International Journal of Applied Engineering Research ISSN 0973-4562 Volume 17, Number 4 (2022) pp. 405-411

Analysis of RACH Procedure for 5G NR Network in NSA

Hien Thi Thu Nguyen, Thuy Thanh Le

Faculty of Telecommunications 1, Posts and Telecommunications Institute of Technology, Km10, Nguyen Trai Street, Ha Dong District, Hanoi, Vietnam.

Abstract

With the goal of providing high-speed, real-time services, 5th generation New Radio (5G NR) networks are the trend of technology and a big challenge in the technological race around the world. In Vietnam, developing 5G NR network is one of the central directions of improving the capacity of digital infrastructure, serving national digital transformation, so mobile service providers have successfully tested 5G NR networks by the end of 2020. However, in order to implement this direction, one of the especially important solutions is that Vietnam needs to study and master the design and manufacture of 5G NR network chips and equipment. In particular, Vietnam expects that the 5G NR networks with 100% domestic equipment will become popular by 2023 - 2025 [1]. It is also the aim in development strategy [2]. Therefore, in this paper we will present the test and emulation results of "random access channel" procedure of 5G NR networks in non-standalone (NSA) mode.

Keywords: 5G NR network, non-standalone mode, random access channel procedure, socket programming, client server model.

INTRODUCTION

5G New Radio networks are being developed to meet all the requirements of life including manufacturing activities, healthcare, education, defense,... and connect everything to services. The increase in demand, the number of users and smart phone devices will open up many new services such as automated production models that reduce human presence, allow us to create smart cities, smart factory, smart home... where devices can communicate with each other; virtual reality services, real-time interactions, high-quality video, ensuring human communication needs. All make life more modern, more convenient and safer. To do this, the requirements for the 5G NR network are a drastically increase in data rates, a significant reduction in latency and real-time assurance.

In general, in mobile communication network, the "random access channel" procedure (RACH) is one of the important procedures that allows mobile devices to synchronously establish a connection with the Base Station. In the 5G NR network, it plays a very important role in analyzing and evaluating RACH procedure to ensure that mobile devices correctly execute messages, accurately synchronize with the system, minimizing latency.

In the rollout road map, initial 5G NR network launches will depend on existing 4G LTE infrastructure in non-standalone (NSA) mode, before standalone (SA) mode matures with the 5G core network (5GC). In general, the "Non-Stand Alone" (NSA) architecture (Figure 1) includes the 5G Radio Access Network (RAN) and its New Radio (NR) interface, which is used in conjunction with the existing LTE and Evolved Packet Core (EPC) infrastructure Core Network (respectively 4G Radio and 4G Core), thus making the NR technology available without network replacement. In Vietnam, mobile service providers have chosen to follow the NSA 5G NR network architecture to take advantage of the existing 4G network infrastructure at an early stage.

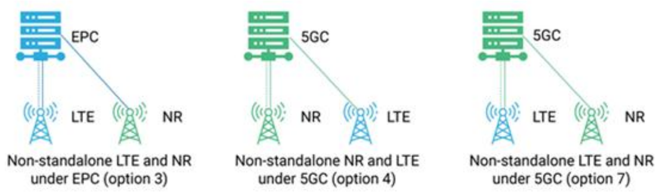

Figure 1. Architecture options of 5G NR network in NSA [3].

Therefore, in this paper we will concentrate on RACH procedure in NSA 5G NR network. The novel contribution of this paper is that we present the test and emulation results of "random access channel" procedure of 5G NR networks in NSA mode, one of the important functions to establish a successful connection between user equipment and gNodeB base station of 5G NR network. The remainder of this paper is organized as follows. In Section 2, a review of a random access channel procedure in NSA 5G NR network is described. Section 3 presents the test model of the RACH procedure and results. The emulation of RACH procedure in non-standalone 5G NR network is considered in Section 4. Finally, a conclusion is drawn in Section 5.

