Design of detection algorithm to mitigate the false alarm and to tackle the multi-user case of mALL preamble sequence

PROJECT REPORT

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CERTIFICATE

This is to certify that this thesis (or project report) entitled ***"Design of detection algorithm to mitigate the false alarm and to tackle the multi-user case of mALL preamble sequence"*** submitted by **UJJAWAL KUMAR** to the Indian Institute of Technology Madras, for the award of the degree of **Masters of Technology** is a bona fide record of the research work done by him under my supervision. The contents of this thesis (or project report), in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma..

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Abstract

Random Access(RA) Procedure in 5G NR is used for up-link synchronization between User Equipment(UE) and Base Station (gNB) that requires a preamble to be transmitted by UE. If the number of generated preambles is limited, it may lead to reuse of preamble and increases the probability of collision. Considering this issue, concept of cover sequence was used to get different combinations of ZC, $m-sequence$, $All-top$ sequences with increased preamble capacity. The detection of these Preamble sequence at the receiver is a crucial aspect of Random Access Procedure. However, one of sequence called as $mALL$ sequence possess higher preamble capacity but it suffers from low detection probability in multi-user scenario. So in our work, we propose a low complexity PDP calculation method to improve detection performance of the $mALL$ sequence. We present the comparison of detection performance of ZC, aZC, mZC and $mALL$ sequences for different number of receiving antennas. We also analyzed the properties like Preamble capacity, periodic correlation, miss-detection probability for different preamble sequences. We then analyze the effect of non-zero Carrier Frequency offset(CFO) on detection performance and also tried to validate the proposed algorithm in terms of false alarm mitigation. During the RA process, multiple UEs can select same preamble leading to contention and failure of RA process. So considering this contention issue we also propose an algorithm that finds such number of users who uniquely selects preambles as well as gets detected also.

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ABBREVIATIONS

RA	Random Access
UE	User Equipment
gNB	gNodeB
ZC	Zadoff-Chu
eMBB	Enhanced Mobile Broadband
URLLC	Ultra Reliable Low Latency Communication
mMTC	Massive Machine Type Communication
RACH	Random Access Channel
FR1/2	Frequency Range 1/2
mmWave	Millimeter Waves
3GPP	$3^r d$ Generation Partnership Project
SNR	Signal to Noise Ratio
RA	Random Access
CAZAC	Constant Amplitude Zero Auto Correlation
ZCZ	Zero Correlation Zone
LCZ	Low Correlation Zone

Chapter 1

Introduction

1.1 Introduction to 5G

The deployment of 5G NR is a step forward in providing Enhanced mobile broadband (eMBB), Ultra-Reliable Low Latency Communication(URLLC), and Massive Machine Type Communication(mMTC) services. Enhanced Mobile Broadband(eMBB) has requirements of data rates up to 20 Gbps along with high mobility support of User Equipment. A robust connectivity as well as very low end to end connectivity of 5ms is required for Ultra Reliable Low Latency Communications(URLLC). As in [5], for IoT devices, Massive Machine Type communications(mMTC) aims for a density of one million connections per square kilometer with low power consumption. Today, the internet and telecommunications is responsible for $4 - 6\%$ of total global power consumption. As per[4], with the 5G and beyond 5G upgrades, it is expected that the telecommunication sector will triple their power consumption. Hence, the investigation and evaluation of the energy efficiency of the 5G communication de-

vices, signal transmitters and waveforms is a matter of importance [3].
There are two ranges of frequency defined by 3GPP in its release 15 and they are: FR1(sub-6 GHz) and FR2(millimeter wave). The FR1 band has large coverage area but low directionality, so the throughput will be low. This FR1 band is used in Long-Term Evolution (LTE). So FR2 band(mmWave) is used in 5G NR to achieve higher throughput and support high mobility speeds for UE.
When UE wants to access the network there is sequence of process between UE and base station (gNB) so that UE acquire uplink synchronization and the base station successfully receives data from user equipment [19], [17] and for this Random access(RA) procedure plays a key role in 5G systems. The preambles are a fixed-length sequence that is used for uplink synchronization and hence they are main component of entire RA process. Generation of these preambles is done on the principle of orthogonality between all different sequences because there is less interference between orthogonal sequences and hence reception and demodulation will be easy for them. To maintain linearity of power amplifiers, it is required to maintain low Peak to Peak Ratio(PAPR) and for that CAZAC(Constant Amplitude Zero Auto-correlation) sequences are considered to be a suitable candidate for preamble generation because these sequences maintain constant Amplitude and hence low PAPR also. Another property of the CAZAC sequence is that any two different sequences in a CAZAC sequence set are orthogonal to each other. The length of a preamble sequence, denoted by $L_{RA} = 139$, is based on numerology defined by 3GPP technical specification [14]. Similar to Long-Term evolution(LTE), 5G random access includes two types of RACH procedure: contention-based random access and contention-free random access [1]. In both types, the first step is that UEs transmit preambles to gNodeB(gNB) through the Physical Random Access Channel(PRACH). But in the contention-free procedure, there are reserved preambles so there is no possibility of collision. Since we are dealing with $L_{RA} = 139$, i.e. short preambles so there are no such restricted sets, hence the contention-based procedure is used. During RA process RACH signals are processed by gNB to detect their presence. This acts as first step of RA process. Once preambles are detected by gNB,

information of detected preambles like preamble ID(PID) and timing advance (TA) is achieved. In the second step gNB transmits RA response(RAR) to UE containing these information . Once UE gets RAR, it transmits PUSCH(Physical Up-link Shared Channel) to the same cell to which it transmitted its preamble and waits for response from gNB and starts Contention Resolution Timer. This serves as third step for RA process. In the final step, gNB transmits Contention Resolution to UE in PDCCH(Physical Down-link Channel) and if the PDCCH is decoded successfully by UE, the Contention Timer Resolution stops and RACH procedure is considered to be successfully completed. Hence, PRACH processing at the base station is vital to the entire RA process.

1.2 Motivation

mALL sequence has higher preamble capacity as compared to other sequences. Inspite of this, when detection performance of *mALL* sequence is compared to other sequences, it suffers from a low detection probability comparatively in multi-user scenario as discussed in section 2.5. A better timing estimation of sequences can help in their better detection. So we have done some literature surveys as in section 2.1 to understand the issues in existing detection algorithms. It is found that method of PDP calculations used earlier does not include any method to cop-up with adverse impact of non-zero CFO. This forms the motivation to propose a new algorithm for *mALL* sequence that can help in improving the detection performance of *mALL* sequence comparatively.

