Implementation of 5G NR Random Access Procedure

Internship report submitted in partial fulfilment of the requirements

for the degree of B.Tech + M.Tech ESD

by

M Abhay Vardhan
(Roll No: ESD15I015)

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

INDIAN INSTITUTE OF INFORMATION TECHNOLOGY,

DESIGN AND MANUFACTURING, KANCHEEPURAM

September 2019

Certificate

I, **M Abhay Vardhan**, with Roll No: **ESD15I015** hereby declare that the material presented in the Project Report titled **Implementation of 5G NR Random Access Procedure** represents original work carried out by me in the **5G testbed lab** at the **Indian Institute of Technology,Madras** during the period of **6/5/2019–6/10/2019**. With my signature, I certify that:

- I have not manipulated any of the data or results.
- I have not committed any plagiarism of intellectual property. I have clearly indicated and referenced the contributions of others.
- I have explicitly acknowledged all collaborative research and discussions.
- I have understood that any false claim will result in severe disciplinary action.
- I have understood that the work may be screened for any form of academic misconduct.

Date: Student's Signature

In my capacity as supervisor of the above-mentioned work, I certify that the work presented in this Report is carried out under my supervision, and is worthy of consideration for the requirements of internship work during the period 6/5/2019 to 6/10/2019.

Advisor's Name: Advisor's Signature

Abstract

5G is the fifth generation cellular network technology. From 3G to 5G world has seen numerous improvements in performance. The fast revolution in mobile communications changes our lifestyle, work, etc. This report focuses on Random Access Procedure or initial access procedure in 5G NR, it is done to get initial uplink grants for UE(user equipment) and to acquire uplink synchronization with gNB(network).In most of the communication wired or wireless, the most important precondition is to establish the timing synchronization between the receiver and transmitter. For the downlink, the synchronization signals get broadcast to all UEs and it is transmitted all the time with a certain interval. The broadcasting is not efficient in case of uplink as it causes a lot of inference to other UEs and its wastage of energy. There are two types of Random Access procedures contention-based and non-contention based. Contention free Random Access procedure occurs in case of handover that is when UE was previously synchronized to another gNB. Contention based RA is applied when UE is not yet synchronized or lost its synchronization. Both the procedures rely on the transmission of random access preamble from UE to gNB. The preamble is transmitted on specific time/frequency resources which are indicated by gNB to UEs on control channels. Random access procedure is used in many cases which include initial access, RRC Connection Re-establishment procedure, handover, Transition from RRC INACTIVE, Request for Other SI(system information), Beam failure recovery. This report contains the basic implementation of the Random Access procedure as mentioned in (3GPP TS 38.321 version 15.0.0)

Acknowledgements

I would extend my sincerest gratitude to the Indian Institute of Technology Madras and Dr.Krishna Jagannathan for giving me an opportunity to work for the 5G testbed lab as an intern for completing the five months mandatory internship.

I would like to express to my gratitude to the people who helped me directly and indirectly to complete this internship successfully.

I wish to express my thanks to Dr. Maheshwaran P who supported me for the successful completion of my internship during this tenure.

I thank all the team members of RACH for making me feel like a part of their team. I would personally like to thank all of them for their continued support and guidance.

I am grateful to my college, Indian Institute of Information Technology – Design & Manufacturing, Kancheepuram for allowing me to do an internship at 5G testbed lab.

Contents

Certificate **i**

Abstract **ii**

Acknowledgements **iii**

Contents **iv**

List of Figures **vi**

Abbreviations **vii**

1 Introduction **1**
1.1 Background 2
1.2 Motivation 6
1.3 Objectives of the work 7

2 Methodology **8**
2.1 Random Access procedure initialization 8
2.2 Resource Selection and Preamble Transmission 9
2.2.1 Selection of the SSB or CSI-RS 9
2.2.2 Random Access Preamble transmission 9
2.3 Random Access Response Reception 10

3 Work Done **11**
3.1 Sending and receiving preamble 12
3.1.1 Preamble assignment 12
3.1.2 Decoding the RACH-ConfigDedicated information element 12
3.2 Random Access Response 13
3.3 Random Access Response Reception 13

4 Results and Discussions **15**

4.1 gNB Operations 15
4.2 UE Operations 16
4.3 Assumptions 17

5 Conclusions and Extensions **18**

A ASN.1 **19**

B Basic Encoding Rules **21**

Bibliography **23**

List of Figures

1.1 Overall Random Access Procedure 2
1.2 MAC structure overview 3
1.3 DL MAC PDU structure 4
1.4 MAC RAR 5
1.5 UE Contention Resolution Identity MAC CE 6

