White Paper

Communication Service Providers (CoSPs), Mobile Network Operators (MNOs)

Intel-Dell Verified Reference Configuration for 5G Core on Red Hat OCP

Scalable, Energy-Efficient 5G UPF with Intel Verified Reference Configurations on Dell PowerEdge R770 for Next-Generation Mobile Networks

Authors

Intel:

Sarita Maini

Siva Prasad Tirulaka

Gordon Noonan

Kashish Singh

Rory Sexton

Andrey Glustsov

Max Coates

Dell:

Suresh Raam

Mike Moore

Allan Paulino

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Introduction

FlexCore 2.0 UPF is a 5G reference design that enables virtualized User Plane Function (UPF) workloads on servers powered by Intel® Xeon® 6 processors. By running on Network Function Virtualization Infrastructure (NFVI), it supports evaluation and benchmarking of 5G core mobile network data planes. In the deployment detailed in this paper, the solution runs on a Dell PowerEdge R770, a 2U platform featuring two Intel Xeon 6 processors (up to 144 cores), 32 DIMMs, dual AC/DC power supplies, and up to sixteen EDSFF E3.S NVMe (SSD) drives.

Intel Xeon 6 processors meet the power, performance, and efficiency demands of telecom environments, Efficient-cores (E-cores) deliver high core density and performance per watt, while Performance-cores (P-cores) handle a broad range of workloads with strong AI and HPC capabilities. These processors provide fine-grained frequency and power control, and, when combined with Intel® Infrastructure Power Manager (IPM), dynamically align CPU performance to real-time traffic conditions, reducing power usage while maintaining throughput and zero packet loss.

FlexCore 2.0 UPF enhances 5G core efficiency through Data Plane Development Kit (DPDK), Vector Packet Processing (VPP), NUMA-aware optimizations, and huge pages. It employs Dynamic Device Personalization (DDP) on Intel® Ethernet Network Adapters, offloading packet parsing, classification, steering, distribution, flow matching, and checksums. This approach frees processor cores for other tasks, improving overall system performance.

Intel VRC for FlexCore 2.0 UPF

This document provides an Intel Verified Reference Configuration (VRC) for FlexCore 2.0 UPF on Intel Xeon 6 processors running on Red Hat OpenShift* Container Platform, incorporating IPM to demonstrate increased throughput and power savings. Tested on a Dell PowerEdge R770 with Intel Xeon 6780E processors and Intel Ethernet 800 Series Network Adapters, this VRC exemplifies a CPU-intensive and I/O-intensive 5G core workload optimized for efficiency.

Intel Verified Reference Configurations such as those for vCMTS employ a multi-node architecture managed by a central orchestrator. The master node handles control, signaling, and Containerized Network Function (CNF) management, while worker nodes run the data plane workloads. As part of the NFVI-FP program, these VRCs support high-throughput workloads including virtualized Broadband Network Gateways (vBNGs), 5G UPFs, and Virtualized Access Gateway Functions (vAGFs).

