Dell Wyse Datacenter for VMware Horizon View with High Performance Graphics

A Reference Architecture for workstation-class virtual desktops in a VMware Horizon View environment

Dell Wyse Solutions Engineering
July 2015

A Dell Reference Architecture

Revisions

Date	Description
March 2014	Initial release v.6.0
July 2015	Added test data for ESXi 6.0 on R730 v.6.7

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Executive summary

VMware virtual dedicated graphics acceleration (vDGA), also known as pass through graphics support, refers to the technology that dedicates the full processing power of a single high-end graphics processing unit (GPU) to an single VMware Horizon View virtual desktop. This gives the user the ability to run intensive graphics workloads comparable to a high-end workstation and also provides native NVIDIA drivers to support the latest versions of OpenGL and DirectX. This solution offers a greater density of high-end graphics users per server when compared to the traditional one-to-one model of a dedicated graphics workstation. As such, cost benefits can be realized by using VMware vDGA, VMware Horizon View and Dell hardware technologies.

The capability for 3D graphics and video in Horizon View further expands the use cases and user groups to which IT can deliver virtual desktops. vDGA allows IT departments to deliver virtual desktops to users who traditionally would have required high-performance workstations in order to get the graphics performance required for running applications like AutoCAD and eDrawings.

The major distinction between vDGA and virtual shared graphics acceleration (vSGA) is that the vDGA virtual machine (VM) has full usage of the assigned GPU. The dedicated GPU is passed through the hypervisor to the VM and the driver is installed locally on the VM, whereas in vSGA mode a single GPU is shared by a pool of VMs.

New for ESXi 6.0 is support for NVIDIA GRID vGPU technology. vGPU, a shared graphics technology, allows many end users to share a single physical GPU, however, it offers far greater performance and application compatibility than vSGA through the use of native NVIDIA drivers. vGPU also supports newer releases of OpenGL and DirectX.

Throughout the extensive testing and validation of this Reference Architecture, various endpoints were used to connect to a vDGA VM on a Dell PowerEdge Server with an NVIDIA GRID K2 card installed.

This document addresses the architecture design, configuration, performance data and implementation considerations for the key components of the architecture required to deliver virtual desktops via Horizon View on a Dell PowerEdge server using VMware vSphere 6.0.

1 Solution architecture overview

1.1 Introduction

The Dell Wyse datacenter solution leverages a core set of hardware and software components consisting of 4 primary layers:

- Networking
- Compute server
- Management server
- Storage

These components have been integrated and tested to provide the optimal balance of high performance and lowest cost per user. Additionally, the solution includes an approved extended list of optional components in the same categories. These components give IT departments the flexibility to custom tailor the solution for environments with unique virtual desktop infrastructure (VDI) feature, scale or performance needs.

In the Shared Tier 1 solution model, an additional high-performance shared storage array is added to handle the execution of the VDI sessions. All compute and management layer hosts in this model are diskless with the hypervisor being installed on a Micro SD card.

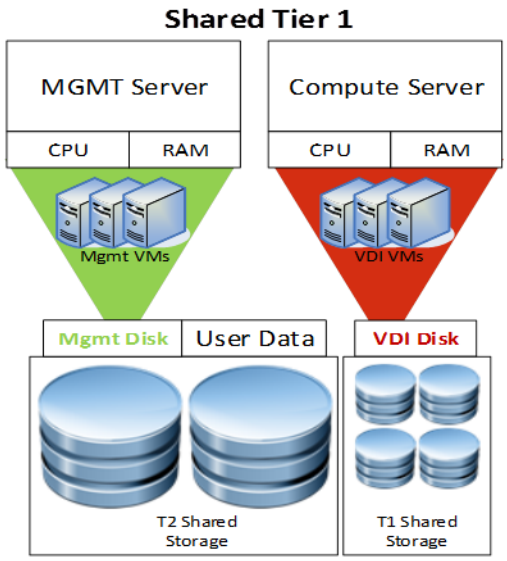


Figure 1 Shared Tier 1 solution model

1.2 Wyse datacenter solution layers

Each server has two gigabit Ethernet adaptors which can be uplinked to your existing network infrastructure. It is also possible to add the following extra Ethernet ports which can be used to connect to

a high speed 10 Gb Ethernet network infrastructure for access to shared storage such as the EqualLogic PS6210XS which is a 10Gb Tier 1 storage array validated configuration.

