



HAL
open science

Performance of Universal Filtered Multicarrier Channel Estimation with Different Pilots arrangements

Kawtar Zerhouni, Fouzia Elbahhar, Raja Ellassali, Khalid Elbaamrani

► **To cite this version:**

Kawtar Zerhouni, Fouzia Elbahhar, Raja Ellassali, Khalid Elbaamrani. Performance of Universal Filtered Multicarrier Channel Estimation with Different Pilots arrangements. 5GWF 2018, IEEE 5G World Forum, Jul 2018, Santa Clara, United States. pp327-332, 10.1109/5GWF.2018.8517030 . hal-03236622

HAL Id: hal-03236622

<https://hal.science/hal-03236622>

Submitted on 26 May 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Performance of Universal Filtered Multicarrier Channel Estimation with Different Pilots arrangements

Kawtar ZERHOUNI, Fouzia ELBAHHAR
LEOST
IFSTTAR
Villeneuve d'Ascq, France
{kawtar.zerhouni, fouzia.boukour}@ifsttar.fr

Raja ELASSALI, Khalid ELBAAMRANI
TIM, ENSA
Cadi Ayyad University
Marrakesh, Morocco
{r.lassali, elbaamrani}@uca.ma

Abstract—Universal Filtered MultiCarrier(UFMC) is a spectrally efficient waveform that applies per-subband filtering to reduce the Out Of Band emissions. Thanks to the orthogonality in complex plane, UFMC retains the simplicity of conventional OFDM while addressing its drawbacks. One of the main advantages of UFMC is its compatibility with the existing OFDM techniques. For instance channel estimation can be built based on OFDM one. Hence in this paper, we address the pilot aided channel estimation. To this end we propose to use the scattered pilot arrangement for UFMC under a fast varying channel. The results reveal that despite the difference in channel gain between subcarriers in UFMC, scattered pilot arrangement has good performance with the minimum number of pilots compared to block and comb type arrangement.

Index Terms—5G waveform, UFMC, pilots pattern, Channel Estimation, Doppler effect.

I. INTRODUCTION

Mobile communications are reshaping the economic growth of the world. In fact, they have become an indispensable part of the daily routines of millions of people around the globe, which led to an explosion of connected wireless devices. Supporting the various requirements of these devices is a daunting task for 4G system, as it relies on Orthogonal Frequency Division Multiplexing (OFDM) on its physical layer. In fact, it has been recognized that OFDM has several limitations. Using Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) blocks, OFDM has a low complexity implementation. However, in an OFDM based communication, strict synchronization is required to maintain subcarriers orthogonality, and the use of a Cyclic Prefix (CP) is essential to prevent Inter Symbol Interference (ISI). Furthermore, CP-OFDM suffers from high Out Of Band (OOB) emissions, all of which involves large signaling overhead and reduces the spectral efficiency. To overcome these shortcomings, in the last few years, 5G research focused on designing non-orthogonal waveforms, with relaxed synchronization needs and lower sidelobe levels. The most promising waveform candidates for 5G are filtered versions of OFDM, each applying a different pulse shape [1] [2].

Universal Filtered Multi-Carrier (UFMC) is one of the most

attractive 5G waveforms, and was first introduced in [3]. It offers a good trade-off between performance and complexity and is suitable to support multiple services [4]. Applying filtering per groups of subcarriers [5] (namely subbands), UFMC achieves low OOB emissions while keeping the simplicity of OFDM [6]. In fact, UFMC decomposes the frequency spectrum into narrow-band orthogonal subcarriers in the complex plane, making the use of the OFDM knowledge straightforward [6]. This holds for the Multiple Input Multiple Output (MIMO) support, Peak-to-Average Power Ratio (PAPR) reduction, pilots structure as well as channel estimation techniques.

