IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501
Vol.2, No6, December 2012

Synchronization Techniques in OFDM Systems

Rakhi Thakur,
Department of Electronics
MANIT
Bhopal,India

Kavita Khare
Department of Electronics
MANIT
Bhopal,India

Abstract-**Orthogonal frequency-division multiplexing (OFDM) is a powerful technique for high data-rate transmission over fading channels. OFDM systems have experienced increased attention in recent years and have found applications in a number of diverse areas including telephone-line based links, digital audio and video broadcasting systems, and wireless local area networks (WLAN). Among modern communication techniques, OFDM has become one of the candidate techniques for future mobile communication due to its high data rate transmission capability and its robustness to multi-path delay spread. However, OFDM systems are much more sensitive to synchronization errors than single carrier systems. So Synchronization is a key issue in the design of a OFDM. Here we will discuss the different techniques for synchronization.**

Key Words : OFDM; Frame Synchronization; Symbol Timing Synchronization.

I. INTRODUCTION

OFDM is an attractive modulation scheme used in broadband wireless systems that encounter large delay spreads. OFDM avoids temporal equalization altogether, using a cyclic prefix technique with a small penalty in channel capacity. The most important wireless applications that make use of OFDM are Digital Audio Broadcast (DAB), Digital Video Broadcast (DVB), WLAN and more recently Wireless Local Loop (WLL).

II. THE SYNCHRONIZATION PROBLEMS IN OFDM SYSTEMS

Synchronization is an essential task for any digital communication system. Without accurate synchronization algorithms, it is impossible to recover the transmitted data. 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. Time and frequency synchronization is used for the start of the OFDM symbol and to align the modulators and the demodulator's local oscillator frequencies. If any of these synchronization tasks is not performed with sufficient accuracy, then the orthogonality of the Subcarriers is (partly) lost. That is, intersymbol interference (ISI) and inter-carrier (ICI) are introduced.

Synchronization must be acquired during a very short time after the start of the packet [1,10]. This requirement comes from the packet-switched nature of WLAN systems and also from the high data rates used. To facilitate the single-shot synchronization, current WLAN standards include a preamble at the start of the packet. The length and the contents of the preamble have been carefully designed to provide enough information for a good synchronization performance while keeping the receiver training information overhead to a minimum.

III. THREE SYNCHRONIZATION ISSUES IN OFDM SYSTEMS

There are three major synchronization issues in the OFDM systems:

With any data communications system, a critical component is the ability for the receiver to detect the transmission of a packet. This can be complicated by the effects of the wireless channel, so it is important to have packet detection algorithms which can account for channel effects. 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. This preamble detection algorithm can also be used as a coarse timing (CT) algorithm, since it inherently provides a rough estimate of the starting point of the packet.

The wireless channel also affects the orthogonality of the subcarriers. If there is an offset between the subcarrier frequencies at the transmitter and the subcarrier frequencies at the receiver, the tones will no longer be orthogonal, and this can cause significant degradation in system performance. To maintain this orthogonality, the transmitter and receiver must be precisely synchronized in terms of frequency. This requires accurate frequency offset calculation at the receiver. 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. We estimate this frequency offset and compensate the received signals for it [2].The frequency offset can be estimated using the phase of the complex correlation between the two consecutive received training symbols When time synchronization is performed at the receiver and after the received signals are corrected for the frequency offset, the channel can be estimated using the known training symbols within the preamble When the timing is performed correctly, we know which received samples correspond to the training part [6],[7].

Another important issue which must be dealt with in OFDM systems is ISI, which can occur in a multipath fading wireless channel. OFDM systems are typically resistant to significant ISI because of the presence of the guard interval at the beginning of each OFDM symbol. The guard interval length in IEEE 802.11a, for example, is 800 ns for each OFDM data symbol. As the length of the channel multipath delay spread is usually 200 ns or less, this length is usually sufficient for preventing ISI in the system. Despite the presence of the guard interval, it is still possible for ISI to occur in OFDM systems. To prevent ISI from occurring, there must be accurate time synchronization at the receiver. 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].

The preamble is used for both frequency synchronization and channel estimation. For frequency synchronization algorithm a repetition of the training symbol is required. For the estimation of the multiple input multiple output (MIMO) channel, it is important that the sub-channels from the different TX antennas to every RX antenna can be uniquely identified. To achieve that, the preambles on the different TX antennas have to be orthogonal and shift-orthogonal for at least the channel length.

