An SDL Implementation of the UMTS Radio Resource Control Protocol Oriented to Conformance Testing

José M. Álvarez[a], Pedro de la Cámara[b], Jesús Martínez[a]
Pedro Merino[a], Francisco C. Pérez[a], Victoria Morillo[c]

[a]*Dpto. Lenguajes y Ciencias de la Computación, Universidad de Málaga*
[b]*Centro Andaluz de Innovación y Tecnologías de la Información y las Comunicaciones (CITIC)*
[c]*Centro de Tecnología de las Comunicaciones, S.A. (CETECOM S.A.)*

Abstract

SDL and other related ITU-T formal languages have been revealed as a valid approach to developing software for critical systems, such as telecommunication equipment. In this context, this paper presents the use of SDL to implement one of the most complex part of UMTS networks, the Radio Resource Control protocol (RRC). SDL has been used at all the steps of the design and the implementation process, making use of the automatic code generation capabilities of well-known SDL tools. The resulting system will be integrated as a part of a conformance testing box for 3G mobile phones, namely MINT, a product developed by one of the certification leaders in the industry, CETECOM S.A.

The main conclusion obtained from this project is that SDL (together with ASN.1) has good capabilities to design and implement realistic complex systems with a very limited use of external languages, like C. During the development, we have been able to take advantages of its formal basis and tool support for simulation and verification. [1]

1. Introduction

The increasing acceptance of 3G mobile telephony moves terminal manufactures to produce new models with improved functionalities (such as high speed Internet access). Unfortunately, as terminals and standards for mobile networks evolve, so does their complexity. Regarding widely adopted 3GPP (3rd Generation Partnership Project) networks, quality of device is certified through the passing of normative tests that will guarantee interoperability among terminal and network elements belonging to different companies. In this context, the equipment for testing has a key role in order to certify 3G products and a great effort should be devoted to ensure its robustness and reliability. Therefore, the development of such complex systems could benefit from using rigorous methodologies, such as formal methods.

The Specification and Description Language (SDL) is a formal language promoted by ITU-T and is widely adopted as a standard to specify telecommunication protocols. SDL support provided by tools such as Tau from Telelogic offers developers not only a visual way to design the system and protocols, but also the availability of additional features such as, for example, the integration with other normative languages (ASN.1 or TTCN), automatic code generation, simulations or automatic verification.

Although SDL has been employed previously to develop protocols for 3G UMTS (Universal Mobile Telecommunications System) [1, 2], most of these implementations are academic or are not oriented to real systems. The main reason for this has been the traditional belief that SDL is not powerful enough to manage complex resources and operations needed by high performance protocols. One way to solve this difficulty in developing such critical systems is to adopt a hybrid approach which uses SDL to model blocks, entities and communications and embedded C code to model complex data management and calculations. This methodology is supported by Tau, which generates code from SDL to C code (respecting the previously embedded C parts, if any). The resulting source code is compatible with the main platforms and operating systems already on the market.

One successful case in the use of this technology is the MINT tester, developed by the one of the certi-

[1]Work supported by projects CITIC - COSMOSTIC and TIN2005-09405-C02-01

fication leaders in the telecommunications sector: the Spanish company CETECOM S.A. The MINT tester is a conformance testing box for 3G mobile phones. During its design, SDL was used to develop layers 1 and 2 of UMTS.

This paper presents the main results of a joint project with CETECOM S.A. in order to develop one of the most complex parts of a resource network controller for UMTS networks: the Radio Resource Control protocol (RRC). This protocol is responsible for the establishment, release and configuration of radio connections between the user equipment (UE) and the mobile network. The main objective of the project has been to incorporate this layer on top of MINT in order to provide the intelligence needed to manage the whole testing process with a user terminal. The new layer will substitute complex test scenarios for new simpler ones, reducing the need for configuring and controlling the completely of UMTS 1 and 2 layers, and allowing test users to focus only on the type of high-level proofs they want to certify.

