The ns-3 LTE module by the LENA project

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High level requirements

- Support the evaluation of:
  - Radio-level performance
  - End-to-end QoE
- Allow the prototyping of algorithms for:
  - QoS-aware Packet Scheduling
  - Radio Resource Management
  - Inter-cell Interference Coordination
  - Self Organized Networks
  - Cognitive / Dynamic Spectrum Access
- Scalability requirements:
  - Several 10s to a few 100s of eNBs
  - Several 100s to a few 1000s of UEs

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Design approach

- Simulation is a tradeoff between:
  - Detail of the model
  - Implementation complexity and run-time scalability
- Choose min detail that satisfies requirements
  - Minimize implementation complexity
  - Minimize difficulty in using the simulator

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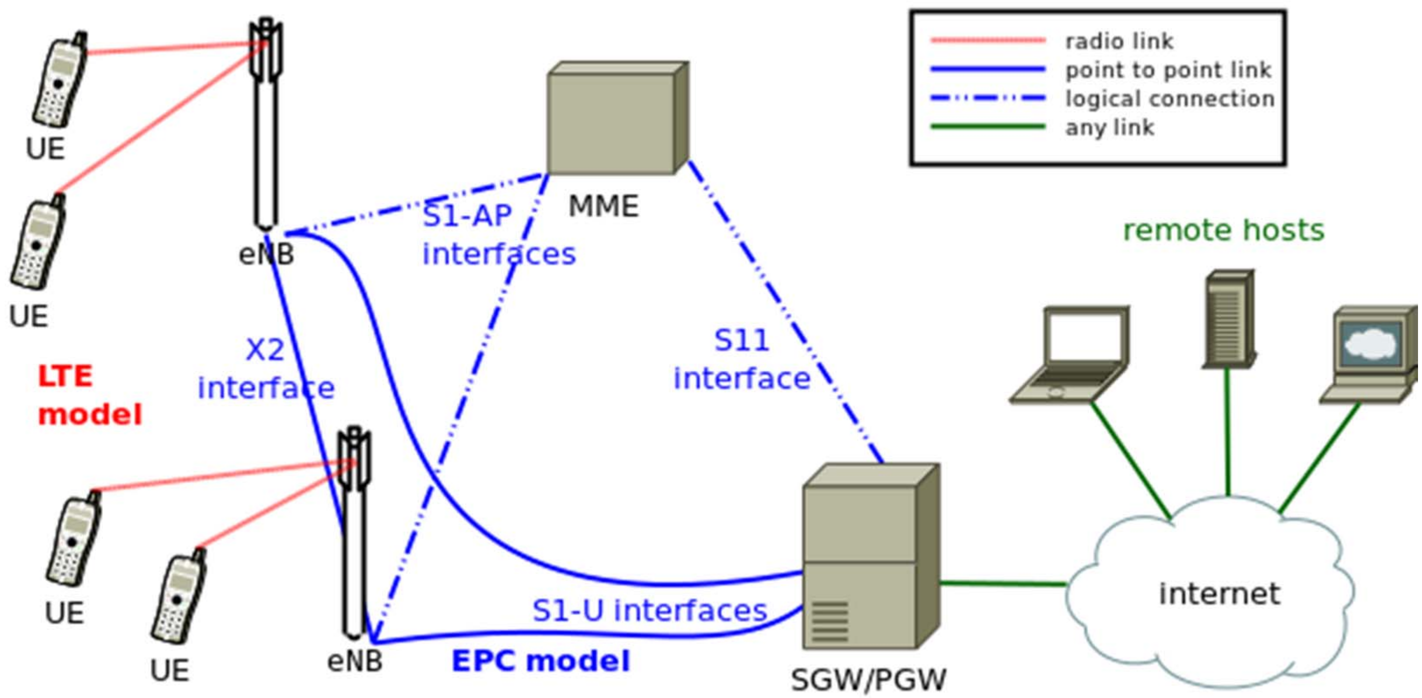
(Some) Important Design Choices

- FemtoForum LTE MAC Scheduler API
- Radio signal model granularity: Resource Block
  - Symbol-level model not affordable
  - Simplified Channel & PHY model
- Realistic Data Plane Protocol stack model
  - Realistic RLC, PDCP, S1-U, X2-U
  - Allow proper interaction with IP networking
  - Allow end-to-end QoE evaluations
- Hybrid Control Plane model:
  - Realistic RRC model
  - Simplified S1-C, X2-C and S11 models
- Simplified EPC
  - One MME and one SGW
  - SGW and PGW in the same node (no S5/S8 interface)
- Focus on connected mode
  - RRC connected, EMM Registered, ECM connected

LENA model overview



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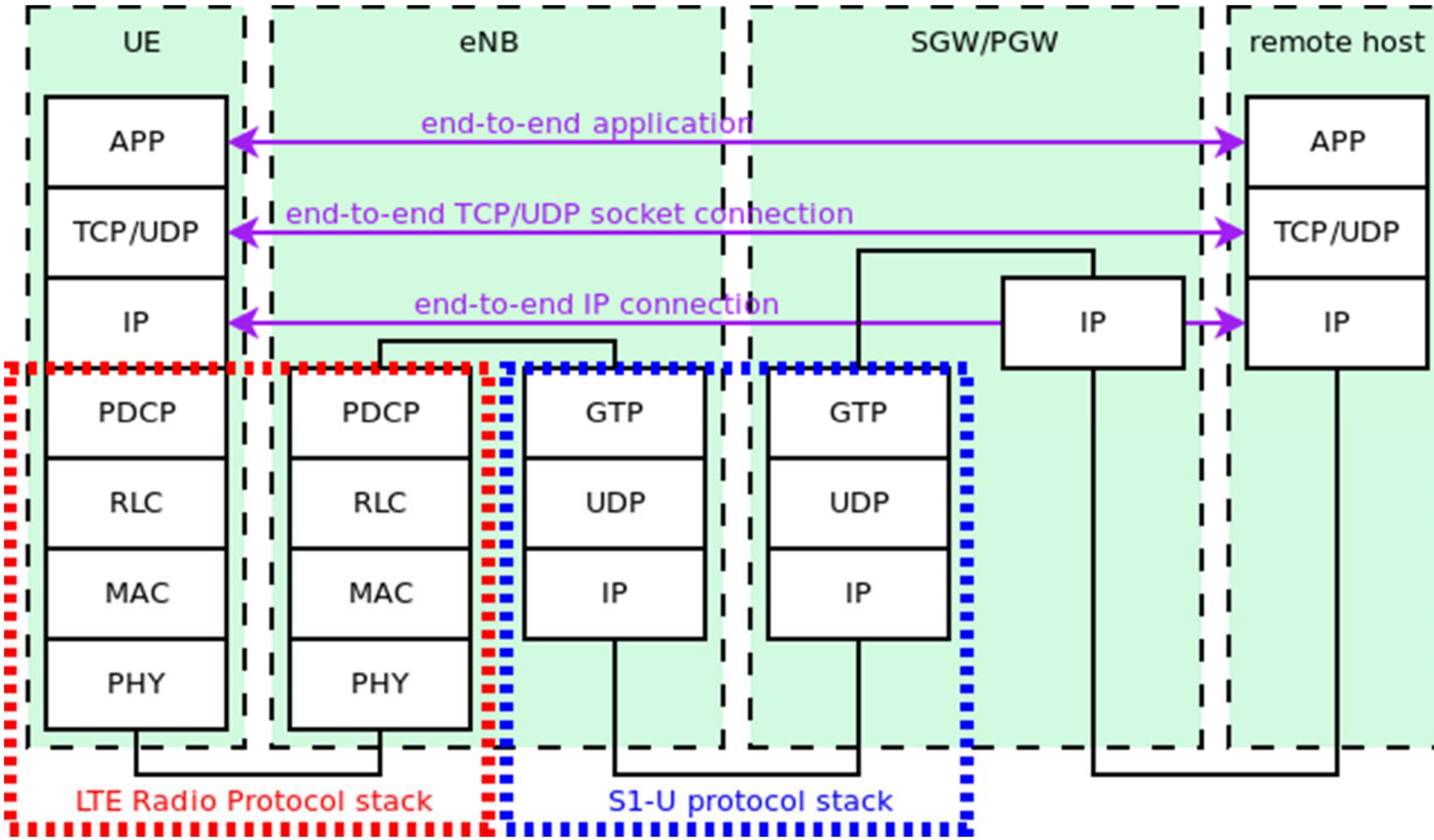
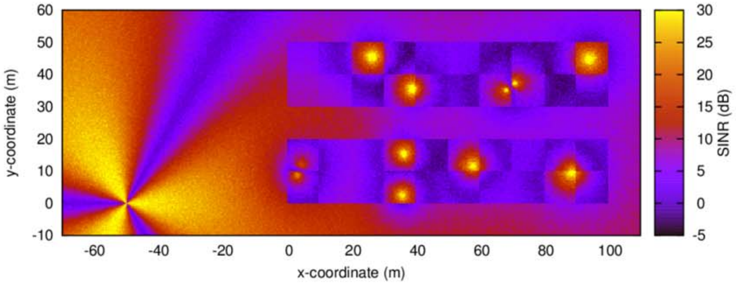
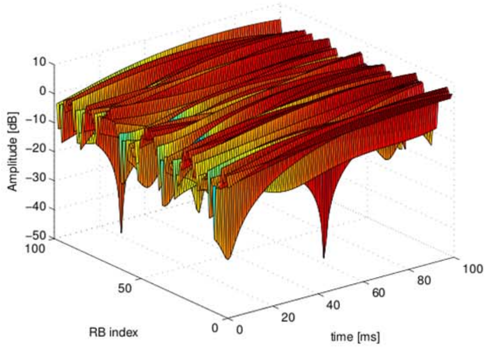
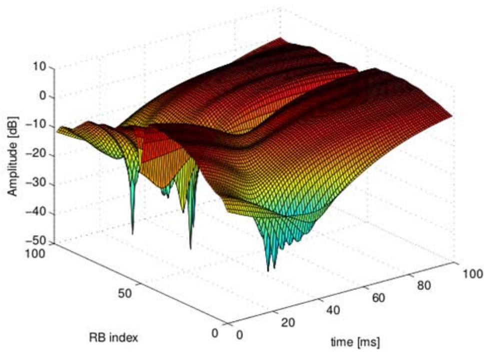
End-to-end Data Plane protocol stack



