

Correlation based-Frequency offset estimation Over UWB Channels in Wireless Networks

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Abstract –The demand for seamless mobile connectivity and wireless internet access across the globe has been increasing. OFDM has been shown to be very efficient in wireless and wire line communication over broadband channels. Frequency offset is mismatch between transmitter frequency and receiver frequency. Frequency offset is produced by unstable receiver clock generator or Doppler Effect. OFDM systems are very sensitive to these frequency offsets. The sensitivity is increased by increasing the number of sub carriers or constellation. Frequency offset degrades the performance of both channel estimation and symbol detection. Ultra-Wide Band (UWB) systems (e.g., impulse radios and transmitted reference schemes to name a few) offer improved ranging precision, better penetration through obstacles, higher data rate, and increased multipath or frequency diversity. By applying auto correlation or cross correlation techniques, the frequency offset of OFDM based UWB channels can be estimated.

Index Terms – OFDM, UWB, Frequency offset, BER

1. INTRODUCTION

The difference between the frequency of the oscillator in the transmitter and the receiver causes frequency offset which if not estimated and compensated could ruin the orthogonality of the sub-carriers thereby causing large bit errors in the received signal. Also the distortion of the signals while travelling through the channel and the movement of the mobility user causes synchronisation problems.

Frequency offset (FO) arises from a number of factors: random Doppler frequency shifts, carrier frequency mismatch between transmitter and receiver oscillators and sampling frequency error between the ADCs. The FO causes severe reduction in signal amplitude and introduces intercarrier interferences (ICI) from the other subcarriers. As subcarriers are spaced out over the channel band- width, the FO must be minimized to a small fraction of the inter-subcarrier spacing in order to avoid severe bit error rate (BER) degradation from these detrimental effects. This thesis focuses on FO from carrier frequency mismatches and Doppler shifts only.

The OFDM systems are very sensitive to the carrier frequency offset (CFO) and timing, therefore, before demodulating the OFDM signals at the receiver side, the receiver must be synchronized to the time frame and carrier frequency which

has been transmitted.

1.1. Multi band OFDM

One of the most important advantages of OFDM over single-carrier schemes is its ability to cope with severe channel conditions, like narrowband interference or frequency-selective fading due to multipath, without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. In order to deal with low emitting power to avoid interference with other systems, an UWB implementation of OFDM [1] was proposed as Multi-Band OFDM (MBOFDM).

Multi band-OFDM transmission, five frequency groups are specified. All of these groups are divided into sub bands, each having a bandwidth greater than 528 MHz. In the each sub band, orthogonal frequency division multiplexing (OFDM) [2] is applied. Frequency hopping (FH) between different bands is supported so that the transmitted signal hops between Sub bands in every OFDM symbol duration is 312.5 ns

The band allocation for MB-OFDM is shown in Fig 1.1. Each sub band contains 128 subcarriers. Ten of these are used as guard tones, twelve of the subcarriers are dedicated to the pilot signals, and 100 are for information. The remaining six tones are set to zero. Multiband OFDM was developed by the IEEE 802.15.3a and standardized by ECMA in. The physical layer and radio interface are well described.

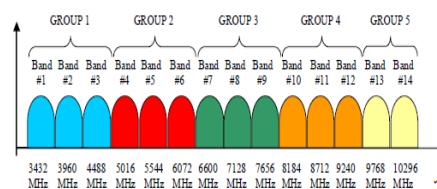


Fig 1.1: Band allocation for MB-OFDM

Time-frequency spreading in Multiband OFDM facilitates multiple user access as each logical channel or piconet is defined by its unique TFC. The information is spread across

three frequency bands to exploit frequency diversity and provide robustness against multipath and interference. The first band is commonly used by five out of seven TFCs to facilitate the reception of beacon frames by user devices and hence aid their synchronization. For example, if the device uses a TFC of [1 2 3 1 2 3], the information in the first OFDM symbol is repeated on sub-bands 1 and 2, the information in the second OFDM symbol is repeated on sub-bands 3 and 1, and that of the third OFDM symbol repeated in sub-bands 2 and 3.

1.2. Ultra Wide Band System

Ultra-Wideband (UWB) is a technology for transmitting information spread over a large bandwidth (>500 MHz) that should, in theory and under the right circumstances, be able to share spectrum with other users. Regulatory settings of FCC are intended to provide an efficient use of scarce radio bandwidth while enabling both high data rate "personal area network" (PAN) wireless connectivity and longer-range, low data rate applications as well as radar and imaging systems.

