Qualcomm Centriq 2400 Server TCO

Methodology & Assumptions

Series sponsored by
Qualcomm Datacenter Technologies (QDT)

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Abstract

This document details the methodology and assumptions used in support of a series of TCO comparison papers. Each TCO paper highlights notable differences between servers based on the Qualcomm Centriq 2400 Armv8 instruction set architecture (ISA) system-on-chip (SoC) and the Intel x86 ISA Xeon Scalable processor for each application tested. This document also describes the baseline configurations, commonalities, and differences among both architectures' underlying hardware and software configurations, as well as the testing methodology and assumptions.

The primary target audiences for the TCO comparison papers are cloud IT datacenters with fixed rack-level power delivery, such as mid-sized public cloud, managed services, and hosting datacenters.

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Table 1: Qualcomm Centriq 2400 & Intel Xeon Scalable Processor Specifications

	Qualcomm Centriq 2452	Intel Xeon Silver 4110	Intel Xeon Gold 5120
Core Generation	Falkor	Skylake	Skylake
Cores / Threads	46 / 46	8 / 16	14 / 28
Base Speed	2.2 GHz	2.1 GHz	2.2 GHz
All Core Turbo Speed	2.6 GHz	2.4 GHz	2.6 GHz
Last Level Cache	57.5 MB	11 MB	19.25 MB
Process	10 nm	14 nm	14 nm
Specified TDP	120 W	85 W	105 W
Production Date	November 2017	July 2017	July 2017

Sources: Qualcomm Datacenter Technologies & TIRIAS Research (See Appendix for notes regarding all Figure & Table sources)

Qualcomm Centriq 2400 Processors

The Qualcomm Datacenter Technologies (QDT) Falkor single-threaded Armv8 core implements the Armv8 RISC instruction set (AArch64 only, with no native 32-bit instructions) including advanced floating point with single instruction multiple data (FP/SIMD) extensions. FP/SIMD was an add-on accelerator called NEON in earlier Arm architectures.

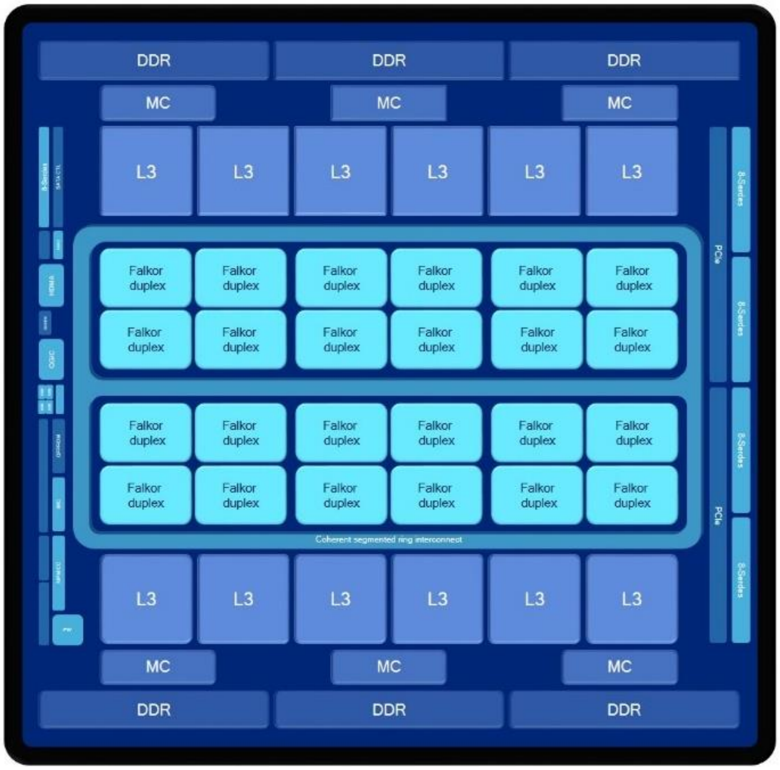
Because the Falkor core is single-threaded, 64-bit only, and is not cluttered with decades of instruction set extensions, it is a simpler design that uses fewer transistors than mainstream x86 cores. Simpler design and a 10 nanometer manufacturing process result in the ability to design many more cores into a system-on-chip (SoC).

