BER Performance evaluation of FBMC-OAQM and OFDM Multicarrier system

Patteti Krishna

Abstract— ***Filter Bank Multi Carrier (FBMC) offers best detestable properties took a gander at over orthogonal frequency division multiplexing (OFDM) to the attack of nonexistent hindrance. FBMC system is a multicarrier structure, particularly sensible for 5G remote correspondences. FBMC beats OFDM as a result of proficient use of the open information move limit and without usage of cyclic prefix (CP). In this paper, we address the issue of remarkable enrollment at the pilot territory and used to audit the channels with pilot picture, in like way consider the fundamental conditions for utilization of the assistant pilot pictures. First and two partner pictures for each pilot plans with power equality uses instead of one picture; it can attainable inspirations driving necessity of OFDM and FBMC depending upon signal to noise ratio (SNR) what's relentlessly possible to improve the introduction of one frivolity pictures by using multiple associate pictures. Finally autonomous the BER execution reenactment results and adornment pilot pictures.***

Keywords— ***Auxiliary pilot patterns, BER, Channel estimation, Cancellation of Interference, FBMC Coding, OFDM and SNR.***

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is the most clear multi carrier balance plan [1], for current remote exchanges structures. Further, OFDM perform poor in frequency space since it handles rectangular pulses [2]. Another multi carrier methodology with by a wide edge unrivaled personality blowing properties is Filter Bank Multi-Carrier (FBMC) with Offset Quadrature Amplitude Modulation (OQAM), in short just FBMC, which commonly uses beats that are bound in both, time and frequency, to the burden of revoking the bizarre orthogonality condition with the less great authentic orthogonality condition [3]. In spite of the way where that FBMC carries on in various perspectives like OFDM, a couple of structures become all the all the all the additionally testing as a result of the nonexistent square, for example, channel estimation [4].

FBMC channel estimation become dynamically fundamental and testing task in light of the weird impedance when stood out from OFDM. In this paper, we address the issue of unpredictable end at the pilot territory and used to survey the channels with pilot picture is known as pilot picture kept up channel estimation (PSACE), correspondingly consider the general conditions on the frill pilot symbols[12-15]. In any case, the PSACE improves as a choice if the brief changes in time since it allows the channel following. To drop the nonexistent finding in PSACE [16] uses one picture for each pilot this is called as collaborator pilot pictures [17], it is uses careless impedance drop, with this structure control correspondence is central disservice.

Fast Fourier Transform (FFT) uses a spreading factor; in any case, has the deficiency of striking impedance and expanded unconventionalities in perspective on the extra FFT [5].A better game-plan is to spread pictures with a diminished Hadamard structure since it requires no multiplications so the extra multifaceted nature ends up being low. Such technique was first modify with join FBMC with Alamouti's space-time square coding [8]-[10].

Overview of the Paper

The number of pilot symbols is closely spaced or more than one does not allow per auxiliary symbol per pilot [16]. Therefore, we consider a generalised procedure to select the auxiliary symbol per pilot to avoid the limitations of closed spaced pilots per auxiliary pilot symbols.

Firstly, consider two auxiliary pilots per symbols, power offset reduce from 4.3 to 0.8 and relative improvements in achievable capacities of OFDM and FBMC depending on SNR.

This procedure requires arbitrary selection of number of coded symbols per pilot in FBMC. Finally we quantify the complexity difference between auxiliary pilot symbols, FBMC coding and OFDM.

II. FBMC-OQAM SYSTEM MODEL

In multicarrier transmissions, pictures xl, are transmitted over a rectangular time-frequency engineer, with l inferring the subcarrier-position and k the time-position. The transmitted signal (t) of a transmission square containing L subcarriers and K multicarrier pictures can be made as

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

Where $g_{l,k}(t)$ demonstrates the reason beat which is a period and frequency moved alteration of the prototype filter

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

Where T is being the time isolating and F the frequency circulating (scattering). The got pictures yl, are then gotten

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Dr.Patteti Krishna, Professor, Department of Electronics and Communication Engineering, Jayamukhi Institute of Technological Sciences, Warangal, Telangana, India. (E-mail: kpatteti@gmail.com)

by imagining the got signal $r\ (t)$ onto the reason beats $g_{l,k}(t)$

$$y_{l,k} = \left\langle r(t), g_{l,k}(t) \right\rangle = \int_{-\infty}^{\infty} r(t)\, g_{l,k}^{*}(t)\, dt \tag{3}$$