Due to more number of users and limited number of distinct preambles(64) per cell, there will be contention and leads to failure of RA process. Even if there are users who are attempting distinct preambles, it might happen they are not getting detected. This forms second motivation to propose an algorithm which finds number of users which are uniquely selecting preambles and getting detected also.

1.3 Approach

We divide our work into several parts. Firstly, we analyse the performance of $mALL$ sequence as per system model discussed in 2.4 and try to understand the problems with sequence. Then we propose a new PDP calculation algorithm which can cop-up with issues with $mALL$ sequence. Based on proposed PDP calculation algorithm, lastly we propose another algorithm to find number of users who are uniquely selecting preambles and getting detected also. We consider the following points to come to our results and conclusions:

- Studying the properties like correlation property, preamble capacity of different preamble sequences.
- Proposal of new algorithm that includes PDP calculation as used in satellite environment.
- For simulation we have used non-zero value of CFO to check adverse impact of CFO on detection performance.
- False alarm probability is calculated to check whether we are able to achieve better false alarm mitigation or not.
- The effect of more number of antennas, received SNR values and number of contending users on detection performance of different preamble sequences is also considered.

1.4 Aim of the work

First goal of our work is to understand the properties of all existing sequences namely $mALL$, aZC, mZC, ZC. But the mail goal of our to extensively explore the problem with $mALL$ sequence. The $mALL$ sequence as proposed in [18] possess a higher preamble capacity to meet the demands of 5G, specially in mMTC type communication. Based on the proposed method, we find out the detection performance in noisy channel and then observe its effect on detection probability of sequences. We also want to see the effects of non-zero CFO, varying SNR values and equal gain combining on the detection performance of these sequences.

Second goal of our work is to understand the Random access process and find the number of users who are selecting distinct preambles and are getting detected also.

1.5 Outline of Report

Chapter 1 gives a brief introduction about 5G NR and motivation related to project. It also gives the approach, the main goals of our work. Chapter 2 contains background and literature surveys which highlights the fundamentals of all existing sequences, existing detection methods, issues with those methods. It also includes some terminologies and formulas included in our work. In the same chapter we have our system model in which our entire work is done and based on that we have discussed the problem existing with *mALL* sequence. In chapter 3, we present the proposed PDP calculation algorithm and the preamble detection methodology. We also have summarised the entire proposed algorithm in form of pseudo-code. Chapter 4 has all results simulated employing the algorithm discussed. In chapter 5, we propose an algorithm for RA process such that users select unique preamble and gets detected also. In the same chapter, again we have summed up the second algorithm in form of pseudo-code. Finally in chapter 6, we conclude our work and also have given future scope.

Chapter 2

Background

2.1 Literature Review

In surveys [7], [6] ZC sequences and their properties have been broadly studied where it is found that these ZC sequences are sensitive to frequency shifts. So another sequence called as $m - sequence$ is explored in [23] which shows better tolerance to frequency shifts. Some other aggregation techniques are explored in [16] where weighted addition of two ZC sequences constitutes transmitted preamble. A combination of ZC sequence with other CAZAC sequence or near CAZAC sequence is suggested in [20]. But in all these proposals, the major limitation is that the length of sequence restricts the number of sequences that can be generated, especially for mMTC type communications where there is a very high density of connection requests [12], [22]. Due to the limited number of sequences, the probability of collision of preambles increases with the number of UEs and hence leading to failure of RA procedure [1]. To alleviate this problem, the concept of the cover sequence as discussed in 2.3 has been introduced. For example, $m - sequence$ [23]

and *Alltop* [2] sequence which are CAZAC sequences can be used as cover sequences to generate more preamble sequences. The reason behind considering combination of $m - sequence$ and *Alltop* sequence is the reason that in[21] it has been argued that the combination of *Alltop* and ZC sequence may arise some ambiguity in sequences for any arbitrary cyclic shifts. This ambiguity can be avoided with the use of $m - sequence$ instead of ZC sequence. Preamble capacity is defined as number of unambiguous sequences that can be generated from a candidate sequence. The preamble capacity of the $mALL$ sequence [18] is higher than the previously identified sequences namely ZC, mZC, and aZC. Inspite of having a higher preamble capacity, $mALL$ sequence suffers from a lower probability of detection in multi-user and multiple antenna environment. The detection methods of aZC and mZC sequences are proposed by Pitaval $etal$. in [21] and [20] respectively. The detection algorithm in both works assume a prior setting of threshold such that the false alarm can be mitigated as low as 10^{-3}. However the detection methods in [21] and [20] does not address the problem of adverse impact of Carrier frequency offsets(CFOs). Detection methods should also include analysis under non-zero CFOs because a non-zero CFO can actually lead to energy leakage of correlation peaks [11] and can even shift the peaks at wrong timing position under large CFOS. This degrades the detection performance as well. Yang $etal$. [28] and Wang $etal$. [27] uses the peak detector to analyze the detection performance but the adverse impact of non-zero CFOs is not taken in account. Whereas in [26] Generalised likelihood ratio test(GLRT) detector, claivrvyoyant detector is used to analyze the detection performance but with unknown value of CFOs these detectors are practically inapplicable. So in most of these works, they adopted detectors that is dealing with multi-path environment but ignoring CFOs impact. There are few methods in [9] and [13] that takes advantage of conjugate symmetry of ZC sequences to cope with large CFOs. We have used the detection method implemented in LTE satellite systems [29], [24], [8] as a reference because the RA procedure in 5G is similar to that in LTE systems. The proposed preamble detection algorithm is different from the ones proposed in literature [19], [10], [21], [20], [26], [28] in the following aspects. The method of calculation of power delay product (PDP) in all these literature does not talk about issues like the adverse impact of CFOs, false alarm mitigation, and timing detection. Machine learning (ML) approach for preamble detection as discussed in [15], involves the computation of outcome based on prior data. But we are dealing with random events so it's extremely difficult to have prior information. Also, the ML approach fails to deal with a wide range of Signal-to-noise ratio(SNRs). In other literature, as discussed in [25] which is used in powerline communication, there is also major issue in dealing with different levels of SNRs. So, in our work, we have presented employing a single root sequence with some cyclic shifts for constituting delay in sequence and also a method that takes advantage of conjugate symmetry to cope with large CFOs.

