# Improved Burst Detection for Physical Layer of SDR Wideband Waveform


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# DECLARATION

I certify that this research work titled "Improved Burst Detection for Physical Layer of SDR Wideband Waveform" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged / referred.

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# LANGUAGE CORRECTNESS CERTIFICATE

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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# COPYRIGHT STATEMENT

# ACKNOWLEDGEMENTS

Firstly, I am heartily thankful to my Creator ALLAH SUBHAN-WATALA for guiding me throughout this work in every step. I owe everything to my country which provide me a platform to represent this work. I am profusely thankful to my beloved parents who raised me when I was no capable of walking and reading and writing and continued to support me throughout in every department of my life.

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# DEDICATION

I would like to dedicate this thesis to my beloved parents, my wife and adored siblings whose tremendous support and cooperation led me to accomplishment of this work.

# ABSTRACT

Seamless communication for reliable, detailed and precise transfer of informative data is the requirement of future tactical systems. To improve the demand of high throughput in networking radio communication systems, a wideband networking waveform for software defined radios is developed. Multi-mode wideband networking waveform for software define radio attains this quality of communication service. This wideband networking waveform has different aspects of operation. These aspects are including designing of physical layer, sampling clock recovery, burst detection, and carrier frequency offset estimation and compensation. Burst detection plays important role in throughput of burst mode of communication systems. A novel burst detection algorithm using Zadoff-chu training sequence is proposed which reduces re-transmission overhead and increase throughput of communication system. Its helps to improve the quality of service and throughput requirement of user application in wideband networking communication. Detection of start of burst and timing synchronization operations are most important in wideband networking radio waveform in software defined radios. Medium Access Time Adaptive time slot algorithm directly affect by these operations. Especially design Zadoff-chu training sequence is used to calculate timing metric is proposed in burst detection algorithm. Channel conditions are very less affecting the threshold value of burst detection metric.

Proposed algorithm is compared with a set of known existing methods and results demonstrates the improvement of performance. Throughput, computational complexity and performance of proposed algorithm is show through simulation results. This proposed burst detection algorithm is used to improve throughput of wideband SDR waveform-based systems. Both military and commercial based application used high throughput wideband SDR waveform. Voice calls, Video conferencing, Messaging, biometrics, file transfer applications, IP data are some examples of wideband SDR waveform.

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# ABBREVIATIONS

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| ADC | Analog-to-Digital Converter |
| AMC | Adaptive Modulation & Coding |
| ANW2 | Adaptive Networking Wideband Waveform |
| ATDMA | Adaptive Time Division Multiple Access |
| AWGN | Additive White Gaussian Noise |
| BER | Bit Error Rate |
| CDMA | Code Division Multiple Access |
| CFO | Carrier Frequency Offset |
| COA | Centroid of Area |
| CP | Cyclic Prefix |
| CQI | Channel Quality Indicator |
| CRB | Cramer-Rao Bound |
| CSMA | Carrier Sense Multiple Access |
| DDC | Digital Down Converter |
| DM | Differentially Modulated |
| DSP | Digital Signal Processor |
| DSSS | Direct Sequence Spread Spectrum |
| ESCA | Extended Schmidl and Cox Algorithm |

| | |
|---|---|
| FEC | Forward Error Correction |
| FFT | Fast Fourier Transform |
| FIS | Fuzzy Inference System |
| FPGA | Field Programmable Gate Array |
| FRBS | Fuzzy Rule Based System |
| FRM | Fuzzy Rule Matrix |
| GPP | General Purpose Processor |
| HDR | Hardware Defined Radio |
| HSDPA | High Speed Packet Data Access |
| HWT | Haar Wavelet Transform |
| ISI | Intersymbol Interference |
| JTRS | Joint Tactical Radio System |
| LOS | Line of Sight |
| LTE | Long Term Evolution |
| MAC | Medium Access Control |
| MAI | Multiple Access Interference |
| MANET | Mobile Ad hoc Networking |
| MF | Membership Function |
| ML | Maximum Likelihood |
| MMI | Modulation & Multicode Index |

| | |
|---|---|
| MMLDA | Modified Maximum Likelihood Data Aided |
| MMSE | Minimum Mean Square Error |
| MRC | Maximal Ratio Combining |
| MST | Modified Square Timing |
| MSTR | Modified Square Timing Recovery |
| NDA | Non-Data Aided |
| NLOS | Non-Line of Sight |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PN | Pseudo-noise |
| PSD | Power Spectral Density |
| PSK | Phase Shift Keying |
| PTT | Push To Talk |
| QAM | Quadrature Amplitude Modulation |
| QoS | Quality of Service |
| RF | Radio Frequency |
| RRC | Root Raised Cosine |
| S2RO | Sample-by-Sample Residual Offset |
| S4RLSWAM | Steady-State State-Space Recursive Least Squares with Adaptive Memory |
| SCO | Sampling Clock Offset |
| SDNR | Software Defined Networking Radios |

| | |
|---|---|
| SDR | Software Defined Radio |
| SNR | Signal-to-Noise Ratio |
| SPR | Sample Point Reordering |
| STFT | Short Time Fourier Transform |
| STR | Square Timing Recovery |
| SUI | Stanford University Interim |
| TDMA | Time Division Multiple Access |
| TDR | Time Domain Repetitive |
| TWWiN | Tactical Wideband Wireless Network |
| WBNR | Wideband Networking Waveform |
| WNW | Wideband Networking Waveform |

# CHAPTER 1: INTRODUCTION

Hardware elements provided complete ability of traditional radio systems. Because of this reason, those radios named as Hardware Defined Radios (HDR). Several concepts and techniques related to software-controlled radios were introduced with the evolution of software engineering. Nowadays, implementation of factual software defined radios (SDR) through utilizing software configurable components is presented [1]. In SDR radio parameters delineates by the software and reconfiguring the software, the fundamental aspects of radio’s operation can be reformed.[2]

Now a day, in many communication and signal processing applications SDR has become an enabling technology because numerous software configurations offer several functionalities on single platform. According to user requirements, initial configurations and range of frequencies are available in SDR. The ability to provide various protocols and formats make SDR a flexible radio [3]. In SDR platform Field Programmable Gate Array (FPGA), Digital Signal Processor (DSP) and General-Purpose Processor (GPP) are commonly included. GPP and DSP runs intellectual part and FPGA runs computationally extensive part of SDR [4].

To explore the possibility of applying SDR methodology in various wireless communication applications, an extensive research effort has been made for many years. However, mostly high-end applications used SDR based wireless communication transceivers [5]. Base station equipment and military wireless equipment are the examples of SDR based wireless transceivers. Various data intensive applications such as video streaming, biometrics and IP data will have to supported by future SDR based networks.  Latest networks are based on wideband and digital signals to fulfill future requirements. To overcome inadequate capability of narrowband wireless channels wideband networking radio waveform is developed, so that massive data traffic and multimedia supports with high data rate provides by it.

In wideband networking radio waveforms, Orthogonal Frequency division multiplexing (OFDM) and direct sequence Spread Spectrum (DSSS) is unadventurously implemented on physical layer. As spectrum is occupied by licensed users in used spectrum, the main advantage of DSSS scheme is its working phenomena of under noise floor operation of networking radios without interfering main licensed users. Multipath fading effect compensation, efficiency in high frequency, anti-aliasing and non- jamming are the main reasons which make DSSS is best suited for wideband networking software defined radios [7]. Carrier sense Multiple Access (CSMA) and Time Division Multiple Access etc. providing multi user capability in wideband networking radios. As spectral efficiency of spectrum is concerned OFDM is well suited having multipath fading compensation [8]. Regardless the advantages of DSSS/OFDM, detection of start of burst is the key concern for both.

Because of mostly asynchronous burst transmission from multiuser systems, detection of start of respective burst become more complex. In Adaptive TDMA based MAC protocol, adaptive time slot algorithm directly disturbs by wrong detection of start of burst in wideband networking software defined radios. Burst detection stage and MAC switching rate defines start of each time slot, which makes Detection of Start of burst more critical in ATDMA and MAC protocol.

In software defined radios receiver end usually deals burst detection problem separately. By the implementation of this method a limitation of more power consumption is introducing because whole chain of signal processing must run asynchronously prior to the burst detection stage. The proposed algorithm of burst detection reduces power consumption and complexity of the system. Burst detection algorithm placed after down conversion stage of front end. Specific design of training sequence is used for the detection of start of each burst is proposed in this thesis with Zadoff-chu training sequence. For implementation of proposed algorithm, LabVIEW software is used to prove the effectiveness of this technique.

In actual software defined radios efficient algorithms for resource allocation are needed for optimization of scarce SDR resources. Different Quality of Service (QoS) allow different applications like Push to talk, tracking of position, point to point call, messages, transfer of files and video communication etc. In Link Adaptation change the condition and requirement of SDR, an adopting algorithm is required. Link Adaptation is composed of two parts:

1) Changing parameters at physical layer
2) Adaptive TDMA.

In this thesis we propose a burst detection algorithm with Zadoff-chu training sequence for Software Define networking radio waveform to improve detection of valid burst which increase data rate and stability of link between radios.

## 1.1 Fundamental Concepts

### 1.1.1 Digital Modulation

The basic definition of modulation is to transmit an information signal by mixing it with carrier signal by changing its one or more properties. There are two types of modulations one is analog modulation and other is digital modulation. When we transmit an audio signal to long distances then typically analog modulation is used. But when system required high data rate with wideband networking communication then digital modulation is used. Greater quality of information with security and more information capability is provided by digital modulation is communication systems. Other than analog modulation digital modulation is has more capacity to transmit data on large bandwidths.

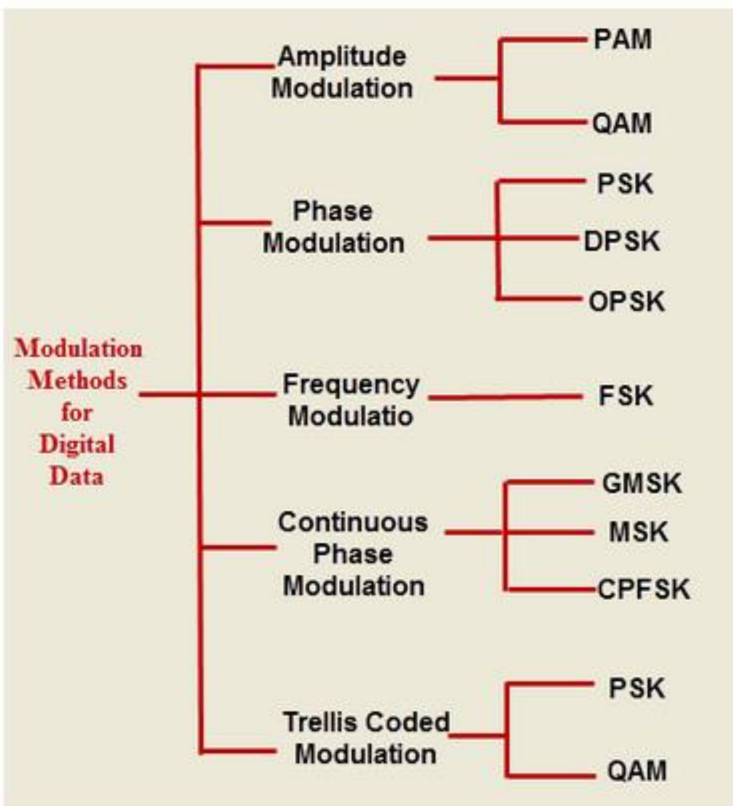


**Figure 1-1:** Different modulation schemes

Figure 1-1 shows different digital modulation methods with their schemes. In our system we use Trellis Coded Modulation technique in which PSK modulation scheme is used. Change of phase of signal during modulation is called phase shift keying (PSK).

