DETECTION OF RANDOM ACCESS IN LTE

A Project Report

submitted by

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in partial fulfillment of the requirements
for the award of the degree of

MASTER OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY MADRAS.

MAY 2019

THESIS CERTIFICATE

This is to certify that the thesis titled **DETECTION OF RACH IN LTE**, submitted by **Mayur Agarwal**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, 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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Date:09 May 2019

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my guide, Professor, Dr. Srikrishna Bhashyam, for his valuable guidance for the project. It is his guidance, timely responses, valuable suggestions and patience that led me towards the completion of my project work.

I would like to thank all the professors, for helping me to improve my knowledge over these two years. I am also thankful to all the technical and non-technical staff of Electrical Engineering department for their services rendered.

I am grateful to all my fellow students in the course and at the lab who spared their valuable time and help whenever required during the duration of this project.

ABSTRACT

KEYWORDS: PRACH, Random Access, Detection, Power Delay Profile

In the long time evolution system, random access is a key procedure for a user equipment to request resource allocation from a base station. The LTE Random Access Channel plays a vital role as an interface between user equipments which are not time synchronized and the orthogonal transmission scheme of the LTE uplink radio access. In this project, we implement the Random Access Channel detection in both additive whiten Gaussian noise as well as fading channels when noise variance is known and when the same need to be estimated. The estimation is carried with the help of power delay profile samples using a two mean method. Chi-square distribution properties of the power delay profile of additive whiten Gaussian noise and the estimated variance are then used to evaluate the detection threshold. The simulation results show the variation of Probability of detection wrt the SNR.

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

MIB	Master Information Block
PCI	Physical Cell Id
PRACH	Physical Random Access Channel
PSS	Primary Synchronization Sequence
RACH	Random Access Channel
RRC	Radio Resource Control
SIB	System Information Block
SSS	Secondary Synchronization Sequence
UE	User Equipment
eNB	evolved Node Base station
RAR	Random Access Response
FDD	Frequency Division Duplexing
TDD	Time Division Duplexing
CP	Cyclic Prefix
GT	Guard Time
PUSCH	Physical Uplink Shared Channel
ZC	Zadoff Chu
ZCZ	Zero Correlation Zone
LTE	Long Term Evolution
CAZAC	Constant Amplitude Zero Auto Correlation
PAPR	Peak to Average Power Ratio
ISI	Inter Symbol Interference
BW	Bandwidth

CHAPTER 1

INTRODUCTION

In LTE, a User Equipment (UE) is scheduled for uplink transmission only if its uplink transmission timing is synchronized. The LTE Random Access Channel (RACH) plays an important role in ensuring that the UE gets the resource allocation for uplink radio access. Random Access(RA) is generally performed when the UE is powered on or turned on from sleep mode, during the handover from one cell to another or when the uplink timing synchronization is lost. When the RA process is initiated, it is assumed that the UE is time-synchronized with the eNodeB on the downlink. The timing synchronization in downlink is achieved through reception of Primary Synchronization Sequence(PSS) and Secondary Synchronization Sequence(SSS). Once downlink timing synchronization is achieved and the UE has read the Master Information Block(MIB) and also the System Information Block(SIB) which has parameters specific to RA, the UE can initiate the RA preamble transmission. Once eNodeB successfully detects a RA preamble, it transmits a Random Access Response(RAR) indicating the received preamble along with the Timing Advance (TA) and other uplink resource allocation information to the UE. The UE is then able to determine if its RA attempt has succeeded or not by matching the preamble index it used for RA with the preamble index information received from the eNodeB. If both the preamble index match, the UE then assumes that its preamble transmission attempt was successful and it further uses the TA information to adjust its uplink transmission. After the UE has achieved uplink timing synchronization, it can then send uplink scheduling.

1.1 Initialization Sequence : From Power-On to PRACH

The undermentioned events give the sequence of major steps from the time a UE "Powers On" till initiation of RACH process.

- Power On UE
- Frequency Search

- Frame and Time Synchronization in downlink by decoding of PSS and SSS.
- Detection of PCI (Physical Cell ID)
- MIB decoding : UE figures out Bandwidth and transmission mode.
- SIB decoding (SIB1 is decoded first followed by SIB2 and then remaining SIBs). SIB2 contains parameters for initiation of RA
- Initiate RACH Process

1.2 RACH Requirement

The main purpose of RACH are described as follows:

- Achieve uplink synchronization between UE and eNodeB
- Obtain the resource allocation for Message 3 (RRC Connection Request)

In wireless communication, achieving timing synchronization between transmitter and receiver is one of the most important requirement for successful and reliable communication. In LTE, the downlink synchronization is achieved through PSS and SSS. These downlink synchronization signals are broadcasted to all the UEs in the cell.

However for uplink, the broadcast method is not efficient, as it will consume too much power which is a premium commodity for the UE. For uplink, the synchronization procedure should adhere to the following criteria:

- It should happen only when there is an immediate necessity.
- It should be dedicated for a specific UE.

The relevant cases where the RACH is used are:

- UE is in "RRC CONNECTED" state, but not synchronized in uplink and need to send new uplink data.
- UE is in "RRC CONNECTED" state, but not synchronized in uplink and needs receive new downlink data.
- UE is in "RRC CONNECTED" state and undergoing handoff from its current cell to a new cell.
- In "RRC CONNECTED" state for positioning purposes where timing advance is needed for UE positioning.
- On transition from "RRC IDLE" state to "RRC CONNECTED" state.
- Recovering from radio link failure.

1.3 Types of Random Access Process

The LTE RA process is of two types, where access is allowed either through a contention-based(risk of collision) process or a contention-free process. For majority of the cases listed in the previous section, contention-based process is used. In this process, a RA preamble signature is chosen randomly by a UE out of the available preambles in the cell, which may result in multiple UEs transmitting the same preamble at the same instant of time, thereby requiring a subsequent resolution of the contention between various contesting UEs. However, generally for the cases where UE is in "RRC CONNECTED" state but receiving *new downlink* data or is undergoing *handover*, the eNodeB prevents contention by allotting dedicated preamble signature to a UE, resulting in contention-free access. Contention free process is faster than the contention-based access and is used for cases where time is critical. A total of 64 preamble signatures is available in each LTE cell, and these are partitioned between those available for contention based access and those reserved for contention-free access.

1.3.1 Contention-Based Random Access Procedure

The contention-based procedure consists of four-steps as shown in figure 1.1:

- Step 1: Preamble transmission
- Step 2: Random access response
- Step 3: Layer 2 / Layer 3 (L2/L3) message
- Step 4: Contention resolution message

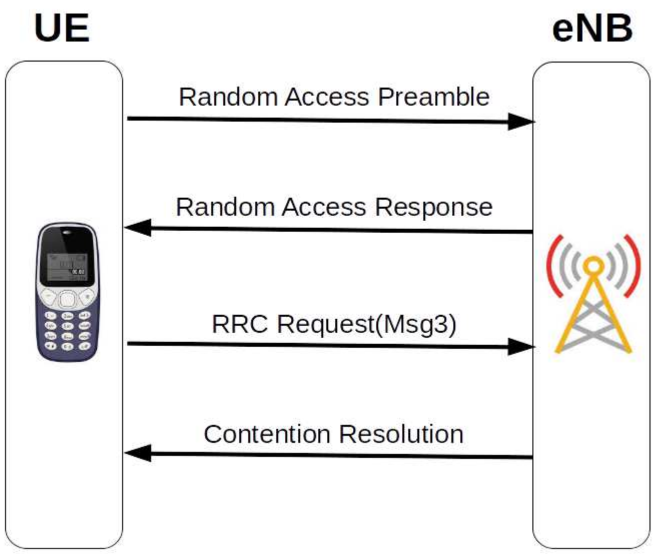

Figure 1.1: Contention-based Random Access Procedure

1.3.2 Contention-Free Random Access Procedure

This process exhibits smaller access delay. The process is simplified and as shown in figure 1.2.

