Framework for Automated Tests of LTE Physical Layers

Felipe A. P. de Figueiredo*, Fabiano Mathilde‡, Luiz R. Pizzini†, Dick Carrillo† and Ingrid Moerman*
*Department of Information Technology, Ghent University, Belgium.
†CPqD – Research and Development Center on Telecommunications, Brazil.
‡Eldorado Institute, Brazil.
Email: *[felipe.pereira, ingrid.moerman]@ugent.be †[lpizzini, dickm]@cpqd.com.br
‡[fabiano.mathilde]@eldorado.org.br

***Abstract*—This paper proposes an automated test framework for eNodeB's physical layer development, comprising procedures for checking data integrity, stability and performance. The proposed framework is based on a simplified LTE MAC layer, which operates as a software element that communicates directly with the physical layer and performs mapping procedures between logical and physical channels, reception and transmission of physical layer data, user data scheduling and data exchange with mobile terminals. All above procedures are performed with no further dependency on other LTE network element, thus providing a stand-alone test framework.**

***Index Terms*—LTE, Physical Layer, Test Framework, MAC.**

I. Introduction

THE Long Term Evolution (LTE) network architecture comprises, among other elements, the Base Station (eNodeB), which provides and controls the air interface. The eNodeB protocol stack is composed of different layers, each one with a specific and well-defined purpose. In terms of air interface performance, the most critical layers of an eNodeB are the physical (PHY) layer and the medium access control (MAC) Layer. Both of them must operate on a precise timing basis, corresponding to a frame duration of 1 ms. Because of this requirement, PHY layer developers need an effective test architecture, capable to follow time response policies.

Based on this requirement, this paper focuses on a test framework that consists of a simplified MAC layer (MAC) targeting PHY layer conformance, performance and integration tests. Such architecture is designed to operate independent from upper layers, as a stand-alone solution. In order to achieve that, the simplified MAC layer (MAC LITE) has been designed to emulate a real MAC layer, covering throughput performance, stability, data integrity and conformance test cases.

The paper is organized as follows. Section 2 presents the motivation for creating the test framework for physical layer development. Section 3 provides an explanation on the eNodeB architecture. Section 4 describes the proposed architecture for testing, while Section 5 presents the main use cases. Finally, section 6 presents the conclusions.

II. Motivation

In September 2012, 3GPP started a Working Item to standardize the 450-470 MHz frequency bands. This initiative aimed at taking advantage of RF propagation characteristics in lower frequency bands, based on a new LTE profile. This profile is useful in scenarios with large coverage requirements in sparsely populated areas. The standardization process finished in September 2013, and band 450-470 MHz has been designated as the new 3GPP Band 31.

In parallel to 3GPP activities, the Brazilian Communications Ministry worked on a way to introduce new broadband Internet services in Brazil. In May 2010, the National Broadband Plan (PNBL) recommended the use of the frequency band 225-470 MHz (BRAZIL, 2010) to leverage broadband Internet penetration in rural areas of Brazil. Also in 2010, the National Telecommunications Agency (ANATEL) allocated the frequency bands 451-458 MHz and 461-468 MHz for fixed and mobile radio services operating on Frequency Division Duplex (FDD) mode (ANATEL, 2010).

Furthermore, ANATEL auctioned Band 31 licenses in June 2012. As a result, Band 31 is now available to all major carriers in the Brazilian market. The winning carriers must meet coverage and capacity targets defined by ANATEL (ANATEL, 2010), while the adoption of specific technology associated with these licenses is open. Licensed carriers will most likely adopt LTE technology to take advantage of superior RF features of Band 31 for providing broadband access [1]-[6].

Besides providing wider coverage area per sector LTE implementation in Band 31 imposes many technical challenges, mostly related to RF characteristics. In order to ensure Band 31 benefits are harnessed, eNodeBs require specific technology development, especially related to RF components and PHY features. In this context, a stand-alone framework is proposed, for PHY conformance, stability, data integrity and performance testing. The prosed framework consists of a simplified MAC layer (MAC LITE) and procedures for test automation.

III. eNodeB architecture

In LTE and LTE-Advanced systems, the Release 8 based eNodeB protocol stack is composed of layers and sub-layers. This layers are: RRM (Radio Resource Management), RRC (Radio Resource Control), PDCP (Packet Data Convergence Control), RLC (Radio Link Control), MAC (Medium Access Layer), PHY (Physical Layer). Each layer performs specific functionalities that are described in [7].

