreading allows to restore complex orthogonality in FBMC within one transmission block, It can be examine interference from neighboring blocks. By inserting a guard timeslot, the signal-to-interference ratio will be improved. In addition to this we investigate the effect of a time-variant channel on such spreading approach. The work is been extended in calculating the Bit Error probability in double selective channels at the speed of 500km/h. we inspect the performance degeneration of OFDM and FBMC in doubly-selective channels, that is, time-selectivity and frequency-selectivity. Here the Signal to Interference Ratio is additionally increased at higher velocities. It is implemented for 4 QAM, 16 QAM, 256 QAM and 1024 QAM. For that, we derive closed-form Bit Error Probability (BEP) expressions for arbitrary linear modulation techniques based totally on one-tap equalizers, with Orthogonal Frequency Division Multiplexing (OFDM) and FBMC being special cases, covered by our general BEP expressions.*

Keywords: OFDM, FBMC, BER, BEP, Interference

I. INTRODUCTION:

Basically, OFDM technique consists of dividing the flow of entrance information over orthogonal channels. In this way, and based on the orthogonality principle, the interference between each transmission channel is minimal. Another benefit that comes from this method is associated to the assumptions about the noise in each channel. Over a massive and unique passband channel it is challenging (impossible in fact, in many situations) to expect that the mannequin noise is AWGN (Additive Noise Gaussian Noise). That is necessary because if the model is know, and it is correct, one can select the satisfactory way of frequency equalization. But, in large passband channels (tenths of MHz) the noise model is unknown and unpredictable. The solution of dividing a unique channel in sub channels simplifies the assumptions of the noise over each sub channel and, of course, one can suppose it approximately AWGN.

II. RELATED WORK

Future wireless systems should support a large range of applications, such as high data rates, massive device conncectivity, machine to- machine communications and low-latency transmissions. This requires a flexible assignment of the available time frequency resources, not possible in conventional OFDM due to its poor spectral behaviour. Filter Bank Multi-Carrier [2] becomes one of the efficient alternative to OFDM. In this paper, we consider FBMC based on Offset Quadrature Amplitude Modulation (OQAM), why because it gives maximum spectral efficiency. Although the integration of MIMO in FBMC is not applies straightly as in OFDM due to because the imaginary interference, there exist techniques which allow an efficient implementation of MIMO [3], making it a viable choice for future wireless systems. which usually employs pulses that are localized in both time and frequency, at the expense of replacing the complex orthogonality condition with the less strict real orthogonality condition [4]. Although FBMC behaves similar in many aspects with respect to the OFDM, some techniques become more challenging due to the imaginary interference, for example, channel estimation [5] or Multiple-Input and Multiple-Output (MIMO) [6]. There exist many works which combine MIMO and FBMC but most of them have very disadvantages, such as [7] which relies on channel information at the transmitter or [8] which requires high computational complexity. A more suitable method to combine MIMO with FBMC is to spread symbols in the time or frequency domain, which allows us to cancel the imaginary interference. Authors in [6] use a Fast Fourier Transform. spreading has the disadvantage of residual interference and increases complexity due to the additional Fast Fourier Transform. A better solution is to spread symbols is with a reduced Hadamard matrix because it requires only additions and no multiplications so that the additional complexity becomes very low.

III. FBMC OQAM

Filter Bank Multicarrier systems are a subclass of multi carrier systems. its basic principle is dividing the frequency spectrum into number of narrow subchannels, Multicarrier systems have been using in wide range of applications such as WLAN, LTE, etc. Cyclic Prefix Orthogonal Frequency Division Multiplexing is one of the most researched and popular type of Multicarrier. Channel estimation and equalization turn out to be trivial tasks but it will be simplified by the high-performance digital signal processors. the frequency selective propagation channel becomes a frequency flat subchannel by the insertion of some redundancy(CP), . The downside of CP-OFDM when compared to other MultiCarrier modulation schemes is a loss in spectral efficiency due to Cyclic Prefix insertion, higher out-of-band and a higher sensitivity to narrowband interferers. Filter Bank Multicarrier techniques have their roots in the pioneering works of Chang [2] and Saltzberg [3] who brought multicarrier techniques around two decades earlier than the introduction and utility of OFDM to wireless communication systems. The FBMC system model can be seen in Figure 1.