A random access channel procedure in 5G NR network for NSA

When we want to connect a UE to 5G NR network, it has to synchronize in downlink as well as in uplink. Downlink synchronization is obtained after successfully decoding Synchronization Signal Block (SSB). In order to establish uplink synchronization and Radio Resource Control (RRC) connection, UE has to perform a random access channel (RACH) procedure. This procedure is a very important function in the 5G NR network that aims as follows:

- Achieving UP link synchronization between UE and gNB.
- Receiving resources for MSG3 message (Example: Request RRC connection setup).

In 5G NR network, downlink synchronization from gNB to UE is achieved by special synchronization signal. This synchronization signal is periodically transmitted to all devices over a certain period. However, in uplink direction (transmitter is UE and receiver is gNB), it is inefficient (actually wasting energy and causing a lot of noise for other UEs) if the UE uses this kind of synchronization mechanism. Therefore, this synchronization must meet the following criteria:

- Synchronization should only take place when it's immediately needed.
- The synchronization should be specific to a given UE.

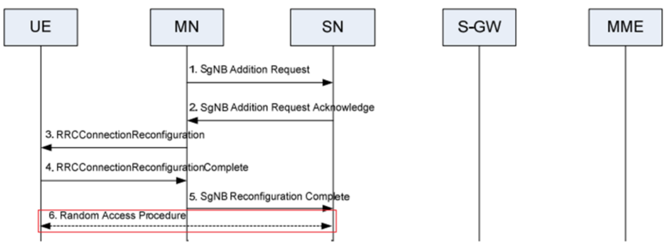

Figure 2: Procedures for registration of 5G NR network in NSA [4].

Another purpose of the RACH procedure is to allocate resources for configuring MSG3 sent from the UE. The RRC connection request is an example of MSG3, and there are several types of MSG3 depending on the particular case. According to the 3GPP TS 38300 standard, the situations that trigger the RACH process are described below:

1) Initial access from RRC_IDLE.

2) Procedure to re-establish the RRC connection (RRC Connection Re-establishment)

3) Transfer.

4) DL or UL data comes in RRC_CONNECTED when the UL sync state is “out of sync”.

5) Convert from RRC_INACTIVE.

6) To set the time alignment when adding SCell.

7) Requirements for other SI.

8) Beam incident recovery.

Figure 2 is an illustrative example of the UE connection establishment process with the NSA 5G NR network (MN: Master Node; SN: Secondary Node; S-GW: Serving Gateway; MME: Mobility Management Entity). To connect the UE to 5G NR network, UE must support dual connection between 4G and 5G and must be within the coverage of gNB. Next, UE is connected to a 4G LTE cellular network that connects to a 5G gNB. When the conditions are met, UE takes the necessary steps to connect to the gNB.

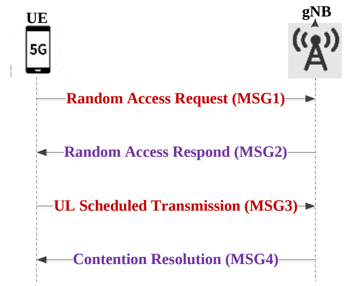

Figure 3: Contention Based Random Access Procedure [5].

There are two types of RACH: Contention Based Random Access (CBRA) and Contention Free Random Access (CFRA). In CBRA (Figure 3), UE selects a Preamble randomly from a pool of preambles shared with other UE. This means that the UE has a potential risks of selecting the same preamble as another UE and subsequently may experience conflict or contention. The gNB uses a contention resolution mechanism to handle this access requests. In this procedure, the result is random and not all Random Access succeeds. CBRA is also known as four step RACH Procedure.

In CFRA (Figure 4), the preamble is allocated by the gNB and such preambles are known as dedicated random access preamble. The dedicated preamble is provided to UE either via RRC signalling (allocating preamble can be specified within an RRC message) or PHY Layer signalling (DCI on the PDCCH). Therefore, there is no preamble conflict. When dedicated resources are insufficient, the gNB instructs UE to initiate contention-based RA. CFRA is also known as three step RACH procedure.

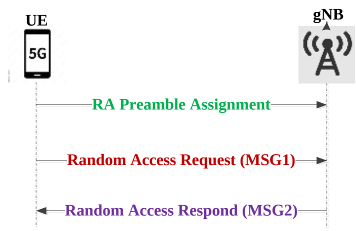

Figure 4: Contention Free Random Access Procedure [5].

