Real-Time LTE Testbed using ns-3 and LabVIEW for SDN in CROWD

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NATIONAL INSTRUMENTS

NYU POLYTECHNIC SCHOOL OF ENGINEERING

NYU WIRELESS

CROWD

Agenda

- Introduction to NYUWireless and CROWD Project
  - *Who are we?*
- Project background and motivations
  - *Why are we doing this?*
- SDR architecture and platform for cross-layer wireless prototyping
  - *High-level architecture, hardware platform, Physical Layer design and L1/L2 interface*
- Modifications to ns-3 LTE module and core simulator
  - *Enhancements for real-time operation, FPGA PHY integration and CROWD resource management*
  - *RT performance characterization*
- CROWD SDN architecture (and some other use cases)
  - *Software-Defined Networking paradigm for controlling dense heterogeneous networks*
- Current/future work and concluding remarks
  - *What are we up to now?*

NYU - NI Collaboration and CROWD

- NYUWireless group (NYU School of Engineering)
  - *20 full-time faculty (ECE, CS, med school), 100 students, 13 industrial affiliates*
  - *Diverse backgrounds and sponsored projects including 5G cellular /WLAN (Physical, MAC and Network Layer) algorithms and systems*
  - *Strong collaboration with National Instruments for wireless prototyping*
- CROWD - Connectivity management for eneRgy Optimised Wireless Dense networks
  - *European Commission Seventh Framework Programme - FP7*
  - *Consortium of 6 EU research institutions and industry partners: INTECS, Alcatel-Lucent , IMDEA Networks, NI/Signalion, Univ. Carlos III Madrid, Univ. Paderborn, Avea*
  - *Focused on management of dense heterogeneous networks*
  - *Partnered with National Instruments Dresden to develop CROWD testbed*

