Western Europe Cloud Service Provider Analysis

Amazon Web Services, Microsoft Azure, Google Compute Engine and T-Systems' OTC

Prepared for T-Systems by Cloud Spectator LLC

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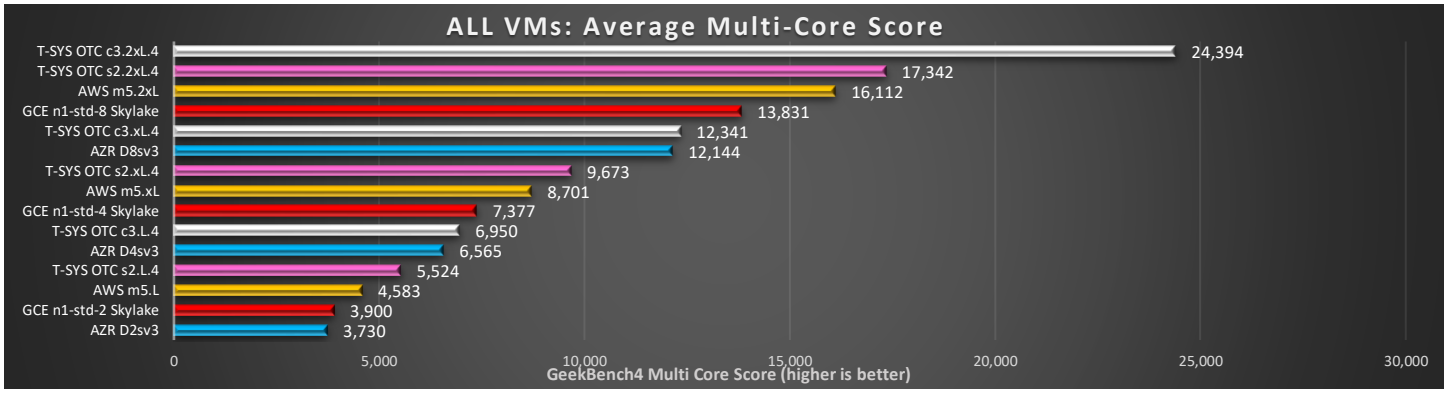
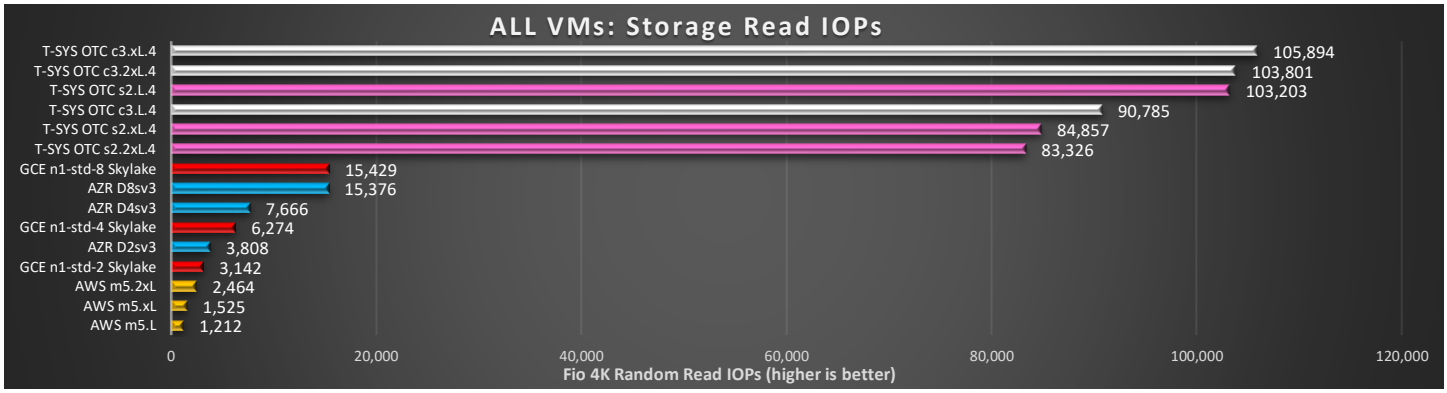
Executive Summary

T-Systems commissioned Cloud Spectator to evaluate the performance of virtual machines (VMs) in Western Europe on four different Cloud Service Providers (CSPs/providers): Amazon Web Services (AWS), Microsoft Azure, Google Compute Engine (GCE) and T-Systems' Open Telekom Cloud (OTC). Cloud Spectator tested three VM sizes with 2, 4 or 8 vCPUs and 1:4 vCPU to RAM ratios to evaluate CPU performance, Random Access Memory (RAM) and block storage for each provider's VMs. The purpose of the study was to understand Cloud service performance among major Cloud providers with similarly-sized VMs using a standardized, repeatable testing methodology. Based on the analysis, T-Systems' OTC VM performance was superior in two of three performance dimensions, while providing the best overall blend of performance characteristics and value. The primary drivers for the OTC's strong performance were threefold, and mapped to key performance dimensions evaluated during this engagement:

1. T-Systems' OTC VMs displayed superior computational ability.



2. T-Systems' OTC Ultra-High I/O drives provided unrivaled read speed.



3. Resulting in the Open Telekom Cloud's excellent price-performance values (Figures 18.1, 20.1 and 21.1).

Key findings and observations from this analysis are highlighted below, with more detailed analysis following in the body of the report.

Key Findings and Observations

The following summary findings are noteworthy based on the testing performed by Cloud Spectator during this engagement:

Computational Performance

Computational performance was tested using the GeekBench4 test suite. The following highlights emerged from these tests:

- T-Systems' OTC s2 (general purpose) and c3 (dedicated general purpose) Elastic Cloud Server (ECS) lineups showed significant gains in performance compared to Azure's Dsv3, AWS' m5 and GCE's n1-standard Skylake platforms for all tested VM sizes.
- OTC s2 VMs achieved the greatest performance improvement among selected VMs when switching from single to multi-core workloads with raw multi-core performance second only to T-Systems dedicated c3 ECS's.
- T-Systems' OTC c3 ECS's are provisioned on dedicated host servers unlike s2 VMs. These machines therefore include a price premium to compensate for increased provider overhead. However, cost was found justified as c3 ECS performance surpassed larger Azure VMs without exception—displaying similar ability to GCE VMs equipped with doubled resources (i.e. vCPUs, RAM).

Storage Performance

Storage performance was tested with FIO (Flexible I/O Tester), and collected data was then evaluated. Notable 4K random read and write results are summarized below. More detailed analyses are discussed in the Storage Performance section of the report.

- T-Systems virtual machines equipped with SSD based Ultra-High I/O block storage posted 4K random read speeds exceeding 103,000 IOPs with associated minimum of 83,500. Machine size and threading had little effect on read values attained from this volume type.
- Read assessment revealed T-Systems' OTC Ultra-High I/O block storage performed operations with 7-85x improved efficacy compared to similar tiered solutions from AWS (EBS), Azure (Premium LRS) and GCE (Persistent SSD).
- Conversely, 4K random write analyses found GCE volumes with a 25-30% performance edge over T-Systems. AWS's EBS write performance benefitted from increased volume size, though remained slower than comparable T-Systems volumes among small and medium VMs.