A test model of the RACH procedure and results

A test model

The test model of the RACH procedure is showed in figure 5, which includes a master node (eNB) and a secondary node (gNB 5G), using CFRA procedure. The eNB plays the role of connecting gNB and UE, establishing a connection, forwarding messages exchanged between UE and gNB, sending RRC_RECONFIG message containing RACH configuration information to UE. When gNB receives SgNB Reconfiguration Complete from eNB, UE and gNB will proceed with random access procedure, the messages will be communicated directly with each other without going through eNB.

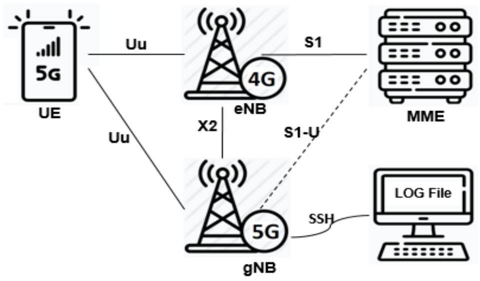

Figure 5. A test model at gNB station in NSA mode.

At the gNB side, the gNB station of non-standalone (NSA) mode consists of 3 main modules: distribution block DU (Distributed Unit), central block CU (Central Unit) and block RRU (Figure 6). When the system starts running, the messages between the modules will be exchanged and results are displayed on the terminal screen and automatically saved as .log file in the /tmp directory of server's memory. When studying the random access procedure, the most interesting thing is the information contained in the du_mgr_main.log file for the DU MGR module (Figure 7) and gnb_du_layer2.log for the MAC and RLC layers.

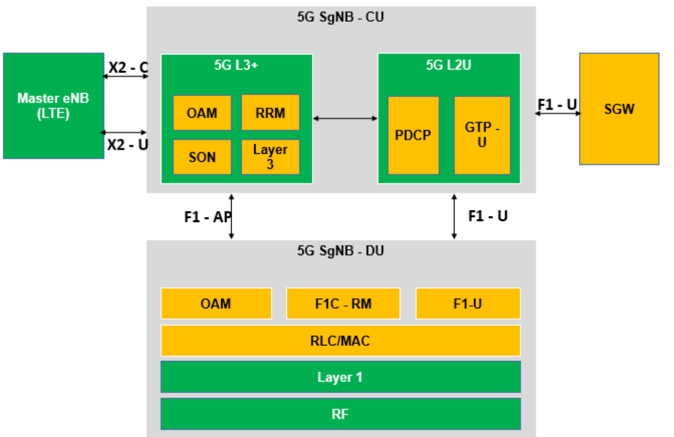

Figure 6. Architecture of blocks in gNB of 5G NR network in NSA.

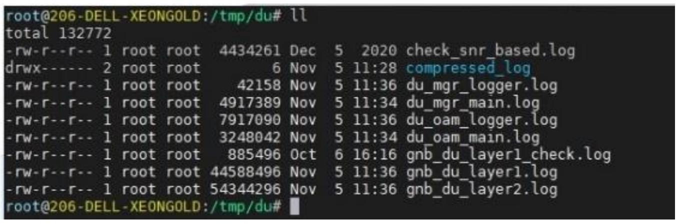

Figure 7. Log files of DU block on server gNB.

At the UE side, in order to receive the messages exchanged between UE and gNB, specialized software and equipment are required to capture and analyze the messages. As follows:

- Smartphone: requires the use of a Qualcomm Snapdragon chip and supports connection of 5G NR network.
- Laptops with Qualcomm 5G QXDM software (Figure 8) pre-installed: Laptops will directly connect to 5G phones via USB connection, use QXDM software and QCAT to capture messages exchanged between 5G phones and gNB (Figure 9, 10, 11).

