INDIAN SPACE RESEARCH ORGANISATION

DEPARTMENT OF SPACE

ISRO TELEMETRY, TRACKING AND COMMAND NETWORK

Bangalore

"Internship report on Sequence selection and optimization based on odd correlation"

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Section 1: About ISRO

Indian Space Research Organisation is a space agency of India founded by Dr Vikram A Sarabhai on 15th August 1969. This organisation has excelled in the field of Science, Engineering and Space technology development.

The primary objectives of this organisation are development and application of space technology and to fulfil this goal, the organisation has established major space systems, which are:

- Communication
- Television broadcasting
- Meteorological services
- Resource monitoring and management
- Space based navigation system
- Launch vehicles like PSLV and GSLV to place the satellite in respective orbits.

ISRO has several centres for different domains of space technology:

1. Department of Space and ISRO Headquarters is situated in Bangalore.
2. ISRO Telemetry and Command Network (**ISTRAC**) located at Bangalore are responsible for tracking support for satellite and launch vehicle missions.
3. Vikram Sarabhai Space Centre (**VSSC**) located in Thiruvananthapuram and is responsible for building of launch vehicles.
4. U R Rao Satellite Centre (**URSC**) is responsible for satellite design and development situated in Bangalore.
5. Satish Dhawan Space Centre (**SDSC**) controls the integration and launching of satellite and launch vehicles located in Sriharikota.
6. Liquid Propulsion System Centre (**LPSC**) located at Valiamala and Bangalore handles development of liquid stages including cryogenic stage.
7. Space Applications Centre (**SAC**) controls sensors for communication and remote sensing satellite along with handling application aspects of space technology established in Ahmedabad.

8. National Remote Sensing Centre (**NRSC**) located in Hyderabad is responsible for remote sensing satellite data reception processing and dissemination.
9. Human Space Flight Centre (**HSFC**) located in Bangalore is responsible for the entire Gaganyaan project.
10. Indian Institute of Remote Sensing (**IIRS**) situated in Dehradun is responsible for remote sensing and geo- informatics of spacecraft missions.
11. ISRO Inertial system unit (**IISU**) established at Thiruvananthapuram is responsible for design and development of inertial systems for launch vehicles and other spacecraft missions.
12. ISRO propulsion complex (**IPRC**) located in Mahendragiri is responsible for manufacturing state-of-the-art cutting edge propulsion technology.
13. Laboratory for electro optics system (**LEOS**) located in Bangalore is responsible for attitude sensing of the satellites.
14. Master control facility (**MCF**) located in Hassan handles monitoring and controls of Geo-stationary satellites.

ISRO has accomplished commendably successful space missions to study various planetary observations, climate and environment, X-ray astronomy and to provide India with communication, navigation services and many more. It has launched 124 satellites including its first satellite built named Aryabhata in 1975 following missions like Gaganyaan, Mangalyaan to present Chandrayaan-3 launched on 14th July 2023. This mission was to demonstrate end to end capabilities in safe landing and roving on moon’s uncharted South Polar Region which took India’s space exploration to different heights.

Section 1.1: ISTRAC

ISRO Telemetry Tracking and Command Network is one of ISRO's organisational bodies established in September 1976 and moved to Bangalore in the year 1984. This organisation provides the ground segment for ISRO's LEO (Low earth orbit) and interplanetary space missions. It is also responsible for Indian regional Navigation missions as well as the launch vehicle missions.

ISTRAC is a centre for multi mission space control for spacecraft operation and co-ordination with network stations. It also consists of communication control facility to establish and control the link between SCC and ISTRAC network stations.

Objectives:

1. Carrying out mission operations of all operational remote sensing and scientific satellites, providing Telemetry tracking and command (TTC) services from launch vehicle lift-off till injection of satellite into the orbit and to estimate its preliminary orbit in space.
2. Radar systems for launch vehicle tracking and meteorological applications.

Missions:

- Tracking and commanding of satellite, health analysis and control, orbit and altitude determination and network coordination support to all satellite missions of ISRO.
- Telemetry data acquisition support for ISRO launch vehicle missions from lift-off until satellite acquisition and down range tracking support for monitoring and determining satellite injection parameters.
- Coordinating between spacecraft and launch vehicle, supporting ground stations from planning till completion of mission for national and international satellite missions.

Section 2: Introduction

Section 2.1: NavIC

Navigation of Indian Constellation (NavIC) or Indian Regional Navigation Satellite System (IRNSS) was established in May 2006 and is one of the major domains of ISTRAC; it aims to provide navigation services to India without relying on foreign satellites. Its main objectives are to provide accurate real-time positioning and timing services.

NavIC satellites cover India and extend up to 1500km around India. There are 8 operational satellites over 7 constellations and 2 standby satellites. The area is enclosed by a rectangle from latitude 30 degree south to 50 degrees north and longitude 30 degrees east to 130 degrees east.

A new satellite centre was established called ISRO Deep Space Network (IDSN) at Byalalu, Karnataka on 28th May 2013. This facility tracks network of 21 satellites across country acquiring data for orbital determination of satellite and monitors navigation signal.

The maintenance of IRNSS constellation is done by various ground segments:

- IRNSS Spacecraft Control Facility (IRSCF) handles launch and early orbit phase and on-orbit phases of IRNSS satellites situated in Hassan and Bhopal.
- ISRO Navigation centre (INC) controls remote operation and data collection with all the ground stations located at Byalalu.
- IRNSS Range and integrity monitoring stations (IRIMS)
- IRNSS Network Timing centre (IRNWT) provides time with accuracy of 2 nanoseconds with respect to Coordinated Universal Time (UTC).
- IRNSS CDMA ranging stations (IRCDR) monitors Code Division Multiple access (CDMA) ranging across 4 IRCDR stations on a regular basis.
- Laser Ranging stations.
- IRNSS data communication network (IRDCN)

IRNSS has 3 satellites orbiting in GEO (Geostationary orbit) which has 0 degree inclination to equatorial plane and 5 satellites orbiting in GSO (Geosynchronous orbit) which has 29 degrees inclination to equatorial plane. The 8 satellites are: IRNSS 1A, 1B, 1C, 1D, 1E, 1F, 1G and 1L. Out of these 1C, 1F and 1G are orbiting in GEO and the rest are orbiting in GSO.

Navigation signal of IRNSS are of 2 types namely, SPS (Standard Positioning Service) for civilian use and Restricted service (RS) for military use and operates in 2 frequency bands L5 (1176.45MHz) and S band (2492.028MHz). SPS signal is modulated using 1MHz BPSK (Binary phase shift keying) signal. Navigation signals are transmitted in L5 band and S band frequency and broadcasted through a phased array antenna to maintain required coverage and signal strength. SPS signal accuracy if of 5-10 meters over Indian land mass and around 20 meters over the Indian Ocean.

NavIC uses a technique called as DS-CDMA which is direct sequence code division multiple access and as the name suggests it is used to provide access to multiple users at the same time. This report takes us through the concepts of this DS-CDMA.

Section 2.2: Spread Spectrum

The information/data signal is a narrow band signal which causes issues when transmitted and they are:

1. Interception by unintended users.
2. More susceptible to jamming

Spread spectrum tries to resolve these issues. The basic idea is to expand each user signal to occupy a much broader spectrum than the original data signal. Here the spreading code is used to spread the spectrum of transmitted signals. There are 2 approaches for spread spectrum modulation.

1. Frequency hopping
2. Direct sequence

This report dwells with Direct sequence spread spectrum technique in more detail. The characteristics of these signals are:

- Difficult to intercept

- Easily hidden
- Resistant to jamming
- Provides immunity to distortion due to multipath propagation
- Asynchronous multiple access capability

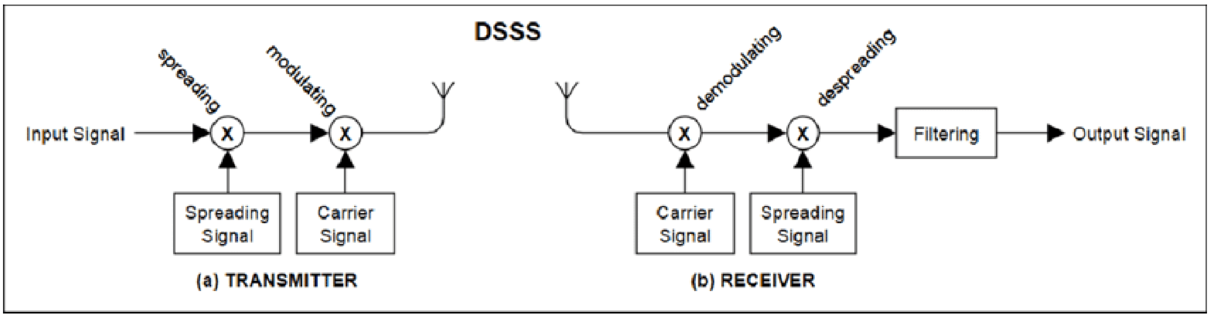
Before getting into direct sequence spread spectrum, we need to know about PRN sequence.

Section 2.3: PRN sequences

Pseudo-random noise sequence or PN sequence is a spreading code used to spread a narrow band signal to wide band signal by simply multiplying it to the data signal. These sequences are series of 0's and 1's and have higher bit rate than the data signal. Even though the name has random in it and also looks random, these sequences are not actually random but deterministic in nature generated by a deterministic algorithm. Only if the algorithm is good, resulted sequences pass a reasonable test of randomness. The main idea of this sequences is not only to spread signal over a wide frequency band but also to make the data signal secure and to do this, there has to be a seed used in the algorithm which only the transmitter and the respective receiver has access to in order to decode the data signal. This provides more security to the information transmitted.