Ultra Wideband was traditionally accepted as pulse radio, but the FCC and ITU-R now define UWB in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 500 MHz or 20% of the centre frequency. Thus, pulse-based systems—wherein each transmitted pulse instantaneously occupies the UWB bandwidth, or an aggregation of at least 500 MHz worth of narrow band carriers, for example in orthogonal frequency-division multiplexing (OFDM) fashion—can gain access to the UWB spectrum under the rules. Pulse repetition rates may be either low or very high. Pulse-based UWB radars and imaging systems tend to use low repetition rates, typically in the range of 1 to 100 mega pulses per second. On the other hand, communications systems favour high repetition rates, typically in the range of 1 to 2 giga-pulses per second, thus enabling short-range gigabit-per-second communications systems. Each pulse in a pulse-based UWB system occupies the entire UWB bandwidth, thus reaping the benefits of relative immunity to multipath fading (but not to intersymbol interference), unlike carrier-based systems that are subject to both deep fades and intersymbol interference. A significant difference between traditional radio transmissions and UWB radio transmissions is that traditional systems transmit information by varying the power level, frequency, and/or phase of a sinusoidal wave. UWB transmissions transmit information by generating radio energy at specific time instants and occupying large bandwidth thus enabling a pulse-position or time-modulation. The information can also be imparted (modulated) on UWB signals (pulses) by encoding the polarity of the pulse, the amplitude of the pulse, and/or by using orthogonal pulses. UWB pulses can be sent sporadically at relatively low pulse rates to support time/position

modulation, but can also be sent at rates up to the inverse of the UWB pulse bandwidth. Pulse-UWB systems have been demonstrated at channel pulse rates in excess of 1.3 giga-pulses per second using a continuous stream of UWB pulses (Continuous Pulse UWB or "C-UWB"), supporting forward error correction encoded data rates in excess of 675 Mbit/s. Such a pulse-based UWB method using bursts of pulses is the basis of the IEEE 802.15.4a draft standard and working group, which has proposed UWB as an alternative PHY layer.

One of the valuable aspects of UWB radio technology is the ability for a UWB radio system to determine "time of flight" of the direct path of the radio transmission between the transmitter and receiver at various frequencies. This helps to overcome multi path propagation, as at least some of the frequencies pass on radio line of sight. With a cooperative symmetric two-way metering technique distances can be measured to high resolution as well as to high accuracy by compensating for local clock drifts and stochastic inaccuracies.

Another valuable aspect of pulse-based UWB [3] is that the pulses are very short in space (less than 60 cm for a 500 MHz wide pulse, less than 23 cm for a 1.3 GHz bandwidth pulse), so most signal reflections do not overlap the original pulse, and thus the traditional multipath fading of narrow band signals does not exist. However, there still is multipath propagation and inter-pulse interference for fast pulse systems which have to be mitigated by coding techniques.

2. Multi Band OFDM based UWB System Model

2.1. Multi band OFDM PHY Layer

A multi-band OFDM system [4] divides the available bandwidth into smaller non-overlapping sub bands such that the bandwidth of a single sub-band is still greater than 500MHz (FCC requirement for a UWB system). The system is denoted as an 'UWB-OFDM' system because OFDM operates over a very wide bandwidth, much larger than the bandwidth of conventional OFDM systems. OFDM symbols are transmitted using one of the sub-bands in a particular time-slot. The sub-band selection at each time-slot is determined by a Time-Frequency Code (TFC). The TFC is used not only to provide frequency diversity in the system but also to distinguish between multiple users. The proposed UWB system utilizes five sub-band groups formed with 3 frequency bands (called a band group) and TFC to interleave and spread coded data [5] over 3 frequency bands. Four such band groups with 3 bands each and one band group with 2 bands are defined within the UWB spectrum mask. There are also four 3-band TFCs and two 2-band TFCs, which, when combined with the appropriate band groups provide the capability to define eighteen separate logical channels or independent piconets. Devices operating in band group #1

(the three lowest frequency bands) are selected for the mandatory mode (mode #1) to limit RF phase noise degradations under low-cost implementations.

Fig. 2.1 shows the presence of a time frequency kernel in a typical OFDM TX architecture. Time-frequency kernel produces carriers with frequencies of 3.432MHz, 3.960MHz and 4.488MHz, corresponding to center frequency of sub band 1, 2 and 3. The MB-OFDM [6] based UWB PHY layer proposal submitted to IEEE 802.15.3a working sub-committee for WPANs specifies parameters for different modules of PHY layer.

