Complexity analysis on 5G Candidate waveforms for DVB-T2: A survey

Anne-Carole Honfoga
Electromagnetism and Telecommunications Department
University of Mons
Mons, Belgium
anne-carole.honfoga@umons.ac.be

Michel Dossou
LETIA (of Polytech. Sch. of Abomey-Calavi)
University of Abomey-Calavi
Calavi, Benin
michel.dossou@epac.uac.bj

Véronique Moeyaert
Electromagnetism and Telecommunications Department
University of Mons
Mons, Belgium
veronique.moeyaert@umons.ac.be

***Abstract*—In this work, a literature review of filter-based waveforms proposed in the Digital Terrestrial Television (DTT) standard context improvement is presented. It also compares low complexity algorithms of Filter Bank Multicarrier (FBMC) and Universal Filtered Multicarrier (UFMC) applied to the next generation of Digital Video Broadcasting-Terrestrial, second generation (DVB-T2) system. As known, Orthogonal Frequency Division Multiplexing (OFDM) and both FBMC and UFMC have common characteristics like the use of Fast Fourier Transform (FFT) in their functional blocks diagram. However, the FBMC and UFMC are mainly based on different filtering operations, which induce a high implementation complexity but present a better performance in a broadcasting system when compared to the classical OFDM. Their computation complexity is studied to highlight the optimal low complexity algorithm. Furthermore, the compromise between FBMC and UFMC waveforms applied to DVB-T2 in terms of Signal to Noise Ratio (SNR) performance gains, spectral efficiency, and complexity is established. This paper shows that UFMC is a good compromise as its complexity is reduced to the same complexity as OFDM while having advantages.**

***Index Terms*—Spectral efficiency, broadcasting, gain, complexity, filtering, UFMC, FBMC, DVB-T2**

I. INTRODUCTION

In the past few decades, multicarrier modulations have been the object of many researche pieces to increase the system capacity and spectral efficiency [1]. Indeed, OFDM is the waveform used in many communication systems like the European broadcasting standard DVB-T2 [2], mobile communication standards Long Term Evolution (LTE) [3], and 5G [4], G3-Power Line Communication (PLC), and HomePlug AV2. It presents a high performance in the presence of fading channels compared to single carrier modulation. However, OFDM has some hindrances like the mandatory use of Cyclic Prefix (CP) to deal with Intersymbol Interference (ISI), the induction of a higher Out Of Band (OOB) power leakage, the use of large guards band to deal with Adjacent-Channel Interference (ACI).

Hence, for 5G communications, filter-based waveforms are proposed. This system is designed to provide a better performance for specific services with high data rate, [5] and some waveforms do not need a CP as well. The multicarrier waveforms meeting the requirements as aforementioned proposed to enhance DVB-T2 are called UFMC and FBMC [6]–[8]. The filtering operation is done per subcarrier in FBMC, whereas this is done per sub-band in UFMC. The transmission performance of these waveforms in fading channels has been highlighted compared to OFDM and shown that UFMC outperforms FBMC, which in turn outperforms OFDM. However, filtering operation done in these waveforms induces a high complexity.

To reduce their complexity using different techniques is the work of many. However, a comparison of all complexity reduction algorithms proposed in the literature is not published yet. Neither their implementation complexity for the next generation enhancement broadcasting is presented, to the best of our knowledge. This paper aims to establish first a technical comparison of low complexity FBMC and UFMC implementation algorithms and in second, to apply this review to the DVB-T2 system context.

The paper is structured as follows. Motivations about FBMC and UFMC application in DVB-T2 are depicted (§I). Multicarrier modulations and their complexities are respectively presented (§II and §III). (§IV) presents low complexity algorithms. Finally, the paper concludes with a discussion and a conclusion (§V and §VI).

II. MOTIVATION OF THE APPLICATION OF 5G WAVEFORMS IN DVB-T2 TRANSMISSION

DVB-T2 is the standard published by European Telecommunications Standards Institute (ETSI) in 2009. It presents better performance than the first generation DVB-T published in 1997 because of the increase in capacity (from 31.67 Mbps to 50.32 Mbps), the network coverage, the flexibility of choice of parameters, and the evolved version of Forward Error Correction (FEC) coding [2]. This allows the system to be deployed worldwide, mainly in Europe and Africa. With the advent of 5G standard, the audiovisual signal broadcasting service is forecasted in the recommendations [4]. It is foreseen to work with both Low Power Low Tower (LPLT) and High Power High Tower (HPHT) networks. It means that complementarity is required between 5G and digital broadcasting networks. FBMC and UFMC have been proposed for 5G mobile communications. They have also been tested on the DVB-T2 set of parameters, as both systems are anticipated

978-1-6654-0306-1/21/$31.00 ©2021 IEEE

to have a complementarity. It has been proved that these waveforms were bringing DVB-T2 closer to the Shannon limit than classical OFDM. The DVB-T2 system and its parameters are presented in [9], [2]. The possible subcarriers numbers in DVB-T2 are 1K, 2K, 4K, 8K, 16K and 32K (with $K = 1024$).

