

# Design and Implementation of Radio Link Control as a Part of the WCDMA Radio Interface Protocols by using SDL

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## ABSTRACT

The Universal Mobile Telecommunication System (UMTS) is the most powerful technology in the third generation (3G) mobile communication and it is the base for the 4G technology. The Wide band Code Division Multiple Accessing (WCDMA) is the radio access technique for the UMTS system. The Radio Link Control (RLC) Protocol is apart from layer 2 of WCDMA protocol architecture. In this paper, we present the RLC Protocol and focus on the Acknowledged Mode (AM) of RLC to explain its complicated functionality. The used methodology is the design, implementation, and verification of the functions of the AM RLC mode using SDL language. The AM RLC functions are confirmed and verified via the simulation results.

**Keywords:** UMTS, RLC, AM, SDL

## 1. INTRODUCTION

The Access Stratum protocol (AS) as a part of the UMTS radio interface in the WCDMA system consists of Radio Resources Control (RRC) [1], Radio Link Control (RLC), and Medium Access Control (MAC).

Figure 1 shows the physical layer (L1), the Data Link Layer (L2), and the Network Layer (L3). The layer 2 splits into two sub-layers: the RLC and the MAC. In addition, two other sub-layers: the Packet Data Convergence Protocol (PDCP) and the Broadcast/Multicast Control Protocol (BMC) in the user plane [2].

RLC protocols provide a range of transport services between RLC entities in both UE and RNC sides. The RLC sub-layer provides three types of data transfer services of operation;

Transparent Mode (TM), unacknowledged mode (UM), and Acknowledged mode (AM) Mode.

Recently, the researchers have provided call handling logic, message transfer procedures and configuration parameter values in the RRC. In addition, they have represented the RLC Coordinator process as part of RLC sub layer in Access Stratum system [3]. A light version of the LTE protocol for the access stratum user plane uplink and downlink connection has modeled by using the SDL Suite tool. The packet propagation from L2 to L3 has focused only on the UM mode in RLC process by using the packet switching techniques. In addition, the ARQ procedure has not implemented in this version and a unidirectional channel has been assumed [4].

The Specification and Description Language (SDL) describes, designs, and verifies the RLC sub-layer especially the AM mode. ITU Recommendation Z.100 standardizes SDL [5]. SDL is one of many introduced suits by Telelogic tau that is a leading toolset for analyzing, designing, testing and implementing reliable real-time and other advanced software systems. The SDL Suite consists of a graphical editor and syntax analyzer, a simulator and validator, and several optimized code generators for compilation to executable code [6].

The design and verification include the following functions: Error Correction (ACK/NACK), Flow Control, Sequence number check, segmentation, concatenation, reassembly, Add Header, and Data Transfer.

The paper organization is as follows: section 2 develops AM mode model. The model design is given in section 3. Section 4 shows the simulation results. Conclusions and future work are provided in section 5.