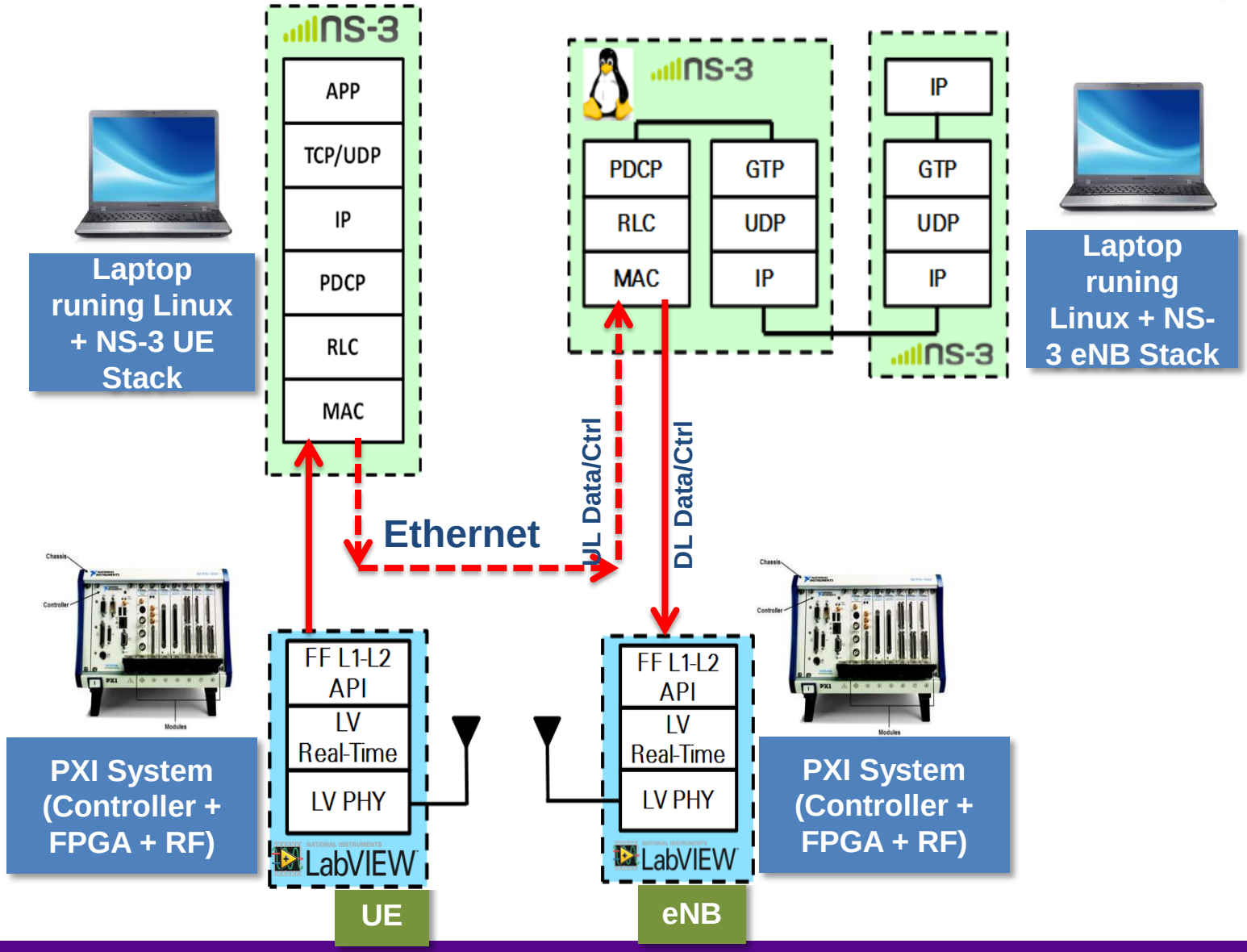
Background and Motivations

- Interest in a robust Software Defined Radio (SDR) prototyping platform
  - *Cross-layer experimentation and rapid prototyping of novel 4G and 5G cellular systems*
  - *Flexibly integrate real-time software emulation with hardware (FPGA) implementation*
- Limitations of commercially-available closed-source hardware/stacks
  - *Commercial "Big Box" emulators, closed-source stacks lack configurability, programmability*
  - *Other open-source stacks too tightly integrated to be readily modified or require custom hardware (e.g. Open Air Interface)*
- ns-3 and LTE/LENA module for network emulation
  - *Initially to test upper-layer protocols over real-time simulation of LTE network*
  - *Some work in 2011-2012 demonstrating RT performance was possible for small networks*
- Development of LTE-like Physical Layer on National Instruments platform
  - *Demonstrated basic concept for integrated ns-3/Linux-based LTE emulator and NI FPGAs*
  - *Basic architecture adopted by NI Dresden for developing CROWD testbed*

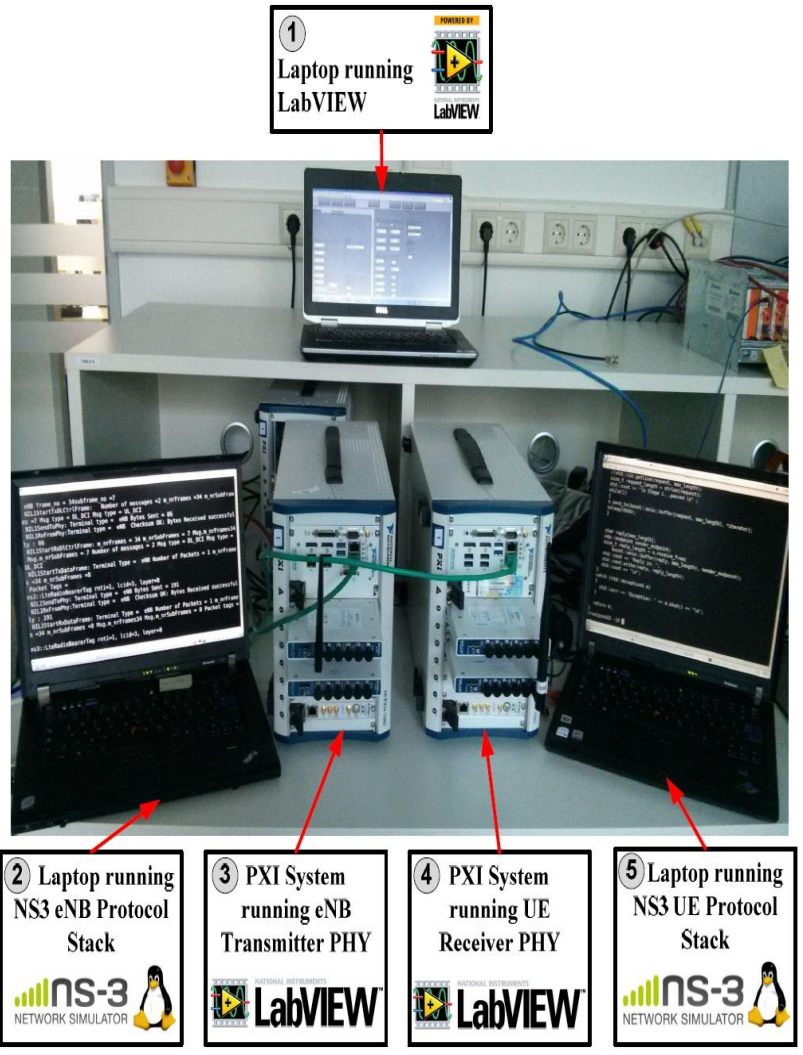
Cross-layer Testbed Features

- Real-time emulation of LTE Radio Access and core network
  - *Open-source ns-3 framework (C++) runs on standard Linux host*
  - *Upper-layer LTE stack and EPC protocols*
- SDR Physical Layer in LabVIEW on NI PXI platform
  - *High-throughput FPGA implementation of eNB and UE PHY*
  - *FPGAs natural choice for baseband signal processing*
  - *Modular, programmable design in LabVIEW FPGA/Real-Time*
  - *Small Cell Forum–based API for interfacing with ns-3 MAC*
  - *Over-the-air wireless transmission using analog front-end modules*
- Application-layer protocols can be programmed natively in Linux
  - *Multiple emulated network nodes/devices run in separate VMs*
  - *Seamlessly run over top of virtual network environment*