An ideal property of the reason heartbeats is orthogonality, that is,

$$\left\langle g_{l_1,k_1}(t), g_{l_2,k_2}(t) \right\rangle = \delta_{(l_1-l_2),(k_1-k_2)}$$

since it improves the territory structure. Dreadfully, it is senseless to plan to discover reason beats $g_{lk}(t)$ which are (superb) orthogonal, have most fundamental silly adequacy of $TF = 1$ subject to Balian-Low theory [11-12

In OFDM, $\theta_{l,k} = 0$ the prototype filter is normally picked a rectangular motivation behind constraint. In this way, frequency covering isn't satisfied. In like manner, a Cyclic Prefix (CP) is regularly included practice, so the orthogonality condition transforms to a bi-orthogonality condition transmit and get heartbeats are uncommon) and insane ability is given up, $TF > 1$, to get charitableness in frequency express channels.

In FBMC, we fulfill the Balian-Low theory by dislodging the mistaking orthogonality condition for the less senseless guaranteed orthogonality condition, so basically veritable respected pictures, $xl \in \mathbb{R}$ can be transmitted. The thought is to structure a prototype filter which is (diserse) orthogonal for a period frequency spreading of $TF = 2$. The time dispersing also as the frequency circulating at that point reduced by a factor of two $TF = 1/2$ (guaranteed pictures), which is undefined from $TF = 1$ (complex pictures almost as transmitted data per time unit. Such time-frequency pummeling causes impedance which, in any case, is moved to the totally nonexistent space by the stage move $\theta_{l,k} = \frac{\pi}{2}(l+k)$. So as to unwind conclusive examinations, we reformulate our transmission structure model in framework documentation. Testing the transmitted signal (t) and making it in a vector engages us to reformulate (1) by

$$s = Gx \tag{4}$$

Where the territory vectors of G address the surveyed reason beats $gl,(t)$, written in cross segment documentation with the target that it looks the transmitted picture vector $x \in \square^{LK\times 1}$ defined as

$$x = vec\left\{ \begin{bmatrix} x_{1,1} & \cdots & x_{1,K} \\ . & . & .. \\ x_{L,1} & \cdots & x_{L,K} \end{bmatrix} \right\} \tag{5}$$

$$= \begin{bmatrix} x_{1,1} & x_{2,1} & \cdots & x_{L,1}\, x_{1,2} & \cdots & x_{L,K} \end{bmatrix}^T \tag{6}$$

In every sober minded sense, (4) is constrained by a FFT together with a polyphase system and not by a cross section multiplication [14]. Regardless, giving the structure in such a way gives extra effective bits of learning. Stacking the got pictures yl, in a vector

$$y \in \square^{LK\times 1}$$

$$y = \begin{bmatrix} y_{1,1} & y_{2,1} & \cdots & y_{L,1}\, y_{1,2} & \cdots & y_{L,K} \end{bmatrix}^T \tag{7}$$

in like manner, tolerating an Additive White Gaussian Noise (AWGN) channel, attracts us to reformulate our transmission framework model of (3) in cross zone documentation as

$$y = G^H r = Dx + n \tag{8}$$

with n ~ $\mathcal{CN}(0, \mathcal{P}_n D)$ being the enthusiastic noise and D the transmission arrange, depicted as

$$D = G^H G \tag{9}$$

In OFDM, the transmission cross fragment is a character sort out, that is $D = I_{LK}$. In FBMC, then again, we watch offbeat obstruction at the off-corner to corner pieces and just by taking the veritable part, we end up with a character cross region, that is $\Re\{D\} = I_{LK}$.

III. PSACE IN FBMC-OQAM SYSTEM

The special data or pilot symbols known at the receiver priori in pilot symbol aided channel estimation (PSACE). The channel estimation in OFDM received symbols at the pilot location are divided according to data symbols which immediately deliver an estimation of channel coefficient at the location of pilot symbols.

In FBMC channel estimation is based on taking real part because imaginary inference elimination. In order to employ PSACE in FBMC, we have to mitigate the imaginary inference with the help of auxiliary pilot symbols.