**Table 1-1:** Symbols rate of different modulation schemes

| Modulation | Bits per symbol | Symbol Rate |
|---|---|---|
| BPSK | 1 | 1.0 × bit rate |
| QPSK | 2 | 1/2 × bit rate |
| 8-PSK | 3 | 1/3 × bit rate |
| 16-QAM | 4 | 1/4 × bit rate |
| 32-QAM | 5 | 1/5 × bit rate |
| 64-QAM | 6 | 1/6 × bit rate |

Table 1-1 shows different types of symbol rates with respect to bits per symbol. There are multiple types of PSK like BPSK, QPSK, 8PSK and OQPSK etc. In QPSK there are four types of possible phase shifts therefore one symbol transmits on two bits on a set of four bits (00 01 10 11). In this case maximum achieve able phase shift is $90^{\circ}$. QPSK modulation has high data rate and less Bit Error Rate (BER). Figure 1-2 and 1-3 shows the constellation and sys diagram of QPSK modulation scheme.

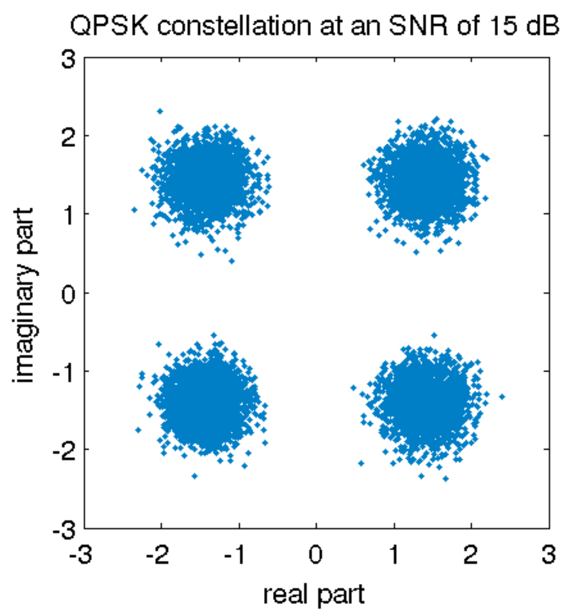


**Figure 1-2:** Constellation of QPSK

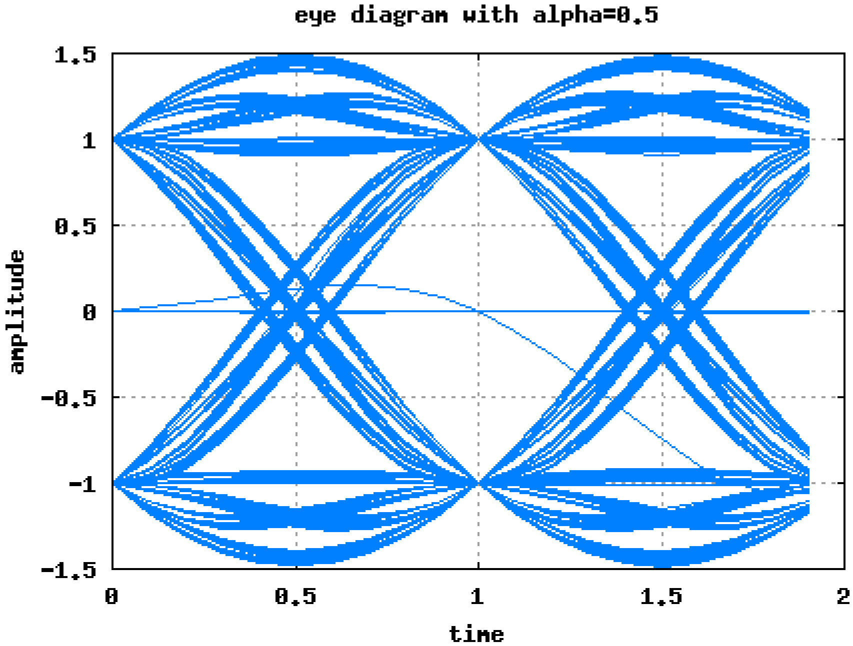


**Figure 1-3:** EYE Diagram of QPSK

### 1.1.2 LabVIEW Software

In modern development of software, virtual instruments for simulation of almost all algorithms in every field of life is possible. This development not only increase the process of teaching and learning but also supports in reduction of cost. Algorithm developers first verify and test their algorithms on such type of software without using any hardware, and then implement it on hardware for working with system. Because of this time and cost of hardware for research and development is saved to a large extant. National Instruments LabVIEW is a type of software in which graphical development environment is used for developing of scalable and flexible algorithms, and their testing is performed on nearly equal to actual parameters. LabVIEW software is easy to use for all users and the development procedure is so fast because of its huge number of examples, libraries and user-friendly contents of help. In LabVIEW scientist and engineers have access to real time signals, mathematical models, data analyzers, networking blocks, data base toolkits, communication systems examples, different type of control systems, vision example, photo editors and many more. Each user can easily find his type of working things in LabVIEW. LabVIEW is actually a mapping tool of real things to virtual form such as temperatures meters, scopes, digital voltage and current meters etc. In LabVIEW there are two panels of working one is front panel in which inputs and outputs of program are visible and we can change it either before start of running program or during it, while the other panel is block diagram window in which actual coding is done. In block diagram programmer use different graphical blocks to program its algorithm. First program verified on simulation and then by using National Instrument hardware this program can practically worked with actual data values. For example, a signal is generated from virtual blocks of LabVIEW software and analyze it in virtual Radio Frequency Signal Analyzer and then this virtual signal can be easily generated from signal generator of Vector Signal Transceiver VST 5646 PXIe card of National Instrument. And from the same card this signal can be analyze on receiver.

Figure 1-4 shows the front panel of LabVIEW software. This is an example of temperature monitoring program. We can set higher limit and lower limit of temperature with the help of control inputs. Resulting temperature variation can be seen on output indicator graph. By pressing start button Virtual Instrument (VI) start running and variation of temperature on graph is shown.

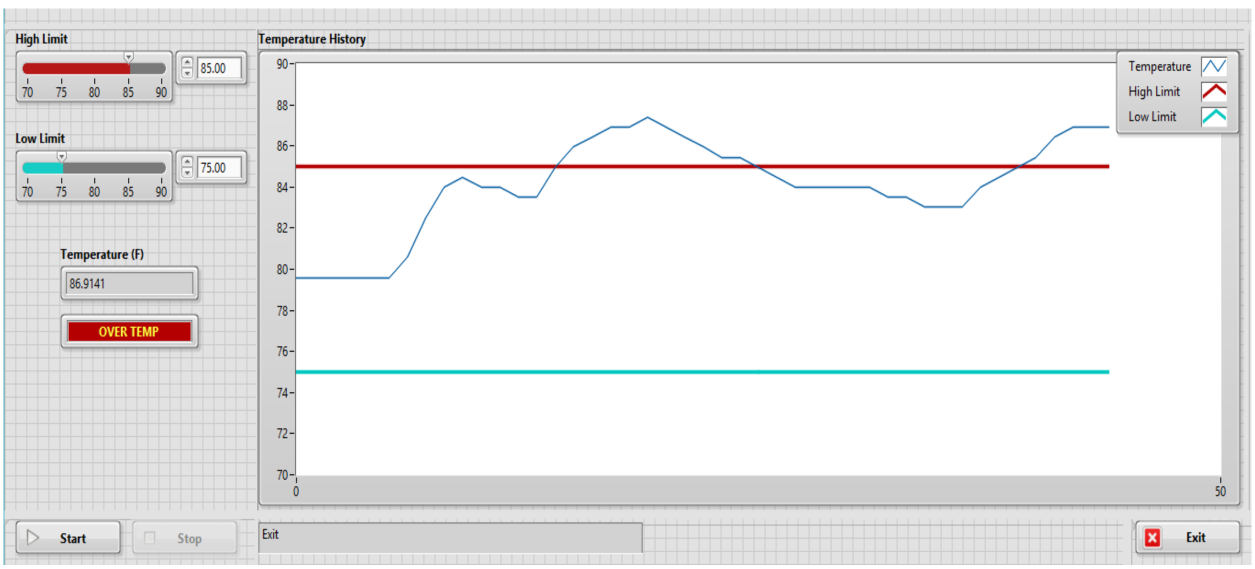


**Figure 1-4:** Front Panel of temperature monitoring VI

Figure 1-5 shows the block diagram of same VI. On block diagram programmer can decide that which processes are performing on the inputs and send data to the output indicators. Loops, mathematical interpolations and control mechanisms are programed on block diagram. Built-in blocks are available for basic functions of programming like calculating mean, performing correlation, controlling limits of a function etc.

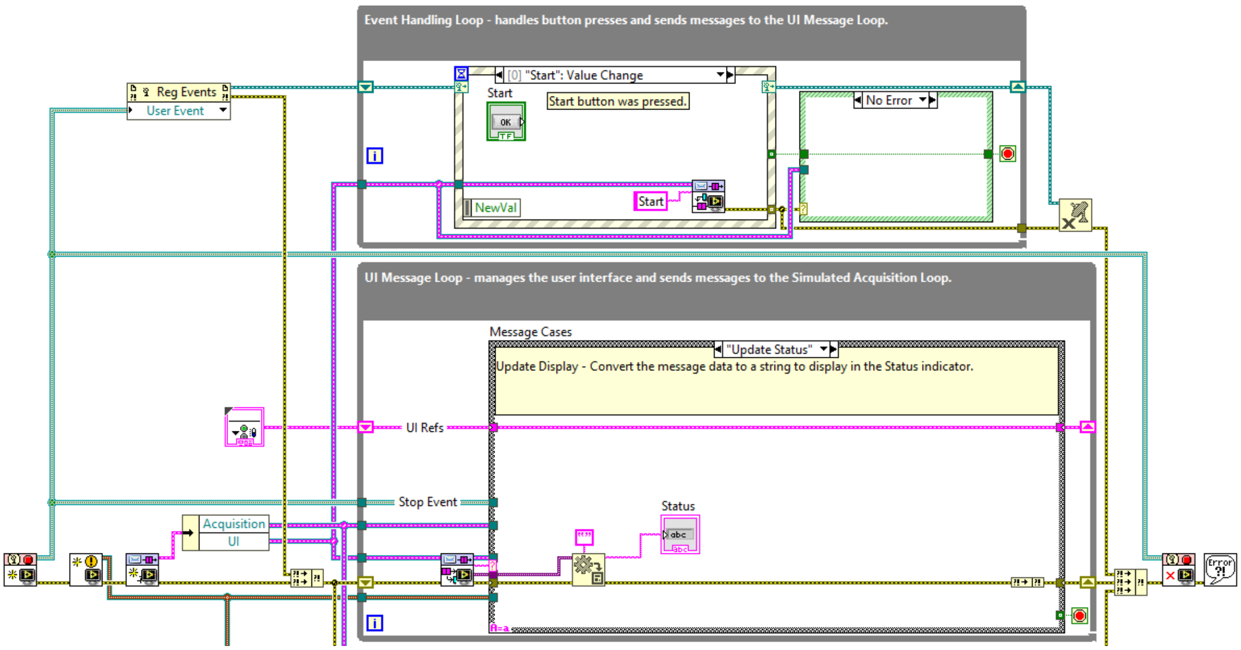


**Figure 1-5:** Block Diagram of temperature monitoring VI

In this thesis LabVIEW is used as algorithm development software and simulation is done on it. LabVIEW is a powerful development toll in which we can develop a software and verified it by simulation and can be implemented on National Instrument hardware easily.

