Solution Brief

Elastic and Energy Proportional Edge Computing Infrastructure

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Executive Summary

The impact of global warming can be summarized colloquially as “Weather on Steroids” – more flooding, more droughts, and an increase in natural disasters as well as dire consequences for our planet’s ecosystem and vulnerable populations as a result. Many countries (covering 89% of global emissions) have made net zero announcements[1].

Most companies are pledging net-zero carbon in the next two decades, which will require ~ 40-50% reduction by 2030[2]. In addition to "net-zero" goals, edge computing infrastructure being deployed by network operators faces unique challenges such as balancing latency, security, distributed management, and thermal ambient temperature for outdoor equipment. There is also the challenge of increasing energy costs due to climate and socioeconomic events.

To overcome the energy aspects of this distributed edge infrastructure challenge, we present the **"Elastic and Energy Proportional Edge Computing Infrastructure"** reference architecture and blueprint toward "net zero" deployment using the concept of elastic energy and energy proportionality. The main objective and novelty of the design is to treat energy as a global and elastic resource that can be used smartly by moving compute and data to energy-efficient edge locations. Furthermore, the objective is to expand the interplay with the grid to understand where the renewable sources are more effective and apply such elasticity to locations where the impact to carbon emissions is possibly lower.

Introduction

Today’s deployments are trending to architectures that are highly distributed and leverage cloud-native paradigms to decompose use cases in microservices. These large-scale distributed deployments will be challenged by six factors:

- Large variability in dynamic use cases (such as compute, network, and AI) and loading conditions (users connected, road or city traffic)
- Energy and space constraints for outdoor tiers such as Roadside Unit (RSU), Base Transceiver Station (BTS), and highly complex renewable and traditional energy grid-based distribution systems
- Thermal and ambient conditions that may sometimes restrict compute power availability for spiky workloads (perf/watt)
- Lack of holistic system and infrastructure-centric approach to lower Power Usage Effectiveness (PUE) using scalable energy consumption under time/space-shiftable workloads
- Lack of standards across the industry that include critical areas such as carbon emissions attestation or application-centric APIS to understand carbon being generated and act accordingly
- Lack of zero-emission architectures that connect edge-to-cloud compute infrastructure with the energy grid providers

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[1] https://zerotracker.net/
[2] https://sdgs.un.org/2030agenda

Solution Overview

To address the challenges described above, our vision is to build an edge-to-cloud system architecture that is resilient to climate conditions, self-sustainable and able to cope with energy supply unpredictability caused by climate changes and global energy disruptions. To achieve this, we consider a full system approach from the hardware platform enabling up to applications and services.

This paper introduces two key strategies. Firstly, the Elastic Energy concept, which is the ability to prioritize, increase, and move workloads at different locations based on the Renewable Energy Ratio[3]. Secondly, the Energy Proportionality, which is the ability to dynamically manage energy in proportion to compute demand at a particular location of the compute infrastructure.

Thus, *The Sustainability Optimized System Architecture Framework* comprises of end-to-end approach across all layers, as shown in Figure 1 below, where each layer is optimized for sustainability and energy elasticity[4]:

- **Optimized Facilities**: Implementing higher energy efficiency designs for cabinets and various advanced cooling technologies to achieve innovative ways to increase energy efficiency and re-use (example, heat re-use).
- **Optimized Platforms**: Optimized hardware platforms for power efficiency using advanced power management features. This includes everything from new hardware form factor designs to new types of platform system telemetry or power management (example, power capping per discrete device).
- **Optimized Resource and Service Orchestration**: Includes two fundamental areas - 1) **Telemetry and Observability** to provide specific insights to understand and characterize Service Level Objectives (SLO) and reach the most optimum energy-efficient orchestration; 2) Optimized Cloud Native **Service and Resource Orchestration** with energy and carbon aware software plugins pivoting across the various observability inputs to guide the orchestration decisions.
- **Application and Services**: Designed and deployed with carbon footprint and energy consumption awareness with support of energy elasticity plugins.