In this paper, we focus on pilots pattern and pilots based channel estimation in UFMC. Both of which can be built based on the techniques developed for OFDM. In the literature, mainly three pilots arrangements are used, the Block type, the Comb Type and the scattered pattern. Block type channel estimation for UFMC has been studied in [7], while the comb type has been addressed in [8]. Both these patterns have been studied in low mobility environment. Our goal however, is to evaluate UFMC performance in high speed scenarios. Hence in this work, we propose the use of scattered pilots pattern in UFMC, to perform channel estimation over a fast fading channel. Being a filtered version of OFDM, UFMC has different filter gains at different subcarriers [8], which may alter the performance of scattered pilots compared to OFDM. The results however, reveal that like OFDM, when the pilots spacing in time and frequency are chosen carefully, the scattered arrangement reduces the number of pilots used while retaining a good performance. This pattern show similar results to the comb one for UFMC in a fast varying channel, while outperforming the block-type arrangement.

The remainder of this paper is organized as follows. Section II introduces the system model used herein. Section III presents the pilots arrangements considered as well as the studied channel estimation techniques. In section IV the simulation environment and results are presented. Finally, section V concludes this work.

II. SYSTEM MODEL

In this paper, we consider a system model as depicted in Fig. 1. A data source generates random bits, which are then modulated using a Quadrature Amplitude Modulation (QAM) mapping. Afterwards, the mapped data is rearranged in a time-frequency grid, and N_p pilots are inserted following one of the patterns described in section III-A. This grid is then shaped in multicarrier symbols, using either UFMC or OFDM waveform, before passing through the wireless channel. At the receiver side, the multicarrier symbols are demodulated using the corresponding waveform. The received frequency-domain pilots are extracted to perform channel estimation using either a Least Squares (LS) or Minimum Mean Square Error (MMSE) estimation as described in section III-B1. A simple zero forcing equalizer is then applied before the QAM demodulation. Finally, the system Bit Error Rate (BER) is computed by comparing the transmitted bits to the received ones. It should be mentioned that the block "Filter Equalization", presented in gray color, is used only for UFMC symbols.

In the sequel, the most important blocks of the presented diagram are further explained.

A. Channel model

In order to investigate the effect of high mobility on UFMC, we consider the following complex baseband time varying channel model:

$$h(t, \tau) = \sum_{l=0}^{L_{ch}-1} h_l(t) \delta(\tau - \tau_l) \quad (1)$$

where L_{ch} denotes the number of propagation paths τ_l , and $h_l(t)$ is the time varying channel gain associated to the l -th path.

The time-frequency correlation function of the channel can be expressed as [9]:

$$R(\Delta f; \Delta t) = R_t(\Delta t) R_f(\Delta f) \quad (2)$$

Where $R_f(\Delta f)$ denotes the spaced-frequency correlation of the considered channel. Considering a Tapped-delay line multipath fading with known Power Profile Delay (PDP), $R_f(\Delta f)$ is given by (3):

$$R_f(\Delta f) = \sum_{l=1}^{L_{ch}} P_l e^{j2\pi \Delta f} \quad (3)$$

On the other hand, $R_t(\Delta t)$ is the spaced-time correlation. For a fading channel with a Jakes Doppler Spectrum it is given by (4):

$$R_t(\Delta t) = J_0(2\pi f_d \Delta t) \quad (4)$$

where J_0 denotes the first kind of zero-th order Bessel function, f_d is the maximum Doppler shift. The correlation in this case is measured over the time separation Δt , and the frequency separation Δf .

B. Signal model

Mainly two waveforms are considered in this work, UFMC and conventional OFDM.

In UFMC scheme, the entire band of subcarriers N_c is subdivided into S subbands, with Q subcarriers each. A prototype filter of length L , shifted to the appropriate subband frequency [5], is then used to filter each subband. Hence, each UFMC baseband signal is the superposition of the subband wise filtered subcarriers [5]. The discrete signal can be expressed as follows:

$$x_{ufmc}[n] = \sum_{s=0}^{S-1} g_s[n] \otimes x_s[n] \quad (5)$$

where \otimes denotes linear convolution and $g_s[n]$ is the filter used in the s -th subband. It is defined as in (6) :

$$g_s[n] = g[n] e^{j\frac{2\pi Q/2n}{N_c}} e^{j\frac{2\pi(S_0+sQ)n}{N_c}}. \quad (6)$$