Section 2.4: Direct Sequence Spread Spectrum

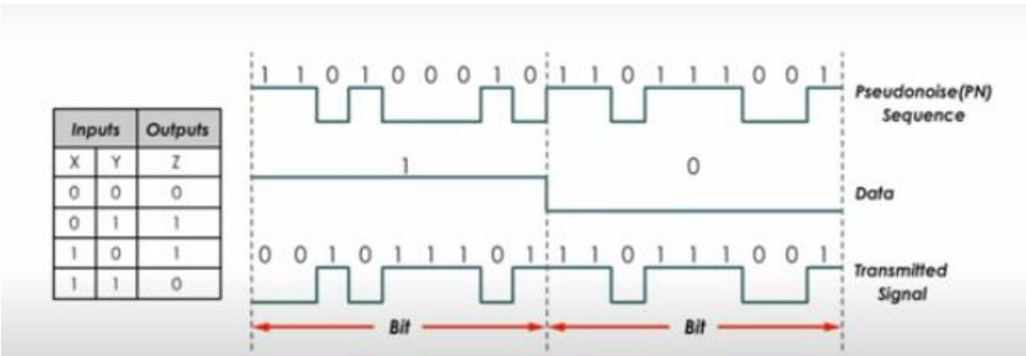
DSSS is a spread spectrum modulation technique which primarily focuses on reducing interference on the signal. It converts a narrowband data signal into a wide band transmitting signal. Conversion process is carried out by PRN sequence discussed before. At the transmitter end, the data signal is spread over a wide frequency band using a PRN sequence and is transmitted through a channel. At the receiver end, the transmitted signal is despread using the same PRN sequence to retrieve the original data signal.



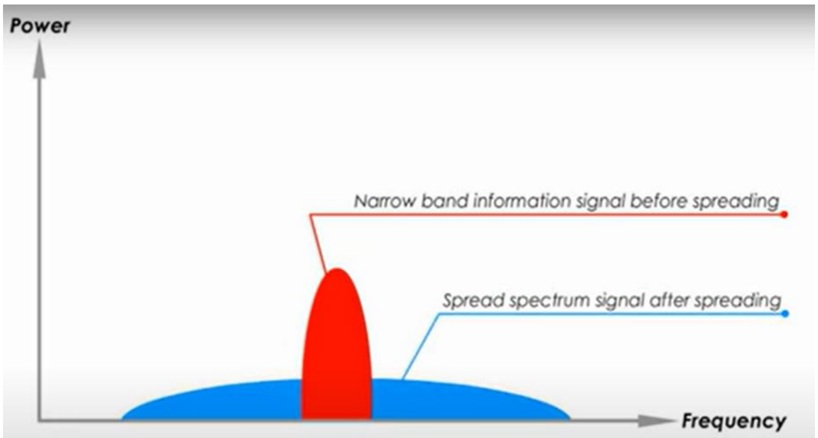
PRN sequence also called as chip is a radio pulse much shorter in duration than the data signal. The smaller this duration is, the larger the bandwidth of resulting DSSS signal.

<u>How is the data signal spread using PRN sequence?</u>

The answer is by performing an XOR operation. Let's take an example, considering a 2-bit data signal and as we know bit rate of PRN code should be higher and hence take a PRN sequence 10 times higher bit rate than data signal as shown in the figure. By simply performing an XOR operation between data and PRN sequence we get a transmitted signal.



The narrowband signal gets easily jammed, similar to the traffic on a single lane road in a rush hour. More power is required in order to overcome the jamming and interference but after spreading, even though the power is same, the power density is spread out resulting in lower power and noise like signals making it harder to interfere and detect.



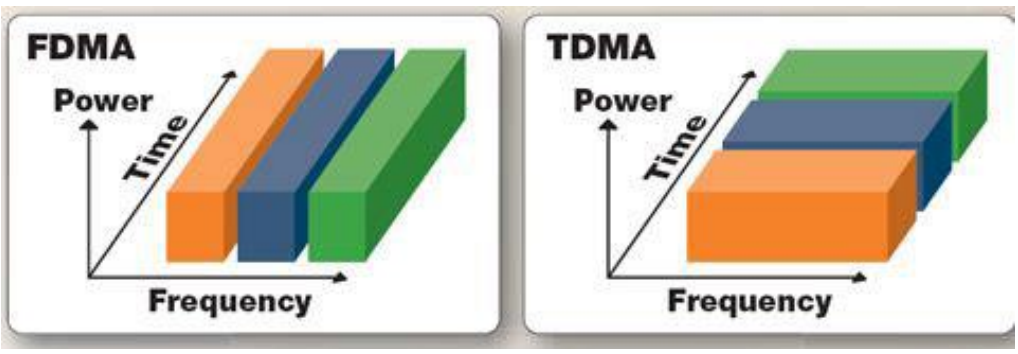
Section 2.5: CDMA

Code division multiple access is a technique in DSSS for multiple users. It assigns unique code to each user to differentiate between the users.

But why CDMA and not other techniques, to answer this question let's take a look at other techniques.

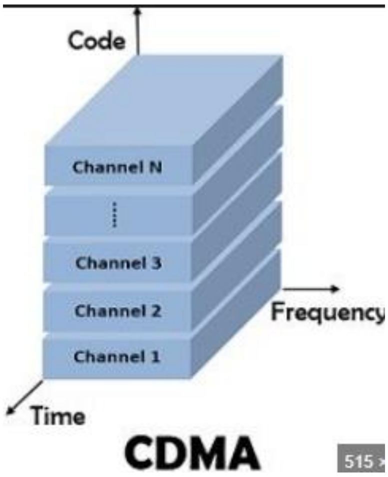
FDMA- Frequency Division multiple access is a technique where each user is given separate frequency band with no restriction on time period. It is separated by guard bands to avoid interference as shown in the figure.

TDMA- Time division multiple access is a technique where each user is assigned a particular time period over an entire spectrum of frequency where there no restriction on frequency band as shown in the figure.



These 2 techniques fail to provide a continuous access for multiple users without interference and hence CDMA is preferred.

CDMA technique provides each user complete frequency range with no restrictions on time period. It provides access to multiple users in the same frequency band by allocating each user with a unique code as shown in the figure.



With respect to satellite communication, each satellite is assigned a unique PRN code to differentiate between each satellite.

Working

Let’s consider 2 satellites A and B, both the satellite wants to send a data signal which is a narrow band signal. These signals are multiplied to a unique PRN code, code A for satellite A and code B for satellite B, these signals are now a wide band signals which are transmitted over a channel. At the receiver end, say a ground station, the receiver will have book of PRN sequences of each of its satellite. When the receiver receives a transmitted signal, it synchronises (time correlation function) the code A from the book and the transmitted signals, once recognised that the message is from satellite A, it despreads the signal by multiplying the transmitted with the PRN code to get back the data signal.

To ensure multiple users on a CDMA system cause minimal interference, the spreading codes in this case the PRN codes must be orthogonal to each other but in practical not all PRN codes are perfectly orthogonal to each other. Hence a concept of correlation has been applied. There are autocorrelation and cross correlation.

Correlation(C) is a mathematical measure of similarity between 2 sequences. It calculated by taking difference of agreements(A) and disagreements(D) of bits of 2 sequences. For example, consider 2 5-bit(N) sequences and check its autocorrelation and cross correlation.

Autocorrelation: when a signal from a satellite is received, there is noise disturbing the signal, and this noise is nothing but shifts of bits between the transmitted signal and the received signal. In order to synchronise this shifted signal to original PRN signal at receiver code book, we shift the transmitted signal and then synchronise and hence the correlation between the original and shifted version of the signal is called autocorrelation.

X = [1 0 1 0 0]

Y = [0 1 0 0 1]

C = A-D

A = 1

D = N-A = 5-1 = 4

C = 1-4 = -3

|C| = 3

Similarly, Y is shifted N-1 times and auto correlation is calculated.

Cross correlation: When a sequence is sent a satellite A, at the receiver, we need to identify from which satellite the signal has been received. Due to the noise while transmission, there are chances of some bits getting changed or flipped which might make it similar to some other code of a different satellite say satellite B and the receiver might conclude that the message is sent from satellite B, which is incorrect. Hence the cross correlation which is the correlation between one code with respect to another code through all possible shifts of the second code, is necessary to be least in number.

X = [1 0 1 0 0]

Y = [0 1 1 1 0]

C = A-D

A = 2

D = N-A = 5-2 = 3

C = 2-3 = -1

|C| = 1

Similarly, Y is shifted N-1 times and cross correlation is calculated.

In this way, PRN codes play a huge role with respect to correlation properties. There are 4 types of correlation properties:

1. Even autocorrelation
2. Even cross correlation
3. Odd autocorrelation
4. Odd cross correlation

Even auto and cross correlation is calculated the same way as shown before but odd auto and cross correlation, after shifting the bits, the number of bits shifted will be flipped from the right-hand side and then correlation is calculated.

In general, low even correlation between sequences in CDMA systems used in satellite communication is vital for minimizing interference, enhancing signal detection, improving system capacity, reducing multipath interference, and optimizing power efficiency whereas low odd correlation helps in improving timing synchronization, mitigating multipath interference, enhancing signal detection, reducing interference, and optimizing sequence design. These benefits collectively contribute to more reliable, efficient, and higher-quality satellite communication.

Section 2.6: M-sequences

M-sequences, or maximal length sequences, are a type of pseudorandom binary sequence that are widely used in communication systems, including CDMA (Code Division Multiple Access) systems.