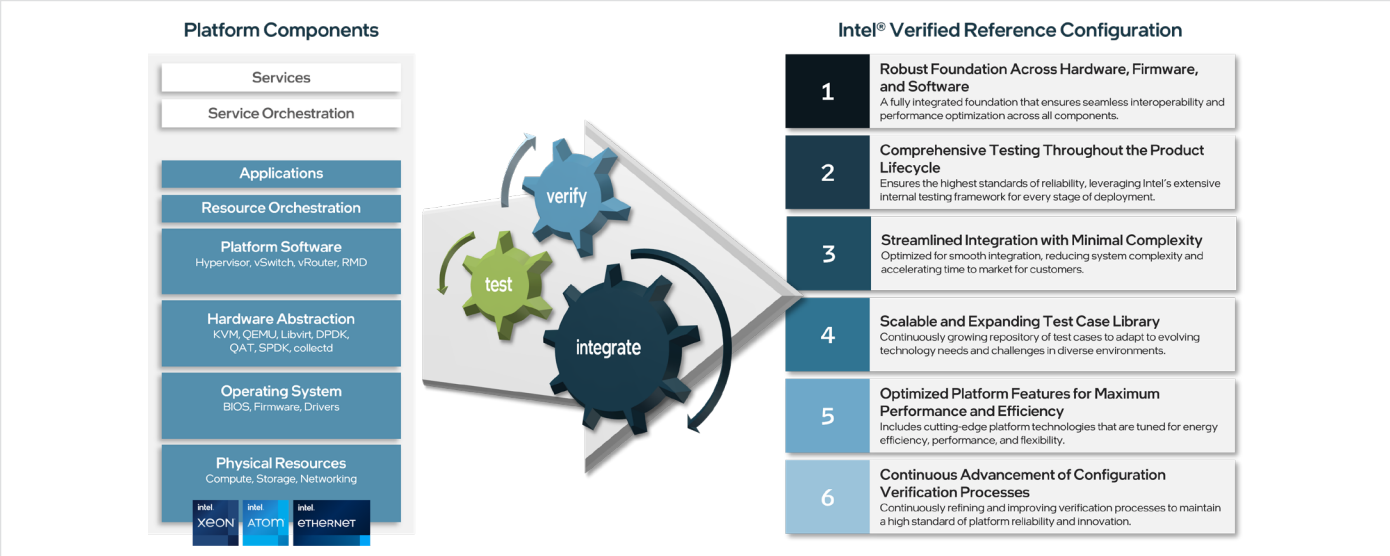


Figure 1. Intel Verified Reference Design Process and Benefits

Dell PowerEdge R770

The Dell PowerEdge R770, powered by Intel Xeon 6 processors, is a 2U dual-socket rack server designed for efficient and scalable deployment of advanced network workloads. This platform delivers balanced performance, optimized power efficiency, and high-density compute, making it ideal for modern 5G core applications.

Figure 2. Dell PowerEdge R770 Server

Key Features:

- **High-Density Compute:** Supports two Intel Xeon 6 processors with up to 144 cores each, providing exceptional throughput and per-watt efficiency for CPU-intensive and I/O-intensive 5G workloads.
- **Optimized for Data Center Efficiency:** Designed to maximize rack utilization and minimize energy consumption, offering a highly efficient platform for virtualization, cloud-native deployments, and large-scale analytics.
- **Flexible Storage and I/O:** Accommodates up to sixteen EDSFF E3.S NVMe (SSD) drives and multiple PCIe Gen5 expansion slots, delivering rapid data access and high-bandwidth I/O for distributed inferencing and fast data processing.
- **Enhanced Cooling and Sustainability:** Features advanced cooling solutions that optimize airflow and reduce energy usage, contributing to long-term operational savings and supporting sustainability objectives.
- **Integrated Security and Management:** Incorporates robust hardware security features and Dell's iDRAC for streamlined remote management, allowing secure, simplified monitoring and lifecycle management of servers.

Overview

Intel VRCs provide a workload-optimized configuration of select hardware and various Intel Xeon processor technologies along with optimized software and BIOS settings. It leverages hardened hardware, firmware, and software which allows customers to integrate on top of this known platform configuration.

The 5G FlexCore 2.0 UPF workload-optimized solution is designed to minimize the challenges of infrastructure deployment and optimization for the best performance with balanced I/O across sockets for core-bound as well as I/O-bound workloads. It runs on Intel Xeon processors, which incorporate unique features designed especially for virtualized network workloads. This solution can be used to compare the performance of various generations of Intel Xeon processors.

