LTE MAC/PHY Prototyping Platform
Based on NI LTE Application Framework and NS-3 Network Simulator

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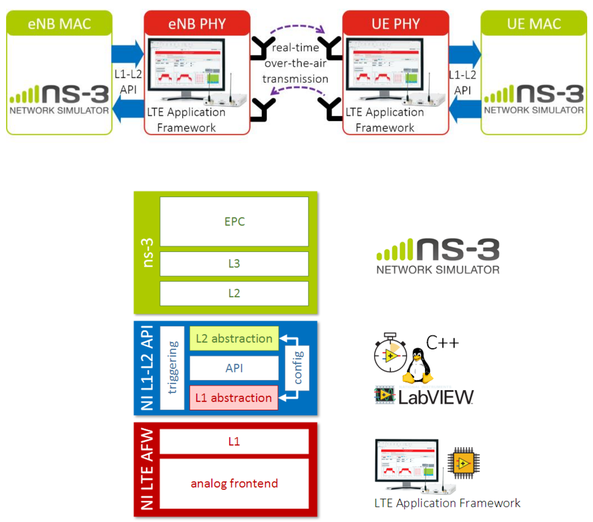
Abstract

Computer-based simulations, while useful in generating nominal performance benchmarks of wireless communication systems, often make inaccurate assumptions of various system model components that largely limit the ability to predict how an actual system will behave in practice. Therefore, functional prototypes that operate over real-world wireless channel conditions in real-time are essential in order to determine the feasibility of new technologies and the extent to which their promised gains in performance can be achieved. Such mandatory prototypes and field trials are necessary in order to gain broader acceptance of next generation technologies within the wireless industry.

Although necessary, prototyping has traditionally presented challenges that stem from the many complexities associated with the various layers in the network communication stack including the PHY, MAC, and Network layers. Furthermore, each layer traditionally has required the use of highly disparate development tools and the expertise of skilled researchers and engineers to perform tasks such as programming FPGAs and designing RF circuits. Consequently, such prototyping design cycles are oftentimes overly lengthy and costly.

In addressing the challenges in prototyping real-time wireless communication systems, NI offers a number of SDR prototyping platforms with capabilities that satisfy a variety of hardware and software requirements, including real-time, over-the-air experiments of heterogeneous networks. As an example, this paper describes a prototyping platform that combines the NS-3 open source upper layer protocol stack with the NI LTE PHY layer. The NI LTE Application Framework is a real-time LTE physical layer reference design that can be combined with the widely used LENA stack and Network Simulator 3 (NS-3) to provide a rich set of PHY, MAC, and network capabilities with which researchers can rapidly begin experimenting and innovating faster.

NI MAC/PHY System Overview



Software Architecture

The NI MAC/PHY prototyping system uses the LabVIEW Communications LTE Application Framework, which serves as a fully real-time, advanced FPGA-based LTE PHY layer reference design that supports over-the-air communications. The LTE Application Framework Host and FPGA source code is fully accessible and can be modified to support new algorithms or protocols that are unavailable in the current implementation.

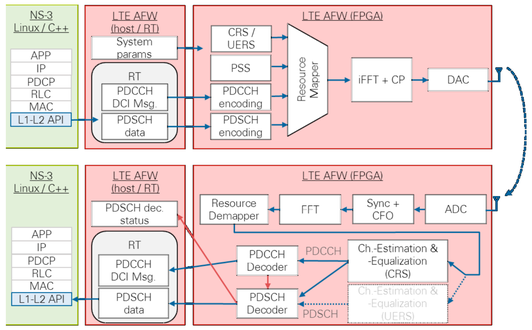
Built in LabVIEW Communications, the LTE Application Framework includes the following features from Release 10 of the 3GPP LTE standard:

- Uplink and downlink transmission with 20 MHz bandwidth in TDD and FDD modes
- LTE-compliant channel encoding and decoding
- Data channels (PDSCH, PUSCH) and a simplified control channel (PDCCH)
- Achievable data rates up to 75 Mbps
- Reference symbols: CRS, UERS, PSS, SRS

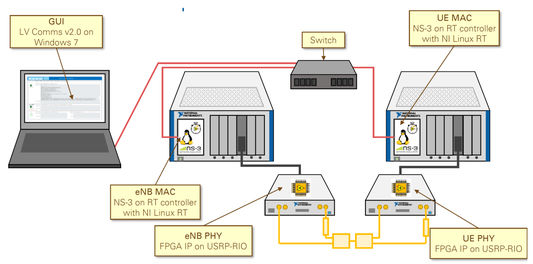
With respect to the receiver, the LTE Application Framework includes the following features:

- RF impairment correction
- Automatic gain control (AGC)
- Time and frequency synchronization
- Cell-specific and UE-specific channel estimation
- Channel equalization of data symbols

Shown below is an overview of the functional split between the host and FPGA targets and the communication interfaces between the various components of the NI MAC/PHY prototyping system. For the host or CPU, the various PHY layer-related functions are shown in red and functions related to NS-3 are shown in green. Note the L1-L2 API highlighted in blue that links control and data information between the MAC and PHY layers.



