End-to-end simulation of 5G mmWave networks

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ABSTRACT

MmWave communications will be a fundamental enabler for the next generation of cellular networks (5G). However, in order to fully exploit the resources available at the physical layer, a smooth interaction with all the other layers in the protocol stack and the nodes in the network is needed. System level simulators are valuable tools that can be used to test the performance of new network architectures and designs. NYU Wireless and the University of Padova have recently developed a simulator for mmWave networks, based on ns–3, and obtained important insights on the performance of a mmWave cellular network. The framework and the main results will be briefly summarized in this work.

1 INTRODUCTION

Millimeter wave (mmWave) technology is expected to play a central role in the 5th Generation (5G) of cellular systems, because of its potential for multi-gigabit-per-second throughput and low latency over wireless links [4]. Recently, there has been considerable progress in understanding the mmWave channel and physical layer techniques such as MIMO and beamforming [8]. However, in order to fully exploit the huge amount of resources available at mmWave frequencies, all the layers of the protocol stack must be carefully designed, either in the Radio Access Network, in the core network, or at the endpoints of the communication.

Discrete-event network simulation is an essential tool for the research and development of end-to-end, cross-layer architectures and algorithms. ns–3 is a widely-used system level simulator that implements a wide range of protocols at different layers of the stack, and it is also used to simulate LTE network [2]. Inspired by the design of the LTE module, we implemented a framework to model end-to-end mmWave networks, which can be used to evaluate cross-layer solutions and the performance of end-to-end architectures. A complete description is given in [5]. A simplified class diagram is reported in Figure 1, where we highlight which are the classes implemented from scratch for this project, and which are the components of ns–3 which were integrated with the mmWave module. In particular, we designed new channel, physical and MAC layers, and adapted the classes of the LTE module for the upper layers of the protocol stack.

2 FRAMEWORK OVERVIEW

The ns–3 mmWave module combines different elements to simulate realistic end-to-end mmWave networks:

- The channel model is a key feature of system level simulations, since the accuracy of the results depends on that of the channel model. We provide state-of-art 3GPP channel models for frequency spectrum above 6 GHz [11], as well as the possibility to use traces from real measurements or ray-tracing softwares. However, given the modular nature of the simulator, new channel models can be easily integrated.

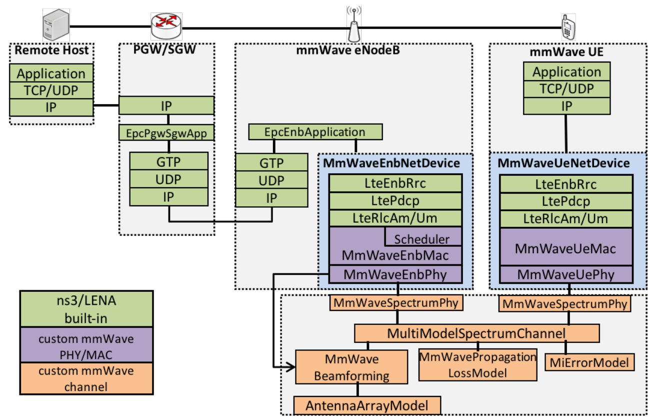

Figure 1: Class diagram for the end-to-end mmWave module.

- The PHY and MAC layer classes are parameterized and highly customizable in order to be flexible enough for testing different designs and numerologies. A Time Division Duplexing scheme is assumed, with OFDM as modulation. The TDD design is flexible, with slots that can be adapted to the size of the data that needs to be transmitted, as we propose in [3]. We also provide several schedulers (round robin, proportional fair, etc), designed in order to work with the flexible TDD allocation.
- The mobile devices can connect to both 4G LTE and 5G mmWave base stations, allowing to test inter-RAT protocol harmonization at the PDCP layer and compare different handover strategies based either on single or dual connectivity. In order to increase the realism of the simulator, the core network model of the LTE module is extended and it accounts for the transmission of control packets from the base stations to the Mobility Management Entity (MME). In this way, it is possible to compare locally coordinated handover solutions against those coordinated by the MME.

