A survey on UFMC filter designs for 5G M2M

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Abstract. As of now, the 5G attempts to address the current OFDM-based LTE issues, for example, Bit Error Rate (BER), Spectral Loss, Signal to Noise Ratio (SNR), Symbol Error Rate (SER) and high peak-to-average power ratio (PAPR). Universal-filtered multi-carrier (UFMC) method can be measured as an up-and-comer waveform for 5G correspondences since it gives advantages by minimizing the Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) reasonable for low-idleness situations. There are various filters for designing an UFMC which suits for a 5G application. This survey is carried out because of the Industrial 4.0 revolutionary is going on at a higher phase for which Machine to Machine (M2M) communication is widely required for suitability and reliability leading to the 5G requirement for high speed data transfer with appropriate filter design.

1. Introduction
The interest on high information transmission rates in remote applications is a main thrust being developed of adaptable remote correspondence innovation. 5G remote frameworks need to suit better amount of isolated relations with improved assist accessible and potential appliance, for example, Internet of Things (IoT), Massive MIMO Communications, Machine-to-Machine (M2M) and a lot extra which need Quality-of-service (QoS) limit similar to deferral, dependability and higher phantom vitality productivity. The newer innovations have to be made with several alterations in all the layers of Open Systems Interconnection (OSI) model removing the difficulties and not changing the required necessities. Specifically, waveform configuration have to be rethought meant for 5G as OFDM system may perhaps not exist reasonable for future remote applications because of more drawn out Transmission Time Interval (TTI). For matching the above applications the 5G development is a major requirement. Current LTE standards use FBMC or OFDM techniques which can be modified with UFMC. The cyclic prefix (CP) used in OFDM has longer length in the transmission which can be overcome by the short length utilized in the UFMC. In FBMC, the subcarriers are analyzed separately which executes for a longer amount of time whereas the UFMC reduces the time because of the analysis carried out for a group of subcarriers. The grouping activity also reduces the ICI between the carriers which are closer. In the method of synchronous communicative systems the carrier retrieval becomes hard enough because of Doppler move. Currently the Carrier Frequency Offset (CFO) in the UFMC is clearly studied to have better solution by the usage of Cyclic Prefix based Orthogonal Frequency Division Multiplexing (CP-OFDM) along with the novelties of Zero Forcing (ZF), Minimum Mean Square Error (MMSE). The Multi User (MU) UFMC is created with minimized SER, BER, SNR and PAPR. UFMC overcomes the OFDM by the parameter of SER in the situations of
multiuser points where the SER is exclusively lesser than that of the previous techniques used in OFDM methodology. UFMC with MMSE identification procedure beats the OFDM in the event of Multi User (MU) – UFMC and MU-MIMO – UFMC [1]. The 5G will be advancement to that of the current LTE standards under usage in terms of higher data rate transmission and reception. The reception of the signal is based upon the station estimation and it should be sound enough for any kind of structure in multi channel systems. The ISI reduction can be done well only with the help of a good Channel Estimation in a multi channel system. By and large, the techniques for the channel estimation can be of the methods like: customary channel estimation based on the Channel Frequency Response (CFR), Parametric Model (PM) - based channel estimation, Iterative Channel Estimation (ICE) and channel estimation for MIMO - OFDM frameworks. The basic structures used will be based upon the CFR-based channel estimation in most of the cased of communicative system. The channel estimations based on PM and the ICE is utilized for its perfection by the proper utilization of channel model. Both the PM and ICE models are not the same and has some similarities in the model. Henceforth the models of PM and ICE are good enough in the utilization of channel estimation terminology [2]. There are many filter banks for UFMC like Time Limited Filters, Band Limited Filters, Localized Filters. The analysis of PSD, BLER, BER and PAPR for the above filters suitably matches the UFMC [3], [7], [8]. The extended Kalman Filter technique used in channel estimation has a good BER performance compared with that of the normal channel estimation methodologies [4].