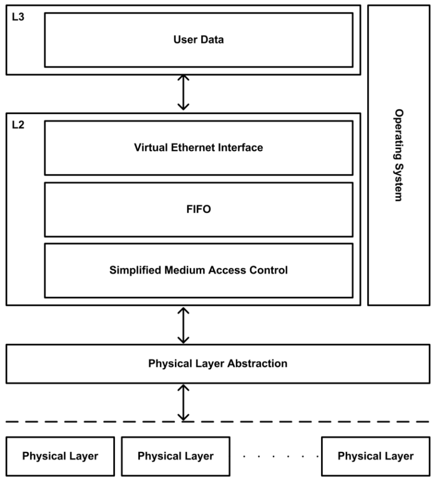

Figure 1. Proposed Framework Architecture.

The layers above the physical layer (RRM, RRC, PDCP, RLC and MAC) are often developed as real time embedded software elements, because of requirements such as flexibility, scalability, upgradeability, among others. In case of LTE, physical layers often use well-structured interfaces for communication with the upper layers, such as the well-known Femto API [8]. The framework described in this paper uses this interface as a reference for communication and operation of physical layer in testing phase.

IV. Simplified MAC Layer Architecture

The proposed architecture was designed as a stand-alone framework for PHY testing, with no dependency on upper layers described in the previous section. In order to make this possible, the creation of a centralized element was necessary to carry out the main test procedures based on the user-defined settings. Such software element contains procedures for master boot, injection, recovery of configuration data parameters. These actions are based on procedures described by the Femto Forum API interface [8], since it also includes the main operating and starting procedures of commercial physical layers. For the full operation of such element, the architecture relies on a few intermediate components as shown in Fig. 1 and described next.

The whole framework has been designed to run on a computer with a generic operating system.

1) User Data: in order to test the LTE physical layer, reference data is sent and compared with the received data, after the processing performed by corresponding layer. Therefore, it is possible to check the error rate and the system throughput as a whole. The framework comprises an abstraction at the operating system level, where data is sent and received through a virtual network interface, thus enabling data injection from any application that supports communication via network, facilitating the testing procedure;
2) Virtual Ethernet Interface: this interface collects reference data and injects it into the system. All modern operating systems support such technology, where the injection of reference data in the system is transparent to the user. These interfaces are addressed by Internet Protocol (IP) stack and facilitate the process of sending and receiving data. Thus, for an application to send or receive data, it only needs to address the data packets with the IP address of the desired interface;
3) FIFO (First In First Out): due to the large data flow that must be supported by a LTE physical layer, the proposed framework provides a high-capacity data queue to avoid bottlenecks in both the acquisition and consumption of such data. The data queue also ensures that they can be consumed at a data rate different from that used during the generation. Virtual network interfaces allow their data to be redirected to other applications, such functionality is known as Bridge (or data bridge). Through a bridge, the data received or sent to the virtual network interface architecture is captured/received by a FIFO, from where they can be consumed by the MAC LITE layer;
4) Simplified MAC (MAC LITE): it is the central mechanism of the proposed framework. It acts as a simplified access layer, performing all startup procedures and execution of stability tests, following the standards pointed by the Femto Forum API. Through a series of parameters passed to this layer via a data base, it performs both data injection and operation of the physical layers attached to it. It supports parallel operation of multiple physical layers, which enables testing carrier aggregation (CA) technology, a key LTE-Advanced feature.
5) Physical Layer Abstraction: it was developed so that different communication interfaces between the MAC and PHY are supported. The communication interface adopted for formatting the messages and procedures is part of the Femto Forum API (FAPI) reference. However, FAPI does not define any protocol for sending the messages to the PHY, and therefore, UDP sockets, shared memory, PCI, among others, can be used to that end. The proposed framework provides abstraction on specific messages transmission to the LTE physical layer, leaving the message packaging to send or receive data up to the developer;
6) Physical Layer: this is the device under test (DUT). The DUT must be compatible with the communication interface defined by the Femto Forum API reference [8]. The way data messages are transported is directly related to the technology adopted at the PHY layer.

The process of communication between the upper layers and the physical layer must meet critical requirements of timing and minimum throughput. Such requirements must be tested during the integration process, and can also be done through the proposed architecture. The following section details the main use cases of the proposed architecture.

Users of the proposed framework are divided into two main groups:

- Developers integrating physical layer with other layers;
- Developers designing physical layers.

The main difference between the two groups lies in the fact that for the first one it is supposed that the physical layer is fully functional, and in this case, the framework is only used to test the messaging protocol. Fig. 2 shows a basic environment based on the proposed framework for such user groups. It should be noted that a tool for capturing and analyzing messages is needed. The tool is selected based on the way messages are exchanged between layers. Through this tool, users can evaluate the behavior of the physical layer under test, leaving the developer to adapt the access layer according to such behavior. These tests are useful to check problems in both timing and order of received messages exchanged between the physical and access layers.