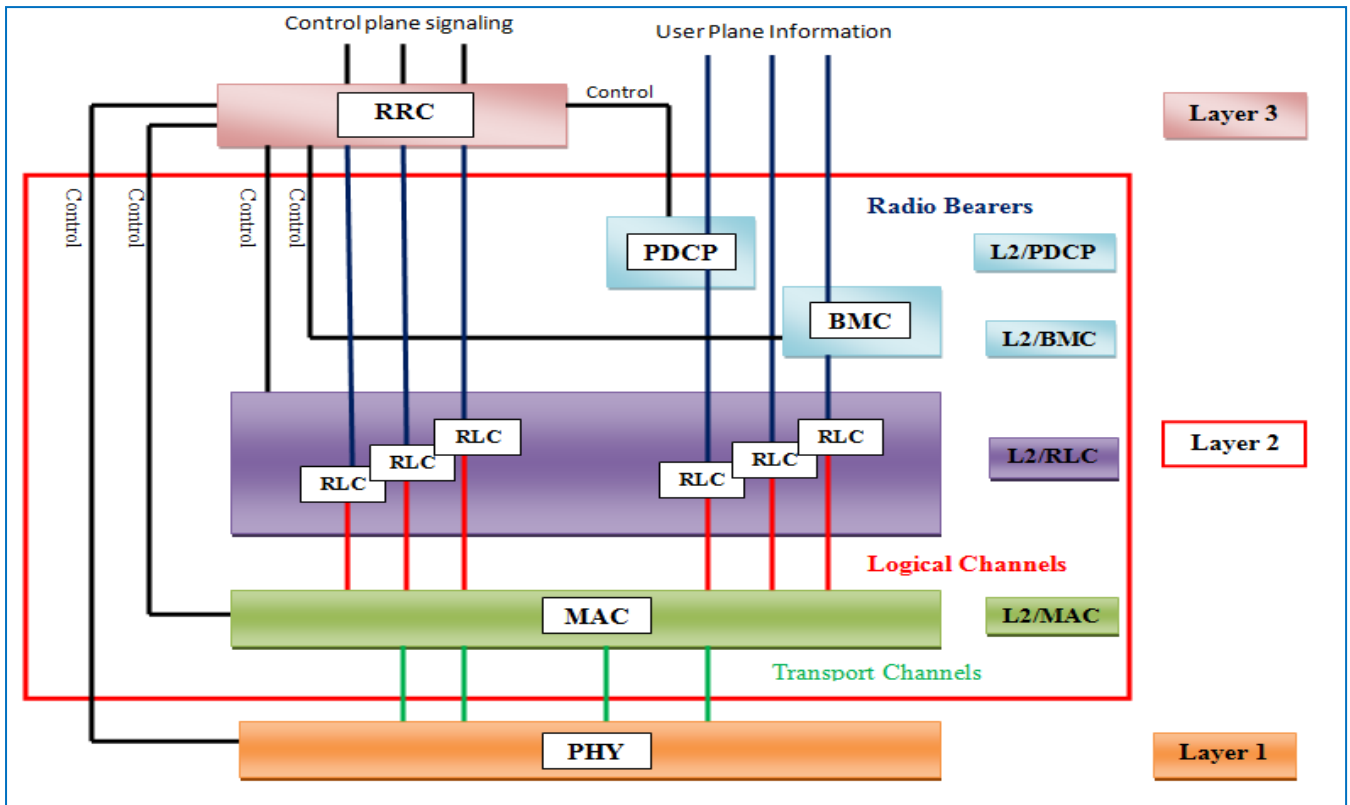


Fig 1: Radio interface protocol structure

## 2. ACKNOWLEDGE MODE MODEL

Figure 2 shows the internal units of AM-RLC model and the connections between them. In AM model, both the transmitting and the receiving side are combined into one entity for both UE and RNC, There are two types of the data in AM RLC: user data called Protocol Data Unit (PDU) and control data (STATUS PDU).

The transmitting side of the AM-RLC entity receives the Service Data Unit (SDU) at the UE higher layer through the Service Access Point (AM-SAP). RLC SDUs are segmented into multiple RLC PDUs. In the concatenation, RLC PDU may contain segmented or concatenated RLC SDUs. The header is a control field in the front of PDU. It contains two-fixed octets, which contain D/C field, the Sequence Number (SN) of PDU, Poll bit (P), and the Header Extension (HE) to extend the header. In addition one /or many optional octets, which contain the Length Indicator (LI) field for the concatenation function, Extension (E) field to indicate the following octets(data or optional header), and a special LI for Padding function (only in last PDU). After this function, a MUX is used to place a copy of the PDUs in the retransmission buffer and to forward it to the transmission buffer. Before data transmission, the p bit is added in the header setting to request the control data from Rx. Finally, each PDU is Ciphared and transferred into Rx- RNC side [7].

In the receiving side of the AM-RLC entity, the reception buffer receives and buffers the PDUs from Tx. One of the following two possibilities occurs when Tx triggers a P bit:

- i) **Positive Acknowledgement (ACK):** the reception buffer receives All PDUs correctly from Tx and a p bit is detected. The Rx acknowledges its peer Tx

side by The Acknowledgement super-field (ACK SUFI), which is one of different types of super-fields. It is included in the STATUS PDU that is transmitted into a retransmission buffer. ACK SUFI carries the Last Sequence Number (LSN) of the PDUs to inform Tx that all PDUs before LSN are received correctly. This causes the retransmission buffer to delete all PDUs that were previously stored, except the PDU of LSN, which should be transmitted. A transmitting window size (buffer) is updated by the number of PDUs that were previously transmitted, while a Receiving window size is updated by each received subsequent PDU to avoid the over flow called Flow control. The reassembly unit reassembles all received PDUs to form the SDU that is sent to the upper layer [8].

- ii) **Negative Acknowledgement (NACK):** the reception buffer receives the PDUs and recognizes that one or more PDU was lost. The Rx sends STATUS PDU to a peer Tx side. LIST SUFI then ACK SUFI are included in STATUS PDU. ACK SUFI carries the LSN of the PDUs received correctly until the lost PDU. LIST SUFI carries SN of one or more corrupted PDUs. Once the control data is transmitted to Tx, the retransmission buffer deletes the acknowledged PDUs before the lost PDU. It then retransmits the lost PDU, which has a priority over the new ones. The number of acknowledged PDUs (before the lost PDU) updates the Tx and Rx window size. Finally, all received PDUs are reassembled in sequence after the retransmission process into one SDU, which in turn, is passed to the upper layer.