Price-Performance

Price-Performance, or the performance per Euro spent of a given Cloud service is summarized below. Price-performance is calculated by simply dividing performance by the monthly price to determine how much computational power is obtained per euro spent. Price-performance is a value metric that shows how much performance is given per Dollar or Euro spent, higher scores indicate more value. The price-performance results are summarized below:

- T-Systems' OTC s2 ECS's reside on shared hosts with other virtual machines. Due to appropriate hyper-visor tuning, provisioning density and economical pricing, these machines attained excellent raw CPU performance, second only to T-Systems c3 VMs. Offering top price-performance for small and medium VM sizes.
- OTC c3 ECS's followed the s2 lineup in price-performance among 2 and 4 vCPU VMs tested while attaining the best value within the 8 vCPU VM group. This is despite the large price premium for dedicated virtual hosts.
- Although other providers may have had lower pricing for certain VMs, those machines were unable to deliver equally-adjusted computational performance, resulting in lower calculated value per Euro.
- Cloud Spectator's synthetic benchmark analysis determined that T-Systems' OTC displayed the highest computational and read value among evaluated solutions, while GCE delivered superior write performance value within each size category.

The details of the testing setup, design and methodology along with full results, are explained in the body of the report.

Introduction

T-Systems commissioned Cloud Spectator to assess the performance of virtual machines (VMs) from four different Cloud Service Providers (CSPs or providers) in Western Europe including: Amazon Web Services (AWS), Microsoft Azure (AZR), Google Compute Engine (GCE) and T-Systems' Open Telekom Cloud (OTC). Cloud Spectator tested various VMs from these providers to evaluate the computational and storage performance of each provider's VMs. The purpose of the study was to understand the VM performance between Cloud providers with similarly-sized VMs using a standardized and repeatable testing methodology. Performance information used for analysis of the specified 2, 4 and 8 vCPU VMs was obtained from Geekbench4 and FIO benchmarking tools. Each VM type was provisioned with a duplicate VM to limit sampling error. Data was then collected during 100 iteration tests.

This project focused on comparison of performance data for CPU, RAM and storage. The CPU-Memory composite and storage scores were evaluated on their own, and then were used to calculate the price-performance value for each provider VM offering. The price-performance value for each VM was calculated by dividing performance averages by monthly cost in Euros, with separate scoring performed for storage read and

write. This simple price-performance formula allows the comparison of VMs offered by the respective Cloud Service Providers included in this analysis.

Using this proven Cloud sampling and testing methodology, Cloud Spectator evaluated the Cloud services based on price-performance calculations, while detailing specific strengths and weakness of each provider's VMs based on the objective performance results. Given the inherent variability of Cloud services, these methods are necessary to provide reliable and comparable analyses of Cloud-based infrastructure-as-a-Service (IaaS) providers.

VM Specs and Selection Methodology

Virtual machines (VM) for this engagement focused on 2, 4 and 8 vCPU VMs. They were grouped and classified as small (2 vCPU), medium (4 vCPU) and large (8 vCPU) VM categories. All machines were deployed with a current release of Ubuntu 18.04 LTS from the respective providers. Persistent, premium block storage offerings were employed for all root volumes. Two general-purpose ECS types were supplied by T-Systems for study: the s2 lineup which reside on shared host servers, and non-over committed general purpose c3 series deployed on dedicated hardware. All VMs are targeted for general purpose workloads with 1:4 vCPU to RAM ratios.

The VMs selected for this engagement are listed in the tables below:

Provider	VMs	VM Class	vCPU	RAM (GB)	Disk (GB)	Storage Type	Location	Hourly Price €	Monthly Price €
Amazon Web Services	AWS m5.L	General Purpose	2	8	100	EBS SSD - gp2	Frankfurt	0.132 €	83.63 €
Google Cloud Platform	GCE n1-std-2 Skylake	General Purpose	2	8	100	SSD Persistent Disk	Frankfurt	0.129 €	81.62 €
Microsoft Azure	AZR D2sv3	General Purpose	2	8	128	Premium LRS	Netherlands	0.150 €	95.03 €
T-Systems Open Telekom Cloud	T-SYS OTC c3.L.4	Non-Overcommitted General Purpose	2	8	100	Ultra High I/O	Magdeburg	0.172 €	109.09 €
T-Systems Open Telekom Cloud	T-SYS OTC s2.L.4	General Purpose	2	8	100	Ultra High I/O	Magdeburg	0.129 €	82.08 €

Table 6.1 – Small VMs (2 vCPU)

Provider	VMs	VM Class	vCPU	RAM (GB)	Disk (GB)	Storage Type	Location	Hourly Price €	Monthly Price €
Amazon Web Services	AWS m5.xL	General Purpose	4	16	200	EBS SSD - gp2	Frankfurt	0.264 €	167.27 €
Google Cloud Platform	GCE n1-std-4 Skylake	General Purpose	4	15	200	SSD Persistent Disk	Frankfurt	0.258 €	163.87 €
Microsoft Azure	AZR D4sv3	General Purpose	4	16	256	Premium LRS	Netherlands	0.297 €	188.70 €
T-Systems Open Telekom Cloud	T-SYS OTC c3.xL.4	Non-Overcommitted General Purpose	4	16	200	Ultra High I/O	Magdeburg	0.343 €	217.45 €
T-Systems Open Telekom Cloud	T-SYS OTC s2.xL.4	General Purpose	4	16	200	Ultra High I/O	Magdeburg	0.260 €	164.89 €

Table 6.2 – Medium VMs (4 vCPU)

Provider	VMs	VM Class	vCPU	RAM (GB)	Disk (GB)	Storage Type	Location	Hourly Price €	Monthly Price €
Amazon Web Services	AWS m5.2xL	General Purpose	8	32	500	EBS SSD - gp2	Frankfurt	0.543 €	344.97 €
Google Cloud Platform	GCE n1-std-8 Skylake	General Purpose	8	30	500	SSD Persistent Disk	Frankfurt	0.523 €	331.91 €
Microsoft Azure	AZR D8sv3	General Purpose	8	32	512	Premium LRS	Netherlands	0.590 €	374.73 €
T-Systems Open Telekom Cloud	T-SYS OTC c3.2xL.4	Non-Overcommitted General Purpose	8	32	500	Ultra High I/O	Magdeburg	0.701 €	444.72 €
T-Systems Open Telekom Cloud	T-SYS OTC s2.2xL.4	General Purpose	8	32	500	Ultra High I/O	Magdeburg	0.534 €	338.87 €

Table 6.3 – Large VMs (8 vCPU)

The test design and methodology used in this analysis are described in the following sections.

Test Design and Methodology

The test design and methodology are described below for each of the VM performance dimensions evaluated including CPU, RAM, and storage random read/write. Synthetic testing was performed on the selected VMs to enable objective comparisons of performance.

Synthetic Testing: CPU & RAM

CPU and memory testing were conducted with the Geekbench4 benchmarking suite, which allows modern testing scenarios such as floating-point computations, encryption and decryption, as well as image encoding, life-science algorithms and other use cases.

Synthetic Testing: Storage

Storage results were obtained using FIO (Flexible I/O tester) using 4KB blocks and threads corresponding to vCPU count. Several hundred 60-second random iterations were conducted to compensate for the high variability often seen when stressing storage volumes. Results were gathered and represented in IOPs (input/output operations per second).

Test Design Considerations

Testing was conducted on specific VM types for each provider. Provider VM configurations may yield different results based on underlying infrastructure, virtualization technology, settings (e.g. shared resources), and other technology factors. Furthermore, issues such as user contention or physical hardware malfunctions can also cause suboptimal performance. Cloud Spectator therefore provisioned multiple VMs with the same configuration to better sample the underlying hardware and enabling technology, as well as to improve testing accuracy and limit the effects of underlying environmental variables.

The VMs selected for this engagement were generally-available specified offerings from the various providers. While better performance can often be attained from providers when additional features or support services are purchased, the selected VMs used in Cloud Spectator's testing do not leverage such value-added services. This helps provide data and test results that are indicative of real-world customer choices and ensures the most direct comparisons possible.