Radio Propagation models



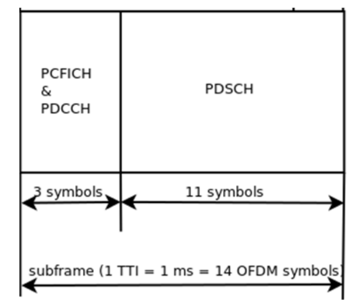


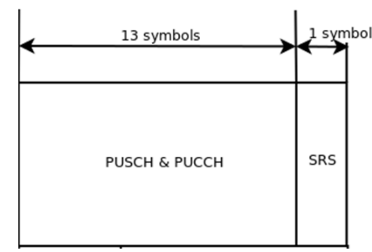


- Buildings model
  - Add buildings to network topology
- Path loss model
  - Okumura Hata (outdoor)
  - ITU-R P1411 LOS & NLOS (outdoor)
  - ITU-R P1238 (indoor)
  - External & internal wall losses
  - Log-normal shadowing
  - Pathloss logic chooses correct model depending on node position
- Fast fading model
  - Trace-based
  - Freq & time dependent
- Antenna models
  - Isotropic
  - Sectorial (cosine & parabolic shape)

PHY model

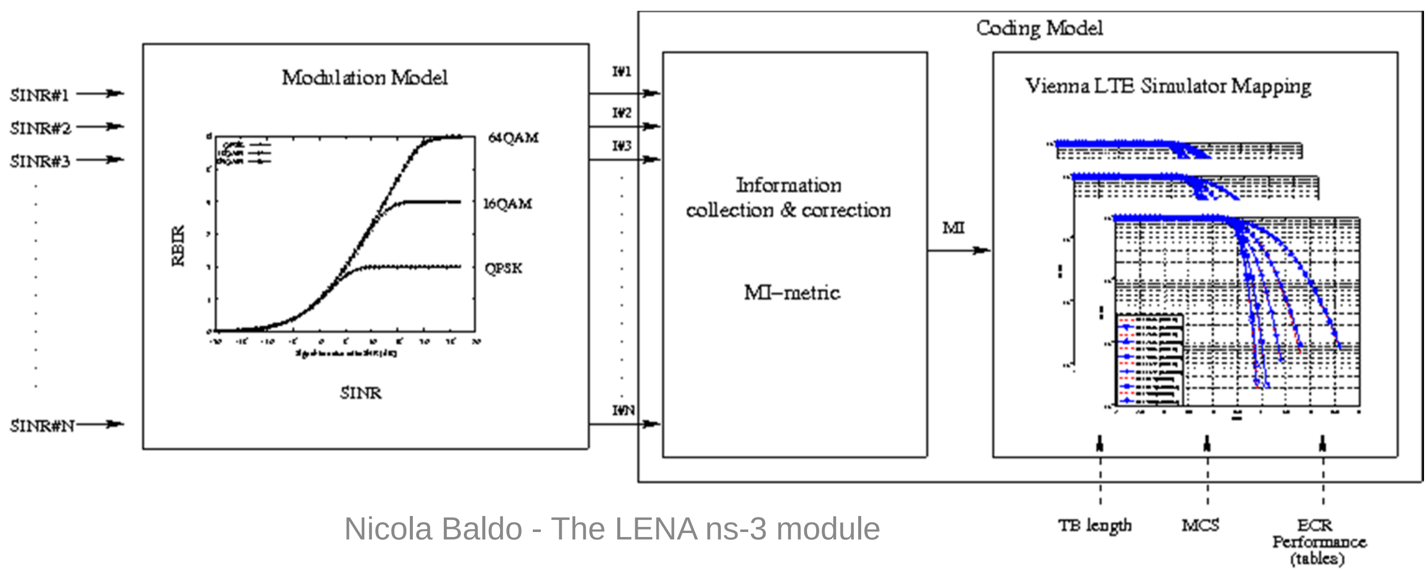
- Only FDD is modeled
- Freq domain granularity: RB
- Time domain granularity: 1 TTI, further divided into
  - DL: ctrl, data
  - UL: ctrl+data, SRS
- Gaussian Interference model
- CQI feedback
- Signal processing not modeled accurately
- ⇒ use error model
- SISO propagation model
- MIMO modeled as SINR gain over SISO
  - different gains for different TX modes
- Supports different freqs and bandwidths per eNB
  - leveraging on the ns-3 Spectrum module





PHY Data error model

- Transport Block error model
- Used for PDSCH and PUSCH
- based on Link-to-System Mapping
  - SINR measured per Resource Block
  - Mutual Information Effective SINR Mapping (MIESM)
  - BLER curves from dedicated link-level LTE simulations
  - Error probabilty per codeblock
  - Multiple codeblocks per Transport Block



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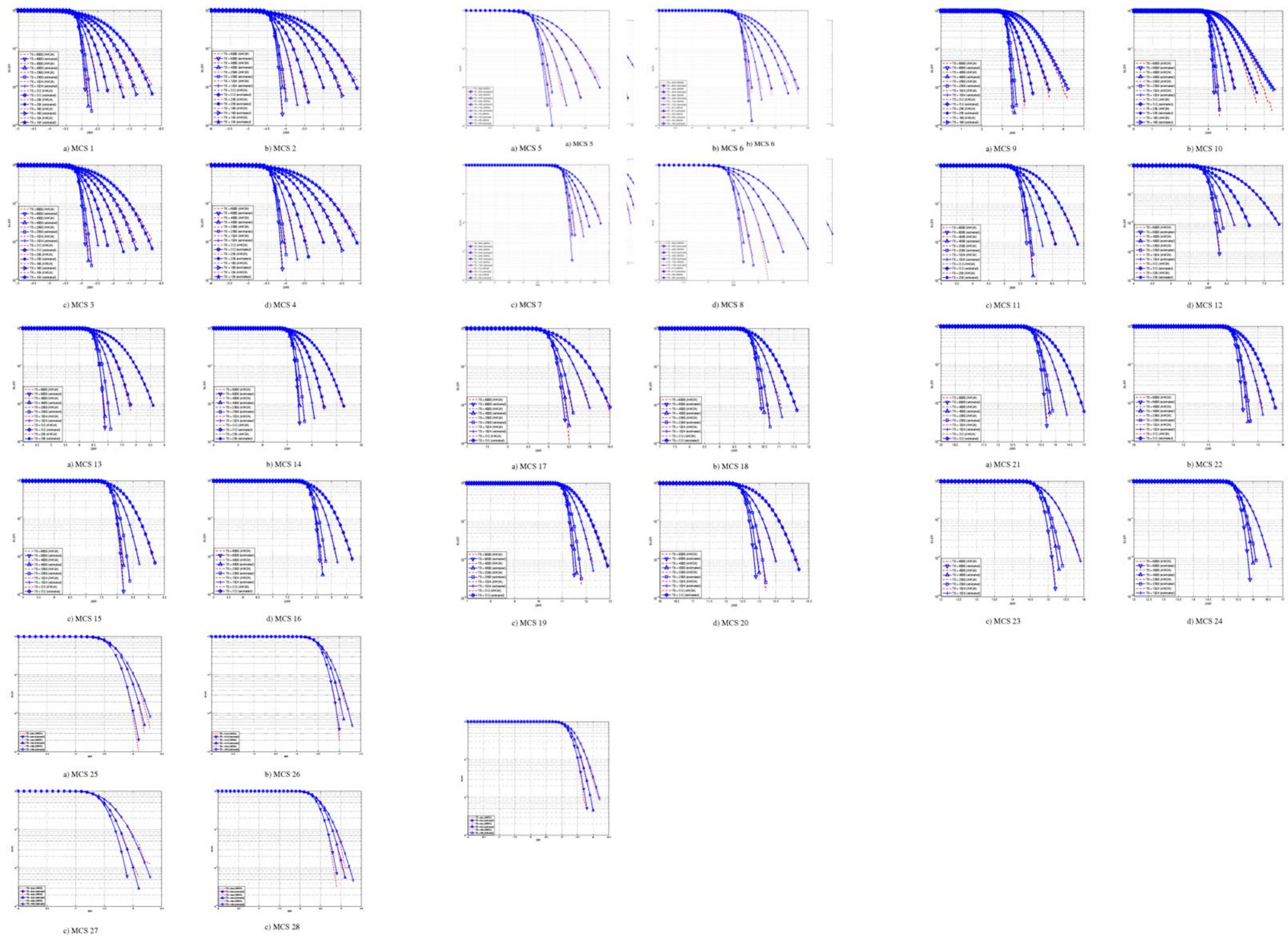
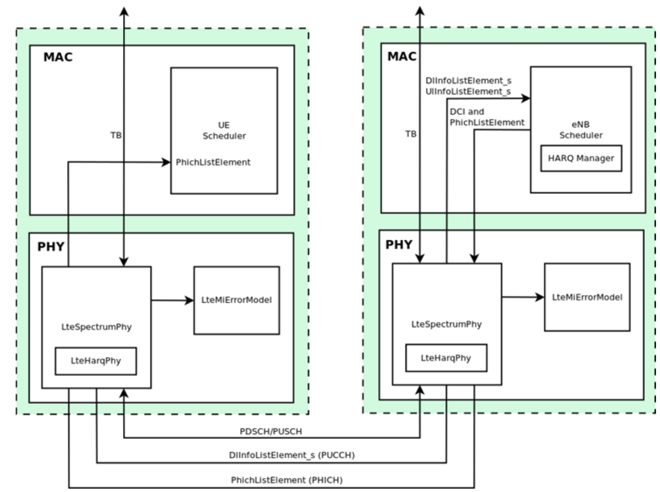
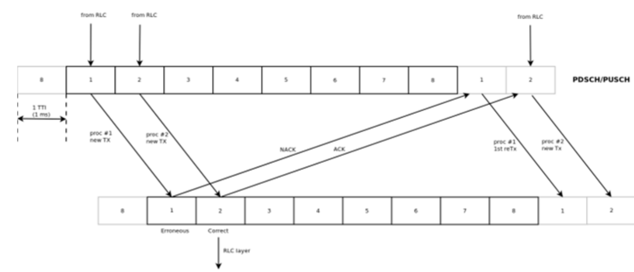
BLER Curves