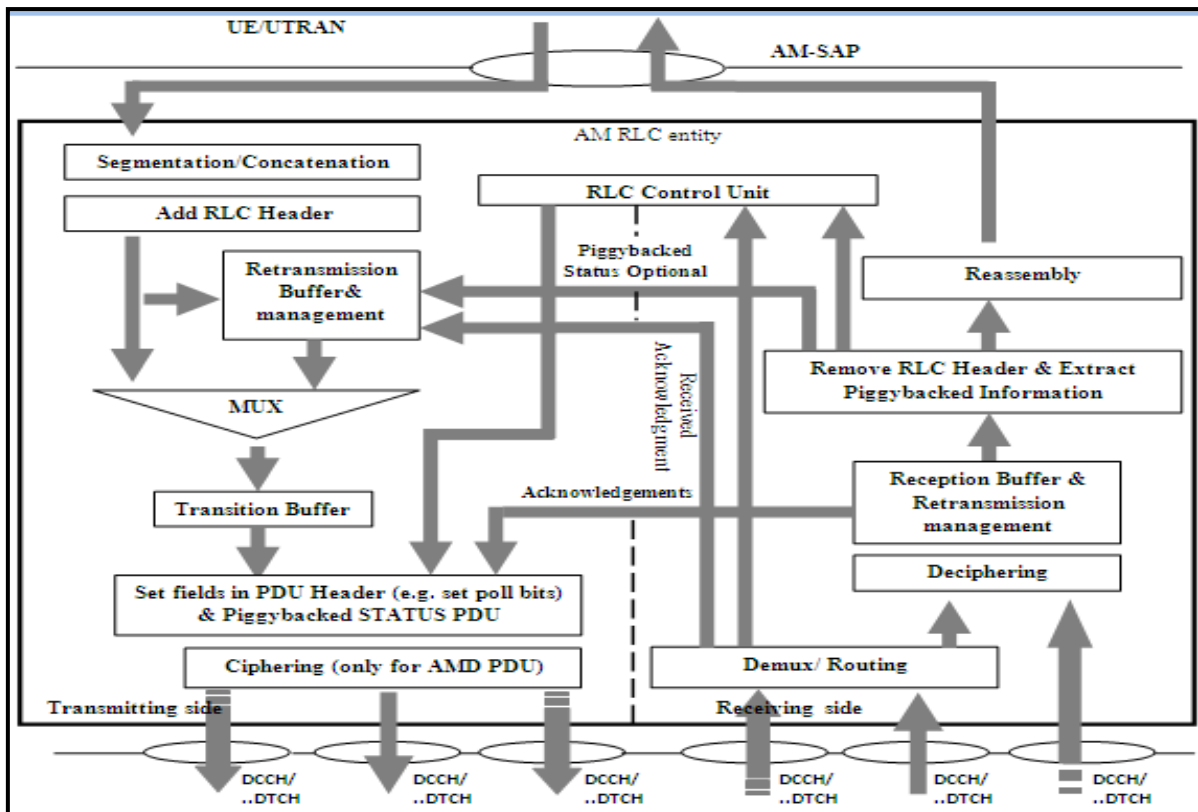


Fig 2: Acknowledged mode model

### 3. MODEL DESIGN AND IMPLEMENTATION

An SDL static structure forms a system. A system consists of blocks. A block is composed of processes. The SDL system structure describes the model design graphically in three hierarchical levels: AS System design, RLC block design, and AM process design.

#### 3.1 AS system design

The **access\_stratum\_radio\_interface\_protocols** system is shown in figure 3. This system consists of Upper Layer, RRC, and RLC block from top to down in both UE and RNC Sides as described in Fig 1. In User Equipment (UE) side, these blocks are termed **UE\_Upper\_Layer**, **UE\_RRC**, and **UE\_RLC** respectively. In Radio Network Control (RNC) side, it is called **RNC\_Upper\_Layer**, **RNC\_RRC**, and **RNC\_RLC** respectively. In the user plane, the Upper Layer block is the source of information to RLC block. While in the control plane, the RRC block configures the RLC block by signaling messages and carries all the configuration parameters of the layer 3 and the layer 1. A channel is a connection among the Blocks in this system like a **Radio\_interface** that is a connection between UE\_RLC and RNC\_RLC blocks in both sides.

#### 3.2 RLC block design

Figure 4 represents the UE\_RLC block. We see that this block consists of five main building processes representing the three modes of operation. These processes are the UE transparent Mode TM Transmitter and Receiver **UE\_TM\_Tx**, and **UE\_TM\_Rx**, respectively, the UE unacknowledged mode UM receiver and transmitter **UE\_UM\_Rx**, and **UE\_UM\_Tx**, respectively and the front-end acknowledge mode AM transceiver **UE\_AM\_Tx\_Rx**. This architecture is required to separate the processors for the transmitting and the receiving

side in TM and UM modes. In addition, the **UERLC\_Coordinator** manages the operation of the five processes forming the RLC via the received control parameters from the RRC block. The processes are connected via signal routes like **Data\_R**, which is a route between UE\_AM\_Tx\_Rx unit in UE\_RLC block and RNC\_AM\_Tx\_Rx unit in RNC\_RLC block.