A. Auxiliary Pilot Symbols

The auxiliary symbol refers an additional data symbol that provides the imaginary interference cancelling at location of one pilot symbol.

$$\chi_p = \begin{bmatrix} D_{p,p} & D_{p,D} & D_{p,A} \end{bmatrix} \begin{bmatrix} \chi_p \\ \chi_D \\ \chi_A \end{bmatrix} \tag{10}$$

The vector $\chi_p \in \square^{|p|\times 1}$ represents transmitted vector x elements at the pilot positions, the data position is denoted as $\chi_D \in \square^{|D|\times 1}$ and $\chi_A \in \square^{|A|\times 1}$ at the auxiliary pilot symbol positions.

$$\chi_A = D_{p,A}^{\#}\left(I_p - D_{p,p}\right)\chi_p - D_{p,A}^{\#} D_p D \chi_D \tag{11}$$

$$D_{p,A}^{\#} = D_{p,A}^{H}\left(D_{p,A} D_{p,A}^{H}\right)^{-1} \tag{12}$$

For example, consider the first auxiliary symbol per pilot the $D_{A,p}$ diagonal matrix is 0.4357, the power offset of auxiliary pilot is defined as

$$\kappa_A = \frac{P_A}{P_D} \tag{13}$$

Where the data symbol power is P_D and the auxiliary pilot symbol power is P_A. Suppose that if we want to cancel number of symbols N=8 means closest imaginary inference then the power offset is $\frac{\left(3.0.4357^2 + 4.0.2393^2\right)}{0.4357^2} = 4.21$.

Therefore the auxiliary pilot power is 4.21 times more than power of the data symbol. Furthermore, we consider two auxiliary pilot symbols, which is cancel equally between them then power offset is $\frac{\left(2.0.4357^2 + 4.0.2393^2\right)}{2.0.4357^2} = 0.8$.

Hence the auxiliary pilot symbol power is lower than the data symbol power. Transmitted signals can be expressed in terms of auxiliary pilot symbol is given as

$$s_A = GA\begin{bmatrix} \chi_p \\ \chi_D \end{bmatrix} \tag{14}$$

Whereas $A \in \square^{LK\times\left(LK-|\mathrm{A}|\right)}$ represents the auxiliary cancellation. The data symbol power P_D is given as

$$P_D = \frac{T}{\Delta t}\frac{K}{|\mathrm{A}|\bar{\kappa}_A + |p|\kappa_p|D|}P_S \tag{15}$$

Where κ_p represented as the power offset of pilot and κ_A the average auxiliary pilot power offset.

B. FBMC Coding

The uncorrelated data symbols $\tilde{x}$ are precoded by a unitary coding/spreading matrix C, so that the transmitted symbols **x** are calculated as

$$x = C\tilde{x} \tag{16}$$

$$\tilde{y} = C^H y \tag{17}$$

$$C^H DC = I \tag{18}$$

. .

In the reference part we present a huge occasion of such system. It is conceivable to discover a coding system [8] that has more than $\frac{LK}{2}$ zones while beginning at starting late fulfilling (18). The eigenvalue disintegration of D demonstrates this is insane (rejecting edge impacts which become pointless for unending *K* and *L*). This makes the integration into existing frameworks unsafe at any rate has no effect if a structure is directed start with no outside help. The titanic favored position of Hadamard spreading, obviously, is that particular decisions at any rate no multiplications are required, so the extra inspiration winds up being particularly low. In all probability, for every datum picture, we generally need log2 (*K*)- 1 additional decisions/subtractions at the transmitter and log2 (*K*) additional choices/subtractions at the recipient. Notwithstanding, we should audit that the general erraticisms of FBMC is around two to multiple events higher than in OFDM..

IV. SIMULATION RESULTS

The FBMC offers high SE than OFDM due to without use of CP and efficient utilization of the available bandwidth. FBMC improvements will be quantify and comparing with OFDM, channel bandwidth of FBMC uses 1.4 MHz(LTE) with subcarrier spacing of F=15 kHz.

We assume OFDM-CP is 4.75 µs, number of OFDM symbols is K^{OFDM} = 14 and time duration of 1 ms, other hand FBMC allows transmit symbol K^{FBMC} = 30 within the same time duration. We further assume OFDM without CP use OFDM symbols are $K^{OFDM,\ noCP\ CP}$ = 15 occupies the same bandwidth i, e. 1.4 MHz and number of used subcarrier is L^{OFDM} = 72 subcarriers (1.08 MHz). FBMC system uses number of subcarrier is L^{FBMC} = 87 so that PSD is below 84 dB of its maximum values of outside channel bandwidth. The data symbol density of OFDM has $\left(\frac{|D|}{LK}\right)$ of 0.9524 then data symbol density of OFDM without CP is 0.9556.