IV. THE IEEE 802.11A PREAMBLE

The IEEE 802.11a standard provides mechanisms for dealing with the synchronization problems noted above. OFDM symbols are transmitted over a channel as part of a packet. The size of this packet can vary, but it is generally several orders of magnitude longer than a single OFDM symbol. The packet consists of a packet header, followed by a data payload. It also contains a preamble which is used for synchronization purposes. There is a standard preamble at the start of every frame according to the standard of IEEE802.lla [2]. It is easy to see from Figure 1 the preamble consists of ten repeated short symbols (forming the Short Training Sequence(STS), and two repeated long symbols (forming the Long Training Sequence (LTS).Each of the short symbols are composed of 16 samples, and each of the long symbols are composed of 64 samples. A guard interval (each contains 32 sampled data) is inserted before the long symbols. This guard interval is composed of samples repeated from the end of the LTS. The preamble design includes repeated symbols because this repetition makes synchronization easier for the receiver. The standard specifies that the first seven short symbols of the STS should be used for signal detection, automatic gain control (AGC), and diversity selection (for Multiple Input Multiple Output systems). The last three symbols of the STS should be used for Coarse Frequency Offset (CFO) calculation, and Time Synchronization. The LTS is designed to be used for Channel Estimation and Fine Frequency Offset (FFO) calculation. It can also be used to refine the time synchronization estimates. The short training symbols are denoted by t1 to t10, whereas T1 and T2 denote long training symbols. The total preamble length is 16 µs. The dashed boundaries in the figure denote repetitions due to periodicity of the IFFT. The SIGNAL field and DATA follow the training structure. After calculating the time-domain preamble sequences, rSHORT(t) and rLONG(t) the sequences are appended together, and placed at the beginning of the packet to be transmitted. The preamble is transmitted over the channel without undergoing coding or interleaving.

$$r_{\mathrm{SHORT}}(t) = w_{\mathrm{T_{SHORT}}}(t) \sum_{k=-N_{ST}/2}^{N_{\mathrm{ST}}/2} S_k e^{kj2\pi\Delta ft} \qquad (1)$$

Where TSHORT = 8 µs is the total length of the STS, NST = 52 is the number of sub-carriers, and ΔF = 312.5 kHz, which is the subcarrier frequency spacing. The w(t) term is a time-windowing function, used to smooth the transition between OFDM symbols.

$$w_{\mathrm{T}}(nT_s) = \begin{cases} 1 & 1 \le n \le 79 \\ 0.5 & n = 0, 80 \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

Where Ts is the sample period, which is 50 ns in 802.11a.

$$r_{\mathrm{LONG}}(t) = w_{\mathrm{T_{LONG}}}(t) \sum_{k=-N_{\mathrm{ST}}/2}^{N_{\mathrm{ST}}/2} S_k e^{kj2\pi\Delta f(t-T_{\mathrm{G12}})} \qquad (3)$$

Where TLONG = 8 µs is the total length of the LTS, and TG12 = 1.6 µs is the length of the guard interval inserted before the first long training symbol.

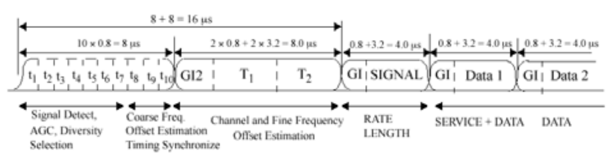

Fig1. Preamble Structure

Synchronization Techniques in the Continuous Modeand 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[3].

V. PACKET DETECTION

The first challenge for the receiver is to detect the packet. One possible algorithm to use is packet detection based on power level. That is, the presence of a packet can be inferred when the signal power exceeds a specific threshold. However, packet detection cannot be done in this manner in wireless systems because of the channel noise and multipath fading, which cause the received power to vary [11].

Another proposal is to use signal auto-correlation, taking advantage of the repetition in the preamble, and correlating the received sequence samples with a delayed copy of the sequence, with the delay being equivalent to the length of one symbol. A moving average of this correlation can be taken over a range of one symbol [2]. This is represented mathematically in Equation:

$$R(d) = \sum_{m=0}^{L-1} \left(r^*_{d+m} r_{d+m+L} \right) \tag{4}$$

Note that rd represents the value of the dth incoming sample, rdж represents the conjugate of rd, and that in the case of the STS symbols, L = 16 samples. Because of the variance of the incoming signal power, it is not possible to use a detection algorithm based on R(d) alone. A method for packet detection was developed in which auto-correlation is normalized by a moving sum of the received power as shown in Equations 2[12].

$$P(d) = \sum_{m=0}^{L-1} \left| r_{d+m+L} \right|^2 \tag{5}$$

$$M(d) = \frac{|R(d)|^2}{(P(d))^2} \tag{6}$$

This value is then compared with a threshold, th, and a packet is said to have been detected if M(d) > th. The values of M(d) should fall between 0 and 1. The value th should be chosen to minimize the incidence of false positive detection, and also the incidence of undetected packets, which occur when the receiver is unable to detect the training sequence.

Other possible packet detection schemes use Maximum Likelihood (ML) detection or Minimum Mean-Squared Error Criterion (MMSE) methods [5]. In a comparison of packet detection approaches, it was shown that there are fewer instances of false alarms using the auto-correlation method. The performance of the algorithm can be summarized with two probabilities:

- Probability of detection Pd, defined as the probability of detecting the packet when it is truly present.
- Probability of a false alarm Pfa , defined as the probability of incorrectly deciding that the packet is present when actually it is not. Setting the threshold lower increases Pd but also increases Pfa. Hence, the algorithm designer must settle for a balanced compromise between the two conflicting goals.

