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End to End Power Consumption Measurements for User Traffic Streams in a 5G Network

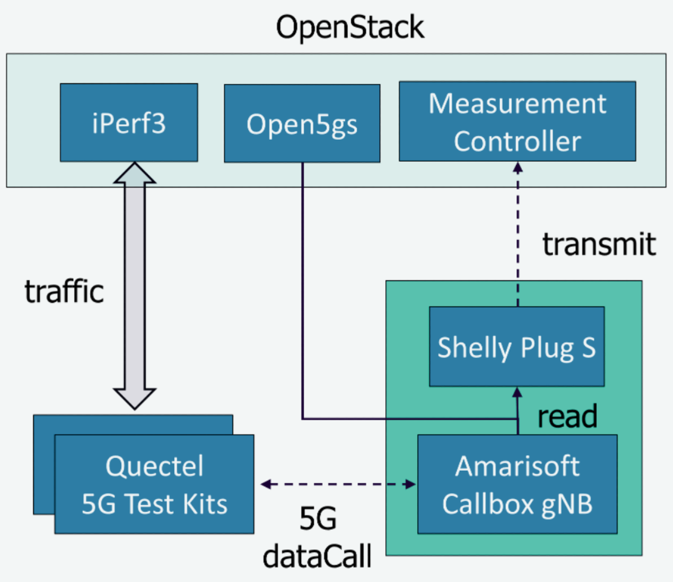
Energy consumption in information and communication technology (ICT) systems, along with the associated carbon emissions, has been steadily increasing due to the rise of digitalization and artificial intelligence (AI). This analysis focuses on the power consumption of a 5G networking infrastructure, which is the energy intensity per unit time.

Objectives

The main objective of this work was to develop a measurement and attribution approach in a 5G system to assess the power consumption at the network function or individual user level, such that this information can be used to minimize service power consumption or incentivize end-users to decrease their power use. This work is split in three parts: (1) the radio access network (RAN), where we focus on measuring power consumption of physical RAN nodes, and the (2) core network, where we focus on the power consumption of virtualized network functions (e.g. UPF) operating in cloud environments and (3) work on minimizing the service power consumption using modeling and reinforcement learning.

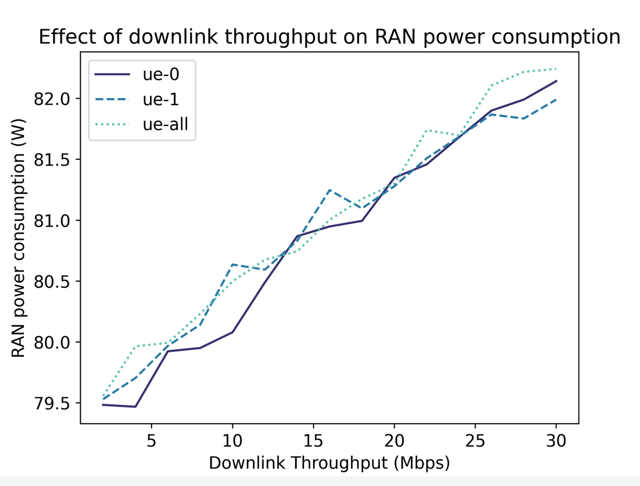
RAN setup - Physical Equipment Measurement

One or two Quectel 5G Test Kits initiate a downlink data stream from 2 to 30 Mbps (standalone – UE-0/UE-1) or 1 to 15 Mbps (joint – UE-all), with increment of 2 Mbps (standalone) or 1 Mbps (joint). The Shelly Plug S smart meter reads the total EC of the Amarisoft Callbox each second, for a duration of 10 minutes, while each experiment was repeated 30 times. The average power of the Amarisoft CallBox is depicted in the graph below depending on the total downlink throughput, with 79 W EC at zero load (idle traffic condition).



Attributed power per UE:

$$P_{ue} = \frac{T_{UE}}{T_{total}} \times P_{Total}$$



Results:

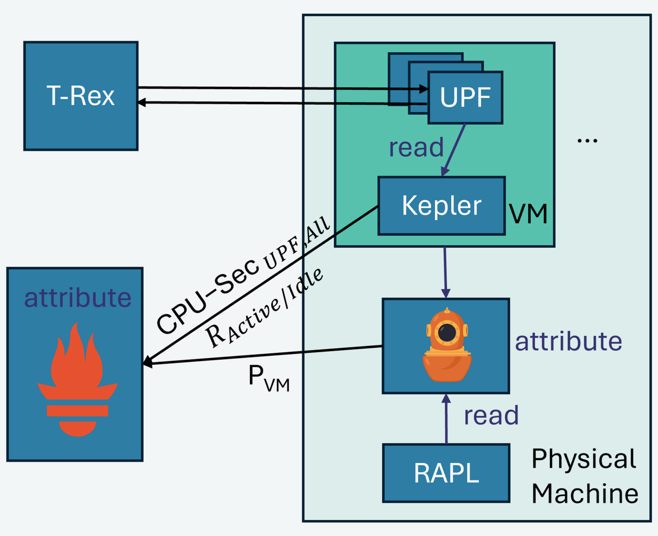
- A linear relationship is observed between the effective throughput and the power consumption.
- There is no power consumption overhead from serving 2 individual traffic streams simultaneously.

Core setup - Virtual Function Attribution

Traffic generator (Trex) was used enabling higher throughputs and more traffic variability. The primary purpose was to develop an attribution approach that can work on virtualized/cloudified infrastructure. We do that by combining measurements from the compute node, VM, and the Open5GS UPF container.