$g[n]$ is the prototype filter of length L , and S_0 denotes the starting frequency of the lowest subband. $x_s[n]$ is the s -th group of subcarriers. It is given by (7):

$$x_s[n] = \sum_{q=0}^{Q-1} s_{s,q} e^{j\frac{2\pi qn}{N_c}} e^{j\frac{2\pi(S_0+sQ)n}{N_c}} \quad (7)$$

where $s_{s,q}$ are the complex symbols (both data and pilots) transmitted on the q -th subcarrier in the s -th subband. UFMC waveform transforms the QAM modulated symbols to time domain, with an Inverse Discrete Fourier Transform (IDFT) of length N_c . The term $e^{j\frac{2\pi(S_0+sQ)n}{N_c}}$ performs frequency shifting of both the data and filter coefficients to the appropriate subband [5].

Considering the multipath channel model described in section II-A, the received UFMC signal can be expressed as follows:

$$y_{ufmc}[n] = h[n] \otimes \sum_{s=0}^{S-1} g_s[n] \otimes x_s[n] + z[n] \quad (8)$$

where $z[n]$ denotes an additive Gaussian noise with variance σ_z^2 .

Because of the convolution with the subband filter, UFMC signal length is $N_{ufmc} = N_c + L - 1$. Hence an efficient receiver proposed in [2], performs a $2N_c$ -point DFT then discards the odd subcarrier, as they carry only interference. Without loss of generality, the received signal after these operations can be written as follows:

$$Y_{ufmc}(k) = H_{ufmc}(k) \sum_{s=0}^{S-1} G_s(k) X_s(k) + Z_{ufmc}(k) \quad (9)$$

where Y_{ufmc} , H_{ufmc} , G_s , X_s and Z_{ufmc} are the $2N_c$ -point DFT of their time domain counterpart, after discarding the odd subcarriers [7]. Knowing that the subcarrier k belongs to the subband s [7], (9) can be expressed as follows:

$$Y_{ufmc}(k) = H_{ufmc}(k) G_s(k) X_s(k) + Z_{ufmc}(k) \quad (10)$$

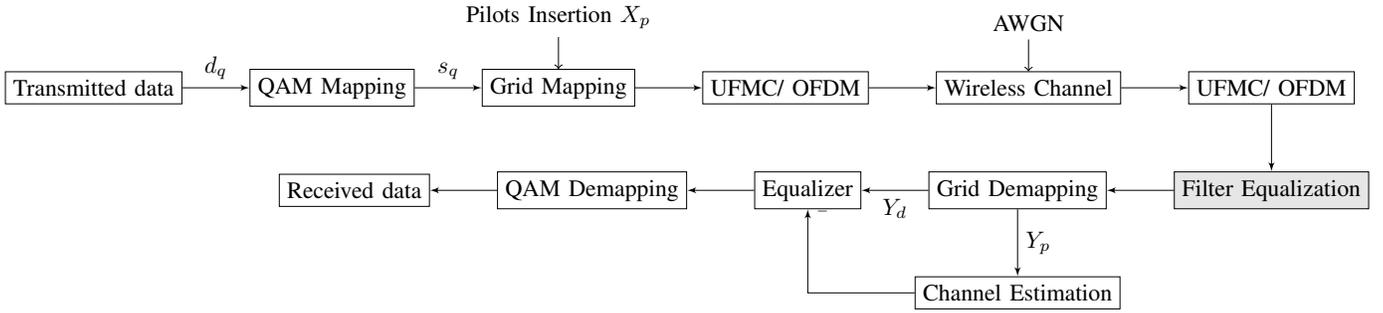


Fig. 1: System model

On the other hand, in the conventional OFDM scheme, the QAM symbols (data and pilots) s_q , are transformed to time domain using an IDFT [10]. It is expressed as in (11):

$$x_{ofdm}[n] = \sum_{q=0}^{N_c-1} s_q e^{j \frac{2\pi q n}{N_c}} \quad (11)$$

To combat ISI, a CP is inserted in each OFDM symbol. The symbol length is then given by $N_{ofdm} = N_c + N_{cp}$. Where N_{cp} denotes the cyclic prefix length.

