Real-time operation of LTE/Wi-Fi interworking via NS-3 and SDR interfacing

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***Abstract*—Recent approaches to augment LTE capacity through carrier aggregation of the unlicensed bands have drawn significant research interest. This carrier aggregation can either be realised via LTE/Wi-Fi interworking or from LTE directly operating over the unlicensed bands. However, these techniques face technological challenges that still need to be addressed in order to guarantee successful operation and fair coexistence with WiFi. This demo presents a unified experimental platform to evaluate and analyze the existing 3GPP LTE/Wi-Fi interworking approaches. This platform can be used to identify the merits and drawbacks of each approach in addition to characterizing their performance in the presence of realistic channel conditions.**

I. Introduction

LTE/Wi-Fi interworking along with unlicensed LTE have emerged as candidate technologies to cope with future traffic demands, effectively integrating heterogeneous radio technologies. To date, there are five different approaches: *1)* LTE-WLAN Radio Aggregation (LWA) [1], *2)* LTE-WLAN Radio Level Integration (LWIP) [1], *3)* Licensed Assisted Access (LAA), *4)* LTE-Unlicensed (LTE-U), and *5)* MuLTEFire. While LWA and LWIP operate offloading data over Wi-Fi through LTE/Wi-Fi interworking, LAA, LTE-U and MuLTE-Fire define mechanisms for LTE operation over the unlicensed bands.

LWA and LWIP facilitate Wi-Fi coexistence by using Wi-Fi protocols at the radio channel. In particular, LWA is based on encapsulating LTE packets into Wi-Fi ones at the Packet Data Convergence Protocol (PDCP) layer. LWIP, in contrast, creates an Internet Protocol security (IPsec) tunnel, effectively hiding the WLAN network to the LTE core network. On the other hand, LAA, LTE-U and MuLTEFire require modifications to LTE to provide fair coexistence with Wi-Fi.

In this work we present our implementation of the LTE/Wi-Fi interworking approaches (LWA and LWIP) in the open source Network Simulator 3 (NS-3) and their interfacing to SDR platforms. This unified system allows evaluation of the real-time operation of the aforementioned techniques under different network conditions using hardware experimentation. To date, the validation of the above mentioned schemes has been performed using simulations at the PHY, MAC and higher layers. We are not aware of any evaluation under real channel conditions through complete system design. In this context, the European Commission funded Horizon 2020 UP-ORCA[1] project in its 1st open call for extension. In this demo, we showcase the outcomes of this extension.

[1]https://www.orca-project.eu/open-calls/1st-orca-open-call-extension/

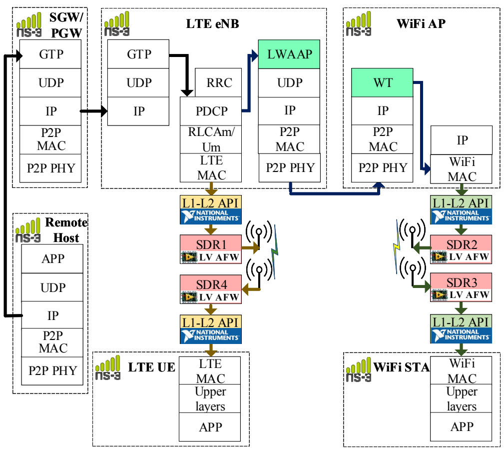

Fig. 1. Demonstration setup for LWA.

II. System Architecture

The LWA and LWIP implementations presented in this work follow Release 13 of the 3GPP specifications. As shown in Figure 1 and 2, multiple network components in NS-3 corresponding to different technologies (LTE, PointToPoint, Wi-Fi) and interfaces have been used together to implement the LWA and LWIP protocols.

In LWA, the traffic initiated between the remote host and the UE within the EPC model attempts to follow the direct path in the downlink (see Figure 1). This traffic can then be diverted fully or partially to the Wi-Fi network at the PDCP layer. In order to extract frames from the PDCP layer of the eNB, a new callback function is added in the PDCP class of LTE in NS-3. For the traffic diverted towards Wi-Fi, the LWAAP node is set as a source socket and the Wi-Fi station node as the destination sink. The implementation includes the design of the Xw interface, split and switched bearers.

In the LWIP implementation (Figure 2), an IPSec tunnel is used to transmit downlink traffic from the eNB to the UE through a Wi-Fi Access Point (AP). Since a callback function extracts and copies the contents (both headers and data) of the packets, the LTE core network is transparent to the P2P and Wi-Fi network. An IP tunnel that wraps UDP packets with new IP headers is created using a VirtualNetDevice. We have not implemented the use of split bearers for LWIP according to 3GPP Release 13 LWIP specifications.