HARQ model

- Models Incremental Redundancy (IR) Type 2
- Asyncrhonous model for DL
- Synchronous model for UL
- Retransmissions managed by Scheduler
- Integrated with error model





MAC & Scheduler model

- Resource allocation model:
  - allocation type 0
  - RBs grouped into RBGs
  - localized mapping approach
- Adaptive Modulation and Coding
  - two algorithms working on reported CQI feedback
  - "Piro" model: based on analytical BER (very conservative)
  - "Vienna" model: aim at max 10% BLER based on error model curves
  - Dynamic TX mode selection supported
    - but no adaptive algorithm currently implemented
- Transport Block model
  - Mimics 3GPP structure
    - mux RLC PDU onto MAC PDU
  - Virtual MAC Headers and CEs (no real bits)
    - MAC overhead not modeled
    - Consistent with requirements (scheduler neglects MAC OH)

MAC Scheduler implementations

- Round Robin (RR)
- Proportional Fair (PF)

→ LENA project

- Maximum Throughput (MT)
- Throughput to Average (TTA)
- Blind Average Throughput (BET)
- Token Bank Fair Queue (TBFQ)
- Priority Set Scheduler (PSS)

→ GSoC 2012

- All implementations based on the **<u>FemtoForum API</u>**
- The above algorithms are for <u>downlink</u> only
- For <u>uplink</u>, all current implementations use the same Round Robin algorithm

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Random Access model

- Random Access preamble transmission
  - Ideal model: no propagation / error model
  - Collisions modeled with protocol interference model
  - No capture effect $\Rightarrow$ contention resolution not modeled
- Random Access Response (RAR)
  - ideal message, no error model
  - resource consumption can be modeled by scheduler
- message3
  - UL grant allocated by Scheduler
  - PDU with actual bytes, subject to error model
- Supported modes:
  - Contention based (for connection establishment)
  - Non-contention based (for handover)

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RLC Model

- Supported modes:
  - RLC TM, UM, AM as per 3GPP specs
  - RLC SM: simplified full-buffer model
- Features
  - PDUs and headers with real bits (following 3GPP specs)
  - Segmentation
  - Fragmentation
  - Reassembly
  - SDU discard
  - Status PDU (AM only)
  - PDU retx (AM only)

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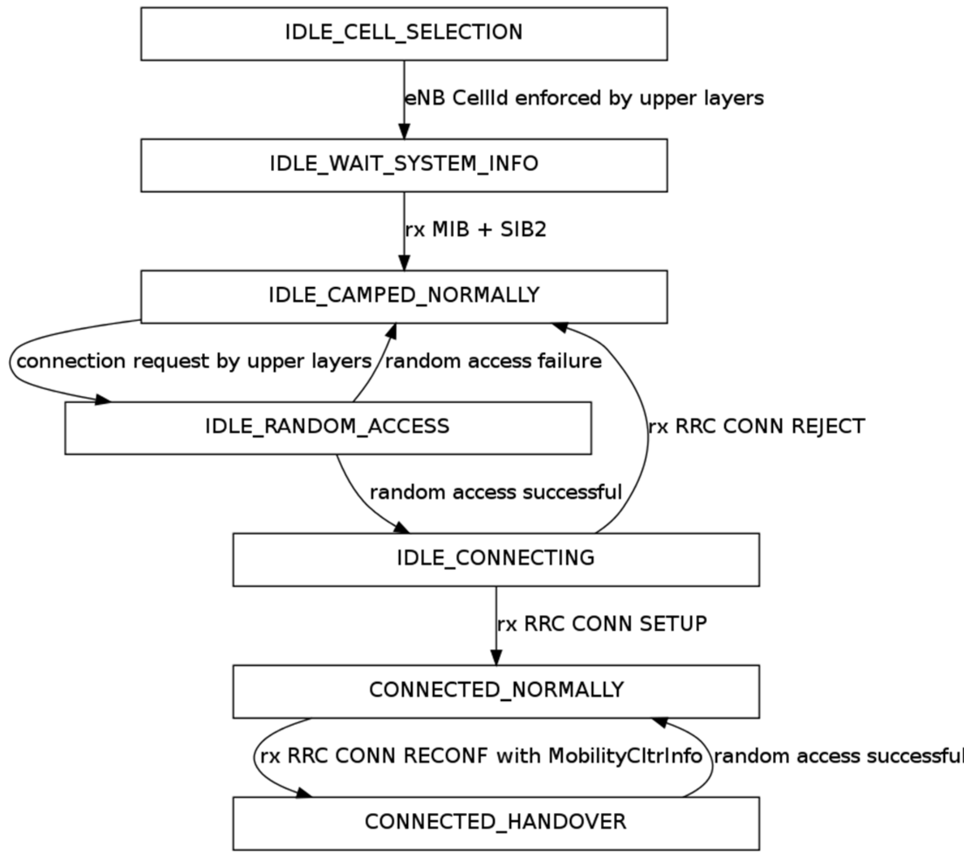
PDCP model

- Simplified model supporting the following:
  - Headers with real bytes following 3GPP specs
  - transfer of data (both user and control plane)
  - maintenance of PDCP SNs
  - transfer of SN status (for handover)
- Unsupported features
  - header compression and decompression using ROHC
  - in-sequence delivery of upper layer PDUs at re-establishment of lower layers
  - duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM
  - ciphering and deciphering of user plane data and control plane data
  - integrity protection and integrity verification of control plane data
  - timer based discard

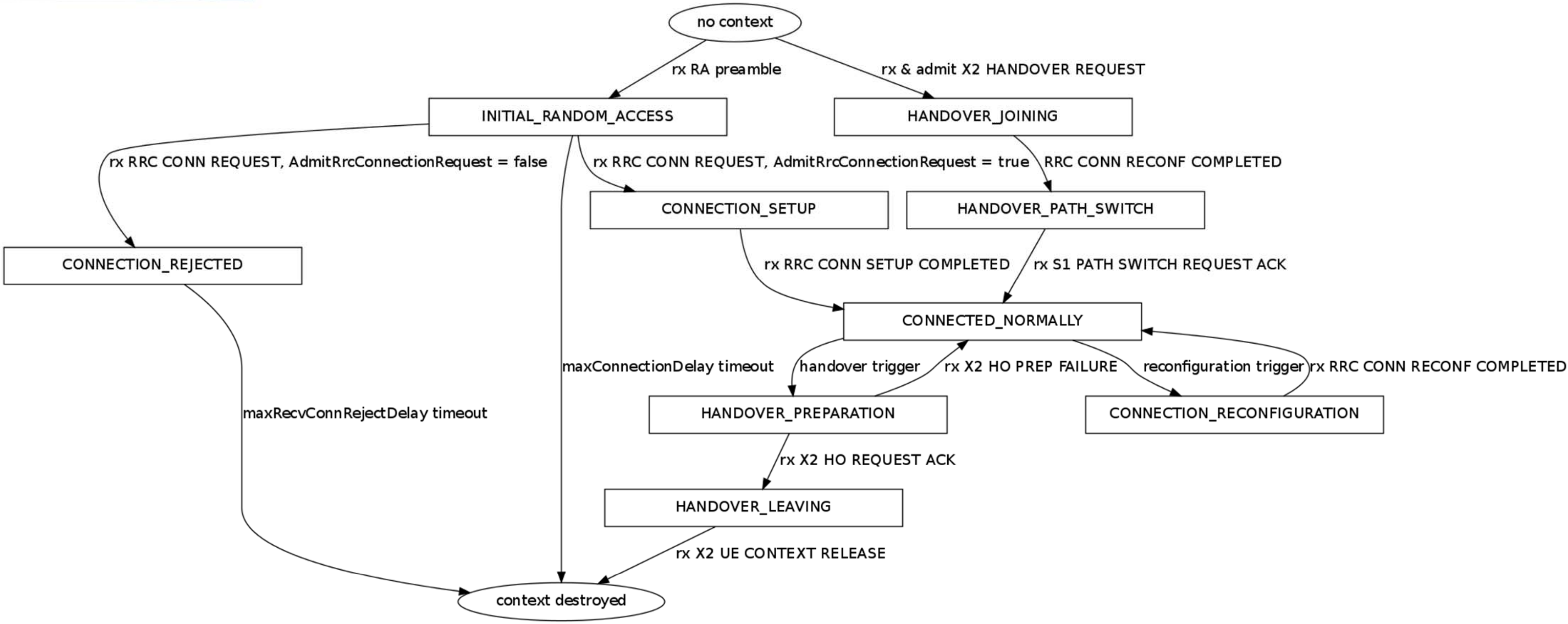
RRC Model

- Modeled features:
  - System Information (MIB, SIBs)
    - Generation at eNB
    - Reception and processing at UE
  - RRC Connection Establishment
  - RRC Connection Reconfiguration, supporting:
    - SRB1 and DRB setup
    - SRS configuration index reconfiguration
    - PHY TX mode (MIMO) reconfiguration
    - Mobility Control Info (handover)
- Model architecture:
  - LteUeRrc: UE RRC logic
  - LteEnbRrc + UeManager: eNB RRC logic
  - Two models for RRC messages
    - Ideal RRC: SRBs not used, no resources consumed, no errors
    - Real RRC: actual RRC PDUs (ASN.1 encoding) over SRBs

RRC UE state machine



RRC eNB State Machine



NAS model

- Focus on NAS Active state
  - EMM Registered, ECM connected, RRC connected
- Logical interaction with MME
  - NAS PDUs not implemented
- Functionality
  - UE Attachment (transition to NAS Active state)
  - EPS Bearer activation
  - Multiplexing of data onto active EPS Bearers
    - Based on Traffic Flow Templates
    - Both UDP and TCP over IPv4 are supported
- Unsupported features
  - PLMN and CSG selection
  - Idle mode (tracking are update, paging…)