2.2 Definitions

2.2.1 Preamble Capacity($PrCapacity$)

Preamble Capacity of a sequence is defined as the total number of unambiguous sequences that can be generated from a CAZAC or near-CAZAC sequences.

- $PrCapacity^{ZC} = (L_{RA} - 1) \times \left\lceil \frac{L_{RA}}{N_{cs}} \right\rceil$
- $PrCapacity^{aZC} = (L_{RA}^2 - 1) \times \left\lceil \frac{L_{RA}}{N_{cs}} \right\rceil$
- $PrCapacity^{mZC} = N_R \times (L_{RA} + 1) \times \left\lceil \frac{L_{RA}}{N_{cs}} \right\rceil$, where $N_R = L_{RA} - 1$
- $PrCapacity^{mALL} = L_{RA}^3 \times \left\lceil \frac{L_{RA}}{N_{cs}} \right\rceil$

2.2.2 Periodic Correlation

For any two sequences $x[n]$ and $y[n]$ of length L, periodic correlation is given by following:

$$R_{x,y}[\tau] = \sum_{n=0}^{L-1} [x[n]y^*[(n+\tau)modL]$$

2.2.3 Power Delay Profile

PDP over two sequences $x[n]$ and $y[n]$ of length L, PDP is calculated as:

$$P_{x,y}[\tau] = |R_{x,y}[\tau]|^2$$

2.2.4 Equal Gain Combining

Equal gain combining also called as diversity combining is a technique in which we accumulate signals obtained from different antennas and then we add them directly. For our work we have used this technique to accumulate the PDP from all receiver antennas at gNB. After equal gain combining the PDPs we have:

$$P^i_{N_{Ant}} = \sum_{l=1}^{N_{Ant}} P^i_l$$

2.2.5 False Alarm probability

False alarm probability($P - false$) is defined as conditional probability of wrong detection of preamble sequence when input is noise only. It should be noted that $P - false \leq 0.1\%$

2.3 Cover sequences

If we look into Preamble capacity formula of ZC sequence as in 2.2, there is only fixed number of preamble sequences that can be generated for a given value of N_{cs} and L_{RA}. Lets denote such set of sequences generated from $X_{\mu}^{v}[n]$ as Q^{ZC}, where
n=0, 1,......,$L_{RA} - 1$
μ=1, 2,......,$L_{RA} - 1$
v=0, 1,.......,$\lfloor \frac{L_{RA}}{N_{cs}} \rfloor$
Consider another sequence $a[n]$ from which N_c number of sequences can be generated which are orthogonal(non-ambiguous) to each other. Set of this N_c number of sequence is defined as P^c such that:
P^c=$\{a_1[n], a_2[n], a_3[n], ..., a_{N_c}[n]\}$.
Therefore we define cover sequence $y[n]$ as element wise multiplication of sequence from P^c and Q^{ZC} and is given as:
$y[n]$=$a_l[n] \circledast X_{\mu}^{v}[n]$
where, l=1,2,.....N_c and $\circledast$ represents element-wise multiplication. This concept of cover sequence is used to generate $mALL$ sequence with very high preamble capacity.

2.4 System Model

We consider a 5G cellular environment comprising of a multi-antenna base stations. We consider that the base station is equipped with N_{ant} number of antennas. We assume that K number of users present in the cell are attempting the preamble transmission. Each cell consist of 64 distinct preambles available for random access. When users attempt to access the network in a given time slot, each user in the cell randomly chooses a preamble from the set of 64 distinct preambles. The preamble transmitted by the UE is affected by the noise and is received at the gNB as $Rx = \sqrt{P} * Tx + n$, where Tx is the preamble sequence that is randomly chosen and transmitted by UE, P is received power of signal and n is a noise vector that contains any additive noise. In this work, we propose an algorithm to calculate the PDP based on the periodic correlation for the better timing estimation of *mALL* sequence. The periodic correlation between two sequences X and Y is given by the following equation.

$$R_{x,y}[T] = \sum_{n=0}^{L_{RA}-1} [X[n] * Y[(n+T) mod L_{RA}],$$

where L_{RA} denotes the length of the random access sequence. Initially, we neglect the impact of CFO and analyse the preamble detection performance. Equal gain combining technique is used at the receiver for multi-antenna case. We denote the number of antennas at the gNB by N_{Ant}. Hence, after equal gain combining, the PDP at the gNB is given by

$$P^i_{N_{Ant}} = \sum_{l=1}^{N_{Ant}} P^i_l$$

where $l \subseteq N_{A_{nt}}$ and P^i is PDP at individual receiving antenna. This information is further used in our system for detection threshold calculation. Further, we evaluate the effect of CFO by introducing arbitrary value of CFO to the received sequence. Table 5.1 shows the simulation parameters that are used in our work.

2.5 Problem with *mALL* sequence

In this section we present the MATLAB simulation results which shows the performance of different preamble sequence in terms of detection probability, miss detection probability. Based on PDP calculation method as discussed in [18], we compare the detection probability of *mALL* sequence with all other sequences and tries to find out the problem with *mALL* sequence. Simulation is carried at a higher and a lower value of SNR. Also it should be noted that here we have taken CFO=0. All other parameters are same as in Table2.1. In subsection2.5.1 we discuss the performance of sequence for SNR=-20dB and in subsection2.5.2 we discuss the performance of sequences for SNR=-1dB.

Table 2.1: Parameters for proposed PDP method's simulation

Parameter	Value
L_{RA}	139
Iteration(iter)	10000
SNR (dB)	-20, -1
Number of Users	100
CFO	0, 0.6
Number of Antennas (N)	1, 2, 4, 8
Threshold Factor (α)	10, 8, 6, 4
zCzC	11
$zCZC_{values}$	1 to 15

2.5.1 Performance evaluation at SNR=-20dB

When SNR=-20dB, for number of antenna(N)=1, threshold factor(α)=10 as in Fig.2.1, the detection probability of $mALL$ sequence is low as compared to ZC, aZC, mZC sequences. The corresponding miss-detection plots as shown in Fig.2.2 gives a better comparison of detection probability of sequences. When N=2, $\alpha = 8$, detection probability of mALL sequence is still lowest. For N=4, $\alpha = 6$, the detection probability of $mALL$ sequence gets better as compared to aZC but mZC sequence is observed to have best detection probability comparatively. For N=8, $\alpha = 4$ we can see that detection probability of $mALL$ sequence is still lowest. Thus at a lower SNR value $mALL$ sequence is said to possess low detection probability.