2. Channel Estimation
The training sequence is one parameter of a channel estimation which it highly depend upon which is based on the parameters of either frequency or its inversely proportionate property of time. This channel estimation has various contenders to it as follows:

2.1. Conventional Least Square
It is a common method for the estimation of channel in transmission of data. It is widely used in OFDM standards with the pilot based technique for the channel estimations. The estimation will be based on two data i) observed data and ii) expected value of data. The estimation will be done by reducing the square difference between the two data. The fundamental thought for the calculation of channel estimation is to find the pilot channel as a step one process as indicated by the realized nearby pilot reference sign, and afterward go through the straight addition technique to get information subcarrier direct estimation as per the attributes of pilot conveyance [9]. It estimates without considering the noise in the channel and the statistical characteristics of the channels. The interpolation errors will be a pathway for performance degradation in all means of the channel. The LS algorithm for UWA [10] was developed and it is highly receptive to the synchronization errors of frequency and noise. Here weighted average of the pilot symbol is utilized for the estimation and thereby the errors are greatly reduced. The LS algorithm performance changes with the changes in the lengths of the training sequences. The LS algorithm specifically for cognitive radio system has been designed for the analysis data detection [11]. For the purpose of frequency selective fading channel estimations the tracking potential needs to be improved. This is done with the inclusion of the variable forgetting factor in the algorithm. Thus resulting in a fast fading surrounding. The tracking capability happens due to the lacking in polynomial categorizations [12].

2.2. Minimum Mean Square
The next contender for the channel estimation schemes utilized for the OFDM is the Minimum Mean Square (MMSE). The estimation is done with the help of 2nd order statistics. The reduction of MMS is one of the basic procedures of any estimators used in OFDM schemes for communicative purposes. It is also nothing but the calculation with quadratic loss assignment. The MSE is based on finding two parameters basically. They are conditional expectation and minima of MSE. Linear types of MSE are also available for the channel estimations. But while utilizing the MMSE when compared with LS algorithms there is a change in parameters. Especially the power is 7dB higher than that of the LS [13]. The MSE for AWGN is calculated by the way of divergence. Evaluating the capacity of the
additive noise channel [14]. The MSE is less complexity compared to that of the LS. The LC-MSE is still more reduces the design complexity and its BER is also lesser [15]. The mismatch in a MSE could lead to errors in the estimation of channels and it is overcome by regret method. This is achieved with the help of deconvolution and dereverberation [16]. Linear Minimum Mean Square Error (LMMSE) is an optimized technique enhanced from the MMSE part which is more optimized in the case of the evaluation of the channel [17]. Minimum Mean Square Error Estimation (MMSEE) for a spatial channel model has been developed for the OFDM scheme based on the Maximum Likelihood Estimation (MLE). The Ment Carlo Method helps in getting the correct channel parameters. The BER performance is also upto the level while using the MMSEE. The main advantage in using the MMSEE in the scheme of OFDM is that it eradicates the intrinsic noise levels by utilizing the correct autocorrelation data [18].

2.3. Iterative Channel Estimation
The channel estimation is made with the help of Soft Decision Control Iterative Channel (SDC-ICE). Using this method the BER and MSE values are reliable and could be used for the IoT applications with minimum complexity [28].

2.4. Channel Estimation Based on Kalman Filter
The channel estimation in the Kalman Filter is a key technique which is based on the conditions of the entire structure of the architecture. In all the channel filters, the estimation errors are high enough. But the Kalman filter reduces that estimation error also [5].

Channel estimation dependent on Kalman channel is isolated into for the most part three stages.
Step 1: State Equation is given as: \( X_{k+1} = A X_k + B u_k + \text{Process Noise} (W_k) \) where \( A \) transition matrix, \( B \) input matrix and \( C \) measurement matrix.
Step 2: Measurement Equation is given as: \( y_k = C X_k + \text{measurement noise} (Z_k) \).
Step 3: Kalman filter equations are given as follows: (Estimator Equation) [6]
\[
K_k = A P_k C^T (C P_k C^T + S_z)^{-1} \\
\hat{x}_{k+1} = (A \hat{x}_k + B u_k) + K_k (y_k - C \hat{x}_k) \\
P_{k+1} = A P_k A^T + S_w - A P_k C^T S_z^{-1} C P_k
\]
Where, \( K_k \) is the Kalman gain, \( \hat{x}_{k+1} \) is the next state estimator, \( P_{k+1} \) is the estimation error covariance, \( A, B \) and \( C \) are matrices, \( k \) is the time index, \( u \) is the own input to the system, \( y \) is measured output of the system, \( S_w \) and \( S_z \) are the process noise (acceleration noise in a vehicle) covariance and measurement noise (instrumentation noise) covariance respectively [6].

The BER value is reduced with the help of the Extended Kalman. For all kinds of digital transmission if the BER is lesser it is much suitable for the M2M communications. Therefore in a UFMC for 5G it is better to utilize the extended Kalman Filter to have efficient and good channel estimation.

