# Patents on Synchronization Techniques in Wireless OFDM Systems

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*Received: October 12, 2007; Accepted: September 21, 2007; Revised: October 25, 2007*

**Abstract:** The latest patents on the synchronization techniques in wireless OFDM communications systems are overviewed in this paper. The novel inventions and methods in those patents, which deal with the symbol timing synchronization, the carrier frequency synchronization as well as the sampling clock synchronization in either the continuous transmission mode or the burst packet transmission mode systems are introduced and analyzed. Based on the corresponding analysis, the technical forecast and the future developments for synchronization techniques in OFDM systems are discussed in the paper as well.

**Keywords:** OFDM, symbol timing synchronization, carrier frequency synchronization, sampling clock synchronization, continuous transmission mode, burst packet transmission mode.

## I. INTRODUCTION

OFDM technique has found its wide applications in many scientific areas due to its high spectrum efficiency, its robustness against multi-path and pulse noises, its highly reliable transmission speed under serious channel conditions, its adaptive modulation abilities for each sub-carrier according to the channel conditions and some other advantages. It has become fundamental technology in the future 4G-multimedia mobile communications systems [1]. Many digital transmission systems have adopted OFDM as the modulation technique such as digital video broadcasting terrestrial TV (DVB-T) [2], digital audio broadcasting (DAB), terrestrial integrated services digital broadcasting (ISDB-T), digital subscriber line (xDSL), WLAN systems based on the IEEE 802.11(a) [3] or Hiperlan2, multimedia mobile access communications (MMAC), and the fixed wireless access (FWA) system in IEEE 802.16.3 standard. OFDM has also found its application in Cable TV systems. Technologies fundamentally based on OFDM, such as vector OFDM (V-OFDM), wide-band OFDM (W-OFDM), flash OFDM (F-OFDM) have also shown their excellent performances in certain application areas.

There are some disadvantages, however, appeared in the OFDM systems, for instance, the large Peak-to Average Power Ratio (PAPR) as well as high sensitivity to the synchronization errors. Synchronization issues are of great importance in all digital communications systems, especially in the OFDM systems. Synchronization errors not only cause inter-symbol interference (ISI) but also introduce inter-carrier interference (ICI) due to the loss of orthogonality among all sub-carriers. Paper [4] covers all the synchronization issues for OFDM/DMT with the corresponding papers referenced. In this paper, we focus on the latest patents on synchronization schemes in the OFDM systems. Fundamental theory for the synchronization is briefly described in Section II and in Section III, the patents on symbol timing schemes are presented. We then conduct the analysis on the carrier frequency recovery as well as the sampling clock synchronization methods in Section IV and V, respectively. In Section VI, patents on the joint estimation of all the synchronization errors including timing, frequency and phase offsets are simply described. Technical forecast and the future developments of synchronization techniques are carried out in Section VII.

## II. THE SYNCHRONIZATION PROBLEMS IN OFDM SYSTEMS

The overall OFDM receiver circuit design including synchronization, channel estimation and equalization, de-interleaving, decoding and other related techniques can be found in the patent [5]. Our focus is on OFDM synchronization techniques in this review paper. Synchronization is of great importance for all digital communication systems. OFDM systems are very sensitive to both timing and carrier frequency offset, especially when combined with other multi-access techniques such as FDMA, TDMA, and CDMA. Therefore, synchronization is extremely crucial to the OFDM systems.

### A. Three Synchronization Issues in the OFDM Systems

There are three major synchronization issues in the OFDM systems:

*a.* The symbol timing synchronization, determinant of the correct symbol start position, i.e., the FFT window position before the FFT demodulation at the receiver end.

*b.* The carrier frequency synchronization (i.e., carrier frequency recovery technique), utilized to eliminate the carrier frequency offset caused by the mismatch of the local oscillators between the transmitter and the receiver, nonlinear characteristic of the wireless channel as well as the Doppler shift.

*c.* The sampling clock synchronization, which is to mitigate the sampling clock errors due to the mismatch of the crystal oscillators.

All these synchronization errors will significantly degrade system performance [6,7].