2.5.2 Performance evaluation at SNR=-1dB

To understand the performance of sequences at higher SNR we changed it to a higher value of signal-to-noise ratio as SNR=-1dB as shown in Fig.2.3. From the figures it can be seen that there is some improvement in detection probability of $mALL$ sequence as compared to plots in Figs.2.1. There is slight improvement in detection probability of $mALL$ sequence for N=4, α=6 same as we saw in corresponding plot in Fig.2.1. It is more clear if we see zoomed plots for N=8, $\alpha = 4$ in Figs.2.1,2.3.So, changing SNR has improved the detection probability of $mALL$ sequence , but the problem of comparatively low detection probability of $mALL$ sequence still exists.

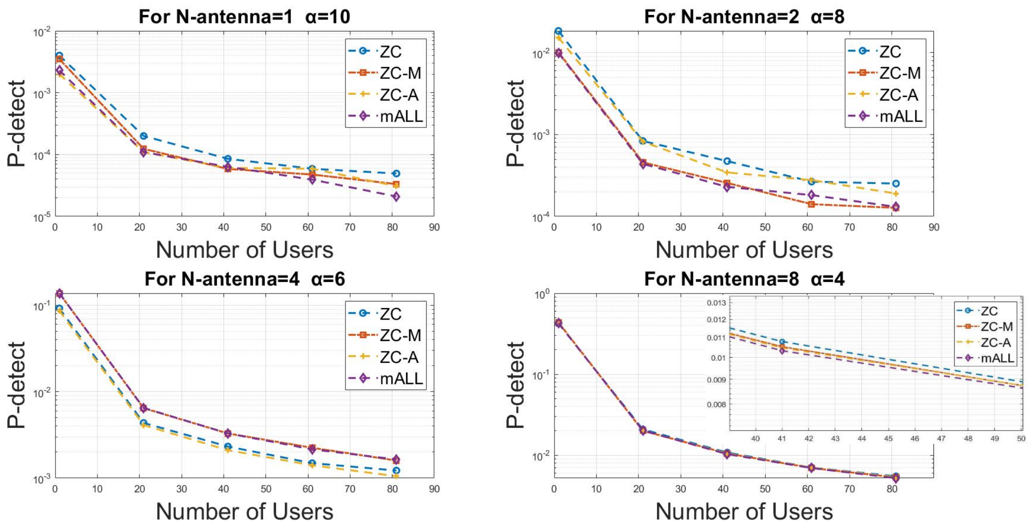

Figure 2.1: P(detect) vs Number of users, SNR=-20dB

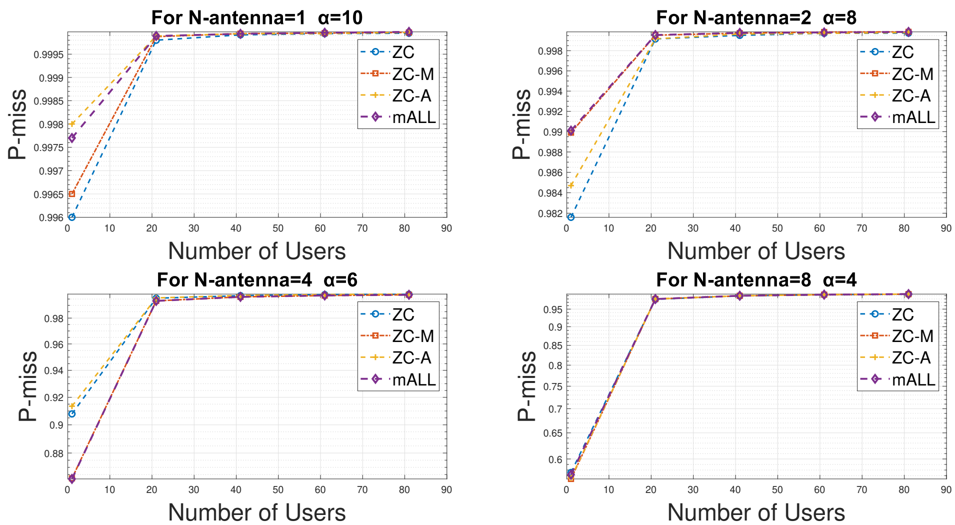

Figure 2.2: P(miss) vs Number of users, SNR=-20dB

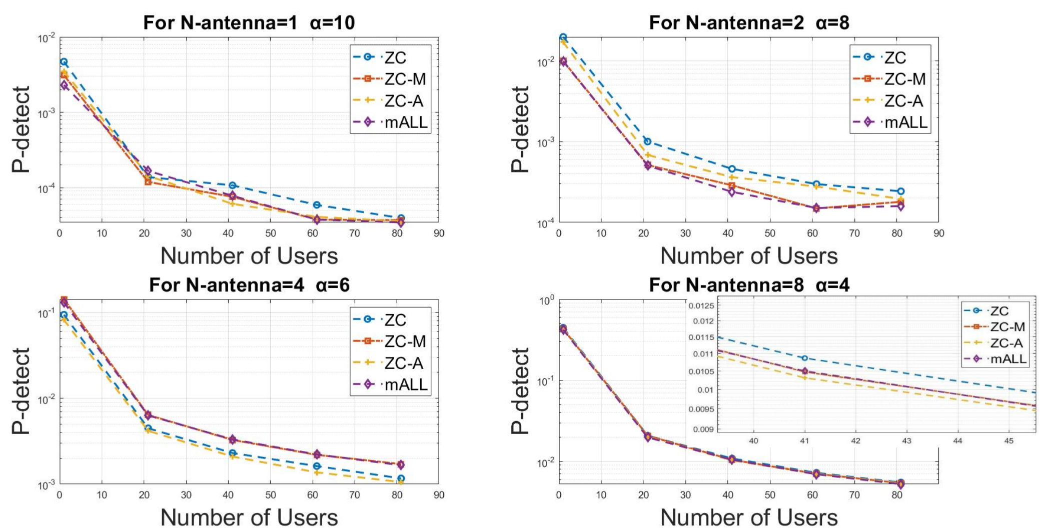

Figure 2.3: P(detect) vs Number of users, SNR=-1dB

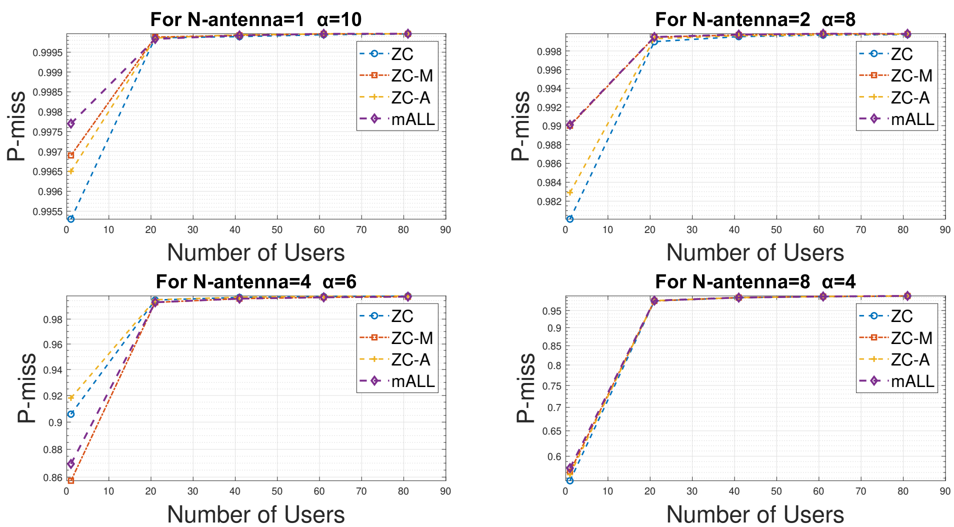

Figure 2.4: P(miss) vs Number of users, SNR=-1dB

Chapter 3

Proposed New Algorithm

To perform the detection of preamble, first we need to know the strength of the received signal quantified in terms of the Power Delay Profile (PDP). In our proposed algorithm, the strength of the received signal is measured by calculating the low-complexity PDP. Our idea of low-complex PDP calculation is motivated by the detection algorithm for 5G enabled satellite random access proposed by Zhen *etal*. [29]. With certain modifications and assumptions in [29], our implementation of the PDP calculation is shown in Fig. 3.1 for the sequences ZC, mZC, aZC, and $mALL$. By operating cyclic shift we can account the delay that the received sequences have encountered at the receiver. So the received sequence(Rx) is circularly shifted by an integral multiple of L_{RA}. For our simulation value of the factor m is taken to be 1 to account for minimum propagation delay. The receiver has bank of all 64 preamble sequences that can be transmitted by any UE during the random access and we call them as reference sequences(Tx). The same operation of cyclic shift is performed on each sequence in the bank containing all 64 preambles Also, there can