#### 3.3 AM process design

The AM process is a dynamic behavior of SDL components. AM process is a number of hierarchical transition procedures based on Extended Finite State Machine (EFSM). We developed the complete AM process using SDL Editor in Telelogic Tau. Figures 5 to 7 show representative parts of UE\_AM\_Tx\_Rx and RNC\_AM\_Tx\_Rx process. These flowcharts describe graphically the functions of the internal units in AM model as given in Fig 2.

Figure 5 explains the segmentation and NACK function in UE\_AM\_Tx\_Rx process Tx entity. We see from this figure that, once the SDU is segmented into PDUs, the header is added in front of each PDU. A copy of it is saved in retransmission queue **Retr.Queue** procedure call. The PDUs are transmitted into the RNC side via **User\_Data\_Transfer** procedure call. In case of NACK, a STATUS PDU is received through the input **STATUS\_Report (LIST\_SUFI)** from RNC side. This input carries LIST\_SUFI ended by ACK\_SUFI [8]. **Received\_ACK** procedure call extracts SN of the lost PDU from LIST\_SUFI. The SN of the received PDU before the lost one is extracted from ACK\_SUFI. Before retransmission of the lost PDU into RNC side, **Retransmission\_management** procedure call deletes the received PDUs before the lost one.

Figure 6 shows the Data transfer and ACK function in UE-Tx entity. After segmentation, the output **ueAM\_to\_rncAM (PDU)** is sent from UE-Tx entity to RNC-Rx entity with

carrying each produced PDU from a segmented SDU. About ACK, the input STATUS\_PDU (ACK\_SUFI) carries ACK\_SUFI that was received from RNC side to acknowledge successful reception [8]. Fig 7 illustrates the STATUS\_PDU creation in RNC\_AM\_Tx\_Rx process for RNC side. In this figure, STATUS\_PDU divides into ACK\_SUFI and LIST\_SUFI procedure calls. The first function at the front of

the figure detects if any of the two decisions ACK or NACK is sent to the UE side.

Finally, for SDL model implementation, we used Tele logic Tau 4.4 compiler to convert the SDL system design into C

code via Microsoft Visual Studio C++ 6.0, which runs on the Windows XP operating system. The C source code generated amounts to 1.62 MB.