SDR Architecture



PHY/MAC Integration



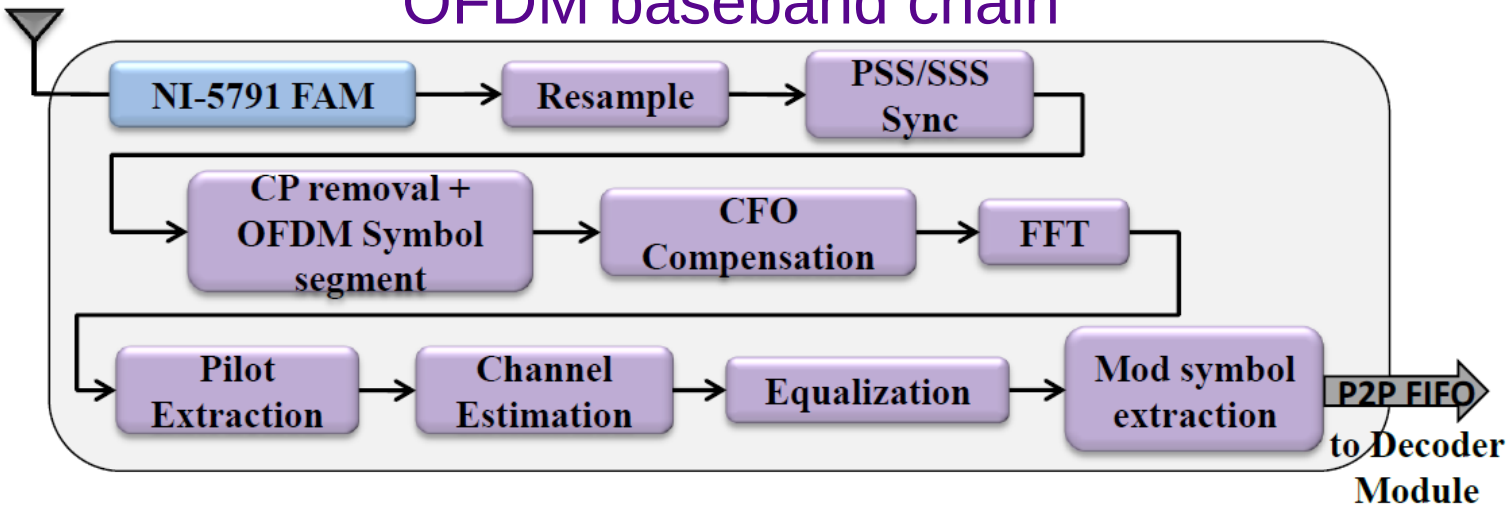
1. LabVIEW PHY deployed to eNB and UE PXI/FPGA targets
2. Synchronization/initial attach of UE to eNB
3. eNB ns-3 instance started on host
4. MAC schedules and generates subframes L2→L1 *TX Request* message serialized and sent over UDP to eNB PXI target
5. PXI controller extracts control and payload, transfers down to FPGA
6. MAC data encoded, modulated, mapped to OFDM resources, etc., transmitted Over-the-Air
7. Subframe received at UE FPGA, decoded data transferred up to PXI controller
8. UE controller generates L1→L2 *RX Indication,* sends over UDP to UE host
9. UE ns-3 instance receives RX indication, creates MAC PDUs

Physical Layer Features

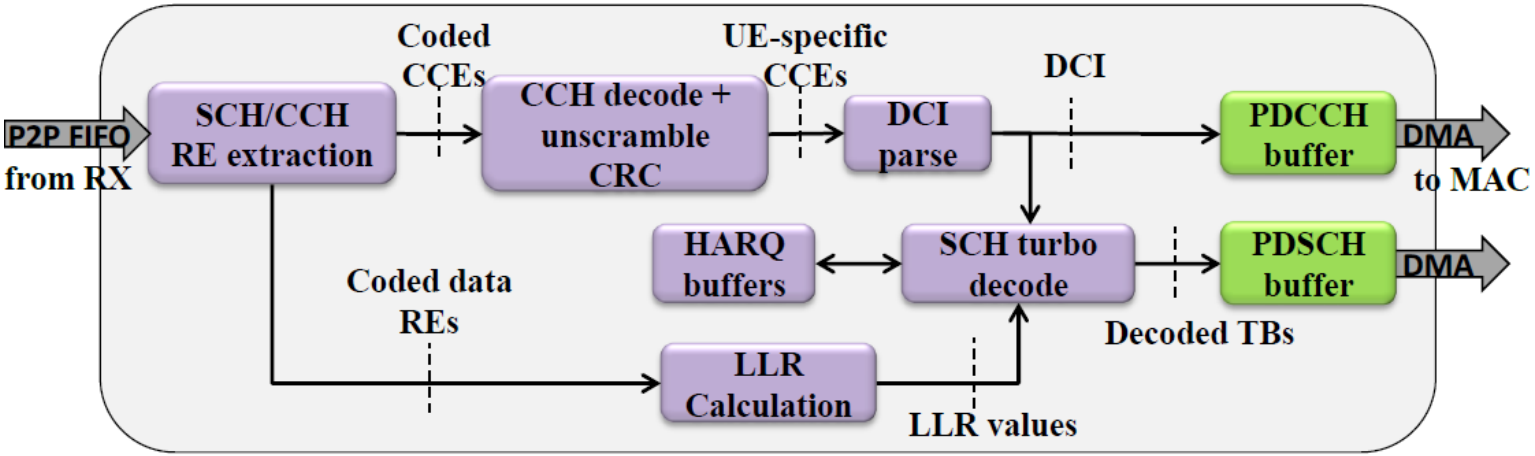
Feature	Current Capabilities
Bandwidth (MHz)	10, 20
Antennas	SISO
Duplex scheme	FDD
CP Length	Extended
Modulation	QPSK, 16 QAM, 64 QAM
PHY Channels	PDCCH, PDSCH
Resource Allocation	Discrete RB group Allocation (type 0)
Multi-user support	Up to 6 users scheduled per-TTI
Throughput	TM1-CAT4 (150 Mbps)
MAC Integration	Per-TTI Configuration of PDSCH via PDCCH,CSI Feedback in UL
Hardware Support	NI PXI/FlexRIO

