SDL Implementation of LTE UE Non-Seamless Random Access Procedure Handling

Mohamed Sami M. Yousef
Electronics Department,
National Telecommunication Institute (NTI);
Cairo, Egypt
e-mail: mohamed.yousef@nti.sci.eg

Hussein A. Elsayed, Abdelhalim Zekry
Electronics and Communications Engineering Department,
Faculty of Engineering,
Ain shams University;
Cairo, Egypt
e-mail: helsayed2003@hotmail.com, aaazekry@hotmail.com

***Abstract*—Random access procedure in Long Term Evolution (LTE) is required in completing the connection establishment procedure. Due to the numerous number of connection requests, collisions may occur, which would cause a failure to be completed in both of the contention-based and the non contention-based random access procedures. This paper focuses on the main problems that may arise during the random access procedure execution in the Medium Access Control (MAC) sub-layer of LTE User Equipment (UE) terminal. It investigates the unsuccessful random access response (RAR) and the unsuccessful contention resolution problems. Specification and Description Language (SDL) is used to implement a design of random access procedure to deal with these problems based on 3GPP release 9 standards. Besides the reduced SDL code, an implementation simulation is performed using the Message Sequence Chart (MSC) simulator trace. The simulation proves the correct functionality and feasibility of the built random access procedure in handling those problems according to the standard.**

Keywords- LTE; random access procedure; MAC Sub-layer; non successful random access response; non successful contention resolution; SDL.

I. INTRODUCTION

Mobile communication passed through many developments since the last few years with the introduction of successive generations. The first generations were primarily designed to support voice communication with capabilities to support data transmission in the later releases. However, the data rates were generally low. As a result of the rapid increase in the Internet based applications in many mobile communication devices with a growing bandwidth demands, starting from the third generation full multimedia data transmission was enabled, as well as voice communications [1]. Fourth generation technology allows greater download and upload speeds to increase the amount and types of content made available through mobile devices. Accordingly, 3GPP main objective is to support: a high data rate, low latency, and packet optimized radio access technology [2][3].

As the MAC layer is connected to the underneath physical layer through transport channels and is connected to the Radio Link Control (RLC) layer above through logical channels; the MAC layer performs multiplexing and de-multiplexing of the data between logical channels and transport channels.

With regards to the upper layer, the MAC layer is responsible for two services: the radio allocation service and the data transfer service. Regarding the former, this includes procedures, such as logical channel prioritization, power headroom reporting, handling of Up Link (UL) grant and Down Link (DL) assignment, etc. Regarding the data transfer service, the MAC layer performs procedures such as scheduling requests, buffer status reporting, random access, and Hybrid Automatic Repeat request (HARQ) [4].

Evolved- Universal Terrestrial Radio Access Network (E-UTRAN) defines two MAC entities: one in the UE and the other in the eNodeB side. The functions performed by each of those entities are different from each other. This paper focuses on UE MAC sub-layer, particularly, the random access procedure and non-seamless scenarios where problems may arise during its execution. It also introduces the appropriate actions to face these issues based on 3GPP release 9 standards. While implementing the design, we corroborated several procedures to reduce the runtime. The design is based on 3GPP release 9 standard [5] and implemented using SDL. As an SDL output, the MSC simulator trace shows the MAC flow for facing the random access procedure problems in both of contention and non-contention based procedure.

Several researches proposed methods and architectures to improve both of contention and non contention based random access process. LTE clustering and non-clustering schemes performance of contention based random access procedure is evaluated in [6]. The proposal in [7] shows how hierarchical control of different users efficiently improves random access success probability and optimize the system performance. The work in [8] suggests a fast random access procedure for use in a mobile communication system. Random access procedure enhancements for heterogeneous networks is presented in [9]. Hybrid random access and data transmission protocol for Machine to Machine (M2M) communications is proposed in [10] to maximize the M2M throughput and to resolve the congestion problem in the random access procedure.

The rest of the paper is organized as follows: Section II provides an introduction on the random access process in LTE and its types. The implemented successful random access process is explained in Section III, while Section IV shows the problems in the random access process and the way the MAC deal with them. In Section V, the simulation results for both unsuccessful RAR and the unsuccessful contention resolution problems are presented. Finally, the conclusions and future work is presented in Section VI.

II. LTE RANDOM ACCESS PROCEDURE

Control of the random access procedure is an important part of the MAC layer functionality in LTE. Sometimes LTE UE wishes to transmit on the Physical Uplink Shared Channel (PUSCH) but it does not have allocated resources to do so. In this case, the mobile sends a scheduling request on the physical uplink control channel. Furthermore, if it does not have the resources to do that, then it initiates the random access procedure to acquire uplink synchronization. After that, eNodeB can schedule orthogonal uplink transmission resources for UE.

There are two forms of the random access procedure: contention-based and non-contention. In both forms, the UE's first step is to transmit a preamble to the eNodeB as an indication of procedure start. For contention-based procedure, the Random access preamble is randomly chosen by the UE, whilst in the case of non-contention-based procedure, the Random access preamble is designated by the eNodeB to guarantee a contention free procedure. The usage of the random access procedure determines which form to be used.

A. *Contention-based Random Access Procedure*

In this process, there is no reserved random access preamble for the UE. Accordingly, UE has to randomly select a Random Access (RA) preamble resource. For LTE, each cell has 64 available random access preambles. A set of these preambles is reserved for non-contention-based random access procedure, while the rest are available for contention-based random access procedure; and are divided into two groups: the random access preamble group "A" and the random access preamble group "B" [11].

Since UEs choose the random access preamble by themselves, it is possible for more than one UE to select the same RA preamble simultaneously. In this case, acknowledgment by the eNodeB of receipt of the RA preamble is not enough, and eNodeB should further perform the contention resolution step, through which eNodeB should indicate which UE's transmission has actually been received. The process consists of 4 steps to send the request and resolve the contention as shown in Figure 1.

Step 1: Random-access preamble transmission:

The procedure starts with the UE transmitting a random-access preamble. The transmission's main objective is to indicate to the base station the presence of a random-access attempt and to estimate the delay between the eNodeB and the terminal.

In contention-based random access procedure, UE has to first select a group from which it chooses a random access preamble. The group selection is based on the path-loss, the estimated size of the MAC Packet Data Unite (PDU), and whether this random access attempt is the initial attempt or a re-attempt. Group B is chosen if the estimated size of the MAC PDU is big and the measured path-loss is small. In this step, the UE also determines the transmission power of the random-access preamble, as well as the frame and sub-frame, which it will use to send the preamble in.