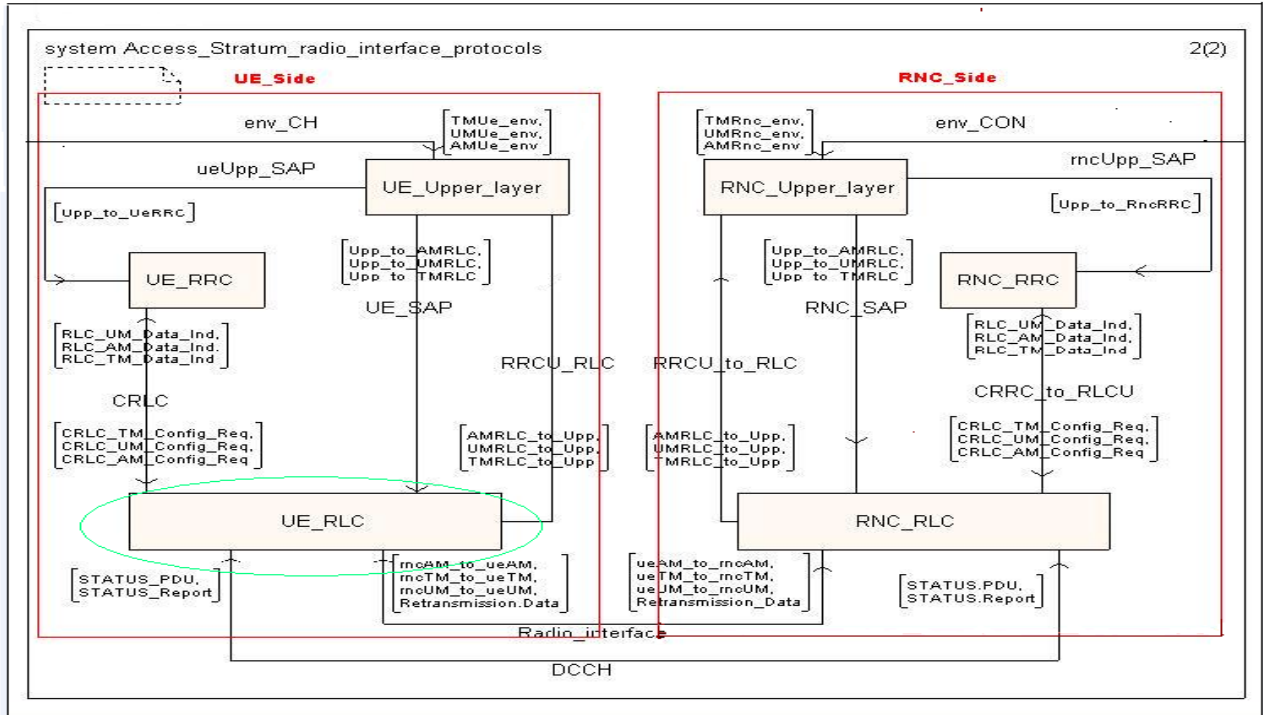


Fig 3: the SDL system diagram

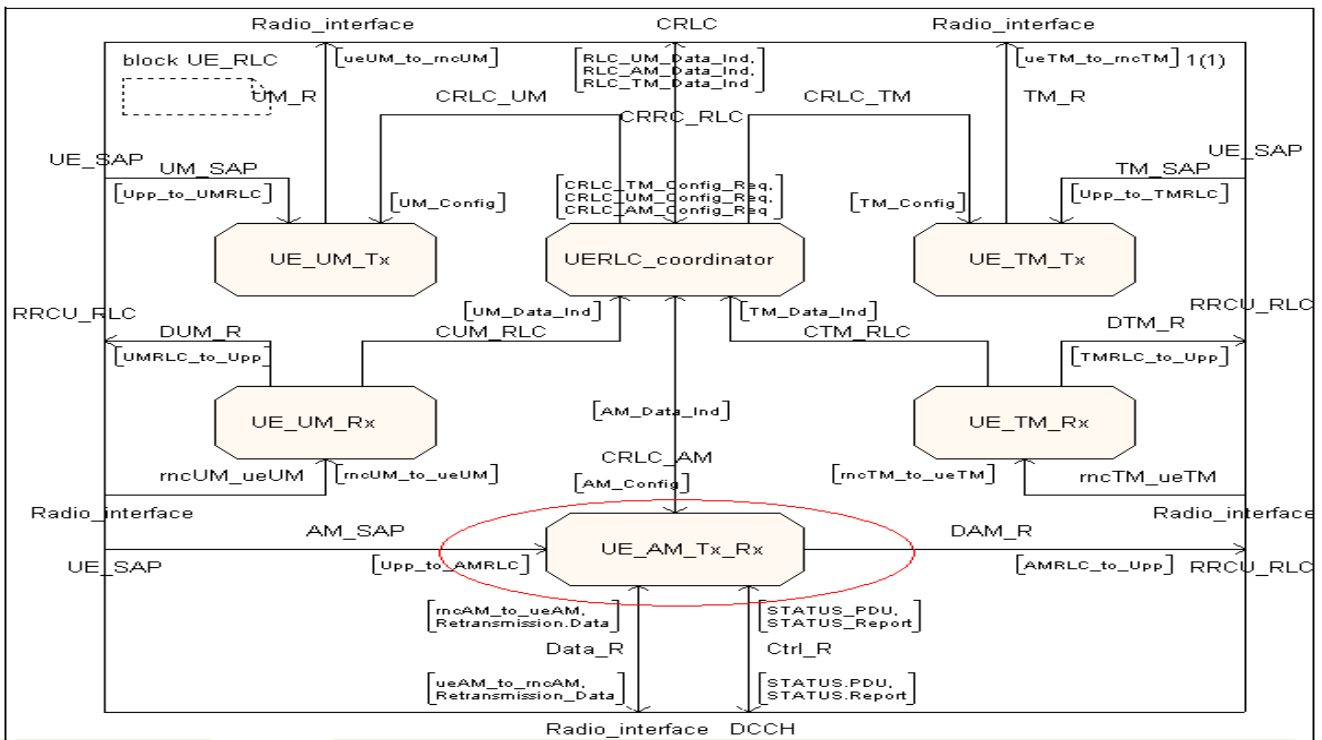


Fig 4: the UE\_RLC Block diagram



#### 4. SIMULATION RESULTS

Telelogic Tau of SDL suite introduces a Simulator UI to analyze and verify the developed system model of the RLC-AM process. Since SDL is a high-level description language particularly suited for communication protocols, the simulation results are focused to demonstrate the functionality of the RLC protocol layer according to 3GPP standard [7]. Specifically, there are two complemented forms of the results in the Simulator UI: the executed transition trace, and Message Sequence Chart (MSC) simulator trace.

Figures 8 to 10 show some representative parts of the executed transitions trace of the AM RLC functions. These results are derived from the data and control PDU format in the AM-RLC model. Figure 8 shows the PDU format (header+ user data) in octets with the padding function in AM mode by using FF octets to fill in the unused space in the last PDU. Figure 9 represents the NACK transition in AM mode. In this figure, the STATUS\_Report output signal carries LIST\_SUFI followed by ACK\_SUFI parameters to request retransmission of the missing PDUs. Both SUFIs contain the required parameters for their functions. Finally, figure 10 introduces the ACK transitions in AM mode. In this figure, STATUS\_PDU output signal carries ACK\_SUFI parameters to acknowledge the successful reception. This SUFI carries the specified parameters for its function. The explained parameters of ACK and LIST SUFIs in fig. 9 and 10 were executed according to the control PDU (STATUS PDU) of AM mode in the protocol standard.