Figure 1: Qualcomm Centriq 2400 Processor (Top & Bottom)

Source: TIRIAS Research

The Qualcomm Centriq 2400 family of server SoCs includes 48-, 46-, and 40-core variants. A 48-core Qualcomm Centriq 2400 SoC with all good L3 cache (60 MB) was configured to emulate a 46-core Qualcomm Centriq 2452 with 57.5 MB L3 cache for this series of papers.

Figure 2: Qualcomm Centriq 2400 Block Diagram



Source: Qualcomm Datacenter Technologies

Intel Xeon Scalable Processors

The Intel 'Skylake" generation of multithreaded, super-pipelined, super-scalar x86 core designs carry the burden of decades of legacy architectural decisions and instruction set extensions. They must be 32-bit backward compatible because of the installed base of legacy business applications. Legacy market requirements contributed greatly to Intel's decision to scale up core complexity and increase core transistor count using multithreading instead of scaling out core count; scaling out core count is more difficult with larger, more complex cores.

These tests compare the Qualcomm Centriq 2400 with either the 8-core / 16-thread Intel Xeon Silver 4110 processor or the 14-core / 28-thread Intel Xeon Gold 5120 processor. These Intel Xeon Scalable processor models are representative of the processors often purchased by cloud customers to run the types of workloads represented by the benchmarks.

Intel processors were configured for all cores to be enabled and to enable turbo mode and multithreading for all cores.

Configurations

Chassis used in this series of comparisons were configured to be as equal as possible (Table 2).

The SPECrate2017_int_base benchmark suite was run on a Qualcomm Centriq 2400 software development platform (SDP), not on a Reference Evaluation Platform (REP). The two platforms share the same logical design, but the layout of the SDP is more spacious and includes many more test points and circuitry for measuring current, voltage, and temperature. QDT considers SDP performance to conservatively represent REP performance, because the REP design has gone through many revisions to correct signal integrity and speed path flaws, whereas the SDP design has remained static. For the purposes of this TCO evaluation, the REP was used to calculate a TCO for the SPECrate2017_int_base Qualcomm Centriq 2400 estimated results.

Table 2: Qualcomm Centriq 2400 & Intel Xeon Scalable Configurations

	Qualcomm Centriq 2400 Configuration		Intel Xeon Scalable Configuration	
Chassis / Mother-board	Qualcomm Centriq 2400 Software Development Platform (SDP)	Qualcomm Centriq 2400 Reference Evaluation Platform (REP)	Supermicro SYS-6029P-WTR (Intel Purley Platform)	Supermicro SYS-6029P-WTR (Intel Purley Platform)
Processor	2452	2452	Silver 4110	Gold 5120
Processor Sockets	1	1	2	2
Chipset	n/a	n/a	Intel C621	Intel C621
Firmware	QDF2400.FW.2.0.r1-00616-QDF2400_REL-1	QDF2400.FW.2.0.r1-00651-QDF2400_REL-1	AMI 1.0a, 6/23/2017	AMI 1.0a, 6/23/2017
Chassis Height	2U	1U	2U	2U
NIC	Mellanox ConnectX-4 Lx 1-port 50 GbE SFP28	Intel XL710 2-port 40 GbE QSFP+	Mellanox ConnectX-4 Lx 1-port 50 GbE SFP28	Intel XL710 2-port 40 GbE QSFP+
Memory	32 GB 2667 MHz Micron 36ASF4G72PZ-2G6D1	32 GB 2667 MHz Micron 36ASF4G72PZ-2G6D1	32 GB 2400 MHz Micron 36ASF4G72PZ-2G6H1R	16 GB 2400MHz Samsung M393A2K40BB2-CTD
SSD	Intel SSDSC2BB48 480 GB 6 Gbps SATA	Intel SSDSC2BB48 480 GB 6 Gbps SATA	Intel SSDSC2BB48 480 GB 6 Gbps SATA	Intel SSDSC2BB48 480 GB 6 Gbps SATA

