IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735
PP 30-36
www.iosrjournals.org

Test bed for Selecting Optimum Sequences for Preamble Structures in MIMO OFDM

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Abstract: *The main challenge faced during the implementation of Multiple Input Multiple Output(MIMO) Orthogonal Frequency Division Multiplexing (OFDM)System is that it is subjected to impairments of frequency and timing offsets which causes performance degradation of the system. Preamble based offset estimation techniques are equipped with mathematical sequences in the header of each OFDM frame. To ensure accurate estimation of offsets, selection of apt sequence is crucial. The sequences with high autocorrelation properties and low autocorrelation side lobes are preferred. A test bed for analyzing the correlation properties and side lobe level of the sequence is developed and discussed in this paper.*

Keywords: *MIMO OFDM, Timing Metric, Schmidl and Cox algorithm, Minn's Algorithm, Gold, Kasami, Barker, GCL.*

I. Introduction

The high bandwidth requirements in the new generation data transmission applications are increasing day by day and demanding efficient exploitation of frequency spectrum. The data throughput can be improved significantly without additional bandwidth or transmit power by placing multiple antenna elements both on transmitter or receiver, the technology referred to as Multiple Input Multiple Output (MIMO). Increased spectral efficiency through spatial multiplexing, improved link reliability through antenna diversity and high capacity are the main attractions of MIMO. Sufficient robustness to radio channel impairments can be provided by selecting Orthogonal Frequency Division Multiplexing modulation (OFDM) scheme. OFDM is a multicarrier system where the modulation is attained through Inverse Fast Fourier Transform and simultaneous transmission of data through closely packed orthogonal carriers is allowed utilizing parallel processing techniques. Dividing the available spectrum into several orthogonal subchannels whose bandwidth is less than coherence bandwidth of the channel, a frequency selective fading channel can be converted into a collection of flat fading subchannels.

Combining the advantages of both the above technologies, MIMO OFDM systems increases data rate as well as improve quality of service against fading which is one of the main challenges in wireless communication. The benefits of MIMO OFDM strongly depend on perfect synchronization and all the transceiver systems based on OFDM/MIMO OFDM are highly sensitive to timing and frequency offsets. It is required that receiver must be synchronized to both the time frame and the transmitted frequency. But in the case of all practical wireless communication systems, frequency and timing offsets are created due to discrepancies between transmitter and receiver oscillators and Doppler shifts introduced by nonlinear channels. The destructive effects caused by the offsets are reduction in signal amplitude and the introduction of inter carrier interference (ICI) caused by loss of orthogonality between subcarriers. As the presence of these offsets degrades the system performance in a non-graceful way, the estimation and correction of offsets in MIMO OFDM have been a topic of active research since last decade.

Different approaches for offset estimation [1-4] include data-aided synchronization which uses preambles before OFDM signals, blind synchronization methods which exploit the inherent characteristics in OFDM signals like redundancy in the cyclic prefix and semi blind synchronization that includes pilot symbols in addition to cyclic prefix. This paper considers offset estimation using repeated training sequence for comparing the performance of different mathematical sequences because of its accuracy and reduced complexity in estimating the errors. Even though the other two techniques are easier to apply and save bandwidth they achieve the target at the expense of added complexity and degraded performance.

This paper is organized as follows. Section II describes the system model of MIMO OFDM. The offset estimation methods in OFDM and conventional methods like Schmidl and Cox Algorithm and Minn's algorithm are reviewed in Section III. Different mathematical sequences used in offset estimation are briefly introduced in

Section IV. The performance of different mathematical sequences is evaluated using MATLAB simulation and results are discussed in Section V. Finally, the paper is concluded in Section VI.