Error Minimizing Considerations

Duplicate VMs were deployed during testing to minimize sources of error prevalent in a Cloud hosting environment. The most notable challenge is the Noisy Neighbor Effect. Testing duplicate VMs mitigates most non-specific errors that could be attributed to a singular parent instance or storage volume. By minimizing possible sources of error, more accurate and precise performance samples can be collected during testing.

Performance Summary

To emphasize the most relevant data, graphs are presented that compare true means (or averages) along with visual representations of data, as well as summary analysis of key findings based on the respective tests. The results of this engagement are presented in sections below.

Price-Performance Ratio

Price-performance, or value, compares the performance of a given Cloud service to the price of that service. Thus, price-performance offers a universal metric for comparing service value. Price-performance is calculated from the average Geekbench4 multi-core score divided by the monthly price in Euros. A higher price-performance score indicates higher value per Euro spent for a given VM configuration. At the time these scores were determined any values gathered in USD were converted at the rate of **.86 Euro:USD.**

** Generally, smaller machines achieve higher price-performance values than larger machines, as large VMs are typically used for specific use cases and have increased cost-overhead.

CPU Performance

Single-core vs Multi-core Preface

Multi-core CPU test averages tend to display large differences based on vCPU count, in contrast to single-core tests. The upcoming result sections provide single-core and multi-core performance overviews followed by breakouts by machine size for granular analysis. However, only multi-core performance scores are used for price-performance calculations.

CPU Single-Core Performance Overview

The chart below depicts the CPU single-core performance of all VMs evaluated in this study. The GeekBench4 single-core score represents the processing speed of a workload prioritized to a single vCPU (core). Although many modern applications are single processes, they are often multi-threaded and therefore capable of parallel processing on multiple cores. Exceptions do exist (e.g. web applications using in-process session data); however, the primary yield of single-core performance analysis is to serve as a universal baseline for comparison of VMs with differing vCPU allocations.

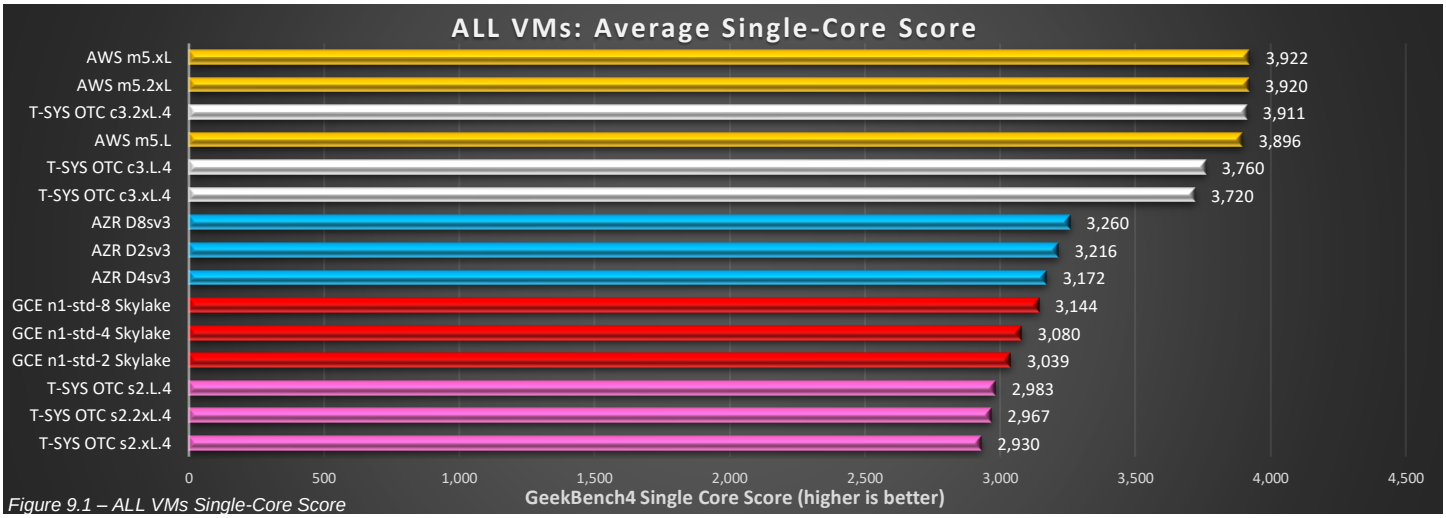


Figure 9.1 – ALL VMs Single-Core Score

The single-core values find T-Systems' OTC c3 VMs are among the highest performing VMs within the study group, while T-Systems' OTC s2 ECS's are at the bottom of the chart. Additionally, observations show AWS m5 VMs deliver superior single-core performance versus Azure Dsv3 and GCE n1-standard Skylake VMs. Although OTC s2 and c3 platforms may share certain features; s2 VMs reside on multi-tenant parent servers, while c3 VMs are provisioned on a dedicated virtual hosts.

In most production scenarios, it should be reiterated, all vCPUs will be utilized if an application is able to exploit them. As such, the multi-core performance metric provides data more indicative of real-world consumer, business and enterprise workloads.

CPU Multi-Core Performance Overview

The chart below depicts the CPU multi-core performance of all VMs covered in this study. As core count, or vCPU quantity, increases VMs generally produce higher scores. In the following graph, each CSP VM series is depicted with a unique color along with respective scores for each VM. Findings are summarized below.

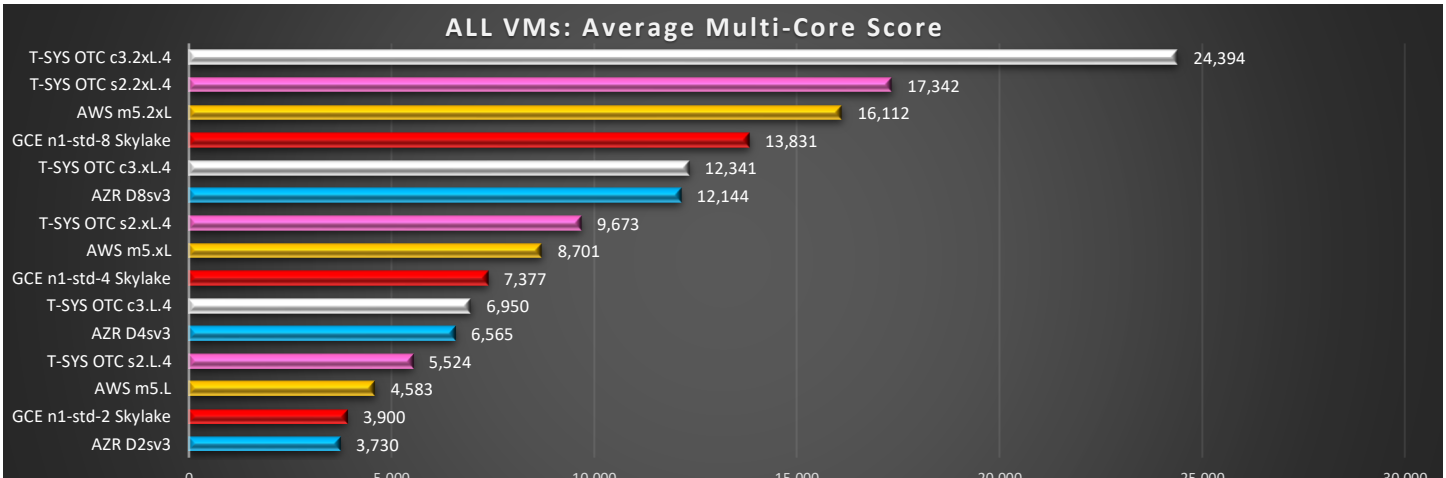


Figure 10.1 – ALL VMs Multi-Core Score

- T-Systems' OTC largest VMs for both s2 and c3 series outperformed competing 8 vCPU from rival Microsoft Azure, Amazon Web Services and Google Compute Engine.
- OTC c3 VMs also achieved superior performance than larger Azure Dsv3 VMs and similar scores to GCE's costlier n1-standard machines with increased available resources.
- T-Systems' OTC s2 multi-tenant hosts did not provide the same level of performance as c3 dedicated hosts, though still averaged a 13% performance boost over equivalently sized VMs from other CSPs.
- Among tested CSPs, multi-core performance trends were consistent with AWS's m5 VMs leading GCE's n1-standard Skylake and Azure's Dsv3 machines.