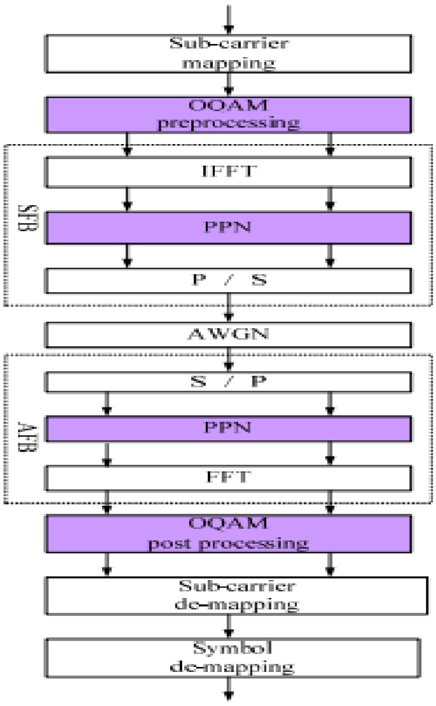

Fig1: FBMC System Model

Filter Bank Multicarrier modulation can be considered as an develoed OFDM. The filter banks address the main drawbacks of OFDM stated above. First, their sub channels can be optimally designed in the frequency domain to have favored spectral containment. Second, Filter bank Muticarrier systems do not require redundant Cyclic Prefix and for this reason greater spectral efficient. With high OOB(out of Band) attenuation of the sub-band filters, the filter bank itself can provide sufficient frequency isolation to enforce the needed reception and selectivity. This permits us to move all signal processing functions after the filter bank to the lowest sampling rate. In case of multiuser, the groups of subchannels allocated to the users are spectrally separated as quickly as an empty subchannel is present in-between. so that users do no longer want to be synchronized before they get access to the transmission system. This is one of the most important thing for uplink in traditional base station centric networks or in future dynamic spectrum access systems. For cognitive radio systems, Filter bank Multicarrier offers the possibility to simultaneously carry out spectrum sensing and transmission functions with the same system. As a multicarrier scheme, Filter Bank Multicarrier can benefit from multi-antenna systems. MIMO(Multi Input Multi Output) techniques can also be applied. Further research is still required in this area.

3.1 Filter Bank Multicarrier (FBMC) Transmitter

The working process of the Transmitter in FBMC-OQAM system is as follows. Firstly, after channel coding and symbol mapping of serial high-speed data OQAM(Offset Quadrature Amplitude Modulation) is used to modulate symbols. The main objective of OQAM preprocessing is to keep orthogonality between subcarriers. Offset Quadrature Amplitude Modulation(OQAM) is a pretreatment process of complex symbols in real part and imaginary part and interlaces half a symbol period in time interval to become transmission symbols. In this way, the real and virtual parts of the interleaved prolong are delay are divided into subcarriers. Any subcarriers are orthogonal distribution at sampling time and adjoining subcarriers. Then IFFT(Inverse Fourier Transform) operation is carried out on the transmission symbols after that the prototype filter banks with different offsets are filtered. Finally, the synthesized signals in the time domain are superimposed and finally it will be sent, this process is called the modulation of Multicarrier technology.

3. 2 Filter Bank Multicarrier (FBMC) Receiver

The working process of the receiver inFilter Bank Multicarrier(FBMC)-OQAM system is as follows. A set of prototype filters are used, which have the identical performance as the prototype filter banks at the transmitter end and are symmetrical. In this the original signal is filtered by prototype filter banks with unique offsets. Then the original signal is recovered by Fast Fourier Transform(FFT) and OQAM. The post-processing of OQAM is takes the real part of the symbol modulated to the subcarrier and then reconstruct the real symbol into the complex signal through the mutual conversion of the real number and the complex number. Assuming that the transmission channel is AWGN.