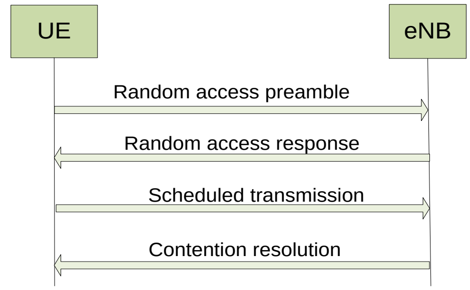

Figure 1. Contention-based Random Access Procedure steps

Step 2: RAR:

The UE receives the RAR, as an indication of receiving the preamble, within a pre-specified time window. If the terminal does not receive a RAR within the time window, the attempt will be considered failed and the procedure will be repeated from the first step.

As the preamble is randomly selected by the UE, there is a probability that multiple terminals use the same random-access preamble at the same time. In this case, multiple terminals will react upon the received RAR and a collision occurs. Accordingly, steps 3 and 4 are used to solve this collision.

Step 3: Terminal identification:

The UE step sends its first scheduled uplink message on the PUSCH. The message reflects the reason behind the random access procedure, which may be a Radio Resource Control (RRC) connection request, tracking area update, or scheduling request. This message also includes a unique identity for the UE, which is required for contention resolution in the fourth step.

If a preamble collision has occurred at Step 1, i.e., more than one UE selected the same preamble, the same temporary C-RNTI will be received by the colliding UEs through the RAR and they will also collide in the time-frequency resources during the transmission of their terminal identification message. This scenario may result in such interference that none of the colliding UEs can be decoded by the eNodeB; and so the UEs restart the random access procedure after waiting for backoff time (if exists). However, if eNodeB decoded one UE successfully, the other UEs will not recognize the contention and so contention resolution message (step 4) would be used to resolve the contention.

Step 4: Contention resolution

The contention resolution message is the last step in the random-access procedure. It is a downlink message used to ensure that a terminal does not incorrectly use another terminal's identity.

As multiple UEs initialize random-access procedure using the same preamble sequence in the first step where only one of these UEs has been detected by the eNodeB, a possible reason for this is that the undetected UE sent the message with low power relative to its distance from the eNodeB. Accordingly, all of the UEs will receive the same RAR (step 2) and therefore each UE assumes that it receives a correct RAR. As a next step, all the UEs who receive a correct RAR will send terminal identification message including their identity. UEs are now waiting for the contention resolution message, as the UE may have a C-RNTI or not. There are two contention resolution mechanisms [11]. If the terminal already had a C-RNTI assigned, contention resolution is handled by addressing the terminal on the Physical Downlink Control Channel (PDCCH) using the C-RNTI. Upon detection of its C-RNTI on the PDCCH, the terminal declares the random access attempt successful, and there is no need for contention-resolution-related information on the DownLink Shared Channel (DL-SCH).

The second mechanism occurs when the terminal does not have a valid C-RNTI, in which the contention resolution message is addressed using the TC-RNTI, and the associated DL-SCH contains the contention-resolution message. The terminal will compare the identity in the message with the identity transmitted in the third step. Only a terminal which observes a match between the identity received in the fourth step and the identity transmitted as part of the third step will declare the random-access procedure successful and promote the TC-RNTI from the second step to the C-RNTI [11].

Terminals that do not detect PDCCH transmission with their C-RNTI or do not find a match between the identity received in the fourth step and the respective identity transmitted as part of the third step are considered to have failed the random-access procedure and need to restart the procedure from the first step. Furthermore, a terminal that has not received the downlink message in step 4 within a certain time from the transmission of the uplink message in step 3 will declare the random-access procedure as failed and need to restart from the first step [11].

B. Non-Contention-based Random Access Procedure

The non-contention-based random access procedure provides delay and capacity enhancements compared with the contention-based procedure. The procedure is executed in only three steps as shown in Figure 2.

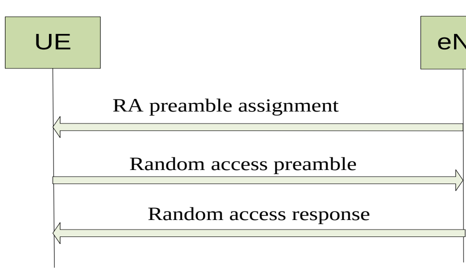

Figure 2. Non contention-based random access procedure steps

Step 1: Random access preamble assignment:

The eNodeB allocates a designated RA preamble to the UE. Besides the preamble, some restrictions for the frequency and time resource can be signaled so that the same sequence can be simultaneously allocated for UEs that transmit on different PRACH sub-frames.

Step 2: preamble transmission:

As for contention-based random access procedure, the UE transmits the random-access preamble where also it determines the transmission power, the frame, and sub-frame which it will use to send the preamble.

Step 3: RAR:

In the non-contention-based RA procedure, as the designated RA preamble is used by only one specific UE there is no possibility of collision. As soon as the eNodeB detects the RA preamble, the eNodeB knows of the access by the UE and the procedure is terminated by transmission of the RA response, i.e., contention resolution is not needed as the preamble shall not be used by other UEs.

III. SUCCESSFUL RANDOM ACCESS PROCEDURE FLOW

Initially, MAC is in Idle state till it receives a request for random access process; either CMAC_RANDOM_ACC_REQ signal in case of contention based process request or CMAC_RANDOM_ACC_REQ_non_cont signal in case of non contention based process request accompanied by the Random Access Preamble and the PRACH Mask Index designated by eNodeB for the UE. After receiving the request, UE initiates the random access procedure. The following subsection explains the random access procedure steps in UE:

A. Random Access Resource selection and transmission step

Upon receiving the request, the MAC sub-layer instructs the physical layer with the preamble_value signal including the preamble index to be sent to the network side. If contention based request was sent, the UE randomly selects Random Access Preamble from the available set of preambles.

According to the restrictions given by prachconfigIndex and PRACH Mask Index, MAC sends frame_value and subframe_value signals to the physical layer indicating the selected frame and sub frame of the PRACH to carry the random access preamble. received_target_power signal is then sent by the MAC to instruct the physical layer with the appropriate preamble transmission power based on the estimated path-loss signals in addition to a configurable offset. Now, the physical layer is ready to send the preamble, while MAC is in Random_Access_Response_Reception state after starting RAR_window_timer timer waiting for the eNodeB reply.

B. RAR reception step

The MAC starts reading the RAR PDU contents shown in Figure 3 [5], when it receives Random_Access_Response_MAC_PDU signal from physical layer. RAR PDU header is divided into sub-headers; there are two types of sub-headers: MAC RAR sub-header and Backoff Indicator sub-header as shown in Figure 4 and Figure 5, respectively. If PDU contains a Backoff Indicator sub-header, UE has to set the back_off_parameter_value to the value determined in the BI field of the subheader, else the backoff parameter value is set to 0 ms.