Our contributions to existing RRC implementations (see for instance [3]) are related to the fact that we have dealt with an existing device which works in real life scenarios. Therefore, our decisions in the design have been influenced mainly by integration and performance concerns. In the original MINT, the 3GPP test scenarios were provided by TTCN scripts. Each test consisted of signals arrived at the MINT tester where the protocol layers were configured to establish communication with the UE. In contrast, our RRC is an intelligent layer (composed by several concurrent processes) which can execute the same set of tests but having also its autonomous behaviour.

Moreover, the RRC protocol is decoupled from the MINT existing layers, reducing this way the performance impact by maintaining a dedicated processor for the intensive work needed by layers 1 and 2. Communications between RRC and the other layers are done through network sockets. This distributed solution has also allowed us to design the whole RRC protocol in SDL. With this approach, we have available all the verification and simulation capabilities in Tau. The final solution has been demonstrated to perform well in real test executions.

2. Technology Background

Abstract Syntax Notation number One [4] (ASN.1) is an International Telecommunications Union (ITU) standard formal notation used for describing data types independently of of either physical representation, the language implementation or the application using it. Typically, those values are encoded into binary format to form the messages used in computer communication.

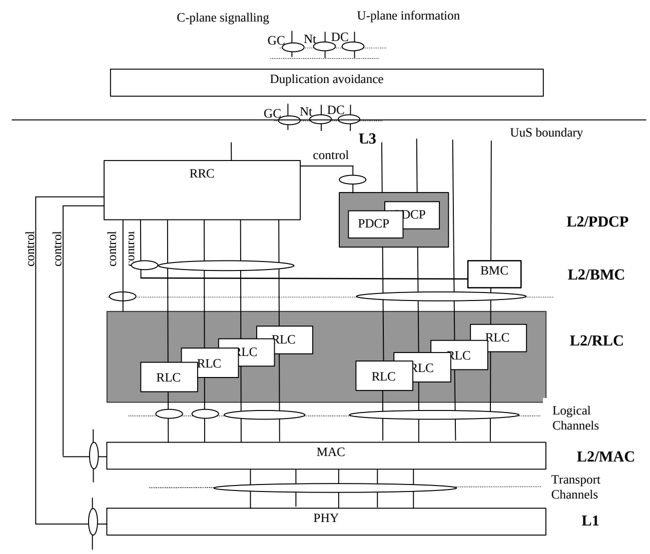

Figure 1. Air interface architecture in UMTS

Testing and Test Control Notation (TTCN) [5] is another ITU standard language used to write detailed test specifications. TTCN has been used to specify tests for many kinds of applications, especially in the context of telecommunications.

The Specification and Description Language (SDL) [6] is another ITU standard language used to specify complex systems, including their architecture, their communication with the environment, their behavior and their internal information.

Telelogic's Tau SDL Suite is a software development tool that allows developers to specify systems using all the diagrams contained in SDL. It also allows to integrate ASN.1 types to be integrated into the system.

The Universal Mobile Telecommunications System (UMTS) [7] describes the functionality required to support the 3G mobile telephone network, including the user equipment, the radio infrastructure and the core network. The UTRAN protocol stack can be divided into the upper layers, the Non Access Stratum (NAS), and the lower layers, the Access Stratum (AS) protocols. The NAS carries messages that are independent of the underlying access mechanism. The AS protocols are responsible for configuring and controlling the access mechanism and for providing the NAS with the the means to communicate user equipment. The AS is divided in three layers: layer 1, the physical layer, layer 2, that contains the MAC and RLC protocols and layer three containing the RRC protocol.

MINT RF Tester, see figure 2, is a scalable and

Figure 2. MINT RF Conformance Tester

flexible test platform for 2G/2.5G/3G mobile stations, covering not only officially validated Conformance test cases (GCF and PTCRB) but also RF R&D Testing beyond conformance requirements. The MINT RF Tester allows users to customize test conditions in order to create multiple test scenarios and to adapt to their specific testing needs.