II. System Model For MIMO OFDM

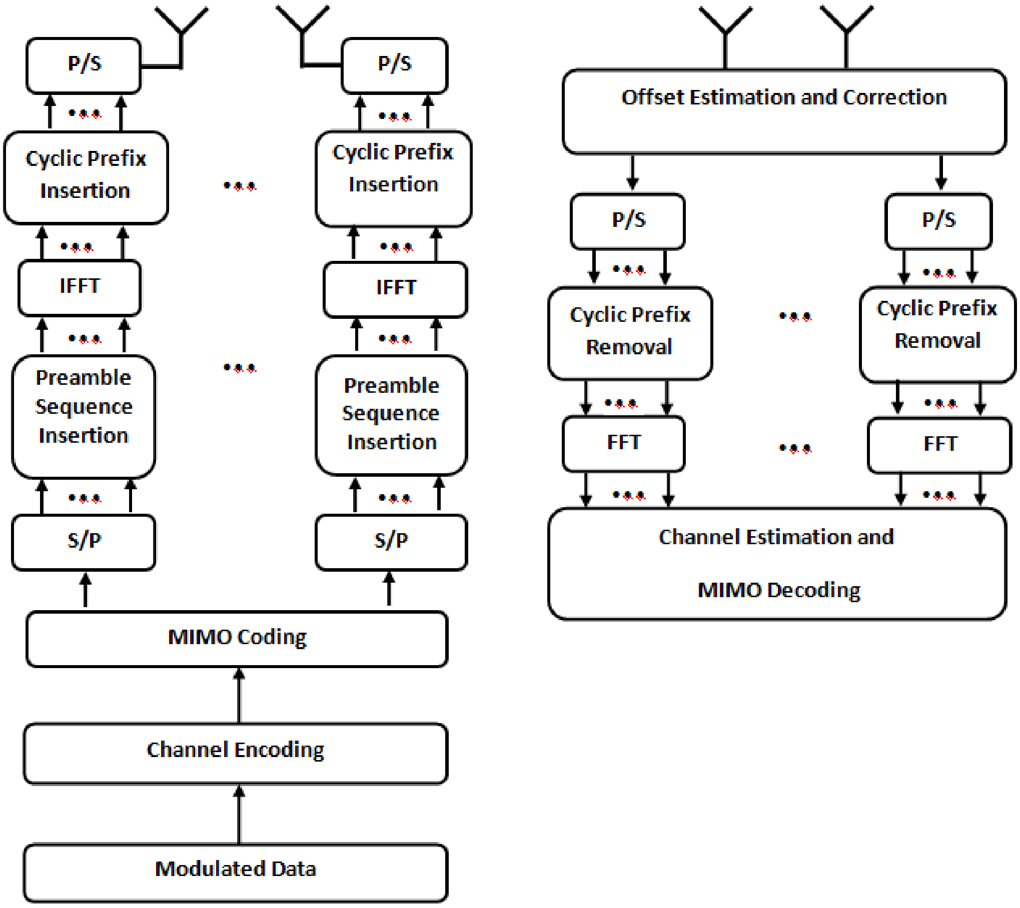

Figure 1 MIMO OFDM Transmitter and Receiver

The input data stream is fed to space time encoder to achieve diversity. Preamble sequence is added in serial to parallel converted data and fed to IFFT processor. Cyclic prefix whose length greater than maximum delay spread of the channel is inserted to guard the OFDM symbol against ISI. At the receiver side, CFO is estimated and compensated by the frequency synchronization unit. Further operations which are in reverse to the operations are made in transmitter are done in the CFO compensated signal.

III. Offset Estimation In OFDM

Paul H. Moose evaluated the degradations in the OFDM performance due to timing and frequency offsets and proposed a frequency synchronization algorithm using two identical repeated training symbols and maximum likelihood principles [4]. Even though the algorithm estimated frequency offsets, the range of estimation was limited to [-1/2, +1/2], i.e., half the subcarrier spacing of repeated symbols. To achieve timing synchronization, the accurate identification of frame starting point at the receiver is crucial and Keller [8] suggested a maximum correlation criterion for frame detection. But the peaks due to the presence of high peak to average power ratio values in OFDM signals was sometimes wrongly counted as peak in correlation metric which resulted in wrong detection of frames. Schmidl and Cox [1] suggested a time synchronization algorithm based on a metric after normalising the squared value of correlation by the power of second training sequence. This method eliminated the above mentioned problem caused by high PAPR and is regarded as reference for frame detection and coarse timing. The procedure in [4] was extended by Schmidl and Cox algorithm (SCA) to achieve a higher acquisition range. If the timing is not correctly synchronised, it results in loss of information. It is very important that the OFDM receiver should know where to start the starting of the OFDM symbol from. So determining the starting of OFDM symbol must be given as priority as finding the initial position of data packet.

The main idea in the SCA is the use of coarse and fine timing metric functions to perform timing synchronization. Coarse timing synchronization detects the beginning of frame where the fine timing synchronization detects the starting of useful data in the frame. Here a preamble structure of type [S S] is selected where S represents the sequence under evaluation. The acquisition is achieved in two steps as given in Fig.1 through the use of a two symbol training sequence.

