



## AI-Based Approach for Optimal Channel Estimation and Equalization for FBMC/OQAM Systems

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**Abstract** – The rapid development of wireless communication systems in future, where Filter bank multicarrier (FBMC) modulation is auspicious candidate modulation method with hopeful waveforms. Although FBMC system indirectly use channel estimation methods for orthogonal frequency-division multiplexing (OFDM) system because of its intrinsic inherent imaginary interference due to its non-orthogonal nature in the imaginary field, which is a barrier to bid multiple input multiple output (MIMO) with FBMC/OQAM. This paper proposes Deep Neural Network (DNN) based Deep learning channel estimation (DL-CE) and equalization to deal with imaginary interference. Channel State Information (CSI) and the method of constellation de-mapping learned by a DNN model and varied with frequency domain sequences are simplified equally to obtain binary bits directly. The proposed methodology is verified on the MATLAB software and simulation results shows DL-CE and other existing schemes performance on equalization and estimation with art performance in terms of bit error rate (BER).

**Key words:** Deep Neural Networks, FBMC, OQAM, channel estimation, equalizer, equalization.

### 1. Introduction

Now-a-days modulation techniques are set up to support asynchronous communications. Among them Filtered Multicarrier Systems such as FBMC [1] are assuring technologies to enhance future internet of thing networks where the transmitters and the receivers need not to be flawlessly synchronized to a common and precise time base to transmit data. Therefore simplification of communication protocols with in turn reduces the over head signalization and saves power.

Although these modulation faces non-linearity issues in the communication systems, the information in the signal will acutely distort due to the channel effects. However it is a critical task to have high reliability of the communication systems by means of good channel estimation and equalization performance because of the intrinsic imaginary interference, there by channel estimation in FBMC systems is more challenging than that of OFDM systems. Hence many channel estimation schemes specialized to mitigate this challenge like preamble-base method [2], FDA scattered pilots-based method [3]. The above channel methodologies having the high symbol duration than the channel maximum delay or that the channel is time invariant.

Although previously cited works provide better performance, the assumptions are not met regarding channel estimation, will suffer from serious performance degradation increased with computational, complexity specifically in interference-limited environments. Recently DL-techniques have attracted an enormous interest in telecommunication due to their functionality to efficiently provide solutions to complex non-linear problems. Our idea is to conceive a non-linear receives that takes assistance from the reasoning and learning potentialities of DNN [4] to blindly and effectively detect data symbols in an uncertain environment. This approach is to determine the transmitted data in the presence of intrinsic interference caused by the over-lapping pattern of FBMC/OQAM signals [5].

Influenced by many applications of DL technology, DNN-model is taken in account for solving the issues of channel estimation in FBMC systems. As DNN-model with more

powerful learning ability to learn this can mitigate this imaginary inherent interference and then obtain excellent performance in channel estimation. Based on DL-technology, formulate the channel estimation as well as equalization problem. DL-based channel estimation [6], is abbreviated as DL-CE in which QAM mapping [7], considered as a black box, continuously approaching their functions in DNN model. Simulation results can achieve better performance in channel estimation with other schemes using DL-CE scheme in terms of bit error rate (BER) and signal to noise ratio (SNR).

### 2. Modeling of FBMC system.

The base band transmitting signal of FBMC in discrete time consists of even  $N_a$  subcarriers  $N_b$  time symbols, expressed as:

$$S[k] = \sum_{n_b=0}^{N_b-1} \sum_{n_a=0}^{N_a-1} x_{n_b,n_a} q_{n_b,n_a}[k] \quad (1)$$

Where  $x_{n_b,n_a}$  is the real valued data carried on the  $n_a^{th}$  carrier of  $n_b^{th}$  symbol,  $q_{n_b,n_a}[k]$  is pulse of the transmitter basis at TF point  $(n_b, n_a)$ , defined as:

$$q_{n_b,n_a}[k] = q[k - \frac{n_b N_a}{2}] e^{j(\varphi_{n_b,n_a} + \frac{2\pi n_a k}{N})} \quad (2)$$

Here  $q_{n_b,n_a}$  which is transmitter basis pulse acts as the synthesis filter corresponding to the  $n_b^{th}$  subcarrier at the  $n_a^{th}$  time instant,  $\varphi_{n_b,n_a}$  is normalized to  $\frac{\pi}{2}(n_b + n_a)$  and  $k$  is the length filter designed  $k = \mathbf{O} \cdot N_a$ , where  $\mathbf{O}$  denotes overlapping factor.