Considering the multipath channel, the received OFDM signal can be given by:

$$y_{ofdm}[n] = h[n] \otimes \sum_{q=0}^{N_c-1} s_q e^{j \frac{2\pi q n}{N_c}} + z[n] \quad (12)$$

At the receiver side, the CP is first discarded before applying a Discrete Fourier Transform (DFT):

$$Y_{ofdm}(k) = H_{ofdm}(k)X(k) + Z_{ofdm}(k) \quad (13)$$

where Y_{ofdm} , H_{ofdm} , X and Z_{ofdm} are the N_c -point DFT of their time domain counterpart. Before further analysis, it should be noted that, in this paper, OFDM CP and UFMC filter length L are chosen to mitigate ISI introduced by the multipath channel.

In the following section, we present the patterns considered to insert the pilots in the time frequency grid.

III. PILOT ARRANGEMENTS AND CHANNEL ESTIMATION

A. Pilots arrangement

Fig. 2a depicts a block-type arrangement, where a multicarrier symbol with pilots at all its subcarriers is transmitted periodically. As all subcarriers contain a pilot, such a strategy is suitable for frequency-selective channels. In order to track the variation of channel characteristics in time, the pilots time-spacing, P_t , should be as frequent as the channel coherence time is [11]. Hence P_t should satisfy the following criteria:

$$P_t \leq \frac{1}{f_d} \quad (14)$$

where f_d denotes the maximum Doppler frequency.

Estimation in fast-fading channels on the other hand, can be performed using the comb-type pilots arrangement, as presented in Fig. 2b. In this configuration, pilots are periodically

inserted at specific subcarriers, in every multicarrier symbol. In order to estimate the channel along the frequency-axis, frequency-domain interpolation is used [11]. This allocation can be advantageous if the pilots frequency-spacing, P_f is smaller than the coherence bandwidth of the channel:

$$P_f \leq \frac{1}{\tau_{max}} \quad (15)$$

where τ_{max} denotes the maximum delay spread.

To get the best of the two aforementioned arrangements, the strategy depicted in Fig. 2c can be adopted. In Scattered-type, also known as lattice-type, pilot tones are inserted in spaced intervals, in time and frequency along the two axes. This strategy facilitate time/frequency-domain interpolations, if the pilot symbol arrangement satisfies both Equations (14) and (15) [11]. When chosen accordingly, the number of pilots needed is significantly reduced compared to the previous designs as will be numerically explained in the simulation section.

B. Channel estimation

Based on the known pilots symbols, a raw channel estimation is first performed. For OFDM signal it is expressed as:

$$\hat{H}_{ofdm}(p) = X(p)^{-1}Y_{ofdm}(p) \quad (16)$$

For UFMC on the other hand, the raw channel estimation at the pilots subcarriers p can be written as [7]:

$$\hat{H}_{ufmc}(p) = (F_s(p)X_s(p))^{-1}Y_{ufmc}(p) \quad (17)$$

where $(\cdot)_{sp}$ means the pilot belonging to the s -th subband. F_{sp} is the known filter frequency response at the pilot subcarrier. From (16) and (17), it is clear that UFMC channel estimation differs from OFDM one only by the filter response. Hence, in the system model diagram (Fig. 1), we propose to add a filter equalization block to account for the filter impact on UFMC received signal, as suggested in [7]. This operation makes UFMC signal equivalent to OFDM afterwards. Hence in the sequel, we drop the $(\cdot)_{ufmc}$ and $(\cdot)_{ofdm}$ subscripts.

1) *Least Squares Estimation:* The least Squares estimation method finds the \hat{H}_{LS} channel estimate by minimizing the following cost function [11]:

$$C(\hat{H}_{LS}) = \left\| Y - X\hat{H}_{LS} \right\|^2 \quad (18)$$

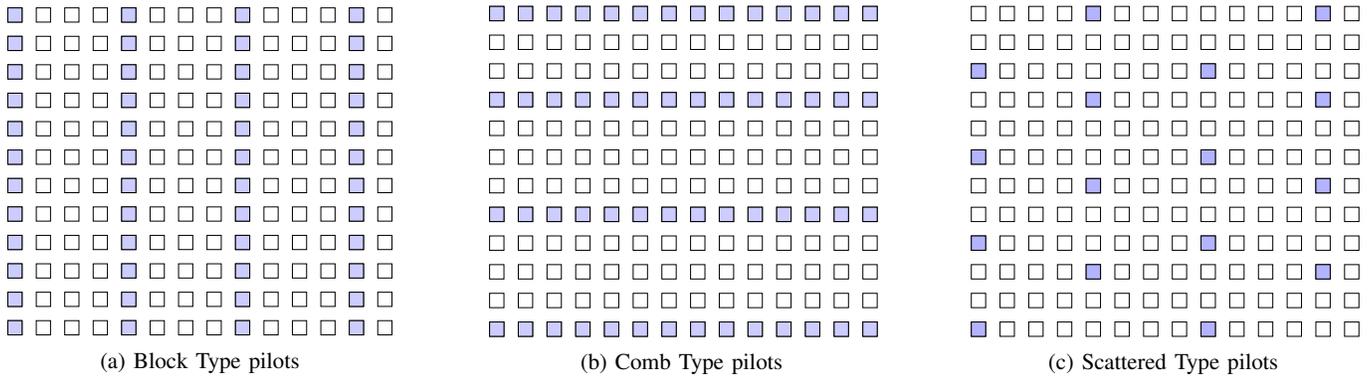


Fig. 2: Pilots arrangement

The solution of equation (18) gives the LS estimation as follows:

$$\hat{H}_{LS} = X^{-1}Y \quad (19)$$

For the Block-type pilots pattern, the LS estimation at the symbol pilot is exactly the raw channel estimation. An interpolation in time is then performed to estimate the channel frequency response along time axis. For the comb-type on the other hand, an interpolation in frequency domain is needed to estimate the channel at the non-pilots subcarriers of each symbol. Finally, for the scattered pilots arrangement, a 2D-interpolation method can be performed to estimate the channel at the entire grid. Due to the computational complexity of 2D-interpolation, estimation is first performed on frequency domain then over time domain.

The LS estimation Mean Square Error (MSE) is given by:

$$MSE(\hat{H}_{LS}) = E[(H - \hat{H}_{LS})^H (H - \hat{H}_{LS})]$$

$$MSE(\hat{H}_{LS}) = \frac{\sigma_{noise}^2}{\sigma_{signal}^2} \quad (20)$$

where σ_{noise}^2 and σ_{signal}^2 denote noise and signal variance respectively. It is worth mentioning that, because of the $2N_c$ -point DFT at the UFMC receiver, the noise variance is enhanced. The noise variance of UFMC received signal is given by $\frac{N_c+L-1}{N_c}\sigma_z^2$ [7]. For OFDM on the other hand, the CP is discarded before applying the DFT and the noise variance doesn't change.

2) *MMSE Estimation*: MMSE estimation minimizes the expected mean-squared error between the actual and estimated channel [11]. To this end, MMSE uses the knowledge of spaced-time and spaced-frequency correlation functions introduced in section II-A to filter the LS estimation. The MMSE filter coefficients are given by:

$$F_w = R_H(R_H + \sigma_{noise}^2(XX^H)^{-1})^{-1} \quad (21)$$

where R_H denotes the channel autocorrelation matrix which can be computed from the time-frequency correlation function. Finally, the MMSE channel estimation is then given as:

$$\hat{H}_{MMSE} = F_w \hat{H}_{LS} \quad (22)$$

In the next section, we will compare the presented pilots patterns. Our goal is to evaluate the suitability of scattered pilots for UFMC, specifically for fast varying channels.

IV. SIMULATIONS AND DISCUSSIONS

This section provides numerical results comparing between the different pilots patterns for UFMC as well as OFDM. Table I summarizes the simulation parameters. These parameters are inspired from the LTE recommendations. One subframe is considered herein, which contains 2 slots of 7 multicarrier symbols each.

In order to evaluate the impact of mobility on the different patterns, the 3GPP Vehicular A channel model is considered. Its PDP is given in [12], and its Doppler spectrum follows a Jakes model.