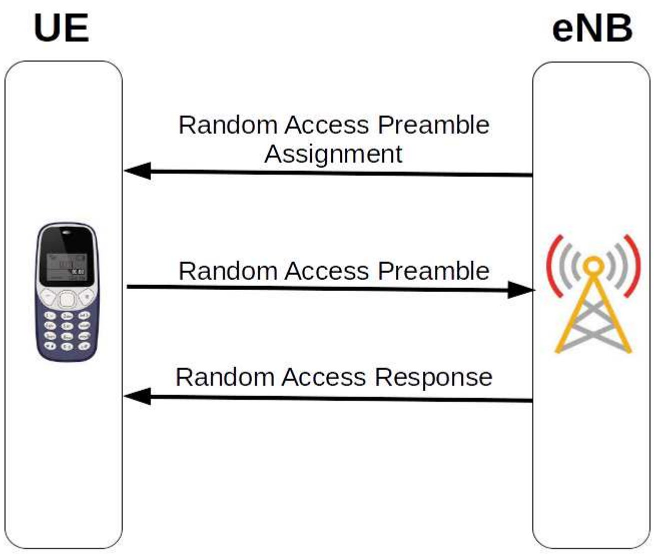

Figure 1.2: Contention-free Random Access Procedure

- **Step 1**: Preamble assignment
- **Step 2**: Preamble transmission
- **Step 3**: Random Access Response

CHAPTER 2

PHYSICAL RANDOM ACCESS CHANNEL DESIGN

The RA preamble part of the random access procedure is mapped at the physical layer onto the PRACH. A detailed explanation of the RACH is available in (Stefania Sesia,Issam Toufik, Matthew Baker, 2011) and (3GPP 36.211, 2011) from where the undermentioned details have been gathered.

2.1 LTE FRAME STRUCTURE

PRACH resource allocations are different for FDD mode and TDD mode in LTE, and different types of radio frame structures are supported for these modes. Frame structure shown in figure 2.1 is applicable to FDD mode in LTE. Downlink and uplink transmissions are organized into radio frames with $T_f = 307200 * T_s = 10$ ms duration where T_f is the frame duration and T_s is the sampling period. We restrict ourselves to the FDD frame structure in this report.

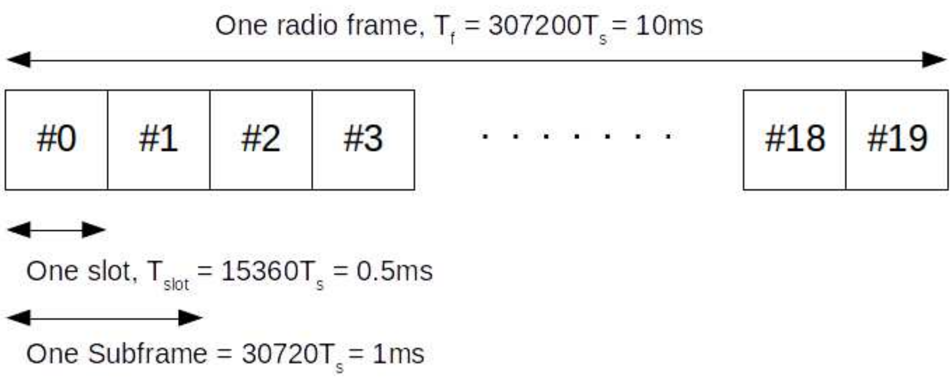

Figure 2.1: LTE FRAME structure FDD

In this report, the size of various fields in the time domain is expressed as a number of time units $T_s = \frac{1}{(15000*2048)}$ seconds. The sub carrier in LTE Single-Carrier Frequency Division Multiple Access(SC-FDMA) is of 15Khz bandwith and the max size of IFFT is 2048.

Every radio frame consists of 20 slots of length $T_{slot} = 15360 * T_s = 0.5$ ms, numbered from 0 to 19. Two consecutive slots are defined as a subframe. In FDD, 10 subframes are available for both downlink and uplink transmission in each 10 ms interval.

2.2 PRACH STRUCTURE

The LTE PRACH preamble consists of a complex sequence along with a Cyclic Prefix (CP). The preamble length is shorter than the PRACH slot so that it can provide room for a Guard Time (GT) to cater for the propagation delay. See figure 2.2.

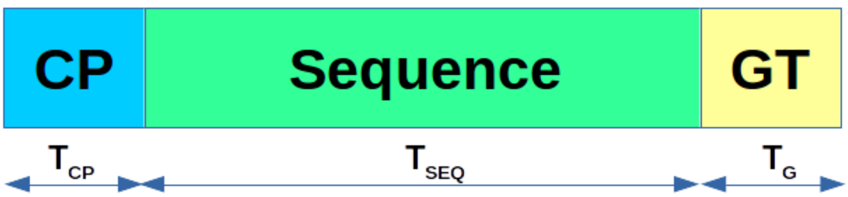

Figure 2.2: PRACH structure

2.2.1 Sequence Duration

The sequence duration, T_{SEQ}, is decided by the following factors:

- Trade off between length of the sequence and overhead: The sequence should be as long as possible to maximize the number of possible orthogonal preambles, while still fitting within a single subframe so as to keep the PRACH overhead small in most deployments
- Compatibility with the maximum expected round-trip delay
- Compatibility between PRACH and Physical Uplink Shared Channel(PUSCH) subcarrier spacings
- Desired Coverage performance

Maximum round-trip time : The lower bound for T_{SEQ} must allow for unambiguous round-trip time estimation for a UE located at the edge of the largest expected cell (100 km radius), including the maximum delay spread of 16.67 μs expected in such large cells. Hence,

$$T_{SEQ} \geq \frac{200 * 10^3}{3 * 10^8} + 16.67 * 10^{-6} = 683.33\mu s \tag{2.1}$$

Subcarrier spacing compatibility : Another constraint on T_{SEQ} is given by the SC-FDMA signal generation principle, such that the size of the DFT and IDFT, N_{DFT}, must be an integer number:

$$N_{DFT} = f_s * T_{SEQ} = k, k \in N \tag{2.2}$$

where f_s is the system sampling rate (e.g. 30.72 MHz) depending upon the number of available Resource Block(RB). The orthogonality loss in the frequency domain between the preamble subcarriers and the subcarriers of the uplink data transmissions is minimized if the PUSCH data symbol subcarrier spacing $\Delta f = 15Khz$ is an integer multiple of the PRACH subcarrier spacing Δf_{RA}:

$$\Delta f_{RA} = \frac{f_s}{N_{DFT}} = \frac{1}{T_{SEQ}} = \frac{1}{kT_{SYM}} = \frac{1}{k}\Delta f, k \in N \tag{2.3}$$

where T_{SYM} = 66.67 μs is the uplink subframe symbol duration. Therefore, preamble duration should be an integer multiple of the uplink subframe symbol duration:

$$T_{SEQ} = kT_{SYM} = \frac{k}{\Delta f}, k \in N \tag{2.4}$$

Coverage Performance : Generally, a longer sequence gives better coverage, but better coverage also requires a longer CP and GT. The required CP and GT lengths for PRACH can therefore be estimated from the maximum round-trip delay achievable by a preamble sequence which can fit into a 1 ms subframe.

The potential coverage performance of a 1 ms PRACH preamble is in the region of 14 km. As a consequence, the required CP and GT lengths are approximately

$(2 \cdot 14000)/(3 * 10^8) = 93.3\mu s$, so that the upper bound for T_{SEQ} is given by

$$T_{SEQ} \leq 1000 - 2 \cdot 93.33 = 813\mu s \tag{2.5}$$

Therefore, the longest sequence simultaneously satisfying all the above conditions is $T_{SEQ} = 800\mu$s, and is used for preamble formats 0 and 1. The PRACH subcarrier spacing is $\Delta f_{RA} = 1/T_{SEQ} = 1.25kHz$. The 1600 μs preamble sequence of formats 2 and 3 is implemented by repeating the baseline 800 μs preamble sequence.