As the PDU may include reply to more than one UE, MAC starts filtering the Random Access Preamble Identifier (RAPID) Fields in the received PDU. If UE found RAPID corresponds to the transmitted preamble_value, the RAR reception step is considered successful and UE will apply the MAC RAR fields: Timing Advance Command, UL Grant, and Temporary C-RNTI [5].

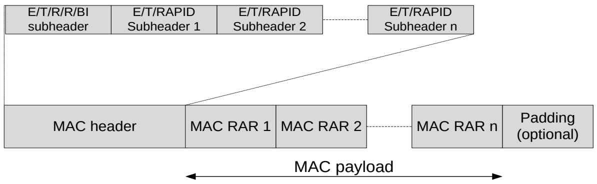

Figure 3. RAR PDU structure [5]

E	T	RAPID

Figure 4. RAR subheader structure

E	T	R	R	BI

Figure 5. Backoff Indicator subheader structure

At this step, the Random access procedure is considered successfully completed if it is non contention based; otherwise, contention resolution step is needed if the process is contention based because more than one UE may transmit the same preamble_value simultaneously.

C. Contention resolution step

To resolve contention, UE sends MAC_PDU_UL signal including its identification information, message. If the UE is already connected to a known cell then it has a C-RNTI (Cell Radio Network Temporary Identifier) assigned to it, which acts as its identifier. Otherwise, the core-network terminal identifier will be used. Consequently, the MAC starts mac_ContentionResolutionTimer timer waiting for MAC_PDU_DL signal, it is now in msg4_Waiting state waiting for the eNodeB reply. If MAC_PDU_DL signal is received including the UE pre-transmitted identification information the contention resolution step is successfully completed and the Random Access procedure is considered successfully completed.

DL-SCH MAC PDU consists of: a MAC header, zero or more MAC Service Data Units (MAC SDU), zero or more MAC control elements (fixed size and variable size), and optionally padding as shown in Figure 6. The MAC header consists of one or more MAC subheaders; each subheader corresponds to either: MAC SDU or MAC control element or padding. The Logical Channel ID (LCID) field in each subheader represents the type of the corresponding MAC control element or padding or the logical channel instance of the corresponding MAC SDU [5].

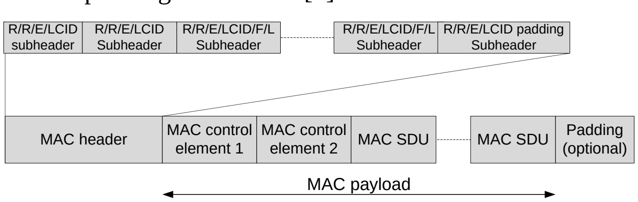

Figure 6. DL-SCH MAC PDU structure [5]

D. Successful RANDOM ACCESS PROCEDURE implementation

The successful random access procedure, using the previous steps and the setup values, has been implemented in [12], but has not considered error handling. So, this paper focuses on implementation and simulation of various cases of error handling methodologies.

IV. RANDOM ACCESS PROCEDURE INVOLVED PROBLEMS

This section focuses on the random access procedure common problems and how the MAC protocols deal with them, which is the main target of this paper. The first one is that the RAR step is considered unsuccessful if the RAR window expired without receiving the RAR or if the RAPID corresponding to the transmitted Random Access Preamble is not received in any of the arrived RARs. The second problem appears in the contention based procedure, where an error could occur due to non successful contention resolution step. This occurs if mac-ContentionResolutionTimer expires before successful Contention Resolution.

A. Non successful RAR problem

As a first step in the random access procedure the UE informs the physical layer with the selected frame, subframe and the power for sending the preamble. After so, MAC sets RAR_window_timer with the window time it has to wait for RAR. Then MAC transits to Random_Access_ Respons_reception state waiting for either a RAR or timer expire signal, Figure 7.

As seen in Figure 7, if there is a received RAR before the RAR_window_timer expires, the UE has to check the received PDU's subheaders: Backoff Indicator (if exist) and RAR sub-headers. Thus, UE determines if there is a RAR corresponds to its transmitted ra_peambleindex, so it transits to check_if_correct_RAR step, if not UE transits again to Random_Access_Respons_reception state waiting for new PDU. Else, the UE resets the RAR_window_timer and apply the Backoff value (if exist).

On the other side, if the RAR_window_timer expires, the random access procedure is considered non successful; and hence the UE transits to non_successful_RAR step following the procedures shown in Figure 8. At that point, MAC starts by incrementing PREAMBLE_TRANSMISSION_ COUNTER by 1, which counts the number of trials of the preamble transmission. Then, if PREAMBLE_ TRANSMISSION_COUNTER value is greater than *preambleTransMax*, it indicates that MAC has reached the maximum number of possible trials. Therefore, MAC sends Non_successful_Random_Access_process signal to indicate a Random Access problem to the upper layer (RRC) then transit to the Idle state. But if the PREAMBLE_TRANSMISSION_COUNTER has not reached the maximum number of trials, UE has to start another Random access procedure attempt. The UE has to wait a backoff delay time before starting the next trial. The backoff delay is a random value chosen between zero and the back_off_parameter_value already sent by the network.

Backof_parameter procedure is called by the UE for determining the backoff time corresponds to the back_off_parameter_value based on [5].

The SDL "**uniform**" operator is used for random number selection. Also, MAC has to inform the physical layer to increase the preamble transmission power in each trial by power_ramping_step value.

B. Non successful contention resolution problem

As stated before, this problem appears in the contention-based procedure, where an error could occur due to non successful contention resolution step. It occurs if mac-ContentionResolutionTimer expires without receiving DL-SCH MAC PDU or the received contention resolution identity MAC control element does not match the transmitted one.

In Figure 9, after UE transmits msg3 and store its value in msg3_buffer it starts mac_ContentionResolutionTimer and transits to msg4_waiting state waiting for the eNodeB reply or mac_ContentionResolutionTimer expire signal. If the timer expire or the received PDU does not match the UE's ID, the UE transits to non_successful_ Contention_Resolution step. In the non_successful_ Contention_Resolution step, the UE transits to non_successful_RAR step repeating the same procedures of Non successful RAR.