Source: Qualcomm Datacenter Technologies

DDR Memory

- All configurations operate using 1 DIMM per channel timings. For the Supermicro Intel Xeon Scalable configurations, 2667 MHz DDR was used, but the selected Intel Xeon Scalable processors' memory controllers are limited to 2400 Mhz.
- The Qualcomm Centriq 2452 SoC and motherboards have 6 memory channels using 32 GB DIMMs at 2667 MHz for 192 GB total.
- Although the Supermicro 2P Intel Xeon Silver 4110 has 12 memory channels using 32 GB DIMMs for 384 GB total, the HHVM benchmark has fixed memory requirements and uses less than 192 GB, making it equivalent to the QDT configurations' 192 GB.
- The Supermicro 2P Intel Xeon Gold 5120 configuration has 12 memory channels. The Redis tests used 16 GB DIMMs for 192 GB total (equivalent DDR size to the QDT configurations) and SPEC CPU2017 testing used 32 GB DIMMS for 384 GB total.

Storage

- The same SSD drive was used in all configurations. The SSD is used for both the OS and user data. All 4 benchmarks are not disk intensive, so additional storage was not needed.

SoC Capabilities

- The Qualcomm Centriq 2400 does not require a chipset, because it is a bootable SoC.

Networking

- Both the Qualcomm Centriq 2400 REP and the Supermicro Intel Xeon Gold 5120 configurations under test leveraged the same XL710 40 GbE NIC. Only RedisBench used network connectivity.

Power Management

- Settings were configured for low-latency and high-performance modes.

Qualcomm Centriq 2400 Configuration

QDT started shipping Qualcomm Centriq 2400 processors to customers for revenue in November 2017. HPE announced support for Qualcomm Centriq 2400 and should bring servers to market in the first half of 2018.

The Qualcomm Centriq 2400 Reference Evaluation Platform (REP) uses the Qualcomm Centriq 2400 Open Compute Motherboard (OCM) for Project Olympus (Revision 0.5; Feb 17, 2017). Project Olympus is a specification fork of the Open Compute Project (OCP).

QDT used a 48-core Centriq 2460 and disabled two cores and 2.5 MB of L3 cache by using the UEFI device manager (Modify Shared Variables). Both the UEFI CPU mask and L3 cache mask fields were modified to emulate a Qualcomm Centriq 2452.

The Qualcomm Centriq 2400 REP uses a single 750 W power supply (non-redundant). QDT used a single 1150 W power supply (also non-redundant) for two motherboard REP configurations, but all configurations under test were configured with only one motherboard.

Figure 3: Qualcomm Centriq 2400 OCM for Project Olympus with NIC

Source: TIRIAS Research

Intel Xeon Scalable Configuration

All Intel Xeon Scalable performance and power measurements were taken from two Supermicro SuperServer 6029P-WTR chassis ordered from Supermicro with the components listed above.

The motherboard in each chassis had either two Intel Xeon Silver 4110 processors or two Intel Xeon Gold 5120 processors. This series of TCO comparisons compares dual-socket Xeon Scalable motherboards to single-socket Qualcomm Centriq 2400 motherboards. TIRIAS Research extrapolated Qualcomm Centriq 2452 single-socket measurements to estimate performance and power consumption for two single-socket motherboards in a chassis.

Supermicro's SuperServer 6029P-WTR ships with dual 1000 W (redundant) power supplies.