In order to simplify analytical investigations, we had reformulate our transmission system model in matrix format. Sampling the transmitted signal (t) and writing it in a vector allows us to reformulate (1) by

$$\mathrm{s} = \mathrm{Gx}, \qquad (1)$$

where the column vectors of **G** represent the sampled basis pulses $gl,k(t)$, written in matrix notation so that it corresponds to the transmitted symbol vector $\mathrm{x} \in \mathrm{C}^{\mathrm{LK}\times 1}$, defined as:

$$X = vec\begin{Bmatrix} x_{1,1} & \cdots & x_{1,1} \\ \vdots & \ddots & \vdots \\ x_{L,1} & \dots & x_{L,K} \end{Bmatrix}$$

$$=[x_{1,1}\; x_{2,1} \cdots \quad x_{L,1}\; x_{L,2} \cdots \quad x_{L,K}]^T \qquad (2)$$

In practice, (1) is calculated by an Fast Fourier Transform together with a polyphase network(PPN) and not by a matrix multiplication. However, expressing the system in such a way provides additional analytical insights. Stacking the received symbols yl, in a vector $\mathrm{y} \in \mathrm{C}^{\mathrm{LK}\times 1}$

$$\mathrm{Y}=[y_{1,1}\; y_{2,1} \cdots \quad y_{L,1}\; y_{L,2} \cdots \quad y_{L,K}]^T \qquad (3)$$

and assuming an AWGN channel allows us to reformulate our transmission system model of (3) in matrix notation as

$$\mathrm{y} = \mathrm{G}^{\mathrm{H}}\mathrm{r} = \mathrm{Dx} + \mathrm{n} \qquad (4)$$

with $\mathbf{n} \sim \mathcal{CN}(\mathbf{0}, P\mathrm{n}\mathbf{D})$ being the random noise and **D** the transmission matrix, defined as

$$\mathrm{D} = \mathrm{G}^{\mathrm{H}}\mathrm{G} \qquad (5)$$

In Orthogonal Frequency Division Multiplexing the transmission matrix is an identity matrix, i.e $\mathrm{D} = \mathrm{I}_{\mathrm{LK}}$. In FBMC, we observe imaginary interference at the off-diagonal elements and only by taking the real part, we have end up with an identity matrix, that is, $\Re\{\mathbf{D}\} = \mathrm{I}_{\mathrm{LK}}$. In this process a natural question is araising whether we lose any information in FBMC by taking the real part. The answer is absolutely no. This can be shown easily by an eigenvalue decomposition of the transmission matrix $\mathrm{D} = \mathrm{G}^{\mathrm{H}}\mathrm{G} = \mathrm{U}\Lambda\mathrm{U}^{\mathrm{H}}$ with the unitary matrix **U**. For $L \to \infty$ and $K \to \infty$, **D** has exactly $LK/2$ nonzero eigenvalues, each having a value of 2. so we can transmit only $LK/2$ complex symbols, this is equivalent to the transmission of LK real symbols. In adding to that we observe the same SNR. Thus, according to theoretic point of view, Orthogonal Frequency Division Multiplexing (without CP), Filter Bank Multicarrier and precoded FBMC exhibit the same rate. If $L < \infty$ or $K < \infty$, the rate may vary, based on the required guard resources in time domain and frequency domain.