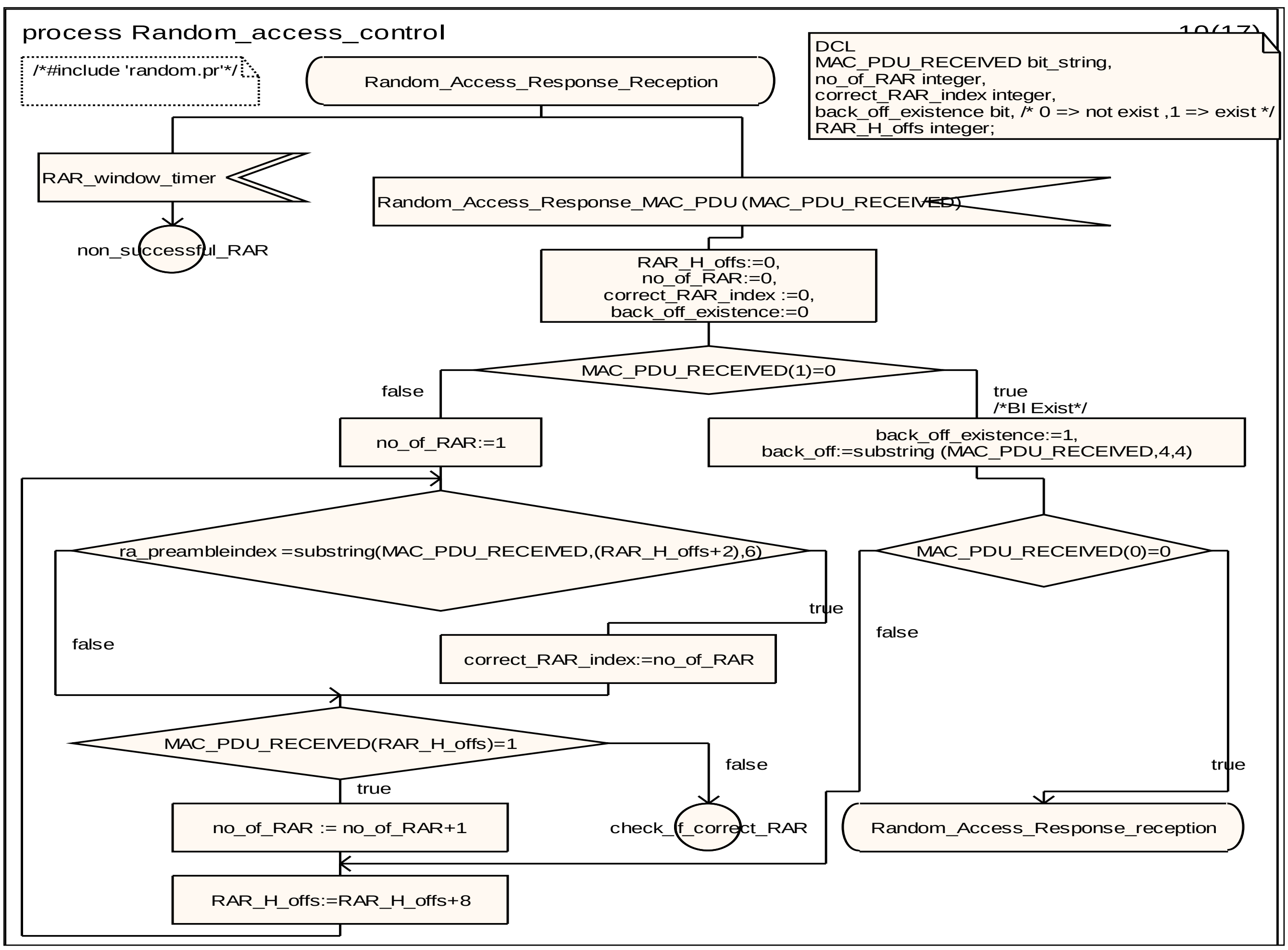

Figure 7. RAR PDU reception

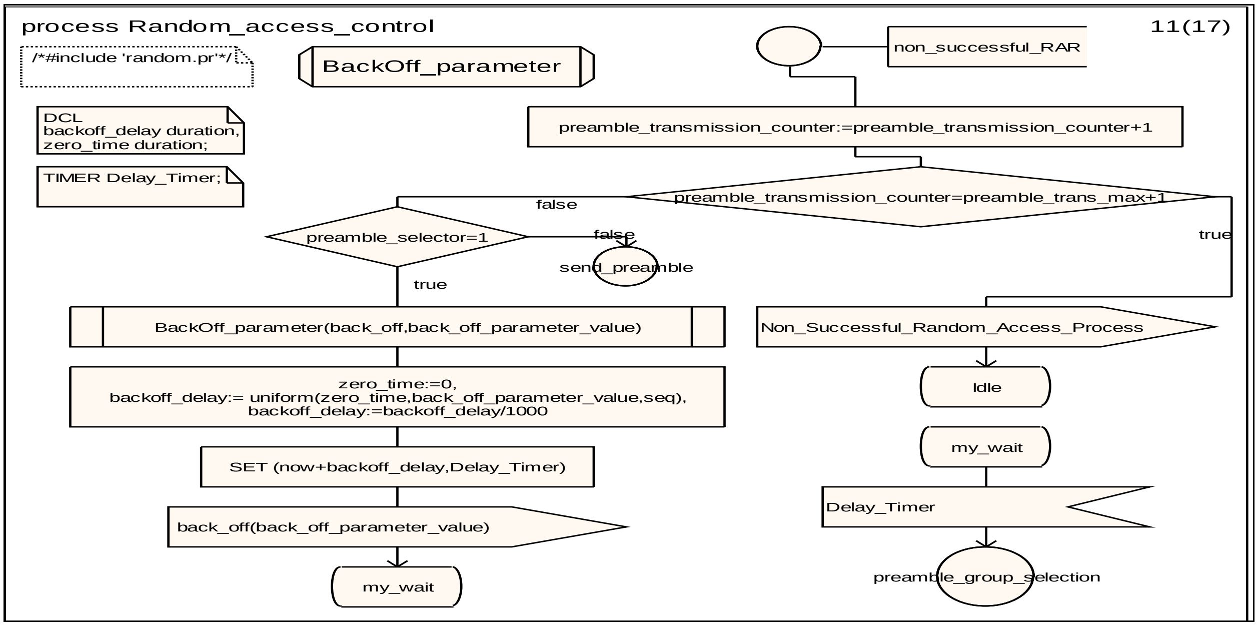

Figure 8. Procedures for non successful RAR

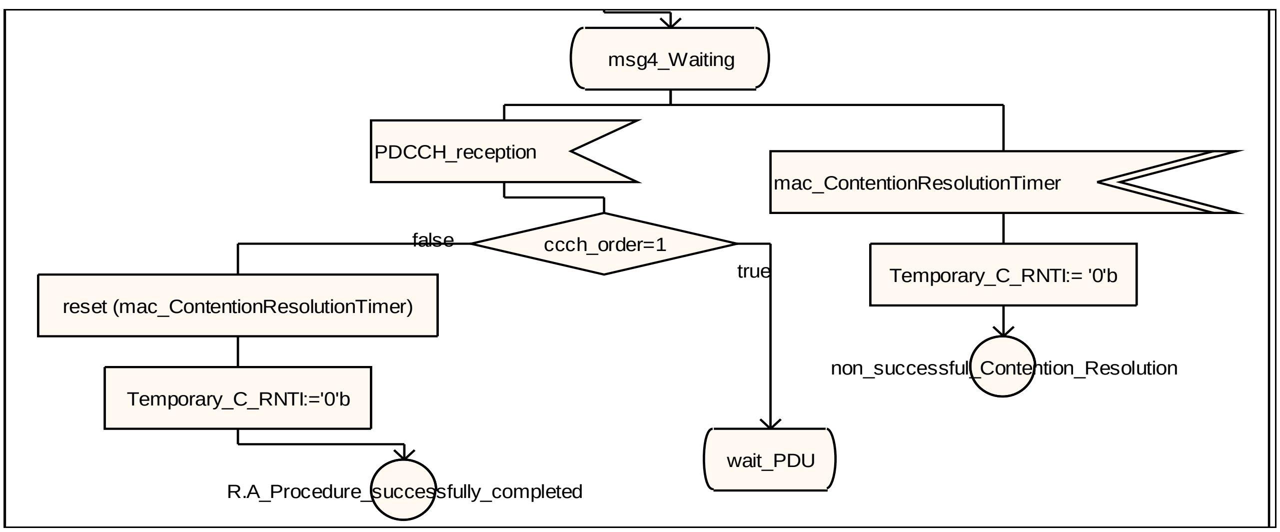

Figure 9. Contention resolution

V. IMPLEMENTATION SIMULATION RESULTS

This section shows the implementation simulation results for Non Successful random access procedure different scenarios and how MAC dealt with them. SDL provides functional simulation, which uses MSC simulator trace introduced by Telelogic Tau SDL and TTCN Suite 4.0, which is launched by the Telelogic Tau Company.

A. *Non successful RAR*

Figure 10 and Figure 11 show the simulation result of a non successful RAR for a contention-based random access procedure, where the preamble_trans_max is set to (2); After receiving CMAC_RANDOM_ACC_REQ signal, the Random_access_control process randomly selects preamble_value (“100110”) and the rest of Random Access Resources including preamble_received_target_power (-68), then it transit from Idle state to Random_Access_ Response_Reception state. The Random_access_control process receives Random_Access_Response_MAC_PDU during RAR_window_timer time, the PDU includes: a backoff ID (“0011”), RAPID (“001000”) and RAPID (“101010”). As none of the received RAPIDs match the transmitted pramble_value, the Random_access_control process will transit to Random_Access_Response_Reception state waiting for a new PDU. Unfortunately, the RAR_window_timer expires without receiving PDU, accordingly the RAR step is non successful and UE has to start another random access procedure trial. The second trial starts after waiting a backoff time (13.1 ms).

The UE starts the second (last) trial and randomly selects preamble_value ("100101"). The preamble_received_target_power is also increased to be (-4). As the first trial the RAR step is not successful, consequently MAC sends Non_successful_Random_Access_process signal to RRC.

B. Non successful contention resolution