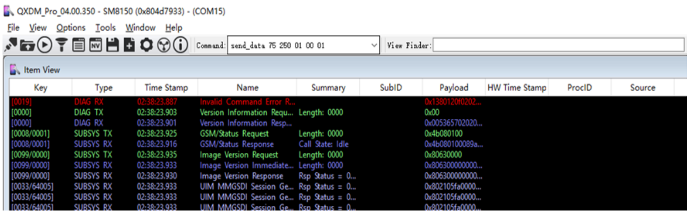

Figure 8. 5G QXDM software.

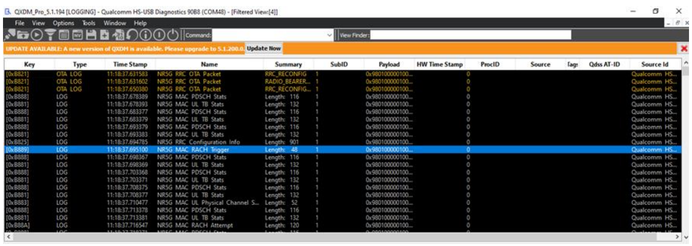

Figure 9. Messages are exchanged between UE and gNB of NSA 5G NR network on QXDM.

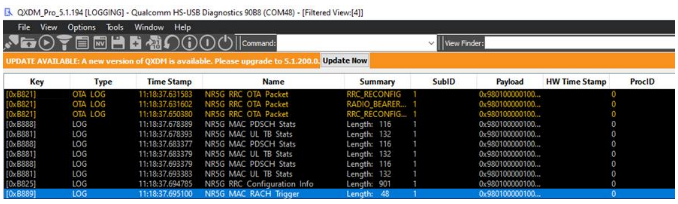

Figure 10. 5G NR MAC RACH Trigger message at the UE.

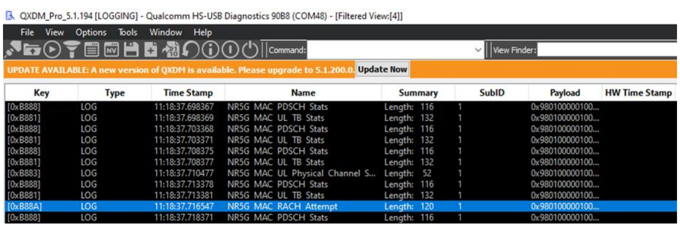

Figure 11. 5G NR MAC RACH Attempt message at the UE.

RESULTS

The results are obtained in table 1 with the following settings: subcarrier distance SCS = 30 kHz, MSG2 message response window size is ra-ResponseWindow = 20 slots corresponding to 1 frame = 10 milliseconds. The procedure success time is shown in table 1. It is proportional to the number of MSG2 message failures. The number of failed MSG2 messages significantly increases the time to complete the RACH procedure. The reason is like that when an MSG2 message is received outside the response window, the UE retransmits the MSG1 message. The time interval for the UE to retransmit MSG1 is shown in figure 12.

Assuming that, UE sends MSG1 message at the time slot 19 of frame n according to RACH configuration, UE will start waiting for RAR response at the time slot 0 of frame n + 1 and finish receiving message at the time slot 0 of frame n + 1. If the RAR message is not sent or received in the response window, the UE must resend the MSG1 message at the time slot 19 of Frame n + 2. The process is ended when the RAR message is received in the response window or number of retransmissions exceed the PreambleTransMax value. For each retransmission, the RACH procedure will be delayed by about 2 frames, equivalent to about 20 milliseconds. Therefore, some solutions to reduce the time delay of the RACH procedure could be: adjusting the size of the RAR message response window (RA-ResponseWindow), scheduling the MSG3 message sending location, setting the appropriate size of dispute resolution timer.

Table 1. List of Time to Completion of RACH.