M-sequences are sequences of length (2^n)-1 that are generated using linear feedback shift registers (LFSRs) with primitive polynomials. They are called maximal length sequences because they achieve the maximum possible length for a given LFSR, cycling through all possible (2^n)-1 states except the all-zero state.

M-sequences are fundamental to the design and operation of CDMA systems in satellite communication. Their excellent auto-correlation and cross-correlation properties, along with their periodicity and balance, make them ideal for spreading signals, enabling multiple access, improving synchronization, and enhancing error detection and correction. These properties contribute to the efficiency, reliability, and robustness of satellite communication systems.

Section 2.7: Gold codes

Gold sequences are a class of pseudorandom binary sequences used in various communication systems, including CDMA (Code Division Multiple Access) systems, due to their favourable correlation properties.

These are generated by the modulo-2 addition (exclusive OR) of two m-sequences (maximal length sequences) of the same length. These m-sequences are carefully chosen such that their periods are the same, and their cross-correlation properties are balanced.

Gold sequences have good auto-correlation and cross-correlation properties. The auto-correlation function is ideal for distinguishing the sequence from delayed versions of itself, which is crucial for timing synchronization and multipath interference rejection. The cross-correlation function between different gold sequences is bounded, which minimizes interference between different users in a CDMA system.

For an m-sequence of length (2^n)-1, the set of Gold sequences include (2^n) +1 sequences. This large set allows for the assignment of unique sequences to many users, which is important for supporting multiple access in CDMA systems. These sequences can be generated efficiently using linear feedback shift registers (LFSRs), making them practical for real-time implementation in communication systems.

In general, Gold sequences are a valuable tool in CDMA systems for satellite communication due to their excellent correlation properties, ease of generation, and ability to support multiple users with minimal interference. Their use enhances the efficiency, reliability, and robustness of satellite communication systems, making them a popular choice in the design and implementation of modern communication networks.

Section 3: Algorithm

Aim: Sequence codes with optimised autocorrelation and cross correlation becomes very important in satellite communication as we need to identify respective satellite with unique code from other satellites in the orbit even in case of noise and interference which does not allow synchronisation of code received from the satellite and the code present in the receiver's code book.

This report presents algorithm for 2 cases:

1. To select sequence with odd auto and cross correlation less than a threshold.
2. To select shifts for a sequence with auto and cross correlation less than a threshold.

Case 1:

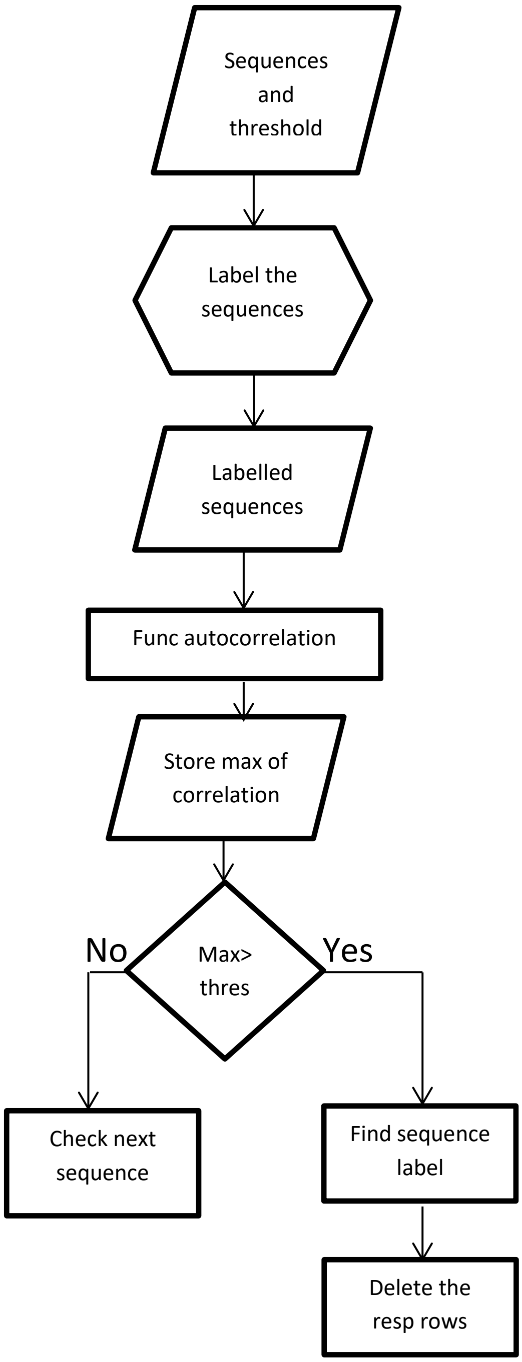
To select sequence with odd auto and cross correlation less than a threshold

This algorithm firstly takes N number of sequences as input; a label is assigned to each sequence. After this step, it computes the odd autocorrelation then finds the maximum of correlation values and stores the results for respective sequence. The next step is to define a threshold for maximum correlation and filter the sequences with maximum correlation greater than a threshold, deletes these rows resulting in sequences of odd autocorrelation less than the threshold. Similarly, by replacing one function, sequences with even auto correlation can also be found.

For cross correlation, same algorithm is used where we first label the sequences, find odd cross correlation of 1 sequence with the rest and similarly for 2,3,4,…..,N. Store these results in such a way that the 1st column is odd cross correlation value, 2nd column is the 1st sequence number and 3rd column is the 2nd sequence number. Compare 2nd and 3rd column and find sequences with cross correlation greater than the threshold and discard these sequences. Finally give the list of sequences of cross correlation less than the threshold. Similarly, by replacing one function even cross correlation can also be found.

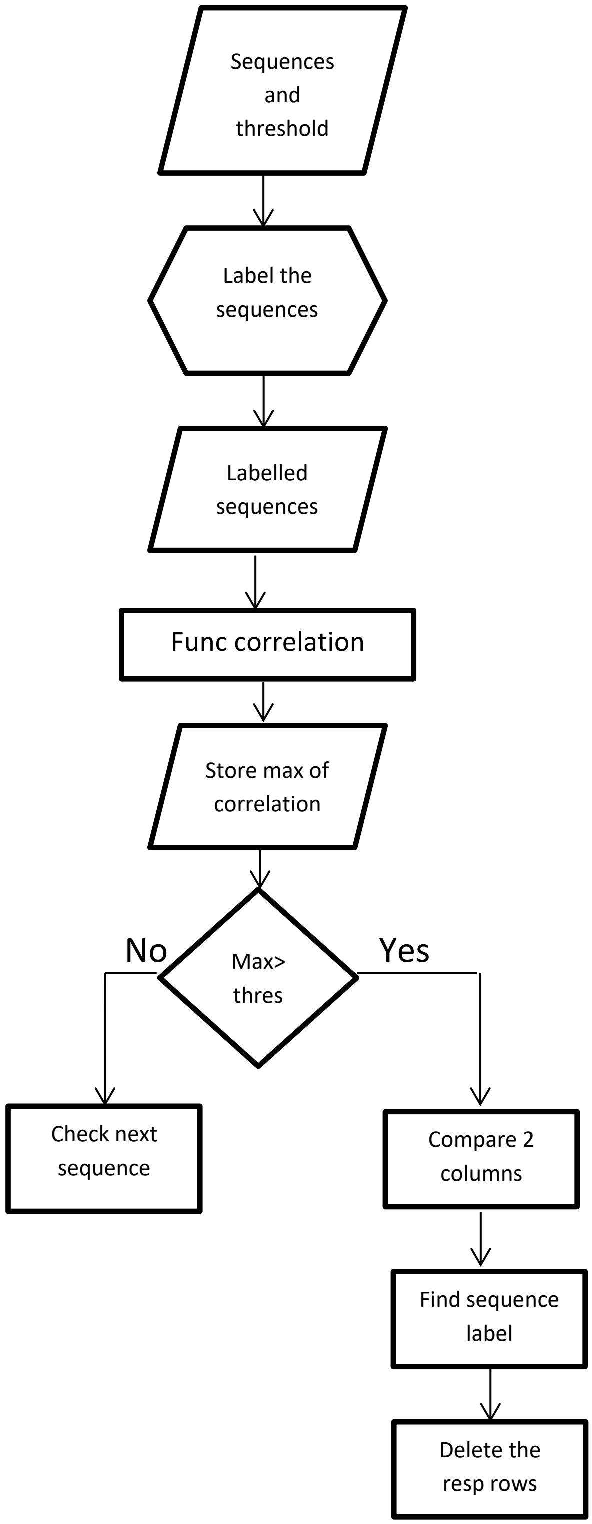
In order to get sequences with both auto and cross correlation less than a threshold, intersect the lists from the above algorithm.