Figure 12 to Figure 15 show a non successful random access procedure due to a problem in the contention resolution step. The preamble_trans_max for this procedure is set to (3); After receiving CMAC_RANDOM_ACC_REQ signal, the Random_access_control process randomly selects preamble_value ("011111") and the rest of Random Access Resources including preamble_received_target_power (-68), then it transit from Idle state to Random_Access_Response_Reception state.

The Random_access_control process receives Random_Access_Response_MAC_PDU during RAR_window_timer time, as it is seen in Figure 12. , the PDU includes RAPID ("01111111") and there is no backoff field.

As the received RAPID match the transmitted pramble_value, the Random_access_control process considers the RAR to be successful and it informs the physical layer with the received parameters (TAC, RAR_Grant).

As the Random_access_control process is now ready to send message3, it first informs the physical layer with the power required to send it (MSG_3_POWER signal). Then, it sends msg3_req signal to the multiplexing_and_assembly process in order to send message3 (including the UE's identity) and to take a copy of it for contention resolution.

After starting the mac_Contention Resolution Timer the Random_access_control process is now waiting for contention resolution message. upon receiving contention resolution message (MAC_PDU_DL signal) the Random_access_control process terminate the timer and starts filtering the received PDU, but unfortunately the identity in the received PDU does not match the transmitted UE's identity. Accordingly, the contention resolution is considered non successful and UE has to start another random access procedure trial, where the UE will starts the new trial immediately (Delay_Timer set to zero) as there is no backoff indication from the eNodeB.

In the new trial, UE selects a new random preamble and repeats the steps again, but also a problem occurs in the contention resolution. The UE starts the third (last) trial, but also a problem occurs. Now, the UE has reached to the maximum number of trials (3), and so Non_successful_Random_Access_process signal is sent to RRC.