### 2.1 System Architecture.

FBMC's trans-receiver implanted with serial to parallel converter consists of initial modulation block, synthesis filter bank (SFB) and followed with a parallel to serial conversion in the transmitter. Similarly at receiver side connected with series to parallel converter, analysis filter bank (AFB) [8], followed by a demodulation block. The generic model of FBMC is shown in below figure.

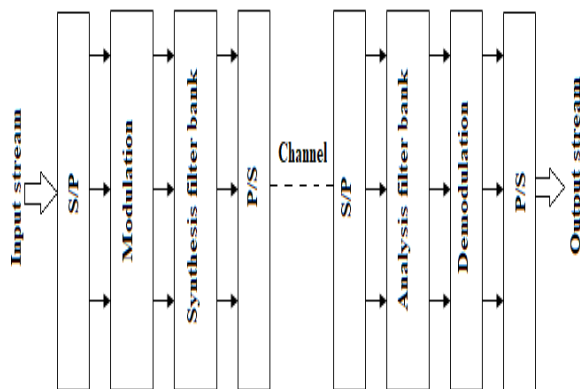


Figure 1: FBMC generic system

After transmitting over an additive white Gaussian noise (AWGN) channel at demodulation block, the received signal

$S[k]$  at the TF point  $(n_{b0}, n_{a0})$  represented as  $y_{n_{b0}, n_{a0}}$  as follows:

$$y_{n_{b0}, n_{a0}} = \sum_{n_b=0}^{N_b-1} \sum_{n_a=0}^{N_a-1} x_{n_b,n_a} * < q_{n_b,n_a}[k], q_{n_{b0}, n_{a0}}[k] > R \quad (3)$$

Where  $< q_{n_b,n_a}[k], q_{n_{b0}, n_{a0}}[k] > R$  represents real part of the internal product of  $q_{n_b,n_a}[k], q_{n_{b0}, n_{a0}}[k]$ . The synthesis filter satisfies the symmetrical property.  $< q_{n_b,n_a}[k], q_{n_{b0}, n_{a0}}[k] > R = \alpha_{n_b,n_{b0}} \alpha_{n_a,n_{a0}}$ , where  $\alpha_{n_b,n_{b0}} = 1$  if  $n_b = n_{b0}$ ;  $\alpha_{n_b,n_{b0}} = 0$  if  $n_b \neq n_{b0}$ , so the receiver can meticulously reclaim the transmitted data.

### 2.2 Problem formulation of Channel estimation and Equalization.

The above statements and equations, the synthesis filter of prototype  $q[k]$  in real field it remains orthogonal, if and only if the effects of the channel and noise are ignored. Although the streamed signal has imaginary interference at the output filter bank and expressed as:

$$\eta_{n_b,n_a}^{n_{b0}, n_{a0}} = < q_{n_b,n_a}[k], q_{n_{b0}, n_{a0}}[k] >, (n_b, n_a) \neq (n_{b0}, n_{a0}) \quad (4)$$

When  $(n_b, n_a) = (n_{b0}, n_{a0}), \eta_{n_b,n_a}^{n_{b0}, n_{a0}} = 1$ , otherwise  $\eta_{n_b,n_a}^{n_{b0}, n_{a0}}$  is zero or imaginary value. If we define  $H_{n_b,n_a}$  as the frequency response of channel linking (CFR) at  $p^{th}$  transmit and  $q^{th}$  receive antennas, received at  $q^{th}$  antenna is expressed as:

$$y_{n_{b0}, n_{a0}} = H_{n_{b0}, n_{a0}}^{(p,q)} + I_{n_{b0}, n_{a0}} + \eta_{n_{b0}, n_{a0}} \quad (5)$$