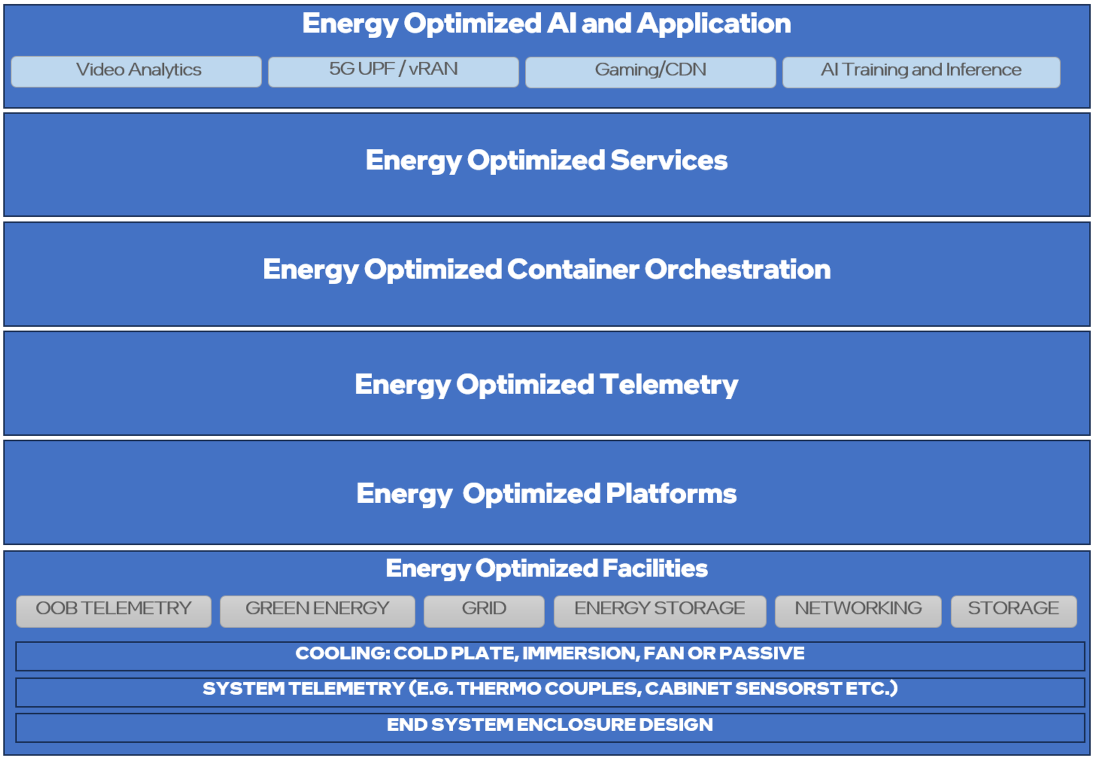

Figure 1. Sustainability Optimized System Architecture Framework

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[3] https://www.ibm.com/docs/en/tririga/10.5.2?topic=metrics-renewable-energy-ratio-metric

[4] Workloads and configurations. Results may vary.

Reference Implementation Overview

The system architecture and reference implementation discussed in this paper provide an end-end approach towards building sustainability-optimized multi-tier edge architectures.

Reference implementations are organized into three approaches based on the use cases at different edge tiers. Each provides a system architecture, which includes all aspects of the system design to achieve energy efficiency and elasticity for the use cases as applicable.

- **Sustainability-optimized software and orchestration** designs using Intent-Driven Orchestration and Intel® Infrastructure Power Manager as baseline to design policies to achieve energy proportionality within an edge location. The architecture also includes the design of meta-orchestration policies across infrastructure to implement elastic orchestration across edge-to-cloud. Both local and distributed, and meta-orchestration are built on top of advanced observability stack.
- **Intel® hardware features such as advanced CPU power management** and associated technologies. This includes access to all the telemetry features that the hardware includes (example, performance counters and thermal telemetry)
- **Precision and immersion cooling designs** to reduce energy consumption and lower the PUE factor defined as

$$\mathrm{PUE} = \frac{\text{Total DataCenter Energy}}{\text{IT Equipment EnergyUse}}$$

  Depending on the location of the edge node, for example far edge, precision cooling designs are more suitable from an operation and maintenance perspective.

The building blocks for end-to-end system architecture optimized for sustainability across the three selected use cases are shown in Figure 2:

1. **Far Edge**: Implements a Video Analytics workload in a Street Cabinet
2. **Central Office**: Mobile traffic DPDK enabled 5G User Plane Function workload
3. **Central Office**: Media traffic Content Delivery Network (CDN) workload

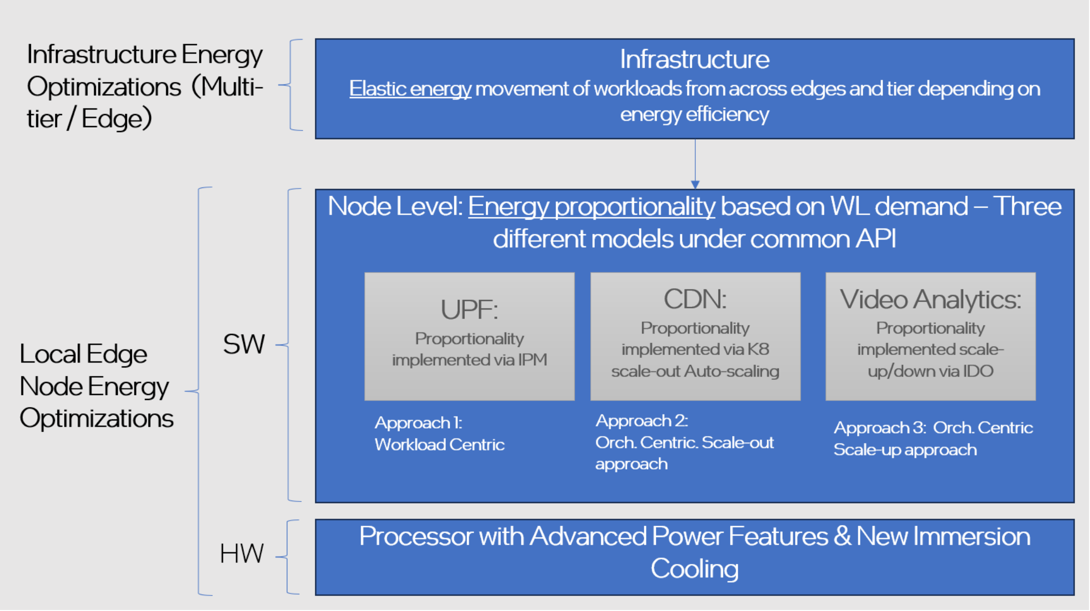

Figure 2. Sustainability Optimized Architecture - Reference Implementation

The system architecture approach applicable to all three use cases can be decomposed in three layers described below and as shown in Figure 3.