The channel estimation of FBMC is based on FBMC coding and one auxiliary pilot symbols that use the same data symbol density of OFDM without CP such as 0.9556. If two auxiliary symbols uses data symbol, density of FBMC is decrease to 0.9333 due to less number of data symbols are used.

The achievable capacity of OFDM and FBMC is expressed as (considered pilot symbols).

$$C^{OFDM} = \frac{|D|\log_2\left(1+\frac{P_D}{P_n}\right)}{KT} \tag{19}$$

$$C^{FBMC} = \frac{|D|\frac{1}{2}\log_2\left(1+\frac{P_D}{P_n/2}\right)}{KT} \tag{20}$$

Here we assumed the equal number of subcarriers L and transmitted signal power P_S.

Therefore, $P_D^{OFDM} = P_D^{OFDM,noCP} = 2P_D^{FBMC,Cod}$ so that $C^{OFDM,noCP} = C^{FBMC,Cod}$ while $C^{OFDM,noCP} > C^{FBMC,Aux}$

The intentional throughput and the theoretical upper bound are appeared in Figure 1. To keep the illustration clear, we considered just the occasion of one extra picture here. Or on the other hand maybe we consider indisputable introduction frameworks expressly straight development (of the three nearest pilot checks) and moving square run of the mill, which midpoints all pilot measures who are inside a period frequency level of 15 time-pictures and 12 subcarriers. The last is conceivable in light of how the direct is altogether related in both, time and frequency, with the target that moving square conventional vanquishes straight improvement by and large 1.7 dB SNR.

The reachable uttermost degrees of FBMC and OFDM structure pilot pictures into record surrendered (19) and (20), we found that for one extra picture, the information picture SNR is moved by 1.22 dB showed up unquestionably in relationship with OFDM. Basically vague, for two associate pictures it is 0.88 dB, for three 0.7 dB and for four 0.55 dB. Beginning now and into the not so distant, by structure up the extent of accomplice pictures, we increment the information picture SNR, yet, the extent of information pictures diminishes. The general impact on past what many would consider possible is appeared in Figure 2 and for the cognizant throughput in Figure 6. For a low SNR, the throughput-headway of a broadly comprehensive information picture SNR beats the throughput-hardship in perspective on less information pictures, with the target that multiple associate pictures per pilot perform superior to anything one right hand picture. For a high SNR, we watch a contrary impact. We other than observe that there is irrelevant favored position of utilizing in excess of two right hand pictures.

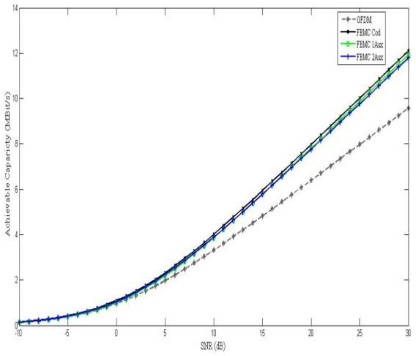


Figure 1: FBMC outperforms OFDM because it uses the available bandwidth more efficiently and does not employ a CP.

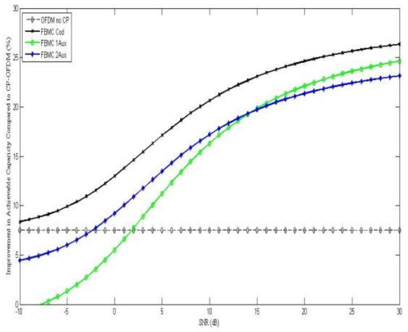


Figure 2: Achievable capacities of OFDM and FBMC: Relative improvement of FBMC compared to OFDM. Depending on the SNR, it is possible to improve the performance of one auxiliary symbol by employing multiple auxiliary symbols.