The second group uses the architecture to check the operation of each one of the physical data channels, as part of the throughput and scalability tests of the physical layer. For this group of users it is necessary to use an external device for checking data integrity, such equipment is known as spectrum analyzer. Fig. 3 shows a basic environment for developers testing physical layers.

V. Proposed Framework

The key component of the proposed framework is the Simplified MAC Layer. The Simplified MAC Layer performs the functionalities described in section 3, but with no real integration with upper layers, since the mapping between logical and physical channels happens in an arbitrary manner, according to the user definition or type of test. In this case, the scheduling of mobile users is static and a list of user identifiers defines which users will be able to receive data from the FIFO. Data is sent from the FIFO to the users according to the maximum data rate supported by the mobile device.

Such layer was designed to support the Carrier Aggregation technology, where the access layer needs to establish communication with various physical layers. In order to prevent performance and high latency communication problems, the proposed framework has been designed with support for multi-processing, i.e., multi-threading, where each CPU core carries out the operations of a physical layer, obtaining maximum performance of multi-processor computer architectures. Each physical layer is controlled by a separate execution thread, and the FIFO is controlled by a dedicated thread. Fig. 4 shows the proposed architecture.

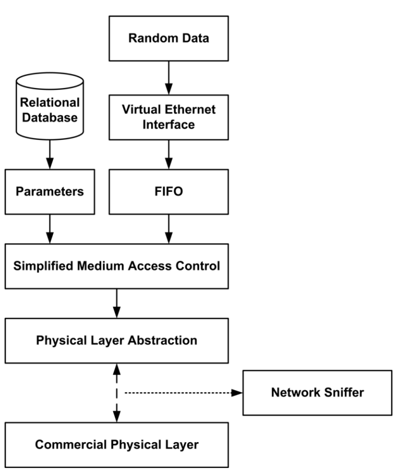

Figure 2. Use case for the integration between the Access and Physical layers.

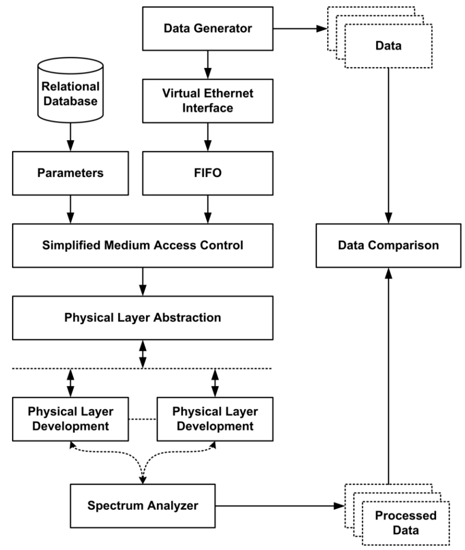

Figure 3. Use case for Physical Layer Development

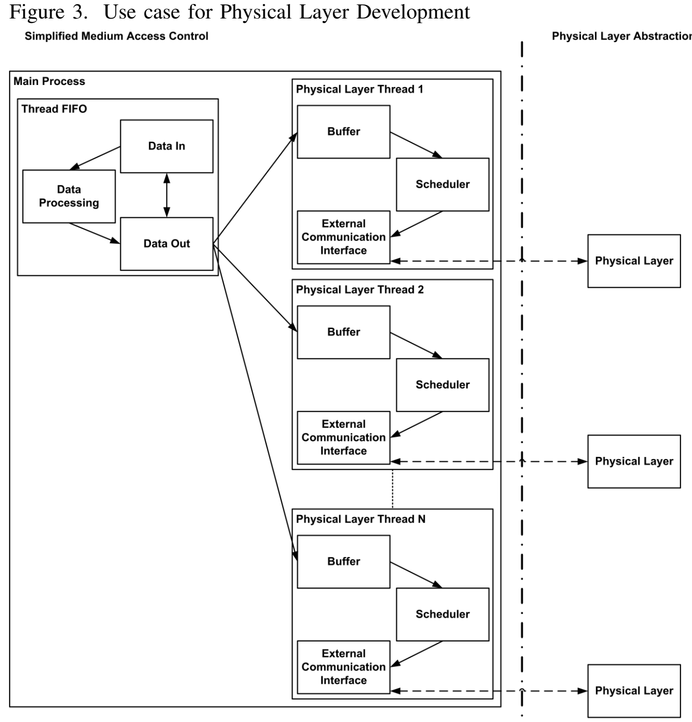

Figure 4. Architecture proposed for the Simplified MAC.