## 1.2 Motivation

In fast fading channels, burst mode of transmission is used in several communication systems to combat multipath fading effects [9]. Within the duration of each burst, burst size is designed so that channel act like time invariant [10]. On each burst equalization, channel estimation, synchronization of frequency and timing etc. are performed independently.

The detection of the start of each valid burst of data is the major challenge in these systems. In wideband networking waveform, at physical layer burst detection is the part of timing synchronization [11]. In wideband networking radio operation detection of burst and sampling clock recovery are very vital because in ATDMA based Medium Access Control (MAC) protocol, adaptive time slot algorithm is directly affected. The relationship between timing synchronization and adaptive time slot algorithm is shown in figure 1-6. Time varying sampling clock offset affects the switching rate of Medium Access Control (MAC). Similarly, the switching rate of Medium Access Control (MAC) and detection of burst specify the start of each time slot. For ATDMA-based MAC protocol, timing synchronization that constitute by detection of burst and sampling clock offset are very important.

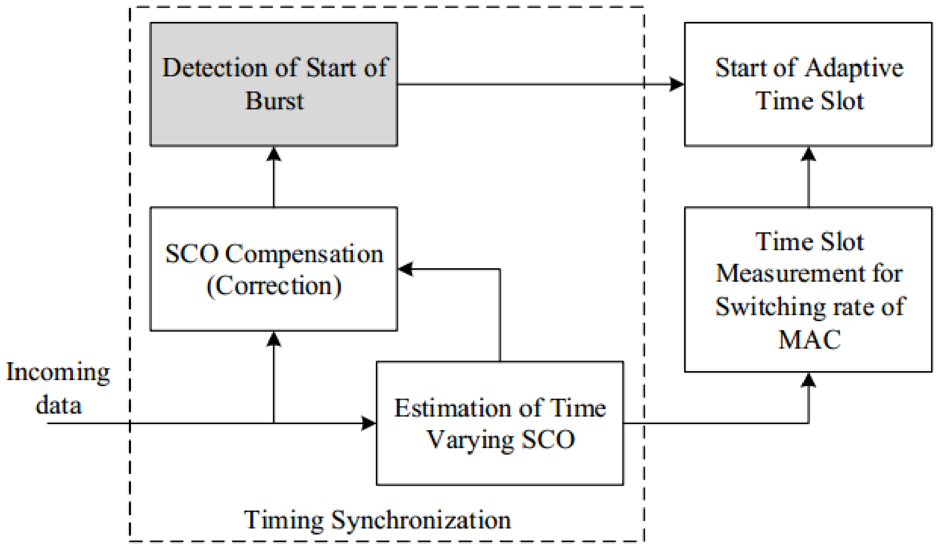


**Figure 1-6:** Adaptive time slot algorithm and its relation with burst detection

## 1.3 Problem Statement

To improve the performance of burst detection in wideband software defined networking waveform using Zadoff-chu training sequence.

# CHAPTER 2: LITERATURE REVIEW

Designing of burst detection algorithm in Software Defined Radio waveform becomes active research area now a days. Researchers focus on the high throughput wideband waveforms which are based on networking for transfer large data files and support heavy applications in war-fields and irregular terrains. Detection of burst is the key role in high throughput software defined radio networking waveforms. In recent years researchers proposed many algorithms of burst detection in networking waveforms. A brief discussion on recent researches is concise in this chapter.

## 2.1 Burst Detection

In Software defined radio hardware is fixed but software my change according to the requirement. Different waveforms are present in the storage device of the software defined radio. User may select the one them to fulfill his need of communication. As an example, for voice communication in long range, analog narrowband waveforms are used and for short range voice communication analog and digital narrowband waveforms are used but for data transfer such as file sharing and video calling, digital wideband networking waveform is used. Modulation, framing, sampling clock recovery, burst detection, carrier frequency estimation are the main components of digital wideband waveform.

Comparing the received signal energy with threshold is the conventional approach of detecting a burst. Algorithms of same kind are given in [12]. For flat and multi fading channels with Additive White Gaussian Noise (AWGN), expressions for detection of burst are developed. Various mobile communication channels are not working well with energy-based detection algorithms because of its simplicity and have no preamble with it. By varying channel conditions and noise level, changes received signal energy. Because of this reason fix thresholding is not a better option for detection of burst. During the period of preamble on-off keying is following by Markov chain search [13] is another technique of detection of burst. Barker sequence of length 7 as preamble is used in synchronization algorithm [14]. Windowing with two step algorithms is developed. In this technique differential phase shift keying is used to modulated preamble before spreading. Tracing of Barker sequence is the condition of correct burst detection. Simulation of Additive White Gaussian Noise (AWGN) and frequency fading channels is used to evaluated the performance of this algorithm. A detection of burst algorithm is developed [13] which is based on hybrid correlator architecture. Correlators in serial structure and matched filters in parallel form makes it hybrid correlator architecture. A constant false alarm rate evaluated the performance of hybrid correlator. Short Time Fourier Transform (STFT) based Direct Sequence Spread Spectrum communication with periodic modification of threshold searching is developed [15]. Detection of signal is based on thresholding set on signal variance, used in Short Time Fourier Transform (STFT) based Direct Sequence Spread Spectrum (DSSS) signal. Performance of author's algorithm is analyzed only in AWGN. But this performance is down to a large extent in fast fading channels. Harr Wavelet Transform (HWT) based Direct Sequence Spread Spectrum (DSSS) signal detection algorithm is developed [16]. First taking HWT then performs autocorrelation of Direct Sequence Spread Spectrum (DSSS) signal is used to detect signal. The performance of this algorithm is better in Additive White Gaussian Noise (AWGN) with low SNR. By using HWT technique symbol period can also be estimated. For Direct Sequence Spread Spectrum (DSSS) signals in cognitive radios, a detection algorithm which is based on autocorrelation is proposed [17]. After autocorrelation of spreading sequence this algorithm finds the peak, and then cumulative peak-to-average calculation made the decision of detection of burst. Metric for signal detection is not present in this algorithm and it uses PN sequence. Detection probability decreases after decreasing sampling points. A precisely design preamble-based detection of Direct Sequence Spread Spectrum (DSSS) signal is proposed in [18]. A spreading sequence spread number of blocks in this algorithm. If frequency offset is not compensated properly then this algorithm degrades rapidly. By using Constant False Alarm (CFAR) an algorithm is proposed in [19]. This algorithm used adaptively varying threshold. Only single user CDMA communication can use this adaptive thresholding technique. For detection of burst an improved adaptively varying thresholding is proposed [20] whose performance is much better than [19]. By using pre estimated correlation energy, the detection threshold my be adjusted accordingly.

## 2.2 Training Sequences

In old era burst detection depends upon the known training sequences which are placed before the transmission packet. On receiver end transmitted known training sequence can be searched by the system and where the sequence is found then the packet of actual data starts. Many researchers use different training sequences for better performance in multiuser fast fading, multipath and noisy channel communication. Different types of training sequences are PN sequence, Walsh sequence, Gold sequence, Golay sequence, Kasami sequence and Zadoff-chu sequence etc. An improved equalization method by using dual PN sequence is proposed in [21]. Dual PN sequence padding is used instead of Cyclic prefix which is computationally extensive due to iterative padding subtraction for improving the efficiency of the spectrum and mitigate inter symbol interference at the receiver side in time domain synchronous orthogonal frequency division multiplexing (TDS-OFDM) modulation scheme.

M- array of Walsh codes is proposed in Ultra-wideband high-speed communication for future systems [22]. By mapping codeword rows of Hadamard matrices generates Walsh functions. For reduce interference of UWB in radio systems M-array scheme of Walsh codes is more effective. By using shift register and time delay elements the maximum sequence generated is named as Maximal-length sequence (m-sequence) (S.W. Golomb, Shift Register Sequences, Aegean Park Press, 1992).M-sequence has two types, Simple Sequence Register Generator (SSRG) and Multi-return Shift Register Generator (MSRG) [23]. In a period of M-sequence, number of '0' and '1' are roughly same. All contents to the right by register shift on each clock time. In synchronous cellular spread spectrum networks, m-sequence has great importance. But m-sequences has not good cross-correlation properties. Two M-sequence with extremely small cross-correlation function makes Gold sequence [23]. Parallel and series are the two types of Gold sequence. Different Gold sequences can be generated by applying different initial state of second M-sequence generator. Gold sequences are mainly useful for multiple access system in which maximum users can access band of frequencies with small mutual interference because gold sequences can supply large number of codes [24]. Cross-correlation of a set of gold sequences are uniform. But the gold sequence has not good auto-correlation properties. In CDMA communication system Gold codes is widely used because of its multi-code ability. The usage of Gold sequences for the sequence acquisition of Direct Sequence Spread Spectrum Code Division Multiple Access (DS-CDMA) systems is proposed in [25]. Due to very low cross-correlation Kasami sequence become important type of binary sequence [24]. For scrambling code in W-CDMA system preferably Kasami sequence is used. For improvement of bandwidth efficiency of spread spectrum system orthogonal functions are used. Flexible code allocation in mobile communication system, orthogonal codes is used.

Golay sequence is actually a member of Golay complementary pair [26]. Golay sequence is used to control peak-to peak power in Orthogonal Frequency Division Multiplexing (OFDM) transmission.

Zadoff-chu (ZC) sequence is widely used in communication systems by replacing old sequences because of its interesting auto-correlation property. Zadoff-chu belongs to poly phase class of sequences having constant magnitude and periodic auto-correlation. With non-zero cyclically shifted version, auto-correlation of Zadoff-chu sequence is zero. Zadoff-chu is mainly used in random access channels, control channels and in synchronization signals etc. For random access initial uplink synchronization, an improved version of Zadoff-chu sequence is proposed [27]. Two algorithms for the reduction of High Peak to Average Power Ratio (PAPR) is proposed in [28] using modified Zadoff-chu matrix transform (ZCT). One is precoding and other is post coding based ZCT technique. PAPR is one of the major problems in Orthogonal Frequency Division Multiplexing (OFDM) communication systems. These two techniques improve PAPR and bit error rate (BER) in OFDM systems. An analysis tool is developed in [29] which analyzed the effect of Zadoff-chu synchronization signal on frequency offset and timing performance.

An improved algorithm for automatic gain control and bursts detection for high throughput wide band networking radio waveform using repeated Zadoff-chu sequences is proposed in [30]. For fixing the gain over complete burst after detection burst by specifically design repeated Zadoff-chu sequence is used. The effectiveness of the algorithm is verified by both simulation and implementation of it on Field Programmable Gate Array (FPGA) on SDR platform.

Due to zero auto-correlation property of Zadoff-chu sequence it can be used in wide variety of algorithms for improvement of performance of communication systems etc. An improved burst detection algorithm is proposed in this thesis by using Zadoff-chu training sequence in a specified way. By fixing the threshold and without knowing the training sequence on receiver side, bursts can be detected with the help of Zadoff-chu training sequence.