S1 interface model

- S1-U (user data plane)
  - Realistic model including GTP-U implementation
  - Data packets forwarded over GTP/UDP/IPv4
  - Communication over ns3::PointToPoint links
- S1-C (control plane)
  - abstract model, no PDUs exchanged
  - Supported S1-AP primitives:
    - INITIAL UE MESSAGE
    - INITIAL CONTEXT SETUP REQUEST
    - INITIAL CONTEXT SETUP RESPONSE
    - PATH SWITCH REQUEST
    - PATH SWITCH REQUEST ACKNOWLEDGE

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X2 interface model

- X2-U (data plane)
  - GTP/UDP/IPv4 over ns3::PointToPoint (similar to S1-U)
- X2-C (control plane)
  - Messages as PDUs over ns3::PointToPoint links
  - Handover primitives:
    - HANDOVER REQUEST
    - HANDOVER REQUEST ACK
    - HANDOVER PREPARATION FAILURE
    - SN STATUS STRANSFER
    - UE CONTEXT RELEASE
  - SON primitives:
    - LOAD INFORMATION
    - RESOURCE STATUS UPDATE

S11 interface model

- abstract model
  - no GTP-C PDUs exchanged between MME and SGW
- Supported primitives:
  - CREATE SESSION REQUEST
  - CREATE SESSION RESPONSE
  - MODIFY BEARER REQUEST
  - MODIFY BEARER RESPONSE

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Simulation Configuration

- Done via ns-3 attribute system
- Several configurable attributes per LTE object
- Default attribute values can be configured:
  - Via input config file
  - Via command line
  - within simulation program
- Per-instance attribute values can be configured:
  - Within siulation program
  - Using GtkConfigStore

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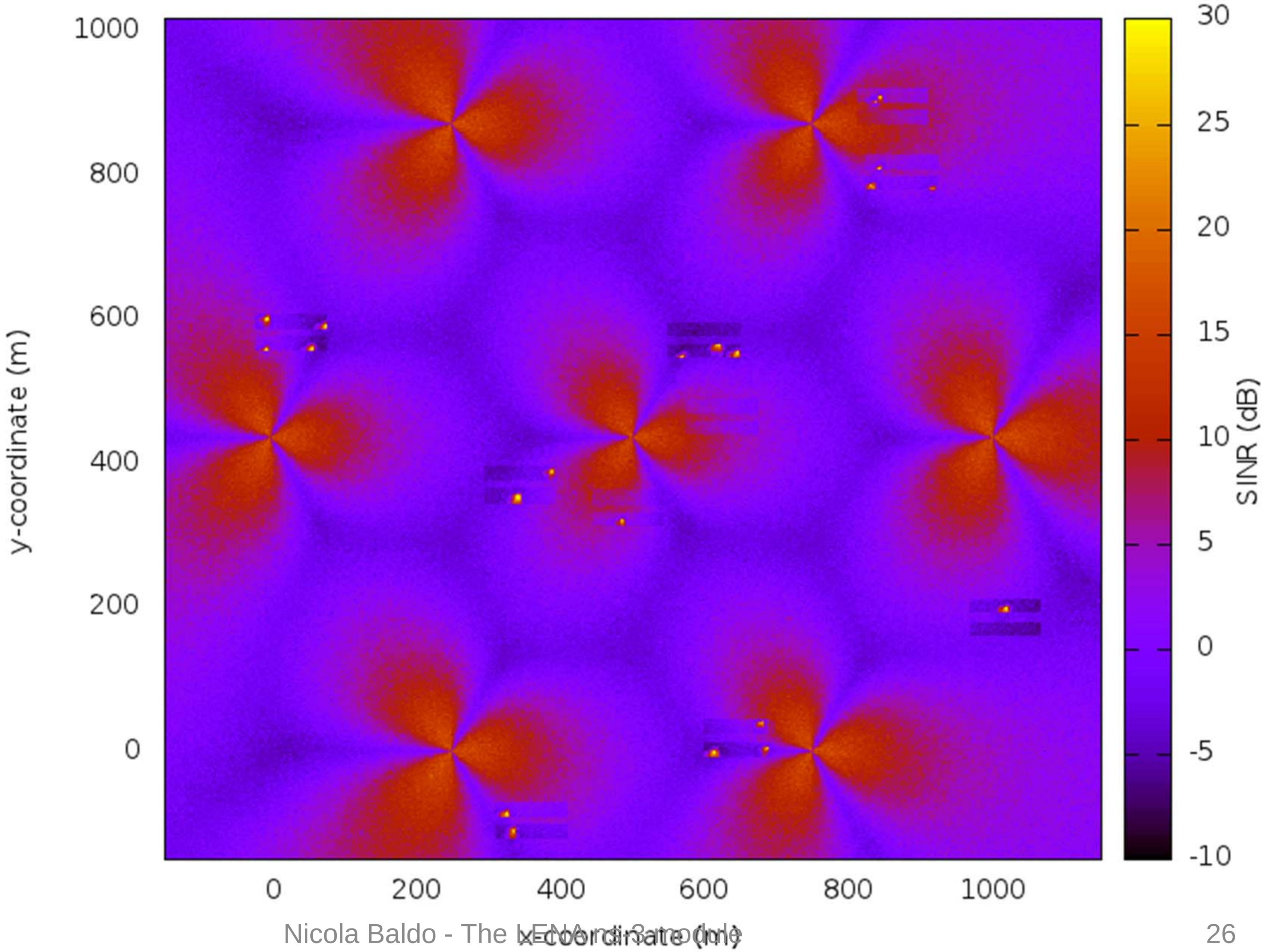
Simulation Ouput

- Lots of KPIs available at different levels:
  - Channel
    - SINR maps
    - pathloss matrices
  - PHY
    - TB tx / rx traces
    - RSRP/RSRQ traces
  - MAC
    - UL/DL scheduling traces
  - RLC and PDCP
    - Time-averaged PDU tx / rx stats
  - IP and application stats
    - Can be obtained with usual ns-3 means
    - FlowMonitor, PCAP traces, get stats directly from app, etc.

Example: 3GPP dual stripe scenario



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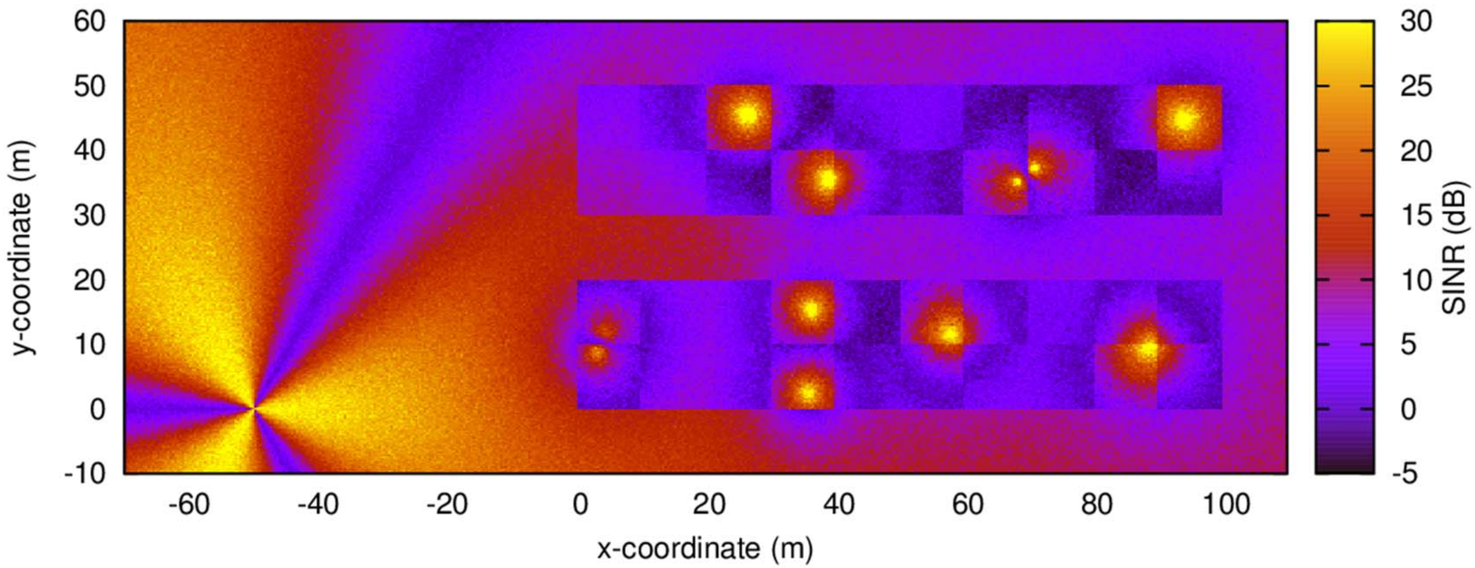

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Testing

- Huge effort in testing:
  - Unit tests
    - Checking that a specific module works properly
  - System test
    - Checking that the whole LTE model works properly
  - Validation tests
    - Validating simulation output against theoretical performance in a set of known cases
  - Valgrind test coverage
    - Systematically check for memory errors
      - memory corruption, leaks, etc. due to programming errors
  - Build tests
    - Provided by ns-3 project for stable LENA code
    - Verify correct build on all supported plaftorms

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Work in progress by the LENA team

- UE Measurements
- Automatic Neighbor Relations
- Idle mode cell selection
- Handover decision

Check it out!

http://iptechwiki.cttc.es/LTE-EPC_Network_Simulator_(LENA)