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### B. Synchronization Techniques in the Continuous Mode and Burst Packet Mode Transmission Systems

It is indispensable of accurate synchronization to suppress the negative impact of the synchronization errors on the communication systems no matter it is in the continuous or the burst packet mode transmission systems. However, to these two transmission modes, there are different synchronization approaches:

*a.* In the burst packet mode, synchronization ought to be established at any time because when data streams are ready to transmit is unknown. The duration of the training symbols used for synchronization in this mode is relatively short and synchronization should be done within a single training symbol time for the systems such as IEEE 802.11(a) [3] and Hiper Lan/2 to avoid the reduction of the system capacity. It is inappropriate to do averaging over many symbols or pilots because of the stringent requirement on synchronization time and the less number of sub-carriers. It is also important for the systems in this mode to establish the synchronization in time domain and thus greatly reduce the acquisition time since it avoids the feedback from frequency domain.

*b.* In the continuous mode such as DAB, DVB-T [2] systems, averaging or filtering method can be used to improve the estimation accuracy because there is no stringent requirement on the acquisition time. In this mode, large numbers of sub-carriers have been utilized, and it is appropriate to apply the cyclic prefix, training symbols or pilots to these synchronization methods.

## III. SYMBOL TIMING SYNCHRONIZATION

When signals are transmitted through severe channel conditions of multi-path fading, pulse noise disturbance and the Doppler Shift, it is priority to solve symbol timing synchronization problem in the design process of an OFDM receiver.

We call $\Delta$ the ISI free region. If the estimated start position of OFDM symbol is located therein, data will not be affected by ISI, and the phase rotation caused by timing offset can be easily corrected after FFT. If the estimated start position is located within the data interval, the sampled OFDM symbol will contain some samples belonging to other symbols, which will cause the dispersion of signal constellation and thus reduce the system performance accordingly.

The symbol timing error can not only disturb the amplitude and the phase of the received signal, but also introduce ISI. In order to perform the FFT demodulation correctly, the symbol timing synchronization must be achieved to determine the starting point (i.e. FFT window position) of the OFDM symbol. Thereby, the cyclic prefix (CP) or Guard Interval (GIB) can be removed afterwards. The concept of the GIB was first proposed by Peled A [8]**,** which can prevent OFDM symbols from ISI disturbance and keep the orthogonality among all the sub-carriers. As shown in Fig. (**1**), accurate and steady symbol timing synchronization can be realized by the combination of the coarse symbol timing, the fine symbol timing as well as the symbol timing controls structure. The coarse symbol timing synchronization is first executed in time domain, followed by the fine symbol timing in frequency domain to ensure a more accurate estimation. The symbol timing control structure including acquisition mode and tracking mode are utilized to coordinate with the operations of the coarse and the fine symbol timing.

### A. The Coarse Symbol Timing Algorithms in the Continuous Transmission Mode

The conventional algorithms for the coarse symbol timing synchronization in time domain are MLE (Maximum Likelihood Estimation) utilizing the cyclic prefix of the OFDM symbols [9,10]. However, ideal performance is achieved only under the AWGN channel. To further improve the MLE estimation performance under AWGN channel, the method of averaging over many OFDM symbols [11] and filtering of the estimation results [12] are proposed. Such methods only work well under AWGN channel, because when the channel condition becomes severely degraded, data in GIB is badly contaminated by ISI, which will lead to significant fluctuation of the estimated starting point of the OFDM symbol. And such fluctuation will have the significant influence on the carrier frequency offset as well as the sampling clock offset estimation in frequency domain. To improve the performance of ML Estimator, proposed are novel schemes utilizing CP and pilots [13], CP and PN sequence [14], CP and training symbols [15] for the coarse symbol timing synchronization. These methods have better performance compared to those [9-12] under the multi-path fading channel. However, the non-negligible fluctuation still exists because of the ISI-contaminated data within GIB and the limited number of pilots used for estimation. In order to mitigate the fluctuation, Schmidl T M [16] and Hua-Wei Company [17] introduced new methods using the specially designed training symbols in time domain, wherein timing functions are defined. Unfortunately, such methods have a "flat region" in the estimation, which, to a great extent, increases the variance of the symbol timing estimator.