CPU and Memory Performance: Small VMs

Multi-core performance observations of small VMs are depicted in the graph below with written summaries following.

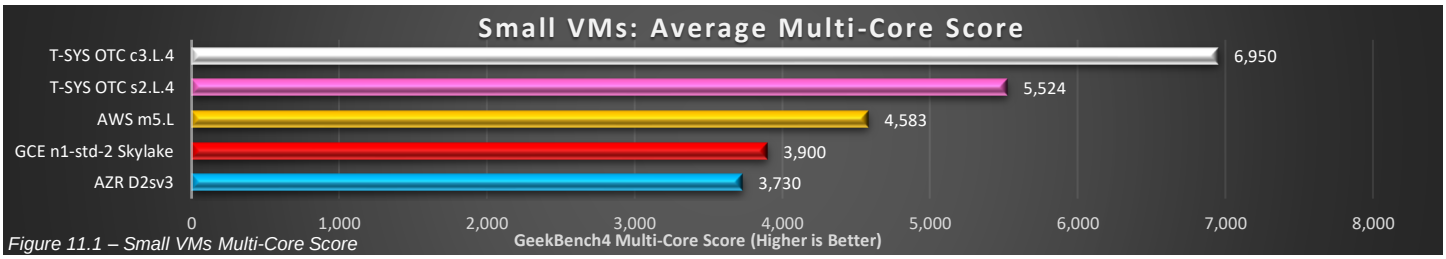


Figure 11.1 – Small VMs Multi-Core Score

- T-Systems' OTC s2.large.4 displayed performance superiority ranging from 20% compared with AWS's m5.large and ~48% against Azure's D2sv3.
- T-Systems' OTC other general purpose ECS, the c3.large.4 with dedicated virtual host, was found 25% faster than T-Systems' OTC equivalent s2 VM. Performance gains over competing CSPs peaked at over 86% compared to the same Azure D2sv3.
- AWS's EC2 platform demonstrated the highest performance among hyper-scale providers. Azure and GCE solutions trailed AWS, showing no appreciable multi-core performance difference.

In summary, T-Systems' OTC Xeon Gold powered machines surpassed AWS's current Xeon Platinum and GCE's Skylake SP platforms as well as Azure's Dsv3 VMs which run on previous generation Intel Broadwell or Haswell processors. When considering hardware characteristics of these providers, T-Systems' OTC provisioning density and hypervisor tuning may be a primary factor influencing their performance edge.

CPU data collected for medium and large VMs are addressed in the upcoming sections.

CPU and Memory Performance Medium VMs

Medium VMs exhibited a similar performance distribution to the small VMs. Observations are detailed below.

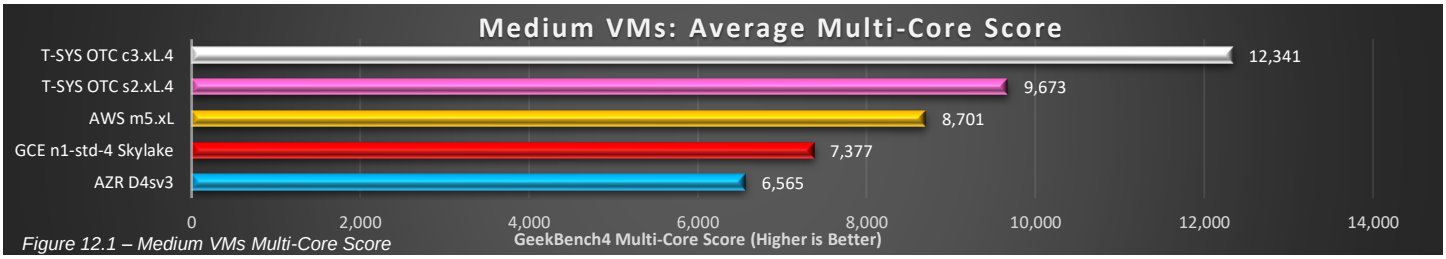


Figure 12.1 – Medium VMs Multi-Core Score

- T-Systems' OTC 4 vCPU s2.xlarge.4 and c3.xlarge.4 continue to deliver superior performance compared to equivalent hyper-scale offerings.
- The OTC s2 VM exhibits an 11% performance edge over AWS' m5.xlarge while the c3 delivers an impressive 41% gain in performance over the same AWS offering.
- Among the hyperscale providers, AWS and GCE VMs show increased performance contrasted with Azure's 4 vCPU equivalent.

To summarize, both OTC s2 and c3 VM flavors exceeded comparable 4 vCPU machines from AWS, Azure and GCE with the c3.xlarge.4 dedicated VM demonstrating advantages over other VMs including T-Systems' OTC more economical s2 ECS due to its dedicated hardware.

With additional cores, VMs become capable of fulfilling more intensive roles such as dedicated database servers, acting as front end web-servers for high traffic web applications, centralized email servers, hosting other business critical software or performing a combination of roles. In the following section, more versatile 8 vCPU VMs are analyzed.

CPU and Memory Performance Large VMs

Large VM multi-core performance is highlighted in the following chart. Detailed narratives of findings are below.

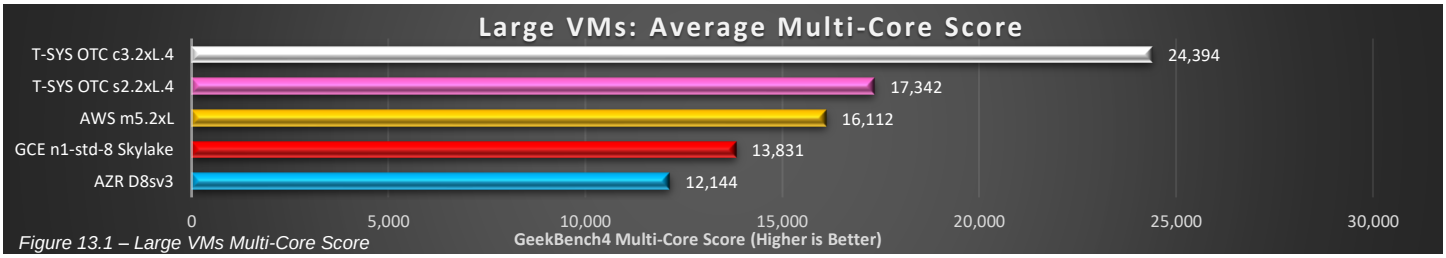


Figure 13.1 – Large VMs Multi-Core Score

- T-Systems' OTC c3.2xlarge.4 scaled beyond nominal expectation from 4 to 8 cores, improving performance by 98% compared the 4 vCPU c3 VM. No other VM flavor within the study group achieved performance scaling from one size to another beyond 90%.
- T-Systems' OTC largest c3 ECS overshadowed rival VMs. It displayed the greatest performance superiority over Azure's D8sv3, achieving 2x better performance.
- T-Systems s2.2xlarge.4 outpaced the best performing rival, AWS's m5.2xlarge, by ~7.5%, surpassed only by T-Systems' OTC high-end c3 ECS.
- Among hyper-scale providers, AWS's m5.2xlarge outperformed Azure's D8sv3 and GCE's n1-standard-8 by 32.5% and 18% respectively.