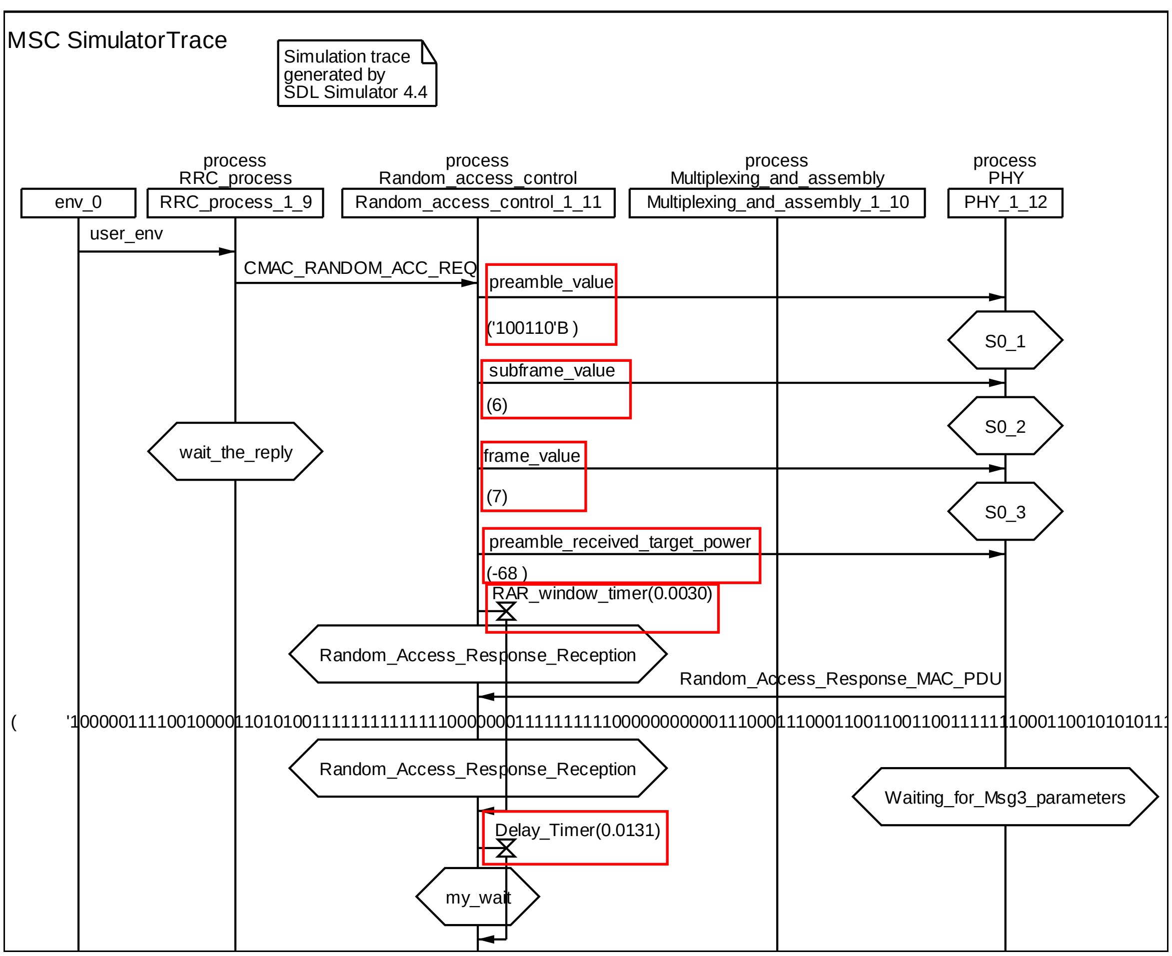

Figure 10. Non successful RAR simulation (1)

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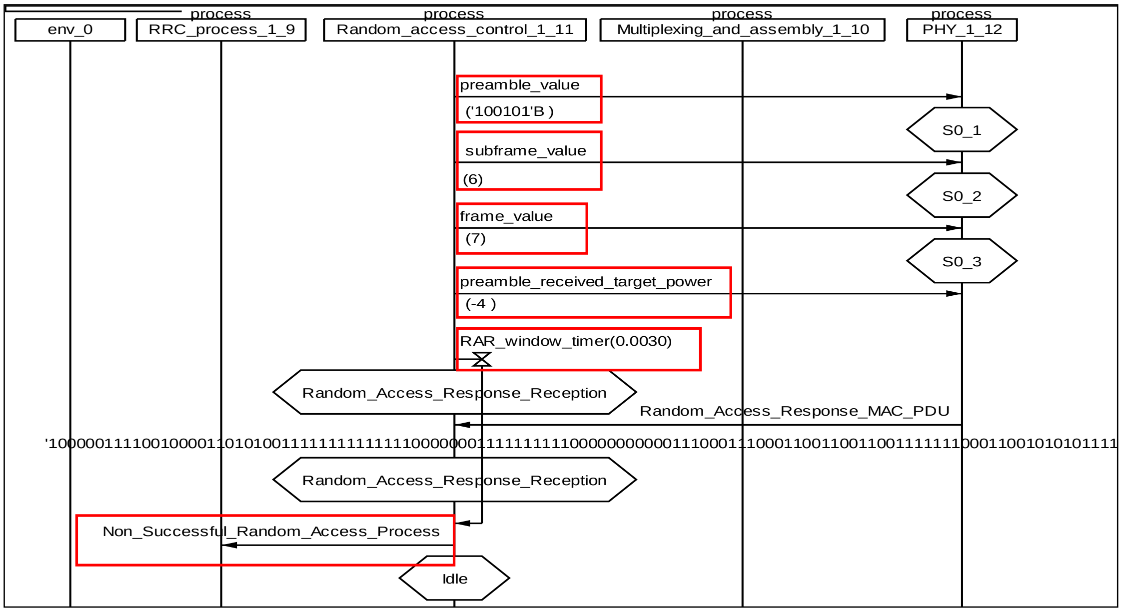

Figure 11. Non successful RAR simulation (2)