2.2.2 CP and GT Duration

Once T_{SEQ} is decided, the CP and GT lengths can be specified more precisely. For formats 1 and 3, the CP is dimensioned to maximize the coverage. The duration of sequence, CP and GT for various cell sizes and preamble formats for them are given as

Preamble format	T_{CP} (μs)	T_{SEQ} (μs)	Typical usage
0	103.13	800	Normal 1 ms random access burst with 800 μs preamble sequence, for small to medium cells (up to ~14 km)
1	684.38	800	2 ms random access burst with 800 μs preamble sequence, for large cells (up to ~77 km) without a link budget problem
2	203.13	1600	2 ms random access burst with 1600 μs preamble sequence, for medium cells (up to ~29 km) supporting low data rates
3	684.38	1600	3 ms random access burst with 1600 μs preamble sequence, for very large cells (up to ~100 km)

Figure 2.3: Sequence CP and GT Durations, (Stefania Sesia,Issam Toufik, Matthew Baker, 2011)

2.3 PRACH FORMATS

Four RA preamble formats are defined for FDD operation and one for TDD. Each format is defined by the duration of the sequence and its CP, as listed in figure 2.4.

The preamble formats 0-3 correspond to LTE frame structure type 1 which is applicable to FDD while preamble format 4 is for frame structure type 2, which is applicable

Preamble format	T_{CP}	T_{SEQ}
0	$3168 \cdot T_s$	$24576 \cdot T_s$
1	$21024 \cdot T_s$	$24576 \cdot T_s$
2	$6240 \cdot T_s$	$2 \cdot 24576 \cdot T_s$
3	$21024 \cdot T_s$	$2 \cdot 24576 \cdot T_s$
4*	$448 \cdot T_s$	$4096 \cdot T_s$

Figure 2.4: PRACH Formats, (3GPP 36.211, 2011)

to TDD. We are using Format 0 for generation of preamble signature for our simulation. In practice, the UE knows which Preamble format it has to use when it generates PRACH according to the PRACH Configuration Index. The PRACH Configuration index is determined by eNodeB through the SIB2 parameters to the UE. Refer figure A.1

2.4 Preamble Sequence Theory and Design

In LTE, prime-length Zadoff-Chu (ZC) sequences are used to generate the preamble sequence. These sequence are used as they improve PRACH preamble detection performance in following ways.

- The Power Delay Profile(PDP) is build from periodic instead of aperiodic correlation.
- The intra-cell interference between different preamble received in the same PRACH resource is reduced.
- Intra-cell interference is optimized with respect to cell size: the smaller the cell size, the larger the number of orthogonal signatures, the better the detection performance.
- The eNodeB complexity is reduced.
- The support for high-speed UE is improved.

2.4.1 Zadoff-Chu Sequences

ZC sequences are non binary unit-amplitude sequence, which satisfy a Constant Amplitude Zero Autocorrelation (CAZAC) property. CAZAC sequences are complex signals of form $e^{j\alpha_k}$. The ZC sequence of odd-length N_{ZC} is given by

$$\alpha_q(n) = exp\left[-j2\pi q\frac{n(n+1)/2 + ln}{N_{ZC}}\right] \tag{2.6}$$

where $q \in [1, \cdots, N_{ZC} - 1]$ is the ZC sequence root index, $n = 0, 1, \cdots, N_{ZC} - 1, l \in N$ is any integer. In LTE, l = 0 is used for simplicity. ZC sequences have the following three important properties:

Property 1: A ZC sequence has constant amplitude and so does its N point DFT thereby limiting the Peak-to-Average Power Ratio (PAPR) and hence generates bounded and time-flat interference to other users. The implementation is also simplified as only phases need to be computed and stored, not amplitudes.

Property 2: ZC sequences of any length have an 'ideal' cyclic autocorrelation (i.e the correlation with its circularly shifted version is delta function). The zero autocorrelation property can be formulated as:

$$r_{kk}(\sigma) = \sum_{n=0}^{N_{ZC}-1} \alpha_q(n)\alpha_q[(n+\sigma)] = \delta(\sigma) \tag{2.7}$$

where $r_{kk}(.)$ is the discrete periodic autocorrelation function of α_q at lag σ. This property plays an important role when a reference sequence is correlated with a misaligned received reference sequence. We can also generate multiple orthogonal sequences from the same ZC sequence on basis of this property. Also, since the the periodic autocorrelation of a ZC sequence provides a single peak at the zero lag, the periodic correlation of the same sequence against its cyclic shifted version provides a peak at lag N_{CS}, where N_{CS} is the number of samples of the cyclic shift. This creates a Zero-Correlation Zone (ZCZ) between the two sequences. As a result, as long as the ZCZ is dimensioned to cope with the largest possible expected time misalignment between them, the two sequences are orthogonal for all transmissions within this time misalignment.

Property 3: The absolute value of the cyclic cross-correlation function between any two ZC sequences is constant and equal to $1/\sqrt{N_{ZC}}$ if $|q1 - q2|$ (where q1 and q2 are the sequence indices) is relatively prime with respect to N_{ZC}(a condition that can be easily guaranteed if N_{ZC} is a prime number). Another useful property of ZC sequences is that DFT of a ZC sequence is a weighted cyclically shifted ZC sequence implying that ZC sequence can be generated directly in the frequency domain without the need for a DFT operation.

2.4.2 Preamble sequence length

The sequence length design depends on the following requirements:

- Maximize the number of ZC sequences with optimal cross-correlation properties.
- Minimize the interference to/from the surrounding scheduled data on the PUSCH.

The first requirement is guaranteed if sequence of a prime length is chosen. For the second requirement, since data preamble OFDM symbols are neither aligned nor have the same durations, strict orthogonality cannot be achieved. However fixing the preamble duration to an integer multiple of PUSCH symbol provides some compatibility between preamble and PUSCH subcarriers. With 800 μs duration, the corresponding sequence length is 864, which does not meet the prime number requirement. Therefore the sequence length 839 is selected for LTE PRACH (FDD case).

2.4.3 Preamble sequence generation

The set of 64 preamble sequences in a cell is found by including first, in the order of increasing cyclic shift, all the available cyclic shifts of root ZC sequence which is decided on the basis of physical root index u, as per table B.1 through the logical root index provided in SIB2 parameters. Additional preamble sequences, in case 64 preambles cannot be generated from a single root ZC sequence, are obtained from the root ZC sequences with consecutive logical index (from 0 to 837) until all 64 preambles are found.

The u^{th} root ZC sequence is defined by

$$x_u(n) = exp\left[-j\frac{\pi un(n+1)}{N_{ZC}}\right], 0 \leq n \leq N_{ZC} - 1 \quad (2.8)$$

N_{CS}	N_{CS} value Unrestricted Set	Restricted Set
0	0	15
1	13	18
2	15	22
3	18	26
4	22	32
5	26	38
6	32	46
7	38	55
8	46	68
9	59	82
10	76	100
11	93	128
12	119	158
13	167	202
14	279	237
15	419	-

Table 2.1: N_{CS} value for preamble generation (preamble formats 0-3)

where u is the ZC physical root sequence index and the sequence length N_{ZC} = 839 for FDD. From the u^{th} root ZC sequence , RA preambles with zero correlation zone of length $N_{cs} - 1$ are defined by cyclic shifts according to

$$x_{u,v}(n) = x_u((n + C_v) mod N_{ZC}), \tag{2.9}$$

where the cyclic shift C_v is given by

$$C_v = \begin{cases} vN_{CS} & v = 0, 1, \ldots, \lfloor N_{ZC}/N_{CS} \rfloor - 1, N_{CS} \neq 0 \quad \text{for unrestricted sets} \\ 0 & N_{CS} = 0 \quad \text{for unrestricted sets} \\ d_{start}\lfloor v/n_{shift}^{RA} \rfloor + (v \bmod n_{shift}^{RA})N_{CS} & v = 0, 1, \ldots, n_{shift}^{RA} n_{group}^{RA} + n_{shift}^{-RA} - 1 \quad \text{for restricted sets} \end{cases} \tag{2.10}$$

N_{CS} values can be found in table 2.1. The cyclic shift offset N_{CS} is dimensioned so that the ZCZ of the sequences guarantees the orthogonality of the PRACH sequences regardless of the delay spread and time uncertainty of the UEs. The minimum value of N_{CS} should therefore be the smallest integer number of sequence sample periods that is greater than the maximum delay spread and time uncertainty of an uplink non-synchronized UE, plus some additional guard samples. The parameter high-speed flag given by the higher layer determines if unrestricted set or restricted set shall be used. We are considering the case for only unrestricted sets.