3.1 Random Access Procedure for CFRA 11

Abbreviations

BWP	**B**andwidth **P**art
CBRA	**C**ontention **B**ased **R**andom **Access**
CE	**C**ontrol **E**lement
CFRA	**C**ontention **F**ree **R**andom **A**ccess
CSI	**C**hannel **S**tate **I**nformation
CSI-RS	CSI **R**eference **S**ignal
gNB	Next **G**eneration **N**ode**B**
NUL	**N**ormal **U**plink
RAR	**R**andom **A**ccess **R**esponse
RACH	**R**andom **A**ccess **C**hannel
PRACH	**P**hysical **R**andom **A**ccess **C**hannel
RNTI	**R**adio **N**etwork **T**emporary **I**dentifier
RS	**R**eference **S**ignal
RSRP	**R**eference **S**ignal**R**eceived **P**ower
SpCell	**S**pecial **C**ell
SSB	**S**ynchronization **S**ignal **B**lock
SUL	**S**upplementary **U**plink
TC-RNTI	**T**emporary **C**ell RNTI
UE	**U**ser **E**quipment

Chapter 1

Introduction

5G NR (New Radio) is the latest cellular wireless technology developed to deliver 10 times fast data rate compare to LTE (i.e. 4G) technology. 5G NR follows 3GPP specifications release 15 and above. Random Access Procedure means a set of processes between UE and gNB(network). It is mainly used for uplink synchronization and obtain specific ID (C-RNTI)for the radio access communication. A 5G NR User Equipment (UE) can only be scheduled for uplink transmission if its uplink transmission timing is synchronized.

The 5G NR Random Access Channel (RACH) plays an important role as an interface between non-synchronized UEs and gNB. Random access is generally performed when the UE powers-on or turns-on from sleep mode (RRC Connection Re-establishment procedure) or during the handover from one cell to another or when it loses uplink timing synchronization or to request for other SI (system information)or Beam failure recovery. Another purpose of the Rach procedure is to obtain the resources for message 3(Msg3). The overall flow of the Random Access Procedure is given in Figure 1.1.

There are two types of Random Access Procedures contention-based and non-contention based. In contention-based random access procedure UE when transmitting PRACH preamble, out of 64 preambles it chooses anyone randomly, hence there is a possibility that multiple UEs can choose the same preamble to transmit.This kind of collision is called contention, and the rach process for this type of collision is a contention-based random access procedure. In case of the contention-free Random Access procedure gNB informs the UE what preamble it must choose. Contention free Random Access Procedure occurs only in specific cases like handover etc.