III. Classical waveforms blocks diagram

In this section OFDM, UFMC and FBMC blocks diagram are briefly presented and compared.

A. OFDM

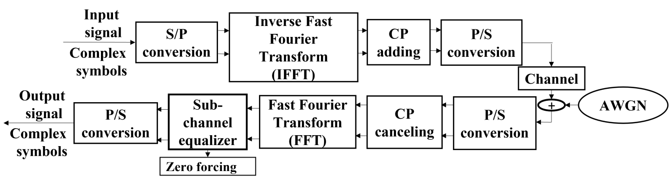

Fig. 1. CP-OFDM block diagram

The OFDM transceiver scheme is presented in Fig 1. On the transmitter side, a set of complex symbols is mapped onto a set of orthogonal carriers using Quadrature Amplitude Modulation (QAM) as a symbol mapping method. The serial to parallel conversion follows this. Afterwards, an Inverse Fast Fourier Transform (IFFT) converts the frequency domain signal into a time-domain signal. Finally, a CP, which represents the partial copy of the signal, is inserted at the beginning of each symbol. The reverse operations are performed on the receiver side. The main drawbacks of OFDM are the use of CP to deal with channel impairment and the use of a large guard band to protect adjacent channels, resulting in reduced OFDM spectrum efficiency.

B. FBMC

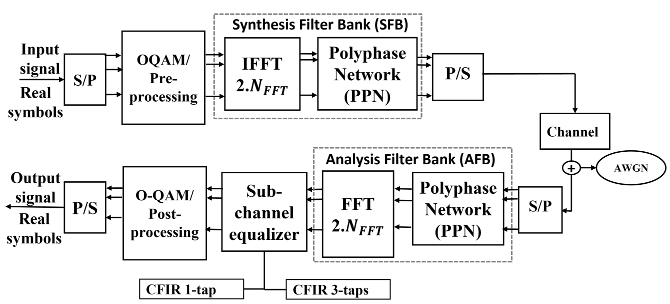

Fig. 2. FBMC block diagram

FBMC and OFDM are both based on the FFT algorithm. The difference is that the IFFT block is followed by a set of digital filters called Polyphase Network (PPN) [10] in this FBMC implementation approach (cf. Fig. 2). The set of IFFT and PPN blocks is called Synthesis Filter Bank (SFB) on the transmitter side. On the receiver side, the set of blocks called FFT and PPN is called Analysis Filter Bank (AFB). The filtering operations are performed per subcarrier. Moreover, Offset-QAM (OQAM) modulation is used in the FBMC instead of QAM modulation in OFDM. This technique is used in FBMC to exploit the total system capacity conjointly with the transmultiplexer response obtained back to back (FBMC transmitter-receiver) using a digital filter bank.

Indeed, the digital PPN filters bank is well localized in the frequency domain, and their implementation is based on the Nearly Perfect Reconstruction (NPR) technique which satisfies the classical Nyquist criterion. These filters have specific features, such as the non-overlapping of the subcarriers with an odd or even index. Only the contributions of immediate neighbor subcarriers appear on the primary subcarrier. This feature is used to transmit the QAM symbol only on even or odd subcarriers. Nevertheless, this method induces the loss of half of the system capacity. Orthogonality is required between two successive subcarriers to achieve total system capacity. OQAM is then used to transmit real symbols. Hence, the Fourier transform operation is performed twice the sampling time used in OFDM. Fig. 3 shows QAM and OQAM symbol mapping respectively in OFDM and FBMC. QAM in-phase and quadrature components are staggered by half of the symbol period (T). Although OQAM is useful in FBMC, its joint implementation with the Multiple Input Multiple Output (MIMO) technique is not straightforward.