In order to decrease the fluctuation of the estimated starting point of the OFDM symbol and make the estimation within the ISI-Free region, some new schemes have been proposed in the literatures [18,19] in recent years to overcome the defects of the algorithms mentioned above, The convolution characteristic of the PN sequences is adopted in [18], to take the advantage of the intrinsic, fairly good correlation property of PN. Kasami sequence is utilized in [19] with the excellent correlation properties; and in [20], a novel timing recovery method for TDS-OFDM (key techniques for the Terrestrial Digital Multimedia/Television Broadcasting System) is developed. This scheme is based on the searching and tracking of the correlation peaks of the PN sequences. Because of the excellent correlation properties of the so-called m-sequence, the performance of these algorithms [18-20] outperforms those [9-12] under the multi-path fading channels.

In the patent [21], a novel idea of estimating ISI-free boundary is proposed, whereby it is easy to separate the ISI region in any mobile environment by utilizing the characteristics of the guard interval and combining the techniques of the delay conjugate multiplication module, phase differential operation, symbol-by-symbol average

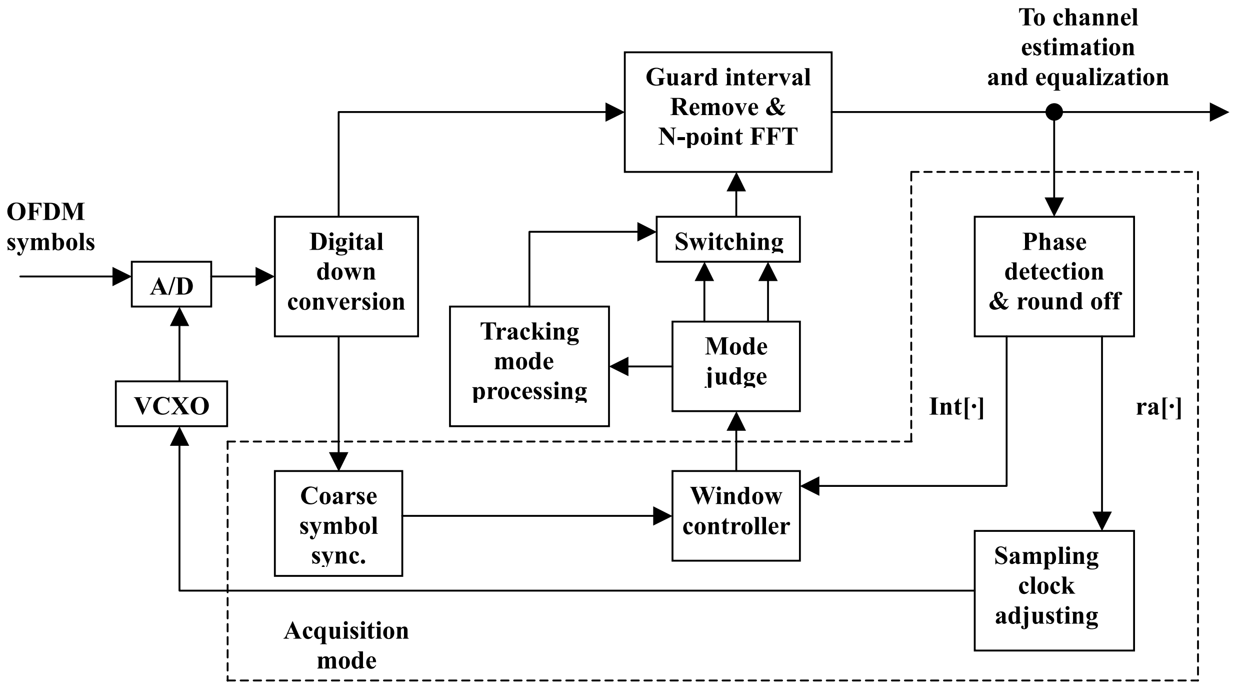


**Fig. (1).** The symbol timing synchronization diagram.

operation and the edge detection. It can guarantee the estimated OFDM starting position within the ISI-free region and avoid the negative effect of ISI accordingly.