VI. CARRIER FREQUENCY 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. That is, if two identical samples are transmitted over the channel, the phase difference between them at the receiver is proportional to the frequency offset, and also proportional to the separation between the two transmission times [9]. For the STS, the phase difference can be extracted from the autocorrelation value R(d) in Equation 7. R(d) can be expressed as:

$$R(d) = e^{-j2\pi L \Delta f} \sum_{m=0}^{L-1} \left| r_{d+m} \right|^2 \tag{7}$$

The relationship between the Δf value in Equation 7 the term R(d) in Equation is given by

$$\phi = \angle R(d) \tag{8}$$

In this case, L = 16 samples, for a total time difference of 16Ts, where Ts is the sample period, 50 ns. Thus, if the phase difference value can be determined, an estimate of the frequency offset can be calculated as:

$$\Delta f = \frac{\angle R(d)}{2\pi \times 16 T_s} \tag{9}$$

The value R(d) will fall between π and − π, and thus the range of possible frequency offset values is:

$$-625\,\text{kHz} \le \Delta f \le 625\,\text{kHz}$$

It is possible to calculate Equations 7 using the LTS rather than the STS, in which case L = 64. When L = 64, the precision improves by a factor of 4, and the range of possible offset estimates is:

$$-156.25\,\mathrm{kHz} \leq \Delta f \leq 156.25\,\mathrm{kHz}$$

Because of the improved precision, performing the calculation with a 64 sample autocorrelation is referred to as fine frequency offset estimation; while the method using a 16 sample auto-correlation is referred to as coarse frequency offset estimation. Because of the limited range in the 64 sample case, the frequency offset is best estimated in two passes, first using the STS, and then using the LTS. The IEEE 802.11a standard states that the maximum tolerance for the central frequency is ±20 parts per million (ppm), which corresponds to a maximum possible frequency offset of 200 kHz, when the carrier frequency is 5GHz.The sampling clock errors will negatively influence the symbol timing synchronization. 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 [8].

VII. Frame/Symbol Time Synchronization

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. There are two methods for timing synchronization which are as follows:

A. Coarse time synchronization

B. Fine time synchronization

Three auto-correlation algorithms (Basic Auto-Correlation method, Auto-Correlation Difference method, and Auto-Correlation Sum method) are considered for coarse time synchronization, and two different cross-correlation implementations (Cross-Correlator, Quantized Cross-Correlator) are considered for fine time synchronization. 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. These algorithms are compared and evaluated, and then a final synchronizer design is decided upon[4].

Conclusion

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 are discussed.

References

[1] A Technique for Orthogonal Frequency Division Multiplexing Frequency Offset Correction IEEE transactions on communications V a . 42, No. 10, October 1994.

[2] T. Schmidl and D. Cox, “Robust frequency and timing synchronization for OFDM,” IEEE Trans. Communication, vol. 45, No.12, 1997:1613-1621

[3] H. Minn, M. Zeng, and V. K. Bhargava “On Timing Offset Estimation for OFDM Systems” IEEE Communications Letters, Vol. 4, No. 7, July 2000.

[4] Byun 'oon Park, Hyunsoo Cheon, Changwn Kang, and Daesik Hong “A Novel Timing Estimation Method for OFDM Systems” IEEE,2002.

[5] Seung Duk choi jung Min Choi and Jae Hong Lee “An initial timing offset estimation method for OFDM Systems in rayleigh fading channel”2006 IEEE.

[6] Yasamin Mostofi, Donald C. Cox “Analysis of the Effect of Timing Synchronization Errors on Pilotaided OFDM Systems” IEEE Communications Society 2003.

[7] Yasamin Mostofi and Donald C. Cox “Timing Synchronization in High Mobility OFDM system IEEE communication society 2004 pp 2402-2406”.

[8] A. I. Bo, G. E. Jian-hua, and Wang Yong, “Symbol Synchronization Technique in COFDM Systems” IEEE Transactions On Broadcasting, Vol. 50, NO. 1, March 2004.

[8] Ch. Nanda Kishore1 and V. Umapathi Reddy“A Frame Synchronization and Frequency Offset Estimation Algorithm for OFDM System and its Analysis”Hindawi Publishing Corporation EURASIP Journal on Wireless Communications and Networking Volume 2006, Article ID 57018, Pages 1–16 DOI 10.1155/WCN/2006/57018.

[9] Yasamin Mostofi and Donald C. Cox “A Robust Timing Synchronization Design in OFDM Systems–Part I: Low-Mobility Cases” IEEE Transactions On Wireless Communications, Vol. 6, No. 11, November 2007.

[10] David Perels, Christoph studer, and W.fichtner “Implementation of low complexity Frame-Start detection algorithm for MIMO system,2007 IEEE.

[11] Ang Ken Li,YewKuan Min ,varun Jeoti “Astudy of frame finding timing synchronization for Wimax applications,international conference on intelligent and advanced systems 2007,IEEE.