# Performance Analysis of Different Spreading Codes in CDMA System Environment for Multi-User Adaptive SDR Environment

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**Abstract**
The software defined radio (SDR) technology embraces **a** flexible radio interface that generally consists of a software-reconfigurable hardware transceiver, and software modules that flexibly changes itself for a given radio system application. In this paper we have simulated a complete CDMA system with its changing environment adaptable by SDR to change spreading codes, fading environment, transmitter characteristics, channel parameters and receiver characteristics for various number of users is simulated. The performance of the adaptive CDMA system with SDR concept shows that it is an immediate generation (4G) which can be best described in one word "MAGIC", which stands for Mobile multimedia Anytime Anywhere Global mobility support, integrated wireless and personalized services. In this paper, the performance of a CDMA system in the presence of different types of codes for spreading and dispreading for variable number of users is discussed. The bit error rate (BER) for each case is evaluated.

***Keywords:***
*CDMA, Gold Codes, QPSK modulation, Bit error rate (BER)*

## 1. Introduction

Future Communication technologies are to provide very high data transfer rates with very speedy wireless internet access to not only stationary users, but also to the mobile users. The advanced technology should trounce the deficiencies of 3G technology in terms of speed and quality. The immediate 3G utilized WiMax and WiFi as separate wireless technologies, whereas 4G is expected to coalesce these two technologies. Hence, one can evaluate how efficient it would become when combining two extremely reliable technologies. 4G can greatly anticipate in evolving and advancing the pervasive computing. The aim of pervasive computing is to attach itself to every living space possible, so that human beings remain intact with the wireless technology intentionally unintentionally. Therefore 4G is be able to connect various high speed networks together, which would enable each one of us to carry digital devices even in dispersed locations. The network operators worldwide would be able to deploy wireless mesh networks and make use of cognitive radio technology for widespread coverage and access.

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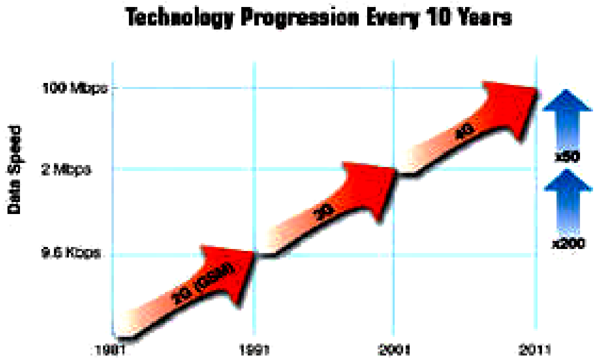


**Figure 1: Technology Progression every ten Years**

Universal Mobile Telecommunication Service (UMTS) which is basically a broadband 3G technology is also a part of 4G. This broadband technology transfers data in the form of frames or packets. Hence it is capable of carrying voice, video, text and other types of multimedia datagram with the speed of 2Mb. UMTS is part of 4G because it can enables 4G to make use of international mobile phone roaming via using GSM (Global system for Mobile Communications). Another wireless telecommunication technology known as time division synchronous code division multiple access (TD-SCDMA) provides support to 4G to transfer both circuit switched data like video and voice and packet switched data.
4G network is based on IPv6 support rather than IPv4. It is IPv6 which is supports network devices. Increased number of IP addresses also removes the need for NAT (network Address translation). NAT is a term referred to sharing minimum IP addresses with larger number of devices. Besides this improvement Nat would also has to communicate with the other devices on the previous IPv4 devices. 4G has also brought improvements in network infrastructure. For example 3G used both circuit switched and packet switched network nodes, while 4G is merely based on packet switching, hence lowering the latency of data. The basic 4G standards include LTE advanced and 802.16m.

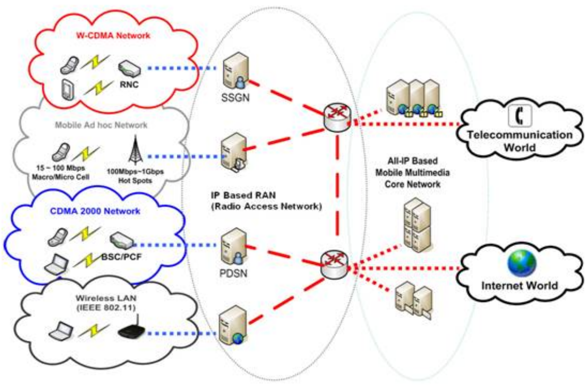


**Figure 2: 4G Network Environment**

This wonder technology is expected to cover the data rate deficiency in previous generations. It is also aimed to achieve quality of services. This technology would provide many multimedia services. These multimedia services would not only include voice chat and video calls but also includes MMS, HDTV, video chat, and voice over the internet. This network would allow interactive roaming with existing LAN and digital broadcasting systems. This network's goal is to provide 100MBps data rate for moving customers and 1GB for stationary users. So that the users can enjoy uninterrupted connectivity with high speed anywhere they go. Very smooth handover over heterogeneous networks. Flawless connectivity and international roaming across innumerable networks of the world is its next target. It should also provide Very high quality multimedia support in order to get approval from ITU.

