

5G Wireless Networks Prototyping

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1 MOTIVATION

Driven by novel 5G use cases like ultra-reliable and low-latency communication (URLLC) and massive machine-type communication (mMTC), as well as the strife for higher data rates in enhanced mobile broadband (eMBB), researchers and engineers evaluate the applicability of new concepts and technologies for future wireless communication systems. Figure 1 provides an overview of the typical life cycle for such a development process.

In the beginning, researchers develop a vast number of new ideas. The most promising proposals are then evaluated with the help of extensive software simulations. The network simulator ns-3 [1] is a very well established tool in this area. One important purpose of the simulations is to guide a downselection of concepts and technologies, which are worth spending the effort of implementation on hardware-accelerated software defined radio (SDR) platforms. This step is supported by IP like the NI LTE Application Framework [2]. The evaluation of algorithms and components in practice and in real-time then allows to identify useful technology to be further evaluated in testbeds can provide end-to-end connectivity. We are proposing a platform that allows make the next step and engage in this stage of the development process. New concepts and technologies that have been proven to work in practice will ultimately find their way into new standards and lastly, industry will adopt them in future products.

The presented system combines an open-source LTE stack and core network, i.e., the LTE EPC Network Simulator (LENA) model in network simulator ns-3, with an FPGA-based real-time implementation of LTE Layer 1, i.e., the NI LTE Application Framework. The resulting platform is a building block for testbeds which assist the design of 5G radio interface and network architecture. It facilitates the prototyping of end-to-end applications, that include

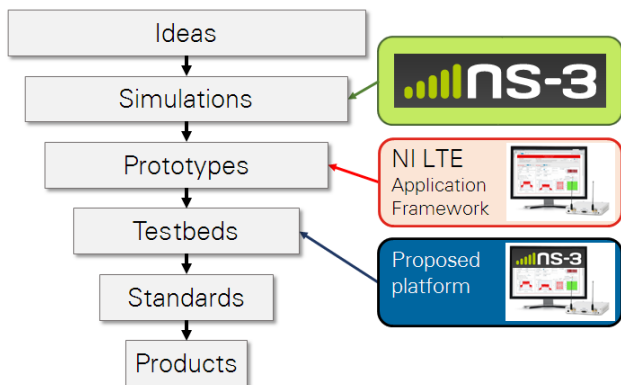


Figure 1: From theory to practice

the functionality of all layers of a wireless communication system, in real-time and over-the-air environments. The platform is envisioned to be used in the European research project ORCA [3].

2 PLATFORM OVERVIEW

An overview of the required functionality, as well as the respective hardware and software realizations, are provided in Table 1. LTE Layer 2, Layer 3 and Evolved Packet Core (EPC) is provided by the LTE model for network simulator ns-3 (ns-3) [4]. This software is executed on an embedded controller with a high performance CPU. A Linux operating system that has been optimized for real-time performance is being used. The computationally complex LTE Layer 1 is implemented by the NI LTE Application Framework on the USRP-RIO SDR [5]. The USRP-RIO integrates FPGA and RF frontend in a single device. Communication between Layer 1 and Layer 2 is achieved with a custom, message based API that has been designed with flexibility and extendability in mind [6]. The presented platform implements both, data path and control path.

From the perspective of ns-3, three main modifications have been introduced:

- (1) Separation of ns-3 eNB and ns-3 UE in order to execute them on physically separated nodes.
- (2) Disabling the physical layer emulation module in the LTE model.
- (3) Adding a Layer 1 / Layer 2 API in the place of the physical layer emulation, in order to integrate ns-3 Layer 2 and above with the LTE Layer 1 executed on FPGA.

The block diagram provided in Figure 2(a) illustrates the concept of the resulting system. The corresponding hardware setup is illustrated in Figure 2(b).

Table 1: Platform functionality

Functionality	Software	Hardware
EPC, LTE Layer 3, LTE Layer 2	LTE model of ns-3	Embedded controller with Linux real-time operating system
Layer 1 / Layer 2 API	UDP-based	
LTE Layer 1	NI LTE Application Framework	FPGA-based SDR (USRP-RIO)

3 AREAS OF APPLICATION

The proposed platform enables researchers and engineers to use existing core network and higher layer algorithms developed for ns-3 in over-the-air trials, without the need for developing an own

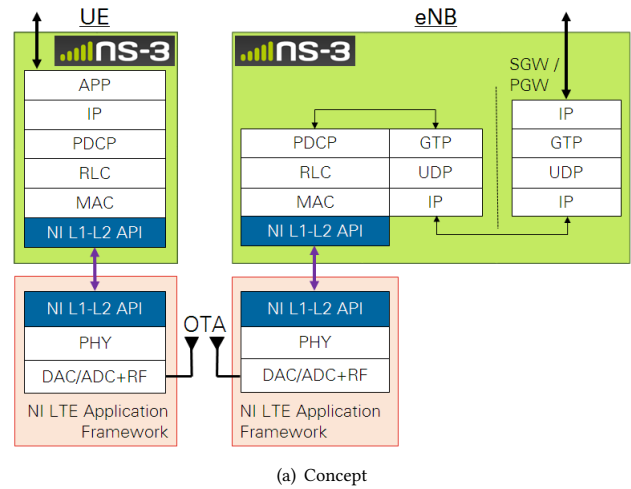
LTE physical layer in FPGA. On the other hand, if modifications to the physical layer IP are necessary, the source code is modular and accessible.

Example application areas for the resulting MAC/PHY platform include:

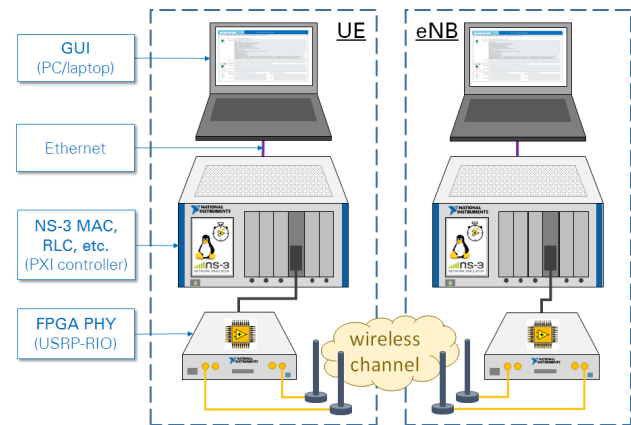
- For the experimental evaluation of LTE Advanced Pro and New Radio physical layer concepts, e.g., short TTIs and Mini-Slots, this platform adds the benefit of providing higher layers functionality that allows to evaluate the latency reduction of a complete end-to-end link under realistic channel conditions.
- For experiments with modified upper layers that include new MAC procedures, e.g., fast uplink access and uplink grant-free transmission, the value of this platform lies in its real-time and over-the-air transmission capabilities.
- Setting up a testbed that consists of multiple of the nodes depicted in Figure 2(b) allows to investigate advanced concepts like base station coordination in certain interference scenarios, spectrum sharing techniques assisted by higher layers or the co-existence between wireless standards (LTE-U, LAA). Since the API between Layer 1 and Layer 2 is based on UDP, the higher layer functionality can be moved from the embedded controller to a centralized server in the cloud.
- Extending the system with new physical layer numerologies and waveforms allows to implement network slicing, e.g., for UR and LLC communication as well as mMTC. This facilitates the optimization of services that are mapped to vertical slices across all layers of a wireless communication system.

REFERENCES

- [1] *Network simulator ns-3*, Jan 2017. <https://www.nsnam.org>.
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(a) Concept



(b) Example hardware setup

Figure 2: System overview