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XXXV Cycle

Hardware acceleration for 5G

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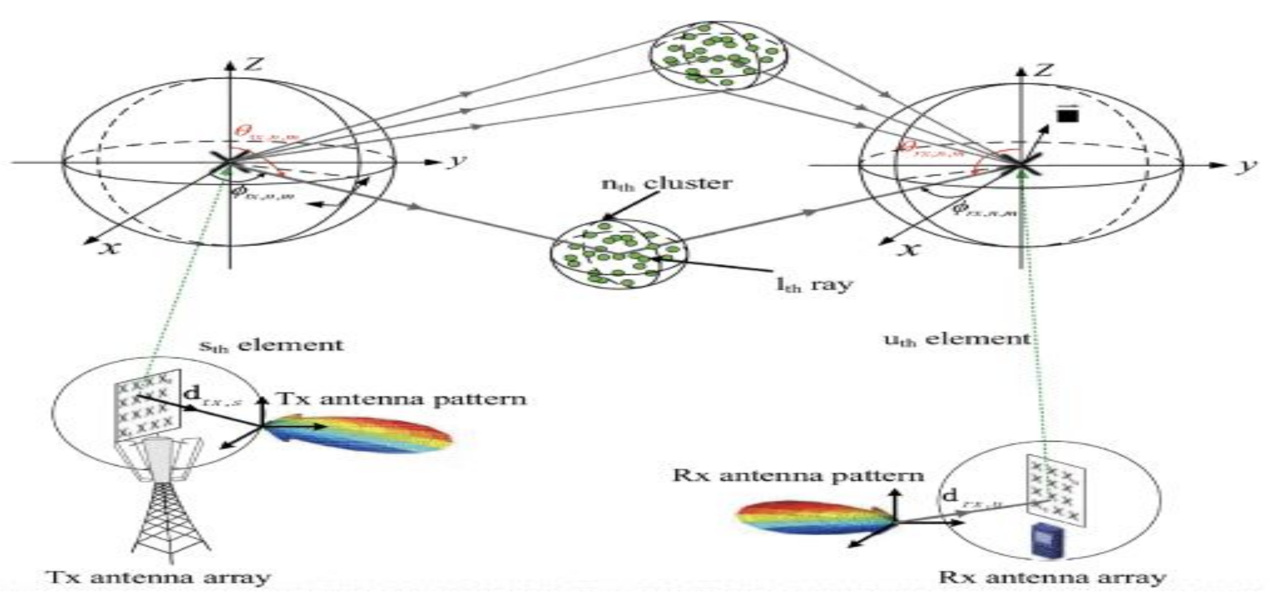
Research context and motivation

- While designing a wireless communication system, it is crucial to understand the nature of the wireless channel involved in communicating between two ends of the link.
- Channel model simulation is vital to accurately model the channel for the design and assessment of fifth generation new radio (5G NR) and beyond wireless networks.
- To obtain a realistic representation of the propagation effects, thousands of radio frequency (RF) parameters need to be adjusted.
- Parameter recalculation is needed even after the deployment, whenever the network configuration changes (i.e., the number or position of antennas change).
- Geometry-based stochastic models characterize channels in simulation environments.
- Channel modelling is required to understand various impairments such as attenuation, multi-path fading, and time variations in the channel.



Addressed research questions/problems

- Channel simulators are used to model the routing protocol performance, traffic flows and evaluate the efficiency of the communication system using real-life parameters in a virtual environment. These simulators enable the designing, testing, and optimization of systems without conducting time consuming and expensive field trials before actual system deployment.
- Multiple-Input and Multiple-Output (MIMO) systems are popular with fifth-generation networks since they assist increase network capacity and energy efficiency.
- MIMO systems incorporate large antenna array and multi-path, leading to improvement in the system capacity and decreasing errors.
- Fast fading coefficients model the fluctuating behaviour of the wireless channel due to changes in the user equipment (UE) movement or multipath scattering.
- Impulse response of multi-path fast fading model having *N* clusters and *M* multipaths, for ray *m* in cluster *n,* UE antenna element *u*, and base station (BS) antenna element *s* is

$$H^{\mathrm{NLOS}}_{u,s,n,m}(t)=\sqrt{\frac{P_n}{M}}\begin{bmatrix}F_{rx,u,\theta}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\\ F_{rx,u,\phi}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\end{bmatrix}^T\begin{bmatrix}\exp\left(j\Phi^{\theta\theta}_{n,m}\right) & \sqrt{\kappa_{n,m}^{-1}}\exp\left(j\Phi^{\theta\phi}_{n,m}\right)\\ \sqrt{\kappa_{n,m}^{-1}}\exp\left(j\Phi^{\phi\theta}_{n,m}\right) & \exp\left(j\Phi^{\phi\phi}_{n,m}\right)\end{bmatrix}$$
$$\begin{bmatrix}F_{tx,s,\theta}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\\ F_{tx,s,\phi}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\end{bmatrix}\exp\left(j2\pi\frac{\hat{r}^T_{rx,n,m}.\bar{d}_{rx,u}}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}^T_{tx,n,m}.\bar{d}_{tx,s}}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}^T_{rx,n,m}.\bar{v}}{\lambda_0}t\right)$$