Baseband Signal Generation

The time domain preamble sequence is generated by the following expression (3GPP 36.211, 2011)

$$s(t) = \beta_{PRACH} \sum_{k=0}^{N_{ZC}-1} \sum_{n=0}^{N_{ZC}-1} x_{u,v}(n) exp\left[-j\frac{2\pi nk}{N_{ZC}}\right] exp[j2\pi[k+\phi+K(k_0+0.5)]\Delta f_{RA}(t-T_{CP}) \quad (2.11)$$

where $0 \leq$ t $< T_{SEQ} + T_{CP}$, β_{PRACH} is the amplitude scaling factor, $k_0 = n_{PRB}^{RA}\ N_{SC}^{RB}$ - $N_{RB}^{UL}\ N_{SC}^{RB}$ / 2. Where n_{PRB}^{RA} is the location in frequency domain and is expressed as an RB number configured by higher layers and fulfilling $0 \leq n_{PRB}^{RA} \leq N_{PRB}^{UL}$ - 6. N_{PRB}^{UL} is the uplink system bandwidth (in RB). N_{SC}^{RB} is the number of sub-carriers per RB and is 12. $k = \frac{\Delta f}{\Delta f_{RA}}$ is the ratio of sub-carrier spacing between PUSCH and PRACH. ϕ is a fixed offset equal to 7 for formats 0-3. Both k and ϕ determine the frequency-domain location of the random access preamble within the physical resource blocks.

CHAPTER 3

PRACH IMPLEMENTATION

3.1 UE Transmitter

For the generation and transmission of the PRACH preamble, the process shown in figure 3.1 was followed. This process represents the generation of a baseband signal.

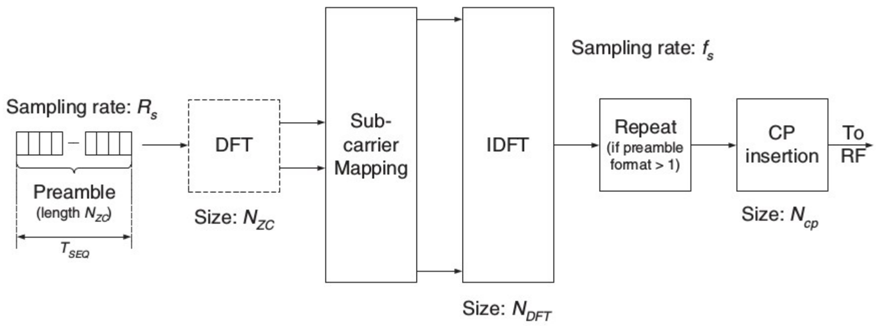

Figure 3.1: Functional structure of PRACH pramble transmitter

The DFT operation after the preamble sequence has been generated to reduce the PAPR and the IDFT operation is to do SC-FDMA modulation. The cyclic shift has been implemented in the time domain.

3.2 eNodeB PRACH Receiver

The whole procedure implemented as PRACH receiver in the eNodeB, can divided in three steps as shown in the figure 3.2. The CP removal block consists on removing the CP added by the UE to protect the PRACH sequence against Inter Symbol Interference (ISI) during the transmission.

- CP removal.
- Computation of PDP.
- Signature detection.

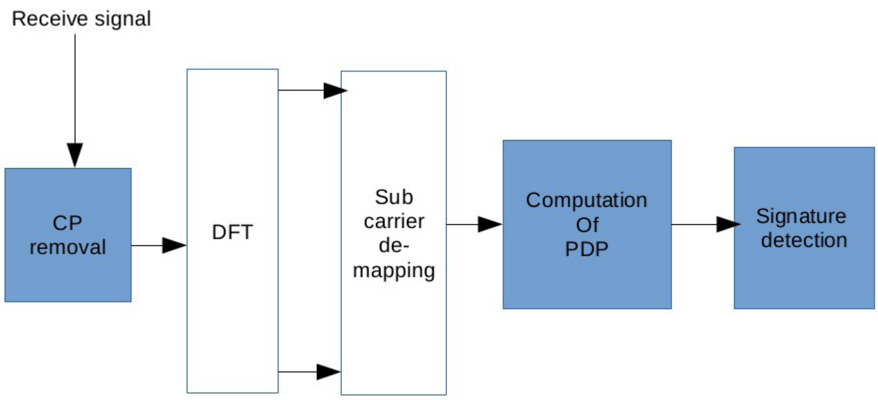

Figure 3.2: Functional structure of PRACH pramble receiver

3.3 Computation of Power Delay Profile

This step is a significant part of the receiver before the preamble detection is done (Stefania Sesia,Issam Toufik, Matthew Baker, 2011). It is based on the correlation algorithm between the received sequence and locally generated ZC root sequences as reference signals. Since the correlation can be computed by the convolution operation in time domain or the multiplication in frequency domain, we implement this step using the frequency domain correlation calculation following the process illustrated in figure 3.3.

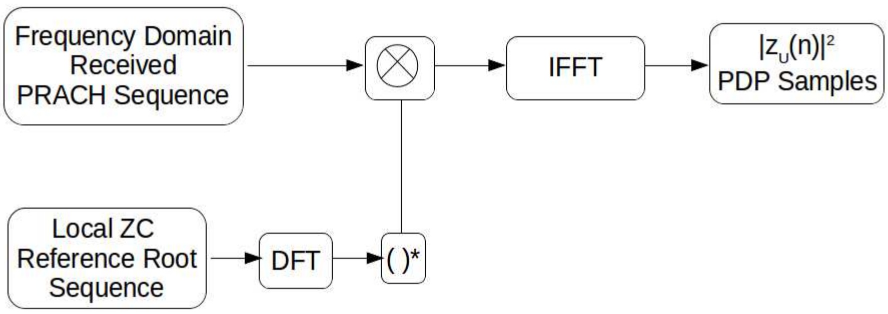

Figure 3.3: Computation of PDP

After cyclic prefix removal and FFT, the frequency domain PRACH sequences are de-mapped from the corresponding time frequency resource blocks. Next, the frequency domain correlation with each of the local ZC root sequences is carried out. For that local ZC root sequences are transformed to the frequency domain by the DFT and the conjugate operation is performed on the corresponding frequency domain sequence.

Then, the cyclic correlation is performed as follows:

$$Z_u[k] = Y[k]X_u^*[k] \tag{3.1}$$

Where $X_u[k]$ is the DFT of a local ZC root sequence, $Y[k]$ is the DFT of the received preamble sequence and $Z_u[k]$ is the frequency correlation result. We then carry out the IFFT operation to get $z_u[n]$ which will be a complex vector. To find the PDP samples we then take square of the absolute values of each of the element of this complex vector. This gives us in one shot the concatenated PDPs of all signatures derived from the same root sequence. We have seen that there are commonly 64 preamble sequences available in each LTE cell, and that we may need more than one ZC root sequences to produce all the possible preamble sequences, the local ZC root sequence used for the frequency correlation are only the unique root ZC sequences that are used to generate the all 64 preamble sequences.

3.4 Signature Detection

We use the fact that different PRACH signatures are generated from cyclic shifts of a common root sequence and hence the the frequency-domain computation of the PDP of a root sequence provides in one shot the concatenated PDPs of all signatures derived from the same root sequence. Therefore, the signature detection process consists of searching, within each ZCZ defined by each cyclic shift, the PDP peaks above a detection threshold over a search window and if the same is present then we continue forward and do peak detection which determines the existence of an access. figure 3.4 depicts the basic functions of Signature detector.

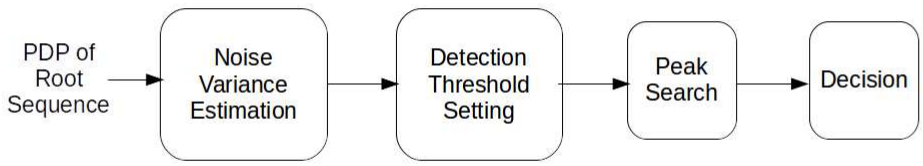

Figure 3.4: Signature Detector per root sequence

The process is implemented as follows:

- A ZC root sequence can generate several preamble sequences by cyclic shifts, and frequency-domain computation of PDP of a root sequence provides in one shot the concatenated PDPs of all signatures derived from the same root sequence. So, by separating the length of the PDP to several search windows, the search process and the detection can be performed in every window. The length of each search window is

$$ZCZ = \frac{N_{cs}}{N_{zc}} * \frac{SamplingFreq}{\Delta f_{RA}} \tag{3.2}$$

where sampling frequency depends upon the number of RBs available. $N_{ZC} = 839$ $\Delta f_{RA} = 1.25Khz$ and N_{cs} is defined through SIB2.

