Prototyping LTE-WiFi Interworking on a Single SDR Platform

Walter Nitzold, Clemens Felber, Vincent Kotzsch
National Instruments, Dresden, Germany
Future Wireless Communication System (aka 5G and beyond)

- Demand for higher throughput and/or lower latency
- Flexibility within radio access technology (RAT) such as LTE and WiFi
- Transparent End-to-End view involves interworking/coordination between different RATs

→ How to study/research these interworking technologies?
Open Source Protocol Stacks (Layer 2 and above)

IP Networks
802.11
LTE UE
LTE eNB
LTE EPC
5G NR UE
5G NR gNB

Linux 802mac
NS-3
OpenLTe
Network Simulator NS-3

- Open source (GNU GPLv2) discrete-event network simulator in C++
- Allows for simulating IP networks including routing algorithms
- Provides various wireless/IP simulation models including LTE, Wi-Fi, ...

Only simulation → Integrate SDRs, but how?
**SDR Integration**

**OSI Model**
- **Layer 1** (Physical Layer)
- **Layer 2** (Data Link Layer)
- **Layer 3** (Network Layer)
- **Layer 4** (Transport Layer)

**3GPP LTE/5G Protocol Stack**

**User Plane**
- IP
- PDCP
- RLC
- MAC
- PHY
- RF + Antenna

**Control Plane**
- NAS
- RRC
- SRS
- SRS
- GCC
- NS-3

- **L1-L2 API**

- Integrity, ciphering, duplicate detect, SN, reordering, dual connectivity
- Segmentation, reassembly, ARQ
- Channel mux, adaptive resource scheduling (incl Beamforming), HARQ, access procedure, carrier aggregation
- Coding, modulation, resource mapping, MIMO
- Air transmission through EM waves

**Air transmission through EM waves**

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MAC-PHY API Concept

Cellular
- LTE PHY/L1 < 6GHz
- RF HW
- 3rd party L3
- L2-L3 API

LabVIEW based MAC/L2
- 3rd party L2
- 3rd party protocol stack (e.g. ns-3)

L1-L2 API

WiFi
- 3rd party 802.11 protocol stack
- 802.11 MAC high functionality

RF HW
- 802.11 MAC low + PHY

L1-L2 API

Aligned on concepts, mechanisms, general structure, ...
Potential of a general L1-L2 API

- Offers the **same ease of use** and mechanisms for different physical layer implementations.
- Enables very **flexible configuration** and E2E user data transmission.
- Enables **faster adoption, extension, migration and integration** of physical layer prototyping systems towards protocol and network level research & applications.
- Increases the level of **system abstraction**, because of no need to understand all details of the underlying physical layer.
- Offers a high level of **re-use** and increases the **transparency** of a complex wireless system.
How does the L1-L2 API work?
L1-L2 API – General principles

Communication based on a common set of 3 message types

- **REQ** → (Service) Request
- **IND** → Indication (status, data, error, …)
- **CNF** → Confirm w/ option to be disabled

Example: TX REQ for data channel
- **CONTROL**
  - MCS, RB allocation, TB size, …
- **PAYLOAD**
  - Transport block bits/bytes
L1-L2 API in action - Message Sequence Chart
L1-L2 API – Interfaces and Modules

**Interfaces and Modules**

**L1**
- **Msg Gen**
- **Msg Handler**

**L2**
- **Msg Gen**
- **Msg Handler**

**Transport medium btw. L1-L2**
- **INDs**
- **CNFs**
- **REQs**

**Implementation specific, e.g.**
- P2P FIFOs
- H2T/T2H FIFOs
- Memory pointers
- C-API
- UDP via Ethernet

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**Can be realized by standard platform components**

**Common message interface**

**Common platform components**

**To be provided by L1**
- compliant with common API

**To be provided by L2**
- compliant with common API
LTE-WiFi Prototyping Setup with USRP-2974

- **USRP 2974**
  - Intel i7 CPU
  - PCIe Expansion
  - **NS-3 Simulation:**
    - Internal client / serv or TapBridge
    - Internet
    - LTE UE or eNB
    - WiFi AP or STA
  - **LV RT LTE API Handler**
  - **NV RT WiFi API Handler**
  - DMA
  - Pipes

- **USRP 2953**
  - Xilinx K7 FPGA
  - **LV FPGA 802.11 AFW**
  - DAC/ADC & RF

- **Interconnection**
  - **eNB** to **AP**
  - **AP** to **UE + STA**
  - **Intel i7 CPU**
  - **Xilinx K7 FPGA**
Measurement of End-to-End Throughput

- Close to capacity limit of LTE PHY layer
- Throughput Increase compared to pure software-based PHY
Conclusions and Outlook

- Generalized API specification to connect PHY and MAC of different RATs
- Interworking research is possible with ns-3 and attached real-time SDR
- Implementation is used in EU-funded research project ORCA (https://www.orca-project.eu)
- Enhanced ns-3 with L1-L2 API implementation available under https://github.com/ni/NI-ns3-ApplicationExample

Next steps:
- Maintain and further extend based on community/research needs
- Investigation and application to other higher layer stacks like Open Air Interface
- Investigation and application to other physical layers like 5G GFDM PIF TUD
Thanks!