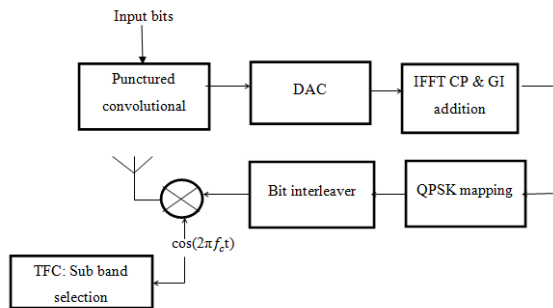


Fig 2.1: TX Architecture of an MB-OFDM System

From the total available bandwidth of 7.5GHz (3.1-10.6 GHz), usage of 1.5GHz (3.1-4.75 GHz) is set mandatory for all MB-OFDM devices. Although sub-band bandwidth is required to be greater than 500 MHz (FCC requirement as stated earlier), hardware constraints impose using as narrow bandwidth as possible. Hence, a sub-band of 528 MHz was proposed in, because it can be generated using simpler synthesizer circuits.

2.2. UWB Propagation Channel Model

In order to evaluate different PHY layer proposals, IEEE 802.15.3a channel modeling sub-committee proposed a channel model for realistic UWB environments. During 2002 and 2003, the IEEE 802.15.3 Working Group for Wireless Personal Area Networks and especially its channel modeling subcommittee decided to use the so called modified Sale-Valenzuela model (SV) as a reference UWB channel model [7]. The real valued model is based on the empirical measurements originally carried out in indoor environments in 1987. Due to the clustering phenomena observed at the measured UWB [9] indoor channel data, the model proposed by IEEE 802.15 is derived from Saleh and Valenzuela using a lognormal distribution rather than an original Rayleigh distribution for the multi-path gain magnitude. An independent fading mechanism is assumed for each cluster as for each ray within the cluster. In the SV models, both the cluster and ray arrival times are modeled independently by

Poisson processes. The multi-path channel [10] impulse response can be expressed as

$$h(t) = \lambda \sum_{l \geq 0} \sum_{k \geq 0} \alpha_{k,l} \delta(t - T_l - \tau_{k,l}) \quad (1)$$

Where k, l, α is the real-valued multi-path gain for cluster l and ray k . The l th cluster arrives at time $l T$ and its k th ray arrives at k, l, τ which is relative to the first path in cluster l , i.e. $0 \leq \tau \leq T_l$. The amplitude k, l, α has a log-normal distribution and the phase k, l, α is chosen from $\{0, \pi\}$ with equal probability.

The baseband equivalent of the channel impulse response in q th band is given by,

$$h^q(i) = x \sum_{l=0}^L \sum_{k=0}^K \alpha_{k,l} e^{-j2\pi f_q (T_l + \tau_{k,l})} p(i T_s - T_l - \tau_{k,l} - \tau_0); 0 \leq i \leq C-1 \quad (2)$$

where, $p(i T_s - T_l - \tau_{k,l} - \tau_0)$ is the delayed impulse response of the combined transmit and receive filter; T_s is the sampling time; T_l denotes the delay of the l th cluster, k, l denotes the arrival time of k th ray in the l th cluster; τ_0 is the delay introduced to satisfy causality; f_q is the centre frequency of q th band; $\alpha_{k,l}$ is the lognormal distributed multipath gain coefficient; $\beta_{k,l}$ is the lognormal shadowing and C is the length of the impulse response. The channel coefficients are defined as

$$\alpha_{k,l} = p_{k,l} \beta_{k,l}$$

3. FREQUENCY-OFFSET ESTIMATION TECHNIQUE

CFO [3] can produce Inter Carrier Interference (ICI) which can be much worse than the effect of noise on OFDM systems. Therefore, it is important for it to be estimated and compensated for. Many algorithms have been proposed for estimating the carrier frequency offset. CFO estimation can be done in two ways either time domain based approach or frequency domain based approach. It is shown that the frequency domain based approach which is our proposed method offers better CFO estimation than the time domain [11] based approaches.