- Estimate the noise variance using 2 mean method from the PDP samples (Li and Wu, 2011) and (Hu *et al.*, 2012).

  Step a Find mean of all the PDP samples

  $$m = \frac{1}{N} \sum_{k=1}^{N} |z_u(n)|^2 \tag{3.3}$$

  Step b Calculate the mean of all the PDP samples that satisfy the condition $\leq scale * m$. The scale is theoretically derived for AWGN based on the false alarm probability. To cut off 10% of samples (highest peaks) , scale is set to 4. We use this as the scale and estimate the noise variance $\hat{\sigma}^2$.

  $$\hat{\sigma}^2 = \frac{1}{N_s} \sum_{|z_u(n)|^2 \leq scale*m} |z_u(n)|^2 \tag{3.4}$$

  where N_s is the number of samples that satisfy the condition.

- Set up the threshold of arrival signal: In the case of absence of preamble, $|z(n)|^2$ follows a chi square distribution with 2 degrees of freedom (Figueiredo *et al.*, 2013). With the target probability of false alarm as 0.001, we set the threshold as $\frac{\hat{\sigma}^2}{2} * 13.816$. The factor of 13.816 is taken from the chi square table in figure C.1. If in search window, the power level is below the threshold, the receiver decides that no RA preamble signature was transmitted in this window.

- If the peak power of the window is above threshold, then the receiver makes a decision that a RA preamble signature is present in the current window. It then finds the position of the sample with maximum value for this reference root sequence PDP samples and within which search window does it lie. It then calculates the cyclic shift and finds the transmitted preamble index.

CHAPTER 4

SIMULATION RESULTS

This chapter summarizes the practical phase of the project and the results of various tests performed. A total of four different simulations were performed for different channel models with known and unknown noise variances. All the four simulations differed mainly in setting up of the detection threshold. For the known variance case, we use the chi square distribution table to set up the threshold. For the unkwon variance case, we first estimate the variance and modify the threshold accordingly. The common aspects for all the cases are as mentioned below.

- The model for the simulation is specified as

$$Y = HX + N \tag{4.1}$$

  The test conditions are specified in (3GPP 36.141, 2011). where X is the transmitted signal, H is the channel coefficient, N is additive white gaussian noise and Y is the received signal.

- We carry out the simulation for different values of SNR. We transmit 10 subframes for each SNR and compute the Probability of detection for each value of SNR and plot the result. The same is carried out for one transmit and one receive antenna.

- We first specify the SIB2 parameters that will be required for generation of the RACH preamble and also the preamble index which need to be transmitted. The parameters used for the simulation are

- Generate the LTE SC-FDMA modulated RACH preamble as per the SIB2 parameters for transmission. The same is carried out by generation of Zadoff Chu sequence of length 839 as per the specified logical root sequence index. The generated ZC sequence is then cyclic shifted to generate the desired preamble signature. This preamble is then further modulated as LTE SC-FDMA via the process as shown in Figure 3.1 including addition of the cyclic prefix as per the specified preamble format, and the transmit wave is generated.

PARAMETER	VALUE
Format	0
Logical root sequence index	22
Cyclic shift index	1
Highspeed	0
Frequency offset	0
Preamble index	10

- The transmitted wave is then passed through four different channel models and is received at eNodeB.
  - Case1. AWGN with known variance
  - Case 2. Fading(ETU) + AWGN with known variance
  - Case 3. AWGN with unknown variance
  - Case 4. Fading(ETU) + AWGN with unknown variance
- The above four cases can be broadly divided into two cases
  - Known variance
  - Unknown variance
- The reference signals which are all the unique root sequences required for generation of all possible 64 preamble signatures are then generated at eNodeB.
- The CP from the received wave is removed and PDP of the received signal is computed with each of the reference signal.
- The threshold for the detection process is fixed using the PDP samples for the case of unknown variances.
- The PDP samples are then compared to a threshold to detect presence of RA preamble. If a signal is present then the position of the peak is identified which in turn gives the root sequence present and the cyclic shift of the same. Both of these are then used to compute the detected preamble index which is suspected to be transmitted.
- The detected preamble index is then compared with the transmitted preamble index and for every successful detection, the detected count is incremented.
- We then calculate the Probability of detection for each SNR and plot the result.
- The performance requirement for PRACH is specified in (3GPP 36.104, 2011) according to which the probability of detection shall be equal to or exceed 99% for the SNR levels listed below, we compare our results with the desired result and verify them.

Propagation Conditions	**SNR [dB]**				
	Format 0	**Format 1**	**Format 2**	**Format 3**	**Format 04**
AWGN	-14.2	-14.2	-16.4	-16.5	-7.2
ETU	-8.0	-7.8	-10.0	-10.1	-0.1

4.1 KNOWN VARIANCE

In this case, we assume that both the real and imaginary part of the uncorrelated complex noise which is added are standard normal Gaussian distributed i.e $\sim \mathcal{N}(0, 1)$ Now, in the absence of preamble transmission, the complex sample sequence received from the antenna is a complex random variable following standard normal distribution. The power envelope of this follows a chi square distribution with 2 degrees of freedom. For a probability of false alarm of 0.001, according to the chi square table, the threshold is 13.816. We set this as the threshold for the PDP samples and carry out our simulation.

4.1.1 Case 1. AWGN with known variance

The channel coefficient in this case is 1. The received signal is only corrupted with noise $\sim \mathcal{N}(0, 1)$. Under the null hypothesis, *i.e* when no signal is present, the receiver only receives the noise samples. The power envelope of this follows a chi square distribution with 2 degrees of freedom. The threshold is set to 13.816 and detection is carried out. The resultant probability of detection vs SNR result is as under.