### B. The Fine Symbol Timing Synchronization in the Continuous Mode

The residual symbol timing error may cause the phase rotation of the sub-carriers in frequency domain. Many methods utilizing this feature, therefore, have been proposed to do the fine symbol timing synchronization in frequency domain [22,23], which is often required to guarantee the estimation accuracy. Training symbol structure is specially designed in the patent [24] to generate a fine symbol timing estimation. Computer simulations and analysis have verified their good estimation performances but low bandwidth efficiency.

### C. The Symbol Timing Synchronization Algorithms in the Burst Packet Transmission Mode

The synchronization requirements vary with the applications, we therefore, should adopt the appropriate synchronization techniques in both the continuous and the burst packet transmission modes, respectively. As discussed in Section II B, it is inappropriate to do the symbol timing synchronization with pilots nor the symbol timing synchronization with averaging over many OFDM symbols [11] in the burst packet mode due to the stringent requirements of synchronization time. In [25,26], the conventional method based on correlation characteristic is presented utilizing the IEEE 802.11(a) OFDM structure including long and short training symbols [3] with a relatively poor estimation performance in a multi-path environment. A specially designed OFDM structure [27] and synchronization acquisition code [28] are also utilized for symbol timing synchronization in the burst packet transmission mode. Methods utilizing the preamble symbols [29-31] and the threshold [32] for the WLAN systems are proposed in the patent [33], wherein the digital phase locked loop structure is adopted to provide rapid acquisition and decoding of the burst mode data signals. The computer simulations based on IEEE 802.11(a) standard [3] illustrate that more accurate coarse symbol timing synchronization can be achieved by the above-mentioned methods in time domain [27,28,32], no matter if it is in the office environment [34] or under much severe Rayleigh fading channel conditions [2].

### D. Symbol Timing Synchronization Control Model

Besides the accuracy of the estimation in the symbol timing synchronization process, the robust and efficient synchronization control structure to ensure the system stability is also requested. A new symbol timing synchronization control model has been proposed in [35]. Similar to those control models in [36], it also has two synchronization states: the acquisition state and the tracking state. The difference is that the threshold and counters are utilized to perform the control process with less computational complexity.

## IV. CARRIER FREQUENCY RECOVERY TECHNIQUES

Carrier frequency offset (CFO) caused by the Doppler shift, local oscillators mismatch between the transmitter and the receiver ends, may introduce ICI and degrade the SNR performances. With the insertion of the GIB in OFDM symbols, symbol timing error within a certain range will not introduce ISI and ICI. OFDM system is more sensitive to the CFO and the sampling clock offset (SCO). Regarding higher modulation modes such as 64-QAM, tiny CFO may introduce severe degradation of the system performance.

Carrier frequency offset $\Delta F$ puts an extra phase factor of $e^{j2\pi\Delta Ft}=e^{j2\pi Fft}$ in the received signal, where $f$ is the sub-carrier spacing, and $F$ is the CFO normalized by $f$ which is usually divided into an integer part $F_I$, (multiple of the sub-carrier spacing, causing a shift of the sub-carrier indices) and a decimal part $F_D$, (less than half of the sub-carrier spacing, causes a number of impairments, including attenuation and rotation of the sub-carriers and ICI).

We can divide CFO into three parts to facilitate the CFO estimation process: the integer, the coarse decimal and the fine decimal part. CFO can usually be compensated for through the following procedures shown in Fig. **2**. First, a coarse symbol starting point for the FFT demodulation is provided by the coarse symbol timing module and then, the estimation and correction of the coarse decimal frequency offset in time domain is performed to minimize the ICI impact on the estimation in frequency domain, with the integer part $\hat{F}_I$ estimated in frequency domain to get the correct sub-carrier index. Finally, the residual frequency offset $\hat{F}_D$, i.e. the fine decimal frequency offset is estimated. A tracking loop structure (the Acquisition and the Tracking Mode Switching module) can be formed to coordinate the coarse decimal part, the integer part and the fine decimal part of the frequency offset. Each step makes unique contribution to the recovery of the carrier frequency offset [37].