Flowchart for autocorrelation



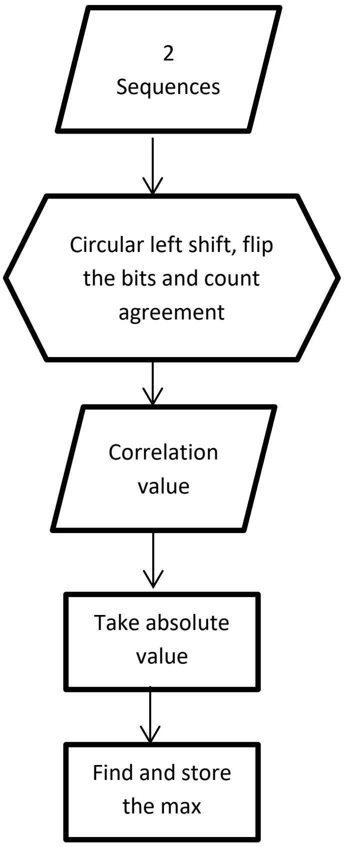
Flowchart 1

Flowchart for cross correlation



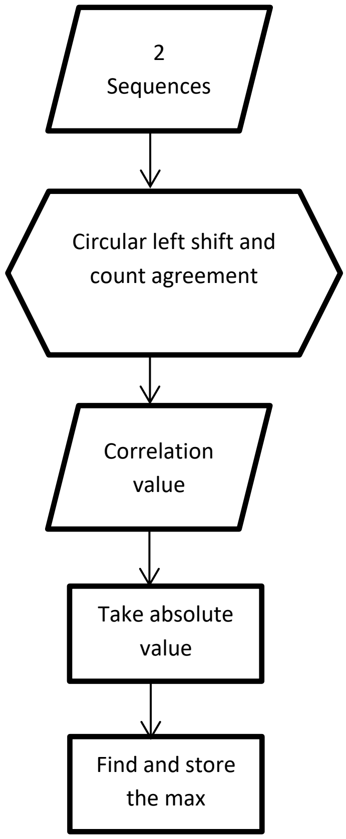
Flowchart 2

Flow for finding max of odd correlation



Flowchart 3

Flowchart for finding max of even correlation



Flowchart 4

For autocorrelation, give same sequence for both the inputs.

Case 2:

To select shifts for a sequence with both auto and cross correlation less than a threshold

Algorithm 1:

This algorithm computes shifts for sequences with odd correlation properties based on a threshold. The input to the algorithm is the sequences and thresholds to find odd auto correlation and cross correlation separately.

For the computation of autocorrelation, first label the sequence using simple for loop. After labelling, compute the autocorrelation for each sequence using algorithm described in flowchart 3. After computation, the autocorrelation shifts are stored in separate structure and fed into the cross correlation algorithm.

The inputs for cross correlation algorithm are the sequences and the autocorrelation shifts for each sequence. The algorithm first labels the sequences and then performs shift operation based on the stored shifts. Later it computes the cross correlation of 1^{st} sequence with other sequences and so on generates all possible combination of shifts for the 1^{st} 3 sequences. Later on, next sequence is added to this list by computing cross correlation of this sequence with the others and is stored in separate structures. All possible combinations are generated using these structures which are then compared to the list containing 1st 3 sequence combinations and thus filters out the shifts based on the threshold desired. This process is repeated till N number of sequences and until all possible combination is generated.

Problems:

1. Since many combinations are possible, the software is running out of memory.
2. The computation time is more
3. This algorithm does not remove shift combination for which a sequence shift does not exist.

Algorithm 2:

To find the shifts of sequences with auto and cross correlation less than a threshold for a large bit sequence has always been a difficult task. This report will present a bucket algorithm to find all the possible shifts for less odd auto and cross correlation values.

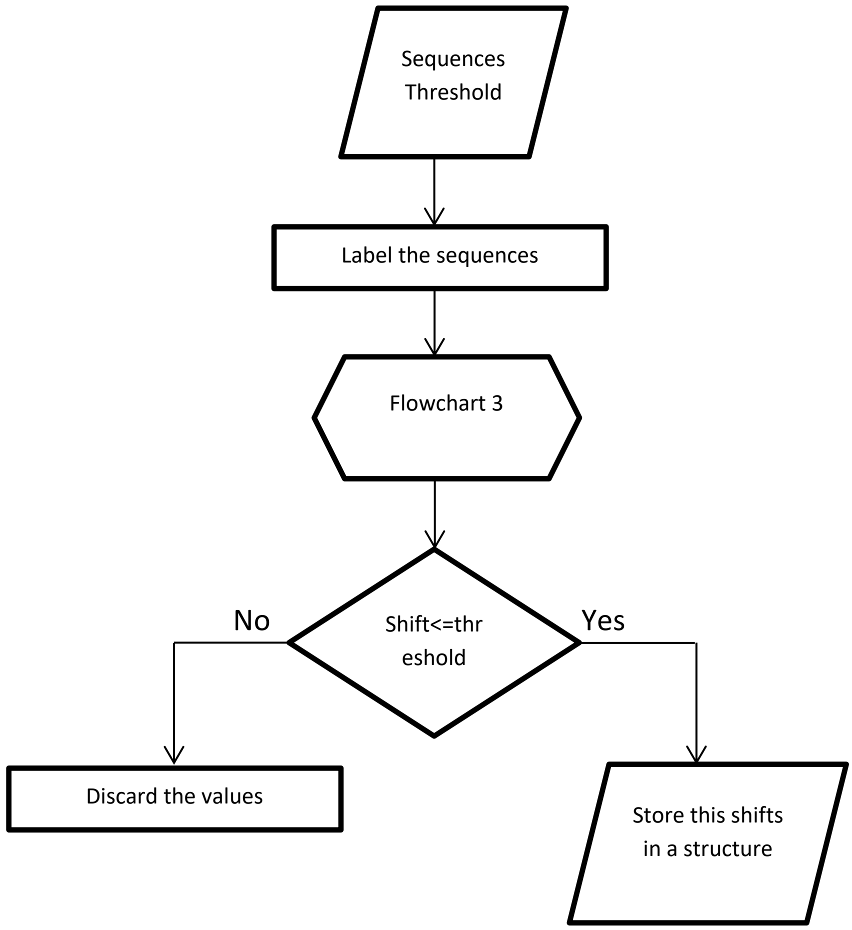
This algorithm will first compute the odd auto correlation for all possible shifts of the sequence and stores the shifts for each sequence in a structure. These shifts are then fed to the cross correlation algorithm.

The odd cross correlation algorithm first computes the combination shifts of 1st 3 sequences using the shifts stored after autocorrelation with simple for loops and is stored in a separate structure let's say X . Since there can be many possible combination of shifts, in order to add the 4th sequence, for which the cross correlation value with respect to all 3 sequences should be less than the threshold, a bucket of desired size is created which consists of rows of combination of shifts of the 1st 3 sequences, for example, 10 combinations of shifts of 1st 3 sequences. For every autocorrelation shifts that were computed for the 4th sequence, calculate the cross correlation of 4th sequence with the 1st 3 sequences separately, using these filter out the numbers by column comparisons separately and generate all possible combinations, finally store the shift values in another structure called Y. Compare these combinations to X and find the if a row in X matches exactly to any row in Y, then store the shift in the respective row's 4th column. There is a possibility that a particular shift of 4th sequence already exist in that place then in that case add a new row with same previous column value along with new shift of the 4th sequence in the 4th column. Similarly, compute for all sequences to generate a set of shifts for each sequence such that, if checked for maximum of cross correlation values then the value should be less than or equal to the threshold value. While computing if condition for any sequence, if there are no shifts possible for the bucket of combinations then discard that set of combinations from A and take the next set of combinations from A. Repeat this process till we get shifts for all sequences.

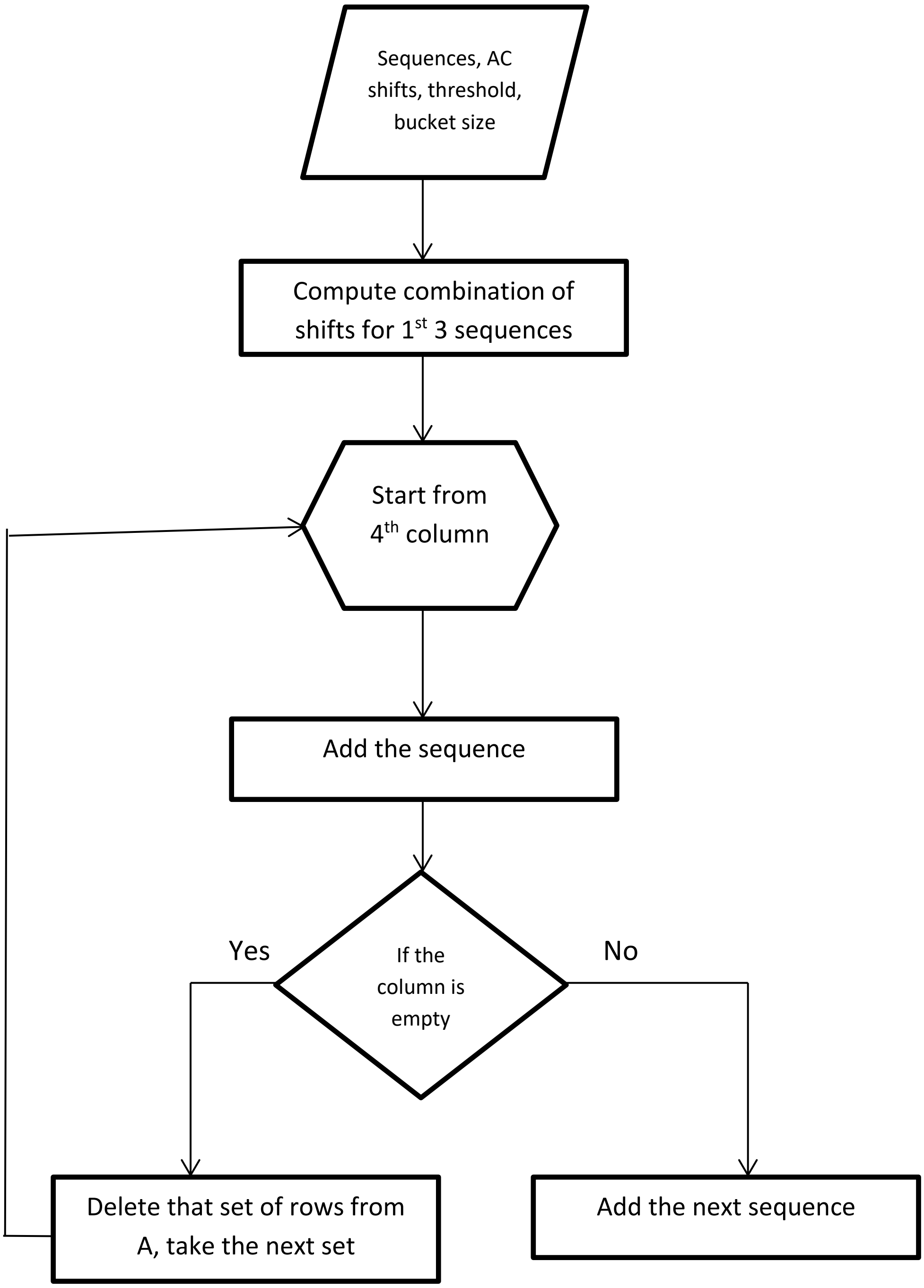
Main algorithm is the same as algorithm 1 but is an improved version:

1. Creating a bucket to avoid memory issues as we filter out the generated combinations before comparing.
2. Less computation time than the previous algorithm as it only needs to check for combinations in the bucket, if a set of shifts are generated then we stop the program.
3. Removal of combinations for which a sequence shift does not exist from the main list (generated combination of shifts for 1st 3 sequences).

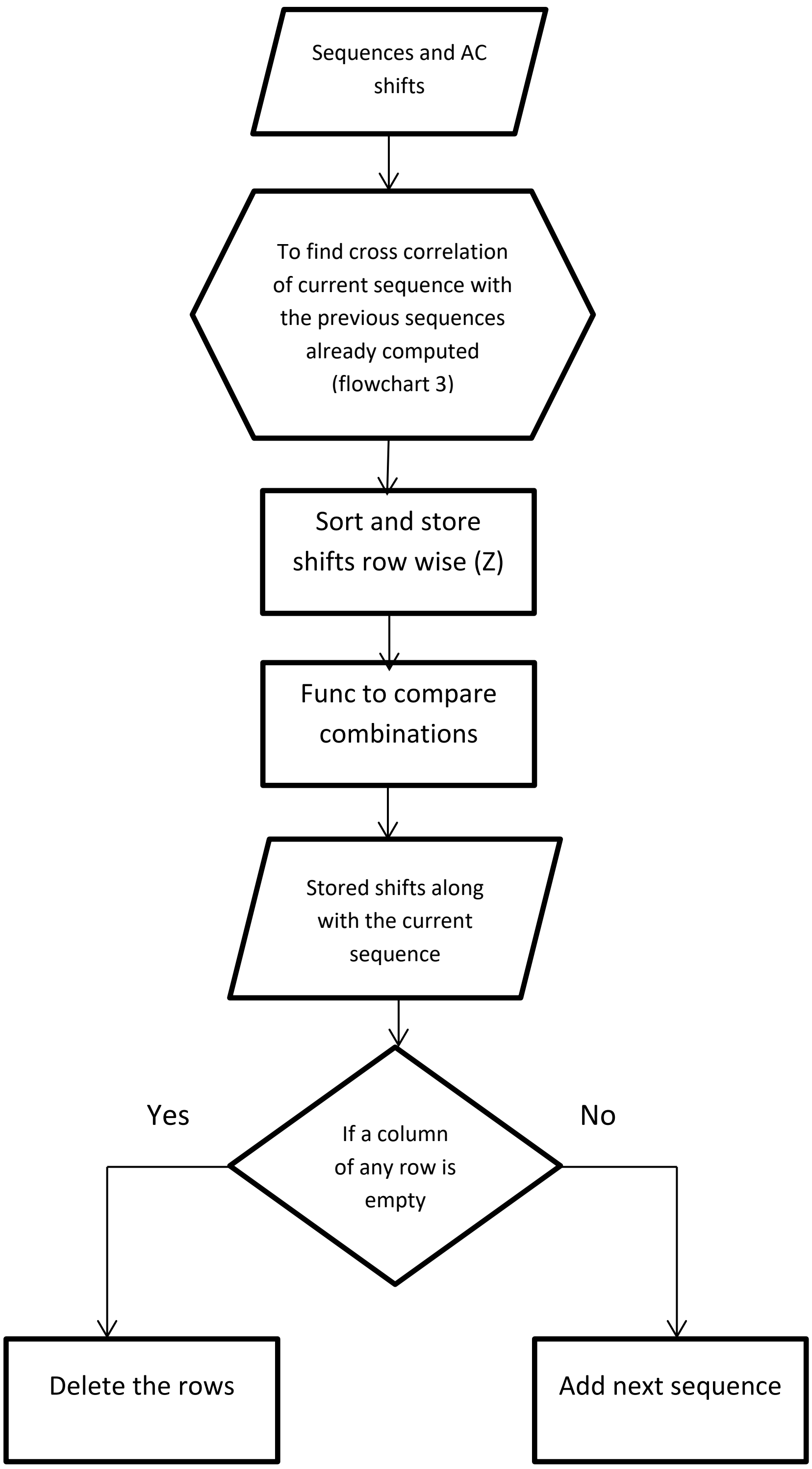
Flowchart to find shifts for odd autocorrelation less than a threshold



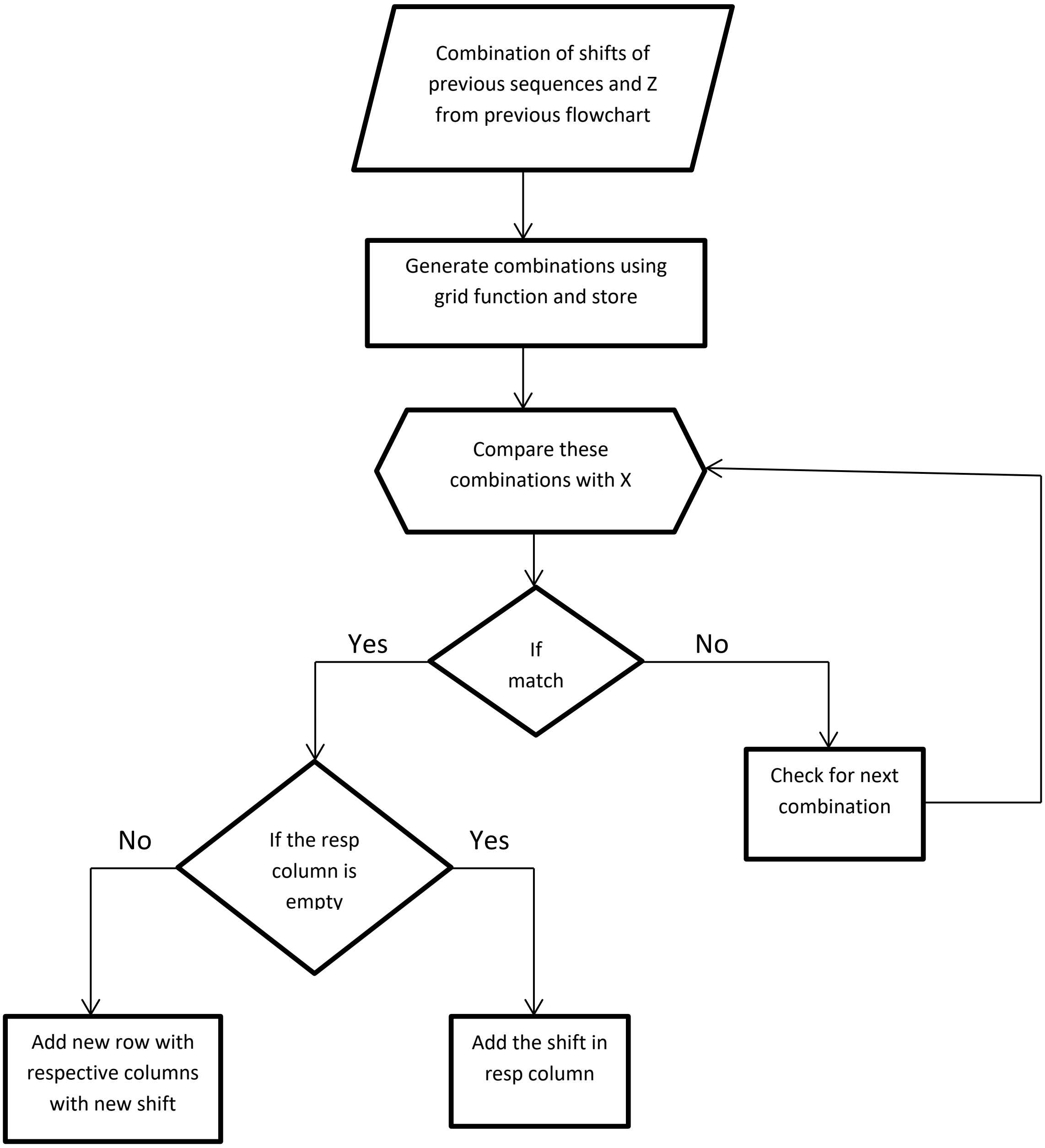
Flowchart for computing shifts for odd cross correlation