Receiver Design

OFDM baseband chain

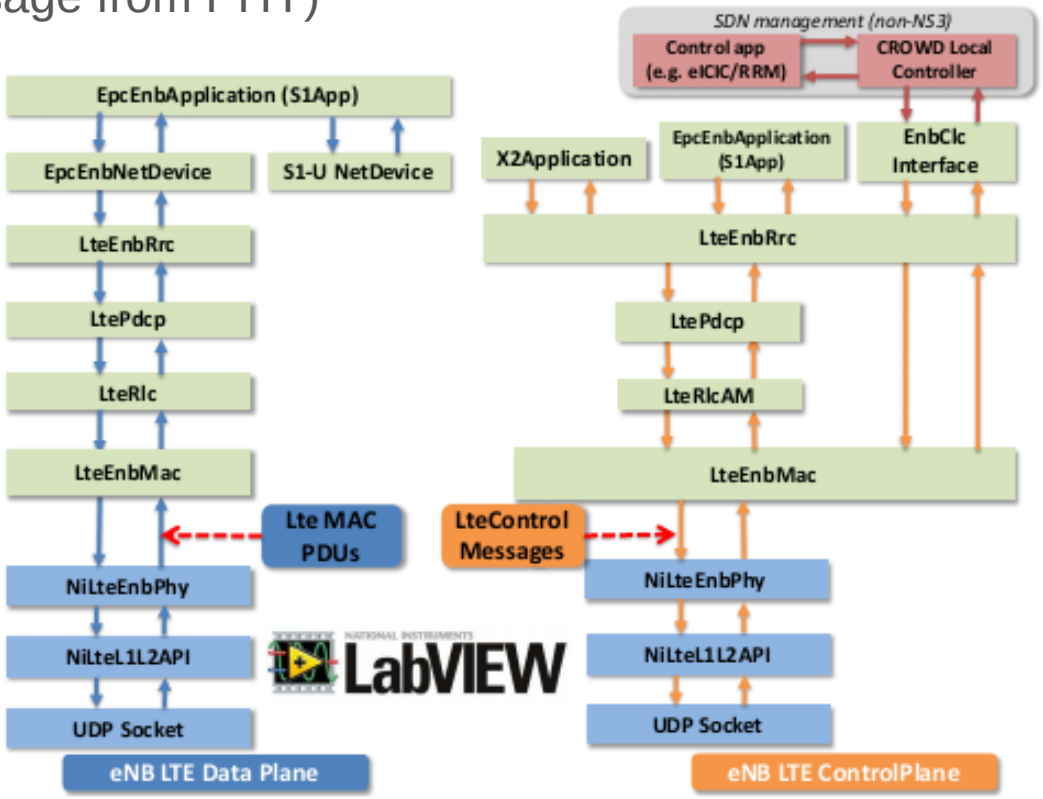


Control and data channel decoder



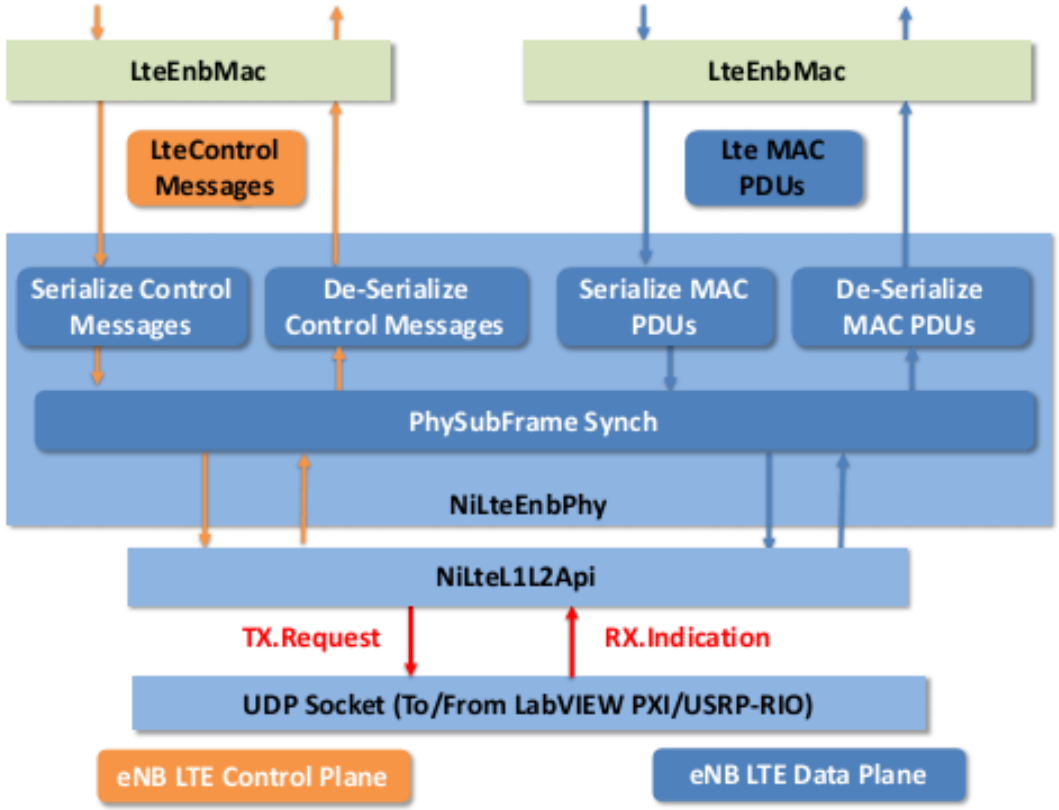
ns-3 LENA Modifications

- **LteSpectrumPhy,** Spectrum Channel no longer needed
- **LteEnbPhy, LteUePhy** replaced by **NiLteEnbPhy, NiLteUePhy**, which call into **NiLteL1L2Api**
- UE code fully independent of eNB (UE subframe generation loop scheduled periodically or triggered by message from PHY)