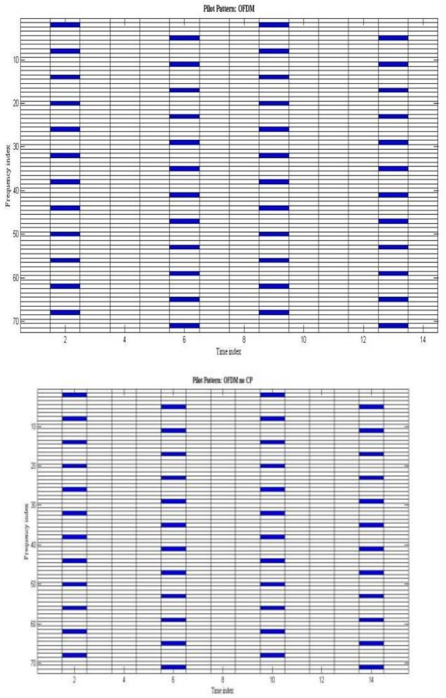
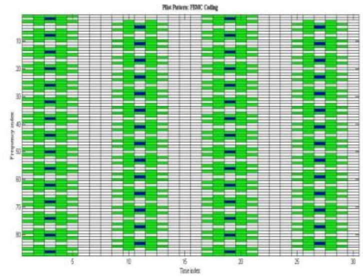
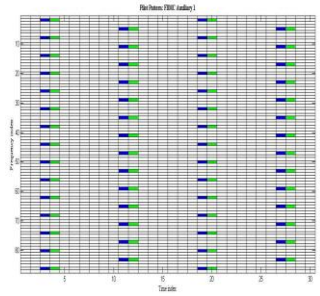


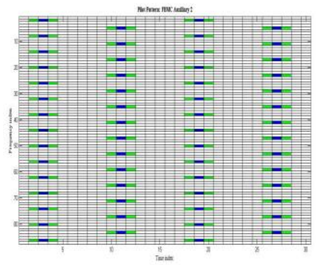
Figure 3: Pilot Patters of OFDM and OFDM no CP



(a) FBMC Coding Pilot Patter



(b) FBMC Coding Power offset 0



(c) FBMC Auxiliary two symbols per pilot with power offset 4.3 high PAPR

Figure 4: FBMC Coding and FBMC First and Second Auxiliary Symbol per Pilot Patters with Power offset zero and 4.3 High PAPR

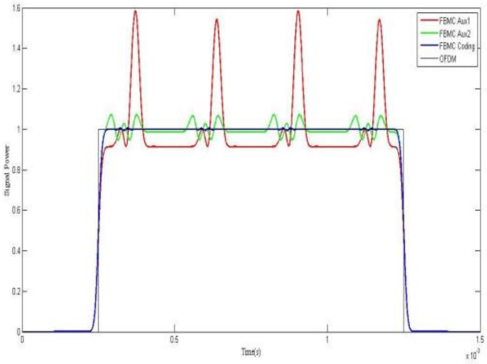


Figure 5: For a fair comparison of different modulation schemes consider the same transmit power $P_S = 1$.

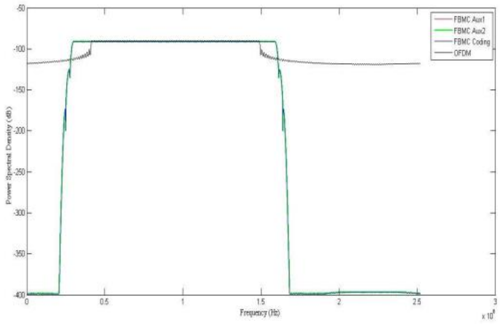


Figure 6: For a fair comparison of different modulation schemes such as FBMC and OFDM, consider the same transmit power $P_S = 1$.

The different channel estimation methods are also evaluated by a comparison of the bit error rate (BER) performance as a function of the Eb/N0 ratio, with Eb the energy per information bit and N0 the noise power spectral density. First of all, it can be seen in Figure7 that in the case of perfect channel knowledge, FBMC/OQAM performs better than CP-OFDM. The performance gain is around 0.26 dB for a BER of 10^{-3}. This gain is mainly due to the no use of cyclic-prefix in FBMC/OQAM (10 log ((1024 + 64)/1024) ≈ 0.26 dB).