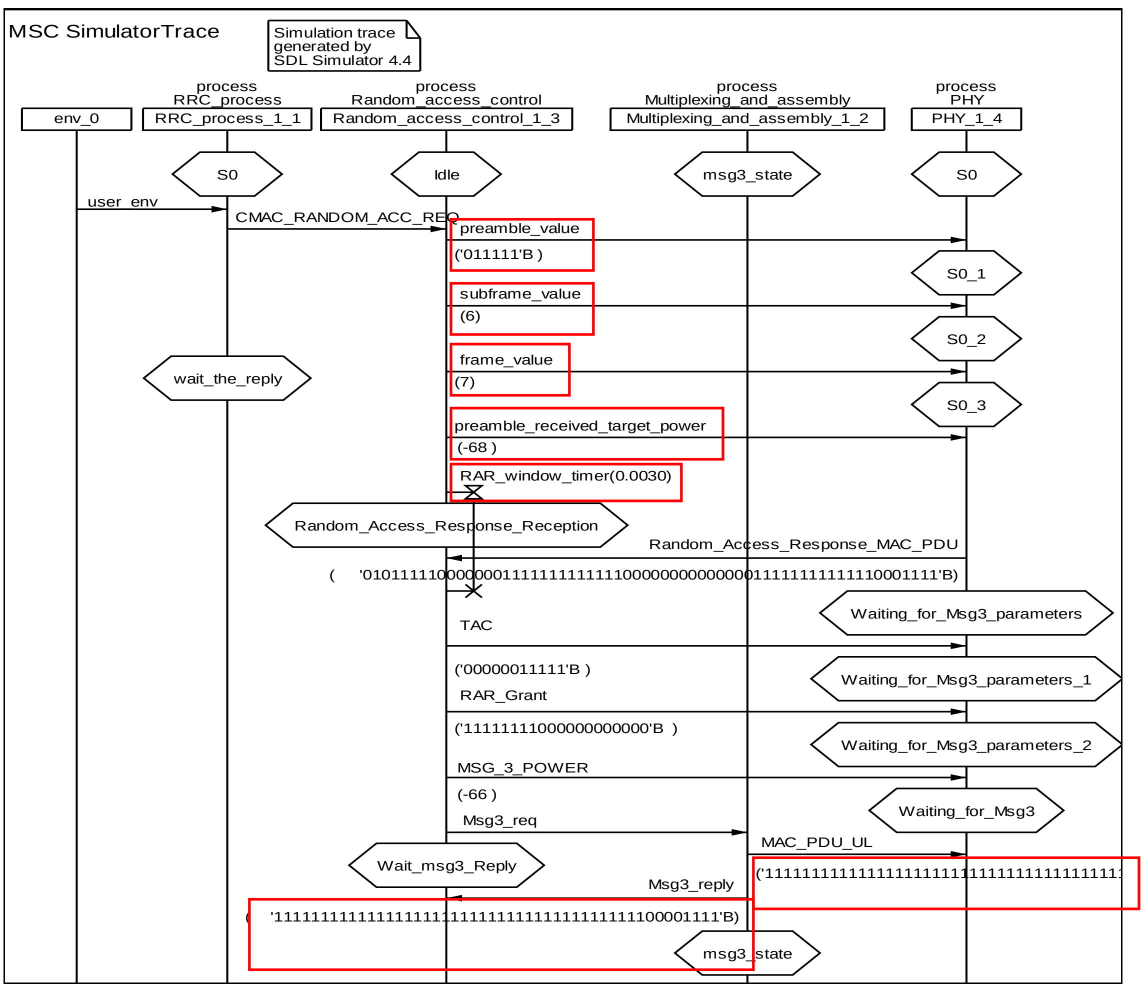

Figure 12. Non successful contention resolution simulation (1)

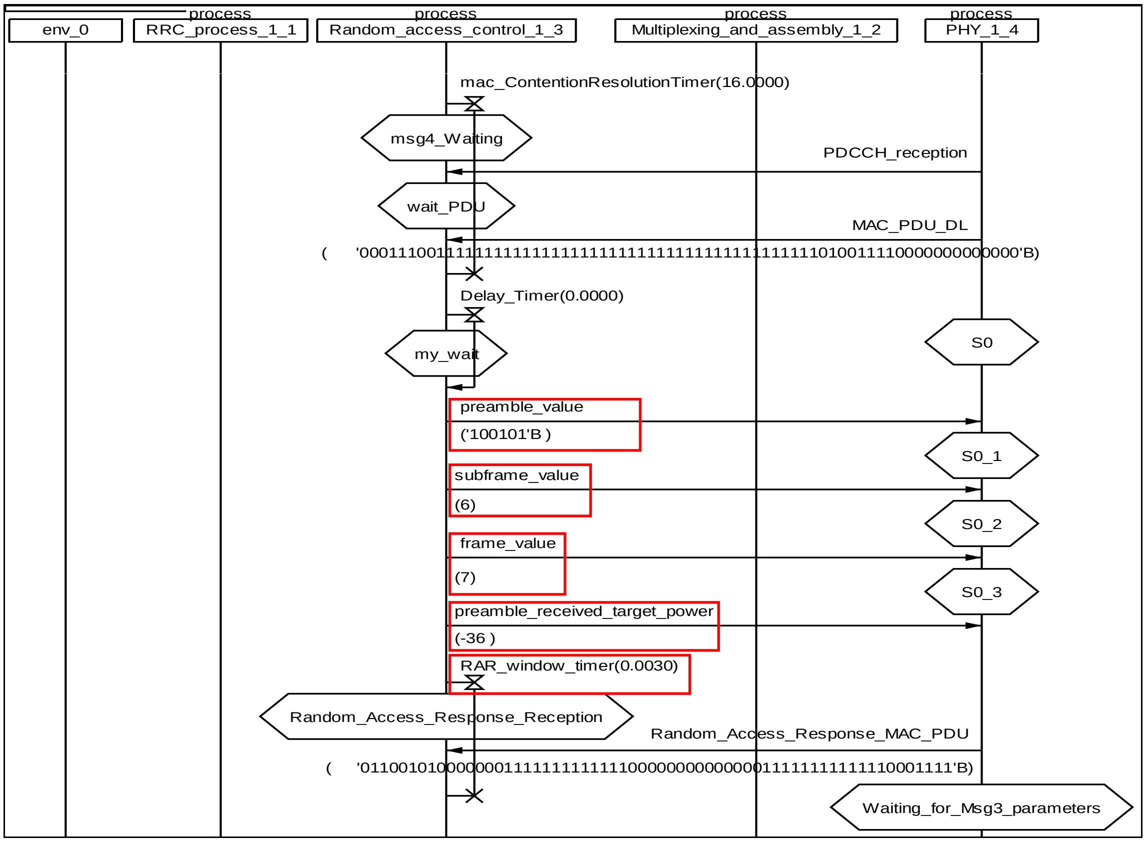

Figure 13. Non successful contention resolution simulation (2)

VI. CONCLUSON AND FUTURE WORK

In this paper, the random access process main problems are considered for both contention and non contention based process and the way MAC sub-layer solve them are explained as stated in 3GPP standard.

SDL/MSC is used to verify and validate the functionality of the proposed solution for both unsuccessful RAR and the unsuccessful contention resolution problems and reporting the upper layer with unsolved ones. A reduced size code is generated, which can be integrated with the rest of the layers' processes, when implemented, to produce a complete E-UTRAN system. Also, the introduced methodology can be used to implement other processes in the MAC sub-layer or any control layer protocols of LTE system.

