

Energy Profiling of OpenAirInterface5G Baseband Software

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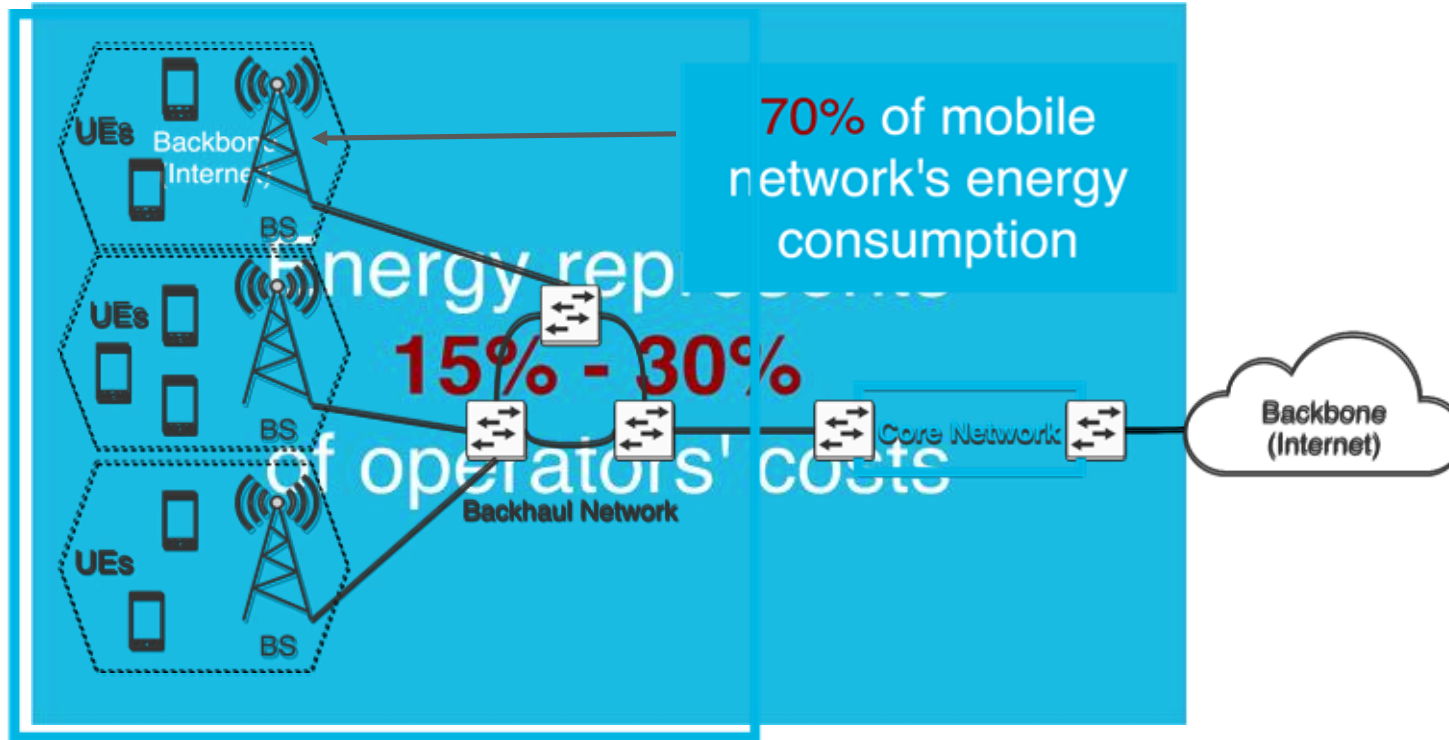
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The logo for Instituto de Telecomunicações, featuring