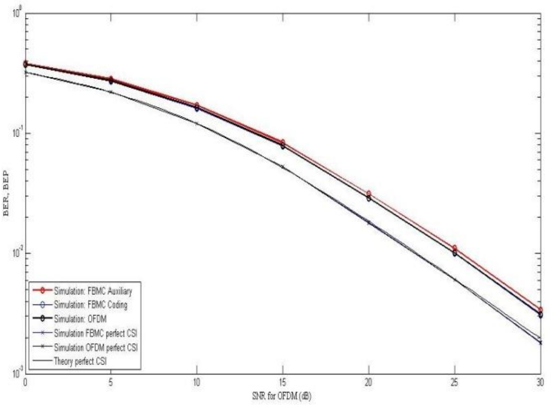


Figure 7: BER performance for the different channel estimation methods

V. CONCLUSION

The FBMC Coding is used for PSACE if the complexity not considered. Hence coding mitigates the nonexistent square withdrawal at pilot position, which offers low PAPR; no centrality is squandered and understood channel estimation frameworks. Notwithstanding, right hand pilot pictures may be better decision if computational whim beast. The one partner pilot picture prompts bona fide power balance, PAPR expansions and dynamically prominent essentialness squandered. Along these lines two accessory pilot pictures configuration ardently diminishes the PAPR and offer high inspiration driving constrainment concerning medium SNR, control parity spared and loss of loss of information pictures.

REFERENCES

1. Alphan Sahin, Ismail Guvenc, and Huseyin Arslan, “A survey on multicarrier communications: Prototype filters, lattice structures, and implementation aspects,” IEEE Communications Surveys & Tutorials, vol. 16, no. 3, pp. 1312–1338, 2012.
2. Behrouz Farhang-Boroujeny, “OFDM versus filter bank multicarrier,” IEEE Signal Processing Magazine, vol. 28, no. 3, pp. 92–112, 2011.
3. Jeffrey G Andrews, Stefano Buzzi, Wan Choi, Stephen V Hanly, Aurelie Lozano, Anthony CK Soong, and Jianzhong Charlie Zhang, “What will 5G be?,” IEEE Journal on Selected Areas in Communications, vol. 32, no. 6,pp. 1065–1082, 2014.
4. Gerhard Wunder, Peter Jung, Martin Kasparick, Thorsten Wild, Frank Schaich, Yejian Chen, Stephen Brink, Ivan Gaspar, Nicola Michailow, Andreas Festag, et al., “5GNOW: non orthogonal, asynchronous waveforms for future mobile applications,” IEEE Communications Magazine, vol. 52, no. 2, pp. 97–105, 2014.
5. Paolo Banelli, Stefano Buzzi, Giulio Colavolpe, Andrea Modenini, Fredrik Rusek, and Alessandro 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.
6. Behrouz Farhang-Boroujeny, “Filter bank multicarrier modulation: A waveform candidate for 5G and beyond,” Advances in Electrical Engineering, vol. 2014, 2014.
7. Robert W Chang, “Synthesis of band-limited orthogonal signals for multichannel data transmission,” Bell System Technical Journal, vol. 45, no. 10, pp. 1775–1796, 1966.
8. B Saltzberg, “Performance of an efficient parallel data transmission system,” IEEE Transactions on Communication Technology, vol. 15, no. 6, pp. 805–811, 1967.
9. Helmut B¨olcskei, “Orthogonal frequency division multiplexing based on offset QAM,” in Advances in Gabor analysis, pp. 321–352. Springer, 2003.
10. Behrouz Farhang-Boroujeny and Chung Him Yuen, “Cosine modulated and offset QAM filter bank multicarrier techniques: a continuous-time prospect,” EURASIP Journal on Advances in Signal Processing, vol. 2010, pp. 6, 2010.
11. 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, 2010.
12. Chrislin L´el´e, J-P Javaudin, Rodolphe Legouable, Alexandre Skrzypczak, and Pierre Siohan, “Channel estimation methods for preamble-based OFDM/OQAM modulations,” European Transactions on Telecommunications, vol. 19, no. 7, pp. 741–750, 2008.
13. Dimitrios Katselis, Eleftherios Kofidis, Athanasios Rontogiannis, and Sergios Theodoridis, “Preamble-based channel estimation for CP-OFDM and OFDM/OQAM systems: A comparative study,” IEEE Transactions on Signal Processing, vol. 58, no. 5, pp. 2911–2916, 2010.
14. Eleftherios Kofidis, Dimitrios Katselis, Athanasios Rontogiannis, and Sergios Theodoridis, “Preamble-based channel estimation in OFDM/OQAM systems: a review,” Signal Processing, vol. 93, no. 7, pp. 2038–2054, 2013.