The CPU multi-score analysis for 8 vCPU VMs revealed pronounced multi-core performance scaling for T-Systems' OTC c3 series from 4 to 8 vCPUs. The observed performance scaling, which approached 98% was unseen in previous VM size groups or other VM series. Further study of larger c3 VMs not included for study may reveal more pronounced scaling effects for virtual machines on dedicated hardware compared to those on shared platforms. If the proposed scaling effects are confirmed, VM selection for intensive enterprise workloads may favor VMs of this type.

This concludes virtual machine CPU analyses. The upcoming sections focus on storage performance.

Storage Performance Preface

Storage performance results are summarized in the sections below. The testing methodology for storage ensured that all machines were tested for a minimum of 100 iterations for read and write operations using FIO with a block size of 4KB, queue depth of 32 running at 1 thread per vCPU for random read and write.

Read: Reading from a disk entails determining data location from a journal and retrieving that data from a drive or array for use on the server. Depending on drive type: Solid State Disks (SSDs), hard disk drives (magnetic disks) or a combination in an array, resulting performance will differ. Implementation of storage technology (e.g. array type and composition, protocols or storage attachment method) may vary greatly from one provider to another. Lastly, it is common for a single CSP to offer multiple storage options with specific characteristics. The general process of reading from a disk, however, requires little processing overhead from storage controllers handling these operations.

Write: Unlike read performance, write performance requires numerous background tasks between operations. This includes determining free blocks for data allocation, journaling and redundancy checks to ensure integrity. Cloud Service Providers typically use large block-storage arrays for increased redundancy (minimizing data loss due to failure of individual drives) and ease of management. Thus, processing overhead for write operations is substantially greater than those of read operations.

In the following sections, storage benchmark data is evaluated.

Storage Read and Write Performance (Small VMs)

Storage random read and write benchmark data for small VMs is depicted in the charts below by key point analyses. All VM series are differentiated with uniquely colored bars.

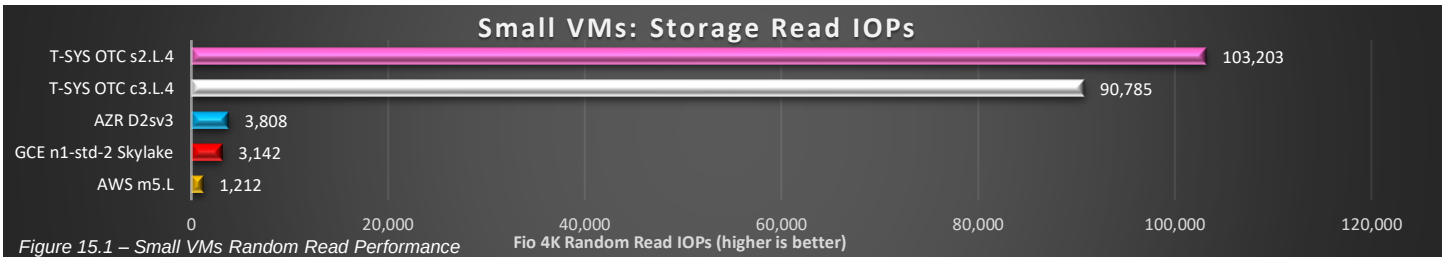


Figure 15.1 – Small VMs Random Read Performance

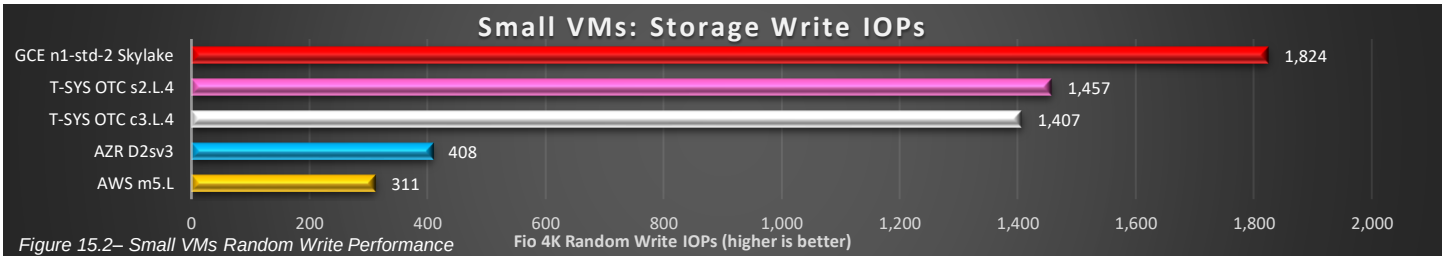


Figure 15.2– Small VMs Random Write Performance

- T-Systems' OTC SSD based Ultra-High I/O drives displayed exemplary 4K random read performance, and overshadowed SSD offerings from Azure, GCE and AWS by a minimum increase of ~24x.
- The OTC VM series does not seem to influence the score, with the s2.large.4 delivering ~13.5% greater read performance than the equivalent c3.
- Azure and GCE provided similar 4K random read IOPs; while AWS' EBS performance averaged less than 50% against these hyperscale providers.
- As mentioned in the Storage Preface, write operations are much more demanding than read operations. The network attached persistent SSDs from GCE edged out T-Systems' Ultra-High I/O drives by 25-30%.
- Both OTC and GCE offerings surpassed Azure and AWS equivalents by significant margins; exceeding 3x the performance of the Premium LRS and EBS equipped machines.

The storage read and write performance analysis revealed significant differences with T-Systems' OTC Ultra-High I/O solution displaying unrivaled read performance, and GCE's persistent SSDs showing superior write performance.

In the following section, medium VM storage performance is evaluated.

Storage Read and Write Performance (Medium VMs)

Medium VM storage read and write performance data is shown in the following graphs accompianed by written summaries of the findings.