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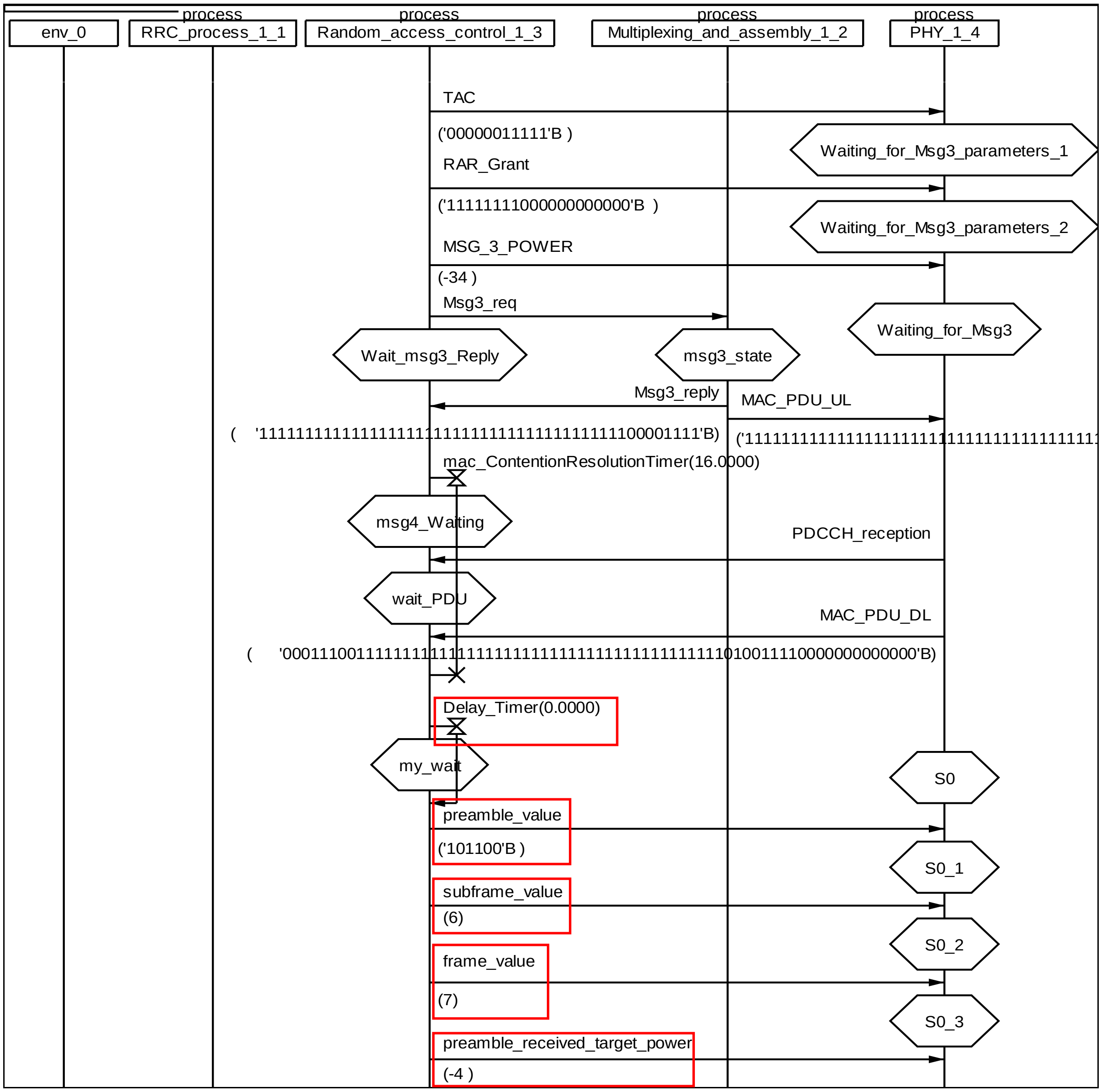

Figure 14. Non successful contention resolution simulation (3)

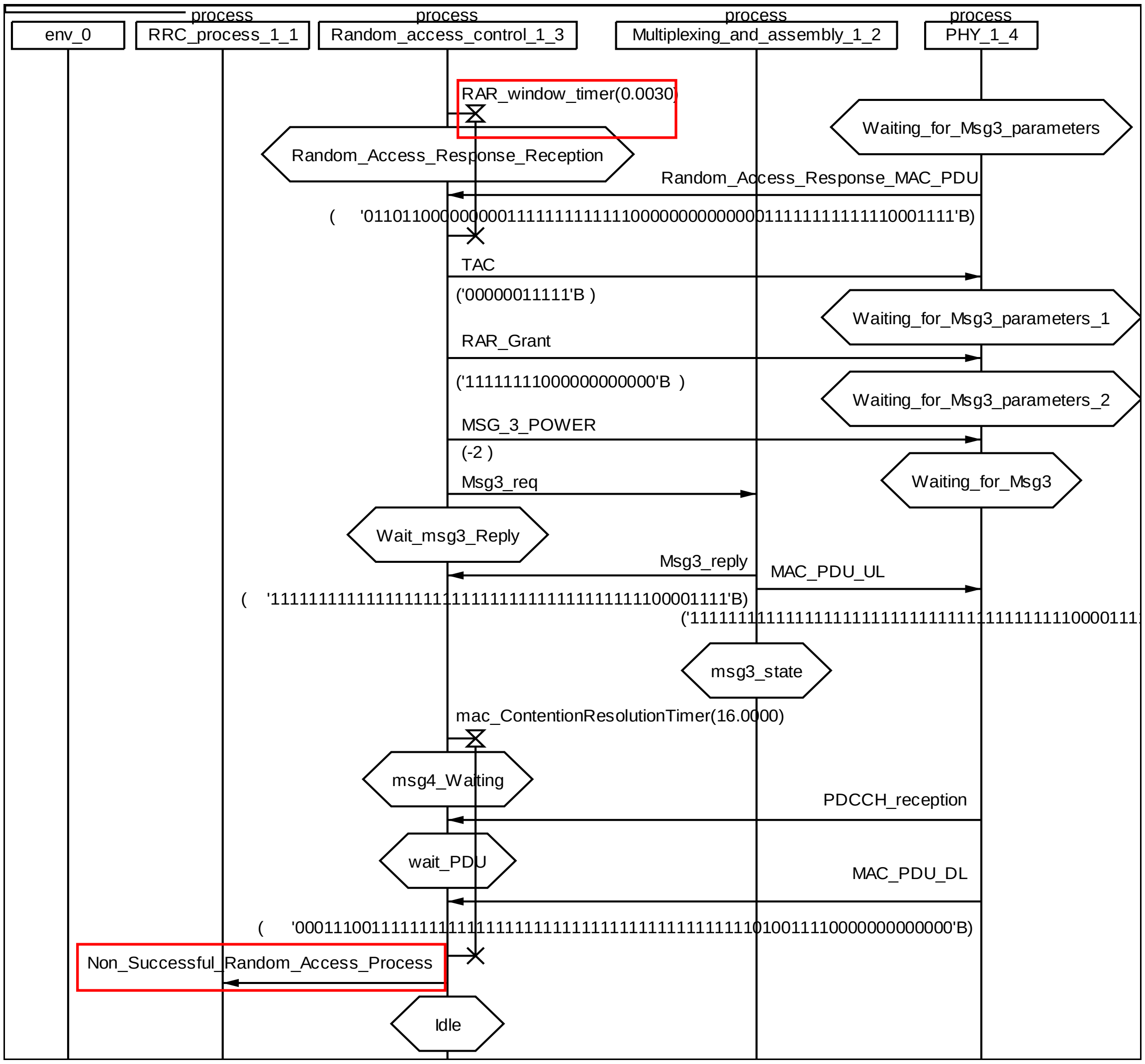

Figure 15. Non successful contention resolution simulation (4)