Frame detection is carried out by searching for a symbol in which the first half is identical to the second half in time domain. After partially correcting the carrier frequency offset, the correlation between the two repeated preambles is computed. The two training sequences remains almost identical even after passing through the channel. Anyway there will be a phase difference between them which is induced by the carrier frequency offset. The conjugate of a sample from the first half is multiplied by the corresponding sample of the second half and phase angle of the product is calculated which will be approximately $\pi\Delta f$. The correlation window is then slided through the length of the symbols and the timing metric corresponding to the index corresponding to the maximum of timing metric is considered as the best timing point. The phase of the correlation metric at the best timing point is estimated as the frequency offset. If there are L samples in one half of the training sequence, the sum of product of conjugate of sample with corresponding pair in the next half can be represented by following equation.

$$P(d) = \sum_{m=0}^{L-1} (r_{d+m}^{*} r_{d+m+L}) \qquad (1)$$

The energy in the received second half-symbol is given by R(d).

$$R(d) = \sum_{m=0}^{L-1} |r_{d+m+L}|^2 \qquad (2)$$

A timing metric can be defined as M(d).

$$M(d) = \frac{|P(d)|^2}{\left(R(d)\right)^2} \qquad (3)$$

The metric reaches a plateau when the window of L samples completely overlaps the first training symbol and the start of the OFDM frame can be taken anywhere in the spread of that plateau.

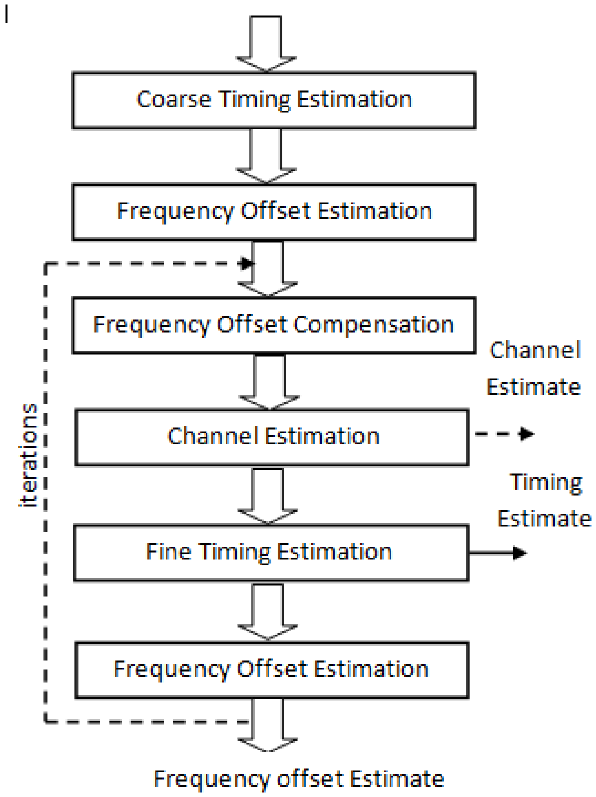

Figure 2 Offset estimation procedure

Minn’s method overcomes the broad plateau issue by selecting a structure [SS –S –S]. The timing metric is same as that of equation3.

$$P(d) = \sum_{k=0}^{1}\sum_{m=0}^{L-1} r^{*}\,(d + 2Lk + m).r(d + 2Lk + m + L) \qquad (4)$$

$$R(d) = \sum_{k=0}^{1}\sum_{m=0}^{L-1} |r(d + 2LK + m + L)|^{2} \qquad (5)$$

The correlation and synchronization properties of different mathematical sequences are analyzed using both SCA and Minn’s algorithm in this paper.

IV. Mathematical sequences aiding synchronization

The preamble based synchronization techniques are equipped with a preamble sequence in the header of each OFDM frame and this sequence indicates the starting position of the frame at the receiver. Selection of this mathematical sequence is important so as to derive optimised offset estimation. They are desired to posses good correlation properties, low computational complexity and low Peak to Average Power Ratio (PAPR). The training sequences must be selected such that their Fourier transforms are of constant magnitude and auto correlation of sequences from various transmitters to be an impulse. Sequences with zero autocorrelation shows to have optimised Cramer Rao Bound since the fluctuations in the received energy is found minimum for them in frequency selective Rayleigh fading channels.

Fredrick Tufvesson [6] have shown that Pseudo Noise(PN) based preamble gives better detection properties, sharp synchronization peaks and lower false detection probability. In 1990, M Grayson and M Darnell reported that bipolar sequences developed by R H Barker posses excellent autocorrelation functions which are either zero or negative at all time shifts except zero and can be considered as optimum preambles. Barker Sequence is a subset of PN sequence of N values of +1 and -1 and can be used for effective frame synchronization. Gold sequence is another type of binary sequence widely used in wireless communication. A set of Gold coded sequences consists of 2^{n} -1 sequences each with a period of 2^{n} -1. Kasami sequences are also binary sequence of length 2^{n} -1 where N is an even integer.