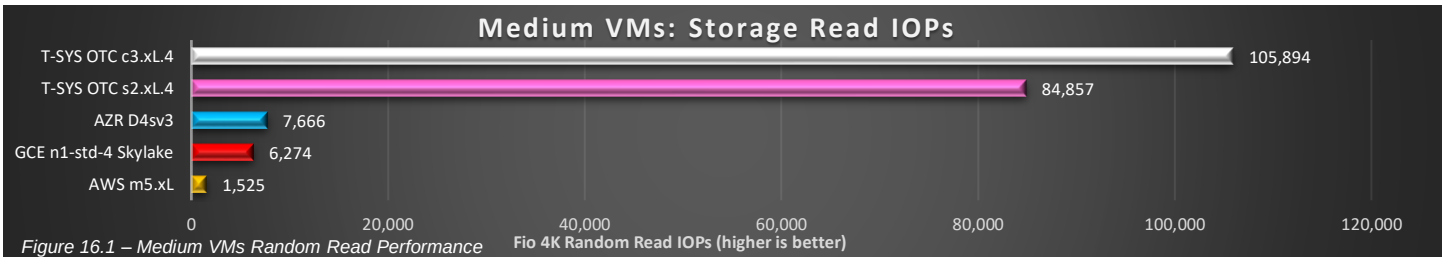


Figure 16.1 – Medium VMs Random Read Performance

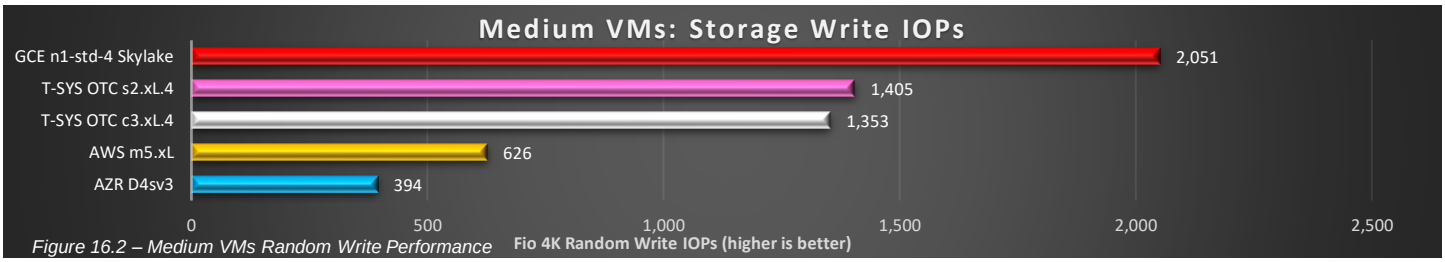


Figure 16.2 – Medium VMs Random Write Performance

- T-Systems' OTC Ultra-High I/O random read scores remain dominant over competing storage options. The c3.xlarge.4 achievied ~25% greater performance than the comparable s2, although the converse was observed among small VMs. Azure's D4sv3 equipped with 256GB of Premium LRS storage was the closest competing offering although performance was found ~14x slower than the s2.xlarge.4.
- Azure's Premium LRS read performance surpassed GCE's Persistent SSDs by a slim margin while AWS's EBS achieved only limited read performance compared to other hyperscale offerings.
- GCE write performance outperformed T-Systems' OTC VMs though neither CSP displayed much improvement compared to the small VMs.
- Azure and AWS write speeds were significantly less than GCE or T-Systems, however, AWS's m5.xlarge displayed a marked improvement over the smaller m5.large. This can largely be attributed to EBS volume size rather than VM size (e.g. AWS EBS volume size determines base IOPs and burst credit accrual).

Large VMs with 500GB block storage volumes are assessed in the following section.

Storage Read and Write Performance (Large VMs)

For large VM multi-core performance, the performance results were similar to the small and medium VMs. The results are illustrated below.

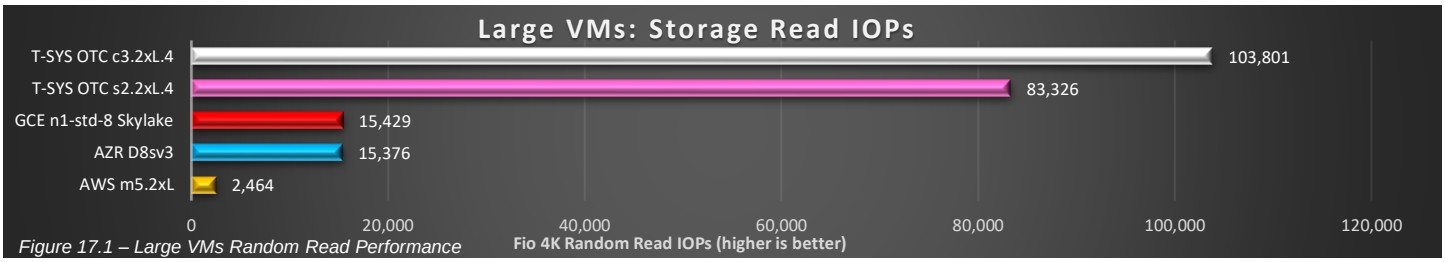


Figure 17.1 – Large VMs Random Read Performance

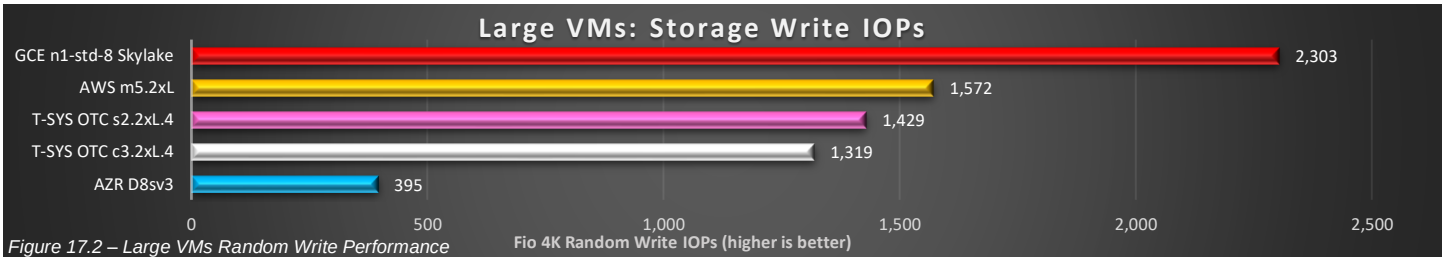


Figure 17.2 – Large VMs Random Write Performance

- T-Systems' OTC c3.2xlarge.4 read speeds eclipsed rival CSP VMs with a ~6.75x improvement, and the equivalently sized s2 ECS delivered a 5.5x increase over the same competitors.
- Both GCE and Azure displayed roughly equivalent read scores, surpassing AWS's m5.2xlarge by a pronounced margin.
- GCE's persistent SSD delivered the best overall random write efficiency.
- AWS's 500GB EBS volumes garnered the greatest observed improvement of VMs evaluated, overtaking both T-Systems' OTC VMs in write performance. This is likely due to increased burst credit availability and base IOPs associated with volume size.

To summarize all storage trends, it was found T-Systems' OTC Ultra-High I/O block storage delivered consistently dominant random read performance compared to equivalent hyperscale solutions. T-Systems' OTC Ultra-High I/O speed does not appear to benefit from increasing machine size or drive capacity for either read or write. The majority of competing CSPs, however, exhibited associated performance gains in at least one storage performance dimension. The combination of storage read and write traits across all VMs, however, does favor T-Systems, as write speeds were competitive and superior to most offerings evaluated while read speed was unrivaled.

The following sections include price-performance analyses, determining the value of each offering per Euro spent.

VM CPU Performance Per Euro (Price-Performance, or Value)

This section focuses on the compute and memory price-performance, or value. The values shown are linear and unweighted, using the multi-core performance scores (figures 10.1) and monthly price (tables 6.1 - 6.3 and figure 18.2). Higher scores are directly correlated with increased value per Euro for a given VM configuration.

CPU Price-Performance ALL VMs

The chart below summarizes all VM sizes evaluated for price-performance. Each provider or VM series is displayed with a specific color.

