The First Experimental SDR Platform for Inband D2D Communications in 5G

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***Abstract*—Experimental setups for cellular communications have always been a rare commodity in academia. The advent of software-defined radios (SDRs) paved the way for researchers to prototype their ideas on real hardware. However, existing SDR platforms and their associated reference design codes mostly provide basic cellular functionality with limitations such as low numbers of users and computational capacity. In this demo, we demonstrate the first SDR-based testbed for inband D2D communications using LabVIEW Communications and the USRP hardware platform. Furthermore, we implement a light-weight quality-aware scheduler which adaptively switches communication links from D2D to cellular and vice versa.**

I. Introduction

A key feature of forthcoming 5G cellular networks is Device-to-Device (D2D) communication. Indeed, D2D is expected to solve part of the network capacity issue by enabling mobile users to communicate directly with each other without traversing the base station. Early research in this area showed that D2D can significantly improve spectral efficiency, reduce energy consumption, and enhance fairness and user experience within the network [1]–[3]. Although research on D2D communication started several years ago, progress has been very slow due to the rigid and hierarchical architecture of cellular networks [3]. Specifically, this has hampered the progress of *inband D2D* communication [2]. In inband D2D, the communication occurs over the licensed cellular spectrum, whereas *outband D2D* users communicate over the unlicensed spectrum. Using the licensed spectrum for D2D communication brings about major challenges in terms of interference and resource management. As a result, implementations of outband D2D already exist while inband D2D is still under discussion in 3GPP standardization, especially from radio access management.

Furthermore, the majority of D2D research proposals are only evaluated analytically or via simulations. These evaluations make simplifying assumptions so as to tackle the complexity of the D2D system within today's available analytical models and computational power. On one hand, these assumptions reduce the reliability/performance of these proposals when implemented in a real-world scenario. On the other hand, experimental evaluation is not possible due to a lack of experimental platforms, in particular in academia.

With the advent of Software-Defined Radios (SDRs), there is a new possibility for researchers in academia to build their own experimental platforms and test their algorithms in real-world scenarios. We believe that this will lead to faster materialization of D2D in cellular networks. Nevertheless, to date, there are only a handful of SDR platforms (e.g., OpenAirInterface, SRS LTE, LTE-ENB) which can be extended to support D2D communication [4]. In this demo, we demonstrate *the first SDR implementation of inband D2D communications* using LabVIEW Communications. Furthermore, we showcase our light-weight quality-aware scheduler that actively selects the suitable communication channel (D2D or legacy cellular).

In the following, we first give a short overview on the capabilities of our software base and elaborate on steps taken to implement inband D2D communication in section II. In section III, we provide details on the demo setup. Finally, in section IV, we give some concluding remarks.

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II. System Design

Our system is composed of an eNodeB (eNB) and several User Equipments (UEs). As our hardware platform, we use the NI USRP, which offers two TX and RX ports as well as a Xilinx Kintex-7 FPGA that is used to offload computationally expensive PHY operations. We build our demo on top of the LabVIEW Communications LTE Application Framework (LTE AFW), which implements the Physical Downlink Control and Shared Channels (PDCCH and PDSCH, respectively) and the Physical Uplink Shared Channel (PUSCH) for the eNB and the UE. However, as of version 2.0.1, the LTE AFW *does not support multiple UEs per eNB in OFDMA and uses the PUSCH for downlink feedback information only.* In what follows, we describe the changes made to the LTE AFW to support inband D2D.

A. eNB

The software architecture of the eNB is depicted in Figure 1. The blue blocks highlight modifications and extensions to the reference design in order to: (i) support multiple UEs with one eNB, for which we optimize and extend the FPGA logic; (ii) enable transmission of D2D Channel Quality Indicators (CQIs) along with downlink CQIs on the uplink channel; (iii) implement a light-weight scheduler for uplink/D2D resources, which takes the reported quality of both the cellular and the D2D link into account; and (iv) implement the necessary signaling messages to control which link UEs should use for data transfers.