Preamble sequences of constant amplitude can be generated by constant amplitude zero autocorrelation waveforms (CAZAC) which is a periodic complex valued signal with modulus one and out of phase periodic autocorrelation equal to zero.

Zadoff Chu Sequence or Chu sequence is a special class of CAZAC with special properties like orthogonality and zero auto correlation of root sequence with its cyclic shifted versions. They are also known by the name Generalised Chirp Sequence (GCL).Training symbol using Chu sequence is expressed as

$$x(n) = \begin{cases} e^{\frac{j\pi Mn\ (n+1)}{N}}, & ifNisodd \\ e^{\frac{j\pi M\ n^{2}}{N}}, & ifNiseven \end{cases} \qquad (6)$$

where N is the length of CAZAC sequence, M is a natural number relatively prime to N and $0 \leq n \leq N-1$. Long Term Evolution (LTE) standard make use of Chu signals as Primary Synchronization Signals (P-SS), Reference Signal (RS) in both uplink and downlink and also in Physical Uplink Control Channel (PUCCH). It enhances power amplification properties of LTE modem signal as the time variations are less. Also channel estimation at the receiver become more flexible due to small frequency variation

V. Results

Simulations have been run in MATLAB 2013 to evaluate metric performance of different mathematical sequences at both high and low signal to noise ratio levels. Preamble structure proposed by Schmidl and Cox was initially selected to test the frame detection capabilities of different signals. Selecting the structure [S S] as the platform, the ratio of correlations was selected as timing metric as given by equation3. Results shows that at both high and low SNR levels the best performance is exhibited by CAZAC and GCL sequences.

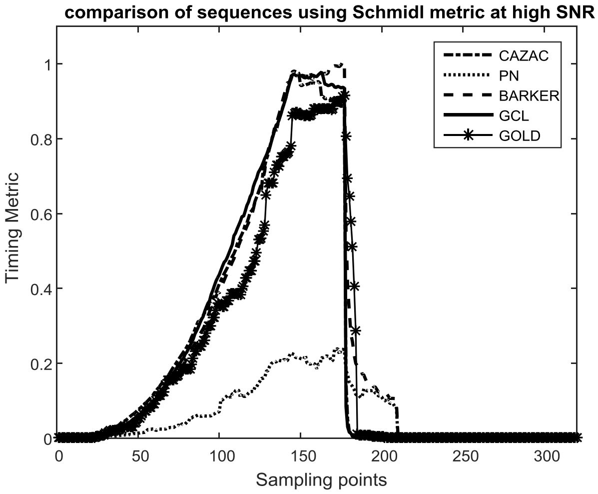

Figure 3 Performance comparison of CAZAC, Chu, PN and Barker sequences at high SNR

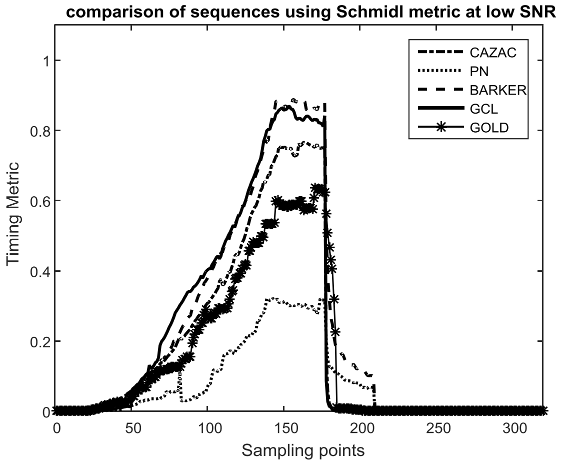

Figure 4 Performance comparison of CAZAC, Chu, PN and Barker sequences at low SNR

To overcome the deleterious effects due to timing offsets, the starting of the frame to be identified accurately at the receiver which can be achieved by sequences with excellent correlation properties. As the above mentioned structure suffers from plateau problem, there is ambiguity in determining right timing position. So in the next simulation a Minn's structure is used as the platform to evaluate the sequences. Here the result shows that GCL and Gold sequences are giving maximum correlation peaks with minimum side lobes.