Where  $I_{n_{b0}, n_{a0}}$  represents corresponding wise components, many channel schemes are anticipated based on the ‘‘Interference approximation method’’ (IAM) [9], assuming flat frequency channel so that  $I_{n_{b0}, n_{a0}}$  can be expressed with in the neighborhood of  $(n_{b0}, n_{a0})$ .

$$I_{n_{b0}, n_{a0}} = j \sum_{n_b=0}^{N_b-1} \sum_{n_a=0}^{N_a-1} H_{n_b,n_a} x_{n_b,n_a} \eta_{n_b,n_a}^{n_{b0}, n_{a0}}, \quad (n_b, n_a) \in \Omega_{n_{b0}, n_{a0}} \quad (6)$$

At the adjacent TF points, the CFR is almost the same i.e.  $H_{n_{b0}, n_{a0}} \approx H_{n_b,n_a}$ , then equation (5) can be simplified to:

$$y_{n_{b0}, n_{a0}} = H_{n_{b0}, n_{a0}} a_{n_{b0}, n_{a0}} + \eta_{n_{b0}, n_{a0}} \quad (7)$$

$$\text{Where } a_{n_{b0}, n_{a0}} = x_{n_{b0}, n_{a0}} + j \sum x_{n_b,n_a} \eta_{n_b,n_a}^{n_{b0}, n_{a0}} \quad ((n_b, n_a) \in \Omega_{n_{b0}, n_{a0}}) \quad (8)$$

To calculate the approximation of CFR the transmitted data at the TF point  $(n_{b0}, n_{a0})$  and its immediate neighbors are known,  $a_{n_{b0}, n_{a0}}$  can be treated as pseudo pilot as follows:

$$\hat{H}_{n_{b0}, n_{a0}} = \frac{y_{n_{b0}, n_{a0}}}{a_{n_{b0}, n_{a0}}} \approx H_{n_{b0}, n_{a0}} + \frac{\eta_{n_{b0}, n_{a0}}}{a_{n_{b0}, n_{a0}}} \quad (9)$$

As ref [10], in the equalization phase, the data vector  $\mathbf{y}$  in equation (5) rewritten as:

$$\hat{\mathbf{y}} = [D][x] + Q^H \boldsymbol{\eta} = Q^H H Q[x] + Q^H \boldsymbol{\eta} \quad (10)$$

In which  $[x] = [x_{1,1} x_{1,2} \dots x_{1,Na} - x_{Nb,Na}]^T \in \mathfrak{R}^{NbNa \times 1}$  denotes the transmitted data bits vector,  $Q^H$  is the hermitian of transmit matrix.  $Q = [q_{1,1} q_{1,2} \dots q_{1,Na}; q_{2,1} \dots -q_{Nb,Na}] \in \mathfrak{R}^{L \times NbNa}$ , vector  $q_{na,nb} \in \mathfrak{R}^{L \times 1}$  represents the basis pulses in equation (2), where  $L$  is the total number of samples in time and  $[H] \in \mathfrak{R}^{L \times L}$  is convolution matrix of the channel.

$$\therefore [H] = \begin{bmatrix} H_{nb}^{(1,1)} & H_{nb}^{(1,2)} & \dots & H_{nb}^{(1,Na)} \\ \vdots & \ddots & \dots & \vdots \\ H_{nb}^{(Na,1)} & \dots & \dots & H_{nb}^{(Na,Na)} \end{bmatrix} \quad (11)$$

And transmitted real symbols by

$$[D] = [d_{nb,na}^{(1)} d_{nb,na}^{(2)} \dots d_{nb,na}^{Na}]^T \quad (12)$$

As the channel is time invariant, the off-diagonal elements becomes negligible for the transmission matrix  $D$ , a one tap zero forcing ( $Z_f$ ) equalizer is ample to obtain a nearly superlative equalization performance. Alternatively to have state of the art equalization performance a full block of minimum mean squared error (MMSE) [11] is derived but having complexity analysis to overcome the situation n-tap MMSE equalizer deal with only interferences from neighboring time symbols and subcarriers to maintain the channel as doubly selective.