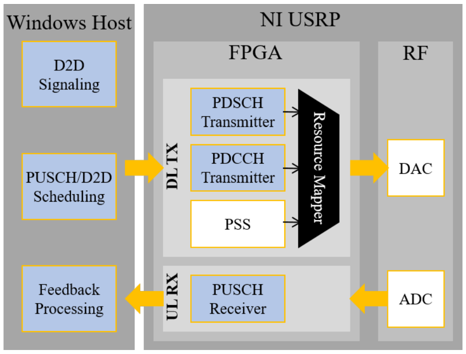

Fig. 1: Architecture of the D2D-enabled eNB. Blue blocks indicate our modifications to the LTE AFW

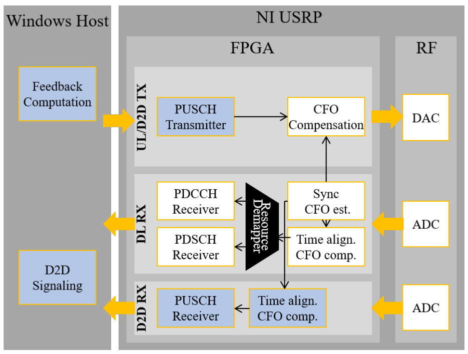

Fig. 2: Architecture of the D2D-enabled UE. Blue blocks indicate our modifications to the LTE AFW

B. UE

In accordance with the 3GPP standard, we use uplink frequencies for D2D communication [5]. Fig. 2 shows the software architecture of the UE. Our modifications of the reference design consist of: (i) the integration of an additional D2D receiver chain, for which we reuse the LTE AFW's PUSCH implementation; (ii) the extension of the PUSCH transmitter to enable simultaneous transmission of uplink feedback and D2D payload data; (iii) the implementation of D2D signaling messages to allow for the eNB to control which data should be forwarded via the D2D link. Synchronization to the eNB for timing and Carrier Frequency Offset (CFO) estimation are achieved by processing the Primary Synchronization Signal (PSS) in the downlink receiver chain. Timing and CFO data are shared across chains to enable time alignment and CFO compensation in all chains.

III. Demo Setup

Our demo setup consists of three Windows notebooks, each equipped with one NI USRP-2954R. One computer acts as the eNB, the other two act as UEs. The eNB streams different videos to both UEs via a legacy cellular link. Video playback, as well as SNRs, throughput rates, spectra and constellation diagrams for each link can be observed at the eNB and the respective UE. A screenshot of our UI can be seen in Fig. 3.

Conference attendees can degrade the channels between UEs and eNB by placing objects or walking through the radio link. Consequently, the observed SNR and throughput at the eNB and respective UE reflect the change in the channel

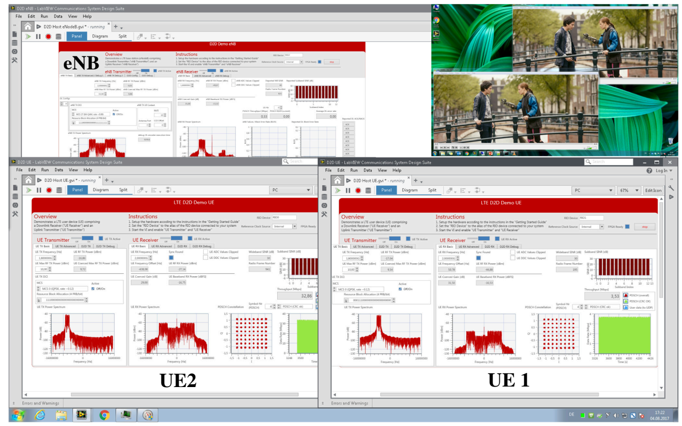

Fig. 3: The user interface of our inband D2D demo

quality. The eNB responds to the channel variation by selecting the best communication mode (legacy cellular or D2D).

IV. Conclusion

We present the first experimental testbed for inband D2D communications in 5G. To this aim, we significantly extend the LabVIEW Communications LTE Application Framework code-base to support multi-UE support. Moreover, we implement support for simultaneous PUSCH transmissions and design a light-weight quality-aware scheduler demonstrating the agility of our inband D2D setup. This demo paves the path for researchers in academia to freely implement their D2D proposals in an SDR testbed and observe the impact of real-world channel characteristics on the system's performance. As a next step, we will extend this testbed to support dynamic D2D pairing with adaptive discovery mechanisms. Furthermore, we will work towards a more sophisticated scheduler for an underlay inband system, where cellular UEs share the same resources as D2D UEs. This is particularly complex, as interference management for frequency re-use within the cell is a challenging task.

V. Acknowledgments

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