IV. BLOCK-INTERFERENCE

In block transmission let us consider it has L number of subcarriers & K number of FBMC symbols. When we go through theoretical, K can approach infinity, because we spread symbols over K time slots, but when came to the practical this is not possible due to delay(latency) constraints and the fact is that the channel varies over time, destroying orthogonality, We further have to think about block-wise transmissions. For analytical research, let us consider 3 transmit blocks and to analyze the performance in block 2. The first block is represents by the transmit matrix **G**1, the second block by **G**2 and the third block by **G**3, whereas these transmit matrices are same except that they are time shifted by KT from each other, So the transmitted signal can be written as

$$\text{S}=\begin{bmatrix} G_1 & G_2 & G_3 \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} \qquad (6)$$

where $\mathbf{X}_1 \in \mathbb{C}LK\times 1$ represents the transmitted symbols of the first block, $\mathbf{X}_2$ of the second block and X_3 third block. As shown in Figure 3, these blocks overlap slightly. In conventional Folter Bank MultiCarrier, such overlapping has no influence on the performance due to the real orthogonality condition, that is $\Re\{G_H^2 G_1\} = \Re\{G_H^2 G_3\} = 0_{LK}$

Unfortunately, this no longer holds true if we apply time spreading within one transmission block, as described in Section III. By ignoring the noise, we obtain the received data symbols of block 2 by:

$$\overline{Y_2} = C^H G_2^H s$$

$$=\overline{X_2} + C^H G_2^H G_1 C \overline{X_1} + C^H G_2^H G_3 C \overline{X_3} \qquad (7)$$

The first term in (7) represents the signal power and the second and third term the undesired interference. The SIR of block 2 can thus be expressed by:

$$SIR_2 = \frac{\frac{KL}{2}}{\sum_{m=1}^{\frac{KL}{2}} \sum_{n=1}^{\frac{KL}{2}} \left| |C^H G_2^H G_1 C|_{m,n} \right|^2 + \left| |C^H G_2^H G_3 C|_{m,n} \right|^2} \quad (8)$$

where $[|C^H G_2^H G_1 C|]m,n$ denotes the matrix element at position (m, n) and $|\,|C^H G_2^H G_1 C|\,|$ the absolute value. Fig 3 shows the SIR for a different number of FBMC symbols per block. As long as the SNR is too smaller than the SIR, block interference can be neglected because the interference is dominated by the noise. Interference between blocks occurs solely at the boarder, So by increasing the spreading length K, we can increase the SIR because the interference is spread over a higher range of symbols. However, if a short spreading length is required, the interference might be so high. By adding a guard slot in time, we can enhance the SIR, see Fig 2, at the expense of spectral efficiency,. The efficiency loss decreases for an increasing spreading length. For comparison we also added the efficiency loss caused by the OFDM (LTE). however, that the overall spectral efficiency loss in OFDM is higher than FBMC and OFDM needs a larger guard band than FBMC.

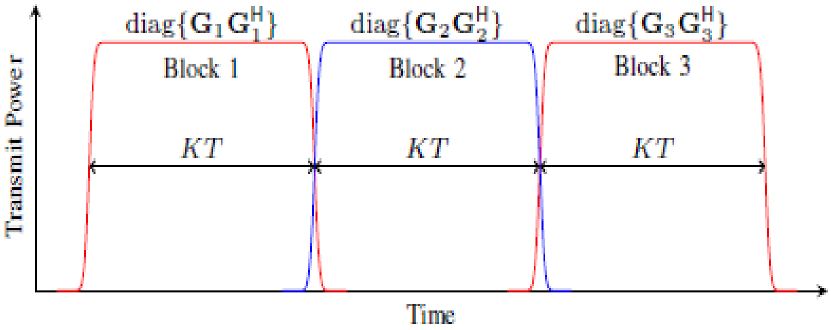

Fig.2. Neighboring blocks cause interference. In conventional FBMCOQAM, such interference can be completely eliminated by taking the real part.