3 POSSIBLE RESULTS

Thanks to the flexibility and the realism of this framework we were able to collect several insights on the performance of mmWave cellular networks. In particular, we focused on two areas:

- The interplay between TCP and mmWave links. We showed that the interaction of the most used transport protocol in the internet (TCP) with mmWave link could be suboptimal, leading to an inefficient utilization of the bandwidth offered by the physical layer and very high latencies in Non

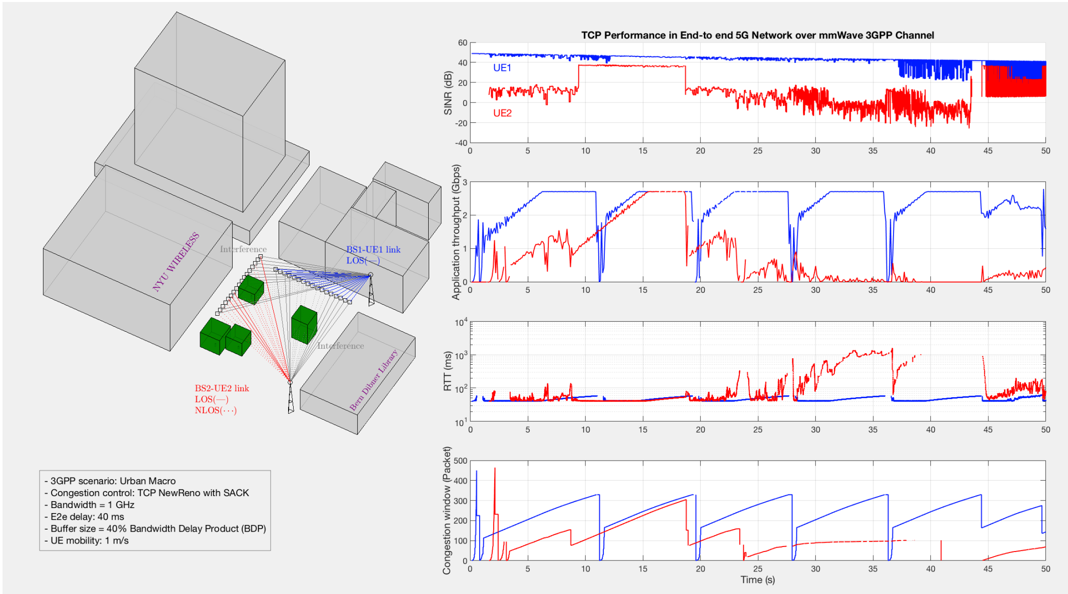

Figure 2: End-to-end simulation of TCP over mmWave in a realistic scenario.

Line of Sight scenarios [7, 9]. An example of end-to-end simulation of TCP using the mmWave framework is shown in Figure 2. This scenario models the NYU Brooklyn campus, with two mmWave base stations deployed in the main square and two test users that are shadowed by trees and obstacles while moving. We show the trend over time of the SINR, the throughput, the round trip time and the congestion window. We also studied cross-layer approaches to improve the end-to-end performance, both in downlink (piggybacking on TCP ACKs) [10] and in uplink (tuning the congestion window at the UE side) [1]. We analyzed the performance of Multipath TCP over combined mmWave and LTE links [7], using the integration with the Linux Kernel provided by DCE.

- The performance of mmWave networks in mobility scenarios, with the first end-to-end study of handover and dual connectivity in mmWave cellular networks [6].

These are only few of the possible results that can be obtained with the ns–3 mmWave module, which can be used, for example, to simulate beam tracking schemes, resource allocation strategies, MAC and physical layer designs, end-to-end performance of applications and other transport protocols, core network architectures.

4 CONCLUSIONS

In this work we presented the latest version of the ns–3 module for mmWave networks developed by NYU Wireless and the University of Padova, which is extensively described in [5]. We introduced the main features of the simulator and the results we obtained so far, highlighting which are the possible areas in which this tool can be used. As future work, we plan to keep increasing the functionalities of the module, adding, for example, more realistic beam tracking techniques.

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