The message sequence chart MSC is the timing diagram of the transmission signals flow with the encoded PDU and STATUS PDU parameters among the layers in the level of processes for both UE and RNC sides. Figures 11 to 13 show

representative results of MSC simulator trace of the standard function procedures of the internal units in the AM diagram respectively as shown in figure 2. These signals flow of the figures represent also the connection lines among the internal units from up to down in AM diagram. The UE\_AM\_Tx\_Rx process shows the internal units in UE-Tx entity. While, the internal units in the RNC-Rx entity is represented by RNC\_AM\_Tx\_Rx process in the MSC results.

Figure 11 shows the configuration messages of the UE\_AM\_Tx\_Rx process. These messages are transferred from the null (initialization the parameters) to Data\_Transfer\_Ready states (transferring data) via UE\_RRC process.

In Figure 12, the MSC shows and verifies the signals of the segmentation/concatenation, ACK, and Reassembly functions. The UPP\_to\_AMRLC signal carrying the SDU is received from UE\_Upper\_Layer process to UE\_AM\_Tx\_Rx process. The SDU is segmented/or concatenated into PDUs. The ueAM\_to\_rncAM signal carrying the PDUs is transferred into RNC\_AM\_Tx\_Rx process. STATUS\_PDU signal is transferred from RNC\_AM\_Tx\_Rx process to UE\_AM\_Tx\_Rx process to return an acknowledgement to the sender. The PDUs are reassembled into the original SDU. The AMRLC\_to\_UPP signal with SDU is transferred into RNC\_Upper\_Layer process. Figure 13 represents the signal flow of NACK and retransmission function. Status\_Report signal is transferred from RNC\_AM\_Tx\_Rx process to the UE\_AM\_Tx\_Rx process in order to inform the sender that the missing PDU requires the re-transmission. The Retransmission\_Data signal retransmits the missing PDU into RNC\_AM\_Tx\_Rx.

```

* PROCEDURE START <<Block UE_RLC/Process UE_AM_Tx_Rx>> Retr.Queue
* DECISION Value: false
* DECISION Value: true
* ASSIGN Back := 23
* ASSIGN Q... := (: 80, B9, 05, FE, A2, A3, FF, FF, FF :)
* ASSIGN Count := 24
* PROCEDURE RETURN <<Block UE_RLC/Process UE_AM_Tx_Rx>> Retr.Queue
* PROCEDURE START <<Block UE_RLC/Process UE_AM_Tx_Rx>> User_Data_Last_Segmented
* ASSIGN PDU := (: 80, B9, 05, FE, A2, A3, FF, FF, FF :)
* OUTPUT of ueAM_to_rncAM to RNC_AM_Tx_Rx:1
* Parameter(s) (: 80, B9, 05, FE, A2, A3, FF, FF, FF :)
* PROCEDURE RETURN <<Block UE_RLC/Process UE_AM_Tx_Rx>> User_Data_Last_Segmented
*** NEXTSTATE NULL
    
```

80, B9: two fixed header, 05: optional octet header, FE: special LI  
A2, A3: Data  
FF: Padding

Fig 8: the padding function in the last PDU at ueAM\_to\_rncAM output signal

```

* PROCEDURE START <<Block RNC_RLC/Process RNC_AM_Tx_Rx>> LIST_SUFI
* ASSIGN LSN := 6
* ASSIGN LIST_SUFI... := 03 Hex -> 0 000 0011 :D/C + control PDU type +SUFI type (LIST=0011)
* ASSIGN LIST_SUFI... := 10 Hex -> 0001 0000 : LENGTH(0001)+SN of lost PDU (4 bits) =0000
* ASSIGN LIST_SUFI... := 06 Hex -> 0000 0110 : SN of lost PDU (8 bits)
* DECISION Value: false
* ASSIGN LIST_SUFI... := 02 Hex -> 0000 0010 : LI (4 bits)=0000 + control PDU type (ACK=0010)
* DECISION Value: false
* ASSIGN LIST_SUFI... := 00 Hex -> 0000 0000: LSN (8 bits)
* ASSIGN LIST_SUFI... := 60 Hex -> 0110 0000 : LSN (4 bits) =0110, Padding = 0000
* OUTPUT of STATUS_Report to UE_AM_Tx_Rx:1
* Parameter(s) (: 03, 10, 06, 02, 00, 60, 00, 00 :)
* PROCEDURE RETURN <<Block RNC_RLC/Process RNC_AM_Tx_Rx>> LIST_SUFI
    
```

Fig 9: LIST\_SUFI parameter of the STATUS PDU output signal

```

PROCEDURE START <<Block RNC_RLC/Process RNC_AM_Tx_Rx>> ACK_SUFI
ASSIGN ACK_SUFI... := 02 Hex → 0 000 0010: D/C (0) + PDU type (000) +SUFi type (ACK=0010)
ASSIGN LSN := 18 0000 0001 0010 : LSN (SN=12 bits)
DECISION Value: true
DECISION Value: false
ASSIGN ACK_SUFI... := 01 Hex → 0000 0001 : LSN (SN=8 bits)
ASSIGN ACK_SUFI... := 20 Hex → 0010 0000 : LSN (SN=4 bits) in MSB
OUTPUT of STATUS_PDU to UE_AM_Tx_Rx:1
    Parameter(s) : (: 02, 01, 20 :)
PROCEDURE RETURN <<Block RNC_RLC/Process RNC_AM_Tx_Rx>> ACK_SUFI
    
```