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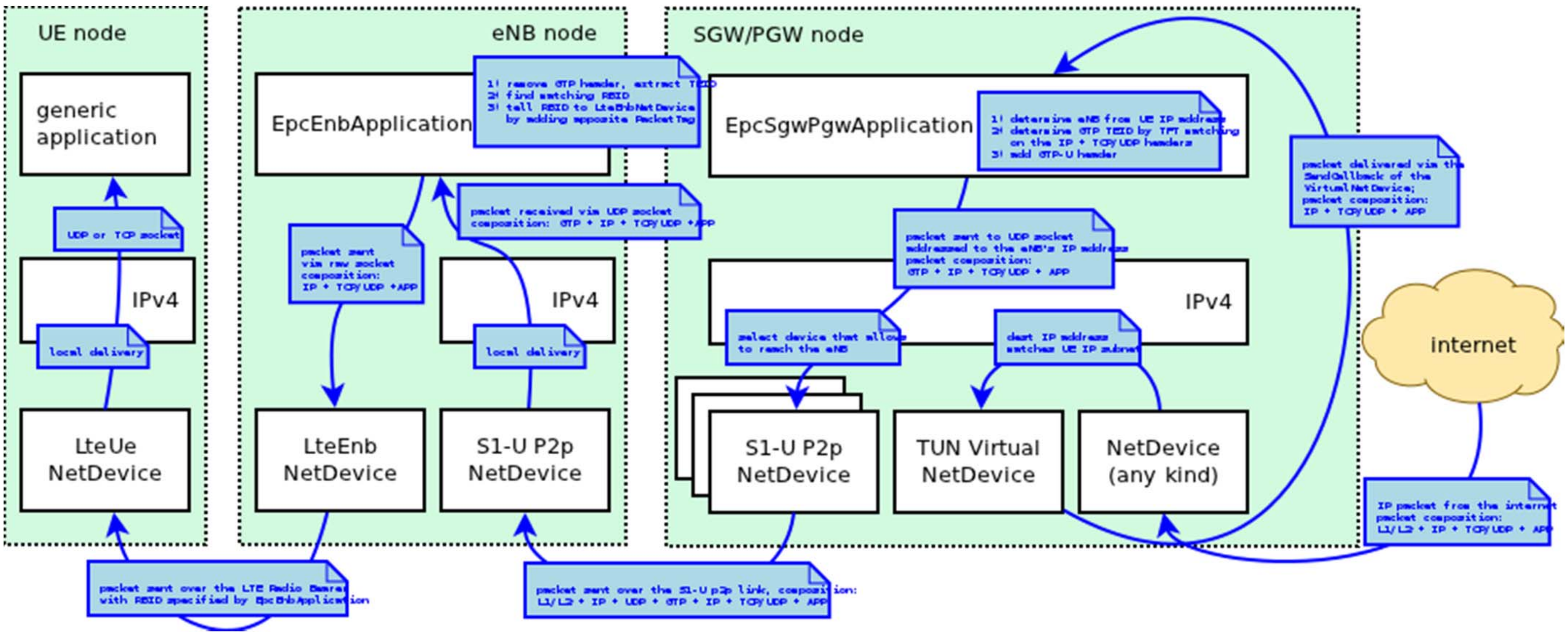
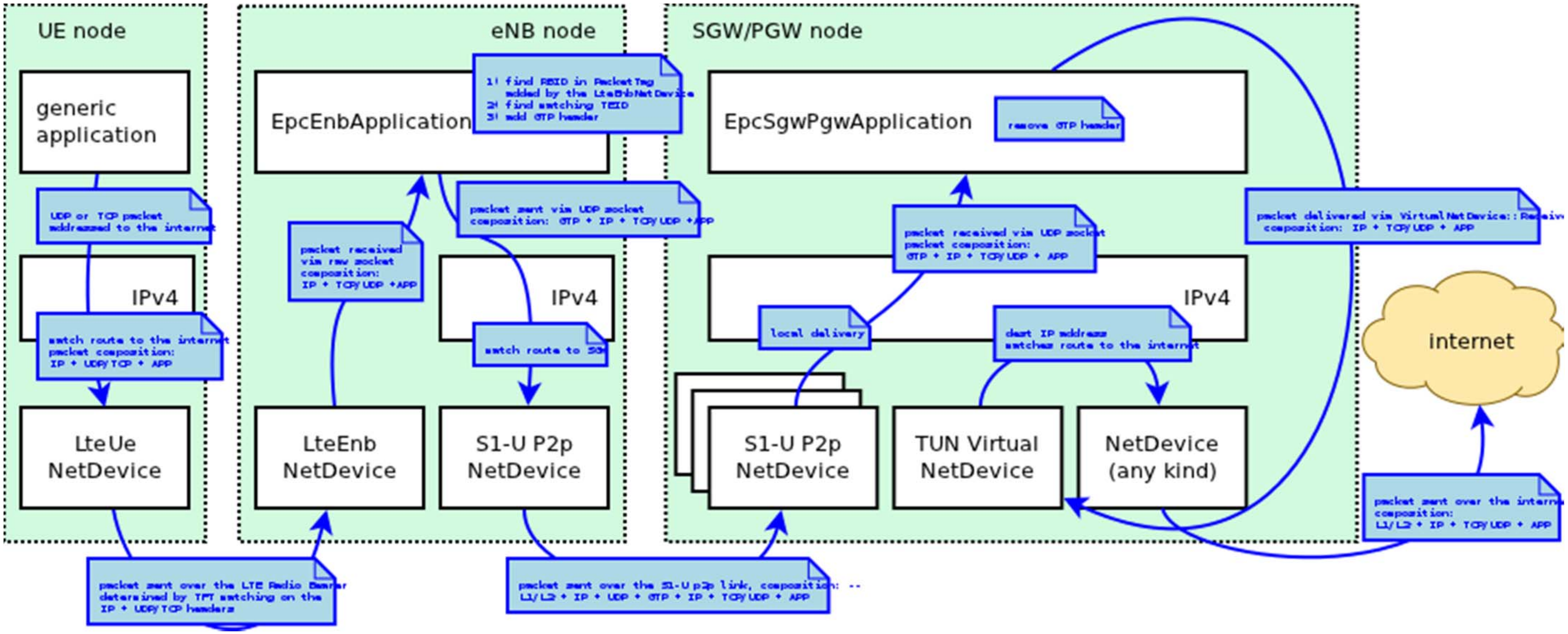
Backup slides

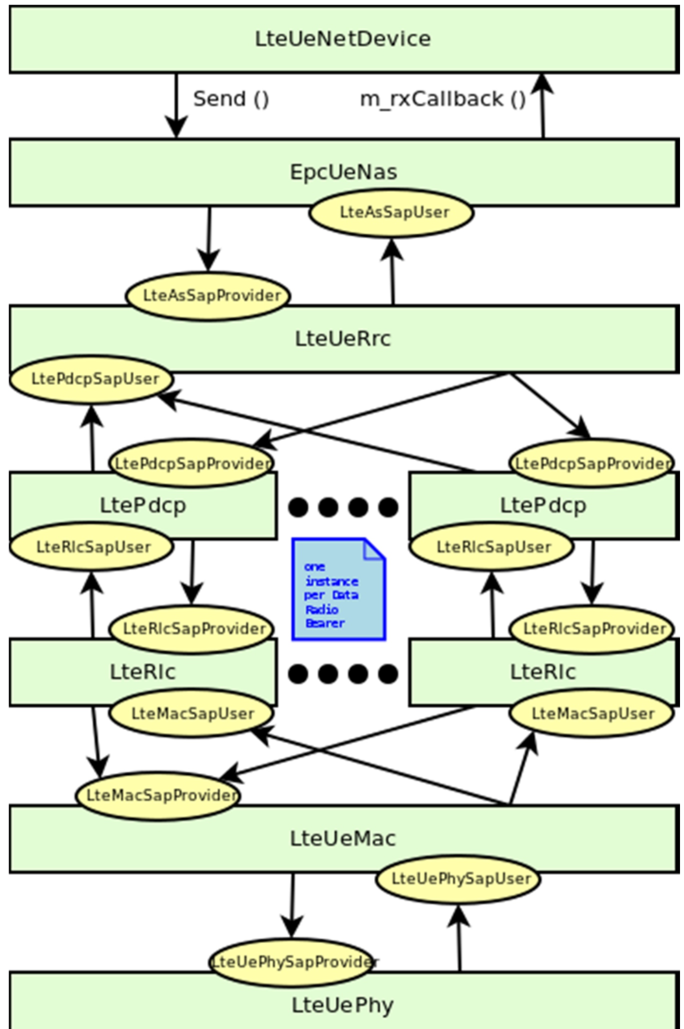
End-to-end Data Plane architecture
(as implemented in ns-3)



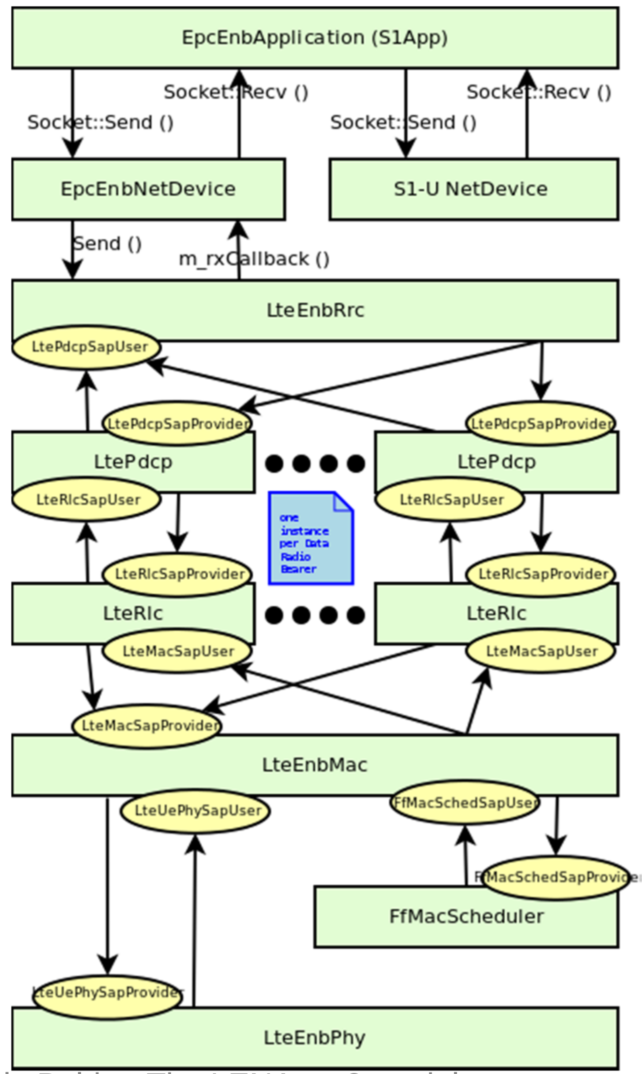
End-to-end Data Plane architecture (same but with UL data flow instead of DL)