3. RRC protocol

The RRC protocol [7] is the main control protocol for the AS [8] and is responsible for the configuration and control of the underlying protocols that establish the radio connection between the user equipment (UE) and the network (UTRAN).

Services provided by the RRC [9] can be classified into three groups, *general control*, which provides information broadcasting services to all the UEs located in a specfic geographical area, the *notification* which provides services for paging and information broadcasting to specific UEs and the *dedicated control*, that provides services for connection establishment and release as well as message transfers throughthat connection.

RRC messages transferred between the UE and the UTRAN control and configure the RRC connection, and can be divided into four categories: RRC connection management, *Radio Bearers* control, RRC connection mobility and RRC measurements.

The RRC protocol RRC is divided into five main functional units, shown in figure 3. The Routing Function Entity (RFE) handles the routing of the messages from the upper layers to different domains in the core network. The Broadcast Control Function Entity (BCFE) handles the broadcast functions. The Paging and Notification Control Function Entity (PNFE) handles the paging of UEs that do not have an RRC connection. Dedicated Control Function Entity (DCFE) handles all functions specific to one UE. Finally, the Transfer Mode Entity (TME) handles the mapping between the RRC entities and the RLC SAPs.

4. Implementation details

Following the description in section section 3, the entities of RRC have been the main guide used in the design of the structure. The SDL system is divided into two blocks, the `NAS_model`, which implements the NAS functionalities needed to run the tests and the `RRC_struct` which implements the RRC protocol. The block corresponding to the RRC protocol consists of five process types: `RFE_RNC`, `BCFE_RNC`, `PNFE_RNC`, `DCFE_RNC` y `TME_RNC`. There is a single instance of each one in this first version of the system, because the functionality implemented is only able to manage a single cell and to deal with one UE at a time.

These processes correspond to the functional elements described in the standard. In addition to them, there is a further process, `GlobalState`, whose role is to monitor the global information common to processes in block `RRC_struct`. The information contained in this process in divided into two categories, the information particular to a cell, and the information that is cell-independent. Both types of information are accessed through remote procedure call, a language feature that guarantees modifications in mutual exclusion.

From all the functionalities offered by RRC, we have taken into account only those required for a UE to establish and release a connection, along with the establishment of incoming and outgoing calls.

Most of the procedures implemented are related to connection management. Examples of these are the *Broadcast of system information*, whcih sends system information from the UTRAN to every UE registered in a cell, the *Paging*, which sends paging information to a set of selected UEs, the *RRC Connection Establishment*, which is initiated by upper layers (NAS) to request and establish a signaling connection between the UE and the RNC, the *RRC Connection Release*, used to release a signalling connection previously established, the *Direct Transfer*, both *Initial*, *Uplink* and *Downlink*, which establish signalling connections through which the NAS messages will be sent in both directions and

