Indian Institute of Information Technology Vadodara

(Gandhinagar Campus)

Design Project Report-2024

On

Green Future Network and Compute for Sustainability

Metering and Optimization of Energy Consumption of VMs and Containers Used in RAN and Core 3GPP Energy Efficient KPIs, Metering ML Deployments

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***Abstract*—Global carbon emissions have been greatly attributed to data centers and communication networks due to increasing energy demand as well as growing environmental awareness. We concentrate on energy metering and optimization of Virtual Machines (VMs) and containers in the RAN as well as Core network. Building upon the Kepler framework, this study presents energy-aware Key Performance Indicators (KPIs) and examines machine learning (ML) models for dynamic optimization of workload planning and scheduling.**

INTRODUCTION

Motivation

The global shift toward cloud computing has increased reliance on VMs and containers for scalable and flexible application deployment. However, the environmental cost of these technologies cannot be ignored. Studies indicate that data centers contribute nearly 1% of global carbon emissions, with energy usage predicted to grow further. In mobile networks, RAN and Core form critical components that require efficient resource utilization.

Objectives

This work aims to:
Implement energy metering using the Kepler model in RAN and Core environments.Develop optimization strategies for workload scheduling to minimize energy consumption.Evaluate environmental benefits using 3GPP-defined Energy Efficiency KPIs.

Outline

The report discusses the technological background, experimental methodology, results, and future directions for sustainable compute systems.

BACKGROUND

Cloud Computing and Virtualization

Cloud computing provides on-demand access to IT resources, enabling scalable infrastructure and services. Technologies like Kubernetes allow orchestration of containerized applications, improving resource allocation and reducing hardware dependency.Virtualization and containerization technologies such as VMs and Docker containers have revolutionized application deployment. While efficient, their growing use emphasizes the need for carbon-aware optimization strategies.

Energy Efficiency in Data Centers

Data centers consume vast amounts of energy, primarily for powering and cooling servers. By integrating green energy and optimizing resource allocation, emissions can be reduced significantly. 3GPP's energy efficiency KPIs provide standardized benchmarks for assessing performance in communication networks.

Kepler Framework

Kepler is an open-source tool that estimates energy consumption in Kubernetes environments using hardware metrics and ML models. It integrates seamlessly with Prometheus for data collection, providing actionable insights for optimizing workloads.

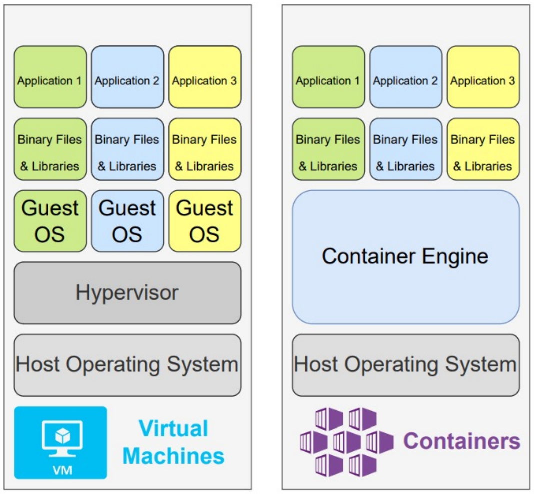

Figure 2: Architecture of virtual machines vs containers

Methodology

Experimental Setup

The experimental testbed consisted of a Kubernetes cluster with worker nodes simulating RAN and Core workloads. The following configurations were implemented:

Nodes: Simulated environments with varied energy consumption profiles.

Kepler: Deployed as a Kubernetes daemon set to monitor energy consumption.

Load Testing: Traffic generators simulated high and low workloads. Metrics and KPIs

Key metrics included

Energy Consumption: Monitored through Kepler using power estimation models.

Carbon Emissions: Evaluated using tools like Electricity Maps to link energy metrics with carbon intensity data.

System Performance: Measured response time, latency, and resource utilization under varying loads.

Optimization Strategy: A scheduling algorithm based on ML predictions dynamically migrated workloads to nodes with lower energy consumption. The decision model considered both current resource usage and carbon intensity to optimize energy efficiency while maintaining acceptable performance levels.