The interoperability with existing network infrastructure is another prominent feature of this technology. It is an all IP switched network and several working groups propose that it should offer an open internet protocol. The early 4G technology comprise of flash OFDM, 802.16e, wireless or mobile WiMax and HC SDMA. The demand of the wireless network users combined with the efforts of the 4G working groups would give technology and edge over its previous counterparts.

The after4G technology (5G) will change the manner in which cellular plans are offered worldwide. A new revolution is about to begin. The global cell phone is around the corner. The global mobile phone will hit the localities who can call and access from anywhere to anywhere of the world. This paper visualizes the future opportunities for the above requirements by Adaptive Multi-carrier spreading codes combined with Software updating option in a Reconfigurable Architecture.

## 2. Software Defined Radio

Software defined radio - the next generation automotive radio platform. As the capabilities of analog to digital converters (ADCs) and signal processors expand, there are new ways for system designers to overcome chronic design challenges. Software defined radio (SDR) is a concept that has grown in popularity over the last few years, not only for broadcasting receivers, but also for portable mobile handsets. An example of an Ideal Software defined radio block diagram is shown in Figure 3.

The principle behind SDR is to run software on a multi-purpose processor to handle the functions of the radio reception path that are typically realized in hardware, as for example, the demodulation and audio decoding. Effectively, the software defines what kind of processing is applied to the signal coming in from the antenna, enabling both analog and digital radio reception with a minimum of components. To fully maximize the potential of SDR, the incoming analog signal should be digitized as soon as possible, and the output signal should be converted back to analog. This way costly hardware blocks can be eliminated while at the same time the flexibility is increased. Another advantage lies in the way the received signal is brought it from the antenna to the radio. Digitizing the RF signal at the antenna output, and transmitting only the digital information can improve the overall performance of the receiver. Moving the workload from the analog to digital domain is not simple, however. True SDR for consumer applications remains a concept or 'vision' right now due to technological limitations.

Digitizing the whole AM/FM band at the antenna output would mean a significant amount of data which would need to be handled and processed. The hardware required to do so is not yet available on a broad basis in the consumer electronics market so it is impossible to realize with reasonable cost and effort.

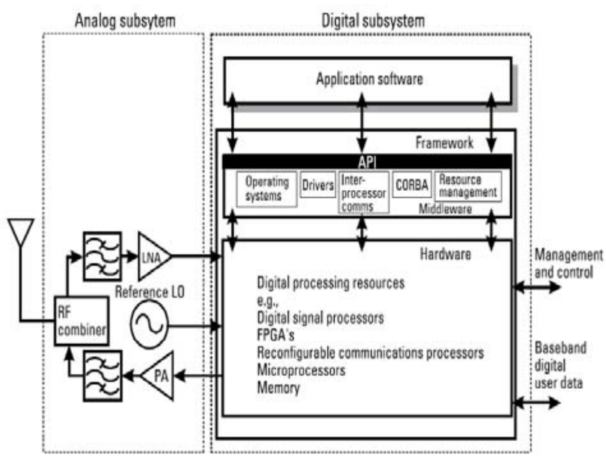


**Figure 3: Ideal Software Defined Radio**

As a result, designers must still use mixers to down-convert the RF signal to an intermediate frequency (IF) that can be handled. However, while limitations for ADCs etc. remain, the advanced possibilities in signal processing allows for some significant enhancements for the next generation of radio systems in the automotive electronics market.

## 2.1 Summary of advantages when using a SDR concept:

(i) Reuse hardware for different customer requirements leads to reduced hardware qualification and development effort
(ii) Software updates to fit new/changing broadcasting standards, fix bugs, support latest
external devices, and not penalize early adopters
(iii) Compact hardware platform requiring less space in the head unit
(iv) Shorter time to market because the hardware is less complex. Development effort moves to software design while hardware stays the same for different customer requirements
(v) Lower bill of materials by eliminating hardware components and re-using hardware platforms
(vi) Allows last-minute design changes because functionality is mainly determined by software

## 3. Multi-carrier System

A multi-carrier system is a system where several subcarriers are used for parallel transmission of data packets. A new multicarrier mechanism is applied to a Code Division Multiple Access (*CDMA*) network. In a CDMA network each data symbol is spread over a larger bandwidth, larger than the bandwidth needed for transmission. This allows transmitting with a spectral energy that is lower than in a non spread spectrum system, a fact that allows the use of parallel transmission channels, at the same time in the same frequency band. The data transmitted in the different channels can be distinguished by the use of a different spreading code for each channel. The data stream consists of a successive sequence of symbols or chips.
In conventional Direct-Sequence CDMA (*DS-CDMA*), each user bit is transmitted in the form of many sequential chips, each of which is of short duration, thus having a wide bandwidth. In contrast to this, due to the Fast Fourier Transform (*FFT*) associated with Orthogonal Frequency Division Multiplexing (*OFDM*), MC-CDMA chips are long in time duration, but narrow in bandwidth. Each symbol of the data stream of one user is multiplied by each element of the same spreading code and is thus placed in several narrow band subcarriers.
Multiple chips are not sequential, but transmitted in parallel on different subcarriers .The MAC protocol of the IEEE 802.11a is based on the CSMA/CA protocol. The time needed, to listen to the medium is called InterFrame Space (*IFS*). The collision avoidance is based on a randomly operating backoff procedure. The Distributed Coordination Function (*DCF*) of the standard is commonly used. As shown in Figure 4, the Mobile Station (*MS*), which has a data packet to transmit, draws a random number between 0 and CW, which determines the duration of the backoff timer in number of timeslots.