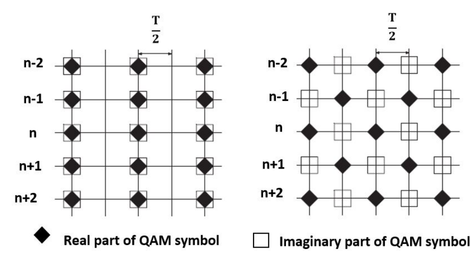

Fig. 3. OFDM (left) and FBMC (right) symbols mapping on subcarriers

C. UFMC

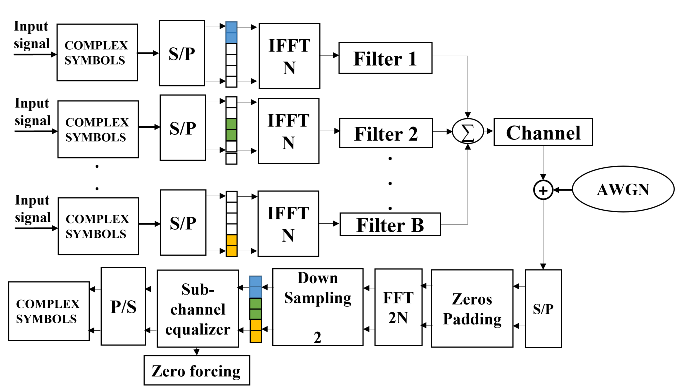

Fig. 4. UFMC block diagram

UFMC is a waveform that inherits all the advantages of FBMC and OFDM while avoiding their drawbacks. The input data is the complex symbol instead of real symbols in FBMC.

Fig. 4 presents the block diagram of a UFMC transceiver chain. Its main parameters are the filter length L, the Side Lobe Level (SLL), the sub-band number B and the sub-band bandwidth M_{NB} (width of subcarrier number which carried QAM symbols). The filtering operation is only performed in emission. Indeed data obtained after QAM (complex data) is subdivided into B sub-bands where each sub-band data undergo processes such as IFFT and filtering. The pulse shape filter used is the Chebyshev window. Before IFFT processing, the QAM symbols of each sub-band are padded by $N_{FFT} - M_{NB}$ zeros. After IFFT, N_{FFT} filter coefficients are computed, and the filtering operation is applied on each sub-band of N_{FFT} data. The Rx stage comprises $2.N_{FFT}$ FFT points, which are then decimated by a factor of 2 to recover the data [11].

IV. Classical waveforms complexity computation

This section presents the computational complexity of classical OFDM, FBMC, and UFMC transceiver (transmitter and receiver). The complexity is quantified in terms of the total number of real multiplications per symbol. The signal processing operations involved in the generation of the multicarrier signal have been considered. Moreover, operations involved during the equalization have been considered. As the FFT operation is commonly used in the three modulations processing (OFDM, UFMC, and FBMC), we focus on the methods used in the literature to compute its complexity. Finally, the complexity of the three waveforms is computed.

A. IFFT/FFT processing

The commonly used algorithms in several works to compute FFT complexity are the split-radix [12] and the modified split-radix [13]. The split-radix is implemented by assuming that complex multiplications are implemented with three real multiplications and three real additions. In contrast, the modified split-radix is implemented by assuming that complex multiplications is implemented with four real multiplications and two real additions. As the computational complexity of the multiplication operator is much higher than that of the addition operator, our study is focused on the number of real multiplications. When computing the number of real multiplications used during the FFT/IFFT processing, the expressions resulting from the split-radix and the modified split-radix methods are respectively obtained in (1) and (2). Among these methods, the split-radix algorithm is the most used in the computation of the filter-based waveform's complexity. N_{FFT} is the number of subcarriers used for the Fourier transform operation.

$$C_{FFT}(N_{FFT}) = N_{FFT}(\log_2(N_{FFT}) - 3) + 4 \tag{1}$$

$$\begin{aligned} C_{FFT}(N_{FFT}) = {} & \frac{34}{9} N_{FFT} \log_2(N_{FFT}) - \frac{124}{27} N_{FFT} \\ & - 2\log_2(N_{FFT}) - \frac{2}{9}(-1)^{\log_2(N_{FFT})} \\ & + \frac{16}{27}(-1)^{\log_2(N_{FFT})} \log_2(N_{FFT}) + 8 \end{aligned} \tag{2}$$

B. OFDM complexity

As previously mentioned, OFDM consists of IFFT operation followed by the CP insertion and the windowing operation on the transmitter side. On the receiver side, it consists of FFT followed by a single tap equalization. Let us consider M_{OFDM} be the number of subcarriers used to transmit data on each OFDM symbol. Where N_{FFT} is the whole number of subcarriers and L_{CP} is the CP length. Therefore, the complexity of the OFDM transceiver presented in (6).

$$C_{OFDM}^{T_x} = C_{FFT}(N_{FFT}) + 4.(N_{FFT} + L_{CP}) \tag{3}$$

$$C_{OFDM}^{R_x} = C_{FFT}(N_{FFT}) + 4.M_{OFDM} \tag{4}$$

$$C_{OFDM} = C_{OFDM}^{T_x} + C_{OFDM}^{R_x} \tag{5}$$

$$\begin{aligned} C_{OFDM} = {} & 2.(N_{FFT}.(\log_2(N_{FFT}) - 3) + 4) \\ & + 4(N_{FFT} + L_{CP} + M_{OFDM}) \end{aligned} \tag{6}$$