No of Attempt	RACH Trigger Timing	RACH Success Timing	No of MSG2 errors (times)	Ex. Time (ms)
1	10:35:29.605	10:35:29.681	4	76
2	10:45:37.353	10:45:37.390	2	37
3	10:46:07.825	10:46:07.879	3	54
4	10:50:27.673	10:50:27.709	2	36
5	11:02:52.218	11:02:52.276	3	58
6	11:09:42.427	11:09:42.465	2	38
7	11:10:04.160	11:10:04.215	3	55
8	11:11:26.593	11:11:26.664	4	71
9	11:11:41.918	11:11:41.974	3	56
10	11:18:37.695	11:18:37.813	6	118

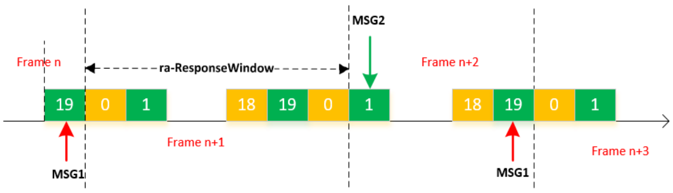

Figure 12. PRACH retransmission in time domain.

Emulation of RACH procedure in NSA 5G NR network

Emulation environment

To simulate the message exchange of the CFRA procedure, the C++ language was chosen for programming. The program is executed on the Linux operating system. Client - Server model is used to exchange messages between gNB and UE (gNB is the Server and UE is the Client). Both gNB and UE will communicate through a socket depicted in figure 13.

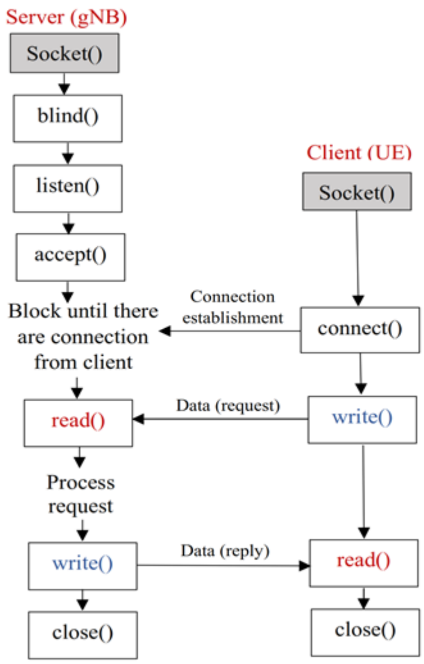

Figure 13. Socket communication model of Client and Server.

The detailed description of the model is as follows:

- Both the gNB and UE sides are set up with a unified socket method of message transmission, a format for the IP address to receive the message.
- At the gNB side, initialize the bind () function, which allows setting the specified IP addresses, port addresses to allow UEs to connect to. The listen () function allows gNB to wait for incoming UEs to connect to.
- The UE side uses the connect () function to request a connection with gNB, both of them conduct handshake procedures to establish a connection.
- gNB agrees the UE to connect using the accept () function.
- After gNb and UE have connected with each other, they begin to exchange messages. The send () or write () function is used to send the message, the read () or recv () function is used to receive the message.
- Realese the connection between UE and gNB by the close () function.

RACH configuration parameters are taken according to parameters in gNB system in 3GPP TS 38.211 standard [4].

Description of emulation program activities

The detailed block diagram of the emulation program is shown in figure 14. The program emulates the process of sending and receiving non-disputed random access procedure messages.

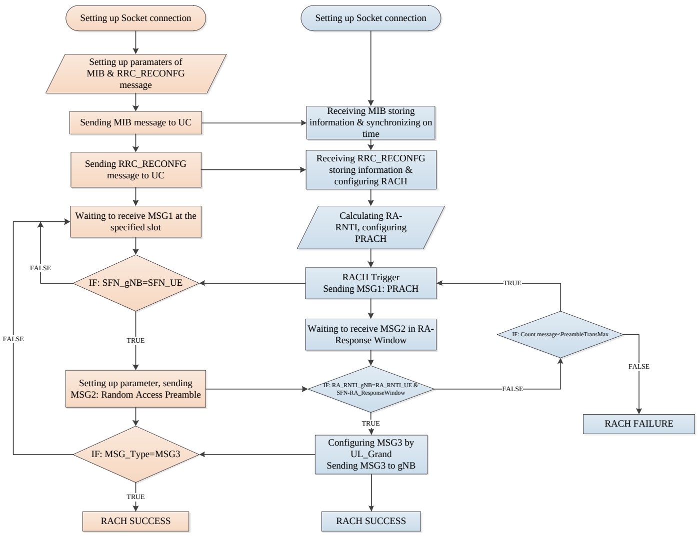

Figure 14. The block diagram describes the operation of the simulation program.