Many literatures have discussed how to make OFDM systems less sensitive to the carrier frequency offset, for instance, to perform the windowing on the transmitted signals or use self-cancellation schemes. However, long prefix utilized in these approaches [16,38,39] results in low bandwidth efficiency. Therefore, we should resort to more effective means to do CFO synchronization. Generally, we can divide the carrier frequency recovery algorithms into three categories:

*a*. Methods are based on training symbols [16,38,40,41] or pilots [42-48], named Data Aided (DA) method.

*b*. Methods utilize the intrinsic structure of OFDM symbols, e.g. cyclic prefix [15,22,49,50], which is called Non Data Aided (NDA) method.

*c*. Blind approaches [51,52], dependent on the signal statistics and often with very high computational complexity, and may have extra requirements for the channel statistics.

### A. Integer Carrier Frequency Offset

The sub-carriers spacing offset can be reduced from being a few ten times that of sub-carrier spacing to only half of it by means of coarse decimal CFO correction. Most algorithms for the integer CFO estimation [15,22,41,43, 50,53] nowadays have two major defects: a. Limited estimation range on CFO; b. Stringent requirement for the symbol timing synchronization. The typical algorithm in this category was presented in the patent [53] with the estimation range $\varepsilon$ limited within $|\varepsilon|\leq 0.5$, that is, only $\pm 1/2$ that of sub-carrier spacing.

Moose P H tried to overcome this problem by increasing the sub-carrier spacing to prevent phase offset from exceeding $\pm\pi$. However, the increase of sub-carrier spacing $f_u$ satisfying $f_u = 1/T_u$ may decrease the useful OFDM symbol duration time $T_u$, resulting in tighter requirements for the symbol timing synchronization. Besides, the increase of the sub-carrier spacing will not extend the range of the integer part estimation significantly.

Schmidl T M *et al.*, later, proposed an improved algorithm [41] with better performance under multi-path fading channel, and its estimation range was one time wider than that by [53]. Unfortunately, a large prefix is still needed. For instance, in DVB-T [2] standard, $2N$=2×2048 prefix (2k mode) have to be used. In addition, it is sensitive to the symbol timing errors and the estimation range is still very limited.

Three improved estimation algorithms are proposed in literature [54] to overcome these defects. All of them use the