AI Revolution Fuels Surge in Energy Demands and Carbon Impact

AI-Driven Energy Demand

AI advancements, particularly models like ChatGPT, significantly increase energy consumption. Data center power demand is projected to grow by 160% by 2030, fueled by AI's rising adoption. By 2028, AI may account for 19% of global data center power usage. Global Power Consumption and Impacts:

Current data centers consume 1-2% of global power, expected to rise to 3-4% by decade's end. Carbon emissions from data centers could double by 2030, with a potential social cost of $125-140 billion. Regional Insights:

US: Data centers will use 8% of US electricity by 2030, necessitating $50 billion in investments in power generation and new natural gas infrastructure. Europe: AI and electrification will drive power demand up by 40-50%, requiring €1.6 trillion investments in power grids and renewable energy sources. Efforts to Mitigate Impact:

Tech companies are exploring renewable energy and emerging nuclear technologies to reduce emissions. AI is recognized as a tool for accelerating innovation in key areas like healthcare and energy efficiency.

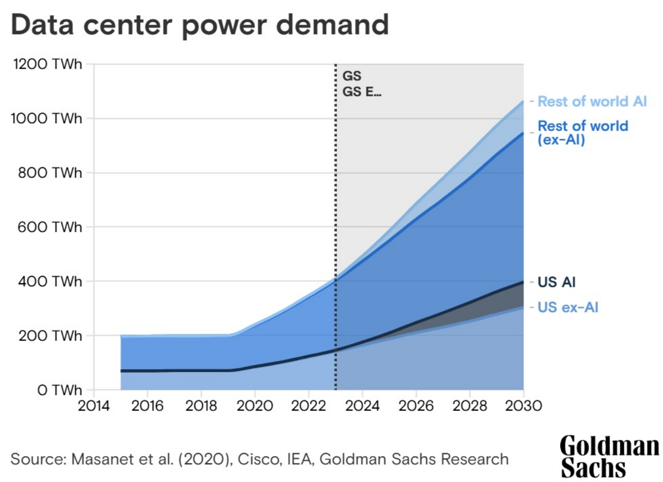

Fig. 1. Data Center Power Demand

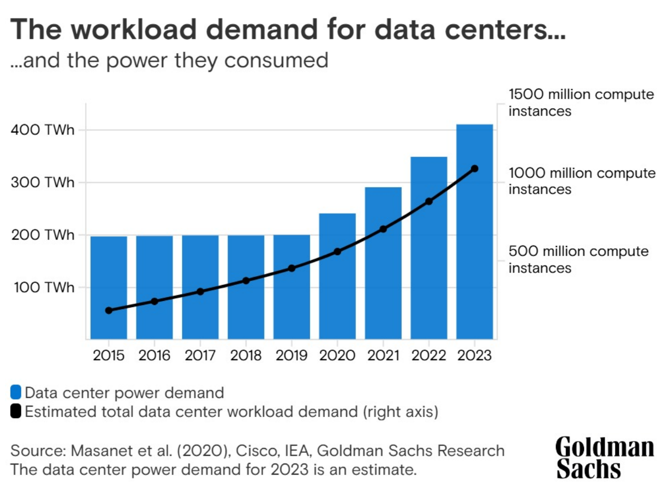

Fig. 2. workload demand for data Centers

Real World Applications for energy efficiency

A. *Telecom Networks and 5G Optimization*

Real-World Insight: Telecom companies like Nokia and Ericsson are working on energy-efficient 5G RAN deployments. Highlight how your work could complement their efforts by optimizing energy consumption at base stations and core networks. Example: Vodafone's use of AI to optimize energy usage in its network towers.

B. *Data Center Operations*

Real-World Insight: Companies like Google and Microsoft implement energy-efficient strategies using renewable energy and AI-powered cooling systems in their data centers. Example: Google's DeepMind AI reduced energy usage for cooling by 40% in their data centers.