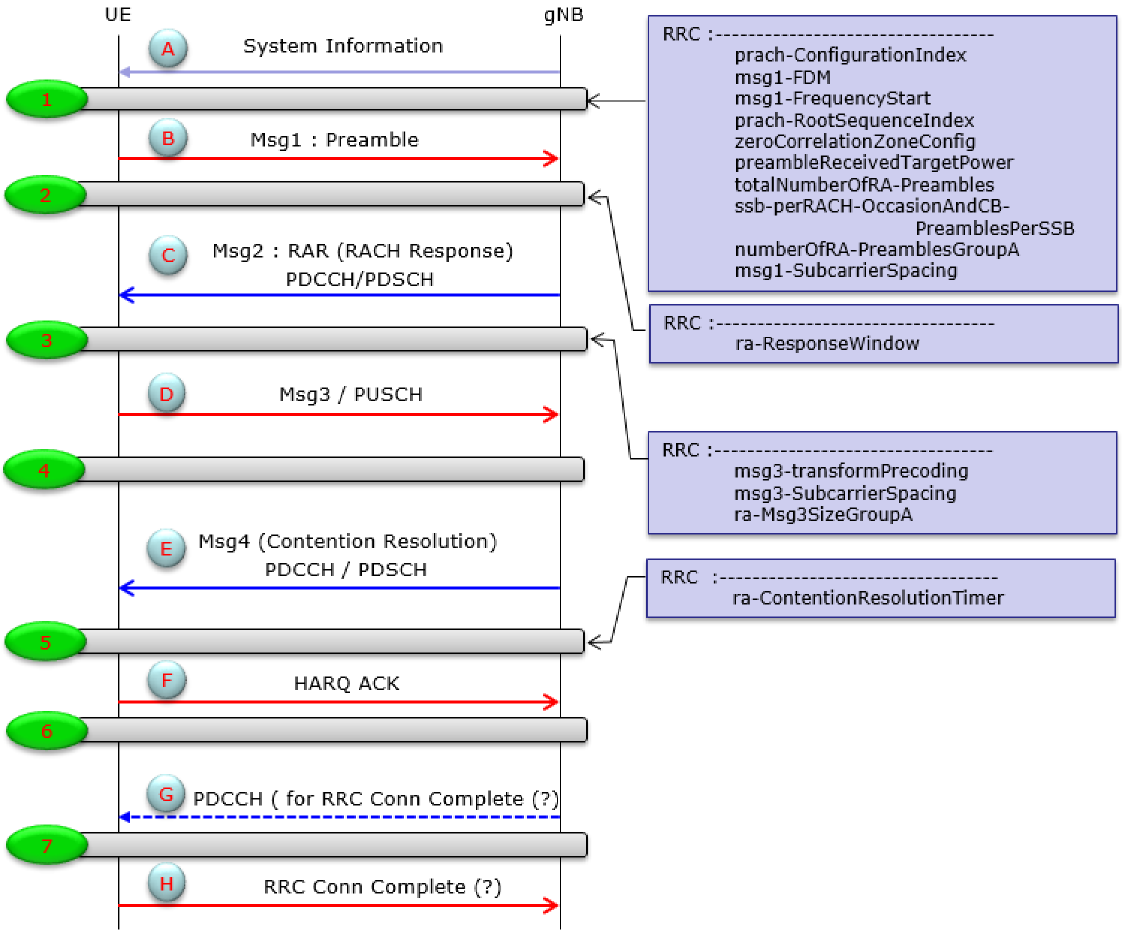

FIGURE 1.1: Overall Random Access Procedure

The fundamental difference between the LTE and NR in the case of Random Access procedure is that in NR beam forming occurs before transmitting PRACH preamble. UE has to detect and select the best beam available for the RACH process.

1.1 Background

5G wireless technology is similar to other cellular wireless technologies such as 2G, 3G, and 4G. It supports the same, as well as advanced features, compares to backward wireless technologies. It supports various frequency bands across the world including above 6 GHz (mm-wave bands), below 6 GHz and below 1 GHz. MAC sublayer is present in layer 2 of 5G architecture. Rach is an independent channel present in MAC architecture as seen in Figure 1.2.MAC layer uses transport channels. Transport channels are used for communication between the MAC - PHY layer interface. Denotes "how is" information carried, such as encoding options, error correction mechanism, modulation scheme, etc.

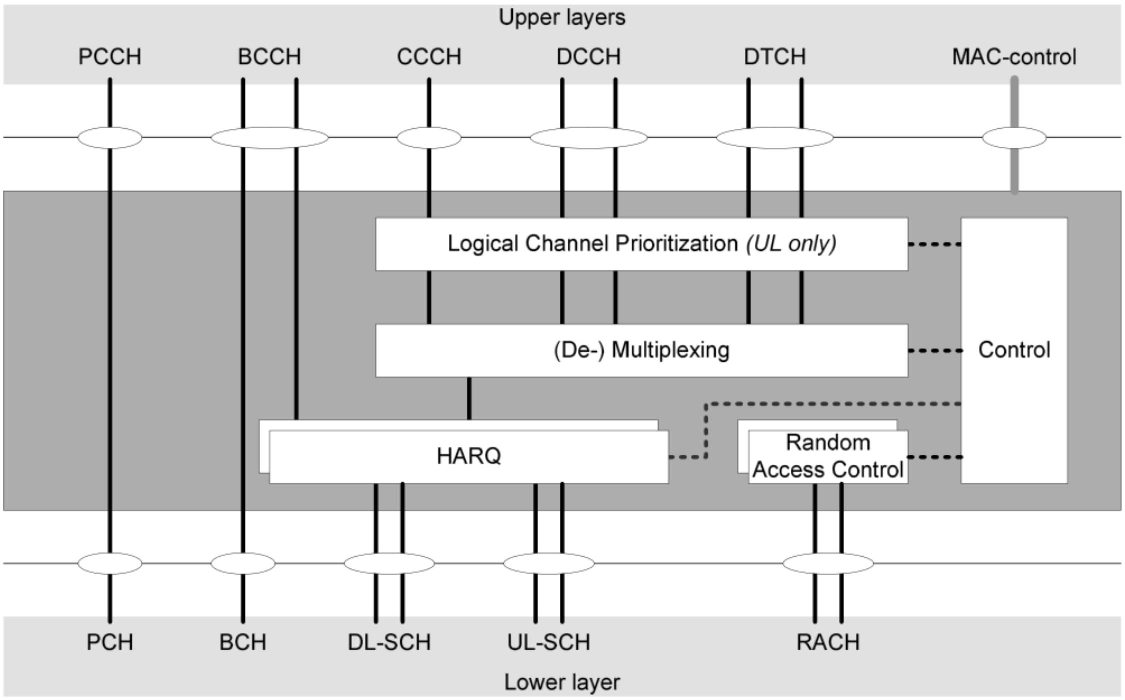

FIGURE 1.2: MAC structure overview

The MAC entity of UE handles the following transport channels:

- Broadcast Channel (BCH)
- Downlink Shared Channel(s) (DL-SCH)
- Paging Channel (PCH)
- Uplink Shared Channel(s) (UL-SCH)
- Random Access Channel(s) (RACH)

1. MAC PDU :PDU stands for protocol data unit, there are different types of PDUs in 5G. PDU term is used when the information is sent from the selected layer to

the lower layers.MAC PDU from gNB is sent to PHY layer and then to the UE MAC.Figure 1.3 shows the basic structure of MAC PDU.A MAC PDU is a bit string that is byte aligned (i.e. multiple of 8 bits) in length.A MAC SDU is a bit string that is byte aligned (i.e. multiple of 8 bits) in length. A MAC SDU is included into a MAC PDU from the first bit onward.A MAC CE is a bit string that is byte aligned (i.e. multiple of 8 bits) in length. A MAC subheader is a bit string that is byte aligned (i.e. multiple of 8 bits) in length. Each MAC subheader is placed immediately in front of the corresponding MAC SDU, MAC CE, or padding as mentioned in (3GPP TS 38.321 version 15.0.0)

A MAC PDU consists of one or more MAC subPDUs. Each MAC subPDU consists of one of the following:

- A MAC subheader only (including padding)
- A MAC subheader and a MAC SDU
- A MAC subheader and a MAC CE
- A MAC subheader and padding

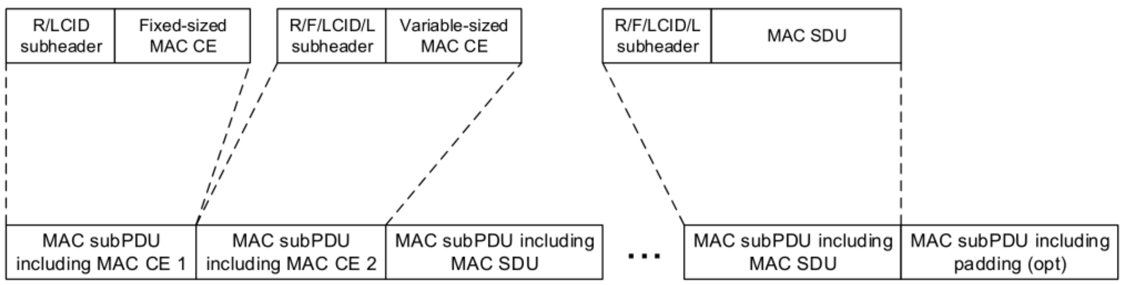

Figure 1.3: DL MAC PDU structure

2. MAC subheader for Random Access Response: The MAC subheader consists of the following fields:

   - E: The Extension field is a flag which indicates if the MAC subPDU including this MAC subheader is the last MAC subPDU or not in the MAC PDU.
   - T: The Type field is a flag indicating whether the MAC subheader contains a Random Access Preamble ID or a Backoff Indicator.
   - R: Reserved bit, set to ”0”.

- BI: The Backoff Indicator field identifies the overload condition in the cell. The size of the BI field is 4 bits.
- RAPID: The Random Access Preamble Identifier field identifies the transmitted Random Access Preamble.

3. MAC payload for Random Access Response : The MAC RAR is of fixed size as depicted in Figure 1.4 and consists of the following fields:

   - R: Reserved bit, set to "0".
   - Timing Advance Command: The Timing Advance Command field indicates the index value used to control the amount of timing adjustment that the MAC entity has to apply. The size of the Timing Advance Command field is 12 bits.
   - UL Grant: The Uplink Grant field indicates the resources to be used on the uplink for message 3. The size of the UL Grant field is 27 bits.
   - Temporary C-RNTI: The Temporary C-RNTI field indicates the temporary identity that is used by the MAC entity during Random Access. The size of the Temporary C-RNTI field is 16 bits.