a stylized blue and red 'it' monogram.
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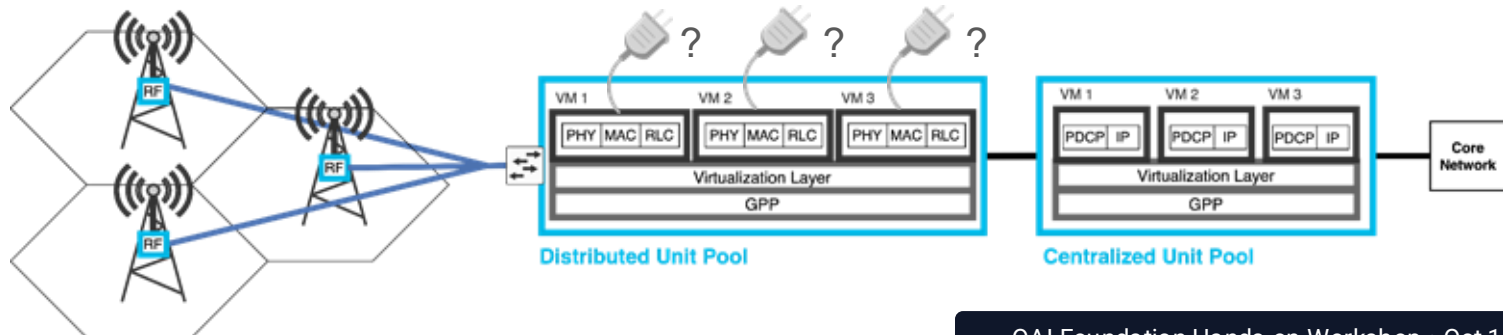
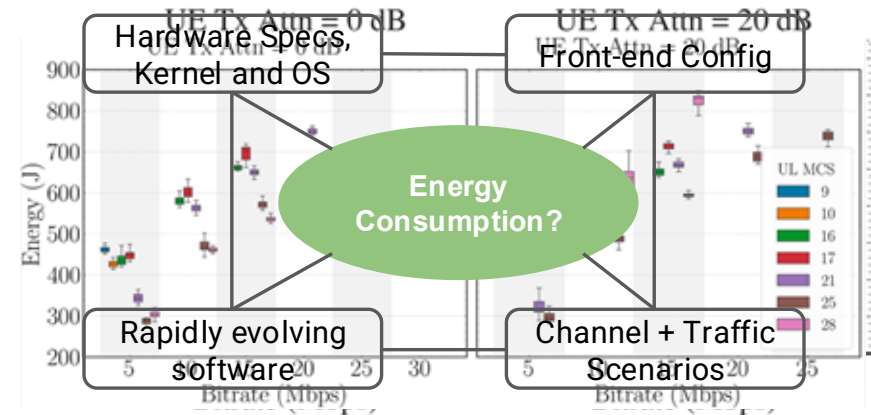
Base Stations consume $\approx 70\%$ of mobile networks' energy!



