Time domain synchronisation estimation algorithm for FBMC vector signal analysis in 5G system

Yunzhi Ling¹, Yu Zhang², Lantian Xu¹
¹The 41st Institute of CETC, Bengbu, People’s Republic of China
²Anhui Province Key Laboratory of Electronic Information Testing Technology, 41st Institute of CETC, Bengbu, People’s Republic of China
E-mail: xult_ceyear@126.com

Abstract: For the challenges of filter bank multi-carrier (FBMC) test applications in the fifth-generation mobile communication network (5G) system, presented is a time domain synchronisation estimation algorithm based on power synchronisation in frequency domain. Through MATLAB simulation, the proposed algorithm is verified to achieve good synchronisation at low signal-to-noise ratio (SNR) and large frequency offset without signal quality changes. As a result, it can be applied in FBMC signal vector analysers, promoting FBMC signal vector analysis functions used in 5G test applications.

1 Introduction

Rapidly growing mobile communications are bringing people infinite convenience. With fourth-generation mobile communication network (4G) coming into large-scale commercial applications phase, R&D globally has been focused on the fifth-generation mobile communication network (5G) towards 2020 year and future beyond. Filter bank multi-carrier (FBMC), as one of the alternative waveforms for the 5G system, has advantages such as good out-band suppression, very high utilisation rate of the spectrum, suitability for scattered fragment frequencies utilisation and so on, compared with orthogonal frequency division multiplexing technology (OFDM) used in the 4G system [1].

FBMC can use scattered frequencies in any combination to effectively improve spectrum usage and solve the problem with high bandwidth applications at the lower band, therefore satisfying expected flexibility needed for various services in the 5G landscape. As one of the hotspot technologies, FBMC has been extensively studied on their core techniques, such as prototype filter design, channel equalisation, and multiple input multiple output (MIMO) transmission as well.

The prototype filters involve PHYDYAS filter [2], Rossi filter [3] and frequency selection algorithm [4]. Channel equalisation involves frequency sampling technique-based linear multitap equaliser [5], minimum mean square error (MMSE)-based enhanced linear multitap equaliser [6] etc. MIMO transmission technology involves Alamouti-based coding scheme [7], maximum likelihood test (MLD)-based innovative mitigation technique [8], and others. However, the investigations are still much insufficient on time domain synchronisation as the first step for FBMC reception. Related literature on domain synchronisation is highly limited [9]. Furthermore, these investigations are mainly on modifications for synchronisation technique based on OFDM. So this cannot meet requirements of FBMC vector signal analysis for domain synchronisation. We presented a time domain synchronisation estimation algorithm with low complexity, easy implementation, and high performance, which can achieve favourable synchronisation performance at low SNR and large frequency offset without signal quality changes. It can be used in FBMC signal vector analysers used in 5G test applications.

2 FBMC principle

PHYDYAS began to conduct FBMC project since 2009 and provided a fast FBMC implementation solution and detailed principle [10–12] that will not be described any more herein. The packet filtering coefficients in FBMC modulation can be expressed as

\[
\begin{align*}
B_i(Z) &= \begin{bmatrix} 1 & 1 & \ldots & 1 \\ w^M & w^M & \ldots & w^{M-1} \\ \vdots & \vdots & \ddots & \vdots \\ \end{bmatrix} H_i(Z)^M \\
B_{\text{M}-i}(Z) &= \begin{bmatrix} 1 & w^M & \ldots & w^{M-1} \\ w^{-M} & w^{-M} & \ldots & w^{-1} \\ \vdots & \vdots & \ddots & \vdots \\ \end{bmatrix} Z^{-M} H_{\text{M}-i}(Z)^M
\end{align*}
\]

where \( M \) is the symbol length; \( B(Z) \) is the Z domain matrix for the filtering coefficients; and \( w = e^{2\pi/M} \), \( H(Z) \) is the Z domain matrix for the prototype filtering coefficients. The filter matrix for packet filtering can be transferred into two matrices in the product form where the first is the matrix for inverse Fourier transform (IFFT), and the second is in the expanded multiphase form to perform the filtering function. So the FBMC modulation can be implemented by firstly converting serial data into parallel through the IFFT module, then processing IFFT output through the multiphase network. The system block diagram is shown in Fig. 1.

For the FBMC signals, sub-carriers are not orthogonal to each other. It is common to use real and imaginary cross mapping as shown in Fig. 2 to ensure orthogonality of a sub-carrier to its adjacent two sub-carriers. However, this obviously will lead to a decrease in transmission speed and spectrum usage by half. It is not expected for 5G. Also, it will cause huge waste because spectrum resources are at a premium in wireless communication systems. Consequently, offset quadrature amplitude modulation (OQAM) modulation is proposed in the FBMC system, where its mapping is shown as in Fig. 3. The basic idea remains that QAM signals are modulated by real and imaginary cross-mapping to avoid interferences between adjacent sub-carriers. Based on this, additionally, OQAM is modulated by splitting data into two channels, which doubles the amount of data to solve decreasing data traffic problem due to real and imaginary cross-mappings. Interferences between two channels are prevented using
What is more, its analysis results, associated with used mature technique. FBMC vector analysis, as a critical test means well. On the other hand, it is estimated that the standard has not been established for the FBMC channel, so it is unpersuasive for conclusions from analysis of interference mentioned above [13–15].