be a carrier frequency offset (CFO) between the received sequence and the reference sequence, and to take care of the CFO, the conjugate of both reference sequences and received sequences are performed as discussed in section 3.1 and is multiplied with the circularly shifted version of the respective sequence. A detailed pseudocode for the PDP calculation is given in Algorithm 1.

Let T_m represents the Hadamard product of circularly shifted version(T_1) and conjugate(T_2) of the reference preamble sequence i.e. $T_m = T_1 \circledast T_2$ (lines 6-8), where $\circledast$ represents the hadamard product. A similar operation is performed for the received preamble sequence and we get $R_m = R_1 \circledast R_2$, where R_1 and R_2 are circularly shifted versions and conjugate of received preamble sequence respectively (lines 12-14). Idea was to calculate sliding correlation as follows: $Correlation = T_m^*(R_m^T)$, where R_m^T represents the transpose of R_m respectively and $(\cdot)^*$ represents conjugate operation. But this involves a lot of complex multiplication and hence more computational complexity and resource overhead.

To reduce the computation complexity, the sliding correlation is replaced by periodic correlation, for which, we use the operation of inverse fast Fourier operation(IFFT), thus reducing the time of complex multiplication, i.e. the above correlation calculation is replaced as $Correlation = A_m^* \circledast B_m$, where A_m and B_m are frequency domain forms of T_m and R_m (line 16). Once the time domain correlation of the received and the reference signal is computed, the PDP is obtained by squaring the correlation (line 17). A detection threshold is determined by scaling the mean PDP value (line 18). The scaling factor α is selected heuristically by trail and error method. The PDP of the correlated sequence is divided into $\left\lceil \frac{L_{RA}}{N_{cs}} \right\rceil$ number of windows. In each window the maximum sample value is compared with the detection threshold as shown in lines 20-27 of the Algorithm 1. From the MATLAB simulation is carried out as presented in 4, it is evident that our method of PDP calculation eliminates the adverse impact of CFOs and helps in achieving better timing estimation