- New helper class **NiLteHelper**

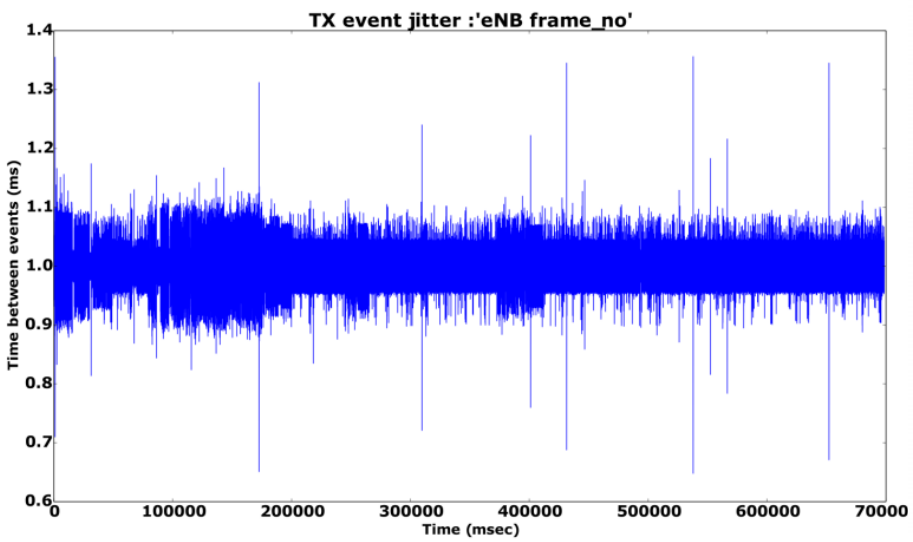


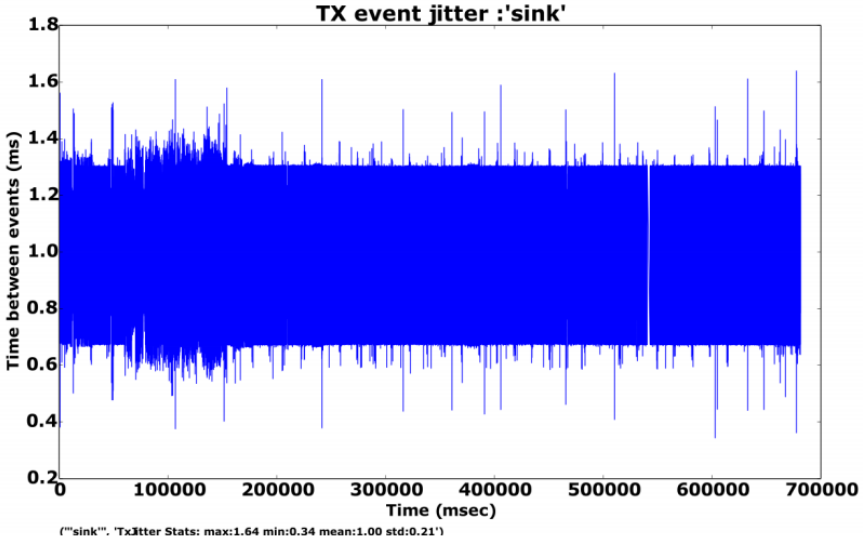
L1/L2 API

- **NiLteL1L2API** called by **NiLte{Enb,Ue}Phy** to serialize/deserialize msgs from **LteControlMessage** (control) and **PacketBurst** (data) objects
- Some messages serialized with Boost, will fully conform to Small Cell Forum API in future
- Separate threads for serialization and sending/receiving over UDP to real-time PXI target/FPGA