3 Time domain synchronous estimation algorithm

Similar to OFDM modulation, FBMC modulation also uses channel equalisation to eliminate influences of time, phase, frequency offsets, and noise, but this will cause damage to signal quality. What is more, its analysis results, associated with used channel equalisation, cannot intuitively reflect signal quality as well. On the other hand, it is estimated that the standard has not been established for the FBMC channel, so it is unpersuasive for using channel equalisation for FBMC analysis; besides, vector analysis, as a traditional means for signal modulation analysis, is a mature technique. FBMC vector analysis, as a critical test means used for FBMC applications, performs signal analysis through time domain synchronisation, frequency offset synchronisation, phase offset correction, and other methods without channel equalisation used. Time domain synchronisation is the first step in vector analysis to determine the optimal moment for signal time domain sampling, and the synchronisation performance will affect the accuracy of the whole vector analysis. For vector signal modulation, interpolation and filtering are conducted in the time domain, but for FBMC modulation, interpolation and filtering in the time domain. We proposed a time domain synchronisation estimation algorithm with power synchronisation in the frequency domain, as shown in Fig. 4.

The symbol synchronisation module performs the judgment of initial position for symbol time domain. For bursting FBMC signal, synchronisation is implemented using power, but for continuous FBMC signal, synchronisation is implemented using the OFDM frame synchronisation method to interpolate ZC sequences.

The time domain interpolation module performs recovery of time domain data to equivalently improve sampling rate and is used to subdivide time domain scale for reducing time domain synchronisation errors. Detailed steps are as the following:

(i) Use results of symbol synchronisation to select an analysis data length $M \times K$, where $M$ is the symbol length and $K$ is the order of prototype filter.
(ii) Perform zero padding between analysis data. Special zero padding number $O$ is determined according to performance requirements.
(iii) Design interpolation filter with order equal to $8 \times O + 1$.
(iv) Proceed convolution operation to complete filtering.

Time domain windowing module performs matched filtering with the window coefficient equal to packet filter coefficient for FBMC modulation. It divides the time domain interpolated data with length $M \times K$ into $M \times K$ sections. Then A value is selected for each section according to time; thus, totally $O$ packets of $M \times K$ data are selected to proceed time domain windowing.

The FET module performs conversion of time domain windowed signal into the frequency domain. It applies FFT with $M \times K$ length to $O$ packets of time domain windowing data with $M \times K$ length, respectively, and then outputs $O$ packets of frequency domain data with $M \times K$ length.

Power accumulation module performs modulo operation on $O$ packets of frequency domain data with $M \times K$ length after FFT, and selects effective frequency domain signals to accumulate power according to signal bandwidth, thus creating $O$ (number) power data.

Power decision module performs decision according to the magnitude of the created $O$ (number) power data, selects power maximum value as time domain synchronisation point, and outputs it as a time domain synchronisation parameter, into subsequent modules for vector analyses, completing final vector analyses.

4 Simulations and analyses

Simulations and analyses of the time domain synchronisation estimation algorithm are proceeded using MATLAB software. First, generate FBMC signal, refer to OFDM data as well as FBMC characteristics for special parameters [16–29], and configure FBMC signal parameters as shown in Table 1.

Generation of FBMC signal is proceeded using MATLAB software, with prototype filter impulse response (Fig. 5), frequency domain characteristics (Fig. 6), and time domain characteristics (Fig. 7).

Table 1 FBMC signal parameters

| Parameter          | Value |
|--------------------|-------|
| symbol length      | 4096  |
| sub-carrier        | 30K   |
| modulation form    | OQAM  |
| bandwidth          | 100M  |
| prototype filter   | PHYDYAS |
| prototype filter order | 4     |
| symbol count       | 16    |

Second, according to the time domain synchronisation estimation algorithm, select $O$ as 16 to perform simulations, with obtained power accumulation module as shown in Fig. 8. Using

![Fig. 2 Real and imaginary cross-mapping of FBMC subcarriers](http://creativecommons.org/licenses/by/3.0/)

![Fig. 3 Comparison between OQAM and QAM mapping](http://creativecommons.org/licenses/by/3.0/)
power to judge output position, output synchronisation position as shown in Fig. 9.

To verify the time domain synchronisation estimation algorithm, first, simulations are proceeded at different SNR values: 0, 10, 20, and 30 dB, respectively. Results from 1000 simulations are shown in Table 2.

Second, simulations are proceeded at different DFs for frequency offset, 100 Hz, 1, 10, and 20 kHz, respectively, with 60 dB SNR. Results from 1000 simulations are shown in Table 3.

Through these simulations, it can be found that good performances are obtained at low SNR, e.g. 30 dB, using the time domain synchronisation estimation algorithm, and to increase synchronisation probability, more symbols can be added to conduct synchronisation; however, good performances are also obtained at large frequency offset using the time domain synchronisation estimation algorithm.

5 Conclusion

The paper proposed a time domain synchronisation estimation algorithm for FBMC vector signal analysis. Through simulations, the algorithm is verified to have resistance to frequency offset and anti-jamming advantages, satisfying requirements of vector analysers for time domain synchronisation. As time domain synchronisation estimations are conducted in the frequency domain, available bandwidth has a direct effect on the performance of the algorithm. For further efforts, we will improve the algorithm to mitigate influence on available bandwidth; in the meantime, we will investigate the frequency domain estimation algorithm for vector analyses to promote FBMC vector analyses used in 5G test applications.
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7 References

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Table 3 Synchronisation probability at different DFs

| DF, kHz | Synchronisation probability, % |
|---------|-------------------------------|
| 0.1     | 100.0                         |
| 1       | 100.0                         |
| 5       | 100.0                         |
| 10      | 100.0                         |
| 15      | 100.0                         |
| 20      | 100.0                         |
| 25      | 100.0                         |
| 30      | 100.0                         |