First, both gNB and UE establish a connection through socket. The gNB side implements the parameter setting function for the MIB and RRC_RECONFIG messages to configure the RACH procedure and synchronization information. When the MIB message is sent to the UE, the UE receives the MIB message, reads information in MIB and sets the time synchronization function with the gNB. gNB continues to send RRC_RECONFIG message, UE receives and reads the information enclosed in the message to configure for the following messages. The UE calculates the RA-RNTI value, sets the parameter for the MSG1 message and sends it to gNB. When receiving the message by gNB side, check if it is MSG1 and receive it in accordance with the required time slot. If the condition is correct, gNB responds with an MSG2 message. If the condition is false, gNB waits to receive the MSG1 message. After sending the MSG1 message, the UE begins to calculate the time it takes to receive the response.

If the UE receives a response in the responseWindow time, the UE checks the information in the RA-RNTI. If the condition is true, the UE schedules the MSG3 message to gNB according to the information in the UL Grant, and if the condition is false or the MSG2 receives outside the ResponseWindow range, UE will resend the MSG1 message and increments the counter by 1. UE will resend the MSG1 message until the counter is greater than the PreambleTransMax value then UE announces the RACH procedure failed. Conversely, the UE sends the MSG3 message to gNB and reports that the RACH procedure was successful. GNB side after sending the MSG2 message, it waits to receive the MSG3 message. If gNB receives an MSG3 message, gNB reports that the RACH procedure was successful. If gNB receives an MSG1 message, it knows that the MSG2 message has failed and UE will resend the MSG1 message.

Emulation results

Figure 15 shows the actual messages being processed, transmitted and received at the gNB side. gNB side performs the selection of the MIB synchronous message transmission time slot, the RRC_RECONFIG configuration message via UE and waits for the MSG1 message to be received at the predetermined time slot frame 614, subframe 9, slot 1.

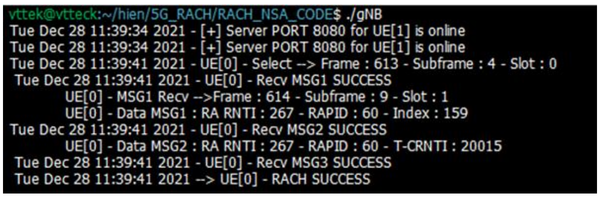

Figure 15. Successful RACH procedure communication at gNB.

When MSG1 is received at the correct slot Time, gNB announces the successful receipt of MSG1, checks the information received in the MSG1 message. When the MSG1 message has been successfully received, gNB sends back the MSG2 message, waiting for the MSG3 message to be received.

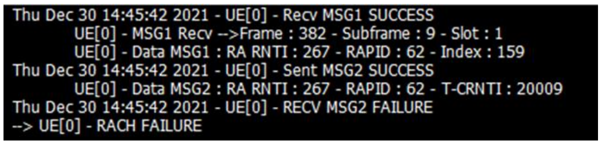

Figure 16. RACH procedure communication is failed at gNB.

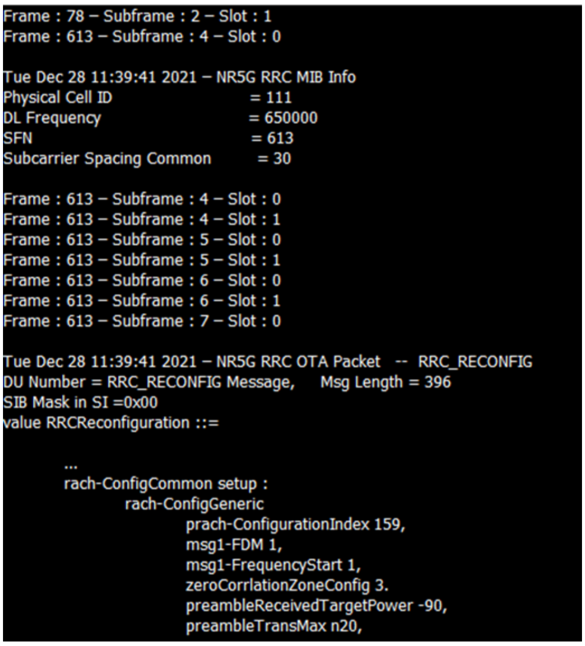

Figure 17. The MIB and RRC_RECONFIG message are received at UE.