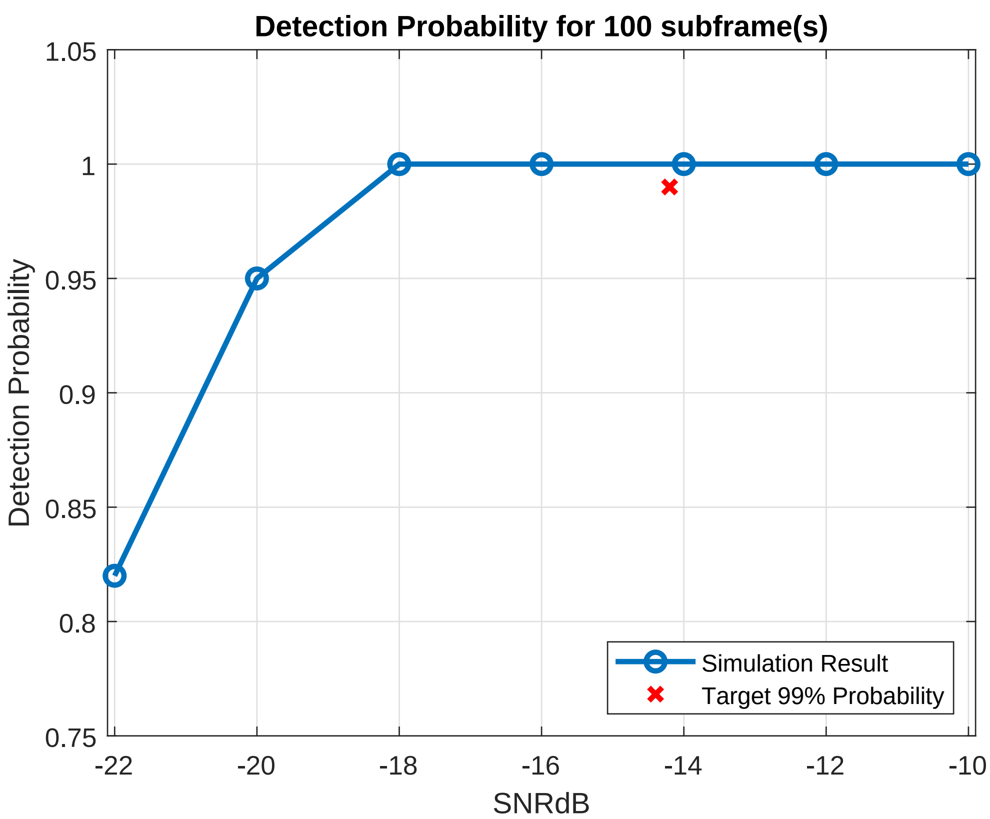

Figure 4.1: AWGN with known variance

4.1.2 Case 2. Fading(ETU) + AWGN with known variance

In this case, the channel undergoes multipath fading as per channel model 'ETU', the details of this model is mentioned in table D.1. We generate the fading model using the LTE toolbox function LTEfadingchannel() for single receive antenna. We then add the Gaussian noise N$\sim\mathcal{N}(0,1)$ to the faded signal. Since in case of null hypothesis, the power envelope of the received signal again follows a chi square distribution with 2 degrees of freedom, the threshold is set to 13.816 and detection is carried out. The resultant probability of detection vs SNR result is as under.

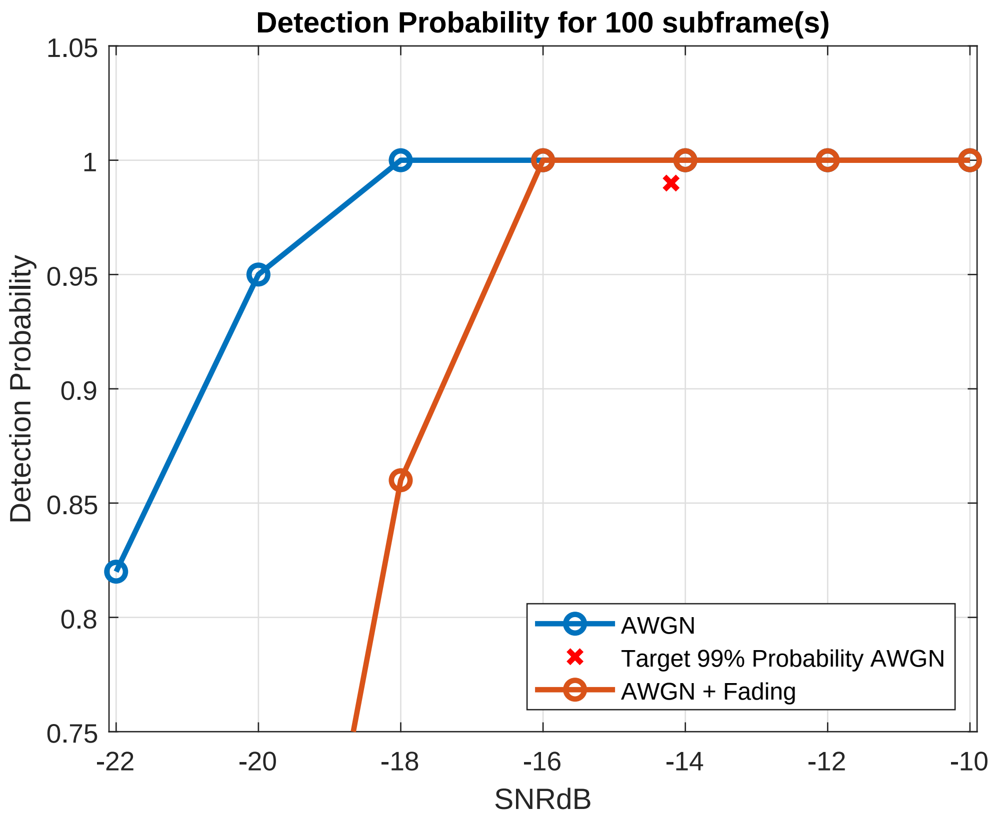

Figure 4.2: Fading(ETU) + AWGN with known variance

4.2 UNKNOWN VARIANCE

In this case, we assume that both the real and imaginary part of the uncorrelated complex noise which is added are Gaussian distributed $\sim\mathcal{N}(0,\sigma^2)$. Now, in the absence of preamble transmission, the complex sample sequence received from the antenna is a complex random variable following gaussian distribution with mean 0 and variance σ^2.

The power envelope of this follows a modified chi square distribution with 2 degrees of freedom. For a probability of false alarm of 0.001, the threshold is $\hat{\sigma}^2/2$ x 13.816, where $\hat{\sigma}$ is the estimated variance and 13.816 is from the Chi Square table. The variance is estimated using a two mean method. In the first step, we calculate the mean of all the PDP samples.

$$m = \frac{1}{N} \sum_{k=1}^{N} |z[n]|^2 \tag{4.2}$$

In the next step we calculate the mean of all the samples that satisfy the condition $\leq scale * m$. The scale is theoretically derived for AWGN based on the false alarm probability. We want to cut off 10% of samples (highest peaks),hence, scale is set to 4. we use this as the scale and calculate.

$$\hat{\sigma}^2 = \frac{1}{N_s} \sum_{|z[n]|^2 \leq scale*m} |z[n]|^2 \tag{4.3}$$

where N_s is the number of samples that satisfy the condition. We use this estimated variance to set the threshold for the PDP samples and carry out our simulation.

4.2.1 Case 3. AWGN with unknown variance

The channel coefficient in this case is 1. The received signal is only corrupted with noise $\sim \mathcal{N}(0, \sigma^2)$. The PDP samples are used to estimate the noise variance $\hat{\sigma}^2$ which is used to set the threshold. The resultant probability of detection vs SNR result is as shown in fig 4.3

4.2.2 Case 4. Fading(ETU) + AWGN with unknown variance

In this case, the channel undergoes multipath fading as per channel model 'ETU', we generate the fading model using the LTE toolbox function LTEfadingchannel() for single receive antenna. We then add the Gaussian noise N$\sim \mathcal{N}(0, \sigma^2)$. The threshold is set and the resultant probability of detection vs SNR result is as shown in fig 4.4