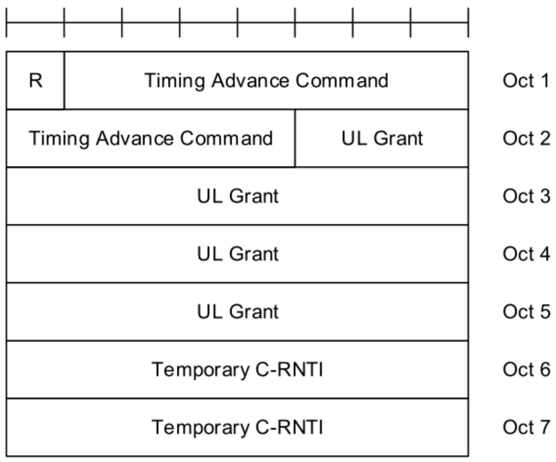

FIGURE 1.4: MAC RAR

4. UE Contention Resolution Identity MAC CE : It is identified is identified by MAC subheader with LCID 62. It has fixed size of 48 bits as shown in Figure 1.5.This field contains the UL CCCH SDU. If the UL CCCH SDU is longer than 48 bits, this field contains the first 48 bits of the UL CCCH SDU.

Reference signals: They are used by UE to determine power level information of the downlink channel. UE uses this power level information as a "reference" to take several measurements, which aids in determining channel conditions, handover scenario and even cell selection. There are different types of Reference signals whose location in frequency/time axis is based upon the antenna ports used for transmission of these signals.

1.2 Motivation

The purpose of Random Access Procedure as mentioned earlier is

- Achieve UP link synchronization between UE and gNB
- Obtain the resource for Message 3 (e.g, RRC Connection Request)

In all types of communication the most important pre condition is that to establish the timing synchronization between the receiver and transmitter. In case of 5G NR this is done by Random access procedure.The synchronization process should happen only when it is necessary and it should be dedicated to only a specific UE.

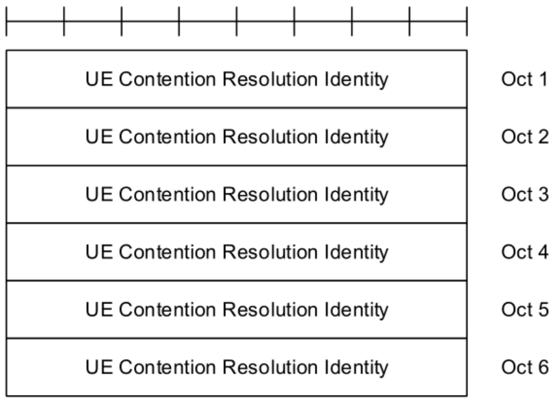

Figure 1.5: UE Contention Resolution Identity MAC CE

1.3 Objectives of the work

To implement basic Random Access Procedure in case of handover (contention free).

Chapter 2

Methodology

2.1 Random Access procedure initialization

After receiving the system information, UE decodes the RACH-ConfigDedicated information element. The MAC layer of UE will

- flush message 3 buffer since it is used in the contention resolution step.
- set PREAMBLE_ TRANSMISSION_ COUNTER to 1, PREAMBLE_ POWER_ RAMPING_ COUNTER to 1, PREAMBLE_ BACKOFF to 0 ms.
- If the carrier to be used is explicitly specified use the specified carrier and set PMAX value of the signaled carrier.
- If the carrier to be used is not specified and Random Access Procedure is configured with SUL then select SUL carrier. Set PMAX value related to the SUL carrier else uses NUL carrier. Set PMAX value related to the NUL carrier.
- set SCALING_ FACTOR_ BI value as configured in Rach-config Dedicated.

2.2 Resource Selection and Preamble Transmission

For contention-free Random Access Procedure preamble to transmit is given by gNB in system information, more specifically in CFRA (contention-free random access) of RACH-ConfigDedicated information element the UE will decode the RACH-ConfigDedicated information element and sends the preamble present in it. Before this UE will implement beam selection based on the threshold values.

2.2.1 Selection of the SSB or CSI-RS

UE will measure the RSRP values using the MeasObjectNR information element for a particular SSB or CSIRS index present in the Rach-ConfigDedicated information element.

If SSB is explicitly provided in the RACH-ConfigDedicated information element, UE has to choose the SSB for which the SS-RSRP is greater than rsrp-ThresholdSSB amongst the associated SSBs, then select the preamble present in the respective SSB.

Else if CSIRS are explicitly provided in the RACH-ConfigDedicated information element, UE has to choose the CSI-RS for which the CSI-RSRP is greater than rsrp-ThresholdCSI-RS amongst the associated CSI-RSs, then select the preamble present in the respective CSI-RS.