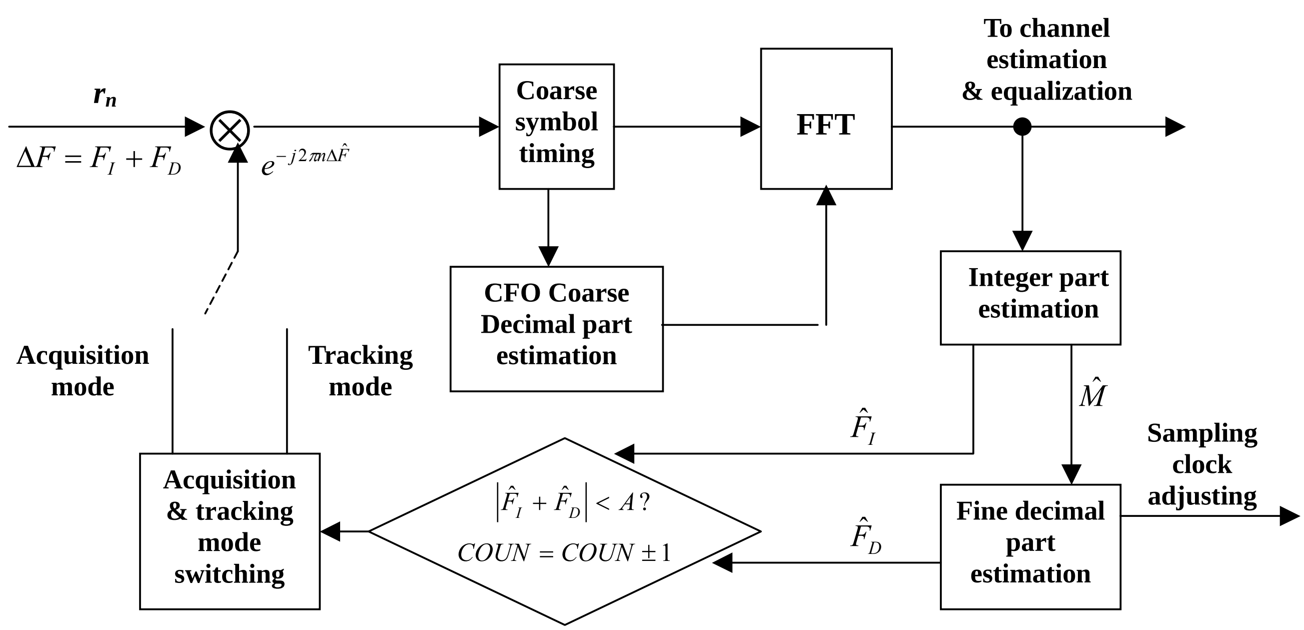


**Fig. (2).** Carrier frequency synchronization estimator.

power and phase characteristic of the known pilots, which is insensitive to the symbol timing errors and has a wider estimation range for the integer part of CFO (i.e., as large as *N*/2, with *N* the total number of useful sub-carriers in one OFDM symbol). Those methods proposed in the patents [38,46,47,55] also have a wider estimation range of the integer part of CFO than those presented in [41,53].

### B. Coarse Decimal Carrier Frequency Offset

As mentioned earlier, CFO estimation should follow three procedures. If the decimal part of CFO can be estimated in fre-quency domain, why do we have to carry out the coarse CFO estimation in time domain first? There are two main reasons:

*a.* To reduce ICI caused by the CFO, which lays the foundation for a more accurate CFO estimation in frequency domain.

*b.* To estimate and compensate for the CFO all in time domain may reduce the synchronization time and is suitable for the burst packet transmission mode systems.

The typical algorithms of the coarse decimal CFO estimation stem from [22,49,50,56] with CP feature exploited. Schimdl TM *et al.*, later, proposed a new algorithm named SCA [41]. However, these methods have a very stringent requirement for the symbol timing. The improved algorithms, less sensitive to the symbol timing errors, were proposed recently in the literature [16,48,57], with only part of data in Guard Interval correlation window for estimation, which prevents data portion from being contaminated by the incorrect phase information from the symbol timing errors.

Computer simulations show that when the decimal part of the CFO approaches to 0.5 of the sub-carrier spacing, the estimated value may, due to the multi-path fading, the phase noises as well as the discontinuity of the arctangent function, jump to the inverse polarity. For example, if the decimal frequency offset in data streams is 0.498 of the sub-carrier spacing, the estimation result of the typical algorithms mentioned above may be -0.467 of the sub-carrier spacing. The strategy to avoid such problem is to reduce the length of the DFT and use larger carrier spacing [56], which will degrade the overall system performance. We can resort to a second-order IIR filtering to settle this problem.

### C. Fine Decimal Carrier Frequency Offset

After the CFO correction based on the coarse decimal carrier frequency offset estimation is fulfilled, the residual decimal CFO in data streams may decrease to only 1%, and then the fine decimal CFO estimation will tackle the residual CFO. The typical algorithms were presented in the patents [42,43], however, they suffered from poor bandwidth efficiency due to the utilizing of pilots or pre-determined carriers. The method proposed in the patent [57] is superior in tracking and the final CFO is obtained by the AFC loop and a PLL loop.

### D. Carrier Frequency Offset Control Model

It is necessary to have a control module to coordinate the operations of the integer CFO, the coarse decimal CFO and the fine decimal CFO. As shown in Fig. (**2**), this module consists of two modes: the acquisition mode and the tracking mode. After the integer part $F_I$ and fine decimal part $F_D$ in frequency domain are estimated, the counter value COUN will increase or decrease depending on the value of $|F_I + F_D|$ in comparison with that of a constant A (set by the system performance requirement, for example, A=0.01%).

The value of COUN determines whether it is in the tracking or the acquisition mode. Performance and detailed analysis of this control model is presented in [37] with excellent estimation, tracking and correction of carrier frequency offset.