# CHAPTER 3: SYSTEM MODEL

In this chapter, we propose a novel algorithm for design of training sequence and burst detection for software define radio for achieving high throughput and stability of link during networking. In training sequence design, we set zadoff-chu sequence in such a way that there is no need of training sequence on receiver because zadoff-chu sequence has good autocorrelation property. Modified burst detection is proposed to improve detection of burst in software defined radio. Overview of physical layer of complete system is shown in figure 3-1. First of all, data stream in physical layer and modulation MPSK (M is the modulation index) mapping is performed. For transmission symbol transitions, bits 1 and 0 encodes in 1 and -1 respectively through symbol mapping table. After this framing of data packet is required for transmission in which symbol burst are formed. Training sequence is concatenated in start of each burst. On the basis of this training sequence burst is detected on the receiver side and data packet can be extracted from frame. After framing direct sequence spread spectrum is applied on the complete frame including training sequence. After direct sequence spreading, upsampling and filtering (Root Raised Cosine) is performed. Then data is mixed with the carrier frequency and transmitted in channel through antenna. Receiver front-end received data after passing through channel. Receiver front-end fed data (including training sequence) to correlation block in which spreading sequence is correlated with data. After thresholding is performed in Burst Detection block for detection of valid burst. Valid burst is then down-converted by spreading gain through direct sequence despreading. The next block is symbol de-mapping after which valid data is extracted on receiver side. The main concern of this thesis was to proposed an efficient algorithm for burst detection with intelligent training sequence which reduces re-transmission of packets from transmitter. By reducing re-transmission penalties increases throughput hence data rate increases.

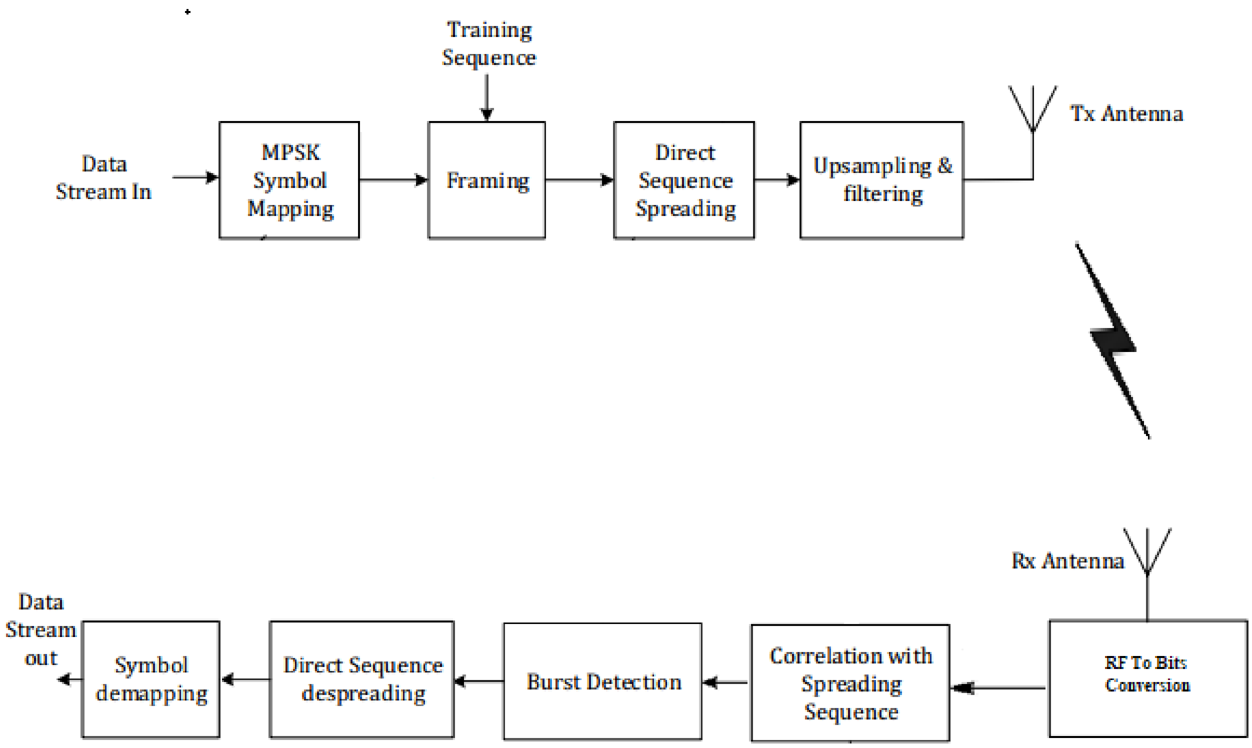


**Figure 3-1:** Overview of physical layer of proposed waveform

Mostly Burst mode of communication is performed in wideband networking software defined radios. For the channel acting like time invariant, size of each burst adjusted accordingly. For valid data processing, detection of start of burst is extremely important. As it directly affects throughput because of re-transmission. A novel algorithm for training sequence and burst detection is proposed. In first time repetitive training sequence is used for detection of burst and Zadoff-chu training sequence is used to detect valid burst.

## 3.1 Mathematical Representation of System Model

In Wideband waveforms, timing synchronization at physical layer in mainly consist of two parts; (1) Detection of Burst and (2) Sampling clock offset estimation and compensation. In ATDMA based Medium Access Control (MAC) protocol, adaptive time slot algorithm directly affected by these two operations in wideband networking waveforms. The relation of time synchronization and adoptive time slot algorithm in wideband networking operation is shown in figure 3-2. The time varying sampling clock offset affects the switching rate of MAC in time slots of ATDMA. The intrinsic gap between transmitter and receiver oscillators generates sampling clock offset. This offset is estimated and compensated by sampling clock recovery.

MAC switching rate and stage of burst detection controls the start of each time slot. Detection of burst failure severely reduce the performance of communication in wideband networking waveform. Detection of burst becomes more critical in multiuser CDMA system because all radios transmit composite signal for each radio. Additionally, due to thermal changes, sampling clock offset varies slowly [31]. The sampling clock recovery consist of three stages, in first stage at chirp level sampling clock offset is estimated by modifying timing estimation. In second stage, to increase the tracking performance, the SCO estimates are post-filtered. Feed forward Lagrange interpolation algorithm is used to compensate estimated SCO in last stage.

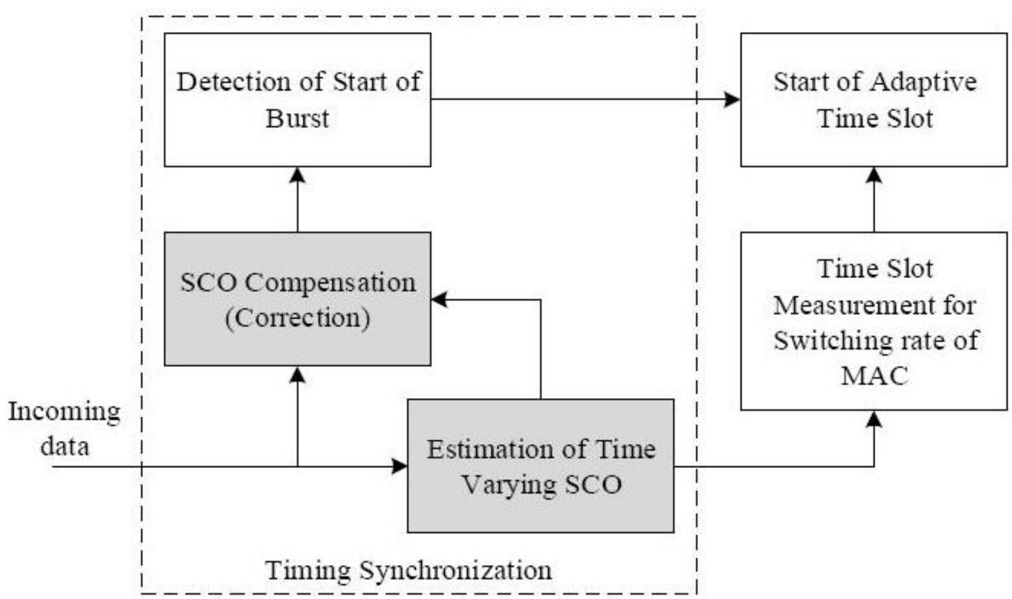


**Figure 3-2:** Adaptive time slot algorithm and its relation with timing synchronization

### 3.1.1 System Model

In wideband waveform, consider N users at physical layer. For Nth user, spreading waveform is given by

$$\pi_k(t) = \sum_{n=0}^{G-1} c_k[n] g(t - nT_c) \tag{3.1}$$

For spreading code of $n^{th}$ user, $\boldsymbol{c_k[n]}$ is the $n^{th}$ sample, chirp level pulse shaping filter is g(t) with time period $T_c = T/G$ and G is the spreading gain. Following is the $n^{th}$ user transmitted signal $s_n(t)$

$$s_n(t) = \sum_i d_k[i]\pi_k(t - iT) \tag{3.2}$$

Where $i^{th}$ transmitted data symbol of Kth user is dk(i) and duration of symbol is T.

Response of channel, for multipath fading environment is as follows [32]

$$h_k(\tau\,, t) = \sum_{l=0}^{\gamma k} \alpha_{kl}(t) e^{j2\pi f_{D,kl} t} \delta(t\ -\ \tau_{kl}) \tag{3.3}$$

Dirac delta function $\delta(t\ -\ \tau_{kl})$ is given as

$$\delta(t\ -\ \tau_{kl}) = \begin{cases} +\infty & if\ t = \tau_{kl} \\ 0, & Otherwise \end{cases} \tag{3.4}$$

It also restricted to satisfy the following

$$\int_{-\infty}^{\infty} \delta(t\ -\ \tau_{kl}) dt = 1 \tag{3.5}$$

and $\alpha_{kl}(t)$, $f_{D,kl}$ , $\tau_{kl}$ and $\gamma k$ are the time varying complex path gain, Doppler spread, delay spread corresponding to the lth path and kth user and number of multipath, respectively.

The received continuous time-based band signal after passing through channel is given as

$$r(t) = \sum_{k=1}^{K} e^{j2\pi \Delta f_k t} \sum_i d_k[i] q_k(t\ - iT) + w(t) \tag{3.6}$$

Where

$$q_k(t) = \sum_{l=1}^{\gamma k} \alpha_{kl}(t)\pi(t\ -\ \tau_{kl}) \tag{3.7}$$

Due to mismatch of frequency and Doppler spread between transmitter and receiver initiated in $K^{th}$ user's CFO is $\Delta f_k$. W(t) is the white Gaussian noise with variance $\sigma^2$and zero mean. Let BT is the length of each burst data where number of symbols of each burst is B. Due to requirement of channel time invariance within the duration of burst, the parameter B is selected accordingly. Therefore,

$$\alpha_{kl}(t) = \alpha_{kl} \qquad\qquad iT \le t \le (i+B)T \tag{3.8}$$

If coherence time is greater than or equal to BT fulfilled this constraint. Doppler spread and coherence time are interrelated with each other. This relation is as below [33]

$$T_{coh} = \frac{0.423}{f_D} \tag{3.9}$$

At sampling rate of $f_s = 1/T_s = N_s/T_c$, the sampling signal we achieved is

$$r(nT_s) = \sum_{k=1}^{K} e^{j2\pi\Delta f_k nT_s} \sum_i d_k[i] q_k(nT_s - iT - \epsilon_k(nT_s)T_c) + w(nT_s) \tag{3.10}$$

For corresponding Nth user, $\epsilon_k$(nTs) is the nth sample of unknown slowly varying time delay and upsampling factor is Ns, that shows the estimated parameter. Due to offset in frequency in oscillators of two communicating devices, this slowly time varying delay is introduced.

