Poster: An Experimental Study of Multi-RAT Systems

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***Abstract*—The most wide-spread wireless technologies are 3GPP cellular networking solutions (e.g., LTE-A) and IEEE WLAN solutions (e.g., WiFi). Traditionally, these two served distinct purposes. Cellular systems were commonly used for outdoor and long-range communication with limited data-rate, whereas WiFi networks provided short-range communication within residential and office environments. The operational distinction between these two technologies has (almost) disappeared within the past few years, encouraging a more seamless multi-RAT capability in 5G networks. In this poster, we illustrate and evaluate a full-stack and real-time implementation of a multi-RAT system, whose implementation will be publicly made available.**

I. Introduction

Today's wireless devices often have a choice between using LTE-A and WiFi, which has been recognized as an opportunity by academia and industry. This opportunity encompasses a vast plethora of enhancements from traffic offloading to load-balancing and spatial reuse. Consequently, 3GPP has foreseen the possibility of LTE-A and WiFi cooperation in Release 15 and 16 [1]. From an academic perspective, there has been a large body of works dedicated to RAT selection with a major focus on flow/path selection among the two wireless interfaces. For smooth multi-RAT interworking, the RATs should interact at a given layer of the protocol stack, which brings us to the question: "how should LTE-A and WiFi RATs interact?".

The majority of the literature recommends MAC layer for this purpose to avoid complex IP adaptation issues [2], [3]. Due to the highly proprietary nature of LTE-A hardware, neither the practical feasibility of this approach nor the impact of the transparency of RAT selection on high layers (above MAC) has been tested in real systems. Furthermore, the computational complexity and the signaling overhead associated with the location of multi-RAT orchestrating entity (e.g., base station in centralized architecture or user equipments (UEs) in a distributed one) have not yet been tested. In this poster, we shed light on these aspects via the full-stack and real-time SDR implementation of WiFi and LTE-A.

II. Related Work

Prior works on multi-RAT selection are evaluated using numerical simulations [4], [5], or event-based simulations (e.g., ns-3), which assume ideal theoretical channel model [6]. Although theoretically insightful, these works do not account for real-world complications such as lack of ideal channels and instantaneous channel quality information. Furthermore, they do not show the imposed signaling/computational overhead

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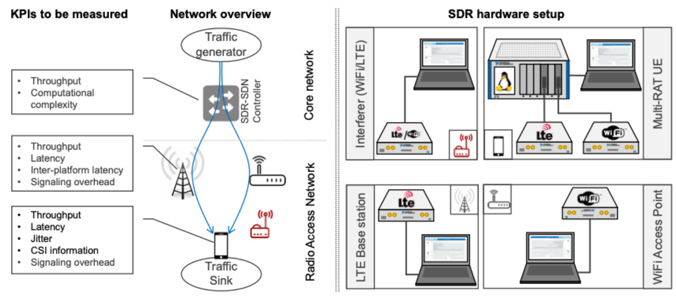

Fig. 1: Overview of the setup from network and hardware perspective. Note that depending on the experiment and the parameters under investigation, the interferer node will run WiFi or LTE. Also, the figure shows the KPIs which can be measured at different parts of the testbed.

to the network and the impact of multi-RAT decisions on higher layers. To the best of our knowledge, there have been two experimental efforts on the topic [7], [8]. A very recent paper by Liu et al. proposes to use deep learning for spectrum sharing in heterogeneous networks [7]. This work, however, only focuses on generic physical layer SDR prototyping and does not consider a specific technology such as WiFi or LTE-A. The most similar work to this project is the latest experimental effort by Ibarra et al. which uses Open-Air-Interface (OAI) to study the problem of LTE-WiFi aggregation and its impact on the higher layers [8]. However, their work only focuses on the co-existence in ISM band. Also, it does not account for the impact of interference on LTE-A.

In this poster, we shed light on the impact of multi-RAT decisions on TCP performance in presence of interference, channel, and traffic dynamics. To this aim, we have extended the implementation of [9] to enable uplink traffic and feedback reporting. Our evaluation illustrated the importance of PHY-layer awareness on higher layers stacks. Furthermore, we design a practical threshold-based RAT-scheduler that increases the throughput while maintaining low delay and jitter. Furthermore, we study additional real-world issues such as lack of immediate channel feedback. The code will be made publicly available with this poster.