C. UFMC complexity

The IFFT operation is processed per sub-band and is followed by the filtering operation, as discussed earlier. Let us remind that B is the sub-band number and M_{NB} the number of data symbols per sub-band while considering that M_{UFMC} the number of data symbols on each symbol. On the transmitter side, each sub-band contains M_{NB} data symbols and zero samples to have a length equal to N_{FFT}. The IFFT and filtering operations are done per sub-band of N_{FFT} samples containing M_{NB} data and $N_{FFT} - M_{NB}$ zeros. On the receiver side, the FFT transform is done on $2.N_{FFT}$ instead of N_{FFT}. This is followed by the equalization term ($4.M_{UFMC}$). UFMC transceiver complexity is shown in (10).

$$C_{UFMC}^{T_x} = B.C_{FFT}(N_{FFT}) + 4B.N_{FFT}.L \tag{7}$$

$$C_{UFMC}^{R_x} = C_{FFT}(2.N_{FFT}) + 4.M_{UFMC} \tag{8}$$

$$C_{UFMC} = C_{UFMC}^{T_x} + C_{UFMC}^{R_x} \tag{9}$$

$$\begin{aligned} C_{UFMC} = {} & B.(N_{FFT}.(\log_2(N_{FFT}) - 3) + 4) \\ & + 4B.N_{FFT}.L + 2.N_{FFT}.((\log_2(2.N_{FFT}) \\ & - 3) + 4) + 4.M_{UFMC} \end{aligned} \tag{10}$$

D. FBMC complexity

The FBMC implementation includes the IFFT and the FFT operations, the OQAM symbol mapping and the polyphase filters. It is notable here that the FFT operation is performed on twice the number of sub-carriers used in OFDM. All operations performed in the FBMC are processed with ($2.N_{FFT}$). It is also necessary to consider the phase shift induced by the OQAM pre and post-processings ($2.2.N_{FFT}$). Furthermore, the complexity caused by the filtering operation ($2.2.K.N_{FFT}$) is taken into account. The multiplication operation of each data by the filter coefficient induces two real multipliers. Let us consider L_{eq} the number of coefficients used per sub-carrier for equalization. For Complex Finite Impulse Response (CFIR) 1 and 3-taps equalizers, we used in previous studies [6], L_{eq} is respectively equal to 3 and 1.

Thus, the complexity of the FBMC transceiver is presented by (14).

$$C_{FBMC}^{T_x} = 2.C_{FFT}(N_{FFT}) + 4.N_{FFT} + 4K.N_{FFT} \quad (11)$$

$$C_{FBMC}^{R_x} = 2.C_{FFT}(N_{FFT}) + 4.N_{FFT} + 4.K.N_{FFT} + 4.L_{eq}.N_{FFT} \quad (12)$$

$$C_{FBMC} = C_{FBMC}^{T_x} + C_{FBMC}^{R_x} \quad (13)$$

$$C_{FBMC} = 2.(2.(2.N_{FFT} + 2.K.N_{FFT} + (N_{FFT}.(log_2(N_{FFT}) - 3) + 4)) + 2.L_{eq}.N_{FFT})) \quad (14)$$

Fig. 5 presents the waveforms' computational complexity when K varies for FBMC and B varies for UFMC. One can observe that FBMC complexity increases with the overlapping factor and the subcarrier number. However, the gap between the complexity of FBMC with K=3 and FBMC with K=4 is negligible. It can be seen that using the classical implementation method, UFMC is at least 100 times more complex than OFDM and FBMC is 5 times more complex than OFDM using the PPN implementation method. The following section summarizes low complexity algorithms for FBMC and UFMC. Note that these algorithms present a negligible signal performance loss.

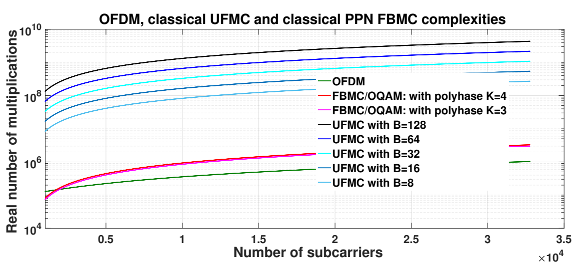

Fig. 5. OFDM, FBMC and UFMC complexity comparison starting from $N_{FFT} = 1024$

V. Low complexity implementations of filter-based waveforms

A. FBMC

The algorithms proposed in the literature focus mainly on reducing the factor two of samples used to perform the Fourier transform in both the transmitter and the receiver classical FBMC [14]. When one algorithm focuses on reducing the cost of two FFT samples operation by combining two purely real input symbols into one complex symbol, the other algorithm focuses on using only the odd or even samples indices to perform the FFT operation (called pruned FFT) [15].