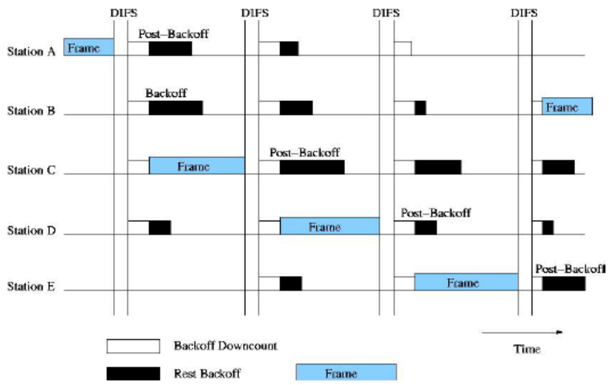


**Figure 4: Distributed Coordination Function**

The Contention Window (*CW*) has a minimum starting value of 15 and it doubles after a collision. Thus its value can rise up to 255 and is decremented after a successful transfer. The receiver acknowledges a successful transmission with an Acknowledgement (*ACK*) frame. While the medium is free the MS counts down the backoff timer until it reaches zero and then after detecting the medium as free for a time of Distributed coordination function Inter-Frame Space (*DIFS*), the transmission starts. If during the countdown another MS occupies the medium all MSs in backoff interrupt their count down and defer until they detect that the medium is free for at least DIFS. Then they continue the countdown of the backoff timer. The transmitter of the previous packet starts a new backoff procedure even if no other packet is waiting in its queue for transmission. The latter is called post-backoff.
In the following two sections 3.1 and 3.2 description on the modified physical layer is given, based on MC-CDMA, and the modified MAC protocol.

## 3.1 Modification of the Physical Layer

The proposed system uses MC-CDMA in the physical layer (*PHY layer*), a modulation technique where one single data symbol is spread in frequency. The 20 MHz channel is split into 52 subcarriers with 48 data and 4 pilot subcarriers, like in the IEEE 802.11a OFDM physical layer.

A Spreading Factor (*SF*) of 4 is chosen, thus the symbol of one user is divided into SF fractions and each of them is transmitted in parallel in a different subcarrier. Since one subcarrier carries a fraction of the user's symbol, it can accept additional load, coming from symbols of other users. At the end the symbol that is transmitted in one subcarrier consists of the sum of n fractions on n symbols that belong to n users, with $n \leq SF$. See Figure 4.1 for a MC-CDMA system with SF=4.

As spreading sequences the orthogonal Walsh Hadamard codes of length 4 are used, leading to a maximum of 4 parallel code channels. Since the Walsh Hadamard Codes lose their orthogonality in asynchronous systems, the use of a multi-user detector is inevitable. The adaptive Minimum Mean Square Error (*MMSE*) multi-user detector performs well for asynchronous MC-CDMA systems in indoor Rayleigh fading channels, leading to a good separation of signals encoded with different spreading sequences and therefore is employed at the receivers of the proposed system.

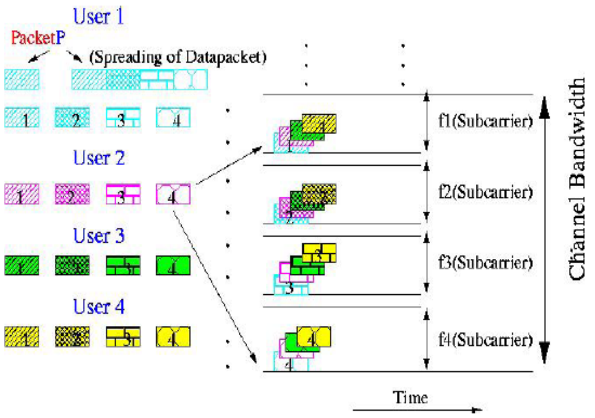


**Figure 4.1: Principle of MC-CDMA**

Other parameters of the PHY layer have been chosen to be the same as in the standard 5 GHz OFDM based system. A convolutional encoder k =7 is used, and data packets are transferred using the QPSK ½ PHY mode, thus achieving a data rate of 12 Mbps. For the control packets, RTS, CTS and ACK, the standard defines the use of a mandatory PHY mode, and for our simulations the QPSK ½ with 12 Mbps is used.

