University of Amsterdam
Informatics Institute

Parallel Computing Systems

Empowering Sustainability: Energy Labelling of Digital Services in the Computing Continuum

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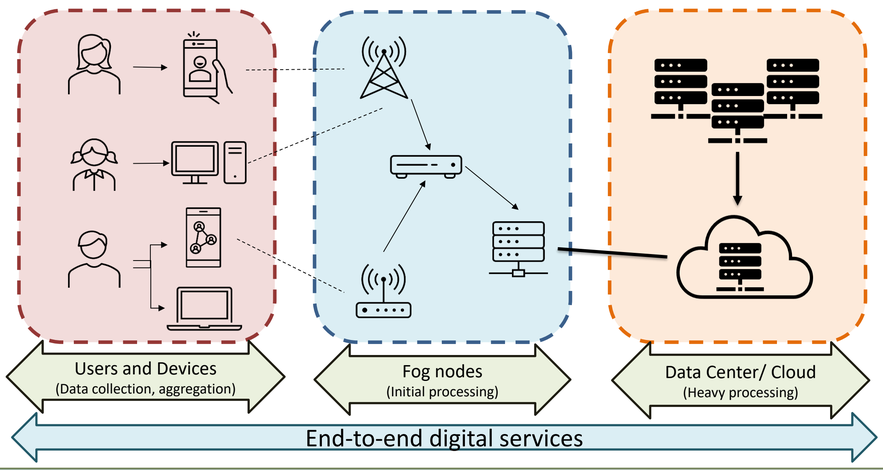
Digital services are vital for the economy → significant, rapidly-increasing energy cost → sustainability concerns.

Quantifying and assessing the energy consumption of digital services within the computing continuum is essential for improving their energy efficiency.

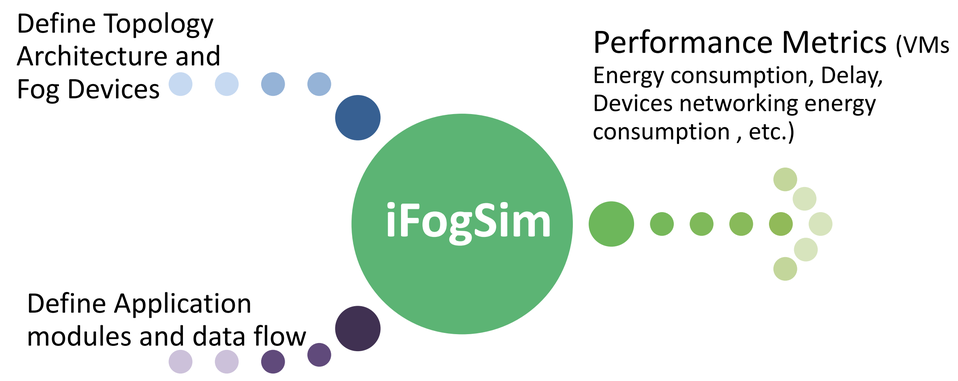
Computing Continuum

Scheduling in the Computing Continuum's **edge**, **fog**, and **cloud** layers affects **QoS** and **energy** use. Measuring energy consumption across the continuum is **challenging**; thus, **simulation** techniques are promising solutions.



iFogSim [1]

iFogSim models IoT and Fog environments, providing fine-grained performance metrics for system and application insights [1,2].



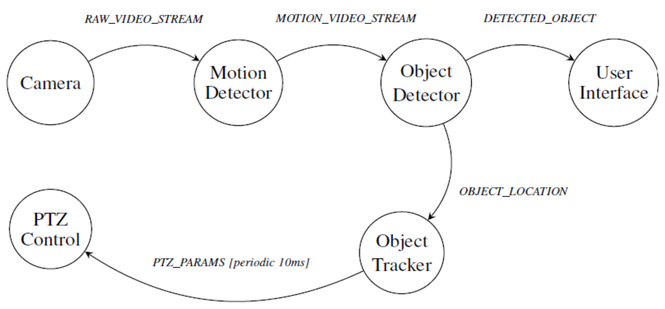
Simulation process in iFogSim.

We design and prototype a simulation-based ***energy labeling system*** that quantifies the energy footprint of digital services and makes it ***comparable*** and ***actionable***. This empowers ***stakeholders*** to understand their energy impact and make ***sustainable decisions***.

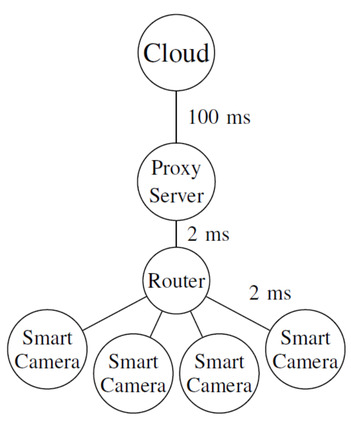
RQ1 End-to-End Energy Estimation [2,3] **RQ2** Multi Application Energy Modeling [3] **RQ3** Energy Labeling Framework [4]

- Application perspective energy report
- Networking energy consumption
  - Time-base and Flow-base model