### 3.1.2 Problem Formulation

The equation 3.6 of received data is re-written as

$$r(nTs) = \sum_{k=1}^{K} e^{j2\pi vk^n} \sum_{i=0}^{B=1} d_k[i] q_k(nTs - iT - \epsilon_k(nTs)Tc) + w(nTs) \tag{3.11}$$

Where up sampling factor is Ts and for $K^{th}$ user $\boldsymbol{v_k = \Delta f_k / f_s \in [-0.5, 0.5]}$ is the normalized carrier frequency offset and due to SCO, the slowly varying time delay is $\boldsymbol{\epsilon_k(nTs)}$. Through cubic interpolation the down sampling of the sequence r[n] by Ns = 4 at SCO compensation stage compensate the estimated SCO and sequence y[n] at $1/Tc$ is generated. A known training sequence spreading over a number of samples in each burst for Data Aided (DA) burst detection algorithm. For detection of data burst, searching of this known training sequence is done by the receiver. Normally without silent interval, transmission of burst is back to back but there can be a silent interval in TDMA-based networking waveform. In this case, for known training sequence let the number of spread samples is N. Therefore, BG—N is the valid spread sample data, where spread gain is G.

# CHAPTER 4: PROPOSED BURST DETECTION

From 1990s, after the formal description of Software Defined Radio (SDR), to explore the possibilities of SDR applications in wide variety of wireless communications an extensive effort has been made. Due to high power consumption and coast Software Defined Radio based wireless communication transceivers are normally used in sensitive high-end applications [5]. Software Defined Radios based networking systems offers wide range of applications such as video/Voice calling, data file sharing, biometrics, and multiple Military based communication with mobility and security. Wideband networking based on digital communication are now become area of research for future networks because of these high demanding applications [6]. To compensate low capabilities of narrowband wireless channels, wideband wireless channels are introduced, so that massive data multimedia application can experience high data rate. In physical layer of wideband networking radios Direct Sequence Spread is used.

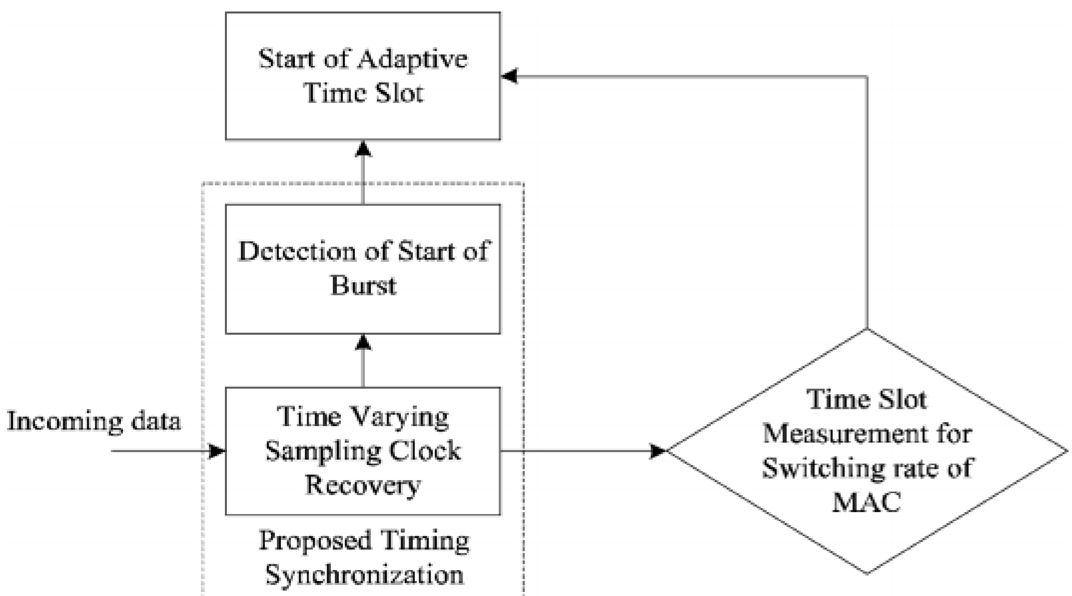


**Figure 4-1:** Timing synchronization relation with burst detection

Different methods are used to detect a burst but comparing received energy of signal with a fix threshold is one of the better approaches [12]. These types of methods have advantages as well as disadvantages. Burst detector which is based on signal energy comparison does not require preambles. But because of different types of fading channels threshold is not fixed and adaptation of communication system according to channel is nearly impossible. The basic reason is that signal energy varies due to signal to noise ratio level and channel effects. And fix threshold is unable to detect a signal. Preambles based schemes are also used for burst detection. One is on-off keying of preamble with Markov chain search [34] and second is differentially encoded barker sequence as preamble [14]. A method of burst detection which is based on hybrid correlator is proposed in [13].

A robust burst detection algorithm is proposed to overcome previous problems and improvement in data recovery. This algorithm is computationally efficient which require less hardware space in FPGA and improved timing requirement which increase data rate of wideband software defined networking radio [11]. The specially design training sequence is used to compute timing metric which compares with fix threshold for detection of burst. Due to this reason, proposed algorithm is very less dependent on channel conditions.

The wideband networking radio point-to-point communication system's physical layer is shown in figure 4-1. QPSK symbol mapping mapped data stream in each allocated time slot on transmitter end. Specific training sequence is concatenated with data in start of each burst. Direct Sequence Spread spreading is performed on data including training sequence. Up sampling and Root Race Cosine (RRC) pulse shape filtering is performed on spreader data. Burst form of communication transmissions are performed for compensation of time varying multipath fading channel effects. Length of burst is adjusted so that channel act as a time invariant. At receiver end, detection of start of each burst of data is the major problem in these systems. Burst detection is the main part of wideband networking radios as it directly effects data rate, quality of communication and in ATDMA based MAC protocol it effects adaptive time slot algorithm etc.

In this chapter, a robust burst detection algorithm is proposed for wideband networking radio. In this algorithm Time Domain Repetitive training sequence method is used in which Zadoff-chu is used as a training sequence.

### 4.1.1 Zadoff-chu sequence

Zadoff-chu sequence is a sequence of special numbers. Different kind of technologies uses different type of sequences. In CDMA mostly Walsh and m code are used, in WCDMA OVSF code is used. These sequences are generated from a special rules and formula. Zadoff-chu basic form is generated by a formula given below

$$x_q(m) = e^{-j\frac{\pi q m(m+1)}{N_{ZC}^{RS}}}, \quad 0 \le m \le N_{ZC}^{RS} - 1 \tag{4.1}$$

Zadoff-chu has some unique type of properties which make these sequence prior then other sequences. Following are the properties if Zadoff-chu sequence:

- Zadoff-chu has constant magnitude.
- Zadoff-chu has zero autocorrelation. By shifting Zadoff-chu sequence, many orthogonal sequences are generated which have zero autocorrelation. Many wireless communication systems have advantages of this type of sequences.
- $1/\sqrt{N_{ZC}}$ is the cross correlation of two Zadoff-chu sequences.

If a sequence has a and b property which are constant magnitude and zero autocorrelation is called CAZAC sequence.

There are other properties of zadoff-chu sequence but not in the scope of this thesis. Zadoff-chu is now a days mainly used in LTE mobile networks for synchronization signals. However, Zadoff-chu used in many applications such as secure communication, Military radios networking applications etc. Zadoff-chu sequence belongs to polyphase type of sequence [11]. Zadoff-chu sequence is defined in equation (2) with period N [29]

$$s_\mu = \left\{ s_\mu(n) = e^{-j\frac{\pi \mu n(n+1)}{N}}, n = 0,1, \dots, N-1 \right\} \tag{4.2}$$

Zadoff-chu has perfect autocorrelation property. For all periodic shifts other than zero, the autocorrelation of Zadoff-chu sequence of length L is zero and has constant magnitude.

$$Z_{c_r}(k) = \begin{cases} e^{j\frac{2\pi r}{L}(\frac{k^2}{2}+qk)} & for\ L\ is\ even \\ e^{j\frac{2\pi r}{L}(\frac{k(k+1)}{2}+qk)} & for\ L\ is\ odd \end{cases} \tag{4.3}$$

where k = 0, 1, …..,L-1 and q is integer and r are the code index [36]-[37].

In modern wireless communication systems like mobile systems, networking radios, satellite communication etc. Zadoff-Chu plays an important role in different aspects such as random multiple access, frequency synchronization, and center frequency offsets, because of its cyclic zero autocorrelation property. In random multiple access, at transmitter end device can select Zadoff-chu sequence randomly from a given set of Zadoff-chu sequences. On receiver end network access device by correlating signal with a given set of Zadoff-chu sequences and detect transmitted sequence. Zadoff-chu is used. By using this technique multiple devices (number depends on the orthogonal Zadoff-chu sequence set) can communicate simultaneously with the same network.

In this thesis we proposed an algorithm in which Zadoff-chu is used as a training sequence for burst detection.

In this section, the proposed Time Domain Repetitive (TDR) training sequence design

## 4.2 Time Domain Repetitive Training Sequence

The designing of frequency domain or time domain training sequence can be done for burst detection. Mostly system which are multicarrier e.g. multicarrier CDMA, OFDM etc. frequency domain training sequence are used [87]. Decision metric platforms which are depend on some training sequences [58] results in high probability of wrong decisions. Therefore, the designing of training sequence which performs a boundless roll in true timing/decision metric platform are great requirement now a days. Besides this the valid data and training sequence data should also be uncorrelated. In Time Domain Repetitive (TDR) [11], L identical parts make training sequence. Mo length sequence is the basic repeated part. Good autocorrelation property is the basic requirement of this sequence. The autocorrelation of Golay Sequence [38], Gold sequence [39] and m-sequence [40]. Sharper peaks and lower out of phase maxima in contrast with other sequences, Golay sequence have better autocorrelation property. Therefore, Golay complementary sequence is used as a basic repeated part in TDR training sequence.

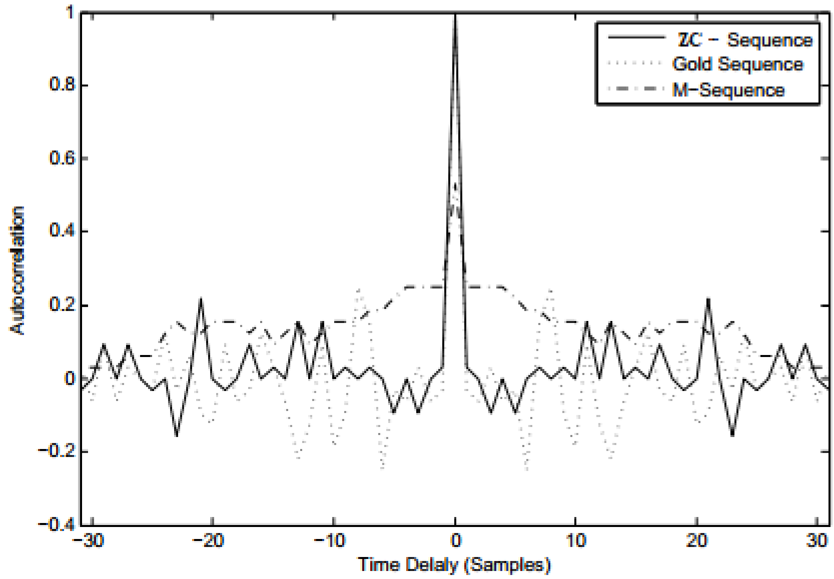


**Figure 4-2:** Autocorrelation comparison of Zadoff-chu, Gold and m-sequences

According to user specific spreading sequence, each repeated part is spread accordingly. M=GMo is the length of each part, Where G is the spreading gain. For TDR training sequence of length N, length M are concatenated for L identical parts as follows

$$M = \frac{N}{L} \tag{4.4}$$

Different sign patterns can be applied on L identical parts [41]. For the detection the calculation of timing metric can be exploited by these sign patterns. For example, sign patterns can be [- + - -] for L = 4. Let A be the length of Mo repeated part, then [-A, A, -A, -A] be the resulting training sequence for given sign pattern. This complete process is explained in figure 4-3.