### 3. Proposed method

#### 3.1 Deep Neural Network (DNN):

Deep Neural Networks achieved great success in communication systems in a wide range of applications including channel estimation, channel coding and decoding, signal detection in physical layer. DNN model can fit arbitrarily complex functions, extract and enact process features as long as the design is reasonable.

Generally using FFT the received signal is transformed in to frequency domain in conventional channel estimation scheme where the extraction of pilot symbols is done first followed by a simple one-tap  $Z_f$  equalizer compensates the distorted data symbols, whereas DL-CE scheme, the finite number of neuron layers are fully connected to each other. If the output of hidden layer is weighted sum of input values and biased value i.e.

$$y_{n,i+1} = \sum \omega_{j,i} x_{j,i} + b_{k,i+1} \quad (13)$$

In which  $\mathbf{b}$  denotes bias value,  $i$  denotes the index of layers,  $\omega$  denotes weight,  $k$  denotes neurons index and  $j$  is the processor layer. This over-all neuron layered structure set-up is activated using activation function of non-linearity nature which can be

the Re-Lu function and other functions ( $\sigma_r(t) = \max(0, t)$ ) or the sigmoid ( $\sigma_s(t) = \frac{1}{1+e^{-t}}$ ).

Therefore at the output layer the output sequences of  $\mathbf{y}$  represented as a non-linear cascaded transformation in terms of  $\mathbf{x}$  sequences from the input layer of DNN.

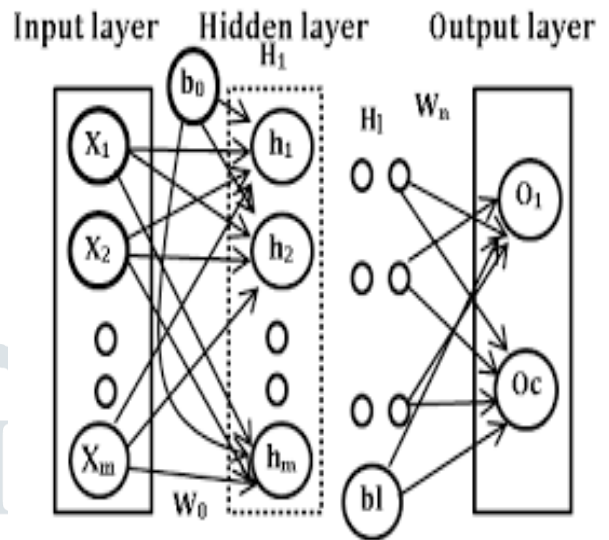


Figure 2: DNN architecture

#### 3.2 Training and testing of DL-CE scheme.

Practical channel models (such as Veh-A and Veh-B models) planted on a generous number of substantial measurements concede us to easily generate sufficient training samples, test samples as follows:

- i. At any rate generate a 4-QAM sequence using modulated frequency domain with length  $N$  and corner it in the first complex valued time intervals set as pilot blocks as a preamble.
- ii. Randomly generate a pack of binary bits and liberate as the training labels.
- iii. The generated sequences which are modulated in above steps are successively passing through schematic blocks such as OQAM staggering, IFFT, filter banks, superposition signal modules and finally the generated time-domain complex value transmitted signal fleeting through a varying channel included with AWGN noise with certain decibel.
- iv. Repeat the steps mentioned above till the severely distorted received signal in frequency domain complex sequences pass through the discussed schematic blocks then the partition of real and imaginary parts of these complex sequences gets separated and chronological order in to a long real valued sequence. In this pattern the training and testing of long real value sequence is executed.