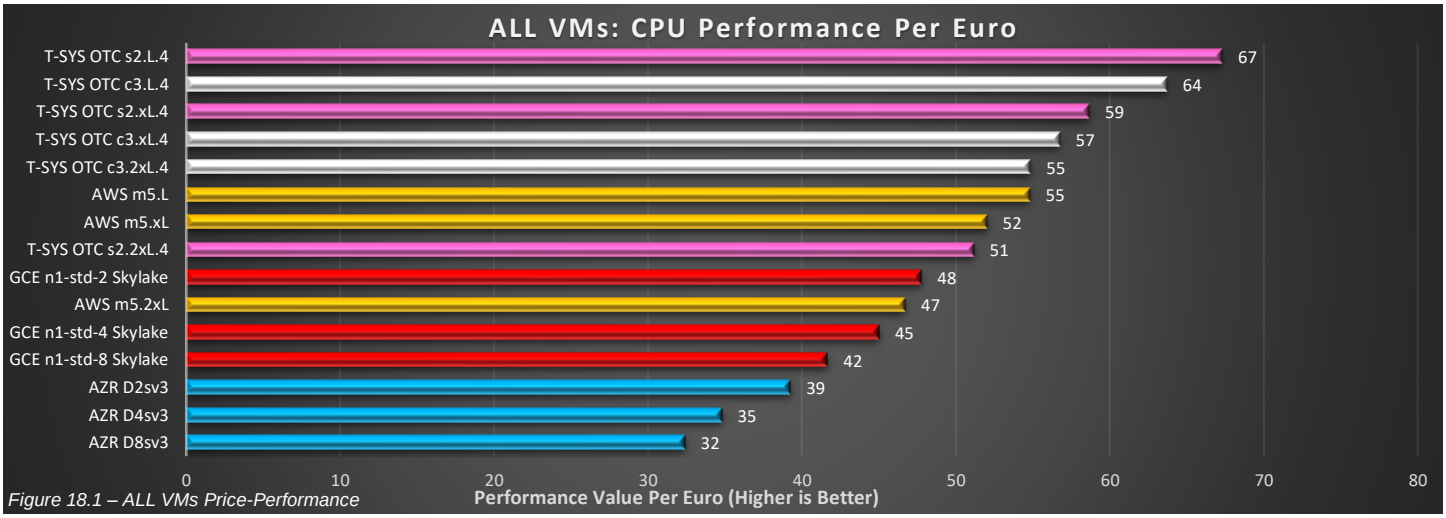


Figure 18.1 – ALL VMs Price-Performance

- T-Systems' s2 and c3 OTC VMs placed highest within their respective size groups for computational performance value.
- Among 2 and 4 vCPU VMs tested, T-Systems' OTC s2 series machines achieved superior price-performance due to excellent CPU performance blended with economical pricing.
- The c3 VMs offset their higher cost among 8 vCPU machines with phenomenal performance scaling.
- AWS' m5 series VMs demonstrated the best price-performance scores when compared against other hyper-scale providers.
- Contributing factors to GCE's and Azure's price-performance shortcomings include relatively weak CPU performance compared to AWS and T-Systems. Azure's faults were further compounded by the high costs of Dsv3 VMs as shown in figure 18.2.

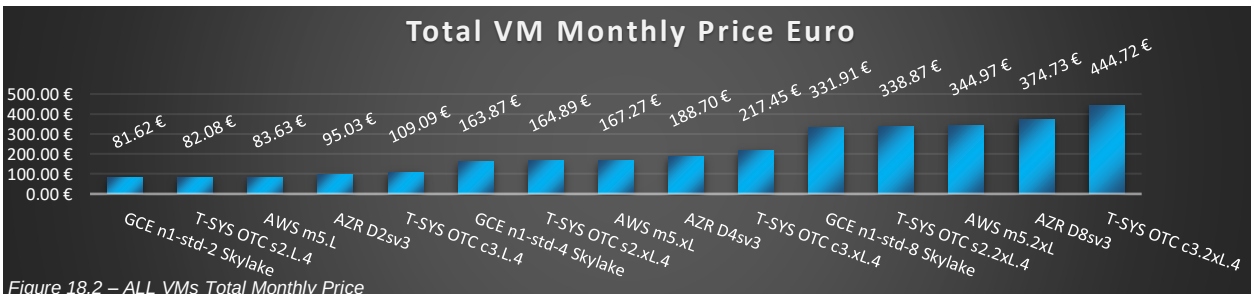


Figure 18.2 – ALL VMs Total Monthly Price

In summary, the price-performance evaluation revealed T-Systems' OTC VMs surpass current offerings from leading hyperscale providers including: Amazon Web Services, Microsoft Azure and Google Compute Engine. T-Systems' OTC derived this superior performance and value via two primary strategies: 1) blending economical pricing and optimal provisioning densities for the s2 ECS series and 2) attaining maximum performance for c3 VMs via use of dedicated host resources.

Storage Performance Per Euro (Price-Performance, or Value)

This section focuses on storage price-performance value. Storage performance can be a major bottleneck for certain applications, and often storage pricing can become a budgeting challenge for enterprises. The values shown in the sections below are linear and unweighted, using the average performance scores for random read (Figures 15.1, 16.1 and 17.1) and random write (Figures 15.2, 16.2 and 17.2), as well as monthly prices (tables 6.1-6.3 or figure 18.2). Higher scores indicate a better price-performance value per Euro spent compared to competing VMs in the same size category.

Price-Performance ALL VMs (Read)

In the chart below, price-performance is compared for the specified VMs based on random read speed. This is most useful when considering read-intensive use-cases. Summary observations are provided below.

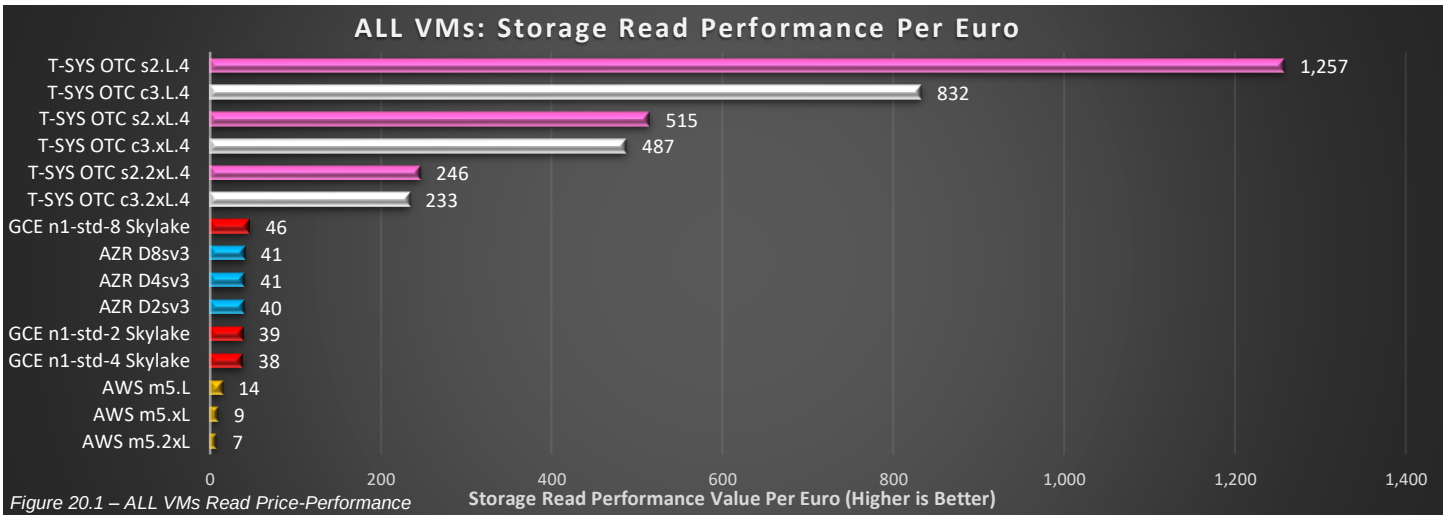


Figure 20.1 – ALL VMs Read Price-Performance

- T-Systems' OTC set a high bar, with minimum read performance above 83,000 IOPs and the maximum approaching 106,000 IOPs. These speeds are rarely observed from network attached storage volumes. This results in an average value gain of 31x compared to competitors across all size classes.
- The widest price-performance disparity was found within the 2 vCPU VM group with T-Systems s2.large.4 delivering a massive 87x value increase compared to the AWS m5.large with 100GB EBS volume. This is in part due to AWS's performance scaling with larger volume sizes while T-System's stays consistent.
- The closest equivalent matchup was within the 8 vCPU VM offerings, where T-Systems c3.2xlarge.4 demonstrated a 5X value improvement over GCE's n1-standard-8.
- AWS, Azure and GCE provide solid storage platforms with their Elastic Block Storage, Premium Locally redundant storage (LRS) and Persistent SSDs respectively. However, their storage performance is constrained based on volume size which contributes greatly to lower overall value per Euro spent from these providers.