10 Gb Ethernet (options)

- Intel X540 dual port 10 Gb Ethernet Base-T adapter
- Intel X520-DA dual port 10 Gb SFP+ adapter

In the Shared Tier 1 architecture model for rack servers, both management and compute servers connect to share storage. All top-of-rack (ToR) network traffic has been designed to be layer 2 (switched locally), with all layers 3 (routable) VLANs routed through a core or distribution switch. The following diagrams illustrate the server NIC to ToR switch connections, vSwitch assignments, as well as logical VLAN flow in relation to the core switch.

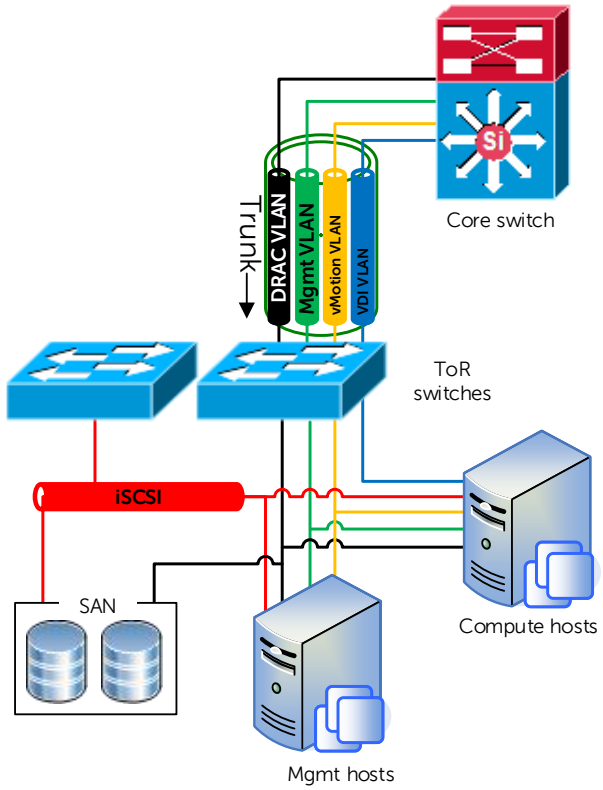


Figure 2 Top-of-rack switch connections and vSwitch assignments

1.3 Shared Tier 1 rack scaling guidance (iSCSI)

The following table shows a combination of ToR switches for LAN, iSCSI and the various EqualLogic array options for using iSCSI storage in a Horizon View environment.

Table 1 Top-of-rack switch combinations

Shared Tier 1 hardware scaling (rack – iSCSI)					
User scale	ToR LAN	ToR 10Gb iSCSI	EqualLogic T1	EqualLogic T2	EqualLogic NAS
0-500	S55	S4810	PS6210XS	-	-
500-1000	S55	S4810	PS6210XS	PS4110E	-
0-1000 (HA)	S55	S4810	PS6210XS	PS4110E	NX3300
0-3000	S55	S4810	PS6210XS	PS6210E	NX3300
3000-6000	S55	S4810	PS6210XS	PS6510E	NX3300
6000+	S60	S4810	PS6210XS	PS6510E	NX3300