## 3.2 Modification of the MAC Protocol

The MAC protocol of the proposed system is based on the MAC protocol of the IEEE 802.11a WLAN, with the modifications needed to support the CDMA PHY Layer. In this case the frequency channel is divided (from the use of MC-CDMA with SF = 4) into 4 parallel code channels. Each of them can be accessed by the MS using the DCF, as described in the standard. A station ready to transmit has to select a code channel. Initially this selection is done purely randomly. For later transmissions, the station does not select code channels for which a Network Allocation Vector (*NAV*) is set.

After the station determines the medium as free for the duration of DIFS, it transmits an RTS packet to signal the intended transmission. All stations able to receive this control packet, and determining that they are not the intended receivers, set their NAV timer and defer from the medium in order not to interfere with the transmission. If the receiver of the RTS is idle and thus able to receive data, it responds with a CTS packet, after a time equal to the Short InterFrame Space (*SIFS*). Mobile stations which receive these CTS set their NAV timer as well. Then the sender can transmit its data packet after SIFS, which is acknowledged by the receiver in case of successful reception through an ACK sent with a delay of SIFS after the end of the reception as shown in Figure 5. This is the procedure for a data transmission in every code channel.

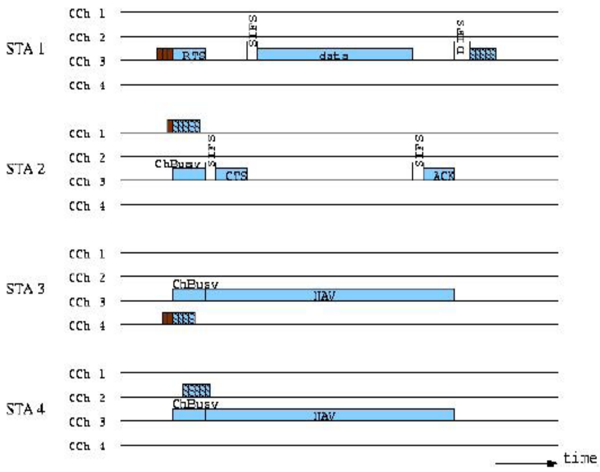


**Figure 5: CSMA/CA with 4 parallel code channels**

In case two or more stations access the same code channel on the same frequency band at the same time a collision occurs. Although the backoff mechanism provides a solution to resolve collisions, in scenarios with many stations, collisions are a limiting factor for the achieved throughput and delay. The proposed modification of the protocol has an advantage in this respect, since each frequency channel is divided into SF parallel code channels, and only n/SF stations compete against each other in accessing this frequency channel. The collisions are therefore reduced allowing the use of a lower value for the minimum CW size.

From Figure 5, it is obvious that each station occupies only part of the available resources. In a situation where only two stations are transmitting, each one in a different code channel, two of the 4 code channels remain idle. Additionally using a SF of 4 the duration for a packet transmission becomes 4 times longer, meaning a bigger delay for the next packet waiting in the queue. To overcome this problem the proposed protocol allows parallel transmissions in more than one code channel. This means that a station with enough traffic, determining more than one code channels as idle for a time DIFS, can use them to transmit more than one packet in parallel. Power Control is done over the RTS CTS packets. An RTS is send with the same transmission power used in the previous transmission to that receiver incremented by 2 dBm. The transmission power is encoded in the RTS packet so that the receiver, upon receiving it, can calculate the path loss. According to the path loss, the interference status at the receiver and the mean Signal to Noise Ratio (*SNR*) of the last received packet of this connection, the receiver might ask the transmitter to correct its transmission power by encoding such information in the CTS packet.

## 4. Typical Spreading Codes used in CDMA

### 4.1 Gold Codes

Gold sequences have been proposed by Gold in 1967 and 1968. These are constructed by EXOR-ing two *m*-sequences of the same length with each other. Thus, for a Gold sequence of length $m = 2^l-1$, one uses two Linear Feedback Shift Register (LFSR), each of length $2^l-1$. If the LFSRs are chosen appropriately, Gold sequences have better cross-correlation properties than maximum length LFSR sequences. Gold (and Kasami) showed that for certain well-chosen *m*-sequences, the cross correlation only takes on three possible values, namely -1, -*t* or *t*-2. Two such sequences are called preferred sequences. Here *t* depends solely on the length of the LFSR used.

In fact, for a LFSR with *l* memory elements,
if *l* is odd, $t = 2^{(l+1)/2} + 1$, and
if *l* is even, $t = 2^{(l+2)/2} + 1$.
Thus, a Gold sequence formally is an arbitrary phase of a sequence in the set *G(u,v)* defined by

$G(u,v)= \{u,v,u * v, u * Tv, u *T^2 v, U * T^{(N-1)} v\}$,

where $T^k$ denotes the operator which shifts vectors cyclically to the left by *k* places, * is the exclusive OR operator and *u*, *v* are *m*-sequences of period generated by different primitive binary polynomials.