3.1 Time Domain Based Approach

- Cyclic Prefix Based Method

In this method the cyclic prefix of the OFDM signal is compared to that of the rear part of the signal. As already said cyclic prefix is nothing but the tail part of the OFDM signal attached to the head part of the signal the phase of both the cyclic prefix and the OFDM signal must be same. Any change in the phase of cyclic prefix and the OFDM signal implies the presence of frequency offset. With perfect symbol

synchronization, for an N point OFDM signal a CFO of ϵ results in a phase rotation of $2\pi n\epsilon/N$ in the received signal. The CFO estimate by using this method is given by

$$\epsilon = \frac{1}{2\pi} \arg\{y_1^*[n]y_1^*[n+N]\}$$

The overall estimate of the N length sequence can be obtained by taking the average of all the samples and is given as

$$\epsilon = \frac{1}{2\pi} \arg\left\{\sum_{n=0}^{N-1} y_1^*[n]y_1^*[n+N]\right\}$$

Since the argument operation $\arg(\cdot)$ performs $\tan^{-1}(\cdot)$ operation the range of CFO estimation in the above equation is $\frac{1}{2\pi}[-\pi, \pi] = [-0.5, 0.5]$. Hence, the CFO estimation range is only for $|\epsilon| < 0.5$ by using this cyclic prefix based method.

- Training Symbol Based Method

In this method two identical signal OFDM are transmitted consecutively and are compared to get the frequency offset. Let us consider an N point OFDM sequence is repeated and we receive a 2N point sequence.

The transmitted sequence is given as,

$$r_n = \frac{1}{N} \left[\sum_{k=0}^{N-1} X_k H_k e^{\frac{2\pi j n (k+\epsilon)}{N}} \right] \quad (3)$$

where $n = 0, 1, 2, \dots, 2N - 1$

X_k = Transmitted sequence

H_k = transfer function of the channel

ϵ = frequency offset

W_n = noise

The k_{th} element of the N point DFT of the first N point sequence is

$$R_{1K} = \sum_{n=0}^{N-1} r_n e^{\frac{-2\pi j n k}{N}} ; k = 0, 1, 2, \dots, N - 1$$

The k_{th} element of the DFT of the second half of the sequence is

$$\begin{aligned} R_{2k} &= \sum_{n=N}^{2N-1} r_n e^{\frac{-j2\pi n k}{N}} \\ &= \sum_{n=N}^{2N-1} r_{n+N} e^{\frac{-j2\pi n k}{N}} \end{aligned}$$

From (3) $r_{n+N} = r_n e^{2\pi j \epsilon} \rightarrow R_{n+N} = R_n e^{2\pi j \epsilon}$

The received signal sequence is

$$Y_{1k} = R_{1k} + W_{1k}$$

$$Y_{2k} = R_{2k} e^{2\pi j \epsilon} + W_{2k} ; k=0, 1, 2 \dots N-1$$

By comparing of phases of these two sequences, the frequency offset is given by

$$\hat{\epsilon} = \tan^{-1} \left\{ \frac{\sum_{k=0}^{N-1} \text{Im}[Y_{2k} Y_{1k}^*]}{\sum_{k=0}^{N-1} \text{Re}[Y_{1k} Y_{2k}^*]} \right\}$$

4. FREQUENCY DOMAIN BASED METHOD

- Pilot Tone Based Method(Implemented Method)

In this method pilot tones are inserted in the frequency domain and transmitted in every OFDM symbol for CFO tracking. A pilot tone is a complete OFDM symbol where the value of each subcarrier is predefined and known in transmitter and receiver. It is repeated with a certain rate that depends on how fast the channel changes. The received signal is correlated with the pilot symbol to detect the OFDM symbol start. The location of pilot tones in terms of subcarriers is defined by the signal protocol. For instance, in the case of 802.11a the pilot subcarriers are -21, -7, 7, and 21.

The frequency offset estimate by using this method is by,

$$\hat{\epsilon} = \frac{1}{2\pi} \max \left\{ \left| \sum_{j=0}^{L-1} Y_{1+D}[P[j]] Y_1^*[P[j]] X_{1+D}^*[P[j]] X_1[P[j]] \right| \right\}$$

Where L=number of pilot tones

$p[j]$ =location of j^{th} pilot tone

$X_1[P[j]]$ =the pilot tone located at $p[j]$

Own Above

5. SIMULATION RESULTS

The Fig.5.2 shows the Normalised CFO estimation for the random generated signal shown in Fig 5.1. The results show the comparison of 3 methods. The black curve represents the Cyclic Prefix method. The Red curve represents the Training symbol based method and Blue curve represents the proposed method that is Pilot based method. The results are obtained by running the code on Matlab. The x-axis represents SNR (dB) and y-axis represents the MSE.