1. Policy and Data Management layer optimizes the overall energy consumption to be proportional to a workload's service level objectives (SLO). This layer needs to be integrated into end-to-end policy and workload orchestration and in future aided by Artificial Intelligence derived from telemetry data below to provide global and local optimizations[5].
2. Telemetry and Observability layer includes SLO-aligned metrics from HW, SW, applications, and services through measurement profiles to build awareness of workload and associated energy consumption and optimizations. It provides a closed feedback loop into local and global sustainability optimizations. The measurement profiles allow the system to dynamically assign measurement strategy per component, enabling (or disabling) the data to be collected according to the SLOs.
3. Hardware Platform Energy and Advanced Power Management (APM) layer uses advanced features for cooling, power, and frequency management, and idle/active state management to optimize energy consumption at platform level.

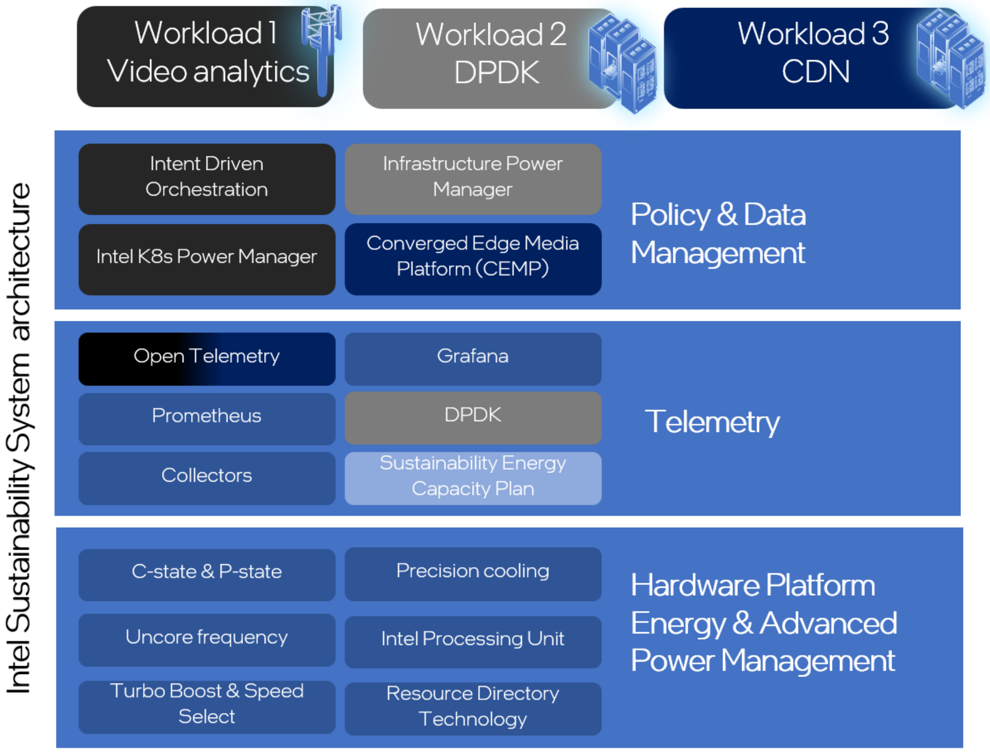

Figure 3. Sustainability Optimized System Architecture Approach

Additionally, Figure 3 describes the main components per layer associated with each use case for reference. The next section outlines the technologies applied per use case and the kind of hardware and software involved.

Technologies Used

This section is broken down into six parts detailing the hardware design and Bill of Materials (BOM) jointly with the applied technology.

Reference Hardware Design and Bill of Materials

The hardware architecture for reference implementation is shown in Figure 4:

1. **Far Edge** uses precision cooling technology with edge server based on 4th Gen Intel® Xeon® Scalable processors and Intel® Data Center GPU Flex Series for the AI inference, video analytics processing.
2. **Central Office** uses precision cooling technology with Data Center server based on 4th Gen Intel® Xeon® Scalable processors, Intel® Data Center GPU Flex Series, and Intel® Ethernet Network Adapters.