RT Performance

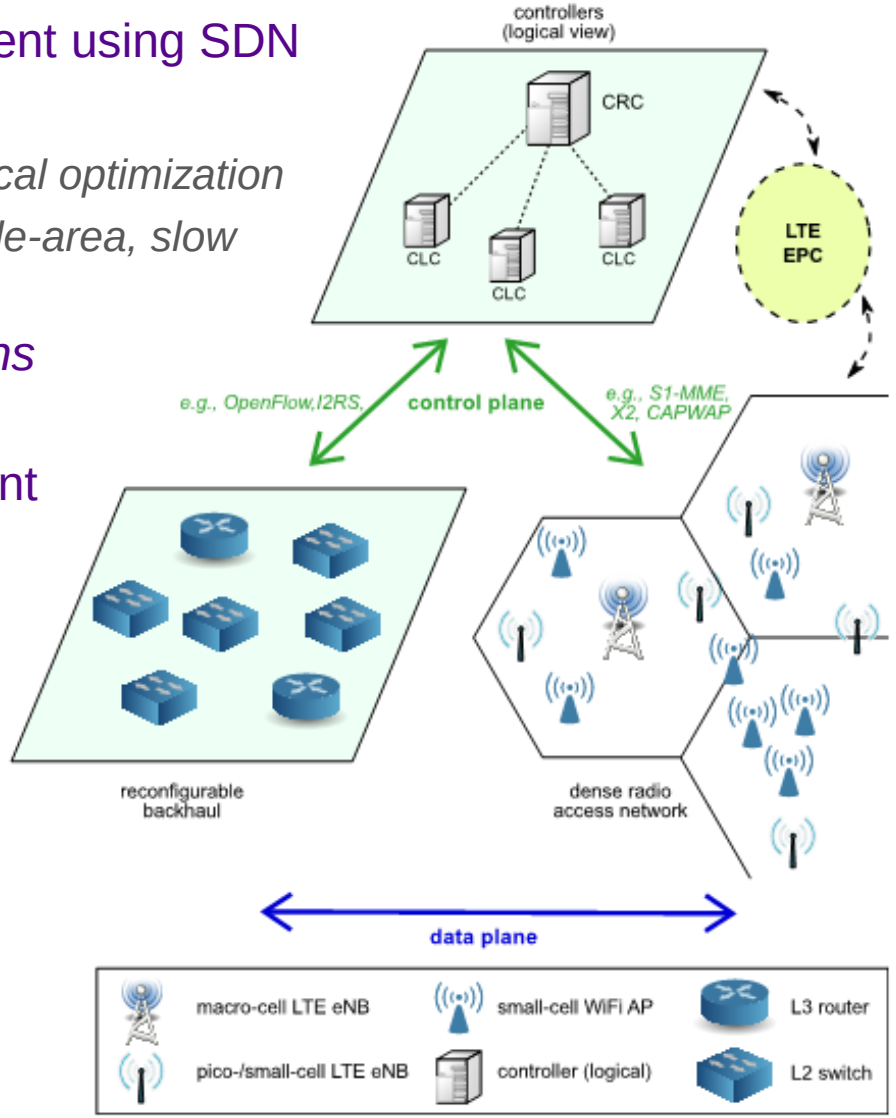




- UDP traffic generated by UdpClient on remote Internet host at ~11.4 Mbps, routed through EPC
- Transmitted over the air, received by UE UdpServer
- RLC Unacknowledged Mode, no Hybrid ARQ, BLER ~= 0
- Real-time priority threads (RT Linux), tracing/logging in separate thread
- Measured jitter of subframe generation events and UDP packet events
  - *Average <200 microsecond jitter for TX events (up to 400 us spikes)*
  - *Average <400 microsecond jitter for UDP sink events (600 us spikes)*