## 4.3 Burst Detection Algorithm

The user specific spreading sequence is correlated with the data sequence[n] (output of SCO compensation stage) for calculating decision timing metric in burst detection algorithm. There must be a method to indicate each spread symbol in time, because training sequence at receiver and received data both are spread with the spreading sequence.

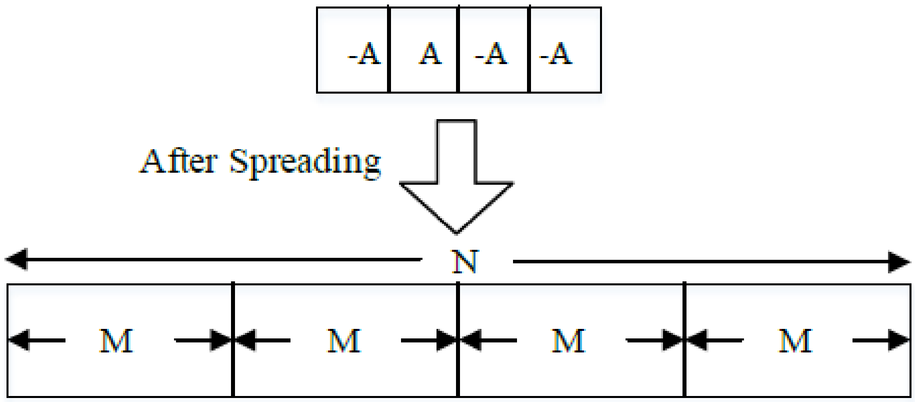


**Figure 4-3:** Concept of TDR training sequence for L = 4

For that reason, spreading sequence of corresponding user is correlated with SCO compensated data. The Kth user compensated data is given as

$$y_{c,k}[n] = \sum_{j=0}^{G-1} y[n+J]c_k^*[j] \tag{4.5}$$

Where spreading gain is G, the $n^{th}$ sample data from Sampling clock offset recovery stage is y[n] and spreading sequence of $K^{th}$ user is $C_k$. In case of multiuser there is no need of this correlation because at sampling clock offset stage there is a correlation performed. $y_{c,k}[n] = y[n]$ In that case. In the calculation of timing metric and energy, correlated data recovered from equation 4.3 is used. The repeated structure of timing metric is used to calculate timing metric and by squaring samples of correlated data gives us energy. Energy (E) and timing metric (P) is given as

$$P[d] = \sum_{k=0}^{L-2} b[k] \sum_{m=0}^{M_o-1} [(y_{c,k}^*[d+(kM_o+m)G]) \,.\, (y_{c,k}[d+((k+1)M_0 + m)G])] \tag{4.6}$$

$$E[d] = \sum_{i=0}^{M-1} \sum_{k=0}^{L-1} \left|y_{c,k}[d+i+k]\right|^2 \tag{4.7}$$

where d = 1; 2; 3,….., b[k] = p[k] _ p [k + 1] = [- - +], the length of L sign pattern of training sequence is p[k] and k=0,1,2,…..,L-2.

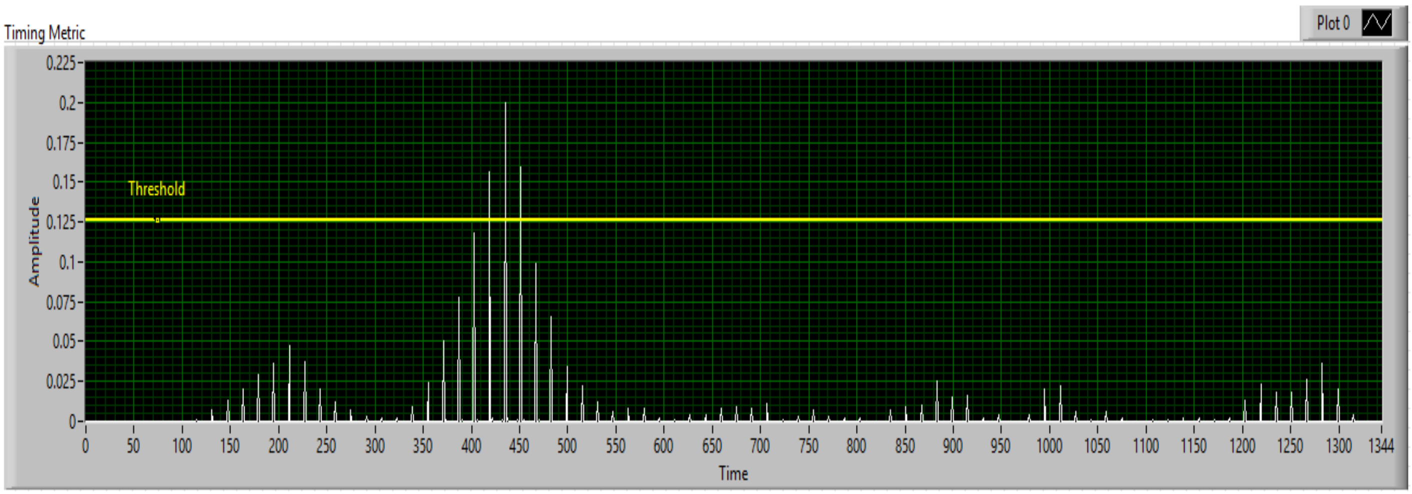


**Figure 4-4:** A typical normalized timing metric using TDR training sequence (G = 16)

In equation (4.5) and (4.6), timing metric and energy is defined. For burst detection the normalized timing metric is given as

$$\mathrm{T}_1[\mathrm{d}] = \left(\frac{L}{L-1}\frac{|P[d]|^2}{E[d]}\right) \tag{4.8}$$

For OFDM system proposed normalized timing metric is as in (4.6), but P[d] and E[d] is not used directly in CDMA system. So, for the calculation of P[d] and E[d] a modified approach is used [11] which calculate timing metric using spreading Gain G and correlated data as input sequence other than using received sequence directly. In figure 4-4 at 16 length Walsh-hadmard spreading code in AWGN normalized timing metric $T_1$ is shown. The ratio of P[d] and E[d] is the normalized timing metric. In figure 4-4 it is clearly seen that a sharp peak is appeared at the start of burst in timing metric by this burst detection method. Repeated structure of training sequence is used in timing metric calculation as said before, so $T1[d]$ will be high in the presence of start of burst and low in the absence of stat of burst but energy will be high either there is a burst or not. Therefore, detection of burst is presented through a binary hypothesis stated as

$$H_0\colon T_1[d] < \gamma, \quad \rightarrow \text{ No burst detected}$$

$$H_1\colon T_1[d] > \gamma, \quad \rightarrow B\text{urst detected}$$

Where threshold is $\gamma$. Searching of peak is the next step after detection of burst which find the maximum value index of normalized decision metric for next $N_w$ samples. In mathematical form it is written as

$$\hat{n}_0 = arg_d max T_1[d] \; for \; next \; N_w \; samples \tag{4.9}$$

An excessive processing delay is introduced if peak search increased beyond $N_w$ samples. In (4.9) index of starting durst data is given. After this index, B symbols of detected burst can be recovered by down sampled this data $y_{c,k}$ by G.

# CHAPTER 5: SIMULATION RESULTS

Proposed burst detection algorithm results are presented in this section. Simulation parameters are as follows

- Each burst containing modulated symbols before spreading ($N_d$) = 288
- Length of training sequence = 28
- Threshold ($\gamma$) = 0.1
- Roll of factor (R) = 0.65

16 length of Zadoff-chu training sequence has been used for spreading of symbols and modulation scheme of QPSK is used for simulation results. Probability of correct detection of burst ($P_d$) describes the actual performance of burst detection algorithm with Zadoff-chu training sequence. As shown in figure 5-1 when timing metric cross the threshold then algorithm find maximum peak of peaks as when algorithm is on exact training sequence then maximum peak is formed. Stanford University Interim (SUI) channel model is used to combined multipath fading effects [42]. Stanford University Interim (SUI) representing 6 channels of modeling line of sight (LOS), Non line of sight (NLOS), delay spread, doppler spread, multipath effects etc. All aspects of Stanford University Interim (SUI) channels are describes in appendix A. In multipath fading channels SUI-4, SUI-2 and AWGN by varying SNR the probability of detection of correct bursts of proposed algorithm is given in figure 5-1.

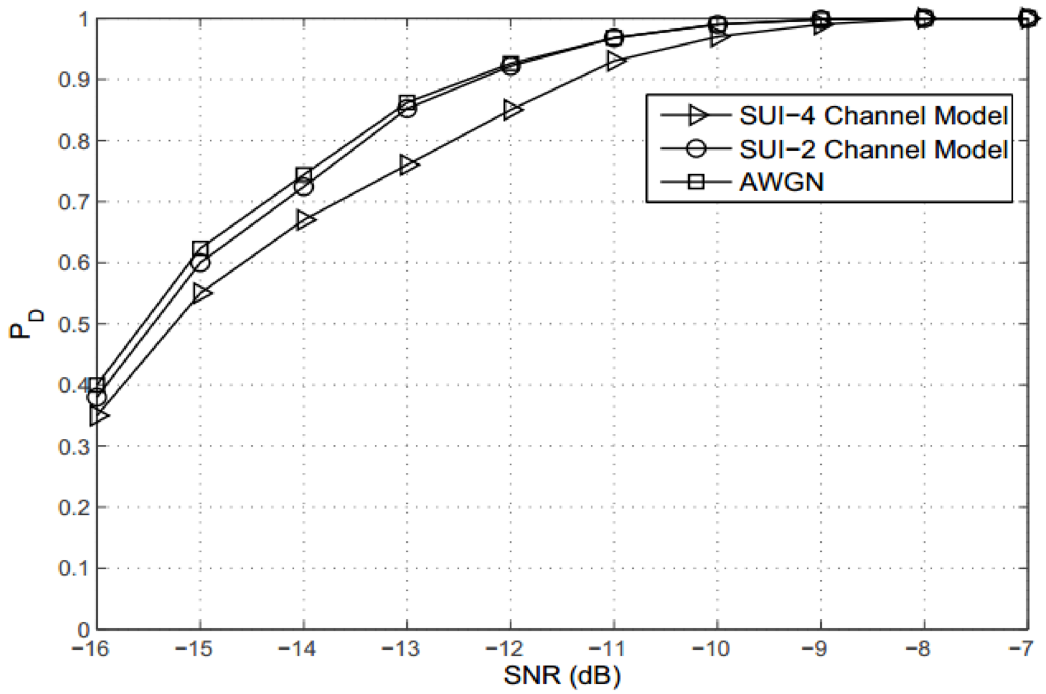


**Figure 5-1:** Proposed burst detection algorithms performance with varying SNR on different fading channels

It can be seen from figure that the performance of burst detection in SUI-4 channel is slight vary from AWGN and SUI-2 channel, but the performance of algorithm in SUI-2 and AWGN are nearly equal to each other. The difference in SUI-4 channel is because of large delay spread and zero line of sight value in model (As shown in appendix A). But at high SNR the performance of burst detection is improved (equal to unity) for all three channels. In multipath fading channels the proposed algorithm of burst detection is robust as shown in figure.

The probability of detection of burst of proposed training sequence in algorithm is also compared with other training sequences for performance analysis. Golay sequence is choose to compare with Zadoff-chu sequence. Golay sequence is also used in Time Domain Repetitive (TDR) [11]. As Golay sequence in TDR is already compared in Additive White Gaussian Noise (AWGN) channel with other sequences like Zaho's algorithm [15] and Deng's algorithm [17]. Figure shows that Golay sequence in TDR algorithm performance is better as compared to other two even at low SNR. Ranging from -16dB to -9dB probability of detection is almost 1dB improved.