Flowchart to add the sequence



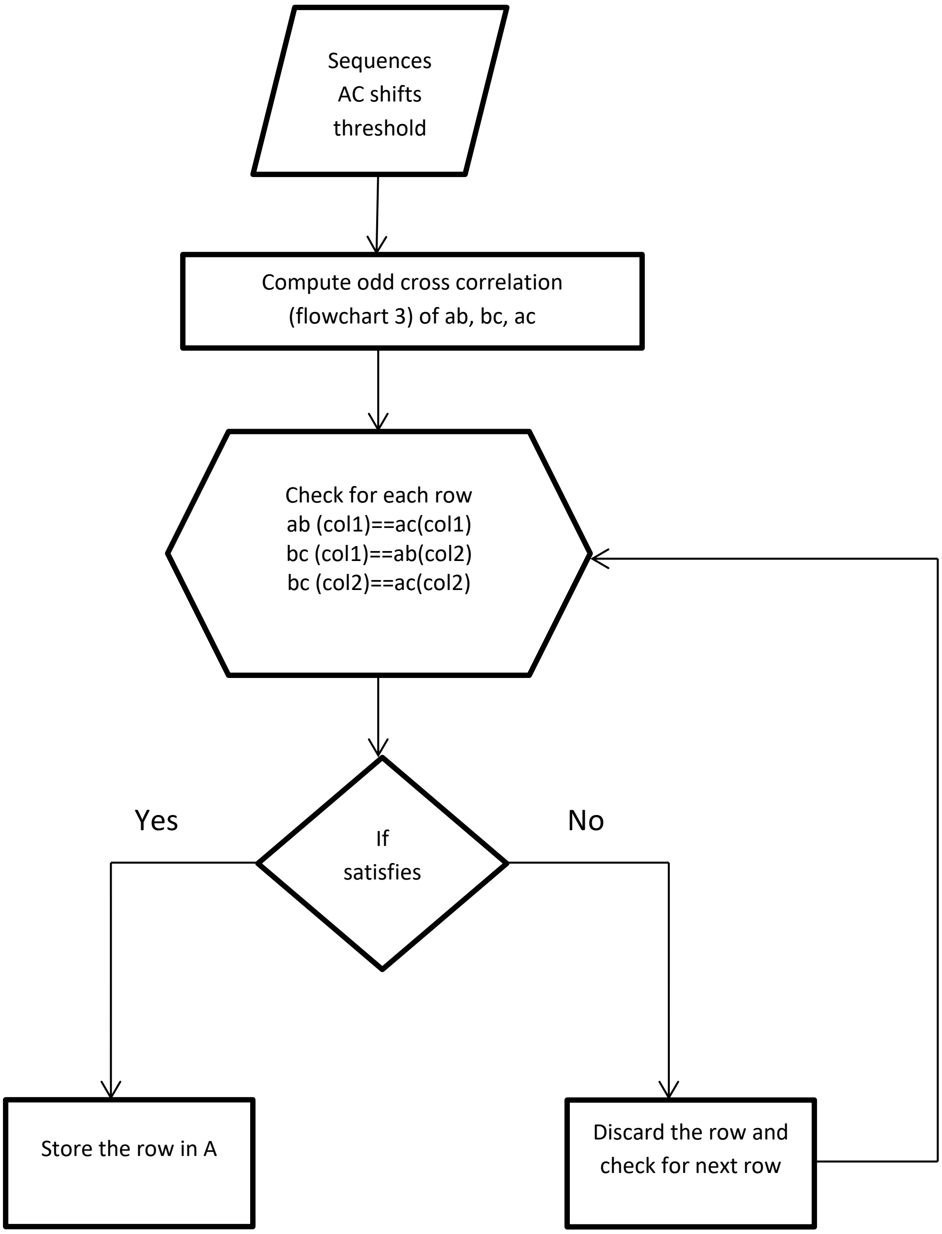
Flowchart to compare combinations



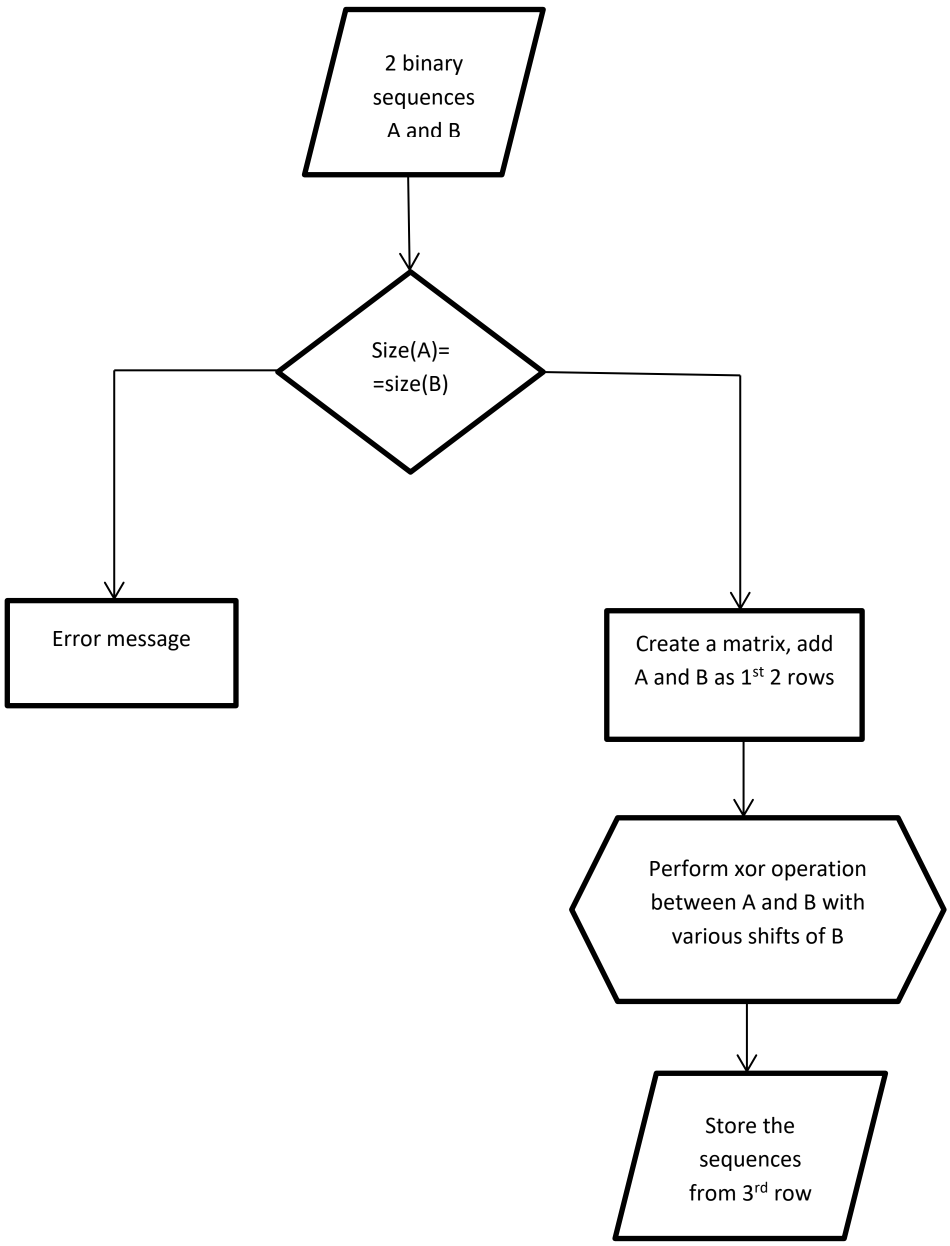
Flowchart to compute combination for 1st 3 sequences

For this, let's take the 1st 3 sequences as a, b, c

col1 is column 1 and col2 is column 2



Flowchart to generate Gold codes



Section 4: Experimentation

This report will demonstrate the algorithm with an example along with calculation and plot of BER (bit error rate) for various SNR in decibels and for various numbers of users.

Here, we have considered 63bit binary sequences of number 2 and generated gold sequences for the same, resulting in totally 65 sequences. This report shows the computation of shifts with odd autocorrelation and odd cross correlation values less than or equal to the threshold.

Number of sequences considered: 15

Maximum odd autocorrelation for original sequences: 31

Threshold odd autocorrelation for optimised sequences: 19

Maximum odd cross correlation for original sequences: 33

Threshold odd cross correlation for optimised sequences: 21

Computation has been done with 4, 6, 8, 10, 12 and 15 users.

SNR values: -30 to +15 in the steps of 5

Number of iterations for which BER is calculated: 1000

Sequences considered:

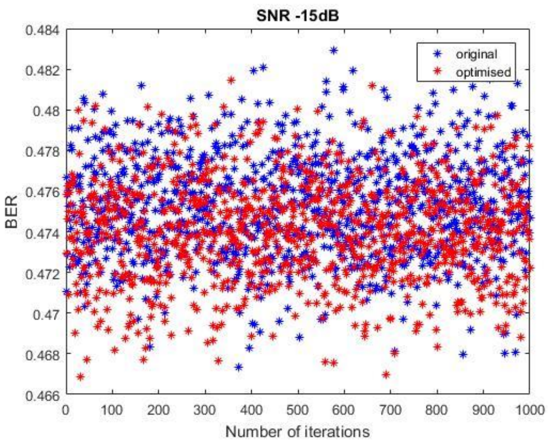
```
A=[0,1,0,1,0,0,0,0,1,0,0,0,1,1,1,1,1,1,0,1,1,1,1,0,1,
0,0,1,0,1,0,1,1,0,0,0,0,0,0,1,1,0,0,1,0,0,1,1,0,1,0,0
,1,1,1,1,1,0,1,0,1,1,0];
B=[1,1,1,0,1,0,0,1,0,0,1,0,0,0,1,1,0,0,1,0,0,0,0,0,0,
0,0,0,0,1,0,1,0,0,1,0,1,1,1,0,1,1,1,1,1,0,1,1,1,0,1,0
,0,1,0,1,0,1,1,0,1,0,0];
```

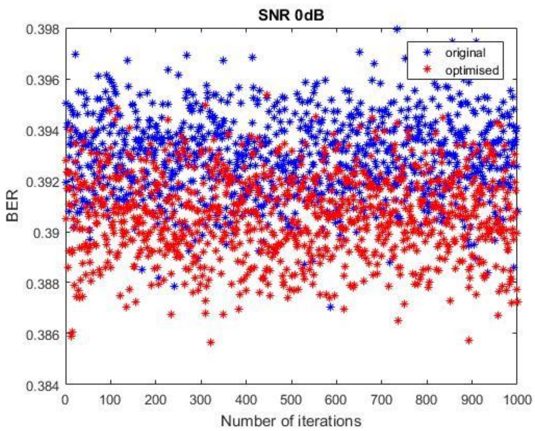
Gold codes using these binary sequences have been computed using the algorithm mentioned.