### 4.2 M-Sequence (Maximal Length Sequences)

Various pseudo random codes are generated using LFSR (Linear Feedback Shift Register). The generator polynomial governs all the characteristics of the generator. For a given generator polynomial, there are two ways of implementing LFSR. Galois feedback generator uses only the output bit to add (in Galois field) several stages of the shift register and is desirable for high speed hardware implementation as well as software implementation. The other known as Fibonacci feedback generator can generate several delays of sequences without any additional logic.
Shift-register sequences having the maximum possible period for an *r*-stage shift register are called *maximal length sequences* or *m-sequences*. A primitive generator polynomial always yields an *m-sequence*. The maximum period of an *r*-stage shift register can be proven to be $2^r-1$. The *m-sequences* have three important properties, i.e., balance property, run-length property and shift-and-add property.

The periodic autocorrelation function $R_a(k)$ is two-valued and is given by

$$R_a(k) = \begin{cases} 1.0 & k = lN \\ -\frac{1}{N} & k \neq lN \end{cases}$$

where *l* is an integer and *N* is the period of the *m-sequence*.
The excellent auto-correlation property comes from the first and the third properties. *M-sequences* have good auto correlation property and are being used in many applications including IS-95. As the cross-correlation property of these sequences is relatively poor compared to Gold codes, the same sequence with different offset are usually used for different users or for different base stations. With this method, the discrimination property between different spreading codes only depends on partial autocorrelation property.

### 4.3 Orthogonal Sequence

In mathematics, an **orthogonal polynomial sequence** is an infinite sequence of real polynomials

$$p_0,\ p_1,\ p_2,\ \ldots$$

of one variable *x*, in which each $p_n$ has degree *n*, and such that any two different polynomials in the sequence are orthogonal to each other under a particular version of the $L^2$ inner product. The theory of orthogonal polynomials includes many definitions of orthogonality.
In abstract notation, is convenient to write

$$\langle p, q \rangle = 0$$

when the polynomials *p*(*x*) and *q*(*x*) are orthogonal.

Let $[x_1,x_2]$ be an interval in the real line (where $x_1 = -\infty$ and $x_2 = \infty$ are allowed). This is called the **interval of orthogonality**. Let

$$W : [x_1, x_2] \to \mathbb{R}$$

be a function on the interval, that is strictly positive on the interior $(x_1,x_2)$, but which may be zero or go to infinity at the end points. Additionally, $W$ must satisfy the requirement that, for any polynomial $f$, the integral

$$\int_{x_1}^{x_2} f(x)W(x)\,dx$$

is finite. Such a $W$ is called a **weight function**.

Given any $x_1$, $x_2$, and $W$ as above, define an operation on pairs of polynomials $f$ and $g$ by

$$\langle f,g\rangle = \int_{x_1}^{x_2} f(x)g(x)W(x)\,dx.$$

This operation is an inner product on the vector space of all polynomials. It induces a notion of orthogonality in the usual way, namely that two polynomials are orthogonal if their inner product is zero.

## 5. Simulation Results and Discussion

### 5.1 Case 1: Gold codes for spreading

The eye diagram plot for the I and Q channel after spreading with Gold Codes for variable number of users (N=3,5,7) is shown in figure 6 to figure 11.