- And the combined impulse response for each transmitting and receiving antenna element pair is

$$H^{\mathrm{NLOS}}_{u,s}(\tau,t)=\sum_{n=1}^{2}\sum_{i=1}^{3}\sum_{m\in R_i}H^{\mathrm{NLOS}}_{u,s,n,m}(t)\delta(\tau-\tau_{n,i})+\sum_{n=3}^{N}H^{\mathrm{NLOS}}_{u,s,n}(t)\delta(\tau-\tau_n)$$

- Accurate 5G channel model simulations require very high computational effort and very long time to execute on general purpose processors.
- Hardware acceleration of such functions is desired
    - to speed up the execution
    - reduce the simulation time
    - reduce energy consumption

Submitted and published works

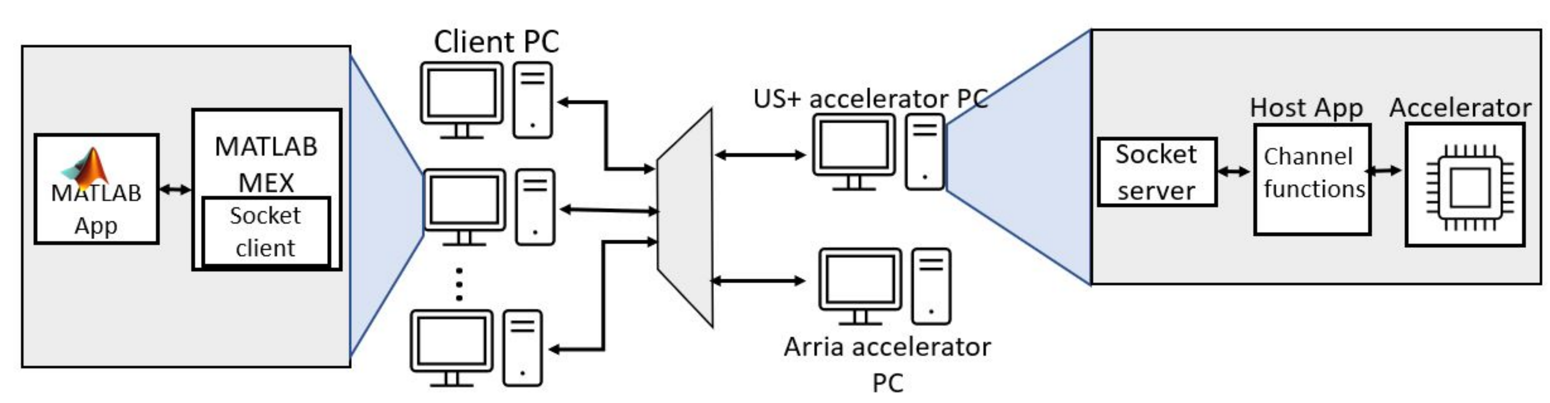
- (Submitted) Shah N.A. , Lavagno L., Lazarescu M. T., Quasso R., and Scarpina S., "*FPGA Acceleration of 3GPP Channel Model Emulator for 5G New Radio*", IEEE Access