3. Channel Equalization
The data transmission in multi-channel is highly distorted due to the ISI. The ISI is more in OFDM standards because of higher amount of data are targeted in a minimum number of cycles. This will be more in the state of 5G communications hence even lot data than the LTE is going to be utilized in the 5G standards. The ISI has the symbols gets collided and imposing noise in the channel which is highly unavoidable and can be greatly reduced by proper utilization of the techniques. In 5G kind of communication it is known that the millimeter wave communication is the toughest contender but it will be imposing higher amount of ISI in the channel. To overcome the ISI standard techniques like adaptive equalization or must pertain to the use of some error correcting codes. The ISI occurs at the reception because of the transmission of signals uses various paths in reaching out the receiver. This various paths for the signal is due to various parameters like reflection, refraction, atmospheric ducting, ionospheric reflection. The various paths that the signal takes in reaching the receiver has different in lengths and time taken to reach the reception is also varied making it harder to calculate
and even correct it. The affecting parameters not only add the path to the signal it also adds up some interesting parameters of amplitude and phase to the signal. The amplitude gets distorted and it may increase or decrease based on the attenuation created by the external parameter. But the change in the phase of the signal has a greater effect at the receiving end of the signal. The ISI is usually high when the signal is going through the channel which is under the condition of band limited. The band limited channels allows only certain symbols to allow through it and thereby cancelling the other symbols which gives high increase in the ISI. The calculation of noise margin helps in analyzing the ISI for the symbol transmission. In 5G type of communication the symbols has to be passed surely through various paths and thereby the ISI will be higher.

So proper equalization techniques needed to be deployed for an efficient reception of the signal. Usually an adaptive equalizer is preferred for faster and efficient means. The Doppler spread is also reduced if we are utilizing the adaptive filter technique. The distortions that have occurred inside the channel has to be removed by the way of equalization technique. Some of the advanced ways of algorithm in equalization are discussed below which will be suitable for the 5G standards.

Minimum Mean Square Error – Decision Deedback Equaliser (MMSE-DFE), a kind of technique [20], [21], [22] reducing the ISI in a MIMO systems. Since it uses two states of error detection the equalization performance is much faster and has less BER.

One tap channel equalization is made with the help of angle based shifting in CFR which is used in Narrow Band (NB) applications. The Figure 1 indicates the structure utilized for one tap channel equalization for LTE [23].

![Figure 1. NB IOT system](image)

The 5G is going to be utilizing the band in a very narrower way and for these band applications [23] will be highly useful. The M2M will be having these kinds of standards for channel equalization. The equalization technique based on MMSE, ZF and MRC are a great companion for 5G because its performance is on the higher side. These equalizations are done for the Phydas filter with an impulse response given by:

\[ p[m] = \hat{p}[0] + 2 \sum_{k=1}^{K-1}(-1)^k \hat{p}[k] \cos \left( \frac{2\pi k}{KM} (m + 1) \right) \]  \hspace{1cm} (4)

The equalization matrices developed for the above mentioned techniques were given as follows:

\[ W_{ZF} = H^H \]  \hspace{1cm} (5)

\[ W_{MMSE} = (H^H H)^{-1} H^H \]  \hspace{1cm} (6)

\[ W_{MRC} = (H^H + \sigma^2 I_k)^{-1} H^H \]  \hspace{1cm} (7)

To improve the performance we need to go for more number of antennas at the reception [24]. The only disadvantage with that of increasing the antenna is that the space or the area that we need to allocate for the functionality.
For going by the applications of 5G the data transfer will be in the range of GB/S, for these applications a new kind of series adaption namely the Burst Mode Equalization is a good measure shown in Figure 3. It uses the status renewal for each burst. The structure is constructed with the help of two blocks of equalizer [25] for a Passive Optical Network (PON) as shown in Figure 2.

A discrete time model has been generated and is applied with linear MMSE equalizer to have better BER report for the signals as shown in Figure 4 [26]. The equation derived is given below:

$$y(kT_s) = \sum_{l=-L}^{L} x(lT_s) l_{k-l} + v(kT_s)$$  \hspace{1cm} (8)$$

The non linear equalization occurs due to the power amplifiers present in the transmitter block as shown in Figure 5. When the radiation power is limited, then automatically the overall effect will be getting reduced.