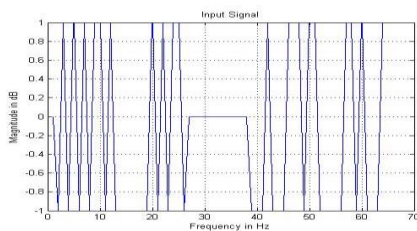


Fig 5.1. Random signal generated for OFD

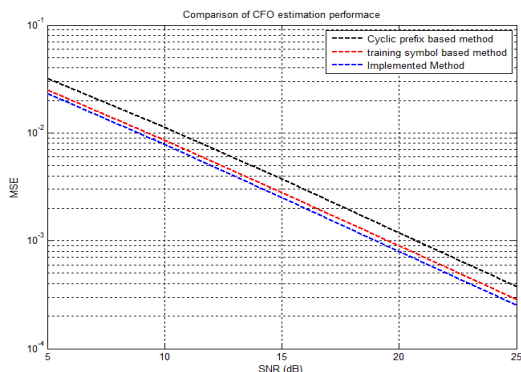


Fig 5.2. Normalised CFO estimation

SNR(dB)	MSE		
	Cyclic Prefix Method	Training symbol based method	Pilot tone based method
5	0.03199	0.02496	0.02313
10	0.011324	0.008614	0.007768
15	0.003724	0.002806	0.002506
20	0.001193	0.000896	0.0007976
25	0.000378	0.0002842	0.0002527

Table 5.1: Performance comparison of the Methods

The table shown below gives the comparison of the three methods based on their corresponding SNR (Signal to Noise Ratio) and MSE (Mean Square value) values of the output result shown in Fig.5.2. From the table it is clear that our proposed method that is pilot based method is better than other two Cyclic Prefix and Training Symbol based Methods. Because it is having less MSE value on the y-axis for the corresponding SNR value on the x-axis.

6. CONCLUSION

The frequency offset estimation method presented in this project for MB-OFDM based UWB Systems is based on pilot tones. Oscillator frequency mismatch introduces different

carrier-frequency offsets in different bands of MB-OFDM systems. The implemented method incorporate the effects of different carrier frequency offsets achieves better performance than the other two methods i.e., CP and training symbol based methods. This algorithm is equipped with lower complexity and is computationally efficient with respect to its peer ones.

REFERENCES

- [1] E. Novakov and J.-M. Fournier, "An Ultra-Wideband Impulse-Radio Communication Method and Transceiver", IEEE - GLOBECOM 2009, Hawaii, USA, 2009.
- [2] N. LaSorte, W. Justin Barnes and H. H. Refai, "The History of Orthogonal Frequency Division Multiplexing", IEEE - GLOBECOM 2008, New Orleans, USA, 2008.
- [3] Defeng (David) Huang, Member, IEEE, and Khaled Ben Letaief, "Carrier Frequency Offset Estimation for OFDM Systems Using Null Subcarriers", IEEE transactions on communications, vol. 54, no. 5, may 2006 813.
- [4] Rappaport, T.S., Wireless Communication (upper saddle river, NJ, Prentice-hall, 2006).
- [5] MIMO-OFDM WIRELESS COMMUNICATIONS by Yong Soo Cho, Jaekwon Kim
- [6] A. Ridolfi and M. Z. Win, "Ultrawide bandwidth signals as shot-noise: a unifying approach," IEEE J. Select. Areas Commun., vol. 24, no. 4, pp. 899-905, Apr. 2006.
- [7] T. Q. S. Quek and M. Z. Win, "Analysis of UWB transmitted reference communication systems in dense multipath channels," IEEE J. Select. Areas Commun., vol. 23, no. 9, pp. 1863-1874, Sept. 2005.
- [8] A. Giorgetti, M. Chiani, and M. Z. Win, "The effect of narrowband interference on wideband wireless communication systems," IEEE Trans. Commun., vol. 53, no. 12, pp. 2139-2149, Dec. 2005.
- [9] A. Batra, et. al., "Multi-band OFDM physical layer proposal for IEEE 802.15 task group 3a," IEEE P802.15-03/268r3, Orlando, FL, USA, Mar. 2004.
- [10] IEEE 802.15 working group for wireless personal area networks (WPANs) "Multi-band OFDM physical layer proposal for IEEE 802.15 task group 3a," Mar. 2004.
- [11] M. Z. Win, "A unified spectral analysis of generalized time-hopping spread-spectrum signals in the presence of timing jitter," IEEE J. Select. Areas Commun., vol. 20, no. 9, pp. 1664-1676, Dec. 2002.
- [12] M. Z. Win and R. A. Scholtz, "Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications," IEEE Trans. Commun., vol. 48, no. 4, pp. 679-691, Apr. 2000.
- [13] M. Z. Win and R. A. Scholtz, "Impulse radio: how it works," IEEE Commun. Lett., vol. 2, no. 2, pp. 36-38, Feb. 1998.