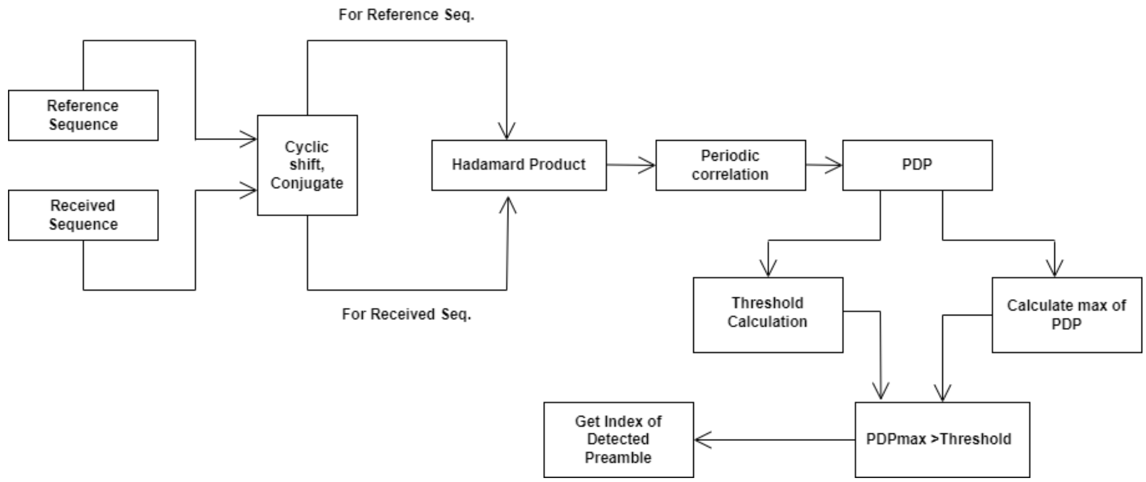

Figure 3.1: preamble detection methodology

3.1 Detection methodology

For each cell there are 64 distinct preambles available for transmission. This set of 64 sequences are generated according to standard specifications [14]. The receiver has bank of all 64 distinct preamble sequences called as Reference sequences denoted as Tx. Each UE goes and randomly selects one of the preambles from the set of 64 preambles. Those selected preambles added at receiver as represented by Rx. The method of PDP calculation is shown in Fig.3.1. Once the PDP calculation is done, then in each window of length N_{cs}(minimum cyclic-shift) the maximum value of PDP and their corresponding index is determined and stored in an array. Further mean of PDP is calculated which is multiplied by the threshold factor(α) to determine the detection threshold. Once the detection threshold(η) is known, the maximum value of PDP in each window is compared with this detection threshold. If the maximum value of PDP exceeds the detection threshold, the preamble is said to be detected and its corresponding index is stored in an array. We have shown the algorithm flow in form of pseudo-code.

Algorithm 1 Pseudocode for PDP calculation and Preamble detection

Inputs: Tx, Rx
Data: $L_{RA} = 139$
function PDP(Tx, Rx)
for $n = 0$ to nusers **do**
    Get **Tx**
    $\boldsymbol{T}1 \leftarrow \boldsymbol{c}ircshift(Tx, L_{RA})$
    $\boldsymbol{T}2 \leftarrow Conjugate(Tx)$
    $\boldsymbol{T}_m \leftarrow FFT(T1 \circledast T2)$
end for
for $n = 0$ to nusers **do**
    Compute **Rx**
    $\boldsymbol{R}1 \leftarrow \boldsymbol{c}ircshift(Rx, L_{RA})$
    $\boldsymbol{R}2 \leftarrow Conjugate(Rx)$
    $\boldsymbol{R}_m \leftarrow FFT(R1 \circledast R2)$
end for
$Periodiccorrelation \leftarrow IFFT(A_m^* \circledast B_m)$
$PDP \leftarrow (Periodiccorrelation)^2$
$Detection_{threshold} \leftarrow Mean_{PDP} \circledast \alpha$
for $eachrow$ **do**
    for $j = 0, j \leq L_{RA}; j = j + N_{CS}$ **do**
        $Window \leftarrow PDP|j : j + N_{CS} - 1|$
        if $MAX_{window} \geq Detection_{threshold}$ **then**
            $Detect \leftarrow 1$
        else
            $DETECT \leftarrow 0$
        end if
    end for
end for

Chapter 4

Simulation Results

Based on algorithm as proposed in chapter3, we have carried out simulation to check and compare the detection performance of different sequences. The performance of the proposed preamble detection is evaluated through MATLAB simulation by two parameters: Probability of preamble detection and false alarm probability. For simulations, we use the system model as discussed in section2.4. Then we show the effect of non-zero CFO on detection probability for varying number of users in subsection4.0.2. Further, we discuss the effect of changing SNR value. Using these results, we discuss the improvement that $mALL$ sequence has achieved as compared to earlier method as discussed in 2.5. Parameters involved in simulation are present in Table 2.1.

4.0.1 Performance Evaluation at SNR=-20dB, CFO=0

Each plot of detection probability is generated for 10000 iterations over a given value of SNR. For a lower SNR value(-20dB) and CFO=0 as shown in Fig.4.1 , When number of antenna(N)=1,2 with threshold factors(α)=10,8 respectively, we

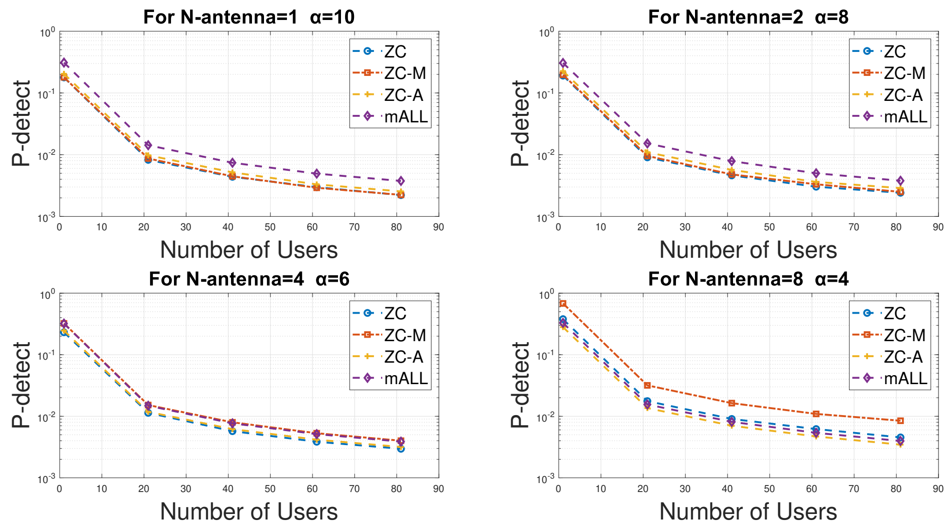

Figure 4.1: P(detect) vs Number of users, SNR=-20dB,CFO=0

can see that the probability of detection for $mALL$ sequence is better as compared to aZC, mZC, ZC sequences when the number of users is small. When number of users increases, contention increases . Hence the detection probability of each sequence goes on decreasing. But from the trend in plots we can see that $mALL$ sequence performs better than other sequences even for higher number of users. When N=4 and α=6, it is observed that mZC starts performing better than $mALL$ sequence but still the detection probability of $mALL$ sequence is better than ZC and aZC sequences. Thus even if $mALL$ sequence has higher cross-correlation, we are able to observe a comparable performance with all other sequences. For N=8 and α=4,mZC sequence is seen outperforming all other sequences. Also ZC sequence has shown a better detection probability as compared to $mALL$ and aZC sequences. But when we compare this plot with corresponding plot as in Fig.2.1 we can see improvement in detection performance of $mALL$ sequence.