**For N=3**; N-number of users

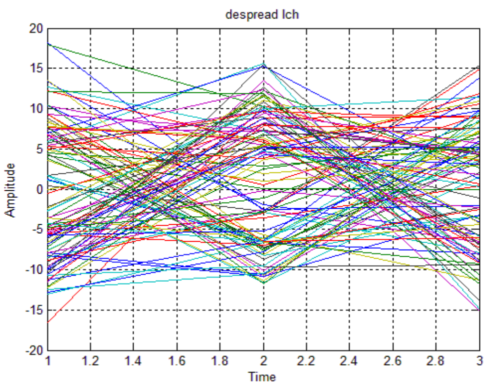


Figure 6: Eye Diagram of De-spread I-Channel using Gold code for 3 users

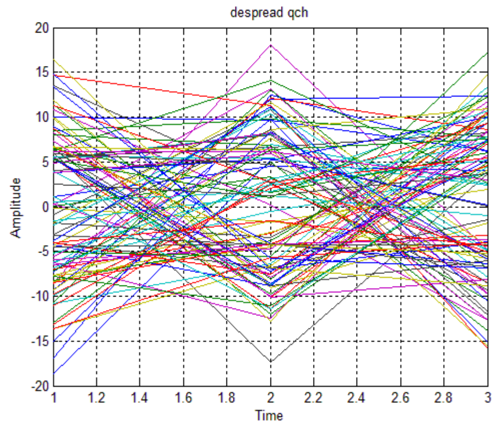


Figure 7: Eye Diagram of De-spread Q-Channel Using Gold code for 3 users

**For N=5**

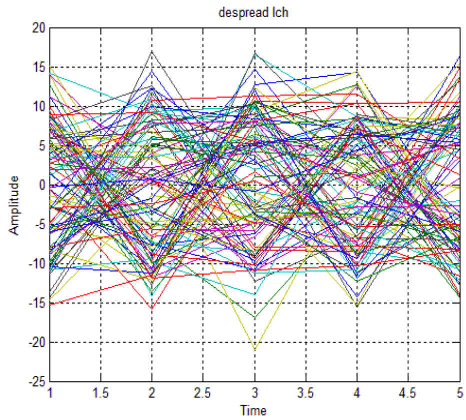


Figure 8: Eye Diagram of De-spread I-Channel using Gold code for 5 users

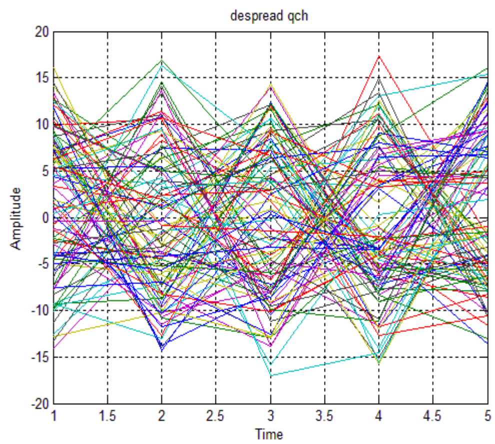


Figure 9: Eye Diagram of De-spread Q-Channel Using Gold code for 5 users

**For N=7**

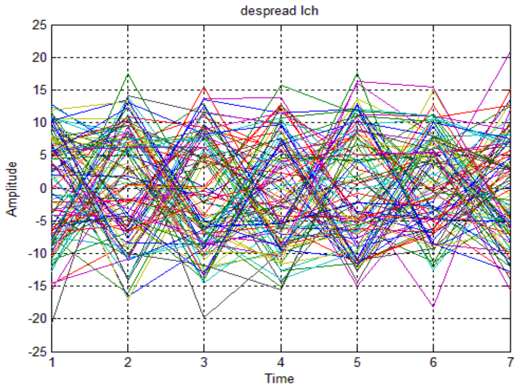


Figure 10: Eye Diagram of De-spread I-Channel using Gold code for 7 users

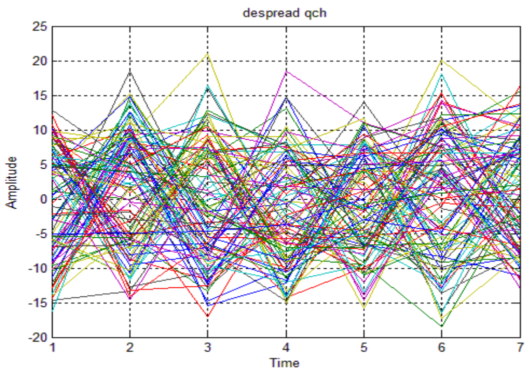


Figure 11: Eye Diagram of De-spread Q-Channel Using Gold code for 7 users

## 5.2 Case 2: Spreading with m-sequence codes

The eye diagram plot using m-sequence codes for spreading in the CDMA system for variable number of users (N=3,5,7) is shown in figure 12 to figure 17.