Software

Table 3: Qualcomm Centriq 2400 & Intel Xeon Scalable Software

	Qualcomm Centriq 2400	Intel Xeon Scalable
Operating System	CentOS 7.3 (1611 AltArch)	CentOS 7.4 (1708)
Linux Kernel	4.11.0-0918.el7.5925f7b4.aarch64	3.10.0-693.2.2.el7.x86_64
Linux File System	CentOS 7.3.1611	CentOS 7.4.1708
Compiler	SPEC CPU2017: GCC 7.1.1 Other Benchmarks: 4.8.5 20150623 (Red Hat 4.8.5-16)	SPEC CPU2017: GCC 7.1.0 Other Benchmarks: 4.8.5 20150623 (Red Hat 4.8.5-16)

Source: Qualcomm Datacenter Technologies

The only reason that different OS / kernel versions were used is simply that QDT used the most current released CentOS distributions for each instruction set evaluated: Qualcomm Centriq 2400 uses AArch64, and Intel Xeon Scalable uses x86.

CentOS defaults are 4K pages for Intel Xeon Scalable and 64K pages for Qualcomm Centriq 2400. All tested configurations (except Redis) used transparent huge pages (THP) set to always.

The HHVM and Redis benchmarks used GCC 4.8.5, because it was included in the CentOS distribution that was included with the Supermicro configurations purchased. SPEC CPU2017 specifies GCC 7.1.x (Table 3).

QDT updated the kernel used for Centriq 2400 benchmarks to the most current version available prior to Spectre and Meltdown patches. Likewise, QDT used an unpatched Linux kernel, distributed with version of CentOS Linux tested, to run the Intel Xeon Scalable benchmarks.

Performance Measurement Methodology

Individual performance benchmarks are described, each in its own paper. Every data point in each benchmark was measured at least three times. The geometric mean of the runs was used as the final data point for comparisons.

For Redis testing, QDT used a Mellanox SN2700 32-port 100GbE Open Ethernet Switch configured for non-blocking connectivity to connect the Supermicro Intel Xeon Silver 4110 and Intel Xeon Gold 5120 configurations. QDT used an HPE Intel Xeon 2699v4 Redis chassis used to generate client queries. The negotiated data rate between the chassis and switch was 25 Gbps.

QDT used a Mellanox SN2100 half-width 16-port non-blocking 100 GbE Open Ethernet Switch to connect the Qualcomm Centriq 2400 REP chassis at negotiated 40 Gbps data rates. The SN2100 switch connected into the SN2700 switch with a negotiated data rate between the switches of 100 Gbps.

The Mellanox SN2100 and SN2700 switches were connected directly to each other via 100 GbE and are non-blocking, so any other traffic present in the switches would not have affected the benchmarks. These switches are representative of the types of switches used in cloud datacenters.

Power Measurement Methodology

Power measurements for all configurations under test were confined to the processor SoC. Power measurements also excluded memory power consumption.

Power consumption was measured during each performance analysis run. Power measurement started at the beginning of each sub-benchmark and stopped at the end of each test. The geometric mean of power runs for each sub-benchmark were used to calculate each sub-benchmark's score. The combined power measurement for each benchmark was calculated as the arithmetic mean of sub-benchmark power measurements.

Intel Xeon Scalable processor power was measured using Intel's Performance Counter Monitor (PCM) power utility. This utility reports energy consumed by the Skylake SoC every second.

Qualcomm Centriq 2400 processor power consumption was measured via a script that reads SoC power from the motherboard baseboard management controller (BMC) over the LAN using the IPMI sensor data record (SDR) command.

Qualcomm Centriq 2400 and Intel Xeon Scalable power consumption was measured internally on typical material at room temperature.

Qualcomm Centriq 2400 Power Measurement

The Qualcomm Centriq 2400 OCM for Project Olympus motherboard uses an ASPEED AST2520 BMC that receives energy consumption samples from the Qualcomm Centriq 2400 SoC. Measurement is performed via sensors measuring voltage and current supplied by voltage regulators and estimation for other power supply chips.