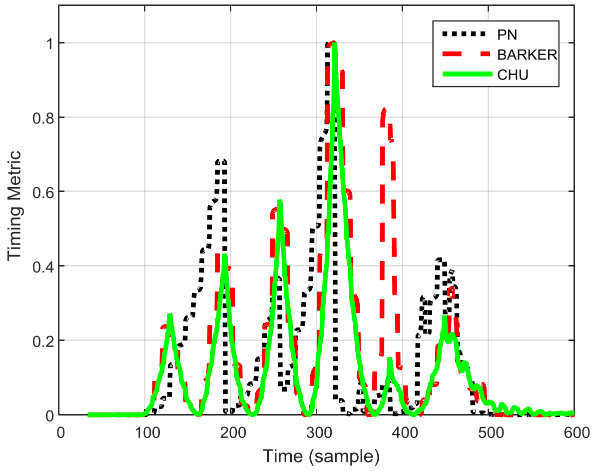

Figure 5 Comparison of PN, Barker and Chu sequences using Minn's algorithm

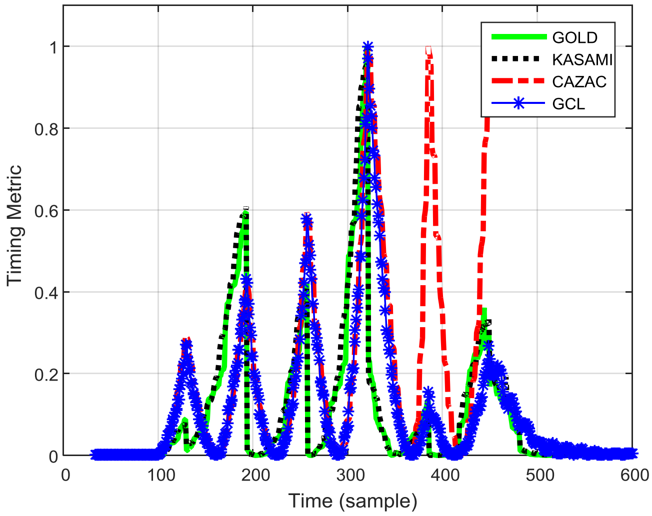

Figure 6 Comparison of Gold, Kasami CAZAC and GCL sequences using Minn's algorithm

The autocorrelation properties of different sequences are also compared via simulation and verified that all the sequences are giving satisfying auto correlation properties required for synchronization. Autocorrelation is impulsive for all the sequences and is negative or zero at all time shifts except zero.

Table 1. Comparison of ISL values for different sequences at different length

Length of sequence	**Name of sequence**				
	Barker	***Gold***	***Kasami***	***Chu***	***Cazac***
32 bits	2300	427	760	1135	1079
64 bits	16808	3069	4602	4572	4256
128 bits	120032	21430	29620	18467	16841
256 bits	928140	152350	231729	77132	66834

The table1 shows that side lobe energy is increasing with number of bits and optimum ISL values are obtained for Cazac sequence.

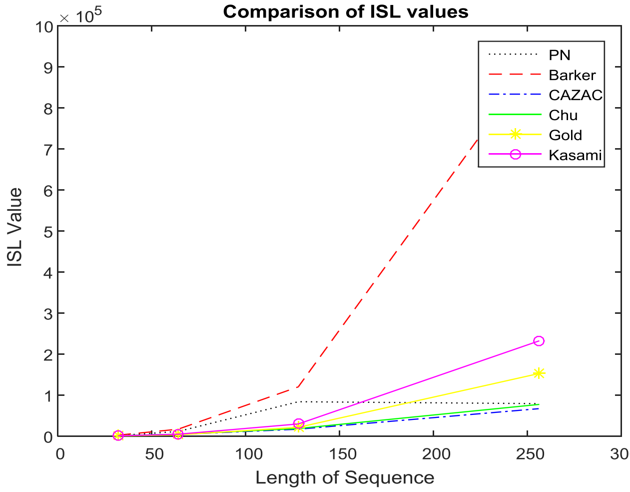

Figure 7 Comparison of ISL values for CAZAC, Chu, PN, Gold, Kasami and Barker

VI. Conclusion

The preamble based synchronization techniques are very effective for accurate estimation and correction in MIMO OFDM. Proper selection of sequences in preamble structure is of great importance for maintaining system synchronization. A system for evaluating correlation properties of sequences is developed. The parameters used for analysis include timing metrics based on Schmidl's structure, Minn's structure and Integrated Side lobe Level (ISL) values.The comparative analysis of different mathematical sequences including Barker, Gold, Kasami, PN, CAZAC and Generalized Chirp Like (GCL) sequence is performed.

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