V. DOUBLE SELECTIVE CHANNEL SYSTEM MODEL

In multicarrier transmission systems, symbols are usually transmitted over a rectangular time-frequency grid. Let us denote the transmit data symbol at subcarrier position l and time-position k by xl,k ϵ A with A denoting the symbol alphabet, for example QAM or PAM. The transmitted signal s(t), consisting of L subcarriers and K time-symbols, then becomes

$$s(t) = \sum_{k=1}^{K} \cdot \sum_{l=1}^{L} g_{lk}(t) x_{lk} \qquad (9)$$

whereas the basis pulses gl,k (t) are, essentially, time and frequency shifted versions of the prototype filter p(t):

$$g_{l,k}(t) = p(t - kT)e^{j2\pi lF(t-kT)}e^{j\theta_{lk}} \quad (10)$$

Note that time spacing T and frequency spacing F determine the spectral efficiency. it is not possible to find basis pulses which have a time-frequency spacing of TF = 1, are localized in both time & frequency and are orthogonal, according to the Balian-low theorem [5]. In OFDM, p(t) is a rectangular function violating frequency localization. a Cyclic Prefix is also added in Orthogonal Frequency Division Multiplexing to improve robustness in frequency selective channels, decreasing the spectral efficiency (TF = 1 + TCPF > 1). Filter Bank Multicarrier usually has a prototype filter p(t) which is localized in time and frequency, based on Hermite polynomials [6]. Such prototype filter is orthogonal at TF = 2. The time spacing as well as the frequency spacing is then reduced by a factor of 2, leading to TF = 0.5. This causes interference which, however, is shifted to the purely imaginary domain by selecting the phase shift as $\theta_{lk} = \frac{\pi}{2}(l + k)$, Because of the imaginary interference only real valued symbols only transmitted, so that we require two real valued symbols to transmit one complex symbol, leading to the same information rate as OFDM without Cyclic Prefix, that is TF = 1. By writing the sampled transmit signal s(t) in a vector **s** ϵ CN×1, we can write (1) by

$$\mathbf{s} = \mathbf{Gx},$$

with

$$G = [g_{1,1}\ g_{2,1}\ \dots\dots g_{L,1}\ g_{L,1} \dots\dots g_{L,K}], \qquad (11)$$

$$X = [x_{1,1}\ x_{2,1}\ \dots\dots x_{L,1}\ x_{L,1} \dots\dots x_{L,K}] \qquad (12)$$

Vector $\mathbf{g}_{l,k}$ ϵ CN×1 represents the sampled basis pulses of (2) and builds the transmit matrix **G** ϵ CN×LK while **x** ϵ CLK×1 stacks all the transmitted data symbols in a large vector. Letus denote the receive matrix by **Q** = [$\mathbf{q}_{1,1} \cdots \mathbf{q}_{L,K}$] ϵ $C_N \times_{LK}$ which is similarly defined as the transmit matrix, see (2) and (4), but a different prototype filter p(t) might be used. With a time-variant convolution matrix **H** ϵ CN×N the whole transmission system can then be expressed as

$$y = Q^H HGx + n \qquad (13)$$

where $y = [y_{1,1\dots\dots}y_{L.K}]^T$

ϵ CLK×1 represents the received signals and **n** ϵ CN(**0**, Pn **Q**H**Q**) the Gaussian distributed noise. Without loss of generality, we can normalize the received matrix so **q**H l,k**q**l,k = 1. In FBMC and pure OFDM, we have **Q** = **G**, while in Cyclic prefix-Orthogonal Frequency Division Multliplexing the transmit and receive matrix are slightly differ from each other, **Q** , **G**. Note that the orthogonality condition of Orthogonal Frequency Division Multliplexing gives that **Q**H**G** = **I**LK and the real orthogonality condition of FBMC that ϵ{**Q**H**G**} =**I**LK. In double selective channels orthogonality doesnot holds longer-, leading to the interference, described by the off-diagonal elements of **Q**H **HG**. The diagonal elements describe the signal elements. To keep the statical investigation simple, see (11)-(13), we utilize the Kronecker product ⊗ to rewrite (6) for the received symbol $y_{l,k}$ by

$$Y_{l,k} = q_{l,k}^H H G_x + n_{l,k} = \left((G_x)^T \otimes q_{l,k}^H\right) Vec\{H\} + n_{l,k} \qquad (14)$$

where vec{**H**} denotes the vectorized time-variant convolution matrix. Finally, the estimated data symbols ˆ xl,k at the receiver are obtained by one-tap equalization, that is,

$$\widehat{x_{l,k}} = Q\left\{\frac{y_{l,k}}{h_{l,k}}\right\} \qquad (15)$$

with $h_{l,k} = q_{l,k}^H\ \mathbf{g}_{l,k}$ denoting the appropriate diagonal element of **Q**H **HG** and Q{·} the quantization operator, that is, nearest neighbor detection. Most of the energy is concentrated at the diagonal elements of **Q**H **HG**, so that one-tap equalizers achieve good performances till some Signal-to-Noise Ratio threshold is reached.