Surveillance Application [1]



Continuum Architecture



- **Fine-grained** energy reporting for computation and networking
- Per-application energy analysis in **multi application** scenarios

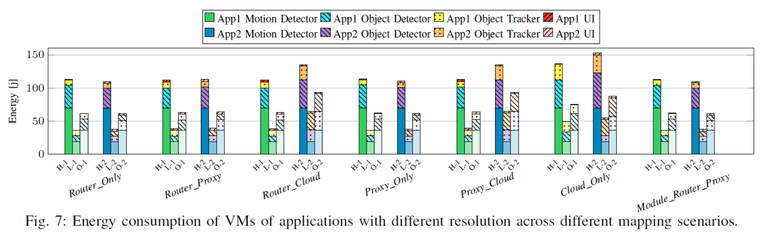


Fig. 7: Energy consumption of VMs of applications with different resolution across different mapping scenarios.

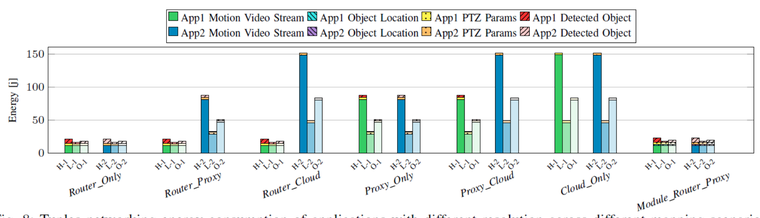


Fig. 8: Tuples networking energy consumption of applications with different resolution across different mapping scenarios.

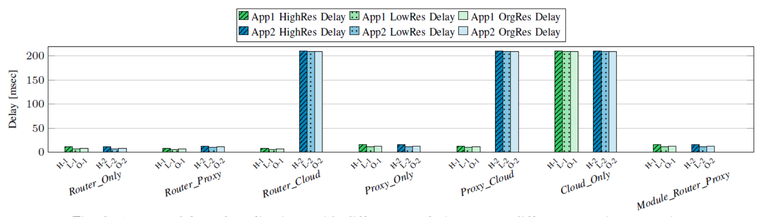


Fig. 9: Average delay of applications with different resolution across different mapping scenarios.

- Actionable energy labeling system
- Evaluating energy class of deployment scenarios
- Evaluating workload intensity impact

Labelling System and Recommendation information

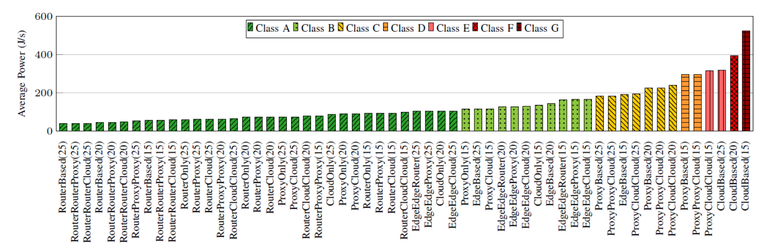


Fig. 4: Integrated Representation of Labeling Energy Consumption of Deployment Scenarios with different Workload Intensities

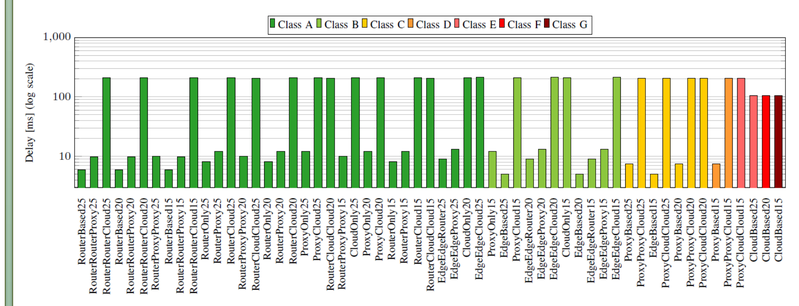


Fig. 7: Average Delay of Application across different deployment scenarios

Contributions and Outcomes

- Extended iFogSim to support:
  - **Fine-grained** application-level energy estimation.
  - **Multi-application** modeling in shared environments.
  - **Networking** energy integration.
- Developed the first simulation-based **energy labeling framework** for digital services.

Ongoing Work

- **Calibrating** the simulation framework using real energy measurements.
- Providing modeling **guidelines** to help users simulate their applications and continuum architecture.

GitHub

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[1] Gupta et al. (2017) A toolkit for modeling and simulation of resource management techniques in the internet of things, edge and fog computing environments. Software: Practice and Experience.
[2] Baneshi et al. (2023) Estimating the energy consumption of applications in the computing continuum with ifogsim. International Conference on High Performance Computing.
[3] Baneshi et al. (2024) Analyzing Per-Application Energy Consumption in a Multi-Application Computing Continuum . In The 9th International Conference on Fog and Mobile Edge Computing , FMEC.
[4] Baneshi et al. (2025) Empowering Sustainability: Energy Labeling of Digital Services Using Simulation. International Symposium on Cluster, Cloud and Internet Computing, CCGRID.