DI5GUISE: A highly Dynamic Framework for Real-Time Simulated 5G Evaluation

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***Abstract*—As the next generation of cellular networks (5G) nears deployment, autonomous smart nodes, such as Internet of Things *(IoT)* and vehicular devices, are already being developed to utilise the increased throughput and improved resiliency of 5G. Evaluating the real-time scheduling and impact of these new devices and their underlying network protocols within the air-interface of 5G is no small feat. This is typically due to high 5G air-interface hardware costs and unrealistic real-time delivery rates.**

In this short paper, we expand upon the mmwave (5G) module for NS-3 and present *DI5GUISE*: a configurable and highly dynamic real-time simulated testbed framework, through which the impact of these nodes can be investigated. We utilise real-time video delivery as an example of high throughput demand applications. The experimental results illustrate that even on low cost commodity hardware, such as Raspberry Pis, over 80Mbps per client in real-time streaming of 4K content can achieve.

I. Introduction

As we progress towards the deployment of the next generation of cellular networks, known as 5G. the promise of increased physical data rates, low-latency, resiliency and reliability is offset against the expected increase in demand for: network resources, bandwidth and context-dependent services [1]. This is especially true for autonomous smart nodes, such as IoT, drone and vehicular devices. Providing realistic evaluation scenarios through which the scheduling decisions at the base stations as well as the routing and packet delivery of content from the devices can be analysed and assessed can prove to be difficult. Numerous options are available for simulating 5G networks, such as Matlab (5G toolbox and Simulink), Omnet++ (SimuLTE), Riverbed (OPNET) and the open-source discrete-event network simulator NS-3 (mmwave). Typically (in most cases), these simulators only offer off-line computation, non real-time simulation and require a license, which are limiting factors.

In this short paper, we present *DI5GUISE*, a multi-client mmwave (5G) extension to our previous award-winning demo "D-LiTE: A platform for evaluating DASH performance over a simulated LTE network" [2]. In our previous work we released a testbed platform offering real-time streaming of adaptive video between physical elements over a simulated LTE network (utilising the open-source NS-3 LENA project [3] for the LTE codebase).

The goal of *DI5GUISE* is to provide a framework to the research community which utilises the full-stack 5G infrastructure of the NS-3 mmwave module [4] and offers realtime evaluation coupled with throughput rates in excess of 80Mbps per node. While these rates are low in comparison to the advertised rate of mmwave in NS-3 (in excess of 450Mbps), they do offer an initial tentative step in the right direction with respect to high throughput real-time delivery.

II. Framework Overview

DI5GUISE at its core is a fully modifiable and extendable NS-3 based tool. DI5GUISE provides a real-time hybrid physical and simulated infrastructural framework to evaluate both high throughput applications and large scale low-rate devices in a 5G network. This is achieved by linking physical hardware (or virtualised hosts) at both the 5G client interface(s) and at the simulated 5G packet gateway *(PG)* of the evolved packet core *(EPC)*. We utilise brctl (Ethernet bridge configuration), tunctl (TUN/TAP network interface) and ifconfig to link the NS-3 simulated nodes (using the NS-3 Tap Bridge model) to the physical PC network card(s) to permit packet routing to/from physical hardware through NS-3.

Over 70 different configuration choices are available in *DI5GUISE*, and these include modification options for Nodes (base-stations/clients): # of nodes, distance(s) between nodes, # of resource blocks and TxPower - Mac Layer: request, radio link, transportation block and Transmission Time Interval *(TTI)* - as well as options for Scheduling, pathloss and mobility models, to name but a few.

To increase overall packet delivery rates we optimise how the packets flow over the network packet core within NS-3. Typically real-time packets in the PG of the EPC of 5G only flow over the simulated air-interface to the IP address of the 5G client(s). To route the packets beyond the client(s) to the IP address of the physical hardware *(PhyH)*, requires modification to the destination IP of every packet at the EPC (writing from PhyH IP to the 5G client IP) and again at the 5G client (rewrite back to the PhyH IP). This causes noticeable transmission delay especially for high throughput real-time applications. In *DI5GUISE*, we optimise the IP range of the clients (5G and PhyH) and increase the network mask to achieve unmodified IP routing.

We offer a modified version of the TTI mac 5G scheduler (which generates the achievable wideband Channel Quality Indicator (CQI) rate for each attached active client in the mmwave evaluation) illustrating how scheduling decision at the base station varies the achievable throughput allocated per client. The code is commented and easily ported to the other schedulers in the 5G mmwave module.