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[5] https://ieeexplore.ieee.org/document/9612603

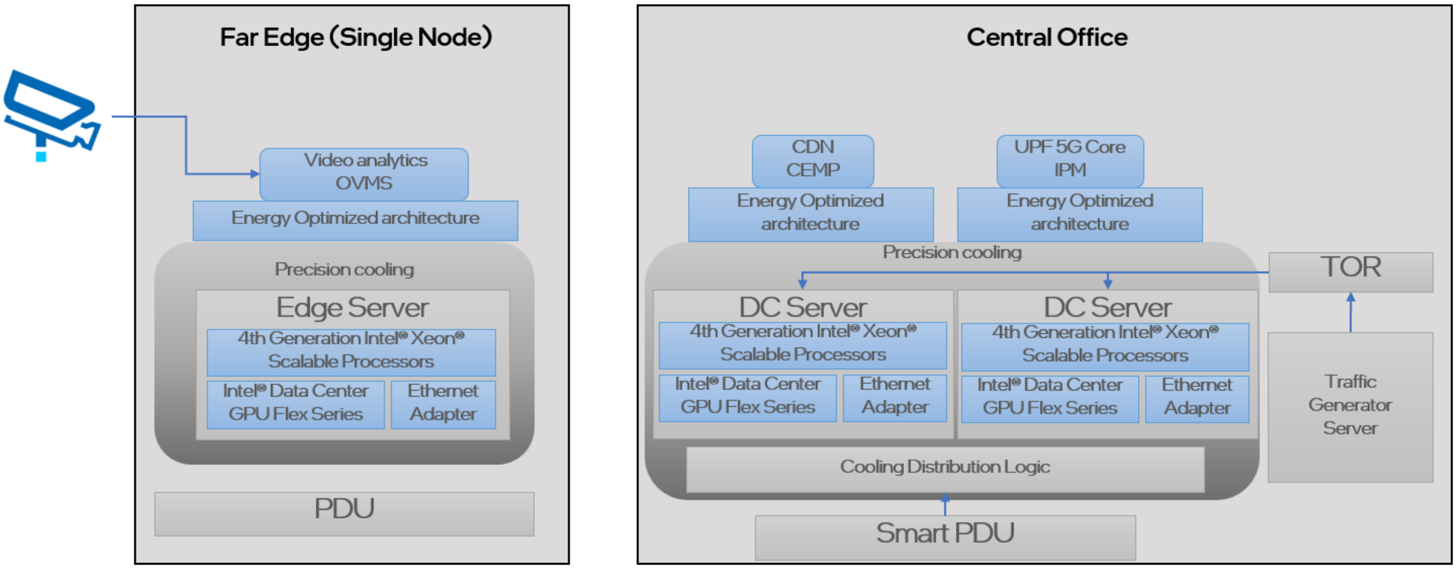

Figure 4. Demo Topology (SW and HW Architecture)

Intel® Infrastructure Power Manager

Intel® Infrastructure Power Manager is reference software that dynamically matches runtime server power consumption with data traffic without compromising key performance indicators such as throughput, latency, and packet drop.

Converged Edge Media Platform

Intel's Converged Edge Media Platform is a reference architecture that provides container-based cloud-native foundational capabilities for providers to deploy multiple media services quickly, efficiently, and cost-effectively to capitalize on fast-growing edge computing opportunities.

Intent-Driven Orchestration

Today's main container orchestration engine solutions promote a model of requesting a specific quantity of resources (for example, number of vCPUs), a quantity range (for example, min/max number of vCPUs), or not specifying them at all for supporting the appropriate placement of workloads. This applies at the cloud and the edge using Kubernetes (although the concept is not limited to Kubernetes-based systems). With Intel-Driven Orchestration, the end-state for the resource allocation is declared, but that state is an imperative definition of what resources are required. The Intent-Driven Orchestration is aligned with the SLO-based telemetry and results in the desired outcome of the intent.

Precision Cooling Solutions

New cooling solutions decrease overall PUE on data center and edge locations. An important aspect of edge deployments is the stability of the overall solution and performing the computation in unfavorable environmental conditions like high ambient temperature or air contaminated with particulate matter like dust. Solution based on precision cooling affirms performance increase, CPU temperature margin extension, reduction of CPU throttling with high ambient temperatures and overall energy savings. That makes a perfect part of the overall Optimized System Architecture for Distributed Edge Computing.

Energy Predictions and RER Factor

In future deployments, we foresee the need to forecast and indicate the level of green energy availability to achieve the best outcome for Carbon impact. The Renewable Energy Ratio (RER) can be defined as the proportion of electricity generated from renewable sources compared to the total electricity generated. Appendix 1 reviews the details of RRE and the calculation it uses in our design. It could be complemented through measurement profiles jointly with the model server to align and adapt different prediction approaches suitable for multiple contexts or scenarios. It represents an added value in heterogeneous and dynamic environments like the edge.

Use-Cases Detailed Architecture Summary and Results

This section deepens the three use cases, providing the description, implementation architecture, key takeaways and results.

Use Case: Video Analytics in a Street Cabinet

Description

The Video Analytics workload is implemented usually at far-edge locations like Street Cabinet or Roadside Units[6]. This use case is represented by security and smart city application examples like traffic condition, safety and parking availability. By using different configurations, we dynamically adjust workload performance towards SLO values based on energy and carbon impact.

When the energy source is not green, the infrastructure software stack scales the performance to the target performance level to reduce carbon footprint. The Renewable Energy Ratio (RER) factor is used as a factor to provide this input to the workload orchestration to achieve this behavior.