Radio Access Network

How can developers optimize BBU software for energy-efficiency?

- Virtualized BBUs → Software, general-purpose hardware
- *Why is it difficult to optimize BBU software for energy efficiency?* Energy behavior results from the interplay of many factors
- Developers need an **agile** methodology to evaluate software energy profiles across diverse scenarios



Solution: Use Hardware Events to Find Energy Hotspots

4-Step Framework

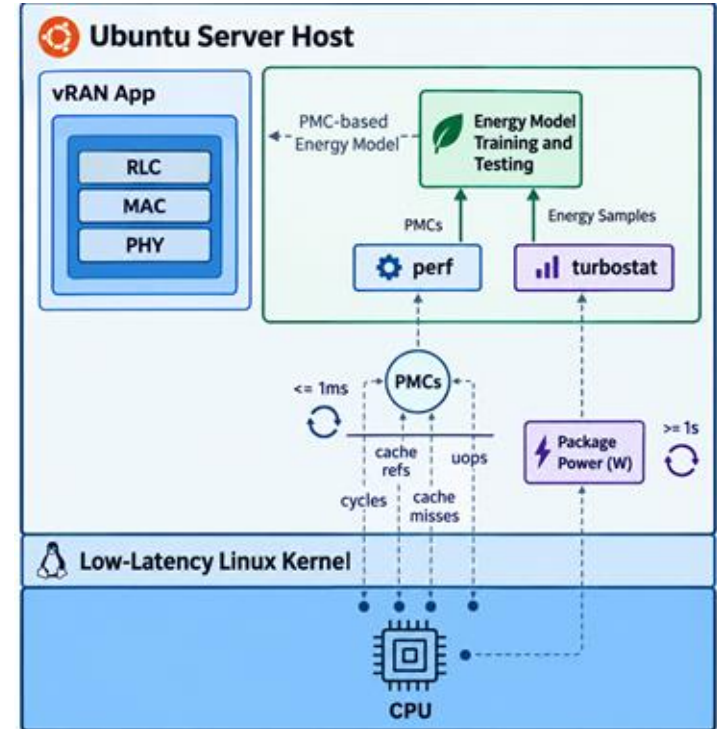
1. **Testbed Setup:** Minimal OS (server editions) to prevent competing processes
2. **Benchmarking:** Representative of real-world traffic & channel conditions
3. **Data Collection:** Collect **PMCs*** & stack traces via **perf**, plus CPU power via **turbostat**
4. **ML Analysis:** Feed parameters into ML pipeline to identify key energy predictors

Zero intrusion: No software changes required to capture parameters

Automated Process: Re-collect data seamlessly when software, hardware, or front-end configurations change

Broad Applicability: Flexible across various functional units (CUs, DUs)

* PMCs: Performance Monitoring Counters



Applying this approach to OAI software: the CU example

Benchmark

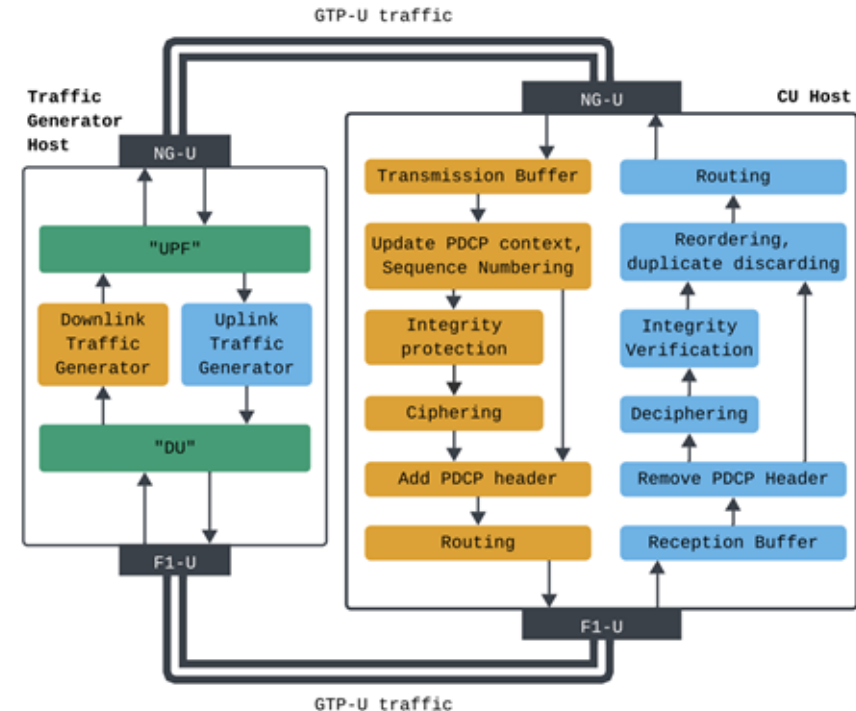
- Bitrates ranging from 8 to 512 Mbps in the UL/DL
- Varying packet sizes: 256B to 9000B (max PDCP SDU)
- Ciphering & integrity algorithms: Null / Snow3G / AES