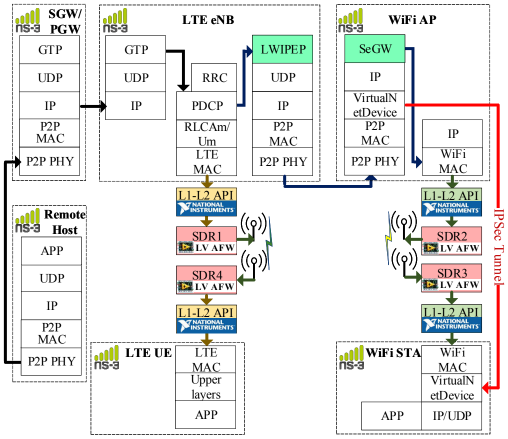

Fig. 2. Demonstration setup for LWIP.

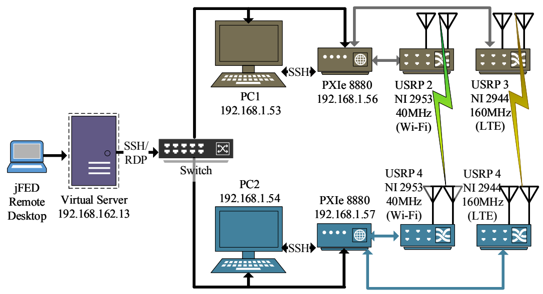

Fig. 3. Demo setup at the TUD testbed.

In order to interface NS-3 LTE and Wi-Fi stacks with realistic physical layers and be able to run the protocols in real time, an Application Programming Interface (API) developed by National Instruments[2] has been used. The LTE L1-L2 API interconnects the LTE MAC, higher layers, as well as the EPC model running on a real-time operating system on a CPU with the LTE PHY layer being executed in real-time on an FPGA through the Labview LTE Application Framework (LV AFW). For over the air Wi-Fi communication, a Wi-Fi L1-L2 API that interconnects the MAC layer (MACHigh class) of NS-3 with the Wi-Fi LV AFW has been used.

III. Demo Description

In this demo we will showcase our LWA and LWIP implementation along with the SDR interfacing through real-time emulation. For this purpose we will use the Online Wireless Lab (OWL) testbed setup available at the Vodafone Chair Mobile Communications Systems lab at the Technical University of Dresden (TUD), Germany. To showcase real-time operation of LWA and LWIP, a setup enabling different instances of NS-3 will be used (see the demo setup at the TUD testbed in Figure 3). The first NS-3 instance is installed at the PXIe with IP address 192.168.1.56 and includes the eNB and Wi-Fi AP functionalities along with methods to enable LWA or LWIP traffic splitting. The second and third instances are installed at the PXIe with IP address 192.168.1.57 and encompass the operations of LTE and Wi-Fi stations. LTE over-the-air transmission is performed using the two USRP NI2944 SDRs that are connected to VERT2450 antennas. For Wi-Fi, the transmissions are performed using the two USRP NI 2953 SDRs which are connected to VERT2450 antennas.

[2]https://orca-project.eu/wp-content/uploads/sites/4/2017/09/ORCA_2.2-08-v1.1.pdf

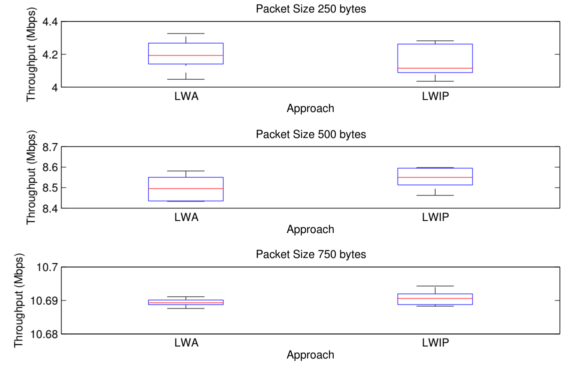

Fig. 4. Saturation throughput using LWA and LWIP (median, 25th, 75th percentiles and most extreme data points).

IV. Evaluation

Using the described demo setup we will showcase LWA and LWIP under different traffic and channel conditions. To better understand the impact of LWA/LWIP interworking schemes, we show the results of the setup described above (1 eNB, 1 Wi-Fi AP and 1 Wi-Fi STA and 1 UE) while the eNB generates downlink traffic towards the UE using IEEE 802.11a configured with QPSK 1/2.[3] Figure 4 shows the saturation throughput of LWA and LWIP for different packet sizes. We expect a slight inefficiency at small packet sizes for LWIP due to added overheads. However, we see this inefficiency is negligible in real channel conditions.

V. Conclusions

In this demo we will showcase our LWA and LWIP implementations in NS-3 and their interfacing to SDR platforms. Moreover, with the help of the setup, we provide a realistic comparison among these LTE/Wi-Fi interworking approaches. The setup we have presented enable researchers and practitioners to devise which approach works best under given traffic and network conditions in real time.

References

[1] 3GPP, "Evolved universal terrestial radio access (e-utra) and evolved universal terrestial radio access network (e-utran); Overall Description; Stage 2, V.13.3.0, Section 22A.1, document TS 36.300," Apr. 2016.

VI. Acknowledgments

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[3]A low modulation and coding scheme have been used due to hardware constraints.