In figure 16, the RACH procedure is failed at MSG2 because the UE side did not receive in response timeout, UE sent back MSG1. When the number of MSG1 retransmissions have exceeded the given limit, gNB reports that the RACH procedure has failed.

In figure 17, MIB synchronization information and configuration information for RACH RRAC_RECONFIG messages are sent by gNB to UE, the UE side will resolve and display the content of the received message.

```
Tue Dec 28 11:39:41 2021 – NR5G MAC RACH Trigger
Header
        Num Records                = 1
CRNTI                              = 20015
Rach Reason                        = CONNECTION_REQUEST
First Active UL BWP                = 0
Carrier Id                         = 0
RACH Contention                    = CONT_FREE
RAId                               = 255
MSG3 Size                          =0
MSG3                               = { 0, 0, 0, 0, 0, 0}
Frame : 613 – Subframe : 7 – Slot : 1
Frame : 613 – Subframe : 8 – Slot : 0
```

Figure 18. NR5G MAC RACH Trigger message at the UE.

Once MIB times, synchronization message and the RRC_RECONFIG configuration message have been received, UE starts to trigger the RACH procedure (Figure 18). According to the configuration information in the RRC_RECONFIG message, MSG1 message will be configured. A Prach Profile value of 159 means that the MSG1 message is in B4 format, the distance between subnets is 30 kHz, the time slot 19 of frame 864 is used to transmit, the identification value of RA RNTI is 267 (Figure 19). After sending, UE will wait to receive the response from gNB in the slot time 20 of frame 865 and frame 866.

```
Tue Dec 28 11:52:35 2021 - RACH Msg1 - UE SEND
---------------------------------------------------------------------------------------
|    |System Time                 |       |       |Preamble|              |     |       |
|    |      |Sub    |     |             |Symbol|Prach |Format   |Preamble   |     |       |
|#   |Frame |Frame  |Slot |SCS          |Start |Config|Value    |Format     |RA Id|FDM    |
     |SCS                 |
---------------------------------------------------------------------------------------
|  0|   864|      9|    1|  30KHZ|     0|   159|      11| FORMAT_B4|   60|              |
---------------------------------------------------------------------------------------
|            |              |RAR Window Start SFN           |RAR Window E SFN          |
|Cyclic Shift|              |      |Sub   |      |          |      |Sub |     |       |
|V           |RA RNTI       |Frame |Frame |Slot  |SCS       |Frame |Fram|Slot |SCS    |
---------------------------------------------------------------------------------------
|          90|           267|   865|     0|     0|  30KHZ|   866|    |    0|  30KHZ|
```

Figure 19. Information in the MSG1 message at the UE side.

Figure 20 depicts the MSG2 message received at the UE side, the response time slot is time slot 0 of frame 865, the identifier value of RNTI = 20015 exactly matches the value sent in the MIB message.

```
Tue Dec 28 11:39:41 2021 - RACH Msg2 UE RECEIVED
------------------------------------------------------------------------------
|   |SFN                          |Max      |        |     |      |              |
|   |      |Sub   |     |         |Backoff  |        |TA   |      |              |
|#  |Frame |Frame |Slot |SCS      |Duration|T RNTI  |Value|Result|SCS           |
------------------------------------------------------------------------------
|  0|   865|     7|    0|  30KHZ|         0|   20015|    2|     1|  NR5G_SCS_30KHZ|

Tue Dec 28 11:39:41 2021 - RACH Msg3
------------------------------------------------------------------------------------------------
|   |            |Msg3   |     |                |
|   |Msg3 Grant  |Grant  |HARQ |                |
|#  |Raw         |Bytes  |Id   |SCS             |Mac PDU
------------------------------------------------------------------------------------------------
|  0|   0x3320000|      0|    0| NR5G_SCS_30KHZ|  00  00  00  00  00  00  00  00  00  00  00  00|
```