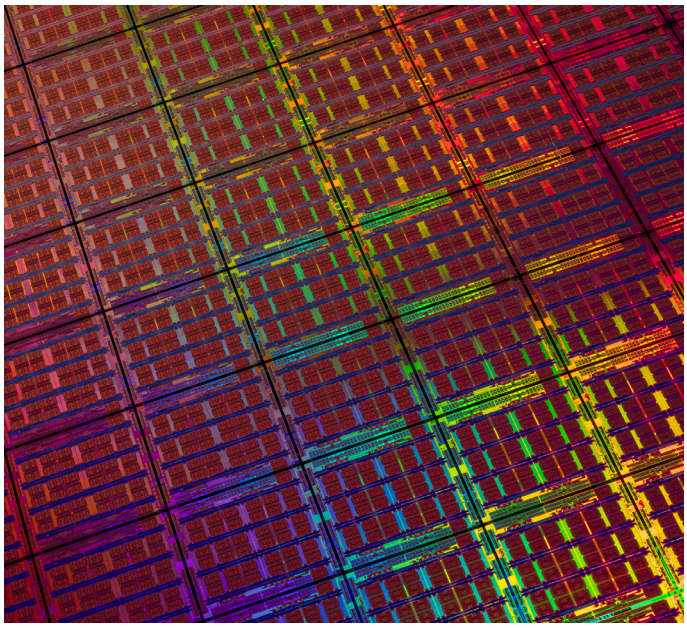
This Intel Verified Reference Configuration document includes the following:

- Impressive performance of FlexCore 2.0 5G UPF with Red Hat OpenShift Container Platform (RH OCP) with Intel Xeon 6780E processors
- Intel Infrastructure Power Manager (IPM) benefits, which help telco and cloud workloads to achieve power optimizations and energy savings goals with IPM, with best-in-class throughput and performance per watt.
- Up to 930 Gbps (93% of the line rate of 1000 Gbps) can be achieved with an acceptable error rate of 0% packet loss with standalone 5G FlexCore 2.0 UPF running in a RH OCP worker node 2-socket Dell PowerEdge R770 server, powered by Intel Xeon 6780E processors , using a Packet Size of 650 Bytes and maintaining a packet loss of 0%, with and without IPM.
- Up to a maximum of 41% power savings and average 38.4% power savings using IPM, depending on the percentage of traffic load, with no impact on I/O throughput. A real-life telco scenario of a 24-hour traffic profile was used for measuring the power consumption.

Hardware and Software Requirements

For the platform to conform to the desired Intel Verified Reference Configuration for 5G FlexCore 2.0 UPF, the following hardware and software requirements must be met:

Hardware	Description
Processor	2 x Intel® Xeon® 6780E processor, 2.20Ghz, 144C
Memory	16 x 64GB Dual Rank DDR5, 6400 MT/s
Storage	1 x 28.6G SanDisk 3.2 Gen 1, 1x 894.2G Dell BOSS-N1, 4x 1.7T Dell NVMe PM1743 RI E3.S 1.92TB
Network Interface Card (NIC)	2 x Intel® Ethernet Network Adapter E810-2CQDA2 1 x Intel® Ethernet Network Adapter E810-CQDA2
LAN on Motherboard (LOM)	1 or 10 Gbps port for Management NIC
OCP Software	**Description**
Host OS	Red Hat Enterprise Linux CoreOS release 416.94.202408132101-0, 5.14.0-427.31.1.el9_4.x86_64
OCP	OCP 4.16
Common Software	**Description**
Intel FlexCore 2.0 UPF	23.07
Intel Infrastructure Power Manager	24.08
Node Feature Discovery Operator	4.16.0-202410251436
SR-IOV Network Operator	4.16.0-202410251436
Intel ICE DDP COMMS Package	1.3.45.0
Trex Traffic Generator	3.0



BIOS Settings

To meet the performance and power requirements for an Intel VRC for 5G UPF platform solution, Intel recommends using the following BIOS settings for Dell PowerEdge R770:

BIOS Setting	Value
CPU Interconnect Speed	Maximum data rate `
Virtualization Technology	Enabled
Kernel DMA Protection	Disabled
Directory Mode	Enabled
Hardware Prefetcher	Enabled
DCU Streamer Prefetcher	Enabled
DCU IP Prefetcher	Enabled
Sub NUMA Cluster	Disabled
MADT Core Enumeration	Linear
UPI Prefetch	Enabled
XPT Prefetch	Enabled
LLC Prefetch	Enabled
Dead Line LLC Alloc	Enabled
Directory AtoS	Disabled
AVX P1	Normal
SST-Performance Profile	Operating Point 2 | P1: 2.3 GHz, TDP: 320W, Core Count: 144
x2APIC Mode	Enabled
AVX ICCP Pre-Grant License	Disabled
Number of Cores per Processor	All
CPU Physical Address Limit	Enabled
Processor Core Speed	2.30 GHz
Processor Bus Speed	24 GT/s
Local Machine Check Exception	Enabled
Family Model Stepping	6-AF-3
Brand	Intel® Xeon® 6780E
Level 2 Cache	144x1MB
Level 3 Cache	108 MB
Number of Cores	144
Microcode	0x3000190
System Profile	Custom
CPU Power Management	OS DBPM
Memory Frequency	Maximum Performance
Turbo Boost	Enabled
Energy Efficient Turbo	Disabled
Memory Patrol Scrub	Standard
Memory Refresh Rate	1x
Uncore Frequency	Dynamic
Dynamic Load Line Switch	Enabled
Energy Efficient Policy	Performance
Monitor/Mwait	Enabled
CPU Interconnect Bus Link Power Management	Disabled
PCI ASPM L1 Link Power Management	Disabled
Workload Configuration	IO Sensitive

System Setup

The test setup incudes a Dell PowerEdge R770 server as a Single Node OpenShift (SNO) cluster, as part of a standard Red Hat OpenShift Platform configuration which consists of a single node that includes the functionality of control plane, master and worker nodes.

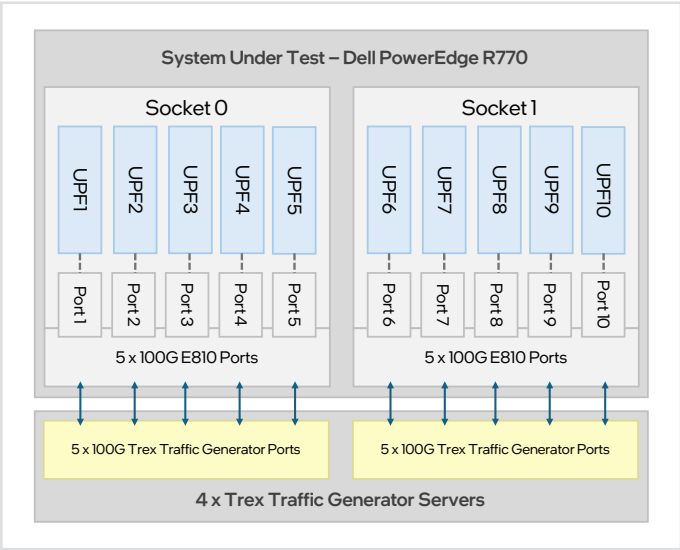


Figure 3. Dell PowerEdge R770 Server

The data network setup for the Dell PowerEdge R770 device-under-test (DUT) as a worker node in the single node RH OCP cluster is shown above in Figure 3. It also shows the TRex Traffic Generator servers which are connected back-to-back to the DUT, using 100 GbE Direct Access Cables.

The DUT needs to be configured with the required hardware components, software components and BIOS settings detailed on Page 3.

5G UPF Traffic Profile Configuration

The following table outlines the key parameters and their corresponding values used to establish a representative 5G traffic environment for UPF performance evaluation.

Parameter	Configuration
Number of UEs	12,500 per UPF x10 UPFs = 125,000
Flows per UE	10
PDU Sessions per UE	1
Packet Detection Rules (PDRs)	20 (10 UL / 10 DL)
Forwarding Action Rules (FARs)	2
Quality Enforcement Rules (QERs)	2 per PDR
Usage Reporting Rules (URRs)	3 per PDR
Uplink/Downlink (UL/DL) Ratio	1:3

5G FlexCore 2.0 UPF Benchmarks

This section shows the benchmarks of 5G FlexCore 2.0 UPF with Red Hat OpenShift Container Platform on a 2-socket Dell PowerEdge R770 as a worker node server with two Intel Xeon 6780E processors. Each processor has 144 cores, 144 threads, a processor base frequency of 2.3 GHz, a maximum turbo frequency of 3 GHz, PCI Express Revision 5.0, a maximum number of PCIe lanes of 88 and TDP of 320 W per processor.