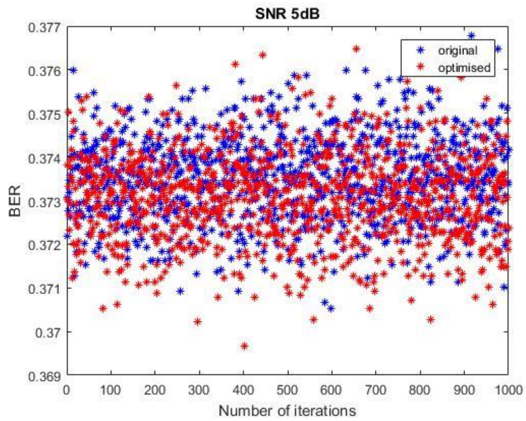
Section 5: Results

4 USERS

SNR	MEAN (ORIGINAL)	MEAN (OPTIMISED)
-30	0.4956	0.4953
-25	0.4922	0.4920
-20	0.4860	0.4855
-15	0.4753	0.4741
-10	0.4556	0.4538
-5	0.4266	0.4241
0	0.3929	0.3906
5	0.3735	0.3731
10	0.3711	0.3712
15	0.3715	0.3715

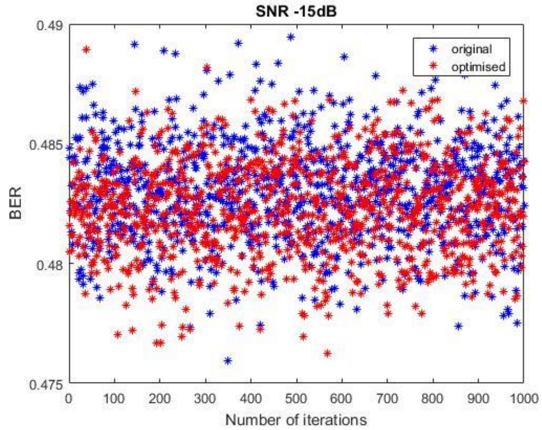


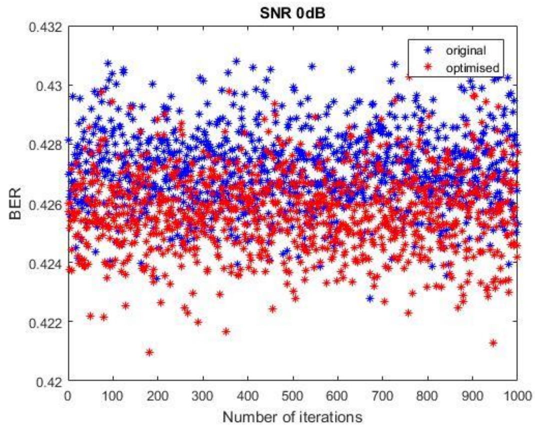


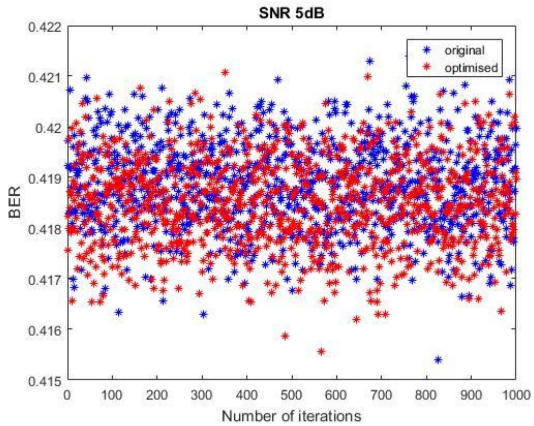


6 USERS

SNR	MEAN (ORIGINAL)	MEAN (OPTIMISED)
-30	0.4970	0.4968
-25	0.4948	0.4945
-20	0.4906	0.4903
-15	0.4830	0.4823
-10	0.4709	0.4697
-5	0.4524	0.4507
0	0.4271	0.4257
5	0.4188	0.4185
10	0.4160	0.4160
15	0.4182	0.4182

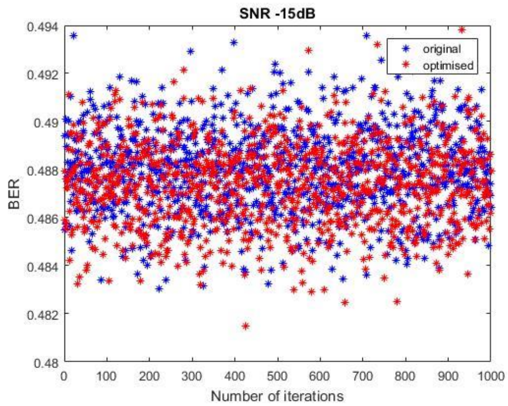


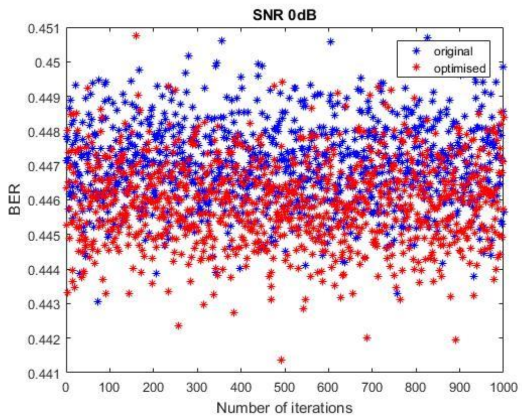


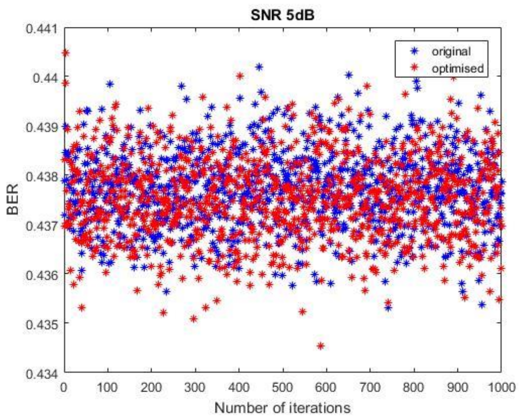


8 USERS

SNR	MEAN (ORIGINAL)	MEAN (OPTIMISED)
-30	0.4978	0.4977
-25	0.4960	0.4958
-20	0.4930	0.4927
-15	0.4880	0.4874
-10	0.4782	0.4773
-5	0.4630	0.4617
0	0.4470	0.4459
5	0.4377	0.4375
10	0.4363	0.4363
15	0.4361	0.4361

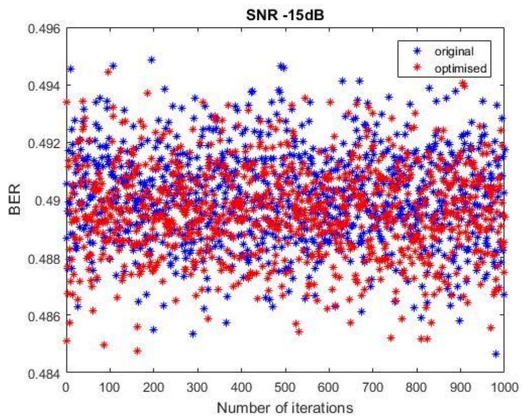


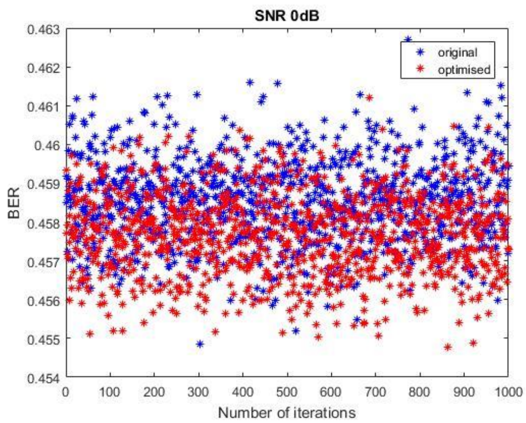


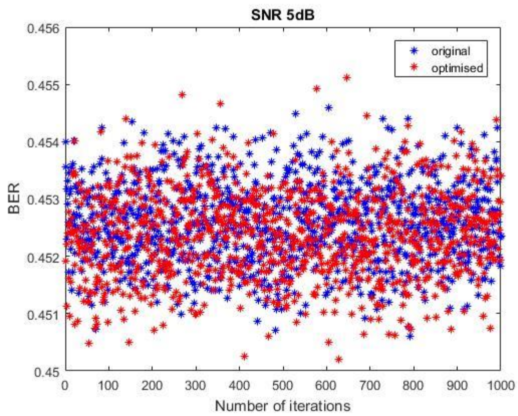


10 USERS

SNR	MEAN (ORIGINAL)	MEAN (OPTIMISED)
-30	0.4982	0.4981
-25	0.4968	0.4966
-20	0.4943	0.4941
-15	0.4901	0.4896
-10	0.4832	0.4824
-5	0.4704	0.4694
0	0.4586	0.4577
5	0.4526	0.4524
10	0.4488	0.4488
15	0.4493	0.4493