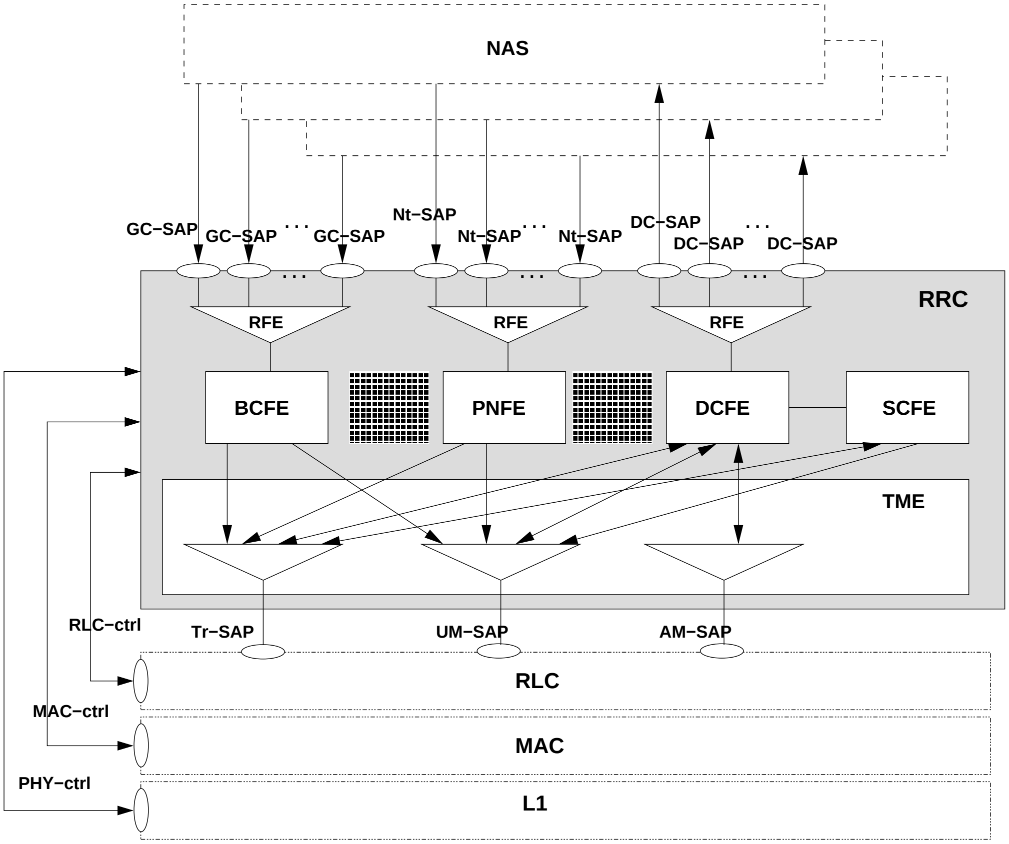

Figure 3. RRC architecture

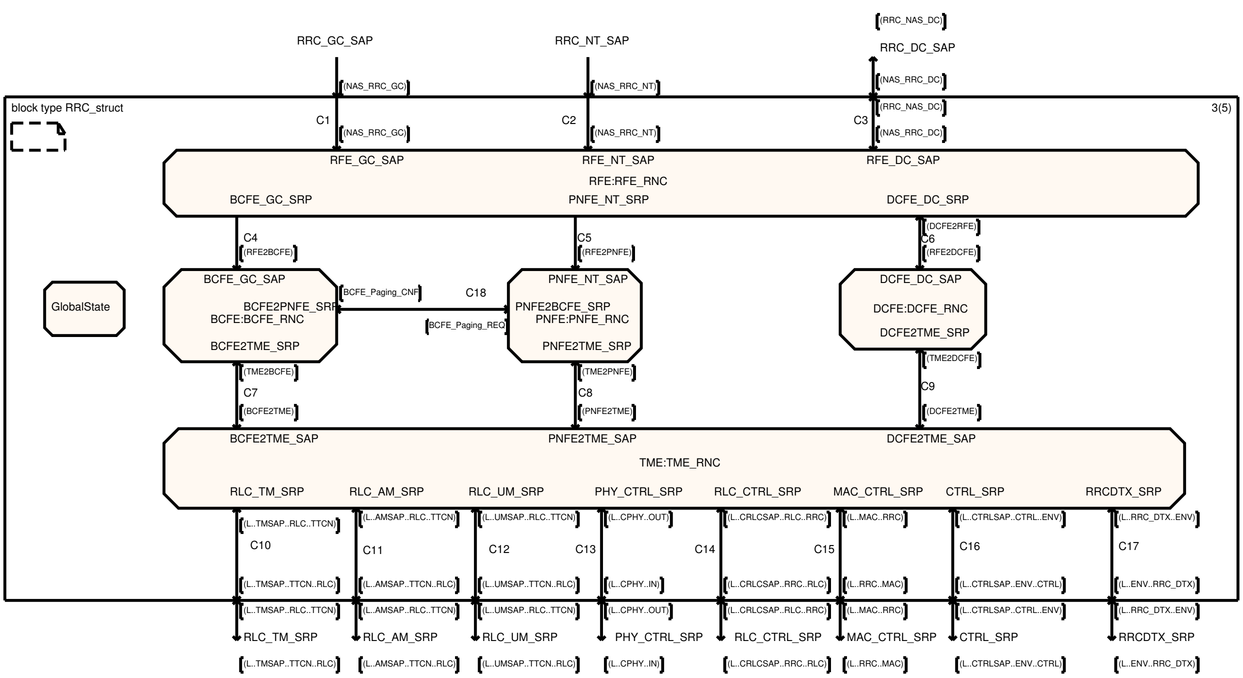

Figure 4. Diagram of the `RRC_struct` block

the Security Mode Control, which starts the ciphering mechanism for the channels of a CN and changes the ciphering configuration.

The other procedure implemented is related to the control of *Radio Bearers*, the *Radio Bearer Setup reception*. With this procedure, UTRAN sends a message to a selected UE to establish new radio bearers. It can include modifications in the configuration of transport and physical channels.

5. Conclusions

3G architectures and protocols are quickly evolving in order to offer new capabilities to terminals. This fact increments the complexity of the new services and the need for rigorous testing on equipment. In order to develop a complete tester for mobile networks, the resulting system must implement compatible radio access protocols based on standards. The MINT tester, by CETECOM S.A., is a good example of a testing box for UMTS environments that provides a way of testing UEs according to 3GPP standard test case scenarios. This project has improved the MINT capabilities by the integrating of the original system with a new RRC layer that controls the configuration parameters for UMTS layers 1 and 2. Our distributed approach has reinforced our idea that SDL offers a good balance between formality and efficiency. Therefore, our solution has consisted of an “all SDL” design without embedded C code, which allowed us to use typical validation tools in the formal methods community such as symbolic simulation or automatic verification by state exploration to debug the software.