Fig 10: ACK\_SUFI parameter of the STATUS\_PDU output signal

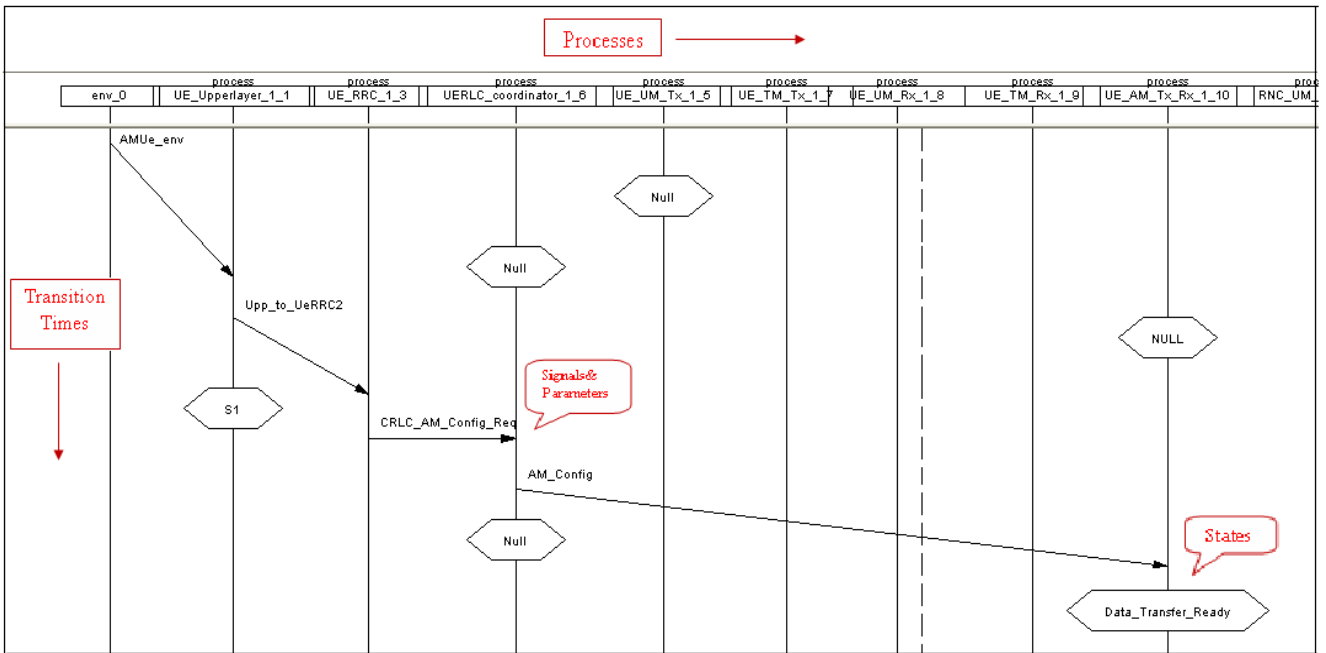


Fig 11: a part of the MSC system - the signaling messages of UE\_AM\_Tx\_Rx process

