Synchronization Issues in Wireless OFDM Systems: A Review

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Abstract - **Orthogonal frequency division multiplexing (OFDM) is a type of multicarrier transmission technique that is used for variety of digital communication applications. It is used in Digital audio broadcasting (DAB), Digital video broadcasting & wireless LANs. OFDM can be viewed as both modulation and multiplexing technique. One OFDM symbol is a set of a large number of orthogonal waves. In OFDM the transmission is divided into smaller sub-bands, each having a low separate rate and is insensitive to dispersive multipath channels. Thus complex equalizers are not needed and a lower complexity is accomplished. Intersymbol Interference (ISI) is avoided by introducing a guard interval between successive symbols.. As OFDM solves the above mentioned problem, it introduces new problems itself. By using high numbers of narrow sub-carriers, the system becomes very sensitive to time and frequency offsets and thus a precise synchronization is needed. In this paper we discuss certain issues related to synchronization.**

Keywords: Synchronization, Delay spread, Multi-carrier, Intersymbol Interference, orthogonal

1. INTRODUCTION

OFDM stands for orthogonal frequency division multiplexing. It is a type of multicarrier modulation technique in which single high rate bit stream is divided into multiple low rate sub streams and transmitted over parallel sub channels. It is a technique that divides the spectrum in to a number of equally spaced tones and carriers a portion of a users information on each tone. A tone can be thought of frequency. Each tone is orthogonal to the other. OFDM is also called multi tone modulation. OFDM can be considered as a multiple access technique, because an individual tone or groups tones can be assigned to different users. Multiple users share a given bandwidth in this manner, yielding the system called OFDMA. Each user can be assigned a predetermined number of tones when they have information to send, or alternatively a user can be assigned a variable number of tones based on the information that they have to send. OFDM can be considered as a combination of both modulation & multiple access technique that divide the communications channel in such a way that many users share it. The division is based upon the frequency.

OFDM has a special property that each tone is orthogonal with each other. There will be frequency guard bands between frequencies so that they do not interfere with each other. OFDM allows the spectrum of each tone to overlap and because they are orthogonal they donot interfere with each other.This will reduce the spectrum

If two OFDM symbols are transmitted, one preceding the other the receiver must pick the correct samples of the actual OFDM symbol and give it to the FFT so the FFT window should be correctly placed. If there is no synchronization, the beginning of the FFT window will be placed too early or too late. If placed too late for example, some samples will be collected from the actual OFDM symbol and the others will be collected from the following OFDM symbol; if no following OFDM symbol exists, the last samples are filled up with noise. If placed too early, samples from the previous OFDM symbol will be collected. Both cases result in ISI. In addition to this, ICI results also from an FFT window mis-alignment because the periodic signal does not anymore fit completely in the FFT window. To point out the effect of ICI, we suppose that the FFT window takes some samples from the actual OFDM symbol and the last samples are filled with zeros. Such a time sequence has no longer definite frequency, so the discrete spectrum will not have single peaks anymore but sidelobes occur Consequently, the orthogonality is lost due to ICI.

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OFDM technique has found its wide applications in many scientific areas due to its high spectrum efficiency .In a single-carrier system, a single fade or interferer can cause the entire link to fail, but in a multi-carrier (MC) system, only a small percentage of the subcarriers (SCs) will be affected The difference between the conventional non-overlapping MC technique and overlapping MC technique is that we save almost 50% of the bandwidth in the latter case .To realize this, however, we need to reduce cross-talk between SCs, which means that we want orthogonality between the different modulated carriers. OFDM can be used either as a modulation or a multiplexing technique

Section 2 contains the detail of already published work for proving synchronization techniques in OFDM systems, section 3 contain the description of synchronization technique, section 4 contains the conclusion and section 5 contains references.

2 LITERATURE REVIEW

Synchronization remains as one of the most important factors to think of while using OFDM. Synchronization of an OFDM signal requires finding the symbol timing and carrier frequency offset. Symbol timing for an OFDM signal is significantly different than for a single carrier signal since there is not an "eye opening" where a best sampling time can be found. Rather there are hundreds or thousands of samples per OFDM symbol since the number of samples necessary is proportional to the number of subcarriers.

Finding the symbol timing for OFDM means finding an estimate of where the symbol starts. There is usually some tolerance for symbol timing errors when a cyclic prefix is used to extend the symbol. Synchronization of the carrier frequency at the receiver must be performed very accurately, or there will be loss of orthogonality between the subsymbols. OFDM systems are very sensitive to carrier frequency offsets since they can only tolerate offsets which are a fraction of the spacing between the subcarriers without a large degradation in system performance

There have been several papers on the subject of synchronization for OFDM in recent years. Moose gives the maximum likelihood estimator for the carrier frequency offset which is calculated in the frequency domain after taking the FFT [2]. He assumes that the symbol timing is known, so he just has to find the carrier frequency offset. The limit of the acquisition range for the carrier frequency offset is the subcarrier spacing. He also describes how to increase this range by using shorter training symbols to find the carrier frequency offset. For example shortening the training symbols by a factor of two would double the range of carrier frequency acquisition. This approach will work to a point, but the estimates get worse as the symbols get shorter because there are fewer samples over which to average, and the training symbols need to be kept longer than the guard interval so that the channel impulse response does not cause distortion when estimating the frequency offset.