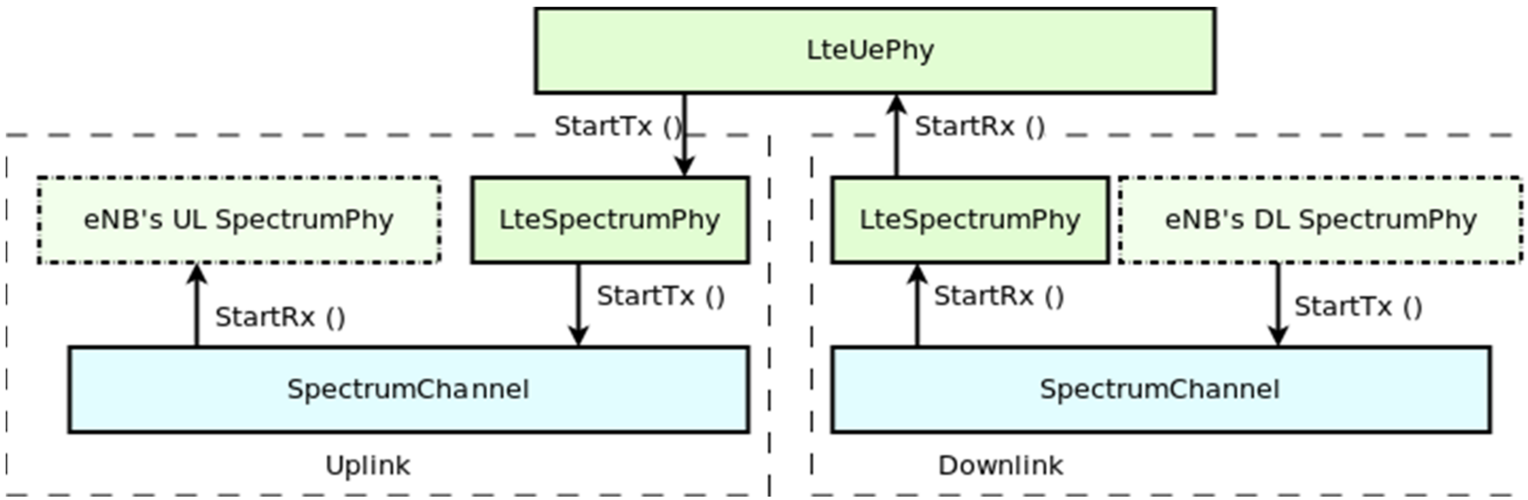
LTE Data Plane protocol stack: UE



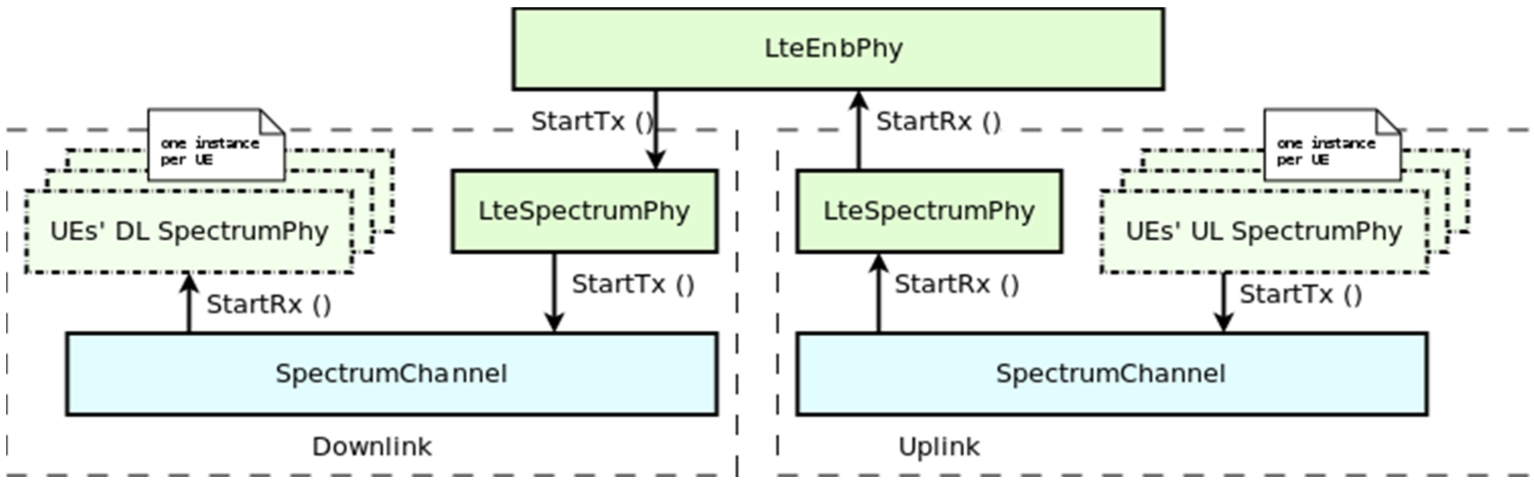
LTE Data Plane protocol stack: eNB



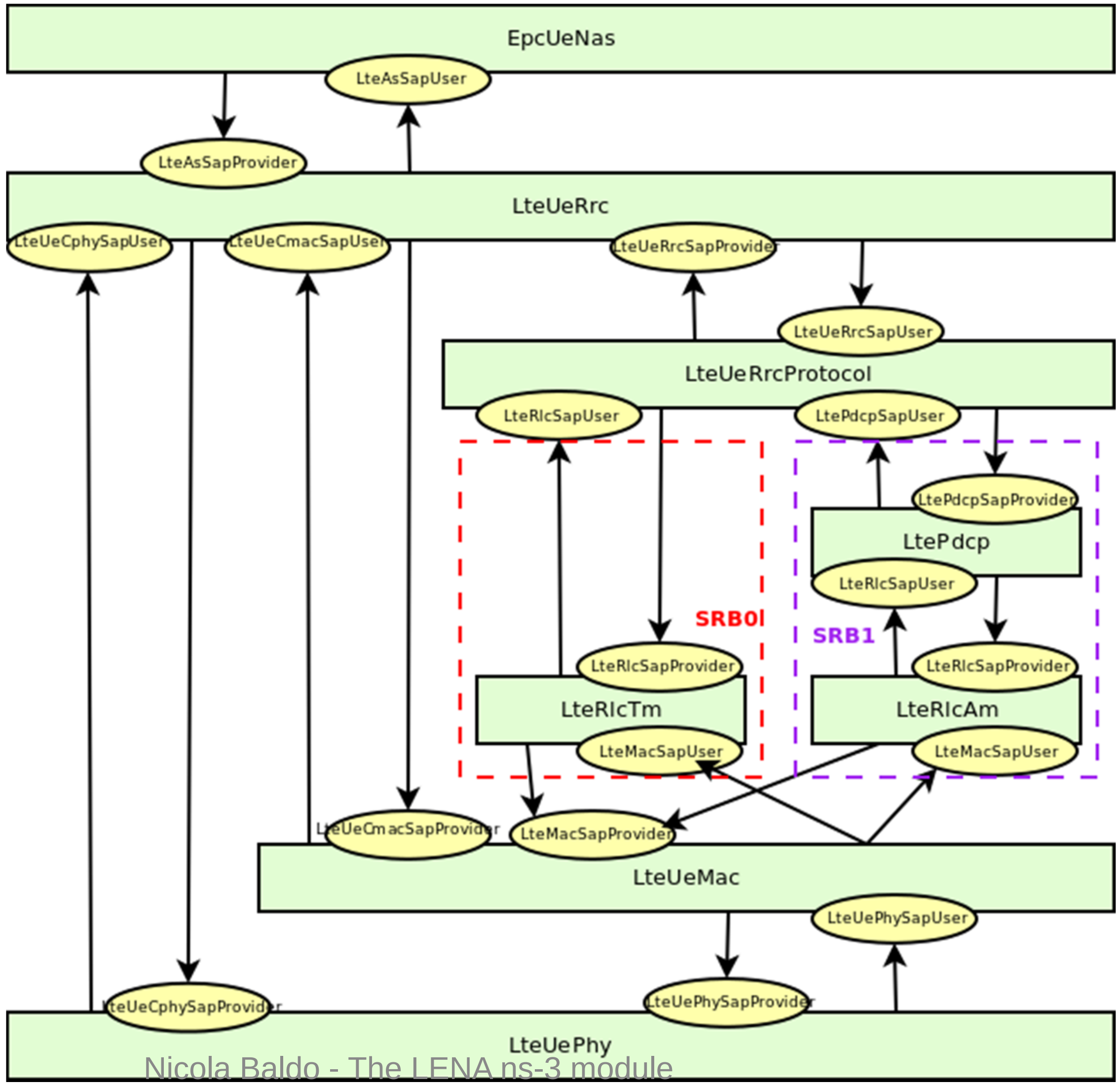
PHY and Channel architecture: UE



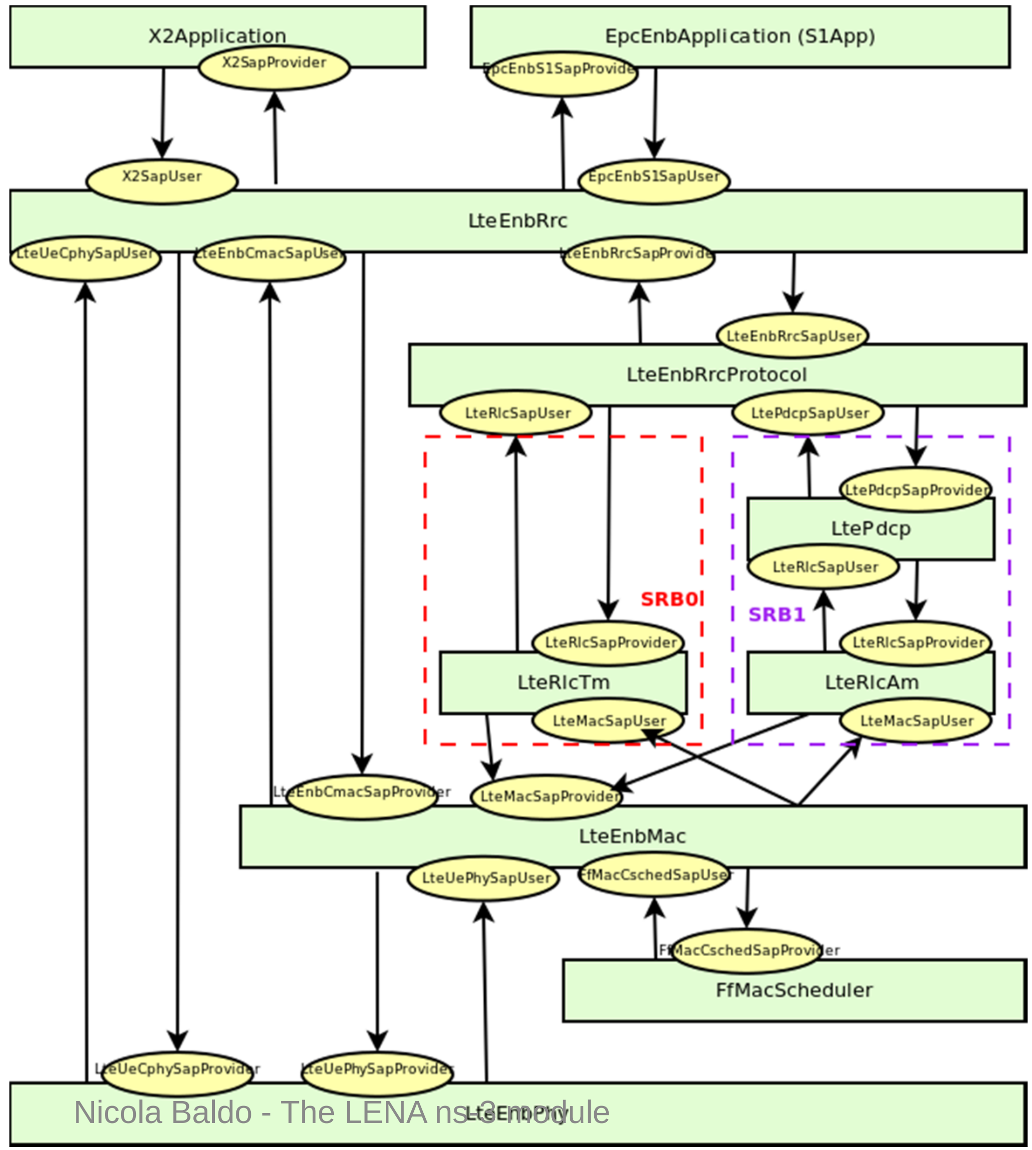
PHY and Channel architecture: eNB