**For N=3**

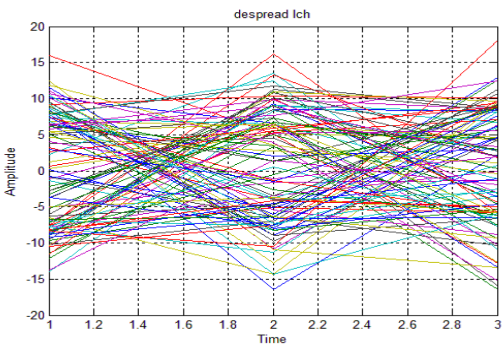


Figure 12: Eye Diagram of De-spread I-Channel Using m-sequence for 3 users

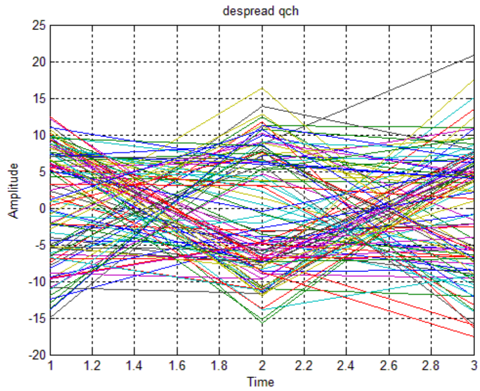


Figure 13 Eye Diagram of De-spread Q-Channel Using m-sequence for 3 users

**For N=5**

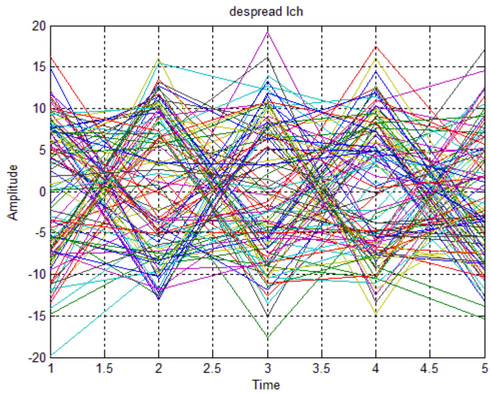


Figure 14 Eye Diagram of De-spread I-Channel Using m-sequence for 5 users

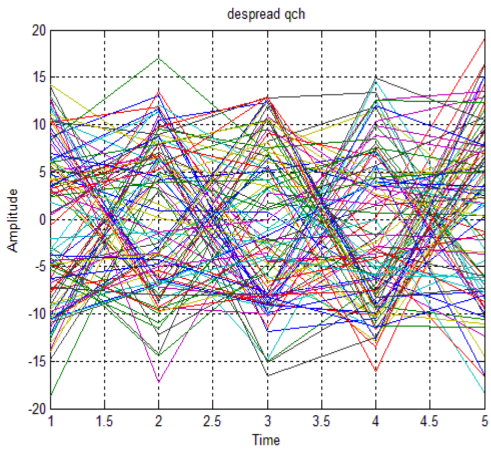


Figure 15 Eye Diagram of De-spread Q-Channel Using m-sequence for 3 users

**For N=7**

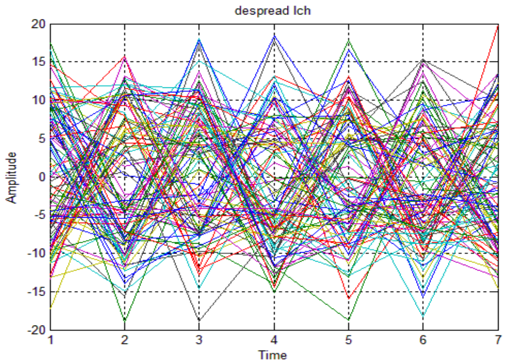


Figure 16 Eye Diagram of De-spread I-Channel Using m-sequence for 7 users

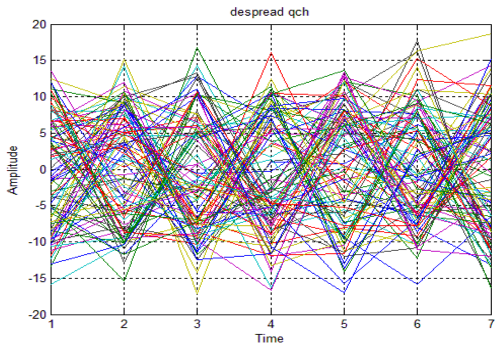


Figure 17 Eye Diagram of De-spread Q-Channel Using m-sequence for 7 users

**Case 3: Results with orthogonal sequence for spread**

The eye diagram for the I and Q channel when using orthogonal sequence codes for spreading in the CDMA system is shown in figures 18 to figure 23.