III. System Setup

Our system setup consists of four entities (c.f. Fig. 1): an eNodeB (eNB), a WiFi AP, an interferer, and a UE with multi-RAT capabilities. From a hardware perspective, the eNB, interferer, and WiFi AP are Linux machines that are equipped with one NI USRP-2954R. On the other hand, the Multi-RAT UE is equipped with two USRPs. From a software point

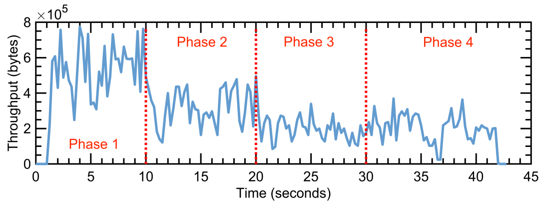

Fig. 2: TCP Throughput (byte/s) of LTE PHY under different channel conditions.

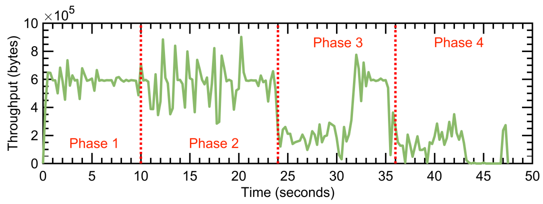

Fig. 3: TCP Throughput (byte/s) of fully switched LWA mode (WiFi PHY) under different channel conditions.

of view, the physical layer functions and some of the time-stringent MAC layer operations are implemented on FPGAs inside the USRPs. The USRPs are connected via L1/L2 API to the ns-3 simulator running on a real-time linux machine.

IV. Results

In this setup, various aspects of multi-RAT systems can be investigated. However, we will focus on a few major KPIs for brevity. In the following, we describe the results that can be observed within the setup.

A. The impact of channel variation on throughput

In order to gain insights on how channel variations affect the throughput and latency of the system, we simulated channel occupation for both LTE and WiFi. We plot the results for LTE PHY in Fig. 2 and for the WiFi PHY in Fig. 3. Over the course of the two experiments, we degrade the channel quality in each phase significantly by increasing the transmission power of the WiFi interferer and by lowering the PRB allocation as well as the used modulation and coding scheme (MCS) in LTE. As expected, we observe that the throughput in both experiments drops significantly as soon as the channel gets degraded. Interestingly, while the WiFi PHY is able to handle phase 2 fairly well, it completely fails in phase 4, where the interferer is turned to maximum throughput. Based on the results of this experiment, we devise a low-complexity multi-RAT algorithm that is able to perform well even under such stressful network settings.

B. Multi-RAT scheduler

Our simple threshold-based multi-RAT scheduler sheds light on the impact of low-layer procedures on higher-layer protocols, e.g., TCP. In order to show its capabilities, we ran another experiment in the same environment as in IV-A and let the scheduler decide at run-time which interface to use. We plot the achieved average throughput and delay in Fig 4. Our results show channel variation has high impacts on the performance of higher layer protocols (TCP in this experiment), and leveraging even simple RAT selection strategy to account for such

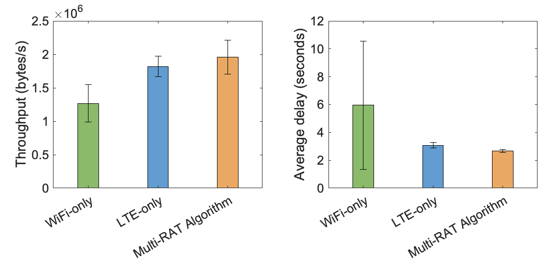

Fig. 4: Latency and jitter under different schemes

variations can significantly reduce the delay/jitter experienced by the applications as well as increase the throughput.

V. Conclusion

Our poster provides a first full-stack and real-time experimental study of multi-RAT systems. In particular, we have shown how selection of RAT impacts the overall network capacity. Furthermore, we demonstrated the effect of RAT selection and rate imbalance between RATs on the higher layers of stack, such as TCP congestion control mechanism. The main challenges we faced were: (i) Measuring the KPIs at the UE; (ii) Feeding the measured KPIs back to the eNB; and (iii) Implementing a RAT-scheduling algorithm based on the received KPIs at the eNB. The outcome of this experiments can be used as design guideline for future multi-RAT systems in particular after integration of millimeter-wave radio which will increase the rate imbalance even further.

VI. Acknowledgments

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