VI. Results:

The results of Bit Error probability with respect to SNR for various bits of QAM is shown in fig 3.

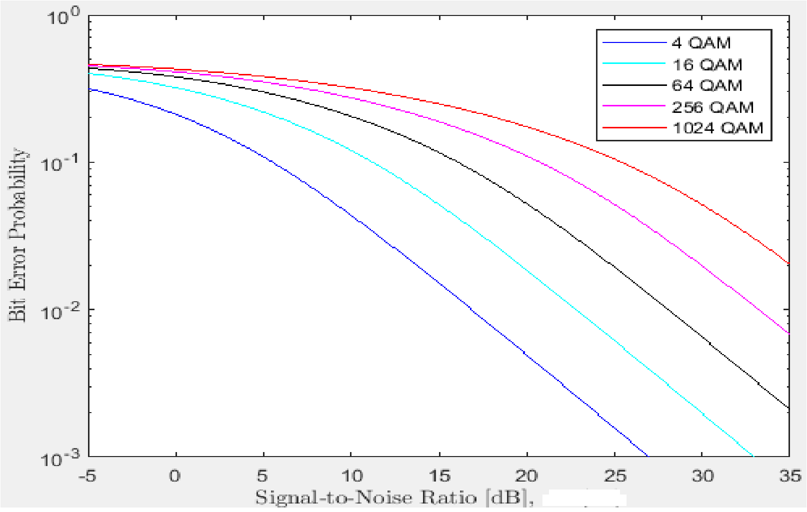

Fig 3. BEP with respect to SNR for various bits of QAM.

From the above results we can observe that the SNR is improved according to the number bits used in QAM and the Bit Error Probability of also decreases according to the QAM technique used. 1024 QAM gives better resolys than 256 QAM. In this project we had taken the 64 QAM as the desired.