The RER is ingested into the system via the advanced telemetry and observability collection layers. Intent based policies are defined to determine how energy elasticity (example, how the infrastructure energy consumption can be adjusted) shall relate to both the RER and meeting/exceeding the target workload performance.

Implementation

The Video Analytics workload is based on OpenVINO™ Model Server. By utilizing the concept of Renewable Energy Ratio, we demonstrate the ability to optimize workload energy consumption while maintaining the SLO to reduce the carbon consumption.

The dynamic ability of the system to adapt to the green energy is encompassed in the orchestration layer where the following policies have been configured:

- When running with renewable energy, the workload can run at maximum performance with minimum GHG emissions.
- When the energy source transitions to traditional energy, the workload is adjusted dynamically to minimize energy consumed (while respecting its Key Performance Goals), hence minimizing GHG emissions.

The following are the three configured states for the system related to energy source awareness:

1. **Range of 80% to 100% Green Energy** – Run the application with maximum performance. The workload can perform at its maximum, delivering the best user experience and throughput. Power settings are dynamically tweaked to facilitate this highest performance condition.
2. **Green Energy reduced to 0%** – Run at the lowest acceptable performance while maintaining targeted workload Key Performance Indicator (KPI). As the energy source changes to zero percent, the workload performance is scaled back to its target threshold while still delivering desired user experience and throughput. Power settings are being dynamically tweaked to facilitate the lowest possible energy consumption.
3. **Green Energy restored to 100 percent** – As the green energy percentage increases to 100 percent, the workload performance capacity is scaled up to its higher threshold, delivering the best user experience again. Power settings are being dynamically tweaked to drive the performance profile. In this case, the system may also benefit from the excess of energy in order to perform no priority tasks such as AI training or log process. The goal is to make sure that no green energy is wasted.

Once intent based policies have been configurated, there is no need for administrators to actively manage the system behavior as renewable energy ratio shifts. The system dynamically changes the throughput and user experience in proportion to the available green energy. While underlying techniques may be like traditional performance and power-based optimization, the unique innovation is to introduce the concept of renewable energy ration awareness and make this a factor on how the system behaves. In addition to the states described above, other intermediate states can be automatically achieved based on the

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[6] Example of deployment model and architecture can be found at “Autonomous Lifecycle Management for Resource-Efficient Workload Orchestration for Green Edge Computing” (https://ieeexplore.ieee.org/document/9612603)

configurations to use the main idea of proportionality of energy allowing operators to reduce the overall GHG for consumed energy in their fleet.

Summary

The first use case demonstrates proportional aware software and solutions. In future, we expect that legislation will require detailed reporting of energy consumption and CO2 emissions per system element. Our solution dynamically adapts the infrastructure to the changing conditions/availability of renewable energy while maintaining the workload key performance indicator.

In summary,

- We achieve our goals using the **Renewable Energy Ratio factor (RER)** as our primary sustainability design criteria. RER represents "how much" energy is green.
- **Intent-Driven Orchestration** modifies power consumption through frequency and voltage changes on the platform while maintaining Service Level Objective.
- **Support industry net-zero transformation** by developing intelligence to scale compute activity proportional to Renewable Energy and building energy efficient silicon, server platforms, thermal/cooling management.

Use Case: Central Office Mobile Traffic DPDK/5G based on Intel® Infrastructure Power Manager

Description

There are various locations to a telecoms network. This use-case solution focuses on the Next Generation Central Office Tier of the Network for Core Mobile network infrastructure.

In this use-case, the mobile traffic power optimization is characterized by an L3 Forwarding with Power Management, demonstrating **power-conscious packet processing using DPDK**. The use case is built upon the pre-existing L3 Forwarding sample application. It incorporates power management algorithms for regulating the P-states of Intel® processors via a dedicated power management library. This is a proxy workload for 5G traffic simulation. The reference architecture can adapt power consumption to the traffic demand – Energy Proportionality.

The proposed system architecture contains the following elements:

1. **Intel® Infrastructure Power Manager (IPM)** provides the ability to perform power management to achieve the lowest possible energy consumption while maintaining the service level, throughput, and latency requirements. IPM can dynamically adjust run-time power consumption using built-in hardware capabilities.
2. **Platform insights** provide SLO-aligned reports based on system telemetry. In future, our vision is to implement "measurement profiles" to adapt dynamically the monitoring strategy, realigning it with SLOs and updates in the model server.
3. **Precision cooling integration** allows the ability to reduce overall energy consumption while maintaining the thermal ambient at desired levels.

Implementation

The following presents two system states. The first state does not apply any IPM optimizations and the second does.

1. In the first state, irrespective of the traffic and system utilization - busy or quiet the power consumption remains the same, thereby increasing overall energy usage, costs and carbon impact.
2. The second state achieves power consumption with IPM implemented. Power consumption is reduced or increased in accordance with system utilization as simulated by busy and quiet times during the day, this is achieved using advanced power management features dynamically via the IPM.