To summarize, T-Systems' OTC displayed exceptional read value across all sizes, exceeding similar offerings from AWS, Azure and GCE by pronounced margins. The standard s2 VMs displayed a price-performance edge over the high-performance c3 machines. This is due to significantly lower costs and roughly equivalent storage performance within each size group.

Price-Performance ALL VMs (Write)

Write speed, irrespective of the drive type or configuration, has always been a technology challenge due to the additional overhead in allocating space and journaling data during write operations. The following summary observations were extracted from the analysis. VMs series and providers are differentiated by bar color.

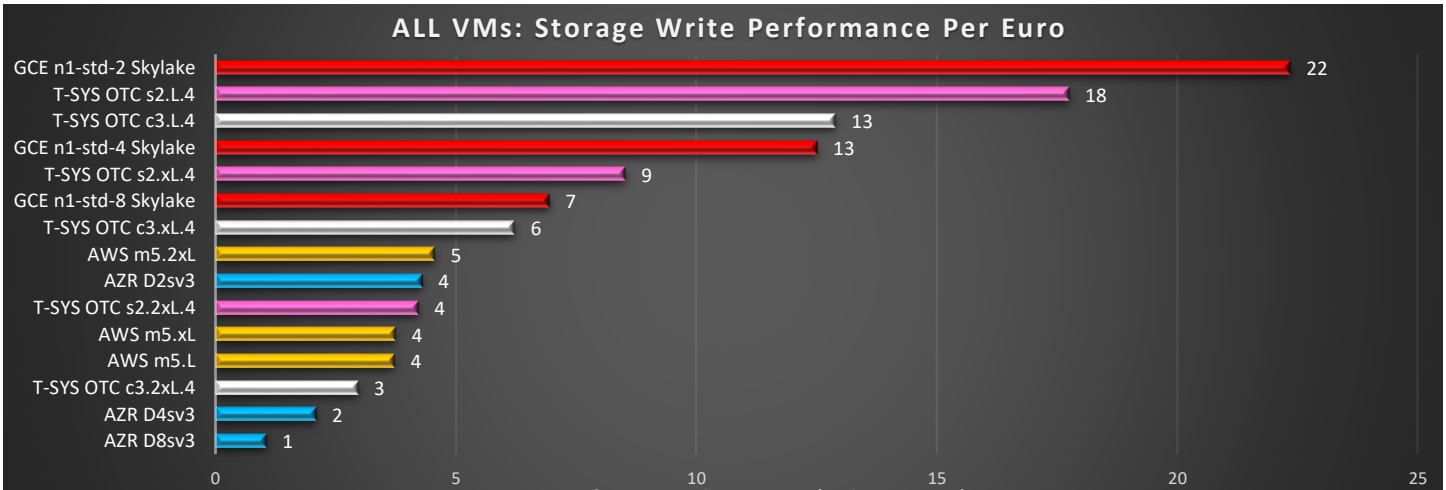


Figure 21.1 – ALL VMs Write Price-Performance

- GCE's n1-standard Skylake machines, being the lowest price within each size group, demonstrated the highest random write price-performance, followed by T-Systems' OTC s2 and c3 machines for 2 and 4 vCPU VMs with 100 and 200GB volumes respectively.
- AWS's m5.2xlarge write price-performance surpassed equivalent OTC VMs only within the large VM group equipped with 500GB volumes.
- Azure VMs supplied with Premium LRS volumes displayed the lowest overall write performance value—with a singular exception among 2 vCPU VMs, delivering an improvement over AWS' m5.large.
- Macro evaluation revealed GCE and OTC write price-performance not only delivered better average price-performance compared to Azure and AWS.
- Larger machines often suffer from higher cost overhead, while smaller VMs benefit from the converse. For AWS, however, the performance gain observed from larger EBS volumes offset the increased price, resulting in greater write performance value.

T-Systems' OTC read value outpaced comparable offerings from AWS, Azure and GCE, however, T-Systems' write value fell behind GCE equivalents. There are two components to storage, both of which are critical for proper function. Some applications depend heavily on either read or write, while many require a mix of both to avoid performance bottlenecks. Given the combination of read and write values observed, T-Systems Ultra-High I/O equipped VMs provided the best overall value for general purpose storage operations.

Conclusion

For this engagement, Cloud Spectator tested Amazon Web Services, Microsoft Azure, Google Compute Engine and T-Systems' Open Telekom Cloud general purpose VMs. Cloud Spectator tested VMs across three size groups with vCPU counts of 2, 4 and 8 and vCPU:RAM ratios of 1:4. The testing and data collection were performed on machines running in Western European data centers. Benchmarks consisted of exhaustive computational and storage tests on the specified VM configurations. From these results, performance and price-performance values for each VM type were determined.

T-Systems' OTC VMs displayed excellent performance in each observed performance dimension. T-Systems' OTC elastic cloud servers (ECS's) demonstrated exceptional CPU multi-core performance. The standard s2 VMs displayed performance advantages over other VMs ranging from an 8% minimum across 8 vCPU offerings to 48% within the 2 vCPU group. Additionally, T-Systems high-performance c3 ECS's delivered better performance than competing VMs ranging from 41% against rival 4 vCPU solutions to over 100% amongst the largest VMs.

T-Systems' OTC Ultra-High I/O block storage dominated read performance, exceeding 103,000 IOPs, with combined average performance gains of 15x over other providers. T-Systems write speeds fell short of GCE's persistent SSDs by 25-30% depending on VM size, but generally provided higher performance than AWS and Azure.

OTC computational and read price-performance was found universally superior for both ECS lineups while GCE provided the best write performance value. Considering general-purpose use-cases, T-Systems' OTC provided superior overall performance and value compared to the latest offerings from Amazon Web Services, Microsoft Azure and Google Compute Engine.

Cloud Spectator's analysis revealed T-Systems' Open Telekom Cloud as a powerful challenger to the current Cloud hyperscale providers. T-Systems provides a comprehensive portfolio of offerings, on par with those of industry giants like Amazon Web Services, Microsoft Azure and Google Compute Engine. T-Systems' OTC general purpose platform was found to provide well-tuned virtual infrastructure. Their s2 ECS's provide an economical solution without sacrificing computational ability, while dedicated host 1resources grant c3 VMs momentous power—far exceeding all other machines selected for this engagement. When equipped with T-Systems' OTC SSD based Ultra-High I/O block storage, read speeds were unmatched by equivalent options from the hyperscale providers blended with competitive write speeds, resulting in a superior performance admixture. The overall value of T-Systems' OTC s2 and c3 platforms showed significant improvements over competing general-purpose machines, which are well-equipped for workloads ranging from small front-end web servers to large multi-role servers for business critical infrastructure. T-Systems appears to have engineered one the most technologically advanced Cloud platforms currently available in Europe—encompassing solutions for small independent consumers to large international corporate enterprises.

About Cloud Spectator

Cloud Spectator is a benchmarking and consulting agency focused on cloud Infrastructure-as-a-Service (IaaS). The company actively monitors several of the largest IaaS providers in the world, comparing VM performance (i.e., CPU, RAM, disk, internal network, and workloads) and pricing to achieve transparency in the cloud market.

The company helps cloud providers understand their market position and helps business's make intelligent decisions related to cloud strategy, cloud readiness, cost reduction and vendor analysis. The firm was founded in early 2011 and is in Boston, MA.

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