The received sequence is termed as follows [27]:

$$y_i = \sum_{l=0}^{L-1} h^* l_{l} x_{l-1} + n_i$$  \hspace{1cm} (9)$$

The probability of choosing the cluster is given by:

$$\rho_p = 1 - (1 - \frac{K!}{K^p})^p$$  \hspace{1cm} (10)$$

By utilizing the sparse characteristics of the mmWave new detectors are developed which helps in equalization of the channels. These are done with the help of KMC algorithm [27].

For a lower delay in the equalization sparse code multiple access plays a major role. This sparse code multiple access also gives a wide usage with its superior ability and band exploitation also.
This SCMA shown in Figure 7 is made with the help of a semi blind algorithm to find the equalization. The SCMA uses the constellation code book. This technique mainly concentrated on the multipath for getting more accuracy. If the multipath gets increased the performance will be degrading. Using the combination of the SCMA and semi blind algorithm for the multipath channels the system performance is more stable with reduction in the BER value [29]. The complete model [29] is shown in the Figure 6.

A residual neural network shown in the Figure 8 [30] category is applied in the channel estimation and equalization schemes of FBMC to have a superior BER value. The 5G has to utilize the MIMO where the estimation and equalization of channels are going to play a major part where the automatic learning of the situation is highly required. For these circumstances the neural network kind of strategy will be highly recommendable for better performance. The deep learning can be done for these categories for better development [30].

The preamble is a kind of recognized signal for both the transmitter as well as the receiver. This helps in the receiver part without any kinds of demapping errors. The discarding of the preamble takes place usually after the channel estimation occurs at the transceiver part. Using the preamble based correction in the channel the optimization achieved is greater for the Phydas filter concept [31]. The system model flow chart used in the reference [31] is shown in Figure 9.

4. Filters  
A filter circuit is an essential part in any communicative system which is able to pass the signal through it or does not allow the signal to go through it. It may be acting like a amplifier in some part of its construction. They are nothing but the data shaping filter which is of the form of FIR. The 5G utilizes the Multi Carrier Modulation schemes which will be enabled with the help of prototype filters. The filters which are going to be utilized must have good localization abilities in terms of time.
5G is going to utilize the UFMC structure which will have many number of sub bands of carrier signals. The filtering needs to be applied for each of the sub bands available in the signal. Hence the filtering is done for all the sub bands of frequencies it should be accompanied with the help of synchronization. While utilizing the filter it should not affect the BER or the PAPR of the system. Various types of prototype filters are available for the purpose of removing the error. The interference characteristics can greatly be reduced with the help of a proper design of a filter in a communicative channel. Reliability is another factor that the filters should satisfy for a greater extent possible. The multi carrier implementation will be leading to a problem of sub band interferences in a UFMC. The filter design and its function will determine the level of sub band interference. Fractional Powered Binomial Filter (FPBF) [32], [19] is a good method in reducing the sub band interference. This is achieved with a help of a single parameter. The filter coefficients are calculated using the FPBF [32]:

$$b_{FPBF} = [b_L]^\beta = \left[\frac{d_L}{\sum_{L=0}^{L_d} d_L}\right]^\beta$$

(11)

The FPBF kind of filter helps in reducing the interference for the side lobes as well as the adjacent channels. The PAPR also gets reduced when compared with that of the PHYDAS filter and Dolph-Chebyshev filters which are the designs used in UFMC [33].

![Figure 10. Resource Block Filter (RBF)](image)

The Resource Block split up is shown in Figure 10 [34]. The resource blocks of frequencies are created by the portion of closest subcarriers in the available frequency. The Figure 11 and Figure 12 depicts the Transceivers used in [34]. This block is utilized for a better spectrum distribution. However at higher SNR the performance gets degraded.

![Figure 11. RBF-OFDM Tx](image)

![Figure 12. RBF-OFDM Rx](image)

The transceivers of FBMC and UFMC are judge against and examine in the [35] work. The multicarrier Channels are well executed by the performance of the UFMC. Filter and Forward (FF) relay for an OFDM transmitter is shown in Figure 13 [35]. The model shown in the Figure 12 is only for SISO and not for the MIMO scheme. The predictability in relay model is better when compared with the repeater models used in other multicarrier models. Each and all connection in the relay model executes the SISO communication. It is a full duplex communication model.
Since the UFMC is of multicarrier type many sub bands are to be analyzed for better performance. Three parameters are compared with that of the Dolph-Chebyshev filter which is nothing but the Power Spectrum Density, Adjacent Channel Power Ratio and Complementary Cumulative Distribution Function. The PSD for a Dolph Chebyshev Filter will be good enough but the Kaiser Bessel Function Filter has greater improvement in terms of PSD. Mainly the Kaiser Bessel filter is intended to lessen the spectral seepage into the sub bands of the carrier signal [36]. The Kaiser Bessel window is given as [36]; The Kaiser Bessel filter works better at noisy circumstances also. The PAPR values are same as that of the Dolph-Chebyshev filter for the Kaiser Bessel function also.