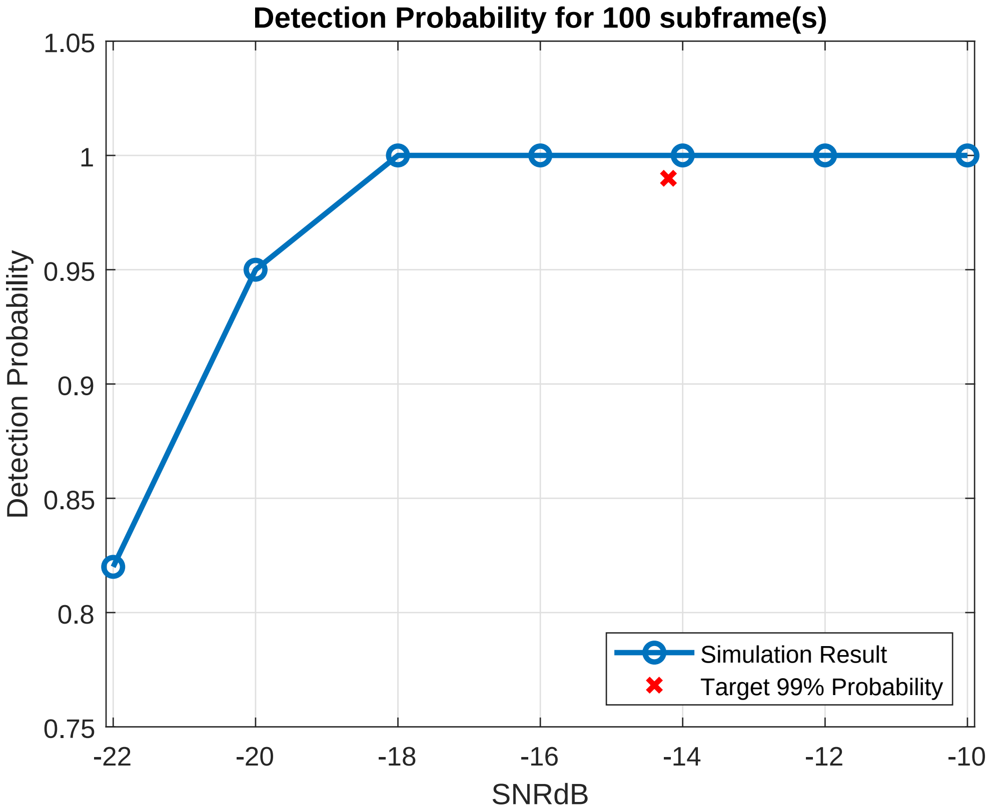

Figure 4.3: AWGN with unknown variance

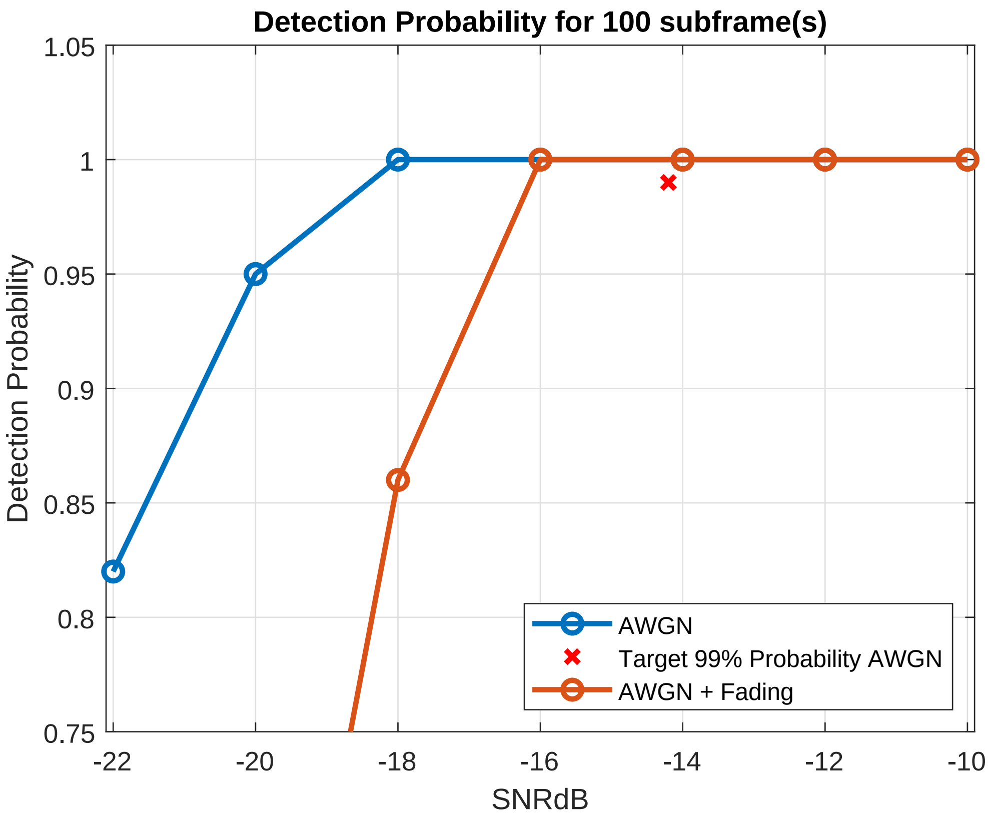

Figure 4.4: Fading(ETU) + AWGN with unknown variance

CHAPTER 5

CONCLUSION

Detection of Random Access is critical to ensure time synchronization in uplink transmission between the UE and eNodeB in LTE. In this project, we have been able to successfully simulate the generation of SC-FDMA modulated Random Access preamble using ZC sequences at the UE, its transmission through both AWGN and multipath fading channel models and precise detection at the eNB. The simulation was carried out for different SNRs and corresponding Probability of Detection for each of them was calculated. The project provided an insight in the ZC sequences and how its properties simplify the detection procedure resulting in faster and efficient detection of RA preambles thereby reducing the access delay. It was also inferred that the two mean method for estimation of the noise variance through the PDP samples provides a very reliable estimate of the true noise variance and hence, facilitates setting up of an accurate detection threshold. We, therefore observe that the results in the case of unknown variance are similar to that in the cases where the variance was known. The results obtained were well within the required parameters laid out in (3GPP 36.141, 2011) which specify the performance requirements in LTE.

APPENDIX A

PRACH Configuration Index

PRACH Configuration Index	Preamble Format	System frame number	Subframe number	PRACH Configuration Index	Preamble Format	System frame number	Subframe number
0	0	Even	1	32	2	Even	1
1	0	Even	4	33	2	Even	4
2	0	Even	7	34	2	Even	7
3	0	Any	1	35	2	Any	1
4	0	Any	4	36	2	Any	4
5	0	Any	7	37	2	Any	7
6	0	Any	1, 6	38	2	Any	1, 6
7	0	Any	2 ,7	39	2	Any	2 ,7
8	0	Any	3, 8	40	2	Any	3, 8
9	0	Any	1, 4, 7	41	2	Any	1, 4, 7
10	0	Any	2, 5, 8	42	2	Any	2, 5, 8
11	0	Any	3, 6, 9	43	2	Any	3, 6, 9
12	0	Any	0, 2, 4, 6, 8	44	2	Any	0, 2, 4, 6, 8
13	0	Any	1, 3, 5, 7, 9	45	2	Any	1, 3, 5, 7, 9
14	0	Any	0, 1, 2, 3, 4, 5, 6, 7, 8, 9	46	N/A	N/A	N/A
15	0	Even	9	47	2	Even	9
16	1	Even	1	48	3	Even	1
17	1	Even	4	49	3	Even	4
18	1	Even	7	50	3	Even	7
19	1	Any	1	51	3	Any	1
20	1	Any	4	52	3	Any	4
21	1	Any	7	53	3	Any	7
22	1	Any	1, 6	54	3	Any	1, 6
23	1	Any	2 ,7	55	3	Any	2 ,7
24	1	Any	3, 8	56	3	Any	3, 8
25	1	Any	1, 4, 7	57	3	Any	1, 4, 7
26	1	Any	2, 5, 8	58	3	Any	2, 5, 8
27	1	Any	3, 6, 9	59	3	Any	3, 6, 9
28	1	Any	0, 2, 4, 6, 8	60	N/A	N/A	N/A
29	1	Any	1, 3, 5, 7, 9	61	N/A	N/A	N/A
30	N/A	N/A	N/A	62	N/A	N/A	N/A
31	1	Even	9	63	3	Even	9

Figure A.1: Random access configuration for preamble formats 0-3, (3GPP 36.211, 2011)

For example, if PRACH Configuration Index is 10 as shown in figure A.1, then preamble format 0 is used.