1) First algorithm [15], [16]: In the classical PPN method, due to the OQAM pre and post-processing, the FFT and filtering operations are done on twice the number of samples used in OFDM. This induces a high complexity in FBMC. For complexity reduction, the two real input symbols are combined as one complex input symbol, reducing the cost of two FFTs to one (17).

$$C_{FBMC-M1}^{T_x} = C_{FFT}(N_{FFT}) + 2K.N_{FFT} + 4.N_{FFT} \quad (15)$$

$$C_{FBMC-M1}^{R_x} = C_{FFT}(N_{FFT}) + 4.N_{FFT} + 2.K.N_{FFT} + 2.L_{eq}N_{FFT} \quad (16)$$

$$C_{FBMC-M1} = 2(C_{FFT}(N_{FFT}) + 4.N_{FFT} + 2K.N_{FFT} + L_{eq}.N_{FFT}) \quad (17)$$

2) Second algorithm [17]: This algorithm focuses on the identification of the symbols' indices needed to compute the FFT butterflies. It takes advantage of the complex conjugate symmetry between odd and even indices of the IFFT frame. So, the Fourier transform computes only the even indices and the data is extended by computing samples of odd indices using the results of the even index. Instead of a standard IFFT, a pruned IFFT is used, and $N_{FFT}/2$ samples are used instead of N_{FFT} for the Fourier transform and the filtering operations (20).

$$C_{FFT}(N_{FFT}/2) = N_{FFT}/2.(\log_2(N_{FFT}/2) - 3) + 4$$

$$C_{FBMC-M2}^{T_x} = 2.C_{FFT}(N_{FFT}/2) + 2K.N_{FFT} + 4.N_{FFT} \quad (18)$$

$$C_{FBMC-M2}^{R_x} = 2.C_{FFT}N_{FFT}/2 + 4.N_{FFT} + 2.K.N_{FFT} + 4.L_{eq}.N_{FFT} \quad (19)$$

$$C_{FBMC-M2} = 2.(2.C_{FFT}N_{FFT}/2 + 2K.N_{FFT} + 4.NFFT + 2.L_{eq}.N_{FFT}) \quad (20)$$

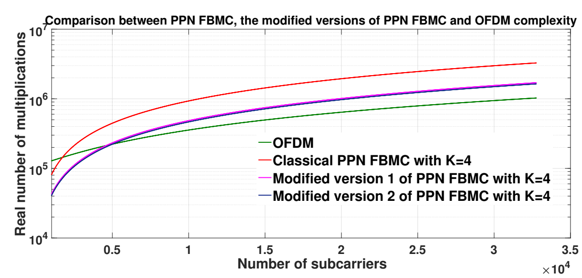

Fig. 6. OFDM and FBMC complexity comparison using the modified versions of FBMC

(17) and (20) indicates that the complexity increases with the sub-carrier number. However, the sub-carrier number needed to process FFT and the filtering is reduced with the second algorithm (modified version of PPN FBMC). This method allows the reduction in complexity. Fig. 6 presents FBMC complexity when the modified versions are used. One can notice that the complexity is further reduced and equals two times the OFDM complexity.

B. UFMC

The proposed algorithms focus on two parts of the transmitter. There is a reduction in the number of subcarriers used for the Fourier transform and the filtering operations. Some algorithms focus on the sub-carrier number or the filtering operation, while others focus on the two methods.

1) In [17]–[20]: These authors focus on the use of the reduced version of the FFT samples number. Instead of N_{FFT} samples for the Fourier transform, N_0 number of samples is used. Also, the FFT operation is followed by the upsampling operation of factor f. Note that $f = \frac{N_{FFT}}{N_0}$. Using this method, filter impulse response is real and filtering is performed only on samples different from zero. Instead of using complex filter coefficients, real filter coefficients are applied only on non-zero samples. The complexity of UFMC at the transmitter can be modified as presented on (21). For example, if $N_{FFT} = 1024$ and the sub-band bandwidth is $M_{NB} = 64$, the upsampling factor equals 16. This method is less complex than the classical one.

$$C^{T_x}_{UFMC} = BC_{FFT}(N_0) + 2BN_0(L) \tag{21}$$

2) In [21], [22]: These authors focus on both the reduction of the samples number used to perform the Fourier transform and the filter prototype used to perform the filtering.

[21] focus their researches on the use of the filtering per sub-group. Instead of computing the filter coefficients of M_{NB} samples, the filtering operation is performed per sub-group using the same filter coefficients for each group. The sub-group is formed by dividing adjacent subcarriers into groups in the sub-band. Using this method, three sub-carriers groups become the optimal number, generating an approximate version of the UFMC signal with negligible performance loss. When one sub-group is used, the filtering coefficients are the same for all the subcarriers in the sub-band, with the noticeable signal performance loss. UFMC complexity is then reduced to 3.6 times when the three subcarriers group are used. As the single-filter (one subcarrier group filtering) reduces UFMC complexity to 1.2 times that for OFDM and induces in counterpart a loss of the signal spectra accuracy, it would be suitable for low capacity receivers that do not require accurate signals.