The total average power saving is over 24 hours. It has been able to achieve up to 30% power saving.[7]

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[7] https://www.intel.com/content/www/us/en/wireless-network/core-network/infrastructure-power-manager-solution-brief.html

Summary	Here is the summary from this use case: 1. Edge Networks Infrastructure must use smart systems to adapt power consumption to the traffic demand to achieve true Energy Proportionality. 2. Intel Infrastructure Power Manager is a software solution built by Intel that dynamically adjusts run-time power consumption using built-in hardware capabilities. 3. Intel Infrastructure Power Manager reference software delivers an estimated average run time power savings up to 30%[8] while maintaining key telco performance metrics by dynamically matching CPU power consumption to traffic. On a per-year basis, this could result in multi Giga-Watt-hours (GWH) of power saved and millions of dollars of operating expense (OPEX) cost savings and significant carbon emissions offset. 4. Run-time power savings are one of the big opportunities for CoSPs to lower significant operating expense (OpEx) energy costs. Intel Infrastructure Power Manager for 5G Core is a breakthrough for CoSPs because it dynamically matches run-time server power consumption with data traffic. The technology significantly contributes to strategic efforts to reduce costs and assist CoSPs in meeting environmental and sustainability goals.

Use Case: Central Office Media Traffic CDN based on Converged Edge Media Platform

Description	Media streaming through CDN has a substantial impact on the environment. For example, a 2019 report estimated that the annual carbon footprint of YouTube* was about 10Mt CO2e – about the annual output of a city the size of Glasgow[9]. This use case focuses on the Content Delivery Network (CDN), the most widely deployed edge workload, with hundreds of thousands of servers deployed worldwide to cache and deliver content to users with the best proximity. With 82% of internet traffic[10], the CDN footprint is growing faster than ever. CDN is an example of one of the heaviest internet traffic utilization workloads. Even a small amount of energy optimization will greatly impact energy savings and carbon emissions. Some media services like CDN, Cloud Gaming, and Live Video will be the dominant part of the $400B[11] edge computing market by 2030. CEMP allows further optimization of resource utilization by allowing storage-centric applications such as CDN to coexist with GPU-centric applications such as Cloud Gaming and Live Video. CDN capacity is provisioned to deliver peak throughput, which is difficult to predict, resulting in underutilization of deployed resources. That means inefficient use of energy and an increased carbon footprint. A cloud-like approach where you allocate more hardware resources automatically when the demand for the application goes up and to reduce the resources when the demand goes down leads to better energy use and lower carbon emissions. Content Delivery Network (CDN) is based on Kubernetes standards and can adjust infrastructure to traffic demand. Converged Edge Media Platform (CEMP) is an Intel solution with framework implementation that addresses power and infrastructure utilization challenges. The use case will showcase the ease of onboarding and managing CDN, a key edge workload, running as a microservice on the Intel CEMP platform, resulting in more efficient use of hardware resources with lower energy consumption and carbon emissions. Video streaming is a fluctuating and unpredictable traffic. Edge infrastructure networks must intelligently adapt their resource level to the traffic demand. Finally, adaptive edge systems should guarantee performance KPIs.

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[8] https://www.intel.com/content/www/us/en/wireless-network/core-network/infrastructure-power-manager-solution-brief.html

[9] https://www.theguardian.com/tv-and-radio/2021/oct/29/streamings-dirty-secret-how-viewing-netflix-top-10-creates-vast-quantity-of-co2

[10] Cisco. “VNI Complete Forecast Highlights.” https://www.cisco.com/c/dam/m/en_us/solutions/service-provider/vni-forecast-highlights/pdf/Global_Device_Growth_Traffic_Profiles.pdf

[11] STL Partners, December 2022. “Edge computing market sizing forecast: Second release.” https://stlpartners.com/research/edge-computing-market-sizing-forecast-2nd-release/

Implementation

This use case architecture showcases cloud-native CDN applications optimally scheduled and auto-scaled based on changing user demand without compromising application performance and service operator SLA. Use the CEMP intelligent orchestrator to allocate resources with guidance from hardware and application telemetry modules in k8s:

1. CDN application is implemented using NGINX to serve media content to users.
2. Uses a streaming traffic simulator to generate concurrent CDN sessions—for example, 24h CDN traffic.
3. Depending on the CDN throughput (number of active sessions), the system will scale the number of Kubernetes CDN pods and adjust the power consumption:
    - Peak CDN demand = higher number of K8s pods
    - Low/average CDN demand = minimal number of K8s pods = lower power consumption
4. CDN is deployed with CEMP on Intel hardware with Intel® Xeon® Scalable processor, Intel® Ethernet 800 Series Network Adapters, and power telemetry enabled with the Power Insights Kit software.
5. Indicators reflect dynamic adaptation of power consumption with changes in user demand and how those compare to the hardware without CEMP. This highlights sustainable use of energy and Power consumption efficiency with changing CDN demand (#sessions).
6. Power-aware telemetry in CEMP enables intelligent placement and scaling of the CDN application for sustainability.
7. To preserve the expected performance/SLA, the architecture scales the number of CDN instances up/down to conserve power without compromising the number of video sessions or video quality.