\[ w_k(n) = \begin{cases} \frac{I_0(\beta)\left(1 - \left(\frac{n}{M/2}\right)^2\right)}{I_0(\beta)}, & \frac{M-1}{2} \leq n \leq \frac{M-1}{2} \\ 0, & \text{elsewhere} \end{cases} \] (12)

The wave shaping filter [37] executes the tradeoff between the various parameters of the UFMC. The filter is designed with the help of the criteria based on sampling, in band alteration, out of band production. This is achieved by converting the above said criteria into linear matrix inequations. The BER calculated is better when compared with that of other filter concepts. If a UFMC system is to be performed better then its BER should be lesser in that means the wave shaping filter has lesser BER when compared with the other traditional methods of filter concepts.

To have reduced PAPR and BER a mixture structure of Wavelet Filtering and DFT spreading is prepared [38]. The performance shows better even for the fading channels. The structure is shown in Figure 14 [38].

The DFT spreading mainly cut down the PAPR in the uplink broadcast achieved by scattering the power of the information prior to the IFET. The wavelet filter has the ability to reconstruct the original signal even with the asymmetrical shaping. This reduces the BER in the UFMC architecture.
Frequency sampling technique is a kind of methodology used in the prototype filter for a FBMC design. This could be achieved with a little modifiable constraint. The Trans-Multiplexer (TMUX) model shown in the Figure 15 utilizes the offset-QAM modulation for the subcarriers [39]. The optimizations of the parameters are also done in order to achieve greater efficiency using the TMUX model scheme. The optimization is analyzed for the parameters of Stop Band Energy (SBE), Total Interference (TOI) and Minimum Stop Band Attenuation (MSA) [39].

5. Carrier Frequency Offset
Synchronization is one of the important parameter in a communicative network. The transmitter and receiver should have better synchronization ability to have complete data transfer without any deviations. The communicative synchronization is based on the parameter of frequency where the transmitter and receiver frequency should be matched for proper communication. Since the UFMC has sub carriers to carry the information there is chance for the CFO to increase in a higher extent. The CFO will be mainly affecting the receiver part of the signal because the synchronization is achieved over at the receiver side only. The local oscillator which generates the synchronizing signal at the receiver plays a major part. The signal generated by the oscillator should synchronize with that of the carrier signal received by the receiver. The CFO will be higher in terms of 5G because of MIMO where multiple antennas are going to be functioning in receiving the signals. So a better way to estimate the CFO is a major parameter in designing a receiver. The CFO is also proportional to the values of ICI so minimized CFO will be automatically leading to a lesser ICI and reduced SNR value.

Interleave –Division Multiple Access is added with the UFMC and OFDM to see the performance and characteristics in [40]. The parameter considered is the CFO. The IDMA is used in order the improve the users. The structure for the system [40] is shown in the Figure 15. The CFO is controllable within a small range in a UFMC system. The structure shown in Figure 16 is for a single sub carrier and it can be increased based on the count of the subcarriers.

A preamble structure shown in Figure 17 is created in order to the synchronization reason to reduce the CFO. The spectrum effectiveness is greatly improved by utilizing this methodology. The CFO inference is completed with the Maximum Likelihood algorithm. The MSE performance is also compared with various multipath fading channels. The UFMC framework to accomplish exact recurrence counterbalance synchronization execution under multipath Rayleigh blurring channels with medium multifaceted nature [41].

**Figure 15.** Direct Form representation of TMUX model

**Figure 16.** Transceiver of a) OFDM and b) UFMC
6. Conclusion

5G requirements is indeed high for the M2M communications in all kinds of applications in the fields of automation in industries, medical fields, household appliances, security systems, traffic systems, garbage clearance systems etcetera. For developing these applications the standards paves a way in achieving it. Various standards and parameters are discussed in this survey which includes Channel Estimation, Channel Equalization, Filters and Carrier Frequency Offset. All these parameters are derived and executed using various methodologies. Each method has its own benefits and some disadvantages. This article will help in developing a good 5G standard for a specific M2M communication.

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