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# Optimizing Energy Consumption and Resource Usage of 5G Edge and Core Network

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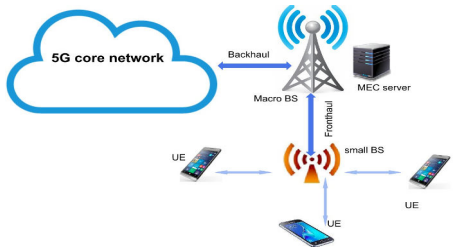
## Research context and motivation

- Improving energy efficiency at least by a factor of 3 is one of the KPIs set by 3GPP
- Optimized use of compute and network resources is vital to achieve this goal
- Optimization of compute resources can be achieved by using virtualization technologies where resources can be allocated and deallocated as needed

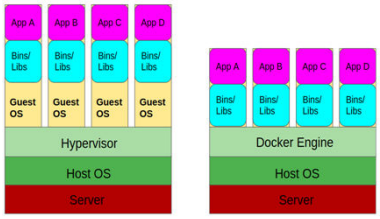



- Main focuses:
  - Power efficient virtualization in MEC, and
  - Characterizing control traffic of cellular MME with IoT support on real-world implementation of 4G network (eNB, UE and core network)
- Previous works have dealt with power efficient traffic allocation in SDN-based backhaul networks

## Addressed research questions/problems

### Energy Efficient Virtualization in MEC

- Virtualization is traditionally implemented with virtual machines until a container-based lightweight alternative was introduced recently
- The performance of virtual machines and containers are studied with various synthetic and real-world applications
- Workloads tested:
  - Synthetic workloads : CPU, memory, network and disk intensive workloads
  - Real-world workloads: FFserver - online video streaming server and Minecraft – online gaming servers




### Characterizing Delay and Control Traffic of the Cellular MME with IoT Support

- Massive-IoT is one of the main use cases of 5G
- Optimized Control Plane Cellular IoT Packet System (CIoT) standard is introduced in 5G to efficiently support MIoT's peculiar traffic pattern (long inactivity times and then synchronous transmission)
- Using 3GPP traffic model for Massive IoT, the inter-arrival time of bearer requests is:

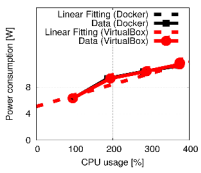
$$F_\beta(\tau) = 1 - e^{\lambda_\beta \tau}, \text{ where } \lambda_\beta = \frac{Q(1-e^{-1})}{T}$$

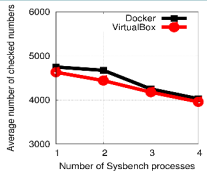
- Assuming the MME as the bottleneck among the EPC components and modeling it as M/D/1-PS queue, the latency at EPC is:

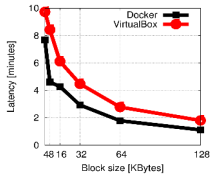
$$F_v(\tau) = \psi e^{-\gamma\tau} \text{ where } \psi = \frac{(1-\rho)(\lambda_\beta-\gamma)}{2\lambda_\beta(1-\rho)-\gamma\rho(2-\rho)}, \quad \rho = \frac{\lambda_\beta}{D}$$

- OpenAirInterface, software implementation of 4G network, is used to validate assumptions and characterize control traffic of Cellular MME with IoT support experimentally

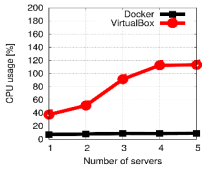
## Novel contributions

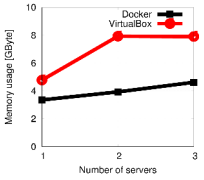


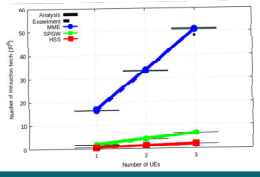




- Containers perform much better than VMs: synthetic applications (figures above) and real-world applications (figures below)
- The need to emulate hardware and installation of OS for each VM has resulted in the larger power consumption and latency in VMs
- Containers instead use the cgroups and namespace features of linux to control resource usage and for isolation, which lead to their better performance