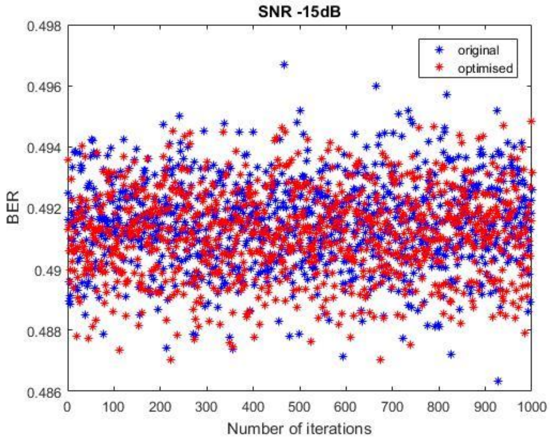


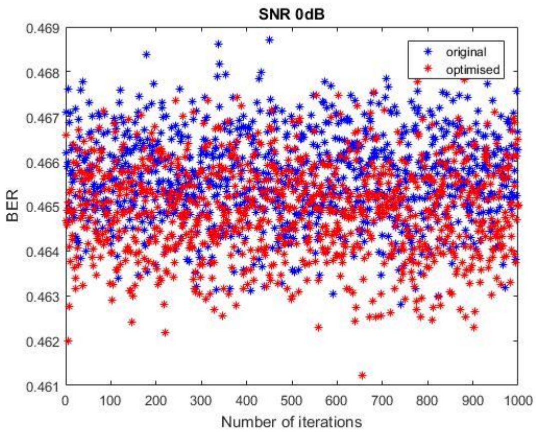


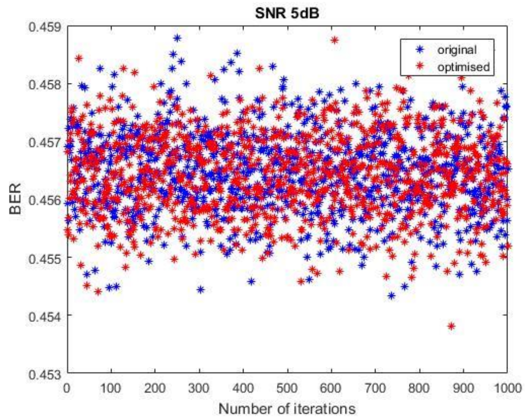


12 USERS

SNR	MEAN (ORIGINAL)	MEAN (OPTIMISED)
-30	0.4985	0.4984
-25	0.4974	0.4972
-20	0.4953	0.4951
-15	0.4915	0.4912
-10	0.4861	0.4856
-5	0.4765	0.4757
0	0.4656	0.4649
5	0.4565	0.4564
10	0.4568	0.4569
15	0.4584	0.4584

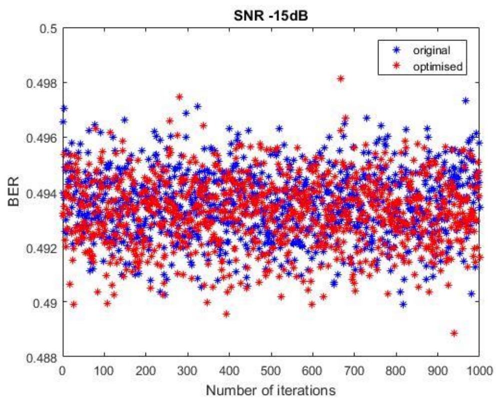


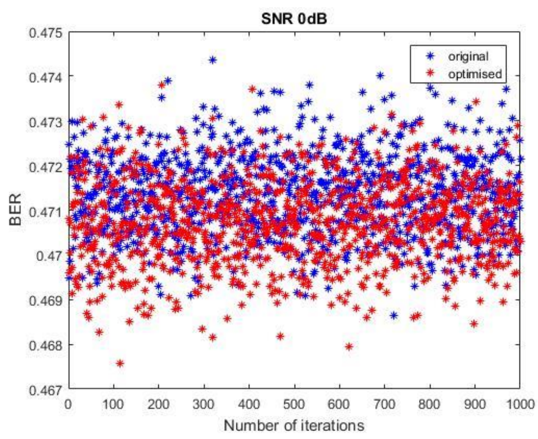


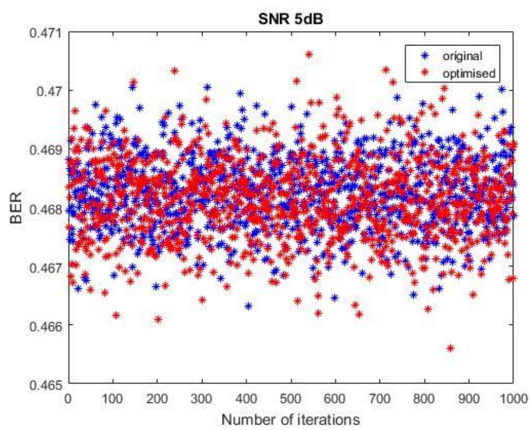


15 USERS

SNR	MEAN (ORIGINAL)	MEAN (OPTIMISED)
-30	0.4989	0.4988
-25	0.4979	0.4978
-20	0.4964	0.4962
-15	0.4936	0.4933
-10	0.4883	0.4879
-5	0.4800	0.4792
0	0.4714	0.4708
5	0.4683	0.4681
10	0.4693	0.4692
15	0.4673	0.4673



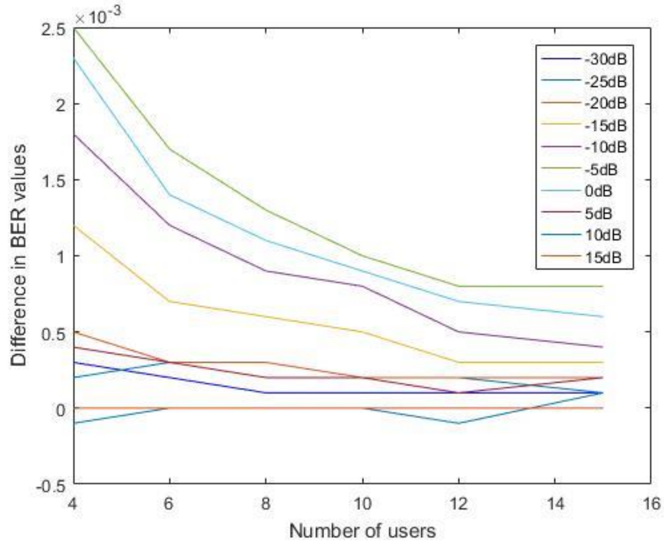




Section 5.1: Difference in BER values between original and optimised sequences

Value=mean (BER (original sequence)) - mean (BER (optimised sequence))

SNR/No. of users	4	6	8	10	12	15
-30	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001
-25	0.0002	0.0003	0.0002	0.0002	0.0002	0.0001
-20	0.0005	0.0003	0.0003	0.0002	0.0002	0.0002
-15	0.0012	0.0007	0.0006	0.0005	0.0003	0.0003
-10	0.0018	0.0012	0.0009	0.0008	0.0005	0.0004
-5	0.0025	0.0017	0.0013	0.0010	0.0008	0.0008
0	0.0023	0.0014	0.0011	0.0009	0.0007	0.0006
5	0.0004	0.0003	0.0002	0.0002	0.0001	0.0002
10	-0.0001	0.0	0.0	0.0	-0.0001	0.0001
15	0.0	0.0	0.0	0.0	0.0	0.0



Section 6: Conclusion

Section 4.1 presents tables and graphs for various users for different SNR values. These graphs show that as the number of user increases, BER value also increases for a certain SNR value. Also, according to the graphs, at -15dB, slightly more number of blue stars (original) is towards the upper end that means it has higher BER value than red stars (optimised). In the case of SNR 0dB, there is clear difference between blue and red stars, where most of the red stars are at the bottom of the graph (lesser BER value) whereas for 5dB SNR, blue stars and red stars are spread out resulting in the very less difference in mean BER value.

The table and the graph from section 4.2 depict that as number of user increases, the change in the BER value from original sequence to optimised sequence decreases. Additionally, as SNR value increases from -30dB to -5dB, BER value has an upward trend but from 0dB to 5dB, the change in BER value decelerates finally reaching zero value either at 10dB or 15dB.

Section 7: Acknowledgement

My experience in ISTRAC will always be memorable and for this I would like to thank my guide Dr Dileep Dharmappa for imparting the amazing knowledge of navigation, NavIC, satellite communication, CDMA and many more. I thank him for his time for teaching me and providing me a detailed tour of navigation department. I thank Shri. Subramanya Ganesh T, DD, NSA for his encouragement and guidance. I would also like to thank Mr B Sankar Madaswamy for providing me this opportunity to work and learn at ISTRAC. It was an honour to meet people of ISTRAC who make our country proud.