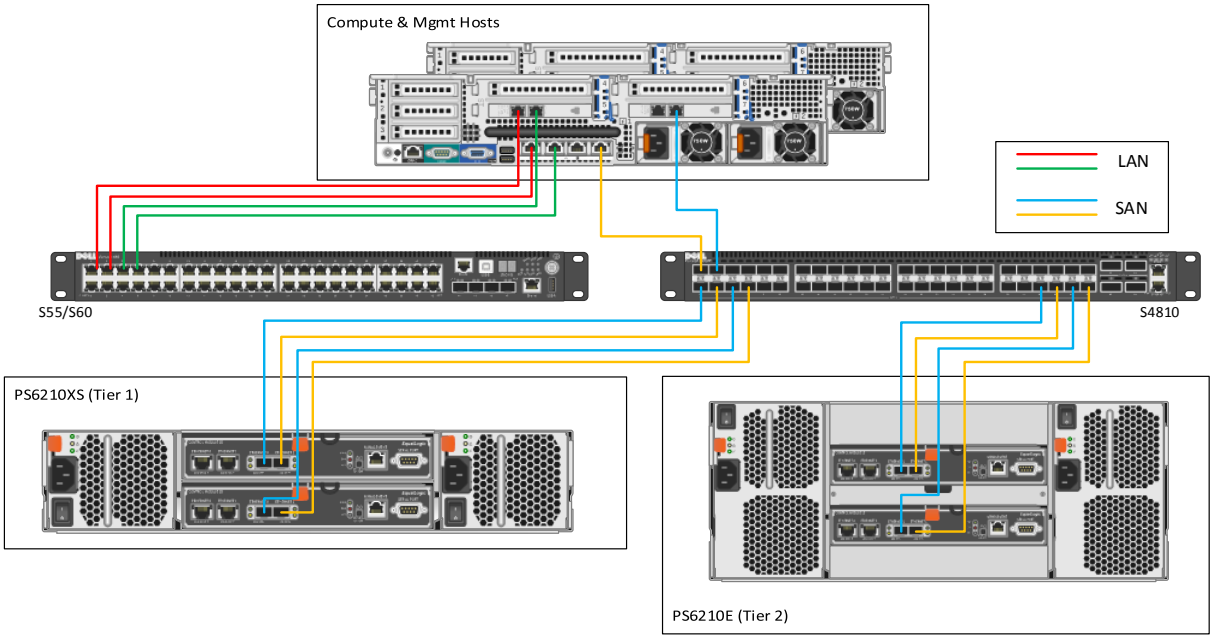


Figure 3 Shared Tier 1 cabling diagram (rack – EqualLogic)

2 Hardware components

2.1 PowerEdge R730

The rack server platform for the Dell Wyse Datacenter solution is the best-in-class Dell PowerEdge R730. This dual socket CPU platform runs the fastest Intel Xeon E5-2600 v3 family of processors, can host up to 768GB RAM and supports up to 16 2.5" SAS disks. The Dell PowerEdge R730 offers uncompromising performance and scalability in a 2U form factor. For more information, please visit: http://www.dell.com/us/business/p/poweredge-r730/pd

2.2 NVIDIA GRID K1 and K2 cards

NVIDIA GRID technology offers the ability to offload graphics processing from the host CPU to the GPU in virtualized environments, giving IT administrators the ability to deliver rich graphical experiences to VM users like never before. NVIDIA's Kepler-based GRID K1 and K2 boards are specifically designed to enable rich graphics in virtualized environments.

In addition to a dedicated graphics mode, these cards can by shared using hardware virtualization of the GPU. This means multiple users can use a single GPU, improving user density while providing workstation-class performance and compatibility.

Patented low-latency remote display technology greatly improves the user experience by reducing the lag that users experience when interacting with their VM. Using this technology, the virtual desktop screen is routed directly to the display protocol.

NVIDIA GRID adapters have an optimized multi-GPU design that helps to maximize user density. K1 adapters, with four Kepler GPUs and 16GB of memory, are designed to host the maximum number of concurrent users. K2 adapters, equipped with two more robust Kepler GPUs and 8GB of memory, deliver maximum density for users of graphics-intensive applications.

For detailed information on NVIDIA GRID boards, please visit:

http://www.nvidia.com/object/grid-boards.html

Table 2 NVIDIA GRID K1 and K2 specifications

	GRID K1	GRID K2
Number of GPUs	4 entry Kepler GPUs	2 high-end Kepler GPUs
Total NVIDIA CUDA cores	768	3072
Total memory size	16 GB DDR3	8 GB GDDR5
Max power	130 W	225 W
Form factor	Dual slot (10.5" x 4.4")	Dual slot (10.5" x 4.4")
Aux power	6-pin connector	8-pin connector
PCIe	x16	x16
PCIe generation	Gen3 (Gen2 compatible)	Gen3 (Gen2 compatible)
Cooling solution	Passive	Passive

2.3 Wyse cloud clients

The following Wyse thin and zero clients were extensively tested and are the recommended choices for this solution.