Intel Xeon Scalable Power Measurement

Intel Xeon Scalable processor complex power consumption was measured using Intel's PCM power utility. The Intel C621 PCH (southbridge) power consumption is specified at 15 W but was estimated at 4 W while running the SPECint_rate2006 benchmark suite (the suite incurs minimal I/O and network traffic); that figure was used as the typical power consumption for the Intel C621 PCH.

TIRIAS Research Fairness Assessment

TIRIAS Research evaluated the performance and power measurement methods described above and found those methods to be a fair basis for comparison of architectures. Each of the TCO comparison papers describes the specifics for analyzing an individual benchmark.

For the SPEC CPU2017 and Redis benchmarks, QDT chose to use marginally faster memory in its own configurations at a significant price premium to the Intel Xeon Scalable configurations. For Redis, QDT chose to use twice the memory per socket with its motherboard as was configured in the Intel Xeon Scalable chassis for Redis. These choices favor Intel's performance per dollar results.

QDT supplied TIRIAS Research with the raw power and performance measurements used to create the tables and charts in the TCO comparisons.

TCO Methodology

TIRIAS Research extrapolated the costs, power consumption, and performance of a Qualcomm Centriq 2400 REP chassis containing one single-socket motherboard to estimate the costs, power consumption, and performance of the same chassis housing two single-socket motherboards.

- Cost extrapolation: One Qualcomm Centriq 2400 motherboard as tested was multiplied by two, the cost of a NIC was subtracted ($15 was added for a NIC riser and an OCuLink connector to share the NIC between the boards), and the chassis configured with one SSD per motherboard (maintaining one SSD per motherboard for performance equivalence).
- Power extrapolation: Typical power consumption per component was used (Table 6), along with the measured power for Qualcomm Centriq 2400 SoC and Intel Xeon Scalable in each benchmark (described in each TCO document).
- Performance extrapolation: Measured performance of one single-socket motherboard Qualcomm Centriq 2400 REP configuration was doubled for each benchmark (described in each TCO document). As none of the benchmarks saturated the NIC, this is a reasonable extrapolation.

The extrapolation for two Qualcomm Centriq 2400 motherboards in a single chassis was used to normalize TCO comparisons with one dual-socket Intel Xeon Scalable motherboard in a chassis.

TIRIAS Research then scaled the chassis-level comparisons to a rack-level comparison.

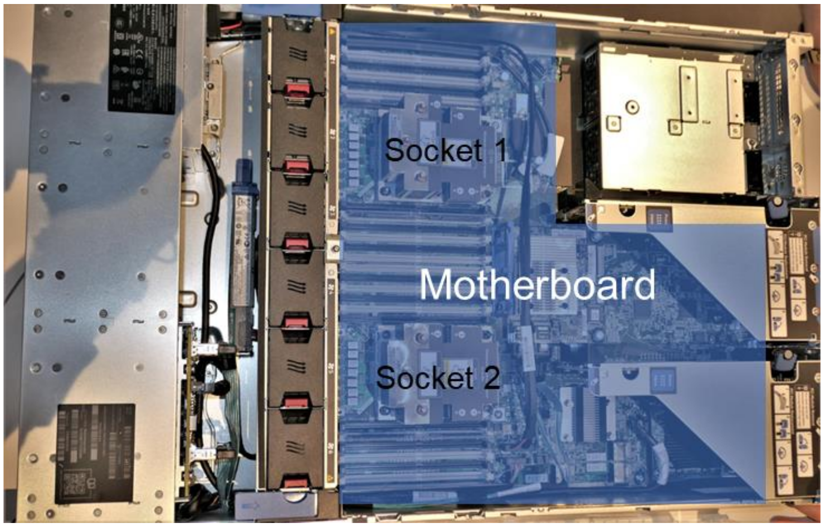
TIRIAS Research reduces TCO analysis to a minimum set of variables that highlight useful differences between products. For server processor TCO calculations, TIRIAS Research reduces the number of constants that apply to all chassis configurations in the comparison. Because processors cannot run workloads without the rest of a functioning server, TIRIAS Research:

- Assembled a representative low-volume bill of materials for a functioning server to obtain capital expense (Capex) estimates (Tables 4 & 5).
- Burdened the measured power consumption by adding estimates of typical power consumption for the rest of a functioning server chassis' components to obtain operating expense (Opex) estimates (Table 6).

The analysis does not extend the TCO estimate beyond evaluating some simple rack-scale metrics, because assuming fixed power distribution to each rack also assumes use of identical switch, power distribution, cabling, and rack costs for both Qualcomm Centriq 2400 and Intel

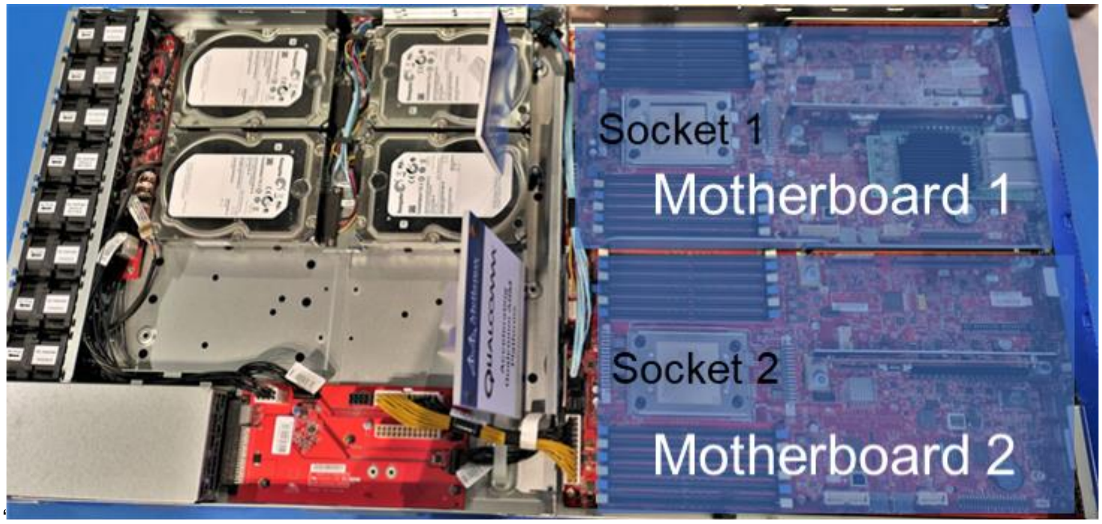
Xeon Scalable chassis. Given that memory, network, and storage components have fixed power consumption and costs between all the platforms tested, adding more of them to a comparison would obscure differences in processor and motherboard pricing and power consumption. These comparisons use a nominal set of components at low-volume prices (Table 4) to enable realistic baseline TCO comparisons at chassis and rack levels.

Figure 4: One Dual-Socket Motherboard (HPE DL380 Gen10)



Source: TIRIAS Research

Figure 5: Two Single-Socket Motherboards (Qualcomm Centriq 2400 REP)



Source: TIRIAS Research

The REP chassis (Figure 5) has a longer, cloud form factor chassis than the Supermicro chassis tested (Figure 4 shows a generic example of a shorter enterprise form factor chassis).

Capital Expense (Capex)

One-time server acquisition costs are amortized over a three-year refresh cycle.

The analysis does not adjust for datacenter infrastructure and physical provisioning costs, such as floorspace. These vary widely by region and by size of installation.