### 3.3 Loss function.

It would be a contingent during the iterative training process with weights  $\omega$  and bias value  $b$  of DNN are updated by the Adam Optimizer [12] with learning rate of 0.001 intended to minimize the difference between the output sequences in terms of  $\hat{x}$  of DNN and the transmitted bits sequences  $\hat{d}$  continuously employed using a loss function expressed as:

$$Loss = \frac{1}{T} \sum_{t=0}^{T-1} (\hat{x}(t) - \hat{d}(\Delta_i + t))^2 \quad (14)$$

Where  $\hat{x}(t)$  is the  $t^{th}$  output estimated value of DNN  $\hat{d}(\Delta_i + t)$  is the  $(\Delta_i + t)^{th}$  transmitted bit of DNN,  $T$  is the number of neurons at the output layer of DNN. As suggested the training of single DNN model is done independently for the estimated bits per group which can be understood by following a below explanation details of a random example. During each training session consider 50-batches of generated samples of batch size set to 1000 with learning rate of 0.001 to minimize the loss value, the batch size of testing process is set to 10000.

### 4. Simulation Results

DL-CE Quick Dense based FBMC-OQAM is applied on channel estimation along with other existing schemes, various sets of simulation tests under the following channel models: Vehicular-A with 200 km/h, Vehicular-A with 500km/hr with subcarriers =128, transmitted signal frequency = 1GHz, over lapping factor = 4, modulation order = 2, fiber length = 1000kms, with DNN iterations = 60, with 20 epochs where 3 epochs per iteration having learning rate = 0.01, with SNR[dB] range up to 15dB.

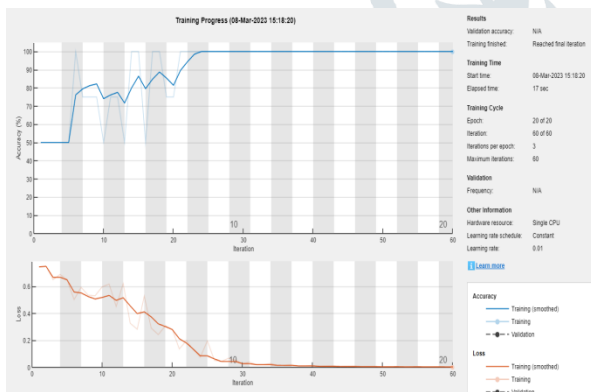


Figure 3 DNN training characteristics of Accuracy (%) and loss (%)

To verify the simulated results of quick dense DL-CE scheme shown in fig.4 confirm that the performance of DL-CE scheme in FBMC system which is splendid as the DL-based CE in OFDM system. Especially the results of QAM demapping module and also replaced with the DNN, known as DL-CE w/o demapping, consequently quick dense w/o demapping (FBMC), quick dense (FBMC), DL-CE (FBMC), DL (OFDM), MMSE (OFDM) [13] and so on and DL outputs are constructed based on it's training developed with predefined iterations shown in

fig.3. In which sigmoid activation function is replaced by the *Leaky Relu* activation function at the output layer.

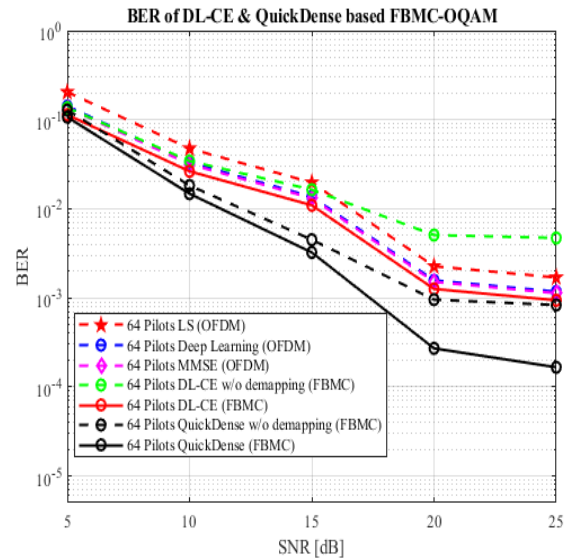


Figure 4: Channel estimation characteristics of proposed method vs conventional methods

Chanel equalization and estimation performance is executed between our quick dense DL-CE and many other enhanced IAM schemes on Vehicular-A channel, 200km/h is represented in fig.5 in which it states that our proposed quick dense DL-based scheme is quit independent usage of filter, but the conventional channel estimation and equalization design schemes depends on high level type of prototype filter.