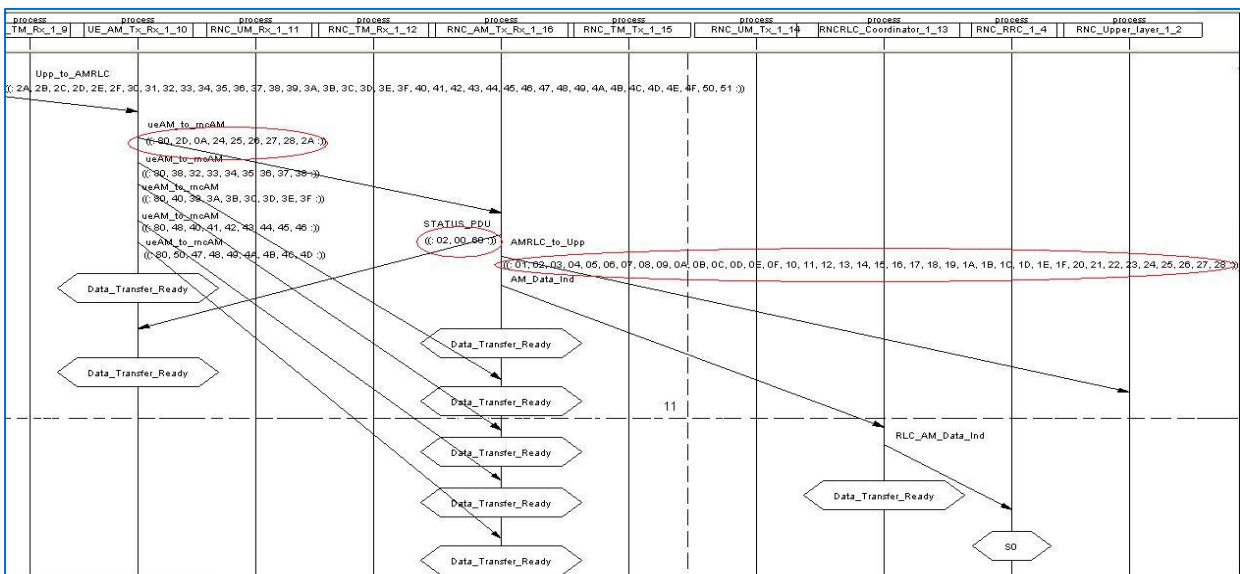


Fig 12: a part of the MSC system –segmentation/concatenation, ACK, and reassembly function

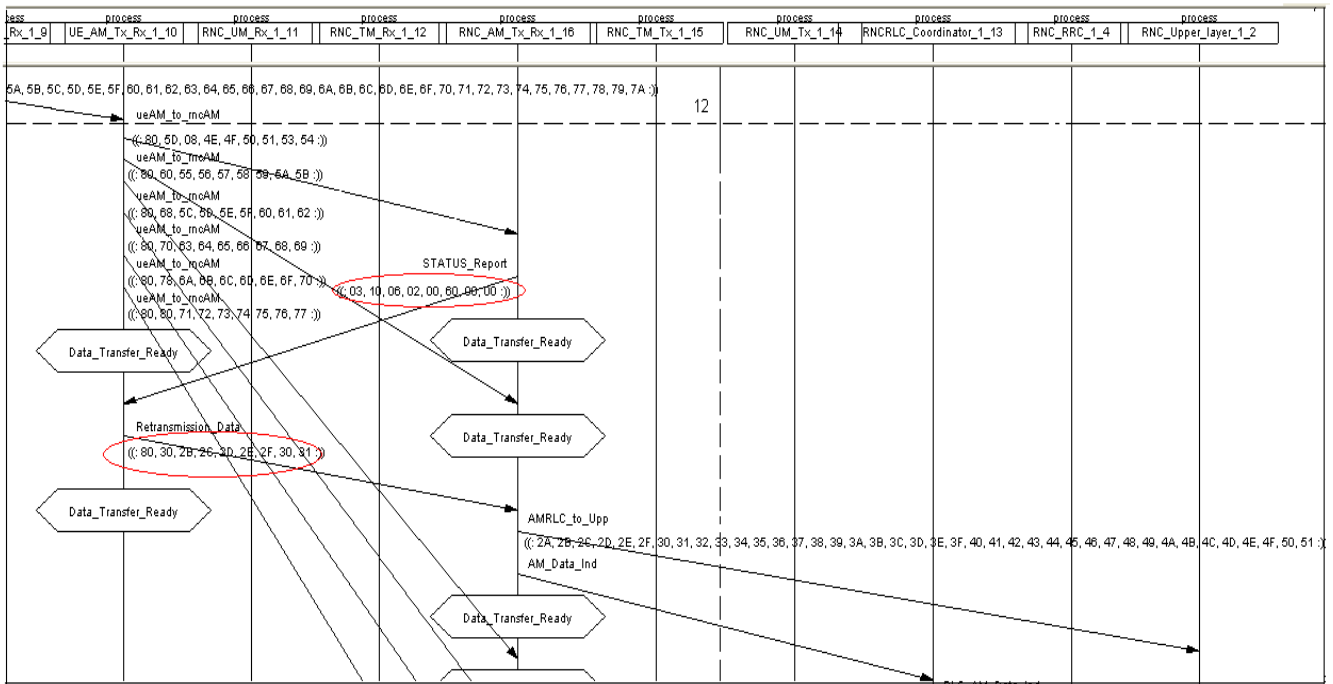


Fig 13: a part of the MSC system - NACK, retransmission

Finally, we see that the SDU is transferred from the UE side to the RNC side (peer-to-peer connection) successfully passing through the RLC functions in AM transfer mode. Therefore, we can conclude that the MSC develops a real time services and verifies the AM RLC mode in AS system.

## 5. CONCLUSIONS

In this paper, we implemented successfully the functions of the AM RLC process which are a part of the protocol architecture of the WCDMA radio interface protocols. To carry out that, we studied the RLC protocol according to 3GPP standards. We utilized SDL to build a model of the RLC AM process. The process is then simulated using the soft ware suite Telelogic Tau. The simulation results showed and verified the correct functionality of the developed model, which complies with the 3GPP technical specifications.

Other processes in the RLC layer or any other control layer protocols can be implemented in the same way. Protocols of the LTE system can also be implemented and integrated by utilizing the great features of the SDL language. Least but not last, one can develop a hardware prototype model based on SoC system.

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