The maximum delay of this model is $2.51\mu s$. Considering the sampling time of the signals, the receivers can efficiently mitigate the effect of ISI. For OFDM, this delay is within the CP duration which is $4.68\mu s$. For UFMC on the other hand, the filter ramp-up and ramp-down at the edges of the symbol guarantees a soft protection against ISI. In fact, the energy contained in the L last samples (or $4.68\mu s$ duration) of UFMC signal is relatively small.

TABLE I: simulation parameters

Parameter	Symbol	Value
IDFT size	N_c	1024
Subcarrier spacing	Δf	15 kHz
Number of used subcarriers	N_{usc}	600
Sampling time	T_s	$\frac{1}{\Delta f * N_c}$
OFDM		
Cyclic prefix length	N_{cp}	72
UFMC		
Number of Subbands	S	50
Subband size	Q	12
Filter Type	-	Dolph-Chebyshev
Filter length	L	73
Filter attenuation(dB)	-	40
Channel Model	-	3GPP Vehicular A

The pilots spacing are chosen to meet the equations in (14) and (15). The maximum target speed in our scenario is 300 km/h. Considering a carrier frequency of $f_c = 2 GHz$, the

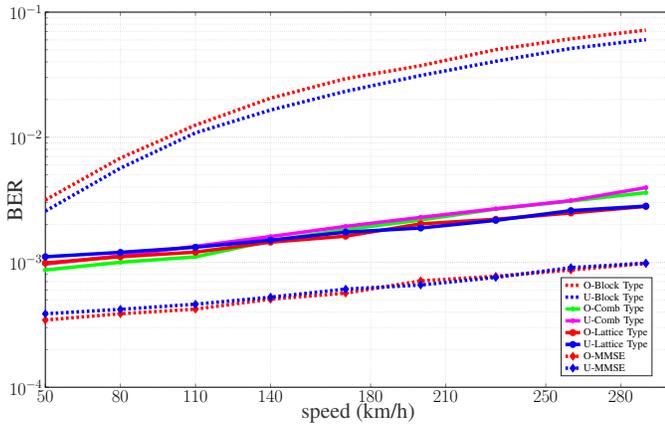


Fig. 3: Patterns comparison

maximum Doppler is $f_d = 555 \text{ Hz}$. Given Nyquist's sampling theorem, the minimum sampling period required to reconstruct a channel with this Doppler shift is $T_{s_{min}} = 1/(2f_d) \approx 0.9 \text{ ms}$. This implies that at least one reference symbol per slot is needed in the time domain in order to estimate the channel correctly. For the Block type pattern, one symbol pilot is considered per slot, which is then used in all the other symbols of the same slot. Considering the number of used subcarriers N_{usc} , the total number of pilots in this configuration is 1200 (2 symbols of N_{usc} each). For the Comb type, the separation between pilots is set to 8 subcarriers in each symbol, which results in 1050 pilots in total. Finally, for the scattered arrangement, pilots are inserted every 6 subcarriers, in two symbols per slot, the 1st and 4th. Which gives 4 symbols total in the time-frequency grid. This pattern has the lowest pilots tones, 400 total. A spline interpolation is used to compute the channel estimate of the entire grid along the frequency and time axis.

Fig. 3 shows the BER performance of the different configurations, for the two waveforms UFMC and OFDM. The speed of the receiver is varying from 50 to 300 Km/h. It is worth noting that UFMC has better performance for the Block-type. As this pattern does not perform well in fast-varying channels, UFMC benefits from its own robustness to frequency offsets compared to OFDM. It is clear that the comb-type arrangement outperforms the block-type one for both waveforms. In fact, as the pilots are transmitted in each symbol, the comb-pattern allows tracking of the time varying channel. For the block type, using 2 pilot symbols per slot might increase the performance, however, it will incur too much overhead. The results show also that the scattered pattern slightly outperforms the comb-type while using the lowest number of pilots. Hence, scattered pattern allows fast fading channels to be estimated, with reduced overhead. The lower pilots number in this configuration, guarantees a higher data rate compared to the two other designs. It is also worth noting, that despite the filter gain differences among subcarriers, once the "filter equalization" is performed, UFMC benefits greatly from this arrangement. An interesting observation from these results, is that both comb and lattice pattern are less affected

by the increasing Doppler shift. The performance degrades, however, the variation is slow.