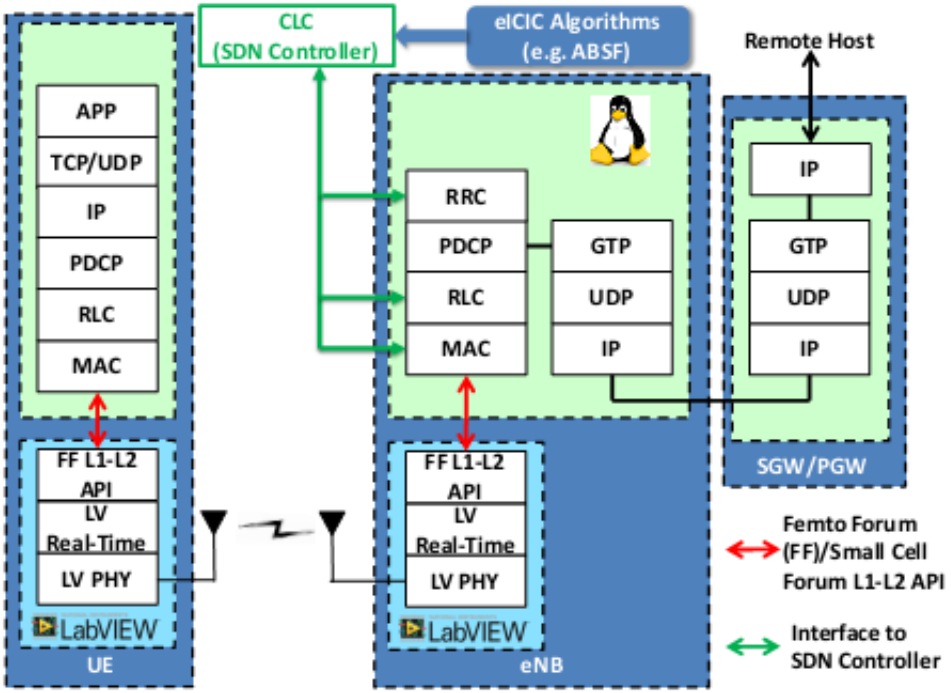
CROWD SDN Architecture

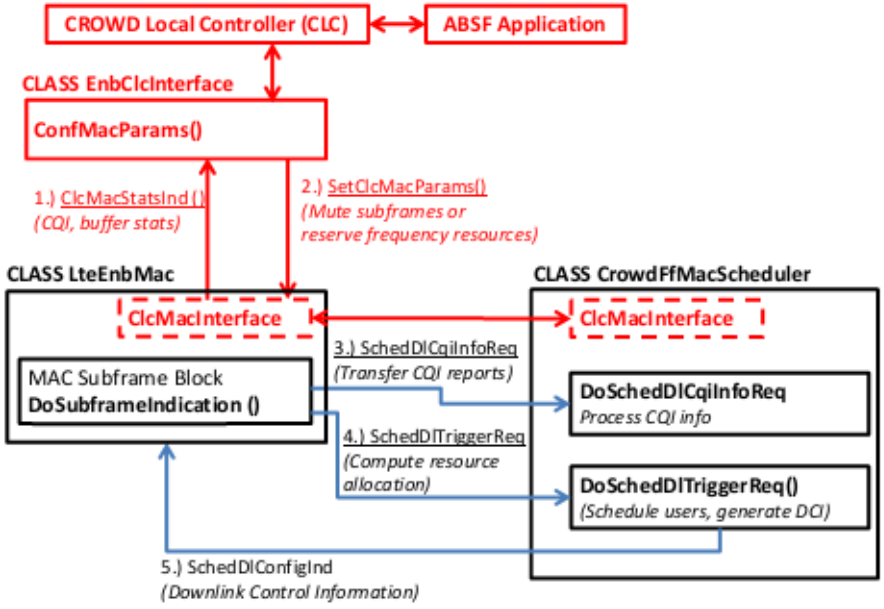
- Framework for unifying network management using SDN
- Two-tier hierarchy SDN controllers
  - *CROWD Local Controller (CLC) for fast, local optimization*
  - *CROWD Regional Controller (CRC) for wide-area, slow timescale network optimization*
- Northbound interface for *control applications*
  - *e.g. eICIC algorithms*
- Southbound interface for controlling different Radio Access and backhaul technologies
  - Interacts with LTE EPC and RAN
  - Macrocells, small cells, WiFi APs



CROWD Interface

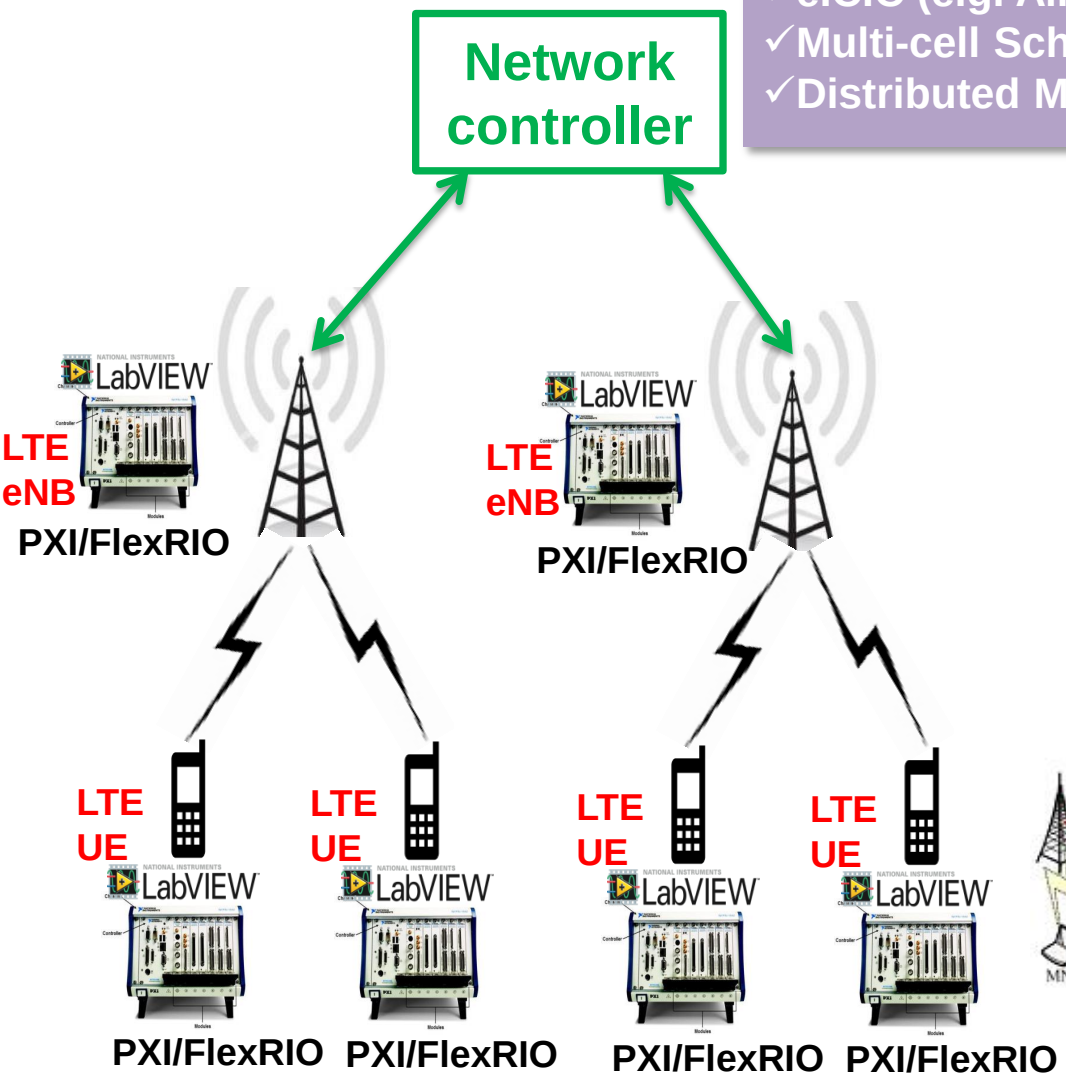
- EnbClcInterface
  - *Provides separate UDP interface to CROWD Local Controller and control applications*
- CrowdFfMacScheduler
  - *Exposes MAC scheduler to CLC*
  - *Configuration of radio resources*
  - *Monitoring of channel quality, buffer status, etc.*
- Some overlap with Fractional Frequency Reuse introduced in 3.21