C. *Cloud Providers*

Real-World Insight: Public cloud platforms like AWS and GCP focus on sustainability goals, aiming for 100% renewable energy usage. Example: AWS provides tools like the "Customer Carbon Footprint Tool" to help users track and optimize emissions.

D. *kepler Framework Deployments*

Real-World Insight: Kepler is used by open-source communities and cloud operators to monitor Kubernetes energy usage. Example: Highlight any large-scale use cases or success stories from Kepler's GitHub repository.

E. *Carbon Credit Programs*

Real-World Insight: Your system's energy efficiency metrics could integrate with carbon credit platforms, enabling organizations to offset emissions. Example: IBM's blockchain-based carbon credit system for data centers.

F. *AI in Energy Grid Management*

Real-World Insight: AI is increasingly used to predict demand and manage energy grids. Example: The UK National Grid uses AI to balance renewable energy inputs with consumption.

Future Work

Here are some Future Work Enhancements can be done for future progress

Temporal Workload Scheduling: - Explore aligning workloads with periods of high renewable energy availability to further reduce carbon emissions.

Real-Time Carbon Intensity Integration: - Incorporate live data on carbon intensity from energy grids to optimize scheduling dynamically.

Scalability and Deployment: - Test and deploy the proposed solutions in real-world production environments to evaluate their scalability and practical feasibility.

Integration with IoT and Edge Networks: - Extend the methodology to optimize energy consumption for IoT devices and edge computing nodes, which are becoming increasingly vital in 5G networks.

Lifecycle Analysis of Energy Use: - Perform a detailed analysis of energy consumption across the lifecycle of VMs and containers for more comprehensive insights.

Enhanced Optimization Models: - Investigate advanced AI models like reinforcement learning for better energy-aware scheduling and resource management.

Collaboration Opportunities: - Partner with cloud service providers or telecom operators to test solutions on a broader scale and gain diverse workload insights.

These enhancements would provide a clear roadmap for advancing your work and showcasing its potential for real-world applications.

Scope for Indian Entrepreneurs in Sustainable Computing and AI Energy Optimization

Indian entrepreneurs have significant opportunities in the fields of sustainable computing and AI-driven energy management. With India's rapidly expanding technology sector and focus on sustainability, the following areas offer immense potential:

Sustainable Data Centers :

- **Opportunity:** Establish green data centers using renewable energy sources like solar, wind, or hydropower.
- **Relevance:** India's data center market is growing due to the adoption of AI, cloud computing, and 5G technologies.
- **Impact:** Energy-efficient designs and carbon-aware technologies can attract global clients.

AI-Driven Energy Optimization Solutions:

- **Opportunity:**Develop AI and ML tools to reduce energy consumption in virtualized environments like VMs and containers.
- **Relevance:** The demand for energy-efficient solutions aligns with India's AI expertise and global sustainability trends.
- **Impact:** Enable cost reductions and support businesses in achieving their sustainability goals.

Renewable Energy Integration Platforms:

- **Opportunity:** Build platforms integrating renewable energy sources into IT operations.
- **Relevance:** India's vast renewable energy infrastructure creates an opportunity for innovation.
- **Impact:** Facilitate smart grid integration and energy management for IT and telecom sectors.

Manufacturing Energy-Efficient Hardware:

- **Opportunity:** Produce energy-efficient servers, cooling systems, and networking equipment locally.
- **Relevance:** The "Make in India" initiative promotes domestic manufacturing and offers incentives.
- **Impact:** Reduce dependence on imports and contribute to job creation in the tech manufacturing sector.

Carbon Footprint Management Software:

- **Opportunity:** Create tools to track and optimize the carbon footprints of IT operations.

- **Relevance:** ESG frameworks and India's energy policies demand transparent carbon reporting.
- **Impact:** Provide customized solutions for Indian enterprises, helping them meet regulatory requirements.

Green AI for Telecom and 5G:

- **Opportunity:** Design AI-driven solutions for energy-efficient RAN and core network optimization in 5G deployments.
- **Relevance:** With India's investment in 5G, telecom operators are seeking sustainable operational strategies.
- **Impact:** Combine cost savings with reduced environmental impact to attract telecom providers.

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