Testbed & Execution Environment

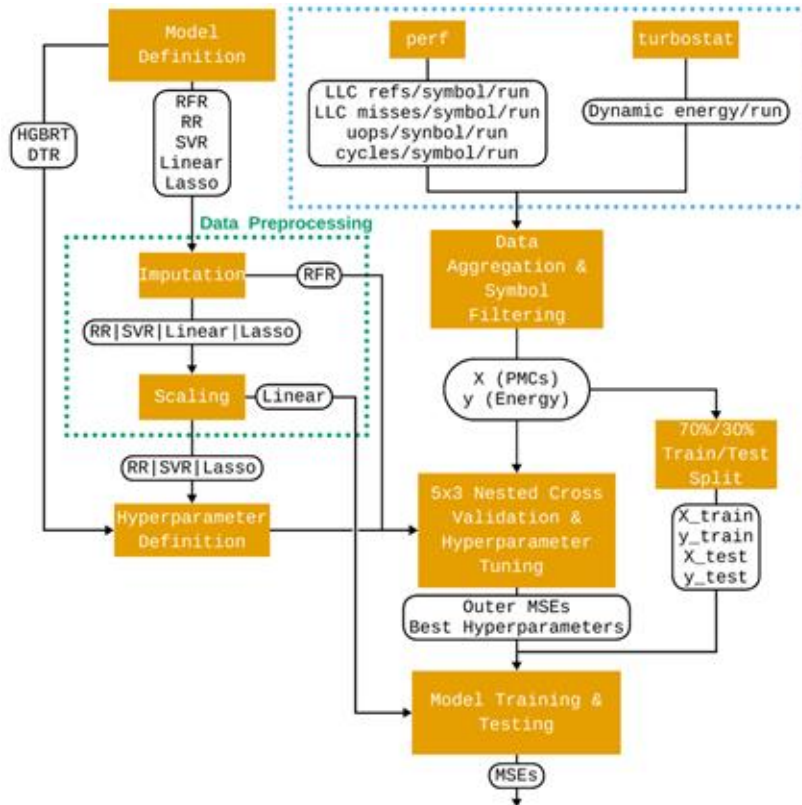
- CU runs Ubuntu Server 24.04.2 LTS with real-time kernel
- Scripts launched in the CU host with **perf** and **turbostat**
- Data collected over 60s intervals
- Synchronize the traffic generator host with the CU host

Energy & Event Profiling

- CPU energy measurements at package domain
- Sample cycles, cache misses, cache refs, uops



ML Modeling for Energy Hotspot Identification



Feature Importance Analysis

- Input parameters: PMC x Symbol pairs
- Output: Energy consumption (J)
- Decision Tree Regressor
- Feature Importance > 10%

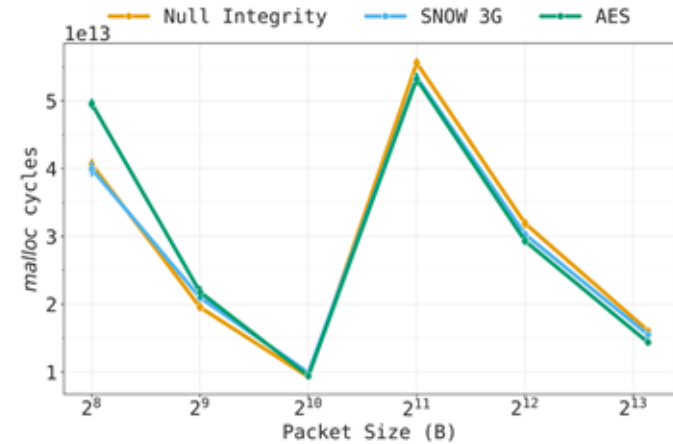
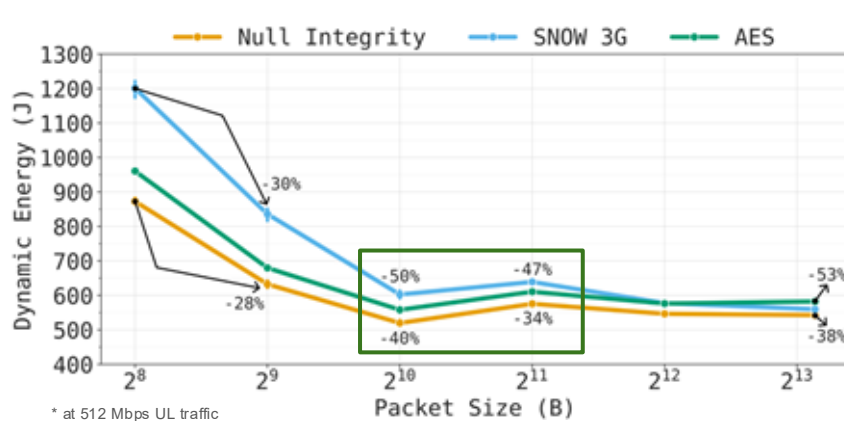
Key Features Identified