This analysis does not assume a discount from low-volume component pricing. If an aggressive cloud-scale high-volume price discount were used, it might overemphasize the TCO contribution of power consumption from the point of view of a Tier 2 cloud service provider or hoster.

Table 4: List Price for Each Component

	Qualcomm Centriq 2452	Intel Xeon Silver 4110	Intel Xeon Gold 5120
Processor	$1,373	$500	$1,555
Motherboard	$460	$763	$763
Chipset	n/a	$57	$57
NIC – Standard (one motherboard)	$180	$180	$180
NIC – Multi-host incl. adapter (two motherboard)	$360	n/a	n/a
Memory 32 GB	$352 / $298†	$298	$298
Memory 16 GB	n/a	n/a	$149††
SSD	$77	$77	$77
Power supply, fans, *etc*.	$290	$290	$290

†Redis & SPEC CPU2017 configuration: 6 x 32G B RDDR4-2667 DIMMs. HHVM configuration: 6 x 32 GB RDDR4-2400 DIMMs
††Redis

Sources: Qualcomm Datacenter Technologies, Intel, & Others

Table 5: Component Quantities per Chassis TCO Bill of Materials

	Qualcomm Centriq 2452 One Motherboard	Qualcomm Centriq 2452 Two Motherboards	Intel Xeon Silver 4110	Intel Xeon Gold 5120
Processor	1	2	2	2
Motherboard	1	2	1	1
Chipset	0	0	1	1
NIC – Standard (one motherboard)	1	n/a	1	1
NIC – Multi-host incl. adapter (two motherboard)	n/a	1	n/a	n/a
Memory 32 GB	6	12	12	12
Memory 16 GB	n/a	n/a	n/a	12
SSD	1	2	1	1
Power supply, fans, *etc*.	1	1	1	1

Source: Qualcomm Datacenter Technologies

Qualcomm Centriq 2400 motherboard costs and component redundancy in a two motherboard configuration result in a total motherboard cost about 22% higher than the cost of one dual-socket Intel Xeon Scalable motherboard. While the Qualcomm Centriq 2400 motherboard does not need the equivalent of Intel's C621 PCH southbridge chip, adding southbridge I/O pins to Qualcomm Centriq 2400 series processors means that the processor socket has more pins and is therefore more expensive. The motherboard has more layers to route the dense I/O from the socket to peripheral chips and sockets, and it requires power management integrated circuits (PMIC) chips that the Intel Xeon Scalable board does not need. A two motherboard Qualcomm Centriq 2400 configuration also requires adding a PCIe socket riser to connect a multi-host NIC and an OCuLink connector to connect the NIC to both boards.

Benchmarking does not require a full complement of storage drives. All benchmarks load test data from storage drives but then run tests directly from memory, ignoring any storage drives. HHVM and Redis are in-memory applications and require little local storage capacity. This analysis includes a nominal complement of one SSD per motherboard in the TCO calculations to load configuration cost and power consumption to nominal but realistic levels.

Assumed pricing for memory and flash (low quantity) in 2H2018:

- DDR4 2400 at $9.31 / GB using 16 GB DIMMs
- DDR4 2667 at $11.00 / GB using 32 GB DIMMs (equivalent to DDR4 2400 today)
- M.2 SSD at $0.30 / GB using 256 GB drives

Operating Expense (Opex)

Power Consumption & Rates

- Electricity cost basis of $0.0727 per kilowatt hour (kWh)
  - US Department of Energy, US Energy Information Administration, Electricity Data Browser, Sales of electricity (EIA 826/EIA 861): Average retail price of electricity, 5.3 Average retail price of electricity to ultimate customers: total by end use sector, Industrial sector 2017Q3
- Includes electricity costs for every hour of entire three-year TCO period
- Includes estimated PUE of 1.45 as representative of Tier 2 datacenters
- Implements baseline assumptions and equations for calculating the infrastructure cost of supplying electricity (including financing and depreciation) and for burdening the direct cost of electricity with PUE and critical load usage as described in James Hamilton's Overall Data Center Costs.