Using the 2-socket Dell PowerEdge R770, this results in a total of 288 cores. Only 160 cores (80 cores from each NUMA node) out of 288 cores are being used to run this workload. The remaining 128 cores are available for the OS and other applications. All active cores were at a core utilization of lower than or equal to 75%. The first 10 cores in each NUMA node were reserved for the OS. To achieve deterministic performance, UPF application cores and remaining unused cores were isolated from the kernel general scheduler by using the "isolcpus" option in the grub command line.

The pie chart below shows the number of cores that were allocated to the OS and the UPF pods. The remaining cores are shown as unused cores which are available for other workloads or applications.

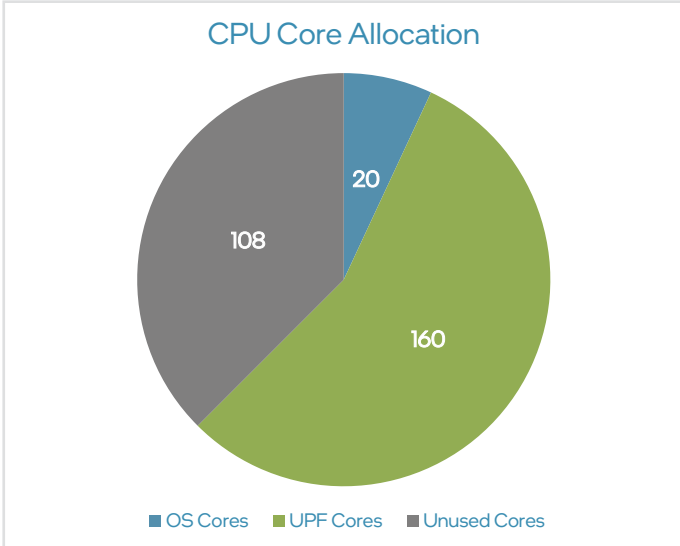


Figure 4. CPU Core Allocation

The maximum throughput is therefore IO-limited not core-bound. Depending on available PCIe risers and ability to add more PCIe NICs, potentially a much higher IO throughput can be achieved, as a significant number of cores are unused.

The benchmarks using Intel Infrastructure Power Manager with the IPM agent running are compared with benchmarks without the IPM agent on Pages 5 and 6.

I/O Throughput with and without IPM

The results of the 5G FlexCore 2.0 UPF in a Red Hat OpenShift Container Platform worker node showed an I/O throughput of up to 930 Gbps using IPM, with minimal throughput changes and a packet loss of 0% using a packet size of 650 Bytes.