Finally, the estimation is also performed using MMSE. For clarity reasons, only the MMSE results for scattered arrangement are presented in Fig. 3. As expected, MMSE estimation outperforms LS one, but introduces computational complexity.

V. CONCLUSION

In this paper, we evaluate the suitability of different pilots arrangements for the new 5G waveform UFMC, specifically in high speed channels. First of all, we give a comprehensive review of the different pilot patterns for channel estimation. Then we propose the use of scattered pilots arrangement for UFMC under a fast varying channel. The considered patterns are then applied for both UFMC and OFDM. By performing the filter equalization prior to channel estimation, the know-how of OFDM is easily applicable. The main difference between the two schemes is the noise variance which is enhanced in UFMC because of the $2N_c$ -point DFT. With the right choice of pilots spacing, the proposed scattered pattern reduces the number of pilot tones while slightly outperforming comb arrangements. These results further assess the superiority of UFMC over OFDM. UFMC achieves similar performance to OFDM without the use of the CP, and with relaxed synchronization needs.

ACKNOWLEDGMENT

The present research work has been supported by SAFER-LC H2020 European Project, InterCor Project, ELSAT 2020 and ANR-CYCLOPE project. ELSAT 2020 project is co-financed by the European Union with the European Regional Development Fund, the French state and the Hauts de France Region Council.

REFERENCES

- [1] A. Bourdoux, P. De Doncker, F. Horlin, "The Performance of emerging multi-carrier waveforms for 5G asynchronous communications," EURASIP Journal on Wireless Communications and Networking, Feb. 2017.
- [2] T. Wild, F. Schaich, Y. Chen, "5G air interface design based on Universal Filtered (UF-)OFDM," Digital Signal Processing International Conference, pp. 699-704, Aug. 2014.
- [3] V. Vakilian, T. Wild, F. Schaich, S.T. Brink and J.F. Frigon, "Universal-filtered multi-carrier technique for wireless systems beyond LTE," IEEE Globecom Workshops (GC Wkshps), 2013.
- [4] L. Zhang, A. Ijaz, P. Xiao, A. Qudus and R. Tafazolli, "Subband Filtered Multi-Carrier Systems for Multi-Service Wireless Communications," IEEE Transactions on Wireless Communications, 2017.
- [5] M. Matthe, D. Zhang, F. Schaich, T. Wild, R. Ahmed, and G. Fettweis, "A Reduced Complexity Time-Domain Transmitter for UF-OFDM," Vehicular Technology Conference, vtc IEEE, July 2016.
- [6] Deliverable 5GNOW, "Final 5GNOW Transceiver and frame structure concept," 2015 May.
- [7] X. Wang, T. Wild, F. Schaich, and S. Brink, "Pilot-aided Channel Estimation for Universal Filtered Multi-Carrier," Vehicular Technology Conference, vtc IEEE, Sep. 2015.
- [8] L. Zhang, C. He, J. Mao, A. Ijaz, and P. Xiao, "Channel Estimation and Optimal Pilot Signals for Universal Filtered Multi-carrier (UFMC) Systems," IEEE PIMRC Workshop WS-09 on "New Radio Technologies (NR)", Oct. 2017.

- [9] A. Varma, C. Athaudage, L. Andrew, and J. Manton, "Optimal Superimposed Pilot Selection for OFDM Channel Estimation, IEEE Signal Processing Advances in Wireless Communications, 2006.
- [10] R. Datta, D. Panaitopol, and G. Fettweis, "Cyclostationary detection of 5G GFDM waveform in cognitive radio transmission," Ultra-WideBand, ICUWB IEEE, Sept. 2014.
- [11] Y.Cho , J.Kim, W.Yang, and G. Kang, "MIMO-OFDM Wireless Communications with MATLAB," Wiley Publishing, 2010.
- [12] 3rd Generation Partnership Project Technical Specification Group RAN1; E-UTRA Physical Channels and Modulation," (Release 10) V10.0.0.