[22] focus their study on both the IFFT operation and the kind of filter used in UFMC transmitter. Instead of performing the IFFT operation on N_{IFFT}, this operation is performed on the number of data samples for each sub-band. This technique is called lightweight FFT. Also, a low pass FIR or a linear phase filter is used instead of a pass band FIR in the classical UFMC implementation. The computational complexity of the UFMC transmitter can be divided into three parts: one is the B lightweight IFFT operations of length M_{NB}, the second is the B interpolation sequences with low pass FIR filters of length L, and the third is the frequency shift operations on the time domain signals of B sub-bands.

- Case of a low pass filter: the complexity of the B lightweight IFFT of size M_{NB} is $B.C_{FFT}(M_{NB})$. The complexity of the B FIR filters of length L is $4B.M_{NB}.L$.The frequency shifting complexity of the B sub-bands time domain signals is $4.B.(N+L-1)$. The reduced UFMC transmitter complexity can be summarised to (22).

$$\begin{aligned} C^{T_x}_{FIR-UFMC} &= B.C_{FFT}(M_{NB}) \\ &\quad + 4.B.M_{NB}.L + 4.B.(N + L - 1) \end{aligned} \tag{22}$$

- Case of a linear phase filter: The term which changes is the complexity term of the B linear phase FIR filters of length L. This is equal to $2.B.M_{NB}.L$. The UFMC transmitter complexity is reduced to (23).

$$\begin{aligned} C^{T_x}_{FIR-UFMC} &= B.C_{FFT}(M_{NB}) \\ &\quad + 2.B.M_{NB}.L + 4.B.(N + L - 1) \end{aligned} \tag{23}$$

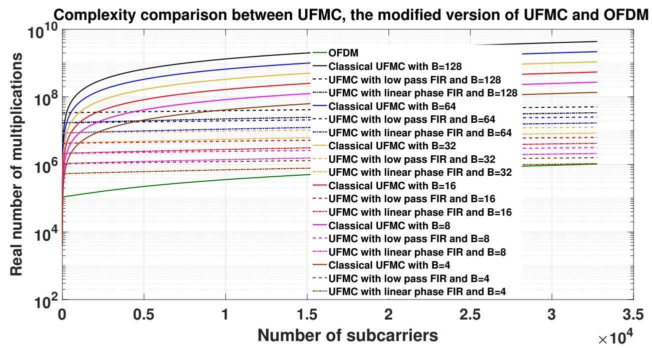

Fig. 7. OFDM and UFMC complexity comparison using the modified versions of UFMC

Fig. 7 presents the complexity of OFDM compared to the classical UFMC, UFMC with low pass FIR and UFMC with linear phase filter. As stated earlier, UFMC is 100 times more complex than OFDM using the classical UFMC scheme. Using the modified versions of UFMC, its complexity is equal to complexity of OFDM when the sub-carrier number increases. Also, this complexity does not quickly increase with the sub-band number, as noticed for the classical UFMC complexity. For subcarrier number ≤ 1024, both low pass and linear phase filters UFMC complexities are at least 5 times higher than OFDM complexity. After 1024, low stability of the complexity is noticed when OFDM complexity increases. A reduction is noticeable among these algorithms when the linear phase FIR is used instead of the Chebyshev or low pass windows. The lightweight FFT is used to reduce the number of sub-carriers regularly used in the processing.