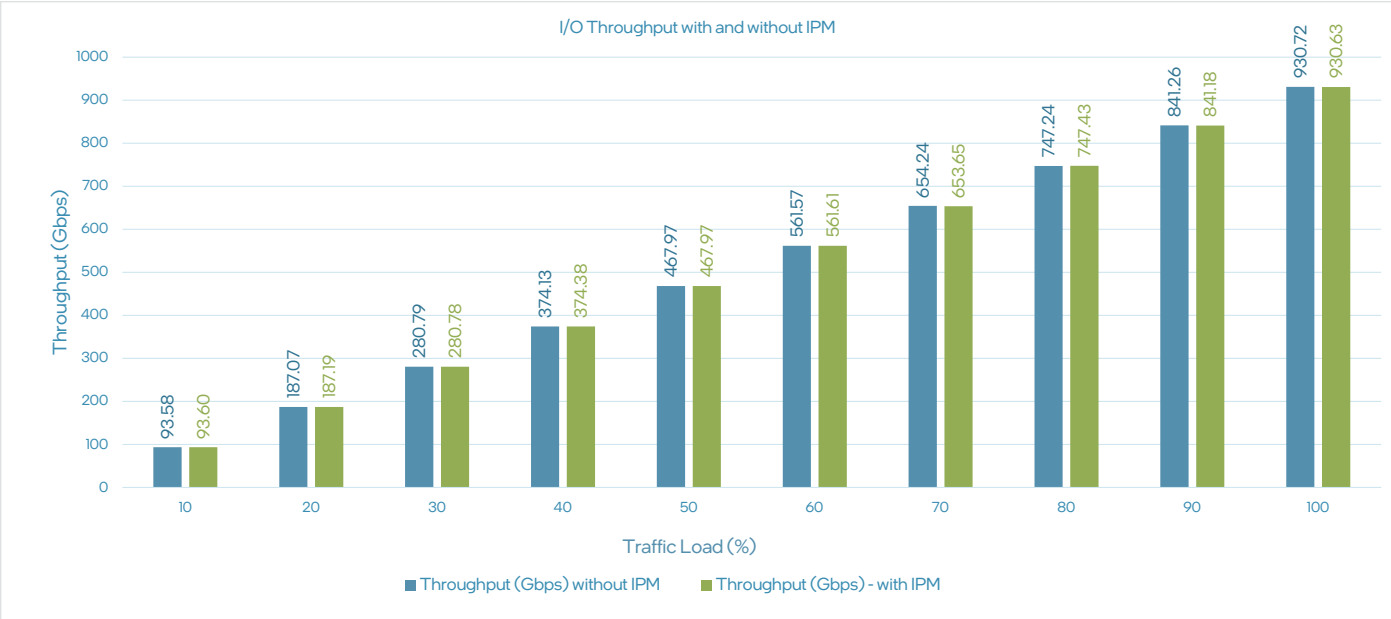


Figure 5. FlexCore 2.0 UPF Throughput (Gbps) with and without IPMs

I/O Throughput with and without IPM

The results of the 5G FlexCore 2.0 UPF using a realistic 75% traffic profile with a packet loss of 0% using a packet size of 650 Bytes, with and without IPM, demonstrated minimal IPM impact on throughput, as demonstrated in the chart below which shows I/O throughput achieved with and without IPM, using a telco 24-hour traffic profile.