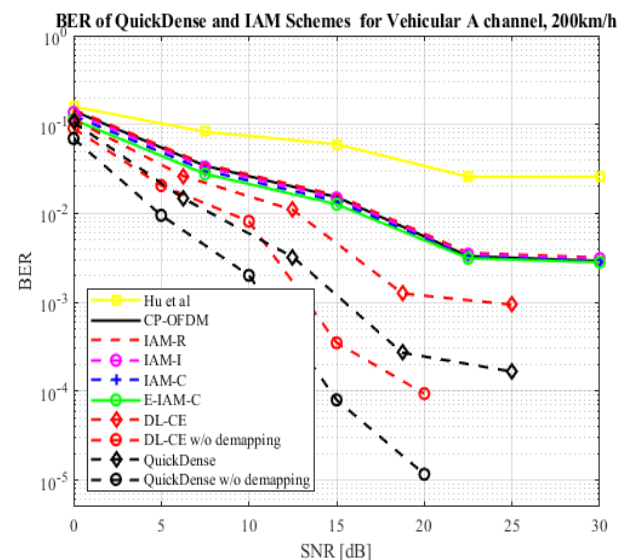


Figure 5: CE characteristics on Veh-A, 200km/h

Chanel equalization and estimation performance is executed between our quick dense DL-CE and many other enhanced IAM schemes on Vehicular-A channel, 500km/h is represented in fig.6 in which it states that our proposed quick dense DL-based schemes is far better than complete block of several n-tap MMSE equalizers[14] and MMSE equalizer. Thus the curves shown in below fig says that DL-CE w/o demapping and the



DL-CE scheme [15] explains that the findings about two parts, primary part says about the gain of the DL based equalization module and secondary part explains about gain obtained by the DL-based demapping module with addition of an adaptive modulation includes tested FBMC symbols are piece-wise modulated by  $4, 4^2, 4^3$  and  $4^4$ -QAM, finally the DL-CE scheme far effective

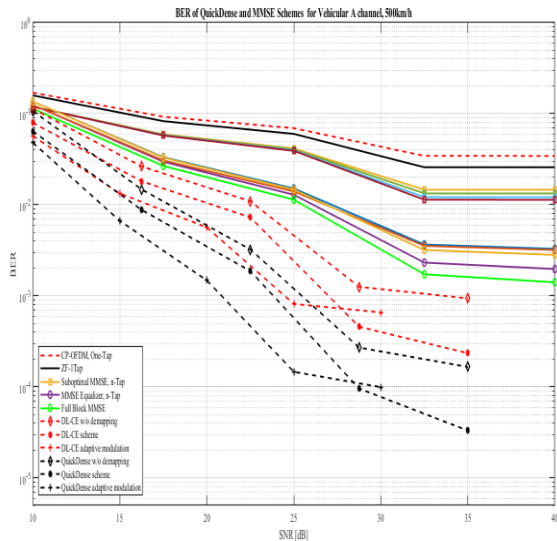


Figure 6: CE characteristics on Veh-A, 500km/h

## 5. Conclusions.

The channel estimation performance is enhanced for FBMC/OQAM systems due to the powerful learning ability of DNN model is discussed comparative analysis is done with conventional DNN base channel estimation DL-CE scheme and far exceeds that of other schemes. The proposed DL-CE and equalization scheme is independent of proto-type filters and only requires real valued symbols as the pilot block. This model ensures a new exclusive design of future FBMC application systems.