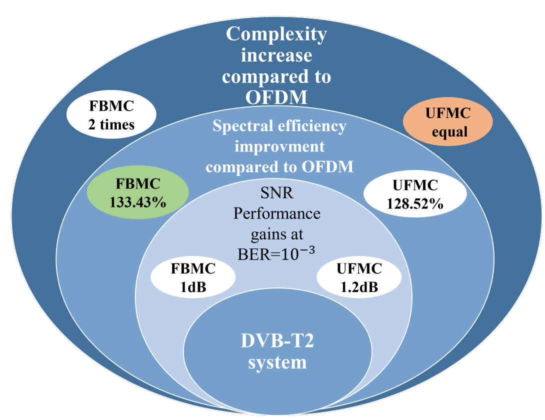

Fig. 8. DVB-T2 system using filter-based waveforms

TABLE I
FBMC AND UFMC COMPLEXITY FACTOR COMPARED TO REFERENCE OFDM

Algorithms	Description	Factor
Classical PPN FBMC	FFT and filtering processing on 2 times N_{FFT} used in OFDM	5
PPN FBMC V1 [15], [16]	FFT and Filtering operation processing on N_{FFT} instead of $2.N_{FFT}$	1.8
PPN FBMC V2 [17]	Subcarriers number reduced to $N_{FFT}/2$ (Pruned IFFT)	1.75
Classical UFMC	IFFT and filtering operation done per sub-band (on $N_{FFT} samples$) using Chebyshev window	100 at least
Algorithms from [17]–[20]	N_{FFT} reduced to N_0 (a divisor of N_{FFT}) – factor varies with N_0 and N_{FFT}	50 at least
Algorithm from [21]	Filtering is performed by sub-group created within sub-band (1 or 3 sub-group) – $N_{FFT} = 1024$	single filter: **1.2**; 3-filter: **3.6**
Algorithm from [22]	Reduction of N_{FFT} (lightweight FFT) and filtering using low-pass and linear phase FIR	Low pass:**1.4**; linear phase:**1**

VI. DISCUSSION

In this work, the complexity of FBMC and UFMC is compared to the OFDM complexity. Even though these waveforms are based on Fourier transform operations like OFDM, they require higher implementation complexity due to their respective filtering operations. While the filtering operation is done per subcarrier in FBMC, this is done per sub-band in UFMC, inducing a different complexity. Low complexity algorithms proposed in the previous study (§V) are based on reducing the subcarrier number or using other kinds of filters. As shown above, PPN FBMC is relatively less complex than the Frequency Spreading (FS) FBMC technique [10], in which a comparison is made on the reduced version of PPN FBMC. The main conclusions from this comparison are summarized in (table I). Linear phase filter UFMC is the low complex algorithm that may provide a complexity equal to the OFDM. Moreover, from the previous studies, FBMC and UFMC performance were evaluated in DVB-T2 system using BER vs SNR and varying the number of subcarriers (FBMC compared to OFDM (8192 and 32768 number of subcarriers), UFMC and FBMC compared to OFDM (1024 and 32768 number of subcarriers)). It has shown that FBMC SNR performance gain increases with the number of subcarriers [6]. UFMC performance gain varies according to the number of subcarriers, the sub-band size, the Side Lobe Level (SLL), and the filter length [7]. UFMC SNR performance gain increases with the SLL [7]. FBMC, and UFMC are respectively 133.43% and 128.52% spectrally efficient than OFDM and also outperform OFDM by respectively $1.2\,\mathrm{dB}$ and $1\,\mathrm{dB}$ SNR gain at a BER of 10^{-3} in DVB-T2 transmission [6], [7]. Conclusively, UFMC is a good compromise in terms of improvement for the next generation of DVB-T2 (Fig. 8). This figure presents the SNR performance gains previously obtained with FBMC and UFMC [6], [7]. It also shows their respective spectral efficiencies compared to the 100% OFDM previously studied [7]. Finally, their complexities are presented. Besides the number of real multiplication considered in this paper, the number of real addition could also be considered to have a complete theoretical complexity analysis like shown in [23] in FBMC case only.

VII. CONCLUSION

In this paper, OFDM and filter-based UFMC and FBMC waveforms hardware complexities were presented and studied. Furthermore, low complexity reduction algorithms proposed in the scientific literature have been gathered and compared. The best low complexity algorithm has been identified for both UFMC and FBMC waveforms. The complexity of FBMC is reduced to twice the OFDM complexity using these algorithms, whereas UFMC complexity becomes equal to that of OFDM by virtue of these algorithms. The survey gives an in-depth comparison of complexities of filter-based waveforms. UFMC based on lightweight FFT and linear phase filter is the low complexity algorithm suitable for better performance in the next generation of DVB-T2. This paper constitutes a review of low complexity of filter-based waveforms applied in DVB-T2 transmission. It constitutes the research basis of DTT standards using filter-based waveforms FBMC and UFMC. The particularity of DTT standards is a wide network coverage usage which means long symbol duration and then a high number of subcarriers. These subcarrier numbers are considered well during the course of this study.

ACKNOWLEDGMENT

This work has been carried out under support from the ARES-CCD within the framework of the PHORAN PFS. The authors would like to thank Danial Saleemi and Véronique Georlette for their english review contributions in this work.

REFERENCES

[1] A. de la Fuente, R. Pérez Leal and Ana G. Armada, "New technologies and trends for next generation mobile broadcasting services," *IEEE communications Magazine*, pp. 217–223, Nov 2016.

[2] European Broadcasting Union, "Digital Video Broadcasting (DVB); Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting systems (DVB-T2)," ETSI EN 302 755 V1.4.1, July 2015.

[3] European Broadcasting Union, "LTE; Overall description of LTE-based 5G broadcast," ETSI TR 136 976, Nov 2020.