In the case of the CBRA preamble index is chosen by the UE randomly from the available total number of RA preambles. After which UE MAC has to inform UE PHY about the next available PRACH OCCASION.

2.2.2 Random Access Preamble transmission

After selecting the preamble to transmit ,set parameters related to power (PREAMBLE_ POWER_ RAMPING_ COUNTER,PREAMBLE_ RECEIVED_ TARGET_ POWER) accordingly as specified in (3GPP TS 38.321 version 15.0.0).Send the parameters to PHY layer.

2.3 Random Access Response Reception

After preamble transmission, UE will start the ra-ResponseWindow configured in RACH-ConfigGeneric present in the RACH-ConfigDedicated information element.

- UE can receive MAC PDU (sub PDU with RAPID alone Or RAPID + RAR)
- Check if RAPID in received RAR is equal to the assigned preamble index
- If the preamble configured for SI request check only RAPID Random Access procedure successful send ACK message to the upper layers.
- Check if it is SRS only Scell, then ignore the received UL GRANT field in RAR.
- Decode and process the UL GRANT field present in RAR, send UL GRANT data to the lower layers.
- If the preamble belongs to the group of CB based preambles continue the Random Access Procedure else Random Access Procedure is successful

Chapter 3

Work Done

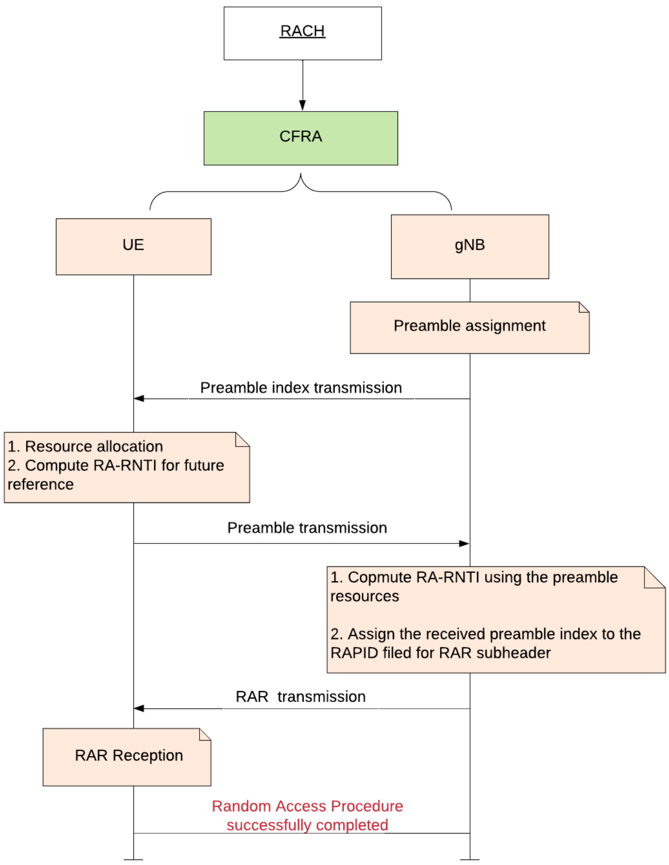

FIGURE 3.1: Random Access Procedure for CFRA

3.1 Sending and receiving preamble

Implementation of sending and receiving data between UE and gNB is done using sockets. This section explains how the preamble is assigned and sent to the UE, how the UE will receive it.

- gNB accepts connections to the master socket.
- When a UE connects gNB will assign a preamble and send it to the respective UE
- After receiving the preamble, UE will proceed to the resource selection and then preamble transmission.

3.1.1 Preamble assignment

- The preamble assignment is done by the function preamble_ assigner it takes max number of UEs as a parameter, and returns the preamble index when UE connects to the gNB.
- The assigned preamble is then used to fill the CFRA information element in which any one of the SSBs and CSIRs.
- Then the RACH-ConfigDedicated information element including CFRA is encoded using ber encoding.

3.1.2 Decoding the RACH-ConfigDedicated information element

The received RACH-ConfigDedicated information element is then decoded using ber decoding. UE then selects the best beam according to the random access resource selection criteria.

UE PHY layer will measure the RSRP measurements for all the available SSBs and CSIRSs. Out of which UE will select the one which crosses the rsrp threshold value.

UE MAC will access the MeasObjectNR information element to get the measurement results (RSRP values). Using the SSB index or CSIRS index present in

Rach-ConfigDedicated information element UE will check the RSRP values of a particular SSB or CSIRS.