### E. Carrier Frequency Offset in the Burst Packet Transmission Mode

There is no stringent requirement for acquisition time in the continuous systems such as DAB, DVB-T [2] and DMB-T [20], averaging method or filtering of many OFDM symbols can be adopted to increase estimation accuracy, where it is appropriate to adopt those methods based on CP or pilots. Some literatures make use of the null sub-carriers for power detection to estimate the CFO. However, regarding the systems in the burst packet mode, repetitive structure is often utilized with homogeneous null sub-carriers and the idle time among neighboring blocks. The above-mentioned methods are, therefore, inappropriate in the burst packet mode. Because of the short duration of packets, it has more stringent requirement for synchronization acquisition time (i.e., acquisition done within a single OFDM symbol). Besides the requirement for estimation accuracy, fast convergence is also needed. The accuracy of the CFO estimation in time domain and non-feed back synchronization model are equally important to these systems and the synchronization should be established only in time domain [39,58,59].

## V. SAMPLING CLOCK SYNCHRONIZATION

The sampling clock errors are basically caused by the mismatch of the crystal oscillators between the transmitter and the receiver. Other factors such as multi-path fading, noise disturbance, symbol timing estimation errors may also lead to the sampling clock offset（SCO）. The sampling clock errors will negatively influence the symbol timing synchronization. For example, assume 1ppm sampling clock offset in 2K mode with a GIB of 512 samples in DVB-T [2], the FFT window will move one sample around every 400 symbols. The higher the sampling clock offset, the more the influence on the symbol timing synchronization. Detailed analysis about the effects of sampling clock offset on symbol timing is presented in [57]. In order to analyze the effects of SCO on the system performance in a more explicit way, SCO is divided into two parts: the sampling clock phase offset and the sampling clock frequency offset. Effects of the sampling clock phase offset are similar to that of the symbol timing offset, leading to the signal phase distortion; while the sampling clock frequency offset introduces ICI. By defining Inter-Sample-Interference, we can examine effects of the sampling clock offset on system performance.

The synchronous sampling and the asynchronous sampling are two different kinds of methods for the sampling clock synchronizations [16,58-64].

*a.* Timing algorithms are usually used in the synchronous systems to control both phase and frequency of a Voltage Control Crystal Oscillator (VCXO) [58,59]. Compared to the asynchronous digital sampling systems, it has significant timing fluctuation due to high-level phase noises. The requirement for the analog circuits makes the system integration inconvenient.

*b.* An independent oscillator is often created for sampling in an all-digital system [16,60-62]. Timing algorithms are used to control NCO (Numerical Control Oscillator) and then use the NCO output to control the interpolator filter. BER performance of the asynchronous system in [16] [62] shows that the asynchronous systems are more sensitive to CFO than the synchronous systems. Computer simulations demonstrate that unrealistic interpolator may cause cyclic tracking errors in asynchronous systems, which never occurs in the synchronous systems.

The estimated sampling clock offset and decimal part of symbol timing error may be considered as an adjusting variable when we do sampling clock synchronization. This sampling clock adjusting variable derives from frequency domain and then fed back to time domain to adjust digital oscillator, which guarantee the stability of the loop control circuit [65].

## VI. JOINT ESTIMATION ALGORITHMS

Some algorithms can be utilized for the joint estimation of the synchronization errors including the symbol timing, the carrier frequency and the sampling clock offsets. Algorithms presented in the patents [24,66] are the typical for the joint estimation of symbol timing and the decimal CFO. The decimal CFO estimation utilizing the detected phase of the received frequency-domain complex data in the pilot sub-carriers [66] or training symbols [24], is proceeded by the estimation of symbol timing errors. However, as analyzed in Section IV. *B*, they all have stringent requirement for the symbol timing synchronization. Some new joint estimation algorithms are proposed recently [67]. The proposed algorithm with a weighted least squares technique generates offset estimates with minimum RMS errors. Multiple received OFDM symbols as an observation interval are utilized in [68], both of which are less sensitive to the symbol timing errors.

The joint estimation of fine carrier frequency offset and the sampling clock offset have been proposed in [39,69], utilizing the phase difference of the pilot carriers.