Hardware Architecture



L1-L2 UDP Interface

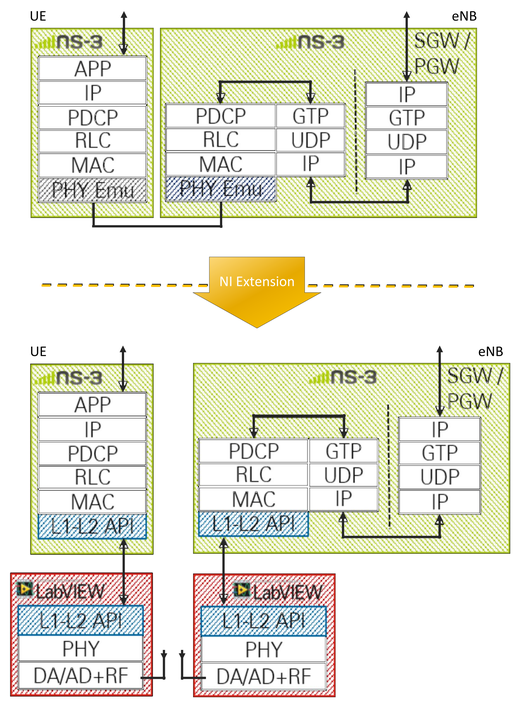
The L1-L2 message interface enables the rapid transfer of control and user plane data between the protocol stack and the PHY layer. This interface is implemented as a flexible UDP based API that consists of two components, one associated with upper layer processes related to NS-3 and the other associated with the LTE PHY layer implemented in LabVIEW Communications.

In general, the MAC and PHY are separate entities that communicate via UDP, wherein communication between the eNB and UE PHY layers occur in real-time and over the air. New real-time capabilities in LabVIEW Communications 2.0, in combination with the NI Linux RT OS, ensure that the strict 1 ms LTE timing requirement for the combined MAC/PHY operations is met, including the exchange of control and user plane data between the two layers.

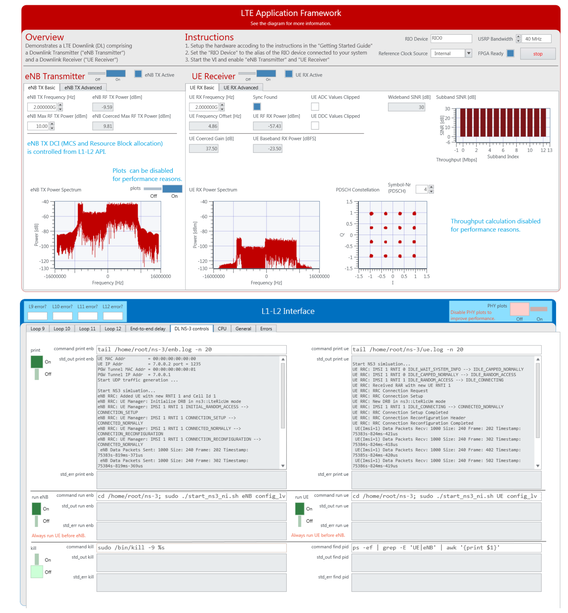
From a source code perspective, the main modifications to NS-3 include the following:

- Modification of the stack to operate in real-time (1 ms TTI timing in LTE)
- Creation of an API to link NS-3 to the PHY layer
- NS-3 configuration to start in either eNB or UE mode

The fundamentally new feature of the LTE MAC/PHY prototyping system is the connection of the NS-3 upper layer protocol stack with the NI LTE Application Framework via a dedicated L1-L2 API. With this system, a fully real-time, end-to-end, over-the-air communications link can be utilized rather than just an emulated wireless channel that inaccurately models the behavior of a real-world communication system.



Graphical User Interface



The GUIs shows the user interface of the MAC/PHY prototyping system (eNB transmitter and UE receiver). The MCS parameter and RB allocation can be configured by the NS-3 MAC during runtime. Further, the execution of the NS-3 binary can be started and stopped from within the LabVIEW GUI and its output is also piped out to the GUI for additional convenience. One important feature in this GUI is that the required configuration scripts to start the NS-3 application on the Linux machines properly are generated automatically and distributed to the Linux systems. Hence, there is no need to edit config files manually in a text editor.

Summary & Future Developments

The NI LTE MAC/PHY prototyping system has been used in the European FP7 project CROWD to successfully demonstrate an SDN algorithm for interference management within dense heterogeneous deployments of cellular wireless networks.

The ability to use Linux-based open source tools and libraries, makes the LTE MAC/PHY prototyping system the world's first wireless testbed that offers all the benefits of NS-3 combined with the real-time over-the-air capabilities of the LTE Application Framework PHY layer.

The NI LTE MAC/PHY prototyping system offers a flexible hardware and software reference architecture complete with a real-time upper layer stack and PHY layer that enables wireless researchers to rapidly prototype networks of LTE devices that communicate over real-world wireless channels. Open and modifiable software IP for all layers of the communication stack, allows users to extend the LTE MAC/PHY prototyping system's set of capabilities to support other novel algorithms and protocols to explore the feasibility of 5G technologies such as software defined networks.

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Download the whitepaper "Real-time Prototyping of 5G Software Defined Networks" from https://goo.gl/MMGhE1
Contact ingo.foldvari@ni.com and igor.Alvarado@ni.com to discuss your specific mmWave research projects

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