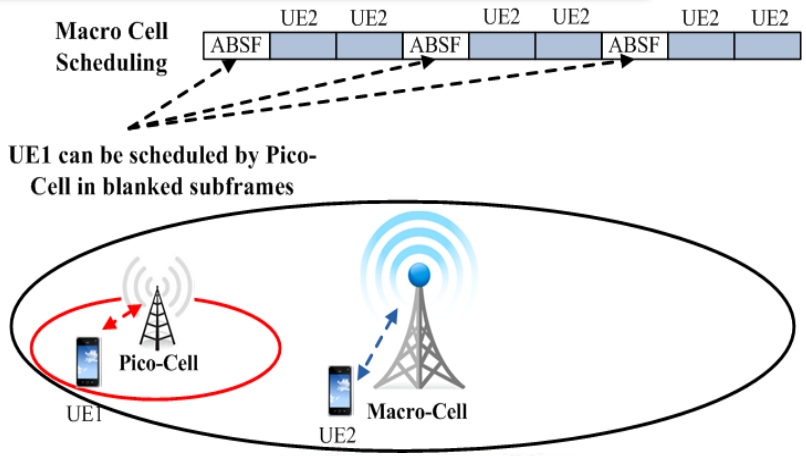


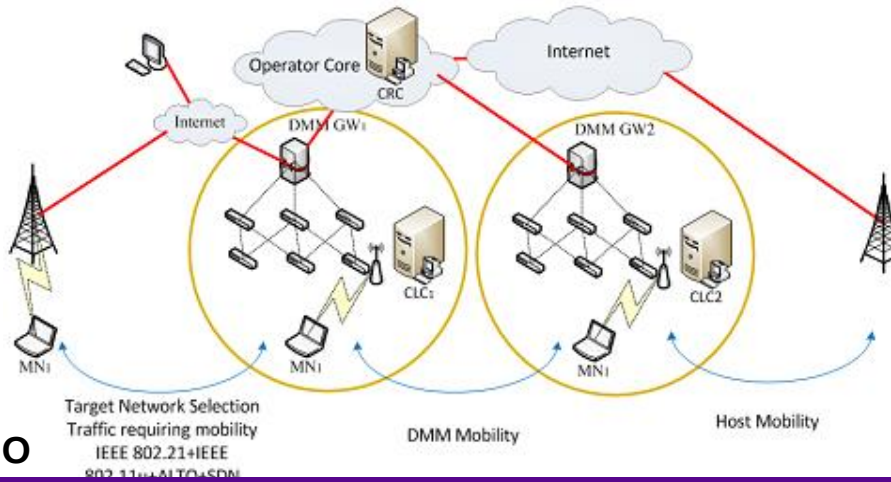


Use Cases

- ✓eICIC (e.g. Almost Blank Sub-Frame –ABSF)
- ✓Multi-cell Scheduling
- ✓Distributed Mobility Management







Future work

- Further optimizations to LTE module and core simulation functions
  - *Parallelization across layers of stack, synchronization, priority levels*
  - *Reduction of buffer allocations, packet copying*
- ns-3 on NI Real-time Linux for PXIe controller
  - *Allows upper-layer stack to be executed directly on controller, interface directly with FPGAs for reduced latency*
- Other hardware platforms
  - *NI USRP-RIO*
    - *Standalone USRP modules with external PCIe connection to main PXI hub*
    - *Scale up networks*
  - *Ettus E-310 USRP*
    - *Xilinx Zynq SoC (dual-core ARM micrcontroller + Xilinx 7-series FPGA)*
    - *Reduced cost*
- Upload source to ns-3 repository

Conclusions

- Proposed flexible SDR architecture to accelerate wireless research
  - *Cross-layer validation of novel 5G algorithms*
  - *CROWD SDN framework and other use cases for testbed*

- Successfully demonstrated integration of ns-3 LTE module with FPGA baseband and RF hardware for Over-the-Air experimentation
  - *Network stack is naturally partitioned at the PHY/MAC interface*
  - *Non-pervasive changes to LENA code*