APPENDIX B

Root Zadoff Chu Sequence

Logical root sequence number	Physical root sequence number u (in increasing order of the corresponding logical sequence number)
0–23	129, 710, 140, 699, 120, 719, 210, 629, 168, 671, 84, 755, 105, 734, 93, 746, 70, 769, 60, 779 2, 837, 1, 838
24–29	56, 783, 112, 727, 148, 691
30–35	80, 759, 42, 797, 40, 799
36–41	35, 804, 73, 766, 146, 693
42–51	31, 808, 28, 811, 30, 809, 27, 812, 29, 810
52–63	24, 815, 48, 791, 68, 771, 74, 765, 178, 661, 136, 703
64–75	86, 753, 78, 761, 43, 796, 39, 800, 20, 819, 21, 818
76–89	95, 744, 202, 637, 190, 649, 181, 658, 137, 702, 125, 714, 151, 688
90–115	217, 622, 128, 711, 142, 697, 122, 717, 203, 636, 118, 721, 110, 729, 89, 750, 103, 736, 61, 778, 55, 784, 15, 824, 14, 825
116–135	12, 827, 23, 816, 34, 805, 37, 802, 46, 793, 207, 632, 179, 660, 145, 694, 130, 709, 223, 616
136–167	228, 611, 227, 612, 132, 707, 133, 706, 143, 696, 135, 704, 161, 678, 201, 638, 173, 666, 106, 733, 83, 756, 91, 748, 66, 773, 53, 786, 10, 829, 9, 830
168–203	7, 832, 8, 831, 16, 823, 47, 792, 64, 775, 57, 782, 104, 735, 101, 738, 108, 731, 208, 631, 184, 655, 197, 642, 191, 648, 121, 718, 141, 698, 149, 690, 216, 623, 218, 621
204–263	152, 687, 144, 695, 134, 705, 138, 701, 199, 640, 162, 677, 176, 663, 119, 720, 158, 681, 164, 675, 174, 665, 171, 668, 170, 669, 87, 752, 169, 670, 88, 751, 107, 732, 81, 758, 82, 757, 100, 739, 98, 741, 71, 768, 59, 780, 65, 774, 50, 789, 49, 790, 26, 813, 17, 822, 13, 826, 6, 833
264–327	5, 834, 33, 806, 51, 788, 75, 764, 99, 740, 96, 743, 97, 742, 166, 673, 172, 667, 175, 664, 187, 652, 163, 676, 185, 654, 200, 639, 114, 725, 189, 650, 115, 724, 194, 645, 195, 644, 192, 647, 182, 657, 157, 682, 156, 683, 211, 628, 154, 685, 123, 716, 139, 700, 212, 627, 153, 686, 213, 626, 215, 624, 150, 689
328–383	225, 614, 224, 615, 221, 618, 220, 619, 127, 712, 147, 692, 124, 715, 193, 646, 205, 634, 206, 633, 116, 723, 160, 679, 186, 653, 167, 672, 79, 760, 85, 754, 77, 762, 92, 747, 58, 781, 62, 777, 69, 770, 54, 785, 36, 803, 32, 807, 25, 814, 18, 821, 11, 828, 4, 835
384–455	3, 836, 19, 820, 22, 817, 41, 798, 38, 801, 44, 795, 52, 787, 45, 794, 63, 776, 67, 772, 72 767, 76, 763, 94, 745, 102, 737, 90, 749, 109, 730, 165, 674, 111, 728, 209, 630, 204, 635, 117, 722, 188, 651, 159, 680, 198, 641, 113, 726, 183, 656, 180, 659, 177, 662, 196, 643, 155, 684, 214, 625, 126, 713, 131, 708, 219, 620, 222, 617, 226, 613
456–513	230, 609, 232, 607, 262, 577, 252, 587, 418, 421, 416, 423, 413, 426, 411, 428, 376, 463, 395, 444, 283, 556, 285, 554, 379, 460, 390, 449, 363, 476, 384, 455, 388, 451, 386, 453, 361, 478, 387, 452, 360, 479, 310, 529, 354, 485, 328, 511, 315, 524, 337, 502, 349, 490, 335, 504, 324, 515
514–561	323, 516, 320, 519, 334, 505, 359, 480, 295, 544, 385, 454, 292, 547, 291, 548, 381, 458, 399, 440, 380, 459, 397, 442, 369, 470, 377, 462, 410, 429, 407, 432, 281, 558, 414, 425, 247, 592, 277, 562, 271, 568, 272, 567, 264, 575, 259, 580
562–629	237, 602, 239, 600, 244, 595, 243, 596, 275, 564, 278, 561, 250, 589, 246, 593, 417, 422, 248, 591, 394, 445, 393, 446, 370, 469, 365, 474, 300, 539, 299, 540, 364, 475, 362, 477, 298, 541, 312, 527, 313, 526, 314, 525, 353, 486, 352, 487, 343, 496, 327, 512, 350, 489, 326, 513, 319, 520, 332, 507, 333, 506, 348, 491, 347, 492, 322, 517
630–659	330, 509, 338, 501, 341, 498, 340, 499, 342, 497, 301, 538, 366, 473, 401, 438, 371, 468, 408, 431, 375, 464, 249, 590, 269, 570, 238, 601, 234, 605
660–707	257, 582, 273, 566, 255, 584, 254, 585, 245, 594, 251, 588, 412, 427, 372, 467, 282, 557, 403, 436, 396, 443, 392, 447, 391, 448, 382, 457, 389, 450, 294, 545, 297, 542, 311, 528, 344, 495, 345, 494, 318, 521, 331, 508, 325, 514, 321, 518
708–729	346, 493, 339, 500, 351, 488, 306, 533, 289, 550, 400, 439, 378, 461, 374, 465, 415, 424, 270, 569, 241, 598
730–751	231, 608, 260, 579, 268, 571, 276, 563, 409, 430, 398, 441, 290, 549, 304, 535, 308, 531, 358, 481, 316, 523

Figure B.1: Root Zadoff-Chu sequence order for preamble formats 0 – 3

APPENDIX C

CHI Square Table

v	α					
	0.100	0.050	0.025	0.010	0.005	0.001
1	2.7055	3.8415	5.0239	6.6349	7.8794	10.8276
2	4.6052	5.9915	7.3778	9.2103	10.5966	13.8155
3	6.2514	7.8147	9.3484	11.3449	12.8382	16.2662
4	7.7794	9.4877	11.1433	13.2767	14.8603	18.4668
5	9.2364	11.0705	12.8325	15.0863	16.7496	20.5150
6	10.6446	12.5916	14.4494	16.8119	18.5476	22.4577
7	12.0170	14.0671	16.0128	18.4753	20.2777	24.3219
8	13.3616	15.5073	17.5345	20.0902	21.9550	26.1245
9	14.6837	16.9190	19.0228	21.6660	23.5894	27.8772
10	15.9872	18.3070	20.4832	23.2093	25.1882	29.5883
11	17.2750	19.6751	21.9200	24.7250	26.7568	31.2641
12	18.5493	21.0261	23.3367	26.2170	28.2995	32.9095
13	19.8119	22.3620	24.7356	27.6882	29.8195	34.5282
14	21.0641	23.6848	26.1189	29.1412	31.3193	36.1233
15	22.3071	24.9958	27.4884	30.5779	32.8013	37.6973
16	23.5418	26.2962	28.8454	31.9999	34.2672	39.2524
17	24.7690	27.5871	30.1910	33.4087	35.7185	40.7902
18	25.9894	28.8693	31.5264	34.8053	37.1565	42.3124
19	27.2036	30.1435	32.8523	36.1909	38.5823	43.8202
20	28.4120	31.4104	34.1696	37.5662	39.9968	45.3147
21	29.6151	32.6706	35.4789	38.9322	41.4011	46.7970
22	30.8133	33.9244	36.7807	40.2894	42.7957	48.2679
23	32.0069	35.1725	38.0756	41.6384	44.1813	49.7282
24	33.1962	36.4150	39.3641	42.9798	45.5585	51.1786
25	34.3816	37.6525	40.6465	44.3141	46.9279	52.6197
26	35.5632	38.8851	41.9232	45.6417	48.2899	54.0520
27	36.7412	40.1133	43.1945	46.9629	49.6449	55.4760
28	37.9159	41.3371	44.4608	48.2782	50.9934	56.8923
29	39.0875	42.5570	45.7223	49.5879	52.3356	58.3012
30	40.2560	43.7730	46.9792	50.8922	53.6720	59.7031
31	41.4217	44.9853	48.2319	52.1914	55.0027	61.0983
63	77.7454	82.5287	86.8296	92.0100	95.6493	103.4424
127	147.8048	154.3015	160.0858	166.9874	171.7961	181.9930
255	284.3359	293.2478	301.1250	310.4574	316.9194	330.5197
511	552.3739	564.6961	575.5298	588.2978	597.0978	615.5149
1023	1081.3794	1098.5208	1113.5334	1131.1587	1143.2653	1168.4972

Figure C.1: Chi square table for desired Probablility of False alarm

Here α is the desired probability of false alarm, v is the degree of freedom and the table values indicate the threshold.

APPENDIX D

ETU Channel Model

TAP	Excess tap delay[ns]	Relative Power[dB]
1	0	-1.0
2	50	-1.0
3	120	-1.0
4	200	-0.0
5	230	-0.0
6	500	-0.0
7	1600	-3.0
8	2300	-5.0
9	5000	-7.0

Table D.1: ETU Channel Model

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