UE will assign its preamble index equal to the preamble index present in the qualified SSB or CSIRS. The selected preamble index is then used for random access preamble transmission.

UE will send the preamble index to the gNB and starts ra-response window timer.

3.2 Random Access Response

After receiving the preamble from UE, gNB should send UE random access response. This process is the most important step in the entire Random Access Procedure. The timing advance value and few other important parameters are set by the gNB for a particular UE. Random Access Response payload will follow the MAC PDU format. There can be two cases possible after receiving preamble from UE

- gNB can send only RAPID when UE is requesting for system information(SI request). In this case, UE sends the preambles reserved for SI request.
- RAPID plus RAR, when UE is in RRC connected state or in RRC ideal state.

In RAR payload gNB also sends the TCRNTI value assigned to the UE. gnB waits for the connections from UEs and fills up the MAC PDU with (RAPID + RAR) s. It updates the MAC PDU whenever a UE connects. Finally, it sends one bid MAC PDU for all the UEs.

3.3 Random Access Response Reception

After receiving the RAR response UE will read the received MAC PDU, it searches for a RAPID that matches the UE's preamble once it finds a match it decodes the rar payload and uses the information present inside it for further communication (timing advance command, TCRNTI, etc).

In the case of CBRA, gNB doesn't assign the preamble to the UE. After RAR reception UE then will send CCCH SDU as message 3 to gNB. gNB then assigns the value present in CCCH SDU to the contention resolution identity present in MAC CE.

Chapter 4

Results and Discussions

4.1 gNB Operations

- Generate the required header files and the files required for encoding and decoding using the ASN1c compiler.
- After generating header files along with standard files for encoding and decoding asn structures, compile the gNB code (code in which the main function is present) along with all other c files generated by ASN1c compiler.
- Mention the file in which encoded data must be stored while compiling.
- Then Master socket is created and bound for the given port, gNB code acts as a server for a particular port and has a unique IP in the network.
- Master socket listens(checks if any UE gets connected to the socket). When a UE gets connected it will store the sockfd(socket file descriptor) of the connected UE in an array of client sockets.
- Later preamble assignment takes place for the connected UE and the encoded data is stored in the file mentioned during compiling. The file is sent to UE which connected earlier by using the sockfd. This step is repeated whenever a new UE gets connected.
- gNB waits for preamble transmission by the UE. When it receives the preamble it checks whether the preamble belongs to the SI request preambles or CFRA preambles

or CBRA preamble. Using the preamble as RAPID it updates the MAC PDU accordingly.

- Finally gNB broadcasts the MAC PDU, the process ends if it is CFRA.
- In the case of CBRA, gNB receives CCCH SDU value sent by the UE and store it in MAC CE for contention resolution. Then gNB sends the MAC PDU with LCID meant for contention resolution.

4.2 UE Operations

- Generate the required header files and the files required for encoding and decoding using the ASN1c compiler.
- After generating header files along with standard files for encoding and decoding asn structures, compile the UE code (code in which the main function is present) along with all other c files generated by ASN1c compiler.
- During compiling we should give the file name from which encoded data can be read, UE code reads the file. Decode the data from the file and store it in the respective structures. Here, it mainly stores the preamble index assigned by gNB along with other parameters present in the Ranch-ConfigDedicated information element.
- Then the socket is created and bound for a given port, UE acts as a client for a particular port and has a unique IP in the network.
- UE then checks which SSB will cross threshold values using the MeasObjectNR information element. After which UE selects the preamble present in that SSB.
- UE sends the preamble index to the server(by its IP), both server and client programs must use the same port for proper transmission.
- After sending the preamble index UE code will start a timer and waits for Random Access Response (RAR). If UE doesn't receive RAR within the ra-response window time then UE will re-transmit the preamble with increased power.

- When RAR is received within the time frame, UE then search for its preamble value in RAPID of the MAC PDU received.Once the UE finds the RAPID matching its preamble it then decodes the RAR payload and informs the UL GRANT values to the lower layer. In the case of CFRA, the Random Access Procedure is successful at this step.
- In case of CBRA UE sends the CCCH SDU value to the gNB, Suppose when the collision occurs both UEs will decode the same timing advance command but only one UE's CCCH SDU will be received by the gNB.
- After sending CCCH SDU UE will start its contention resolution timer and waits for the MAC PDU which has contention resolution identity. Upon receiving the MAC PDU UE checks whether the CCCH SDU value is the same as the MAC CE contention resolution identity if both the values are the same then the Random Access Procedure is successful.