It is possible to see in Fig. 4 two basic types of execution threads:

1) FIFO Thread: is responsible for processing input and output data from the FIFO. Data reception is executed by the Data In module. The input data comes from the virtual Ethernet interface. The data is packaged by the Data Processing Module and divided into blocks with sizes that are integer multiples of the transmission capacity supported by the communication channel between the physical layer and the mobile terminals. Such data blocks are sent to a memory shared among threads named Data Output, which can be consumed by threads responsible for the operation of the physical layer. For simplification purposes, the data flow showed in Fig. 4

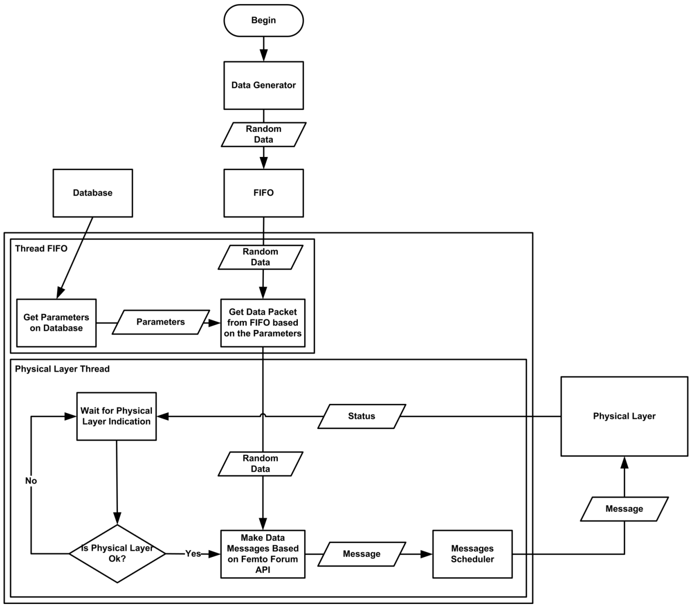

Figure 5. Flowchart of the Simplified MAC Layer.

only presents the data transmission in the direction of the physical layers, and they may also flow in the reverse direction, i.e., it is received by the physical layer through the mobile terminals;

2) Physical Layer Thread: is responsible for interfacing with the physical layer. It reads the data stored in the FIFO thread and sends it to the physical layer. A thread of this kind is instantiated for each physical layer, due to the high data throughput required for operation of the LTE system. Another case of multiple threads is in the Carrier Aggregation functionality, where a single base station can simultaneously operate with multiple physical layers, each at a different carrier frequency. The buffer module constantly checks for data not consumed in the shared memory corresponding to the FIFO thread. If this is the case, the data is sent to the scheduler module, which waits the time of sending to the physical layer. The External Communication Interface module performs direct communication with the physical layer, exchanging data between the scheduler and the physical layer. It also performs all the communication process (synchronization procedure, sending and receiving data) through the Femto Forum API interface.

The joint operation of the threads provides all the basic operation of the proposed Simplified MAC Layer, whose operation is illustrated in the flowchart of Fig. 5. The main steps are as follows:

1) The FIFO Thread accesses system configuration parameters that are stored in a relational database (database);
2) These parameters are used to define the limits of transmission and reception of the Physical Layer, such as rates and packets size;
3) With these parameters, the FIFO thread accesses the FIFO and formats the data packets (Random Data) with a size appropriate to the capacity of the Physical Layer;
4) Such packets are sent to the Physical Layer thread according to the rate set by the configuration parameters retrieved from the database;
5) On the Physical Layer thread side, the Physical Layer constantly sends indications of their status, informing when it is able to receive new data;
6) If so, the data packets (Random Data) provided by the FIFO are encapsulated into packets respecting the Femto Forum API format, and then are sent to the Message Scheduler;
7) The Message Scheduler forwards data messages in the Femto Forum API interface to the Physical Layer during test procedures;
8) The Physical Layer processes the message and returns a status message, restarting then the whole procedure;
9) The Physical Layer thread only sends new messages when the status indication provided by the Physical Layer indicates that it is able to receive new messages. Otherwise, the Physical Layer thread waits for this indication.

The Femto Forum API defines a set of error codes and status for many different situations. The status message returned by the Physical Layer is also used for indications of lack of synchronization, out of sequence messages and unexpected messages. All these indications are used so that the Simplified MAC Layer has more detailed information on the performance and stability of the Physical Layer during the testing procedures.

The messages mentioned above are stored in log files, which can be analyzed by the physical layer developers.

VI. Conclusion

This paper proposes a framework for testing Physical Layers during the development or integration phases. It presents implementation details of a Simplified MAC Layer, focused on conformance, stability, data integrity and performance testing. The paper proposes a simplified test framework aimed at meeting the possible demands originated during the development of eNodeBs. This tool is particularly useful for developing specific features on Physical Layer and RF front end levels, such as in the case of LTE network for Band 31.

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