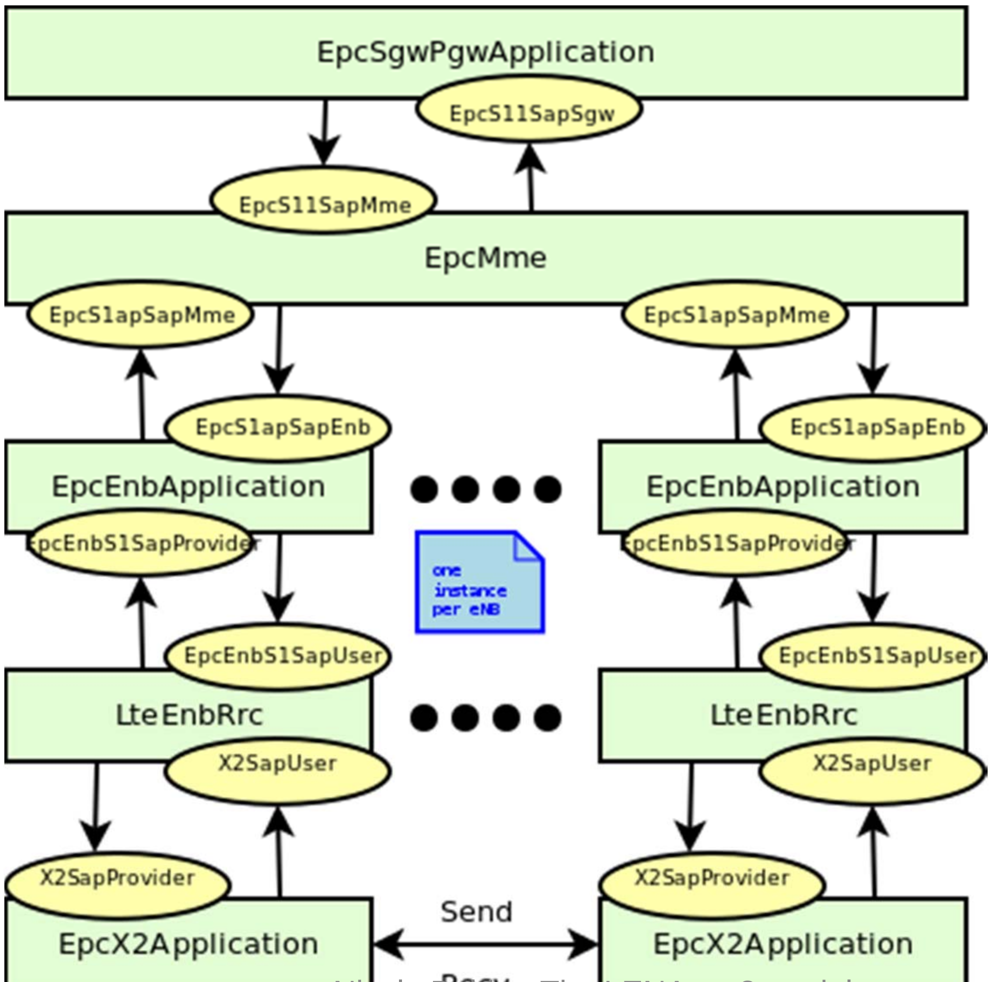
LTE Ctrl Plane protocol stack: UE

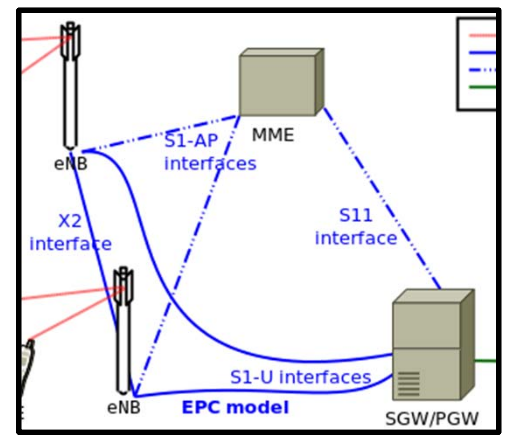


LTE Ctrl Plane protocol stack: eNB



EPC Control Plane Architecture





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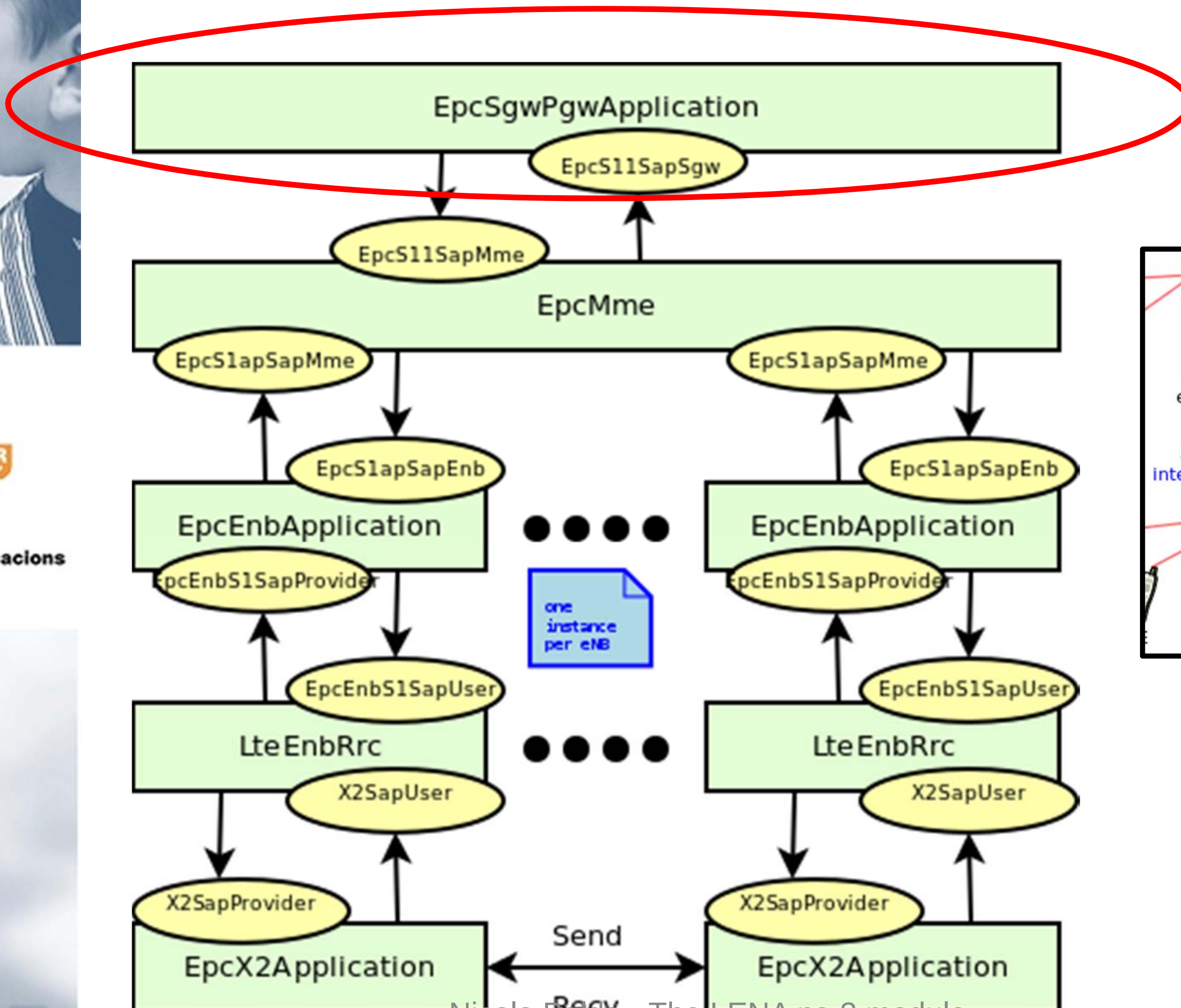