Full details of the optimised changes made to NS-3 and mmwave, and the hardware and software steps required to install and use *DI5GUISE* are available on our website [1].

III. Experimental Results

In this section, we present evaluation and throughput result for our *DI5GUISE* framework. 4K adaptive video streaming [5], [6] is used to illustrate an example of a high throughput demanding application. In our testbed, the video clients are physical Raspberry Pi 2 devices, with a network server containing the video content and a Dell PowerEdge PC, running Ubuntu 16.04, containing the NS-3 simulated 5G network. While a powerful PC containing *DI5GUISE* will provide higher throughput rates, we have utilised low-cost laptops with similar evaluation results for 2 to 3 clients (*note:* the greater the number of clients, the higher transmissions and processing power needed). Note: adaptive video is bursty by nature and as such the experimental results will reflect varying levels of throughput.

In our evaluation, the clients increase in distance from the 5G base station (beginning at 25m). We utilise a rural macro channel scenario (RMa), with a 3GPP propagation loss model (3GPPprop), a TTI mac scheduler and a simulation time of five minutes. Configuration files for this scenario are available on the website. Figure 1 illustrates the variation in throughput of two clients streaming over 5G, while Figure 2 presents the variation for four clients streaming over the same topology.

As can be seen in Figure 1, both clients are allocated varying level of throughput, by the 5G tti scheduler, over the course of the 5 minutes of simulation time, and both achieve in excess of 80Mbps. Client 2 achieves the highest rate overall (nearing 90Mbps). In Figure 2, we observe a considerable increase in the throughput variation. This is due to the burstyness of the video traffic as the clients compete for the highest quality, but also due to the computational demand of the packet messages being processed by NS-3. Most clients receive in excess of 10Mbps overall, with spikes of 60-70Mbps. While 4K streaming is used as an illustration, large scale low-throughput IoT devices could utilise our *DI5GUISE* framework with little modifications required for either a larger number of clients or for routing through a similar number of IoT gateway nodes.

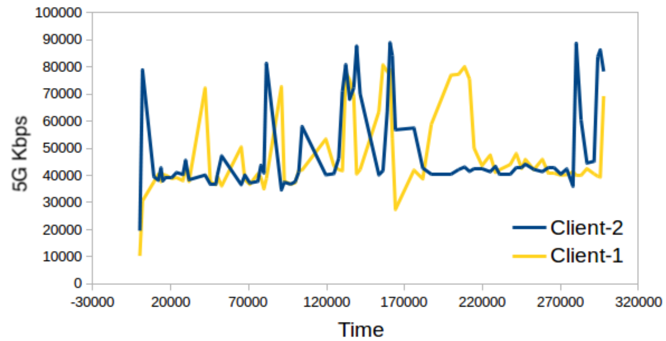

Fig. 1. Throughput variation of two clients streaming over 5G

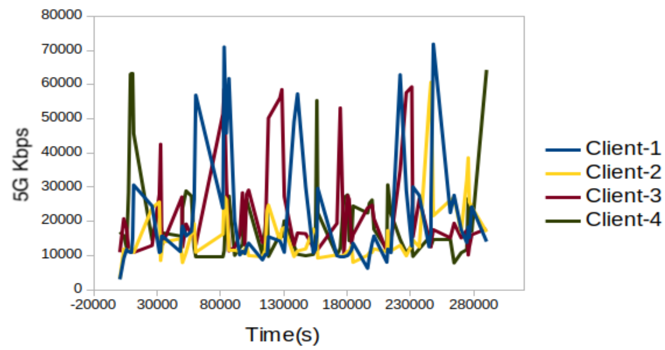

Fig. 2. Throughput variation of four clients streaming over 5G

IV. Discussion and Conclusion

Discussion: While *DI5GUISE* is a step in the right direction, more work is needed to optimise both software and hardware to reach the mmwave advertised scheduling throughput (in excess of 450Mbps) in NS-3. A valid option to increase throughput is to synchronise the distribution of NS-3 network messages between nodes in the topology to different processors on the host machine, known as Message Passing Interface (MPI). Unfortunately, this option in NS-3 is currently non real-time, and as such is the focus of the next iteration of *DI5GUISE*.

Conclusion: In this paper we presented *DI5GUISE*, a configurable and highly dynamic low-cost real-time simulated framework for large scale 5G evaluation. Our 4K adaptive video example illustrated the efficiency of *DI5GUISE* when evaluating competing high throughput demand applications.

[1] http://www.cs.ucc.ie/misl/research/software/di5guise

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