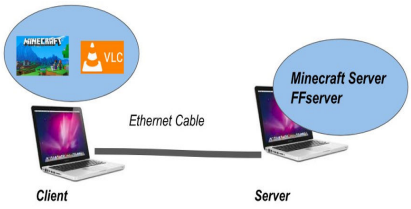



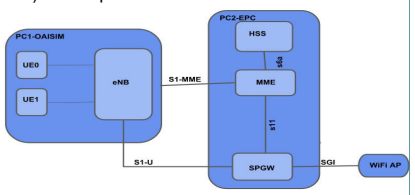

In characterizing control traffic of cellular IoT, we found that MME is the bottleneck and has deterministic job size (figure on the left)

## Adopted methodologies

- Synthetic applications: Sysbench for CPU test, custom Java application for Memory test, Iperf for network test and Flexible IO (fio) for disk test
- Real-world applications: Minecraft online gaming and FFserver video steaming open source servers
- Minecraft client with key stroke emulator, runs on a different machine than the server, connects to the server to play the game
- VLC clients, running on a different machine, request video streams from FFserver




- OpenAirInterface: used to characterize the control traffic of cellular MME with IoT support
- OpenAirInterface EPC implementation has three components: HSS, MME and S+P-GW
- OAISIM: simulation of EUTRAN (UE and eNB) from OpenAirInterface
- Valgrind: used to collect the number of CPU operations in EPC components




## Future work

- Use OpenAirInterface to study the delay characterization at the MME and verify the MME's processor-sharing behavior

## Submitted and published works


- Senay Semu Tadesse, Claudio Casetti, Carla Fabiana Chiasserini, Giada Landi, "Energy-efficient traffic allocation in SDN-based backhaul networks: Theory and implementation", IEEE Annual Consumer Communications & Networking Conference (CCNC), Las Vegas (USA), Jan. 2017, pp. 209-215
- Senay Semu Tadesse, Carla Fabiana Chiasserini, Francesco Malandrino, "Energy Consumption Measurements in Docker", IEEE Computers, Software, and Applications Conference (COMPSAC), Turin (Italy), July 2017, pp. 272 – 273
- Senay Semu Tadesse, Carla Fabiana Chiasserini, Francesco Malandrino, Casetti Claudio Ettore, "Assessing the Power Cost of Virtualization Through Real-world Workloads", IEEE International Symposium on Local and Metropolitan Area Networks (LANMAN), USA(Washington, DC)
- Senay Semu Tadesse, Carla Fabiana Chiasserini, Francesco Malandrino, "Characterizing the power cost of virtualization environment", Transactions on Emerging Telecommunication Technologies (July 2018)
- Christian Vitale, Carla Fabiana Chiasserini, Francesco Malandrino,Senay Semu Tadesse,"Characterizing Delay and Control Traffic of Cellular MME with IoT Support", ACM MobiHoc (July 2019)
- Christian Vitale, Carla Fabiana Chiasserini, Francesco Malandrino,Senay Semu Tadesse,"Characterizing Delay and Control Traffic of Cellular MME with IoT Support", IEEE Transactions on Mobile Computing


## List of attended classes

- 01QTEIU - Data mining concepts and algorithms ( 02/27/17, 4)
- 01RYHRV - Disruption Tolerant Networks: Routing Algorithms and Protocols (07/04/17, 6)
- 01LCPIU - Experimental modeling: building experimental data models ( 02/28/17, 6)
- 01QSAIU - Heuristics and metaheuristics for problem solving: new trends and so ( 05/11/17, 4)
- 01RQXRV - Pattern recognition and neural networks (didactics of excellence) ( 05/05/17, 8)
- 02LWHRV - Communication (02/16/17, 1)
- 08IXTRP - Project management (02/16/17, 1)
- 01RISIV - Public speaking (02/16/2017, 1)
- 01QORRV - Writing Scientific Papers in English (08/06/2017, 3)
- 01SWQRV - Responsible research and innovation, the impact on social challenges(07/11/2018, 4)
- cross-border doctoral workshops(19/09/2018, 1)
- Can a network learn? Machine Learning methodologies and applications for next generation networking (13/07/2019, 5)
- 01NYHOV - System and device programming(03/092019,10)

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