Table 6: Power Consumption for Each Component in Watts (W)

	Qualcomm Centriq 2400		Intel Xeon Scalable	
	Specified	Typical	Specified	Typical
Processor	120	Unique per Benchmark	85 / 105	Unique per Benchmark
Chipset	n/a	n/a	15	4
NIC – Standard	10	6.5	10	6.5
NIC – Multi-host	14	10.5	n/a	n/a
Memory DIMM	7.5	3.5	7.5	3.5
SSD	7.5	6	7.5	6
Motherboard, fans, *etc*.	120	80	225	135

Sources: Qualcomm Datacenter Technologies, Intel, Mellanox, & other manufacturers

TIRIAS Research estimates the power consumption of all the non-processor components as a burden on the measured processor power consumption to estimate a realistic total power consumption for each benchmark.

Enablement Infrastructure

Both SparkBench and Redis clients ran CentOS 7.3.1611 with multithreading and turbo mode enabled, along with low-latency, high-performance processor profile.

Redis

The Redis client was an HPE DL380 Gen9 with a single Intel Xeon E5-2699v4 (Broadwell generation) 22-core / 44-thread processor. Table 7 shows configuration details.

A Mellanox ConnectX-4 Lx (40/50GbE Single QSFP28) NIC was used in the DL380 with a negotiated speed of 25 Gbps to a Mellanox SN2700 switch (described above).

Table 7: Redis Client Specifications

	Redis Client
Processor Model	Intel Xeon 2699v4 (Broadwell)
Chassis / Motherboard	HPE ProLiant DL360 Gen9
Processor Sockets	1
NIC	Mellanox ConnectX-4 Lx 1-port 50 GbE SFP28
Memory	8x 32 GB DDR4-2400 2 DIMMs / channel
SSD	HP VK0480GFLKH 480 GB
Firmware	HPE U32 (8/18/2017)
OS	CentOS 7.4.1708
Linux Kernel	3.10.0-693.2.2.el7.x86_64
GCC	4.8.5 20150623 (Red Hat 4.8.5-16)

Source: Qualcomm Datacenter Technologies

General

Where not specified, all other variables are assumed to be equal, for example labor, datacenter floorspace, business insurance, *etc*.

Appendix

Figure & Table Sources

Unless otherwise noted, all Figures and Tables are based on Qualcomm Datacenter Technologies (QDT) benchmark measurements, Qualcomm Centriq 2400 SoC and motherboard specifications, public competitive processor, motherboard, and chassis specifications, and TIRIAS Research calculations and formatting.

IPMI power measurement script for Qualcomm Centriq 2400 configurations

while :; do { sudo ipmitool -I lanplus -H 10.228.208.205 -U admin -P Password1 sdr | grep "SoC Power"; date; } | tr "\n" " "; echo ""; done

PCM power measurement process and scripts for Intel Xeon Scalable configurations

Source: git clone https://github.com/opcm/pcm

All commands must be run as sudo

On fresh reboot you must execute the two following commands:

modprobe msr #modprobe is required on Ubuntu, but not CentOs

echo 0 > /proc/sys/kernel/nmi_watchdog

For logging power on simple command line test (as defined by $TEST below) use the following syntax:

./opt/pcm/pcm.x 1 -nc -csv=$POWER_LOG_FILE.csv -- $TEST

This will log at a 1 second interval, keeping only the socket data, and formatting as a csv to the file $POWER_LOG_FILE.csv

For logging power on benchmarks that are driven by an external client, start the power logging process on the configuration under test, run the test, then terminate the logger once the test concludes.

Before test run:

ssh -f rtpperf-SUT "sudo /opt/pcm/pcm.x 1 -nc -csv=$POWER_LOG_FILE.csv "

After the test completes run:

ssh rtpperf-SUT "sudo pkill pcm.x"