The joint estimation and tracking of symbol timing and sampling clock errors are presented in [18,57]. The main problem of time synchronization errors is that, the sample rob/stuff phenomenon as a result of the sampling clock frequency offset leads to the FFT window position offset. A joint algorithm for symbol timing recovery and sampling clock adjustment using such characteristic is proposed in [69]. A delay-locked loop (DLL) technique to execute the combined symbol and sampling clock synchronization is presented in [57].

The joint estimation algorithms usually have low computational complexity compared to the separate estimation ones. Its estimation results may suffer from another synchronization estimation errors. Take the joint estimation of the symbol timing and the decimal CFO for example, the estimated symbol timing errors may affect the decimal CFO estimation.

## VII. CURRENT & FUTURE DEVELOPMENTS

Synchronization is one of the most critical techniques in the OFDM and other digital communication systems. It has great impact on the techniques to be implemented in this kind of systems such as channel estimation, equalization, decoding and so on. Based on all the introductions and analyses above, we arrive to the following suggestions for the future development:

1) Frequency domain synchronization plays an active role to ensure the estimation accuracy after the coarse synchronization estimation is completed in time domain. The control model is significantly necessary to coordinate the whole estimation process between time and frequency domains. This is unfavorable for the burst packet mode systems because the FFT calculation and other factors may significantly increase synchronization time. Therefore, it is of great importance to find the useful approaches to perform the synchronization throughout the time domain with the acceptable estimation accuracy. Short acquisition time and low system complexity should be considered as well.

2) As mentioned above, conventional synchronization methods can be divided into three categories: DA, NDA and blind algorithms. Pilots, training symbols or the combination of them are generally applied to the DA-type of methods at the expense of the reduced bandwidth efficiency. For the NDA methods, data used for the estimation may be contaminated by ISI, resulting in the inaccurate estimation. The blind or semi-blind algorithms can improve the estimation accuracy without pilots or training symbols, however, it needs significant amount of statistical information on both signal and channels, leading to high computational complexity. In the future, two major research directions should be considered: efficient design of the distribution patterns of the pilots or the training symbols, and the blind or semi-blind algorithms of low computational complexity.

3) Most schemes at present deal with the synchronization and the channel estimation separately. In fact, the channel estimation may be severely affected by the residual synchronization errors, and in view of system design optimization point of view, these two operations should be considered jointly.

4) The Doppler shift in wireless mobile communications causes ICI and destroys the orthogonality of OFDM symbols. Phase noises in the OFDM systems may introduce Common Phase Error (CPE) and ICI. There have already been many solutions, yet special attention should be paid to deal with them in the OFDM systems.

For the criteria of selecting the appropriate synchronization algorithms, it greatly depends on the applications. For example, different synchronization algorithms have been adopted with different applications such as DVB-T [2], DMB-T [20], and systems in either continuous transmission mode or burst packet transmission mode. In the continuous transmission mode, the synchronization time is not so critical, we can refer to frequency synchronization to ensure the more accurate synchronization results. Synchronization time, system complexity, the required system performance and etc. are all the factors that should be considered when we choose the synchronization scheme for the particular system. In fact, there are other alternatives when the synchronization process fails. For instance, in the patent [70], it utilizes the master branch and the auxiliary branch. When OFDM synchronization fails on the master branch side, it can switch to the auxiliary branch side automatically to ensure a good reception state.

In this paper, we focused on the recent patents on the key synchronization issues in the OFDM systems. Patents related with typical algorithms such as the symbol timing, the carrier frequency and the sampling clock synchronization unfold discussions with emphasis on the difference in choosing of the synchronization techniques between the continuous and the burst packet trans-mission mode systems. The technical forecast about the future trend of synchronization techniques provided at the end of this overview, which is of reference value when addressing the synchronization issues in the OFDM and other related systems.

## ACKNOWLEDGMENT

The authors would like to acknowledge the Talent Funds of Beijing Jiaotong University under Grant 2007RC022 and the Chinese Postdoctoral Funds (2005038094) in China, and also express their great thanks to the anonymous reviewers for their thorough review and constructive suggestions.

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