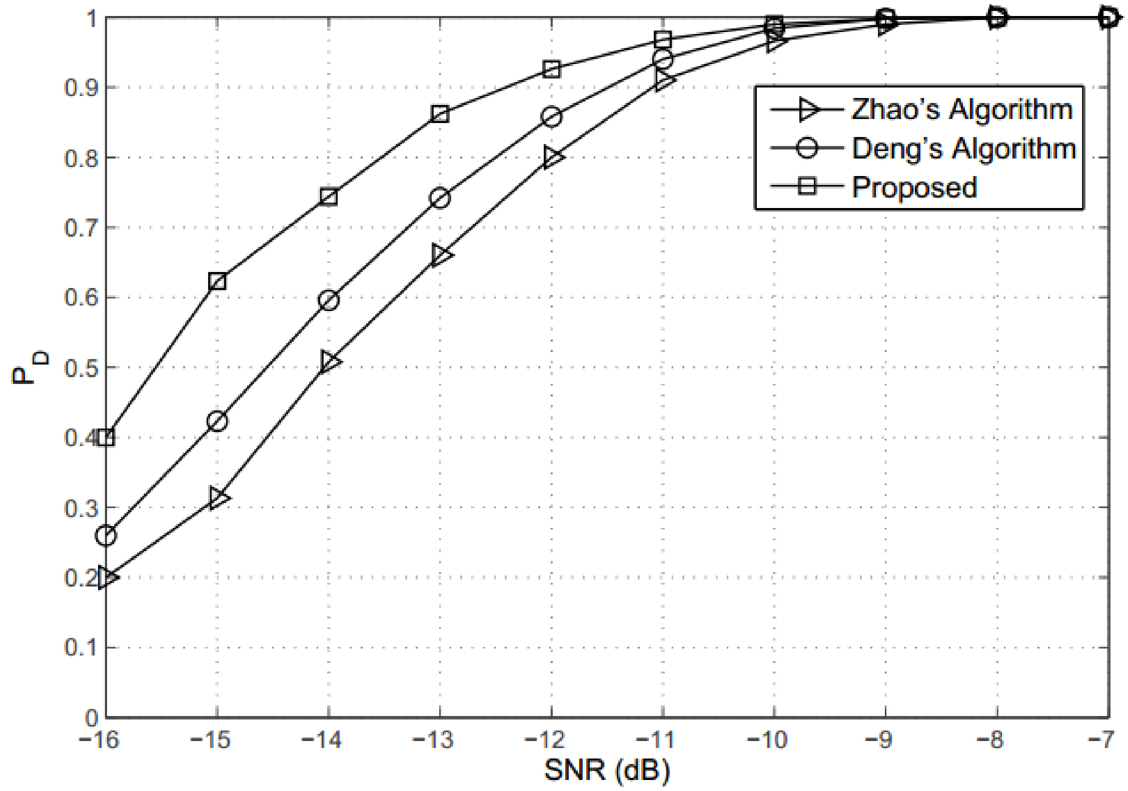


**Figure 5-2:** Comparison of Golay in TDR with Zhao's and Deng's in AWGN channel

Now we compare Zadoff-chu training sequence with Goaly sequence in Time Domain Repetitive (TDR) algorithm. Both training sequences are compared by two methods. One is by fixing threshold and varying SNR and second is by fixing SNR and varying threshold. Figure 5-3 show the comparison of these two sequences on the basis of varying SNR and Fix Threshold. The parameters of comparison are given below:

- Threshold ($\gamma$) = 0.08
- SNR (dB) = -16 to -7

Number of symbols are same as mentioned before. Additive White Gaussian Noise (AWGN) channel is used for comparison. By fixing threshold at 0.08 and varying SNR from -16dB to -7dB performance of both sequences are compared.

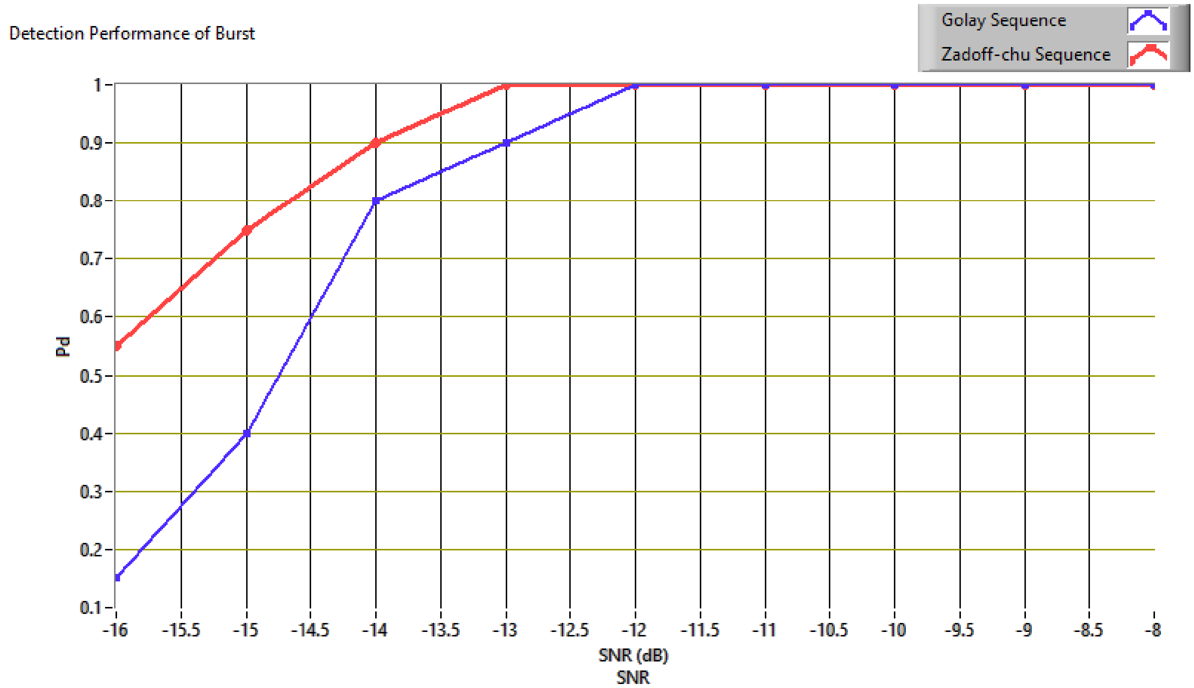


**Figure 5-3:** Comparison of Golay and Zadoff-chu training Sequence with varying SNR in AWGN channel

As shown in graph Zadoff-chu training sequence gives better performance with respect to Golay training sequence. At -16dB with Zadoff-chu training sequence TDR have .55 probability of detection while with Golay sequence it has .15. And Zadoff-chu increases exponentially with increasing SNR from -16 to -7 while Golay sequence increases slowly. At -13 dB with Zadoff-chu sequence TDR have 1 probability of burst detection and Golay sequence have .9. After -12 dB SNR Zadoff-chu and Golay sequence have same response.

Figure 5-4 shows the performance of both sequences when threshold is at 0.1. In this simulation all parameters are same but threshold is change. As threshold is increased Zadoff-chu sequence starting performance in TDR algorithm is slight down but still better than Golay sequence.

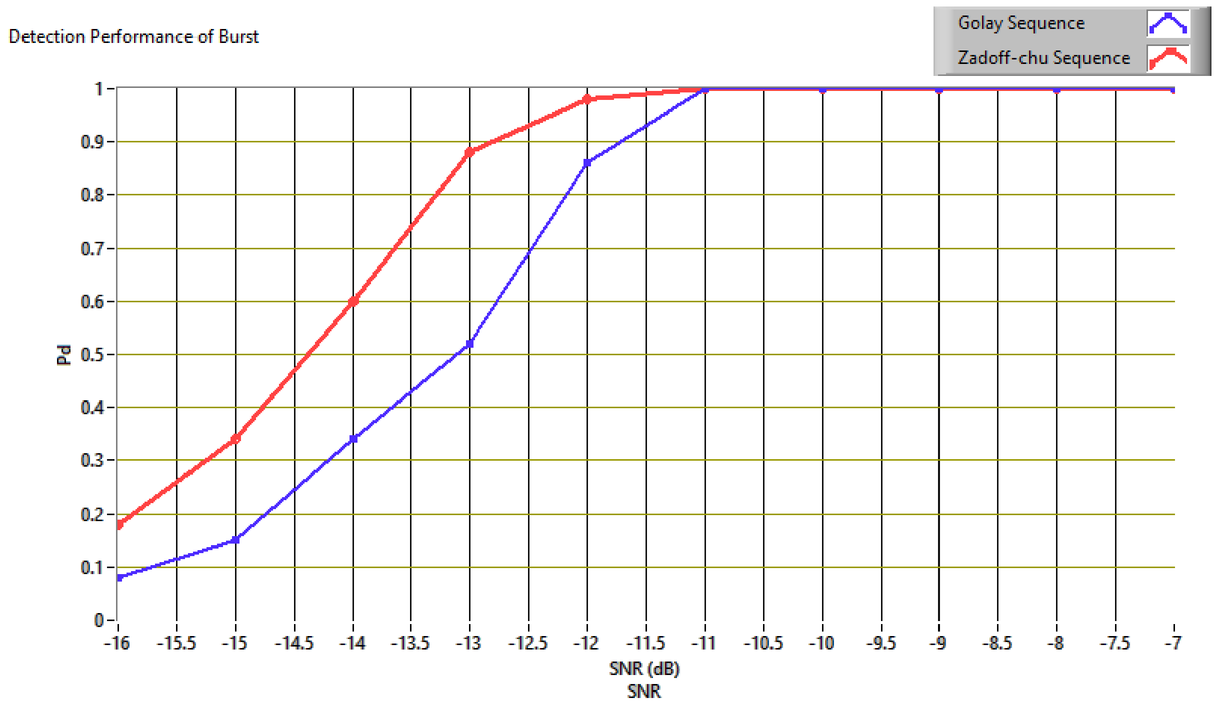


**Figure 5-4:** Threshold 0.1

At -13dB with Zadoff-chu training sequence the Pd value for TDR algorithm is 0.88 while with Golay sequence it has 0.52. Similarly, at -12dB with Zadoff-chu sequence it has 0.98 and with Golay sequence it has 0.88. At -11dB with both sequences it has 1 probability of detection of burst.

# CHAPTER 6: CONCULSION AND FUTURE WORK

## 6.1 Conclusion

The wideband network based seamless communication is the key requirement of Military and commercial systems. In this thesis we have proposed a practically effective detection of burst technique for burst mode of communication systems specially for wideband networking waveform of Software Defined Radios. Timing metric calculation of signal using training sequence is done in this thesis. Zadoff-chu sequence is used as its training sequence. Because Zadoff-chu training sequence has some unique properties. One is the constant amplitude and other is autocorrelation of sequence is zero. The comparison of proposed burst detection algorithm with other algorithms is shown. For multipath fast fading channels detection of burst through this technique is efficient. In Simulation it is clear that by fixing threshold value, proposed burst detection algorithm perform well in the presence of AWGN. This algorithm is the best suited for high throughput in a given bandwidth systems like military applications, IP data, video conferences, sharing data files, biometric, voice calling, networking applications etc.