Nogami and Nagashima [4] present algorithms to find the carrier frequency offset and sampling rate offset. They use a null symbol where nothing is transmitted for one symbol period so that the drop in received power can be detected to find the beginning of the frame. The carrier frequency offset is found in the frequency domain after applying a Hanning window and taking the FFT. The null symbol is also used in [11]. This extra overhead of using a null symbol is avoided by using the technique described in this paper. If instead of a continuous transmission mode, a burst mode is used, it would be difficult to use a null symbol since there would be no difference between the null symbol and the idle period between bursts.

Van de Beek [3] describes a method of using a correlation with the cyclic prefix to find the symbol timing. If this method were used to find the symbol timing, while using one of the previous methods to find the carrier frequency offset, there would still be a problem of finding the start of the frame to know where the training symbols are located.

Classen introduces a method which jointly finds both the symbol timing and carrier frequency offset [5]. However, it is very computationally complex because it uses a trial and error method where the carrier frequency is incremented in small steps over the entire acquisition range until the correct carrier frequency is found. It is impractical to do the exhaustive search and go through a large amount of computation at each possible carrier frequency offset.

OFDM synchronization techniques can be put in 2 categories:
1) non data-aided: make use of the correlation between the CP and the end of the symbol; and 2) data-aided: make use of additional data such as preamble and pilot tones

3. SYNCHRONIZATION TECHNIQUES

Frequency error in OFDM systems is often called *carrier frequency offset (CFO)*. CFO can be caused by frequency differences between the transmitter and receiver oscillators, Doppler shift of mobile channels, or oscillator instabilities. All sub-carriers are affected by the same amount of CFO. CFO is classified into two categories: *fractional sub-carrier spacing CFO*, and *integer sub-carrier spacing CFO* Fractional CFO introduces inter-carrier interference (ICI) between sub-carriers. It destroys the orthogonality of sub-carriers and results in bit error rate (BER) degradation. Integer CFO does not introduce ICI between sub-carriers, but does introduce a cyclic shift of data sub-carriers and a phase change proportional to OFDM symbol number. Therefore, it's necessary to correct this CFO at the OFDM receiver There are several techniques to estimate and compensate for these errors using time-domain or frequency-domain approaches, sometimes called *pre-FFT* and *post-FFT* synchronization, respectively

Pre-FFT Synchronization

Pre-FFT synchronization performs the estimation of CFO before OFDM demodulation (FFT processing). The pre-FFT approach provides fast synchronization and requires less computing power due to the fact that no FFT processing is needed.

Pre-FFT synchronization can be classified into two categories: *non-data-aided* (NDA) and *data-aided* (DA).

- NDA methods exploit similarities between the cyclic prefix (CP) part and the corresponding data part of a received OFDM symbol to estimate fractional CFO [2, 3, 4, 5]. This can be done by correlating the CP and the corresponding OFDM symbol to estimate both timing and frequency offsets [2, 3]. NDA methods that use the CP can only estimate CFO in the range of [-0.5, +0.5] sub-

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carrier spacing [2, 3]. These methods require no additional OFDM training symbols, improving transmission efficiency. If the CP is heavily disturbed by severe multipath fading, part or all of the cyclic prefix of a given symbol will be interfered with by the previous symbol. As a result, the estimation accuracy is significantly degraded, causing degradation of the BER performance. In order to increase the frequency error estimation accuracy and compensate for the impact of multipath fading, NDA frequency synchronization requires a fine timing synchronization technique.

- DA methods exploit a known sequence of OFDM training symbols inserted at the start of every OFDM packet (widely used in 802.11 WLAN [5]) to estimate fractional CFO. The downside of DA pre-FFT synchronization is reduced transmission efficiency due to the insertion of the training symbols. However, this method provides better results and a wider CFO estimation range than the NDA algorithms do: [-1.0, +1.0] sub-carrier spacing [6].

Post-FFT Synchronization

Post-FFT synchronization methods usually perform the estimation of the remaining integer CFO left by pre-FFT frequency synchronization. Integer CFO can be estimated by correlating the received pilot sub-carriers with a shifted version of the known pilot sub-carriers [7]. Depending on spacing between pilot sub-carriers, this approach can estimate CFO range up to several multiple integers of sub-carrier spacing.

Using the pilot sub-carrier approach, one can also estimate sampling clock frequency offset by using a special pilot sub-carrier pattern. This integer CFO synchronization technique is only effectively performed after coarse timing synchronization and coarse frequency synchronization have been established (acquisition stage) to track the residual CFO errors, common phase error (CPE) left by pre-FFT frequency synchronization, and receiver local oscillator phase noise, respectively.

4. CONCLUSION

As OFDM technique is highly band efficient in wireless communication systems but due to synchronization problem it introduces intersymbol interference & inter carrier interference. Due to ISI the orthogonality of subcarriers is lost and system performance degrades.In this paper we discussed various methods to minimized carrier frequency offset & timing offset. Although research is going on to reduce the ISI, ICI and provide better synchronization that will enhance the system performance.

5. REFERENCES

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