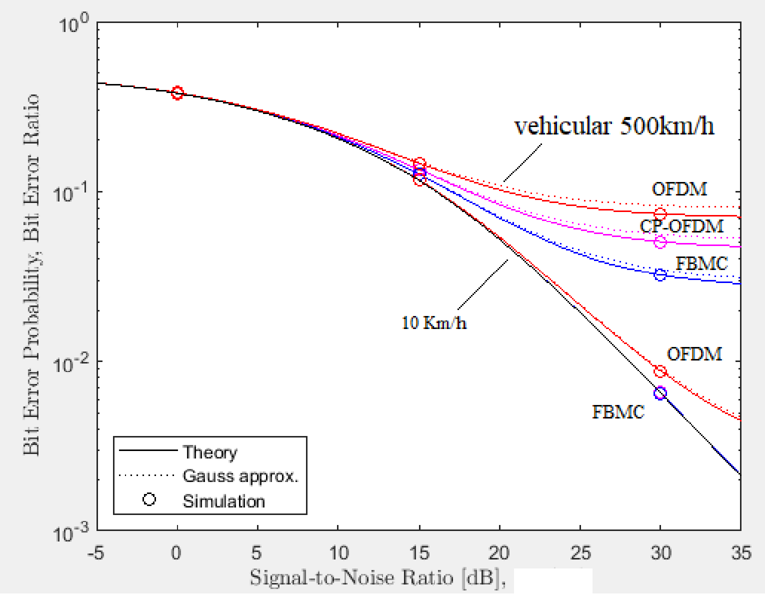

Fig 4. Fig 5.4 Simulations BEP Vs SNR at 10km/h & 500Km/h

Figure 4 shows the BEP over the SNR at 10km/h & 500km/h. As the interference is dominated by the noise, the Bit Error Probablity of a double selective channel accurately describes the transmission system. For a Pedestrian the channel at low velocities, one tap equalizers are good enough for CP-OFDM and FBMC but not necessary for OFDM without CP. In case of a Vehicular the interference in A channel at 500 km/h is mainly dominated by the Doppler spread, that FBMC performs better than OFDM. For a time-invariant channel, the Bit Error probabilty of CP-OFDM becomes the same as for doubly-flat FBMC, and also it, is effected by a relatively high delay spread in a Vehicular A channel, so that it deviates from doubly-flat fading at high SNR values (not shown in the Figure). In practical the relevant SNR ranges less than 20 dB this is no issue.

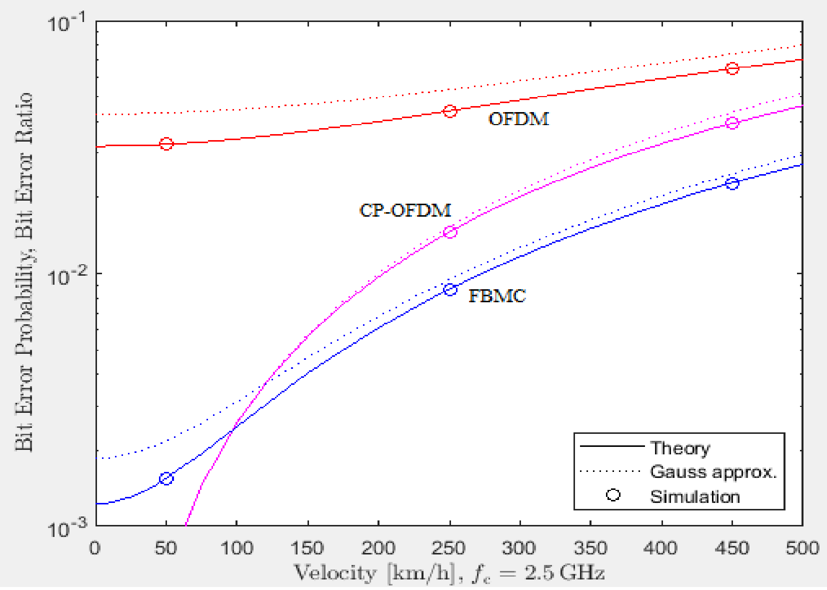

Fig 5. Simulations BEP Vs Velocity

Fig 5 shows how the Bit Error Probability(BEP) depends on the velocity in case of zero noise and a Vehicular A channel model. For lower velocities, Cyclic prefix OFDM shows the lowest Bit error probability because interference caused by frequency selectivity can be completely eliminated at the expense of a lower bit rate. For velocities higher than 100 km/h, however, FBMC outperforms CP-OFDM due to a better robustness in time-variant channels.

Table 1. SIR vs Velocity for different spreading length.

	K=8			k=32		
SIR(Db)	33	32	28	30	22	18
Velocity(km/hr)	10	25	40	10	25	40

VII. CONCLUSION

Multi Input Multi Output works perfectly in FBMC-OQAM by spreading the symbols in the time or frequency domain, with approximately the same MIMO complexity as in OFDM. Because wireless channels are highly under spread, such Filter Bank Multicarrier based MIMO transmission works in many real world scenarios, If block wise transmission is required, we suggest the usage of guard slots in order to improve the SIR. Later developed to derived BEP expressions help to analyze the influence of time-variant multipath propagation in OFDM and Filter Bank Multicarrier. In highly time-varying channels, FBMC performs better than CPOFDM because the underlying prototype filter has the best joint time-frequency localization, although both methods suffer from interference in high SNR Only in highly frequency-selective channels, CP-OFDM outperforms FBMC. finally, in practical cases, the delay spread is so low, that one-tap equalizers achieved better performances in FBMC.

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