## 6.2 Future Work

This thesis proposed efficient burst detection algorithm for wideband networking software defined radios. This algorithm required constant gain during the duration of a burst for correct recovery of bits without any low power signal distortion so that threshold may be work accurately in a complete burst duration. Automatic Gain Control of system should be more efficient for fixing gain of system in a complete duration of burst. In the field of embedded systems controlling the gain of a communication system for burst mode of communication is the good area of research.

# REFERENCES


[1] A. C. Tribble, “The software defined radio: Fact and fiction,” in Proceedings of IEEE Radio and Wireless Symposium, 2008, pp. 5 – 8.

[2] P. B. Kenington, RF and baseband technologies for software defined radio. Artech House, London, 2005.

[3] D. Scaparoth, “Cognitive software defined radio,” Tech. Rep., 2005.

[4] D. Lau, J. Blackburn, and J. A. Seely, “The use of hardware acceleration in SDR waveforms.”

[5] J. Rohde and T. S. Toftegaard, “Adaptive cognitive radio technology for low power wireless personal area network devices,” Wireless Personal Communications, vol. 58 , no. 1, pp. 111–123, 2011.

[6] S. Han, J.-H. Park, H.-H. Shin, and B.-S. Kim, “Performance enhancements in

TDMA-based tactical wireless networks,” in Proceedings of Vehicular Technology Conference, 2012, pp. 1 – 5.

[7] M. Nakagawa, “Consumer communications based on spread spectrum technologies,” in Proceedings of IEEE 3rd International Symposium on Spread Spectrum Techniques and Applications, 1994, pp. 138–145.

[8] S. Lindenmeier, A. Terzis, A DSSS-based wireless short range data-link, AEU Int.J.Electron.Commun. 57 (3) (2003) 161–167.

[9] U. Mengali and M. Morelli, “Data-aided frequency estimation for burst digital transmission,” *IEEE Transactions on Communications*, vol. 45, no. 1, pp. 23–25, 1997.

[10] A. Goldsmith, *Wireless Communications*. Cambridge University Press, UK, 2005.

[11] M. Zeeshan, S.A. Khan, Z. Mehtab, Data aided algorithm for burst detection in wideband networking waveform with FPGA implementation on SDR platform, Proceedings of IEEE HONET Conference – Photons for Electronics, 2014, pp. 154–158.

[12] L. Mailaender, "Detection statistics for a packet-based cdma system," in *Proceedings of IEEE 49th Vehicular Technology Conference*, 1999, pp. 526–530.

[13] G. J. R. Povey, "Spread spectrum PN code acquisition using hybrid correlator architectures," Wireless Personal Communications, vol. 8, no. 2, pp. 151–164, 1998.

[14] Yan, D., & Ho, P., "Acquisition using differentially encoded barker sequence in DSSS packet radio," in Proceedings of IEEE International Conference on Communications, 1995, pp. 1647–1651.

[15] Z. Zhao, Z. Sun, and F. Mei, "A threshold detection method of DSSS signal based on stft," in Proceedings of IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, vol. 2, 2005, pp. 879–882.

[16] L. Chang, F. Wang, and Z. Wang, "Detection of DSSS signal in non-cooperative communications," in Proceedings of International Conference on Communication Technology, 2006, pp. 1 – 4.

[17] Z. Deng, L. Shen, N. Bao, B. Su, J. Lin, and D. Wang, "Autocorrelation based detection of DSSS signal for cognitive radio system," in Proceedings of International Conference on Wireless Communications and Signal Processing, 2011, pp. 1 – 5.

[18] S. Nagaraj, S. Khan, C. Schlegel, and M. Burnashev, "On preamble detection in packet-based wireless networks," in Proceedings of IEEE Ninth International Symposium on Spread Spectrum Techniques and Applications, 2006, pp. 476–480.

[19] H.-S. Oh, D.-S. Han, and K.-H. Park, "Adaptive double-dwell PN code acquisition in direct-sequence spread-spectrum systems," in Proceedings of the 21st Century Military Communications Conference, 2000, pp. 139–143.

[20] S. Yeom, Y. Jung, and S. Lee, "An adaptive threshold technique for fast PN code acquisition in DSSS systems," IEEE Transactions on Vehicular Technology, vol. 60, no. 6, pp. 2870–2875, 2011.

[21] Jian Fu, Jun Wang, Jian Song, Chang-Yong Pan, and Zhi-Xing Yang, "A Simplified Equalization Method for Dual PN-Sequence Padding TDS-OFDM Systems"

[22] Kazuki ESHIMA, Yoshihiro HASE, Shingo OOMORI Fujinobu TAKAHASHI, Ryuji K0HN0 , "M-a,ry UWB System Using Walsh Codes"

[23] Zhang Xinyu, "Analysis of M-sequence and Gold-sequence in CDMA system"

[24] Esmael H. Dinan, Bijan Jabbari, "Spreading Codes for Direct Sequence CDMA and Wideband CDMA Cellular Networks"

[25] Yong-Hwan Lee, Seung-Jun Kim, "Sequence Acquisition of DS-CDMA Systems Employing Gold Sequences"

[26] James A. Davis, Jonathan Jedwab, "Peak-to-mean power control in OFDM, Golay complementary sequences and Reed-Muller codes"

[27] Md Mashud Hyder, Kaushik Mahata, “Zadoff-Chu sequence design for random access initial uplink synchronization”

[28] Imran Baig, Varun Jeoti, “PAPR Reduction in OFDM Systems: Zadoff-Chu Matrix Transform Based Pre/Post-Coding Techniques”

[29] Min Hua, Mao Wang, Kristo Wenjie Yang, and Kingsley Jun Zou, “Analysis of the Frequency Offset Effect on Zadoff–Chu Sequence Timing Performance”

[30] M. Zeeshan, S. A. Jabir, W. Ahmed, “Joint algorithm for burst detection and AGC improvement in high throughput software defined radio waveform” Microprocessors and Microsystems 60 (77–85), 2018.

[31] E. Grass, K. Tittelbach-Helmrich, U. Jagdhold, A. Troya, and e. a. G. Lippert, “On the Single-Chip implementation of a hiperlan/2 and IEEE 802.11a capable modem,” IEEE Personal Communications, vol. 8, no. 6, pp. 48–57, 2001.

[32] K. Fazel and S. Kaiser, Multicarrier and Spread Spectrum Systems. John Wiley and Sons, 2003.

[33] T. Rappaport, Wireless Communications: Principles and Practice. Englewood Cliffs, NJ: Prentice-Hall, 1996.

[34] D. Yan and P. Ho, “On-off keying assisted acquisition scheme for burst mode ds/ss packet radio,” in Proceedings of IEEE 44th Vehicular Technology Conference, 1994, pp. 582–586.

[35] DAVID C. CHU, “Polyphase Codes with Good Periodic Correlation Properties”

[36] STEPHANE NOBILET, JEAN-FRANCOIS HELARD, DAVID MOTTIER, “Spreading Sequences for Uplink and Downlink MC-CDMA Systems: PAPR and MA1 Minimization”

[37] Branislav M. Popovic, “Generalized Chirp-Like Polyphase Sequences with Optimum Correlation Properties”

[38] M. J. E. Golay, “Complementary series,” IRE Transactions on Information Theory, vol. IT-7, pp. 82–87, 1961.

[39] M. B. Mollah and M. R. Islam, “Comparative analysis of gold codes with PN codes using correlation property in CDMA technology,” in Proceedings of International Conference on Computer Communication and Informatics, 2012, pp. 1 – 6.

[40] J. Lindholm, “An analysis of the pseudo-randomness properties of subsequences of long m-sequences,” IEEE Transactions on Information Theory, vol. 14, no. 4, pp. 569–576, 1968.

[41] H. Minn, V. K. Bhargava, and K. B. Letaief, “A robust timing and frequency synchronization for OFDM systems,” IEEE Transactions on Wireless Communications, vol. 2, no. 4, pp. 822–839, 2003.

[42] IEEE 8 02.16 Broadband Wireless Access Working Group., Channel models for fixed wireless applications, 2001, www.ieee802.org/16/tg3/contrib/802163c-01_29r4.pdf.

# APPENDIX A

## Stanford University Interim Channel Models

Stanford University Interim (SUI) channels are modelled to represent three different terrain types and various values of delay spread, Doppler spread, and LOS/NLOS conditions. The summary of these six channel models is given in Table A.1. The detailed specifications of all SUI channel models are given in tables A.2 to A.7. In these specifications, K-factor is the ratio of LOS component to NLOS components. For NLOS case, K-factor is zero.

Table A.1: Summary of SUI channel terrain types

| | **SUI-1** | **SUI-2** | **SUI-3** | **SUI-4** | **SUI-5** | **SUI-6** |
|---|---|---|---|---|---|---|
| Terrain category | C | C | B | B | A | A |
| Terrain type | Flat | Flat | Hilly | Flat | Hilly | Hilly |
| Tree density | Light | Light | Light | Moderate to heavy | Moderate to heavy | Moderate to heavy |
| Line of sight | Strong | Strong | Weak | Weak | Weak | Weak |

| | | | | | | |
|---|---|---|---|---|---|---|
| Delay spread | Low | Low | Low | Moderate | High | High |
| Path loss | Low | Low | Intermediate | Intermediate | High | High |
| Doppler spread | Low | Low | Low | High | Low | High |

Table A.2: SUI-1 channel model specifications

| | **Tap 1** | **Tap 2** | **Tap 3** |
|---|---|---|---|
| Delay ($\mu$s) | 0.0 | 0.4 | 0.9 |
| Power (dB) | 0 | -15 | -20 |
| K-factor | 4 | 0 | 0 |
| Doppler (Hz) | 0.40 | 0.30 | 0.50 |

Table A.3: SUI-2 channel model specifications

| | **Tap 1** | **Tap 2** | **Tap 3** |
|---|---|---|---|
| Delay ($\mu$s) | 0.0 | 0.4 | 1.1 |
| Power (dB) | 0 | -12 | -15 |
| K-factor | 2 | 0 | 0 |
| Doppler (Hz) | 0.20 | 0.15 | 0.25 |

Table A.4: SUI-3 channel model specifications

| | **Tap 1** | **Tap 2** | **Tap 3** |
|---|---|---|---|
| Delay ($\mu$s) | 0.0 | 0.4 | 0.9 |
| Power (dB) | 0 | -5 | -10 |

| | | | |
|---|---|---|---|
| K-factor | 1 | 0 | 0 |
| Doppler (Hz) | 0.40 | 0.30 | 0.50 |

Table A.5: SUI-4 channel model specifications

| | **Tap 1** | **Tap 2** | **Tap 3** |
|---|---|---|---|
| Delay ($\mu$s) | 0.0 | 1.5 | 4.0 |
| Power (dB) | 0 | -4 | -8 |
| K-factor | 0 | 0 | 0 |
| Doppler (Hz) | 0.20 | 0.15 | 0.25 |

Table A.6: SUI-5 channel model specifications

| | **Tap 1** | **Tap 2** | **Tap 3** |
|---|---|---|---|
| Delay ($\mu$s) | 0.0 | 4.0 | 10.0 |
| Power (dB) | 0 | -5 | -10 |
| K-factor | 0 | 0 | 0 |
| Doppler (Hz) | 2.00 | 1.50 | 2.50 |

Table A.7: SUI-6 channel model specifications

| | **Tap 1** | **Tap 2** | **Tap 3** |
|---|---|---|---|
| Delay ($\mu$s) | 0.0 | 14.0 | 20.0 |
| Power (dB) | 0 | -10 | -14 |
| K-factor | 0 | 0 | 0 |
| Doppler (Hz) | 0.40 | 0.30 | 0.50 |