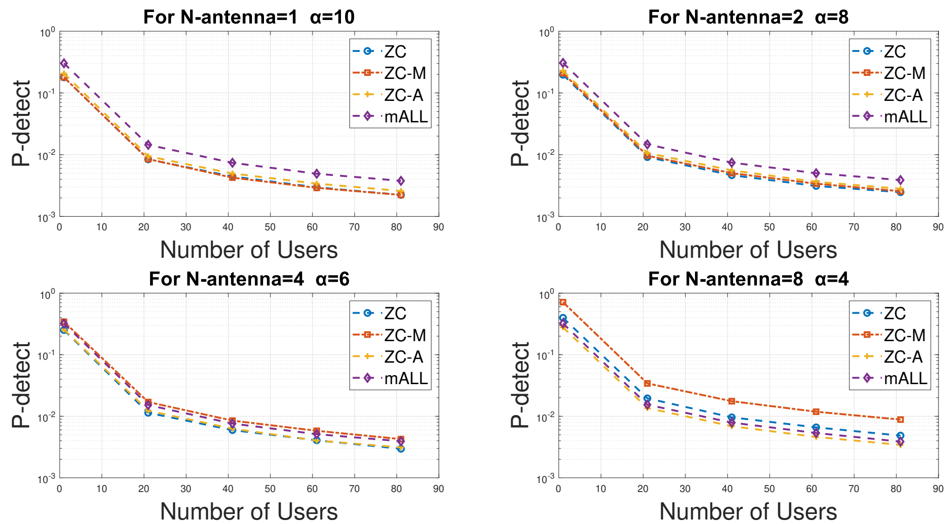

Figure 4.2: P(detect) vs Number of users, SNR=-20dB,CFO=0.6

4.0.2 Performance Evaluation at SNR=-20dB, CFO=0.6

Simulations carried in section2.5 does not include effect of non-zero CFO. So our proposed algorithm is supposed to take care of non-zero value of CFO also. So,to analyze the effect of non-zero CFO, we changed it to CFO=0.6 keeping SNR= -20dB as shown in Fig.4.2. If we compare these plots for different value of N and α with corresponding plots as in Fig.4.1, we can see that the plots shows nearly same behaviour. When plots in Figs.4.1, 4.2 are compared with corresponding plot as in Fig.2.1, the $mALL$ sequence can observed to have an improved detection performance. That means detection performance of sequences is immune to adverse impact of CFOs. This behaviour can be attributed to fact that we have taken advantage of conjugate symmetry to cop-up with large CFOs. Hence we are supposed to have a better timing detection of sequences.

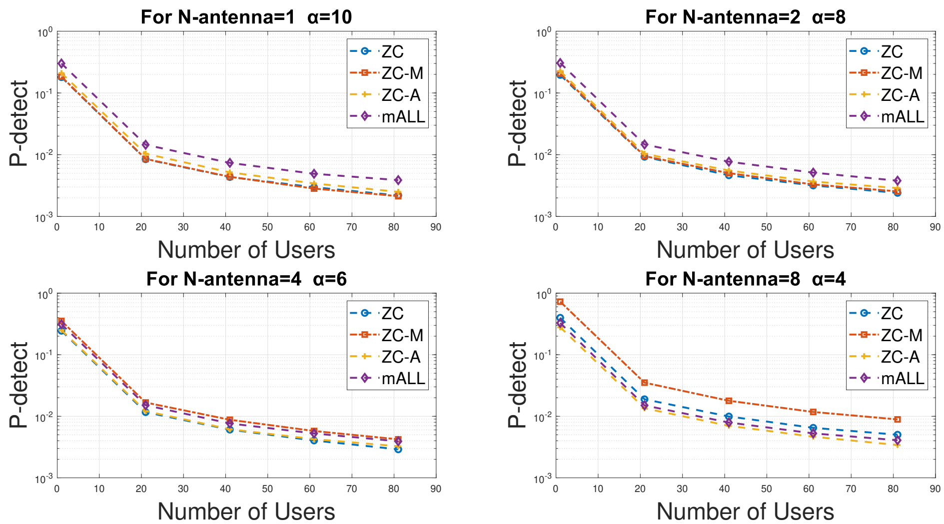

Figure 4.3: P(detect) vs Number of users, SNR=-1dB,CFO=0

4.0.3 Performance Evaluation at SNR=-1dB, CFO=0

Now, to understand the detection performance at a higher SNR value we changed the SNR to -1dB as in Fig.4.3. Still,the *mALL* sequence seems to be performing better. So if we compare with plots as in section 2.5 we can say that detection probability of *mALL* (as compared to other sequences) has improved for increasing number of users and antennas but if we see Figs.4.1,4.3, there is not much change in behaviour of plots observed. That means going from lower SNR(-20dB) to a higher SNR(-1dB) the change in detection probability is very small. Further the false alarm probability for *mALL* sequence is observed near to 0.01 , thus achieving a good false alarm mitigation.

Chapter 5

Random Access Process

During Random access process, users randomly picks preamble from a cell. Since each cell consists of 64 distinct preambles only, so due to more users it may happen that different users picks same preamble. This is termed as collision. RA process is said to be successful if there is no collision and preamble corresponding to user gets detected as well. For our work, those users who picks distinct preambles are termed as successful users and out of these successful users, the users whose preamble is detected are termed as final successful users. The users who fails to select distinct preambles goes and attempt to select distinct preamble from cell. The proposed PDP calculation as in section 3 has improved the detection performance of $mALL$ sequence. So we have used same method of PDP calculation to propose another algorithm which calculates the number of successful users and final successful for $mALL$, aZC, mZC and ZC sequences. Hence, it is expected that $mALL$ sequence shows comparable number of final successful users with other sequences.

Table 5.1: Parameters for RA process simulation

Parameter	**Value**
L_{RA}	139
Iteration(iter)	50000
SNR (dB)	1
Number of Users	300
CFO	0
Number of Antennas (N)	1, 2, 4, 8
Threshold Factor (α)	10, 8, 6, 4
zCzC	11
$zCZC_{values}$	1 to 15
Signature	1, 2, 3, 4
Method	1, 2

5.1 Proposed RA process algorithm

Pseudo-code in Algorithm 2 gives an overview of proposed RA process algorithm. Firstly out of total number of users we find successful users (lines 2-9). Once we have an array containing number of successful users, we have another segment of code which checks whether preamble indexes selected by these successful users are getting detected or not (line 11-28). The detection of preamble indexes chosen by successful users is performed for each sequence. Signature=1,2,3,4 corresponds to ZC, mZC, aZC and $mALL$ sequences respectively. For the detection purpose, initially we generated a matrix (line 20) in which each row contains exactly same number of distinct indexes as there are number of successful users. Sequence corresponding to these indexes are added to receiver and PDP calculation is performed as per section 3(line 26). Now these indexes as generated in line 20, are matched with detected indexes. We then count how many indexes of successful users is present in detected index (line 28). This operation is repeated over 50,000 iteration and then average is taken. This gives us final successful users count against total number of users. It should be noted that we have considered AWGN noise for simulation.