Figure 20. The MSG2 message is received at the UE side.

```
Tue Dec 28 11:39:41 2021 - NR5G MAC RACH Attempt
 Header
 Num Records                       = 1
 Num Attempt                       = 0
 SSB ID                            = 0
 CSI RS ID                         = 0
 Carrier ID                        = 0
 RACH Result                       = SUCCESS
 Contention Type                   =CONT_FREE
 Contention Type                   = 0
 RACH Msg Bitmask                  =0x07
```

Figure 21. NR5G MAC RACH Attempt message in case of a successful RACH attempt at the UE side.

When the MSG2 message is successfully received, UE will send the MSG3 message configured by the UL Grant in the MSG2 message, UE will notify the successful RACH procedure via an NR5F MAC RACH Attempt message with the RACH Result field = SUCCESS (Figure 21). Figure 22 shows NR5G MAC RACH Attempt message in case of a RACH failure at the UE side.

```
Tue Dec 28 11:52:25  2021 - NR5G MAC RACH Attempt
Header
Num Records                   = 1
Frame : 894 - SubFrame : 1 - Slot : 0
Num Attempt                   = 21
SSB ID                        = 0
Frame : 894 - SubFrame : 1 - Slot : 1
CSI RS ID                     = 0
Carrier ID                    = 0
RACH Result                   = FAILURE_MSG2
Contention Type               = CONT_FREE
Contention Type Value         = 0
Frame : 894 - SubFrame : 2 - Slot : 0
RACH Msg Bitmask              = 0x07

 Tue Dec 28 11:52:35 2021 - RACH Msg1 - UE SEND
-----------------------------------------------------------------------------------------------------------
----------------------
|   |System Time                |     |      |Preamble|           |    |        |           |           |
f   |                    |
|   |      |Sub   |    |        |Symbol|Prach |Format  |Preamble   |    |        |           |Cyclic Shift|
on  |                    |
Frame : 894 - SubFrame : 2 - Slot : 1
|#  |Frame |Frame |Slot |SCS    |Start |Config|Value   |Format     |RA Id|FDM     |Uroot      |V           |RA RNTI
    |SCS                 |
-----------------------------------------------------------------------------------------------------------
----------------------
|  0|   864|     9|    1|  30KHZ|     0|   159|      11| FORMAT_B4|   60|       0|        119|          90|         267|
  0|  NR5G_SCS_30KHZ|
 Tue Dec 28 11:52:35 2021 - RACH FAILURE
```

Figure 22: NR5G MAC RACH Attempt message in case of a RACH failure at the UE side.

CONCLUSIONS

In this paper, we presented test and emulation results of "random access channel" procedure of 5G NR network in Non-StandAlone (NSA) mode. These above test results are obtained on the actual NSA 5G NR network system between the 5G mobile device and the gNB base station using the no contention mechanism (CFRA) through the QXDM software. We have also achieved the emulation results based on the Client-Server model of socket programming. These results show that the messages are fully compliant with the provisions of the 3GPP standard, such as successful or unsuccessful random access execution, replication errors, procedure completion time and parameters contained in the messages, etc. With the results, we hope that we could fully master the design and manufacture of equipment for 5G NR network.

REFERENCES

[1]. https://thanhnien.vn/tai-chinh-kinh-doanh/du-kien-2023-2025-mang-5g-moi-pho-cap-tai-viet-nam-1318609.html

[2]. https://ictnews.vietnamnet.vn/vien-thong/5g/se-thuong-mai-5g-bang-100-thiet-bi-viet-nam-vao-

thang-10-2020-257929.html

[3]. https://www.alepo.com/5g-sa-vs-5g-nsa-what-are-the-differences/

[4]. 3GPP TS 37.340," Evolved Universal Terrestrial Radio Access (E-UTRA) and NR; Multi-connectivity", 3GPP, 3GPP TS 37.340.

[5]. https://www.techplayon.com/5g-nr-rach-procedure-overview-cbra-cfra/