[4] European Broadcasting Union, "5G for the distribution of audiovisual media content and services, " TR 054, May 2020.

[5] B. AKM, A. A. Rafee and A. Azwad, " Novel Methods of Filtering For FBMC/UFMC Based 5G Communication Systems", *7th International Conference on Smart Computing & Communications (ICSCC)*, Sarawak, Malaysia, Sep 2019.

[6] A-C Honfoga, T. T. Nguyen, M. Dossou and V. Moeyaert, "Application of FBMC to DVB-T2: a Comparison vs Classical OFDM Transmissions," *IEEE GlobalSIP conference*, Ottawa, ON, Canada, Nov 2019.

[7] A-C Honfoga, M. Dossou and V. Moeyaert, "Performance comparison of new waveforms applied to DVB-T2 transmissions," *IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, Paris - France, Oct 2020.

[8] A-C. Honfoga, M. Dossou, P. Dassi and V. Moeyaert, "Filtered based UFMC waveform applied on joint DVB-T2/NUC system", *EAI AFRICOMM – 12th EAI International Conference on e-Infrastructure and e-Services for Developing Countries*, Cap town, Dec 2020.

[9] A-C. Honfoga, M. Dossou and V. Moeyaert, "Comparison of low complexity demapper algorithms applied to rotated constellation in DVB-T2", *6th IEEE Congress on Information Science & Technology-2nd IEEE Women in Engineering International Symposium*, Agadir-Essaouira, Morocco, June 2021.

[10] M. Bellanger,"FBMC physical layer: a primer," PHYDYAS, June 2010, accessed on Oct 2021.

[11] R. Chandarsekhar, M. V. L. Padma Priya, K.Abhishek, K.Suresh Vidya and M.Prem Kumar, "Comparison of OFDM FBMC and UFMC under Different Parameters," *Journal of Applied Science and Computations*, pp. 2965-2973, Jan 2019.

[12] P. Duhamel and H. Hollmann, "Split radix FFT algorithm," *Electronics letters*, vol. 20, no. 1, pp. 14–16, 1984.

[13] S. G. Johnson and M. Frigo, "A modified split-radix FFT with fewer arithmetic operations," *IEEE Trans. Signal Process.*, vol. 55, no. 1, pp. 111-119, Jan 2007.

[14] A. Bedoui and M. Et-tolba, "A Comparative Analysis of Filter Bank Multicarrier (FBMC) as 5G Multiplexing Technique," *International Conference on Wireless Networks and Mobile Communications (WINCOM)*, Rabat, Morocco, Dec 2017.

[15] A. A. Husam and Z. Kollar, "Complexity Comparison of Filter Bank Multicarrier Transmitter Schemes," *11th International Symposium on Communication System Networks and Digital Signal Processing (CSNDSP)*, Budapest, Hungary, July 2018.

[16] L. Varza and Zs. Kollar, "Low complexity FBMC transceiver for FPGA implementation," *23rd International Conference in Radioelektronika*, pp. 219-223, Pardubice, Czech Republic, April 2013.

[17] R. Knopp, F. Kaltenberger, C. Vitiello and M. Luise, "Universal filtered multicarrier for machine type communications in 5G," *European Conference on Networks and Communications (EUCNC)*, Athens, Greece, June 2016.

[18] T. Wild and F. Schaich, "A reduced complexity transmitter for UF-OFDM," *in Proceedings of the 2015 IEEE 81st Vehicular Technology Conference (VTC Spring)*, Glasgow, United Kingdom, May 2015.

[19] A.R. Jafri, J. Majid, M.A. Shami, M.A. Imran and M. NajamUl-Islam,"Hardware complexity reduction in universal filtered multicarrier transmitter implementation," *IEEE Access*, vol. 5, pp.13401–13408, July 2017.

[20] M. Saad, A. Al-Ghouwayel, and H. Hijazi, "UFMC transceiver complexity reduction," *in Proc. 25th Int. Conf. Telecommun. (ICT)*, pp. 295-301, Saint-Malo, France, June 2018.

[21] M. Matthe, D. Zhang, F. Schaich, T. Wild, R. Ahmed and G. Fettweis, "A reduced complexity time-domain transmitter for UF-OFDM," *in VTC Spring*, Nanjing, China, May 2016.

[22] Z. Guo, Q. Liu, W. Zhang and S. Wang, "Low Complexity Implementation of Universal Filtered Multi-Carrier Transmitter", *IEEE Access*, vol. 8, pp 24799–24807, Jan 2020.

[23] M. K. Al-Haddad and H. T. Ziboon, "Theoretical and Complexity Analysis of FBMC", *IEEE Access*, vol. 8, pp 24799–24807, Jan 2020.