Novel contributions

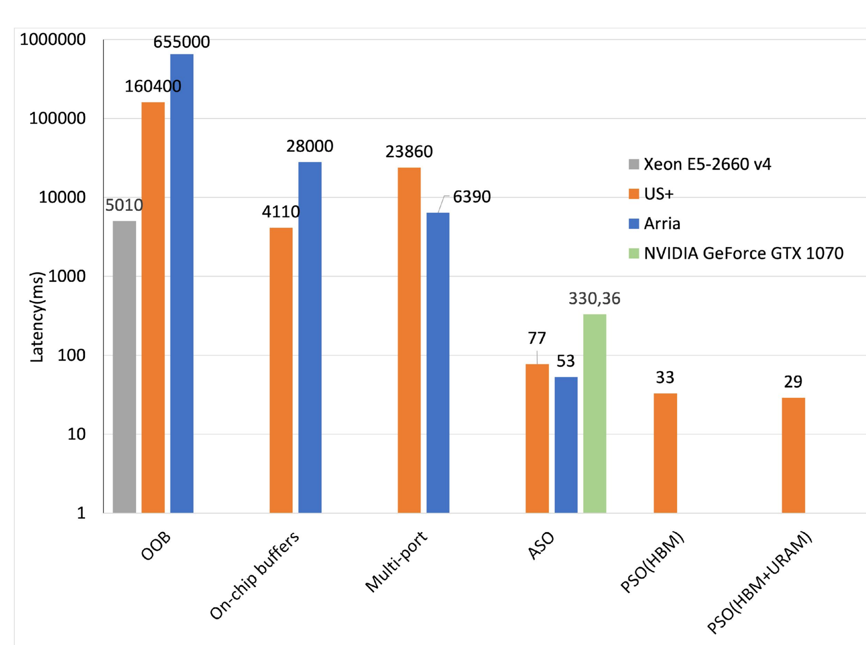
- This work exploits the **accuracy and generality of the 3GPP GBSM** to study the evolution of the radio standard and to maximize the planning quality of mobile networks by means of fast simulation tools, leveraging advanced **methods and optimizations for acceleration on FPGA platforms**.
- This work investigates the use of efficient high-performance FPGAs for **accelerating the channel model in radio link simulators** by means of different optimizations .
- The **reduction of the energy per computation** is analyzed compared to implementations on CPU and GPU platforms.
- The accelerated channel model is then **integrated within the MATLAB-based simulation** system via a socket-based client/server architecture.
- Finally, we analyze **the effort required when targeting the FPGA platforms** using High-Level Synthesis (HLS) tools.

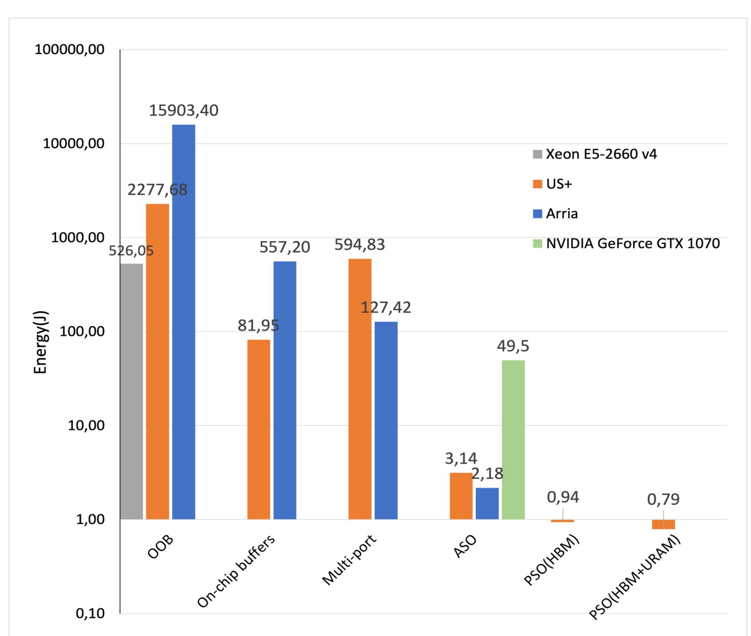
Adopted methodologies and results

- **System architecture**



- **Achieved Latency** (left) and **energy consumption** (right) after the adoption of different optimization strategies.





Future work

- Extending the channel model capabilities
    - multiple simulations in parallel using multi-threaded application
    - multiple on-chip compute units to increase throughput
- Acceleration of adjacent blocks in 5G simulators to reduce data-transfer using host-bypassing.

External Research Activity

- Inria-DFKI European Summer School on A.I. (IDESSAI 2022)

List of attended classes

- 01UJBRV – Adversarial training of neural networks(1/7/2020, 3 credits)
- 01UJRIU – Computing Paradigms for Error-Tolerant Applications(17/4/2020, 5 credits)
- 01TVUQW – Embedded Electronic Systems for AI / ML(7/2/2022, 6 credits)
- 01UNRRV – Entrepreneurship and start-up creation(31/5/2021, 8 credits)
- 01SCSIU – Machine learning for pattern recognition(19/10/2020, 4 credits)
- 01MNFIU – Parallel and distributed computing(22/7/2020, 5 credits)
- 01DUCRV – Principles of digital image processing and technologies(22/7/2022, 5 credits)
- 01QSCIU – Reconfigurable computing(20/7/2020, 4 credits)
- 01QORRV – Writing Scientific Papers in English(26/3/2020, 3 credits)
- 01RESRV – Public speaking(11/7/2022, 1 credit)
- 08IXTRV – Project management(11/7/2022, 1 credit)