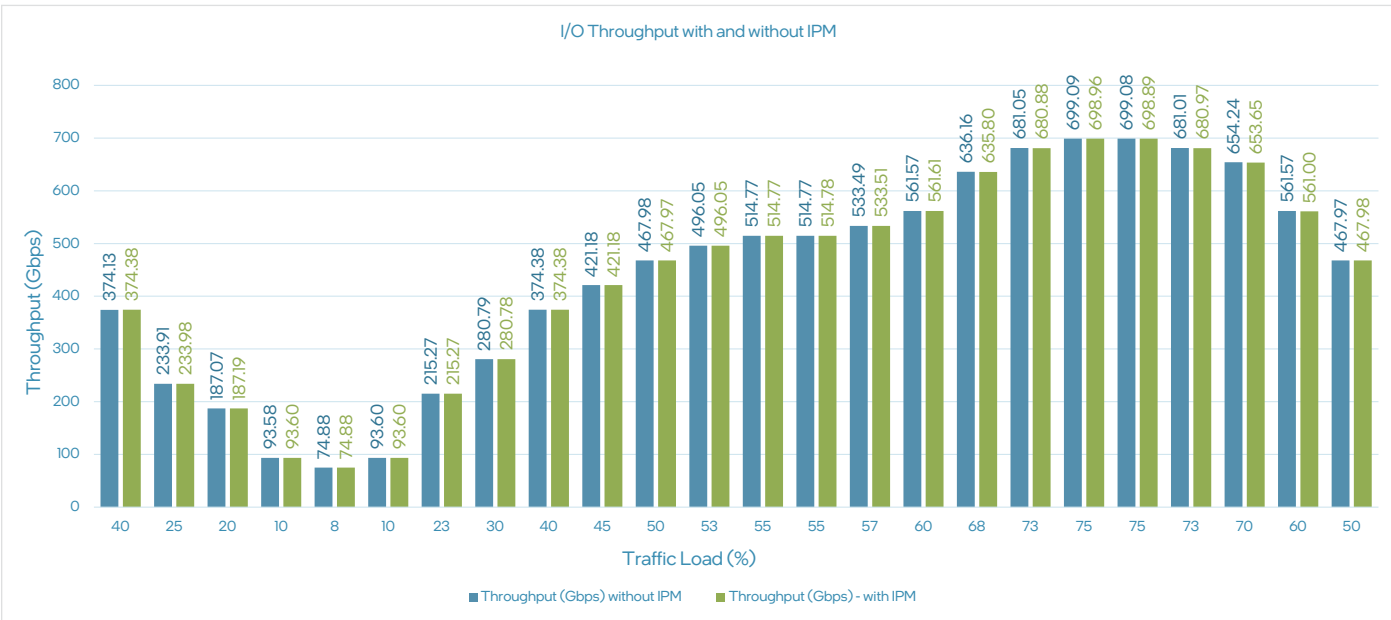


Figure 6. FlexCore 2.0 UPF Throughput (Gbps) with and without IPM

Power Usage with 24-hour Traffic Profile

The results of the 5G FlexCore 2.0 UPF benchmarks in a RH OCP worker node with and without IPM, using a realistic 75% traffic profile, showed an average 38.4% power savings with IPM, with a packet loss of 0% and a packet size of 650 Bytes. Using IPM which leverages the DPDK telemetry cores "busyness" to determine actual CPU load for the monitored active UPF worker cores, the CPU frequency was downshifted or upshifted by IPM, depending on the core utilization which changed based on the traffic load percentage, resulting in much lower power consumption and impressive energy efficiency.