**For N=3**

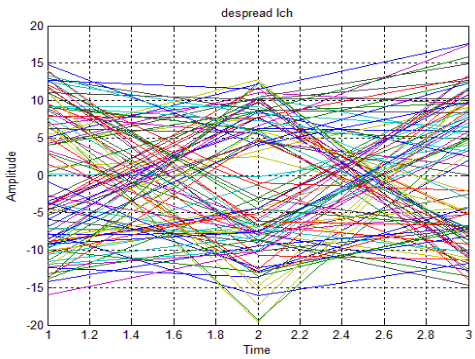


Fig. 18 Eye Diagram of De-spread I-Channel Using Orthogonal sequence for 3 users

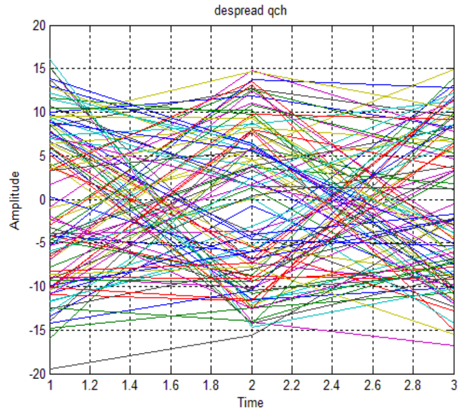


Fig. 19 Eye Diagram of De-spread Q-Channel Using Orthogonal sequence for 3 users

**For N=5**

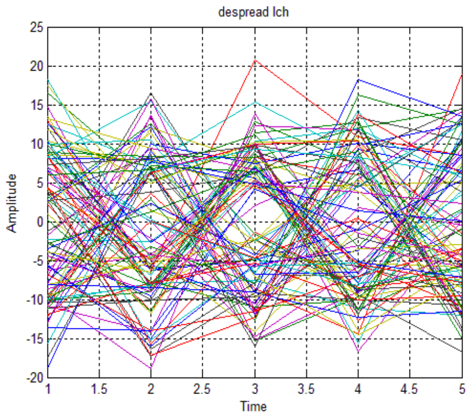


Fig. 20 Eye Diagram of De-spread I-Channel Orthogonal sequence for 5 users

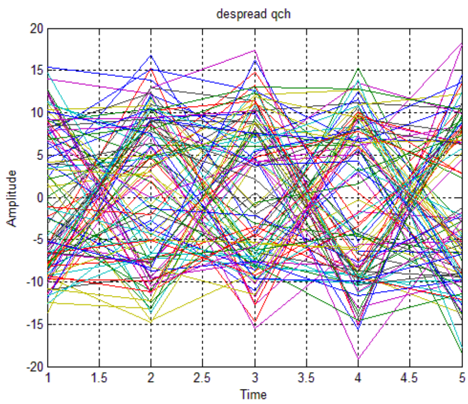


Fig. 21 Eye Diagram of De-spread Q-Channel Using Orthogonal sequence for 5 users

**For N=7**

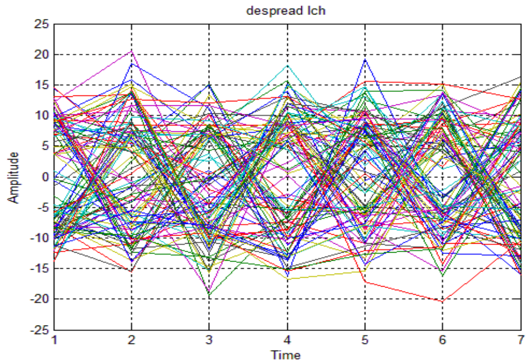


Fig. 22 Eye Diagram of De-spread I-Channel Using Orthogonal sequence for 7 users

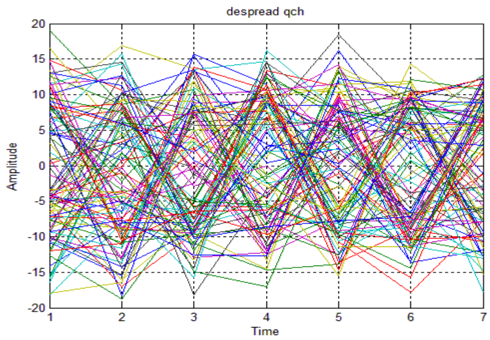


Fig. 23 Eye Diagram of De-spread Q-Channel Orthogonal sequence for 7 users

## 6. Algorithm for complete CDMA System Environment simulation

**Step1:** Initialize the CDMA system simulation by giving symbol rate, number of modulation levels, Bit rate, number of symbols and signal to noise ratio.
**Step2:** Give the filter specifications: Number of filter taps, number of over sample, roll off factor, T filter function and R filter function.
**Step3:** Initialize the spreading code by entering number of users, type of spreading code, number of stages, position for taps in the stages and initial value for register in the stages.
**Step4:** Generate the spread code for the selected type as per the above specifications.
**Step5:** Initialize the fading conditions: Type of fading, delay time, attenuation level, number of waves to generate fading, initial phase of delayed wave, set fading counter, number of direct wave and delayed wave, time resolution, Doppler frequency, flat Rayleigh environment and number of fading counter to skip.
**Step6:** Start simulation for specified number of times to transmit the data.
**Step7:** Start transmitter simulation parameters: QPSK modulation, spreading, over sampling, filter and finally transmission.
**Step8:** Start fading environment simulation after transmission.
**Step9:** Start receiver simulation parameters: attenuation calculation, AWGN, filter, dispreading, QPSK demodulation.
**Step10:** Finally calculate Bit error rate from the information available from transmitter and receiver simulation parameters.

## 6.1 BER for different codes used for spreading

As per the algorithm discussed in section 6 of this paper the input values are given and the simulation was performed and the results of performance for various spread codes with different users are tabulated in table 1.

**Table 1: Bit error Rate for Different Spread Codes with different number of users**

| No. of Users | M-Sequence | Gold Sequence | Orthogonal Sequence |
|---|---|---|---|
| N=1 | 2.292000e-002 | 2.257000e-002 | 2.270000e-002 |
| N=2 | 2.706250e-002 | 2.737250e-002 | 2.262000e-002 |
| N=3 | 3.178167e-002 | 3.249000e-002 | 2.333167e-002 |
| N=4 | 3.665500e-002 | 3.649250e-002 | 2.289000e-002 |
| N=5 | 4.108700e-002 | 4.141900e-002 | 2.260100e-002 |
| N=6 | 4.598333e-002 | 4.619583e-002 | 2.315000e-002 |
| N=7 | 5.089286e-002 | 5.078643e-002 | 2.263357e-002 |

## 7. CONCLUSIONS

A future generation SDR based complete CDMA system was simulated under all environment conditions and the results are tabulated. The tabulation shows the spreading codes along with number of users under specified conditions are comparably well suited for adaptive SDR system and this can be visualized by their BER. In future this can be upgraded for multi-carrier and multi-mode CDMA system to ensure high speed communication.

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