5.2 Performance evaluation of different sequences

The plot for final successful users against total number of users is generated at SNR=1dB and CFO=0 as shown in Fig.5.1 for ZC, mZC, aZC and $mALL$ sequences. From the plot we can see that, initially when number of users increases, the final successful users also go on increasing. This can be attributed to fact that initially we have comparatively less number of users. So the contention will be less and hence more more users selects distinct preambles. But as number of users keep on increasing then it happens that users start selecting same preamble due to limited number of distinct preamble available in each cell. Thus the number of final successful users start decreasing as shown in Fig.5.1.

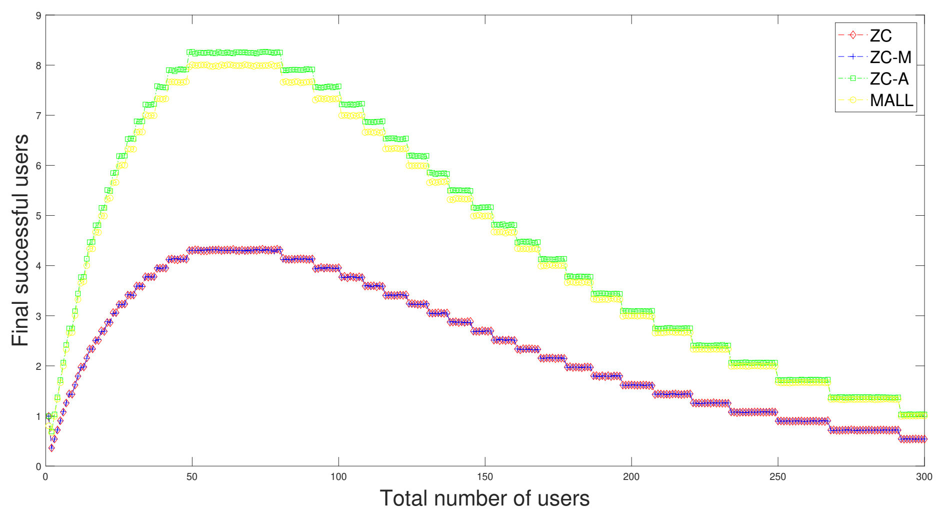

Figure 5.1: Final successful users vs Total number of users

Similar trend is observed for all four sequences. From the figure, we can see that in case of aZC sequences the number of final successful users is more than other sequences, while for ZC and mZC sequences it is nearly same. As we have seen in section 4, the $mALL$ section shows better detection performance. So we used the same method of PDP calculation in our algorithm and expected that instead of having very higher cross-correlation for $mALL$ sequence, we will be able to get better performance for $mALL$ sequence in terms of final successful users. And it is clear from Fig.5.1that for $mALL$ sequence we are able to get comparable number of final successful users. Also Final successful user count for $mALL$ sequence is much better than ZC and mZC sequences. Table 5.1 shows other parameters used in simulation.

Algorithm 2 Pseudocode for RA process

Data: $maxn = 300$

```
for i = 0 to maxn do
    for iter=0 to 50,000 do
        A=randi([1,64],i,1)
        B=Unique(A)
        Unique occurrence= Sum(B==A)
        C(itr)= sum(Unique occurence==1);
    end for
Get the average of C for total iter values
Run the loop to get 1 × maxn array for successful users
end for
for signature=1 to 4 do
    for k=1 to length(SNR) do
        for iter=1 to 50,000 do
            Choose=Generate 300 × 64 matrix
R=number of rows in choose
C=number of columns in choose
index=1
            for w=1 to R do
                for f=1 to C do
                    if f >users(index) then choose(w,f)=0
                    end if
                end for
            end for
index=index+1
Add these indexes in choose at receiver
Do PDP calculation
            if Sequence index at receiver is in detected index then
count number of detected index
end loop for iteration
end loop for SNR
end loop for signature
```

Chapter 6

Conclusion and Future scope

6.1 Conclusion

We investigate the detection performance of a particular preamble sequence known as the *mALL* sequence under multi-user and multi-antenna scenario. To counter the low detection probability of *mALL* sequence, we have proposed a new algorithm which includes calculating a low complexity power-delay profile(PDPs) by taking ideas from 5G-enabled satellite communication systems. Simulation results shows that the proposed algorithm is immune to effect of non-zero CFO and is able to improve the detection probability of *mALL* sequence comparatively, but when performance is evaluated under different SNR value it is observed that when SNR is changed from low to high the change in detection probability of every sequence is very minimal. Also a better false alarm mitigation as low as 0.01 is achieved through proposed algorithm. In the other segment of our work, where we proposed another algorithm for Random access process, it is observed that for *aZC* sequence the number of such users who are uniquely selecting preambles and are getting detected also is more as compared to other sequences. While mZC and Zc sequences shown almost equal number of such users. Whereas, for $mALL$ sequence the observed number of such users found to be more than ZC and mZC sequences and very much comparable to aZC sequence. Hence it can be concluded that even tho $mALL$ sequence has highest cross correlation, the proposed PDP calculation algorithm has improved the detection probability of $mALL$ sequence and gives a comparable detection performance with other sequences but with a flaw that varying SNR does not impact detection probability much.

6.2 Future Scope

In our first work we have proposed a PDP calculation method so that we can analyze the detection performance of sequences particularly for $mALL$ sequence under multi-users, multiple antennas and non-zero CFO value. But detection of sequences does not show much variation when SNR value is changed. So, there is still a scope of much better detection algorithm that can eliminate the adverse impact of CFO and also shows good variation in terms of detection probability when SNR is varied. In our second work we have taken in account only those users who selects unique preambles. That means there are users who fails to do so. These failed users again can attempt to select unique preambles. This part can be explored further in our proposed algorithm too.

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