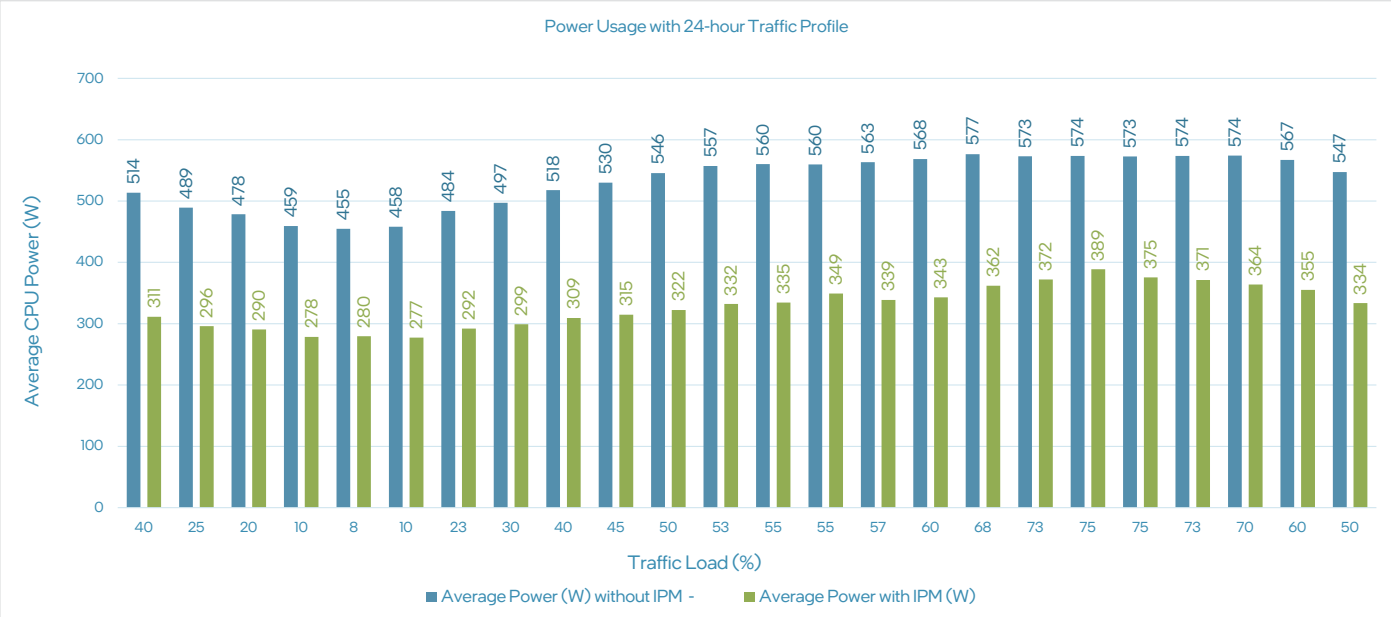


Figure 7. Server Power Savings with 24-hour traffic profile using IPM

Key Outcomes:

- **High Throughput:** Achieved up to 930.7 Gbps (over 93% of line rate) on a 2-socket Dell PowerEdge R770 with Intel Xeon 6780E processors running FlexCore 2.0 UPF on Red Hat OCP 4.16, with 650-byte packets and zero packet loss.
- **Significant Power Savings:** Realized an average 38.3% power reduction under a realistic 24-hour telco traffic profile, and up to 41% power savings at idle, with minimal to no impact on I/O throughput.
- **Intelligent Power Management:** Power efficiency gains driven by:
  - **Dynamic CPU Frequency Scaling:** Intel Infrastructure Power Manager (IPM) dynamically adjusted P-states based on UPF core utilization.
  - **Uncore Frequency Reduction:** A static reduction in uncore frequency further improved energy efficiency.
  - **Resource Efficiency:** Only 160 out of 288 available cores were used for UPF workloads, demonstrating ample processing headroom for additional functionalities or expansion, while still maintaining strong performance and energy savings.

Conclusion

This Intel Verified Reference Configuration defines the hardware, software, and BIOS settings required for a 5G UPF workload on a Dell PowerEdge R770 server with Intel Xeon 6 processors. Optimized for network virtualization and microservices, the platform leverages Dell Open Server Manager built on OpenBMC™ to enhance adaptability and interoperability.

Under testing, the Dell PowerEdge R770 with Intel Xeon 6780E processors and Intel Network Adapters achieved up to 930 Gbps (93% line rate) at 650-byte packets with zero packet loss, regardless of Intel Infrastructure Power Manager (IPM) usage. With IPM enabled, power savings reached a maximum of 41% and averaged 38.4% without impacting throughput or packet loss. By dynamically adjusting CPU core power based on DPDK telemetry, IPM ensures optimal efficiency for next-generation 5G deployments, supporting both high performance and sustainability goals.

Learn More

Dell PowerEdge R770 Server

Red Hat* OpenShift Container Platform 4.16

Intel® Xeon® 6 Processors

Intel® Infrastructure Power Manager 24.08 Release

Intel® Ethernet E810 Network Adapters

Intel® Verified Reference Configurations

Notices & Disclaimers

Availability of accelerators varies depending on SKU. Visit the Intel Product Specifications page for additional product details.
Performance varies by use, configuration and other factors. Learn more at www.Intel.com/PerformanceIndex.
Configuration: Test by Intel as of 11/21/2024. 1-node, 2x Intel(R) Xeon(R) 6780E, 144 cores, 320W TDP, HT N/A, Turbo On, Total Memory 1024GB (16x64GB DDR5 6400 MT/s [6400 MT/s]), BIOS 1.0.1, microcode 0x30001b3, 10 x Ethernet Controller E810-C for QSFP, 1x 28.6G SanDisk 3.2Gen 1, 1x 894.2G Dell BOSS-N1, 4x 1.7T Dell NVMe PM1743 RI E3.S 1.92TB, Red Hat Enterprise Linux CoreOS 416.94.202408132101-0, 5.14.0-427.31.1.el9_4.x86_64
Performance results are based on testing as of dates shown in configurations and may not reflect all publicly available updates. See configuration disclosure for configuration details.
No product or component can be absolutely secure.
Intel does not control or audit third-party data. You should consult other sources to evaluate accuracy.
Your costs and results may vary.
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