Regarding performance, our approach also benefits from having a distributed scheme that communicates through sockets. Thus, the MINT box focuses on intensive calculations needed for establishing UMTS connections. The RRC box is running as a supporting background process to reconfigure and adapt MINT to new testing conditions. The resulting system has proven to be efficient enough to be used in real scenarios by CETECOM S.A.

References

[1] Sipilä, J., Luukkala, V.: An SDL implementation framework for third generation mobile communications system. In Reed, R., Reed, J., eds.: SDL Forum. Volume 2078 of Lecture Notes in Computer Science., Springer (2001) 288–299

[2] Song, P.J., Noh, M.H., Kim, D.H.: Design and implementation of W-CDMA radio interface protocols using SDL development environments. In Lee, J.Y., Kang, C.H., eds.: CDMA International Conference. Volume 2524 of Lecture Notes in Computer Science., Springer (2002) 442–452

[3] Jung, K.R., Choi, J., Song, P., Nam, Y.H.: Design and implementation of a radio resource control protocol in WCDMA using SDL. In: Vehicular Technology Conference, IEEE VTS 54th. Volume 2. (2001) 990–994

[4] (Technical report)

[5] International Telecommunication Union: Testing and Test Control Notation version 3 (TTCN-3): Core Language. Technical Report ITU-T Z.140 (2001)

[6] International Telecommunication Union: Specification and Description Language. Technical Report ITU-T Z.100 (2002)

[7] Terminal Specification Group Terminals: User Equipment (UE) Conformance Specification; Part 1: Protocol Conformance Specification (Release 1999). Technical Report 3GPP TS 34.123-1. version 3.4.0, 3rd Generation Partnership Project (3GPP) (2001)

[8] Richardson, A.: WCDMA Design Handbook. first edn. Cambridge University Press (2005)

[9] Technical Specification Group Radio Access Network: Radio interface protocol architecture (release 1999). TS 3GPP TS 25.301 V3.11.0, 3rd Generation Partnership Project (3GPP) (2002)