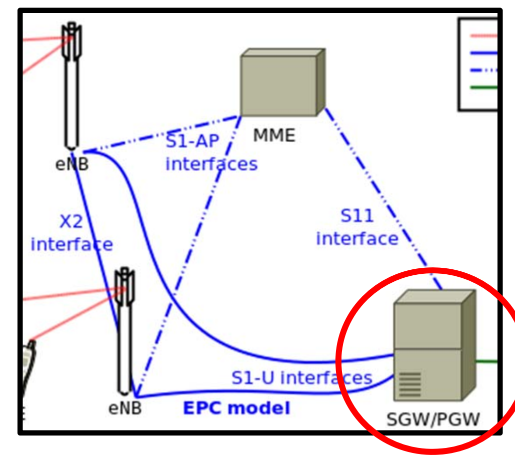

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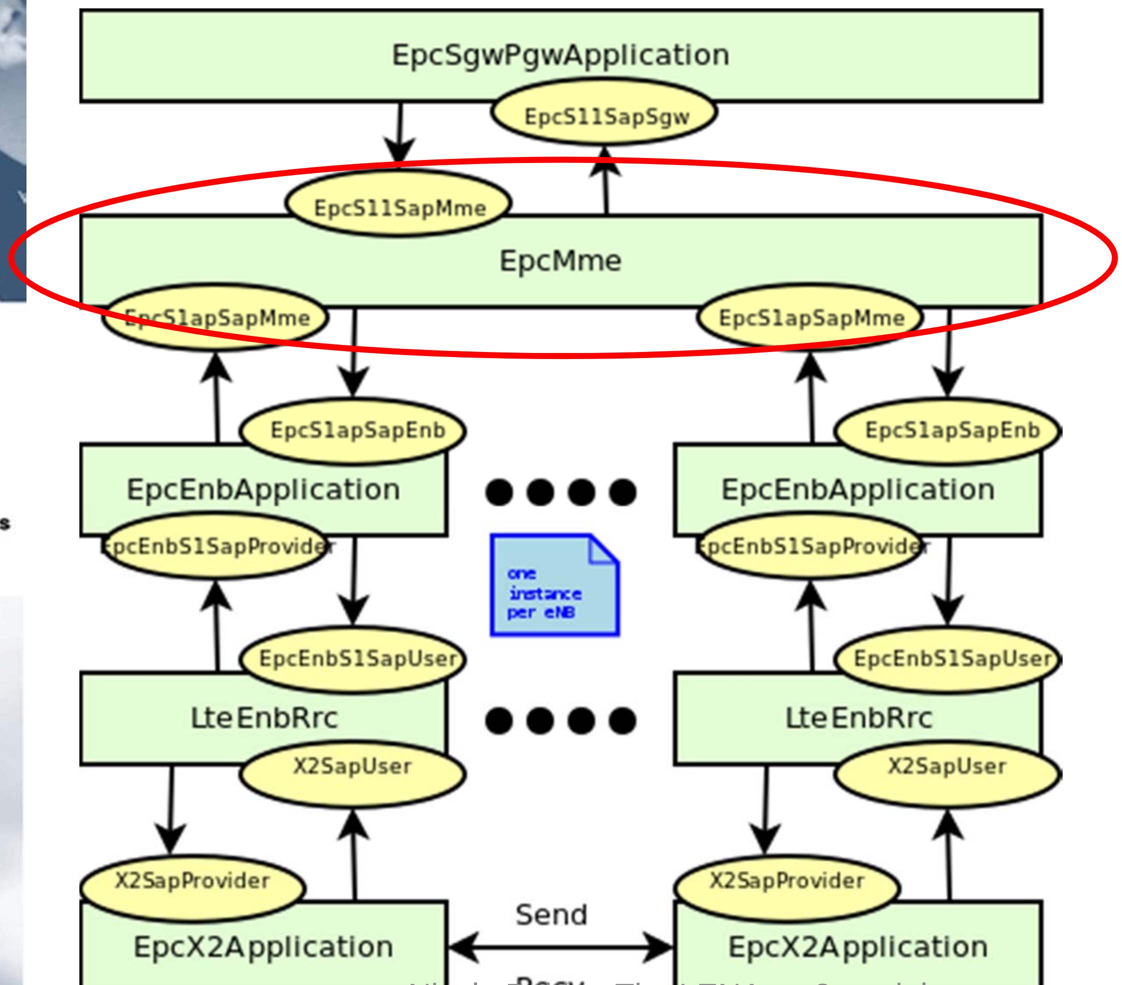
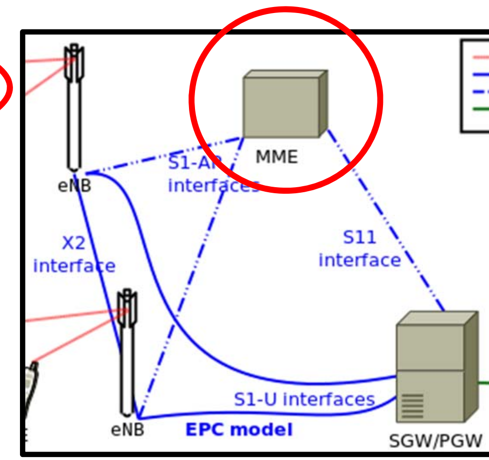
EPC Control Plane Architecture





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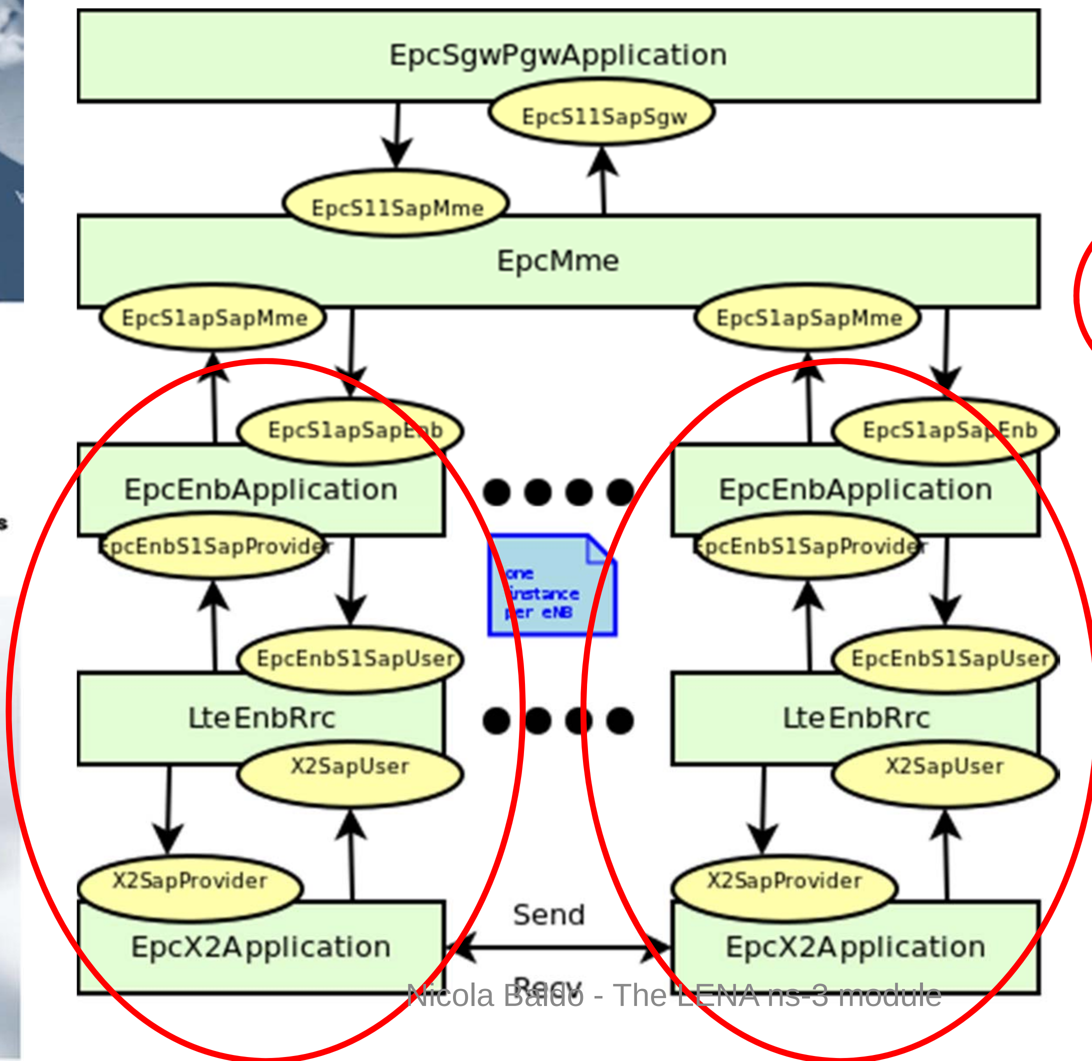

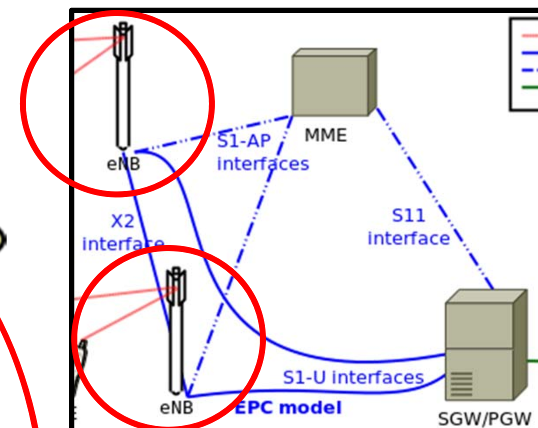

Execution time performance

(5s sim time, 1 UE per eNB, full traffic)