## References

- [1] Ihalainen, T., Hidalgo Stitz, T., Rinne, M. *et al.* Channel Equalization in Filter Bank Based Multicarrier Modulation for Wireless Communications. *EURASIP J. Adv. Signal Process.* **2007**, 049389 (2006). <https://doi.org/10.1155/2007/49389>
- [2] M. A. AboulDahab, M. M. Fouad and R. A. Roshdy, "A proposed preamble based channel estimation method for FBMC in 5G wireless channels," 2018 35th National Radio Science Conference (NRSC), Cairo, Egypt, 2018, pp. 140-148, doi: 10.1109/NRSC.2018.8354382.
- [3] Lacroix, D. & Javaudin, Jean-Philippe. (2002). A new channel estimation method for OFDM/OQAM. 7th International OFDM-Workshop, Hamburg. 2002.
- [4] Z. Zhao, M. C. Vuran, F. Guo and S. D. Scott, "Deep-Waveform: A Learned OFDM Receiver Based on Deep Complex-Valued Convolutional Networks," in *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 8, pp. 2407-2420, Aug. 2021, doi: 10.1109/JSAC.2021.3087241.

- [5] Varlamov, V.O.; Lobov, E.M.; Lobova, E.O. Investigation of FBMC-OQAM Equalization with Real Interference Prediction Algorithm Properties for MIMO Transmission Scheme. *Sensors* **2023**, *23*, 2111. <https://doi.org/10.3390/s23042111>
- [6] M. Soltani, V. Pourahmadi, A. Mirzaei and H. Sheikhzadeh, "Deep Learning-Based Channel Estimation," in *IEEE Communications Letters*, vol. 23, no. 4, pp. 652-655, April 2019, doi: 10.1109/LCOMM.2019.2898944.
- [7] T. Konishi, "A coded modulation scheme for 64-QAM with a matched mapping," 2014 International Symposium on Information Theory and its Applications, Victoria, BC, Canada, 2014, pp. 191-195.
- [8] Bedoui A and Et-tolba M (2021) A Deep Neural Network-Based Interference Mitigation for MIMO-FBMC/OQAM Systems. *Front. Comms. Net* 2:728982. doi: 10.3389/frmn.2021.728982.
- [9] E. Kofidis and D. Katselis, "Improved interference approximation method for preamble-based channel estimation in FBMC/OQAM," 2011 19th European Signal Processing Conference, Barcelona, Spain, 2011, pp. 1603-1607.
- [10] R. Nissel, F. Ademaj and M. Rupp, "Doubly-Selective Channel Estimation in FBMC-OQAM and OFDM Systems," 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), Chicago, IL, USA, 2018, pp. 1-5, doi: 10.1109/VTCFall.2018.8690864.
- [11] Khaled Abdulaziz Alaghbari, Heng-Siong Lim, Tawfig Eltaif, An improved least squares channel estimation algorithm for coherent optical FBMC/OQAM system, *Optics Communications*, Volume 439, 2019, Pages 141-147, ISSN 0030-4018, <https://doi.org/10.1016/j.optcom.2019.01.012>.
- [12] Z. Zhang, "Improved Adam Optimizer for Deep Neural Networks," 2018 IEEE/ACM 26th International Symposium on Quality of Service (IWQoS), Banff, AB, Canada, 2018, pp. 1-2, doi: 10.1109/IWQoS.2018.8624183.
- [13] X. Cheng, D. Liu, Z. Zhu, W. Shi and Y. Li, "A ResNet-DNN based Channel Estimation and Equalization Scheme in FBMC/OQAM Systems," 2018 10th International Conference on Wireless Communications and Signal Processing (WCSP), Hangzhou, China, 2018, pp. 1-5, doi: 10.1109/WCSP.2018.8555649.
- [14] Khaled Abdulaziz Alaghbari, Heng-Siong Lim, Tawfig Eltaif, An improved least squares channel estimation algorithm for coherent optical FBMC/OQAM system, *Optics Communications*, Volume 439, 2019, Pages 141-147, ISSN 0030-4018, <https://doi.org/10.1016/j.optcom.2019.01.012>.
- [15] Vilas Boas, E.C., e Silva, J.D.S., de Figueiredo, F.A.P. *et al.* Artificial intelligence for channel estimation in multicarrier systems for B5G/6G communications: a survey. *J Wireless Com Network* **2022**, 116 (2022). <https://doi.org/10.1186/s13638-022-02195-3>