Summary

Here is the summary from this use case:

1. Intel's CEMP is a cloud-native platform optimized for dynamically deploying and managing multiple media services in power- and space-constrained edge environments. CEMP can streamline Cloud-native CDN deployment and schedule/scale according to peak, average, and idle streaming, reducing energy consumption and cost.
2. CEMP is used to dynamically scale K8s pods based on CDN workload throughput and adjust power consumption.
3. Power Insight Kit collects an overview of system and components power consumption (energy awareness) aligned with a measurement profile and SLOs. A telemetry collector with Prometheus and Grafana are used to collect and report power and carbon footprint.
4. Platform and Silicon with built-in power management and telemetry enable intelligent orchestration of the application for sustainability architecture.
5. Power optimization is achieved through CEMP implementation in NGINX Kubernetes deployment. While increasing horizontal scaling can serve traffic at higher throughputs, it can scale to lower the power consumption with lower traffic.
6. The ability to scale the traffic conditions while optimizing the lowest energy consumption helps in achieving energy efficiency.

Conclusion

This reference architecture introduces some of the key concepts that will be essential for building an energy optimized edge infrastructure:

- Optimizing total system energy at edge tiers using advanced power management capabilities demonstrated in 5G UPF Dataplane use case in Central Office deployment scenario.
- Renewable Energy Ratio based orchestration for reduction of the carbon footprint through a prototype for a Video Analytics use case implemented at Far Edge. Initial results are promising and represent an opportunity to extend applications throughout multiple verticals and Green Energy-aware businesses to converge in extrapolate results.
- Granular Power Management is based on the application requirements without compromising the service-level objectives as demonstrated in the CDN use case at the Network Edge.

As we continue to advance and evolve our system architecture for most optimized sustainability goals, we will continue to publish detailed implementation and reference guides for various edge use cases optimized for sustainability.

Continuous integration of technologies and optimizations into Intel hardware/software co-design systems will be explored towards the goal of achieving increased energy efficiency and performance as well as contributing to the reduction of customers carbon footprint. Initial results from execution are promising and they encourage new developments in this area.

This document is part of the Network Transformation Experience Kits.

Terminology

Table 1. Terminology

Abbreviation	Description
BKC	Best Known Configuration
BTS	Base Transceiver Station
CDN	Content Delivery Network
CEMP	Converged Edge Media Platform
DPDK	Data Plane Development Kit
IDO	Intent Driven Orchestration
IPM	Infrastructure Power Manager
IPU	Infrastructure Processing Unit
KPI	Key Performance Indicator
OpenVINO	OpenVINO™ is an open-source toolkit for optimizing and deploying AI inference.
OVMS	OpenVINO™ Model Server
PUE	Power Usage Effectiveness
RER	Renewable Energy Ratio
RSU	Road Side Unit
SLO	Service Level Objective
XPU	App-suited and aware Processing Unit

References

Table 2. References

Reference	Source
Intel® Infrastructure Power Manager	https://www.intel.com/content/www/us/en/wireless-network/core-network/infrastructure-power-manager-solution-brief.html
Intel's Converged Edge Media Platform: Cloud-Native Media Services at the Network Edge	https://networkbuilders.intel.com/solutionslibrary/intel-converged-edge-media-platform-cloud-native-media-services-at-the-network-edge
Intent Driven Orchestration Planner	https://github.com/intel/intent-driven-orchestration
CDN creates vast quantity of CO2	https://www.theguardian.com/tv-and-radio/2021/oct/29/streamings-dirty-secret-how-viewing-netflix-top-10-creates-vast-quantity-of-co2
Autonomous Lifecycle Management for Resource-Efficient Workload Orchestration for Green Edge Computing	https://ieeexplore.ieee.org/document/9612603
Net Zero Targets	https://ourworldindata.org/grapher/net-zero-targets

Document Revision History

Revision	Date	Description
001	November 2023	Initial release.
002	January 2024	Updated figures.

Appendix 1- Renewable Energy Ratio Calculation Example

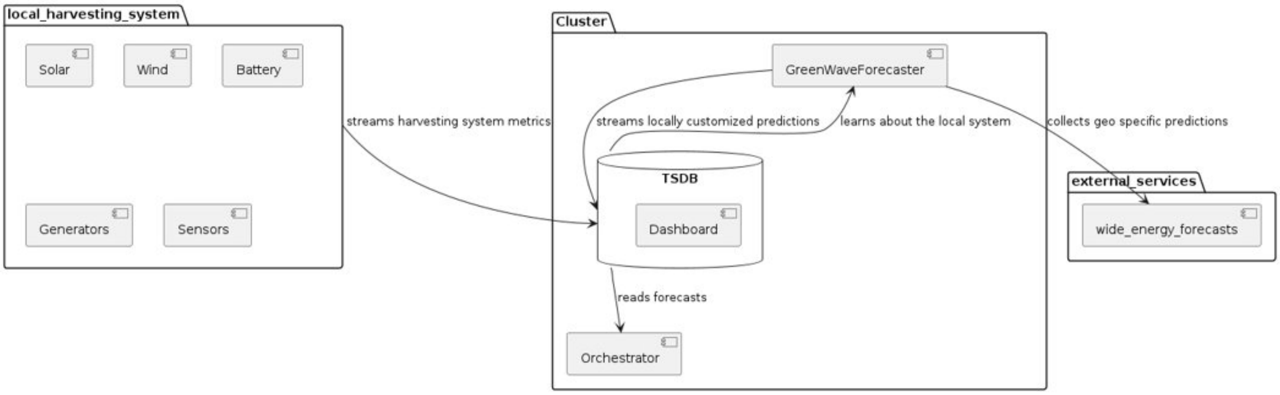

Figure 5. Energy Prediction Component Architecture

Figure 5 mocks the functionality for the calculations by serving simulated forecasts for the harvesting system described below. The simulated dataset is used as a streamed forecast for the energy aspect that has been generated based on the off-grid test.