- # CPU cycles of [nr_free_sdu](#) (I ≈ 53%)
 - Frees the memory allocated to a PDCP SDU after processing and forwarding to the next layer
- # LLC references to [nr_pdcip_manager_unlock](#) (I ≈ 24%)
 - Release of a mutex lock in the pdcip manager data structure

Key Takeaway

Reserve global data structures for non-critical packet paths (e.g., UE attach/detach). Use per-UE structures during PDCP PDU processing to minimize lock contention & energy cost.

Energy Hotspots in Targeted Scenarios



Key Energy Observations

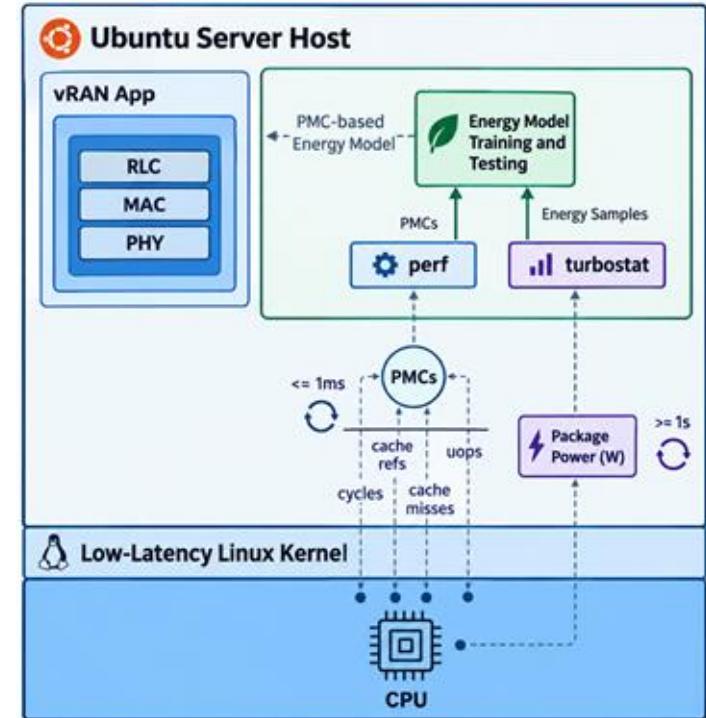
- **Packet Size Impact:** Key determinant of vCU energy consumption — **up to 53% reduction** obtained using larger packets.
- **Ciphering Overhead:** **AES** (utilizing Intel AES-NI instructions) significantly saves energy in vCUs compared to SNOW 3G.

Memory Allocator & Optimization

- **Size-Class Boundary:** Sharp jump when moving from 2^{10} B to 2^{11} B packets corresponds directly to GNU C Library (glibc) memory allocator thresholds.
- **Suggested Strategy:** Optimize allocator behavior tailored to statistical traffic properties to save energy.

Conclusions

- 01 vBBU energy optimizations can unlock significant energy savings across mobile networks
- 02 Developers need an agile solution to identify energy optimization opportunities within the BBU code
- 03 Solution: model energy consumption as a function of PMC x Symbol combinations
- 04 Feature importance analysis can nail down on good targets for energy optimization
- 05 The framework can be easily automated and re-run especially when software is updated, to reveal new optimizations



Thank you!

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Please feel free to
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