4.3 Assumptions

Following assumptions are made during the implementation of the Random Access Procedure

- Rach-configDedicated values are set by the MAC layer so that the gNB knows which preamble is assigned.
- Instead of transmitting preamble sequence by which gNB calculates RA RNTI and then preamble index, UE is directly sending the preamble index as calculation of RA RNTI requires parameters from PHY layer.
- MeasObjectNR information element parameters are already set by the PHY layer.
- gNB waits till some specific users connect to update MAC PDU for RAR. If MAC PDU is full then it sends the RAR immediately.
- buffer size of MAC PDU is 128 including padding bits. The UL GRANT values are received from the PHY layer for a particular UE.

Chapter 5

Conclusions and Extensions

Random Access Procedure is one of the important procedures in 5G NR it is mostly done by the MAC layer of the UE. Random Access Procedure can be of contention-free and contention. In the case of the contention-free, UE will choose the preamble index given by the gNB. Assigning the preamble index to UE is done by gNB.In case of a contention-based Random Access, Procedure collisions occur because UE will choose the preamble randomly, so multiple UEs can choose the same preamble. Contention resolution is done by using timing advance and contention resolution identity.

The executed program will run only for specific cases, many extension can be included such as :

- Performing BWP operation.
- Identifying Prach occasions in case of CBRA.
- Process the received Timing Advance Command.
- Procedure for SPcell and SRS only SCell.
- Implementation of HARQ operation.

Appendix A

ASN.1

ASN.1 is standard to define specifications of abstract data types.It is also used in 3GPP documents. The main reason to use ASN.1 is it is easy to convert the ASN.1 to any other language. ASN.1 sends information(audio,data,etc) in digital communication. It only covers the structural aspects of the information(there are no operators). Therefore it is not a programming language.

We can convert the ASN.1 language to other languages like C,C++ or java by using the respective compiler. In ASN.1 there are certain number of pre defined data types like :

- integers (INTERGER),
- booleans (BOOLEAN),
- character strings (IA5String, UniversalString...),
- bit strings (BIT STRING) and etc.

It is possible to define constructed types such as

- structures (SEQUENCE),
- lists (SEQUENCE OF),
- choice between types (CHOICE)and etc.

The main important part of ASN.1 notation is that it is assosiated with several standardized encoding rules , which can be used in case of bandwidth restriction.

ASN.1 is widely used in industry sectors where efficient (low-bandwidth, low-transaction-cost) computer communications are needed, but is also being used in sectors where XML-encoded data is required (for example, transfer of biometric information).

Appendix B

Basic Encoding Rules

The Basic Encoding Rules or BER represents ASN.1 values as an octet string.

There are three methods to encode an ASN.1 value under BER. The choice depends on the type of the value and whether length of the value is known.The three methods are primitive, definite-length encoding; constructed, definite- length encoding; and constructed, indefinite-length encoding. Simple non-string types employ the primitive, definite-length method; structured types employ either of the constructed methods; and simple string types employ any of the methods, depending on whether the length of the value is known.

BER encoding has three parts in each method:

- Identifier octets : These identify the class and tag number of the ASN.1 value, and indicate whether the method is primitive or constructed.
- Length octets : For the definite-length methods, these give the number of contents octets. For the constructed, indefinite-length method, these indicate that the length is indefinite.
- Contents octets. For the primitive, definite-length method, these give a concrete representation of the value. For the constructed methods, these give the concatenation of the BER encodings of the components of the value.

- End-of-contents octets. For the constructed, indefinite- length method, these denote the end of the contents. For the other methods, these are absent.

There are three methods of encoding

- Primitive, definite-length method :This method applies to simple types and types derived from simple types by implicit tagging. It requires that the length of the value be known in advance.
- Constructed, definite-length method:This method applies to simple string types, structured types, types derived simple string types and structured types by implicit tagging, and types derived from anything by explicit tagging. It requires that the length of the value be known in advance.
- Constructed, indefinite-length method: This method applies to simple string types, structured types, types derived simple string types and structured types by implicit tagging, and types derived from anything by explicit tagging. It does not require that the length of the value be known in advance.

Bibliography

[1] A. I. A. Jabbar, PhD, Fawaz Y. Abdullah. *Effect of RACH Procedure on the Performance of LTE- based M2M Communication.*

[2] https://www.sharetechnote.com/html/5G/Handbook_5G_Index.html

[3] https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3197

[4] https://www.rfwireless-world.com/5G/5G-NR-Initial-Access-Procedure.html