Core components of assumed Energy Harvesting Systems

- Renewable Energy Sources: Solar panels, wind turbines
- Storage Systems: Batteries
- Generators: Oil-based generators

Table 1 lists the underlying metrics that were used for forecasting.

Table 3. Off-grid Harvesting System Metrics

Revision		Description
Signal Mean Solar Power (1h, rounded to full hours, in Watts)	P_s	power_solar
Signal Solar Is Connected (logical)	P_{sh}	power_solar_check
Signal Mean Wind Turbine Power (1h, rounded to full hours, in Watts)	P_w	power_wind
Signal Mean Customer DC load (1h, rounded to full hours, in Watts)	C_s	consumption_service
Signal Mean Inf. DC Consumption	C_i	consumption_infrastructure
Signal Mean Battery SOC	B_{SoC}	battery_soc
Signal Battery SOC Is Connected	B_{SoCh}	battery_soc_check
Signal Mean Battery Amp.	B_a	battery_amp
Signal Mean Battery Volt.	B_v	battery_volt

Networks are responsible for a considerable part of an operator's energy consumption. It is therefore important to find renewable power sources and to measure them. Hence, this KPI represents the percentage out of the total energy consumed by fixed and mobile networks coming from renewable sources such as Power Purchase Agreements (PPAs), Energy Service Company (ESCO) or on-site renewable electricity production.

Renewable Electricity Ratio (RER) = Renewable electricity consumption/Total electricity consumption

It must track the energy sources used to charge the batteries to calculate the proportion of battery storage from renewable sources versus non-renewable sources. It could achieve this via Energy Source Tracking, Time-of-Use Metering, and run calculations based on those factors.

We only include the direct consumption from renewable and non-renewable sources, not the energy stored and later discharged from the battery. The energy used from the battery should only be included in the Renewable Energy Ratio (RER) numerator, provided it was charged from renewable sources.

Including the battery in the Renewable Energy Ratio (RER) calculation for the last hour could be tricky, as the energy used to charge the battery might be used in future periods. Hence, the calculations must include Monitor Energy Flows, Calculate Total Energy Consumption, and Track Renewable Energy Contribution factor.

In these cases, **RER would be computed** like this - Divide the sum of renewable energy generated and the renewable energy discharged from the battery by the total energy consumption in the time window. This will give us the RER for that specific time window.

The list of all needed calculations is detailed as follows:

General RER calculation

$$R_t, R_i, R_s = \frac{P_s + P_w}{C_t}$$

RER incl. battery

$$RER_{[n,n+1]} = \frac{P_{s[n,n+1]} + P_{w[n,n+1]} + P_{br[n,n+1]}}{C_{t[n,n+1]}}$$

Delta of Battery SoC for given period.

$$\Delta B_{SoC[n,n+1]} = B_{soc[n+1]} - B_{soc[n]}$$

Total power consumption in given window.

$$C_{t[n,n+1]} = C_{s[n,n+1]} + C_{i[n,n+1]} + I_{e[n,n+1]}$$

Amount of power lost due to site efficiency factor.

$$I_{e[n,n+1]} = ((C_{i[n,n+1]} + C_{s[n,n+1]}) \times (100 \times (1 - I_e)) - (C_{i[n,n+1]} + C_{s[n,n+1]})$$

RER.

$$RER_{[n,n+1]} = \frac{P_{s[n,n+1]} + P_{w[n,n+1]} + P_{bd[n,n+1]}}{C_{i[n,n+1]} + C_{s[n,n+1]} + \left((C_{i[n,n+1]} + C_{s[n,n+1]}) \times I_{ef} + P_{bc[n,n+1]}\right)}$$

Appendix 2 – Hardware Bill of Materials

Data center server configuration:

- Dual socket populated with Intel® Xeon® Gold 6338N Processor (185W)
- Memory preferred 256 GB (32 GB per DIMM) per socket using 1DPC
- Two NVMe (1TB) for boot & workload
- 8 NVMe (1 TB) for Storage (CDN)
- x1 Intel® Ethernet Network Adapter E810-CQDA2/HP P21112-B21 200GB network adapter per socket

Far edge server configuration:

- One Socket System with Intel® Xeon® Gold 6338N Processor (185W)
- Memory preferred 128 GB (16 GB per DIMM) per socket using 1DPC
- Two 960 GB NVMe for boot and application
- x1 Intel E810-XXVDA4T Ethernet 10/25GbE 4-port SFP28

Performance varies by use, configuration and other factors. Learn more at www.Intel.com/PerformanceIndex.

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