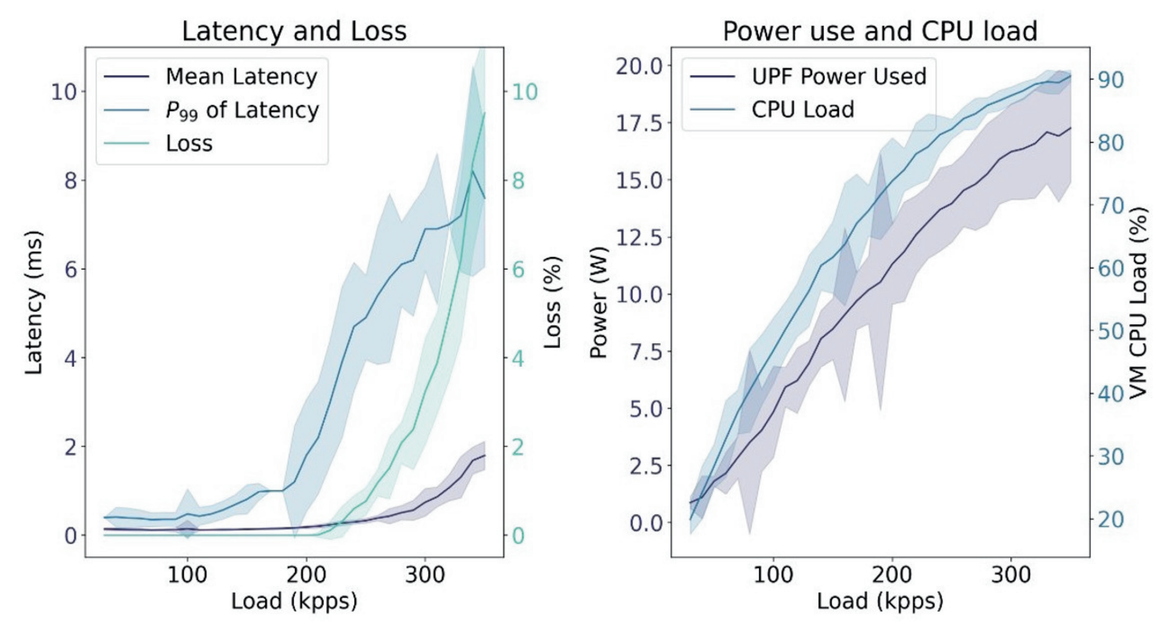
Attributed power per UPF:

$$P_{UPF} = \frac{CPU\text{-}Sec_{UPF}}{CPU\text{-}Sec_{All}} \times R_{Active} \times P_{VM}$$



Results:

- To get the correct power attribution for a virtualized network function, information from the compute node is needed. Power consumption of the UPF scales proportionally to the traffic load/CPU load. The power consumption overhead of serving multiple traffic streams is limited.



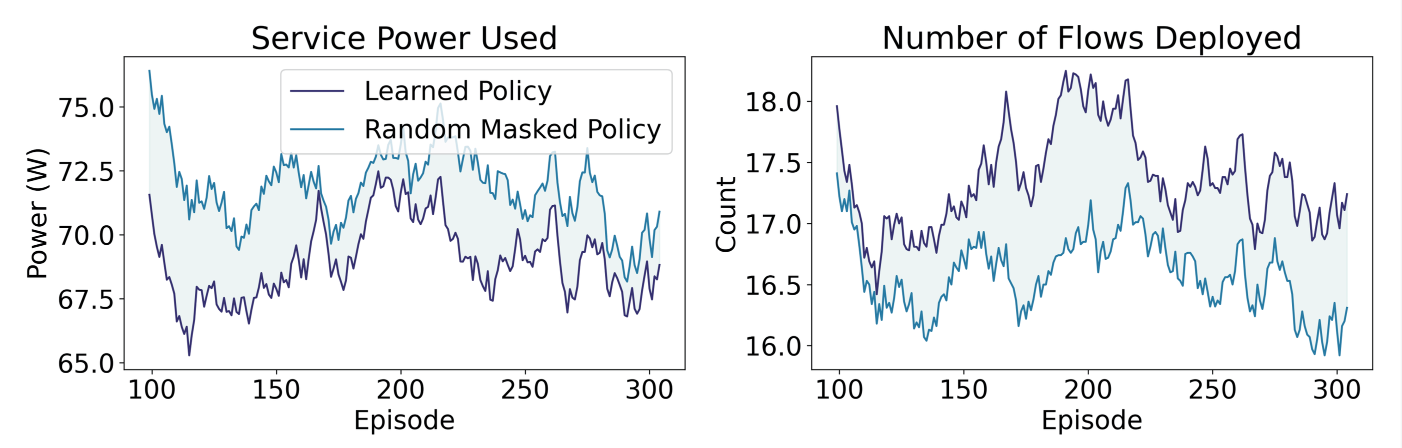
Minimizing Service Power Consumption

Double DQN network with NoisyNet(s) was used to distribute user network flows while minimizing IDLE+LOAD based power consumption on a 50-node edge compute infrastructure:

$$\min \sum_{n=0}^{N} P_{n,IDLE} + P_{n,LOAD}$$

Results:

- The algorithm improves the power consumption by 2-5% over the random masked baseline.
- Further improvements are being explored with Pointer Networks and REINFORCE.



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Key Takeaways

(1) Power consumption scales proportionally to the traffic load (2) Measuring power consumption in virtualized environments is complex and requires information from multiple domains (e.g., cloud providers, cloud tenants), (3) Power consumption can be attributed to users and used as an incentivization tool, (4) Power measurements and attribution provide a great foundation for minimizing service power consumption

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