2.3.1 Wyse P25

Uncompromising computing with the benefits of secure, centralized management. The Wyse P25 PCoIP zero client for Horizon View is a secure, easily managed zero client that provides outstanding graphics performance for advanced applications such as CAD, 3D solids modeling, video editing and advanced worker-level office productivity applications. Smaller than a typical notebook, this dedicated zero client is designed specifically for Horizon View. It features the latest processor technology from Teradici to process the PCoIP protocol in silicon and includes client-side content caching to deliver the highest level of performance available over 2 HD displays in an extremely compact, energy-efficient form factor. The Wyse P25 delivers a rich user experience while resolving the challenges of provisioning, maintaining and securing enterprise desktops.

2.3.2 Wyse D10DP

The Wyse D10DP is a high-performance and secure ThinOS 8 thin client that is absolutely virus and malware immune. Combining the performance of a dual core AMD G-Series APU with an integrated graphics engine and ThinOS, the Wyse D10DP offers exceptional thin client PCoIP processing performance for Horizon View environments that handles demanding multimedia applications with ease and delivers brilliant graphics. Powerful, compact and extremely energy efficient, the Wyse D10DP is a great VDI endpoint for organizations that need high-end performance but face potential budget limitations.

2.3.3 Wyse P45

Uncompromising computing with the benefits of secure, centralized management. The Wyse P45 PCoIP zero client for Horizon View is a secure, easily managed zero client that provides outstanding graphics performance for advanced applications such as CAD, 3D solids modeling, video editing and advanced worker-level office productivity applications. About the size of a notebook, this dedicated zero client designed specifically for Horizon View. It features the latest processor technology from Teradici to process the PCoIP protocol in silicon and includes client-side content caching to deliver the highest level of display performance available over 4 HD displays in a compact, energy-efficient form factor. The Wyse P45 delivers a rich user experience while resolving the challenges of provisioning, maintaining and securing enterprise desktops.

2.3.4 Wyse Z50D

Designed for power users, the Wyse Z50D is the highest performing thin client on the market. Highly secure and ultra-powerful, the Wyse Z50D combines Dell Wyse-enhanced SUSE Linux Enterprise with dual-core AMD 1.65 GHz processor and a revolutionary unified engine for an unprecedented user experience. The Wyse Z50D eliminates performance constraints for high-end, processor-intensive applications like CAD, multimedia, HD video and 3D modelling.

2.3.5 Wyse Z90D7

A super high-performance Windows Embedded Standard 7 thin client for virtual desktop environments. Featuring a dual core AMD processor and a revolutionary unified engine that eliminates performance constraints, the Wyse Z90D7 achieves incredible speed and power for the most demanding embedded windows applications, rich graphics and HD video. With touch screen capable displays, the Z90D7 adds the ease of an intuitive multi-touch user experience and is the ideal thin client for the most demanding virtual desktop workload applications.

2.3.6 Chromebook 11

With its slim design and high performance, the Dell Chromebook 11 features a 4th Generation Intel Celeron 2955U processor, up to 10-hours of battery life and 16GB embedded Solid State Drive which allows it to boot in seconds. The Chromebook 11 is available in two models with either 2GB or 4GB of internal DDR3 RAM. This provides options for the education ecosystem, allowing students, teachers and administrators to access, create and collaborate throughout the day at a price point that makes widespread student computing initiatives affordable. The Dell Chromebook 11 features an 11.6-inch, edge-to-edge glass screen that produces exceptional viewing clarity at a maximum resolution of 1366x768 and is powered by Intel HD Graphics. The high-performing display coupled with a front-facing 720p webcam creates exciting opportunities for collaborative learning. The Dell Chromebook 11 is less than one inch in height and starts at 2.9lbs, making it highly portable. With two USB 3.0 ports, Bluetooth 4.0 and an HDMI port, end users have endless possibilities for collaborating,

creating, consuming and displaying content. With battery life of up to 10-hours, the Chromebook is capable of powering end users throughout the day. With a fully compliant HTML5 browser, the Dell Chromebook11 is an excellent choice as an endpoint for connecting to an HTML5/BLAST Horizon View VDI desktop (vSGA mode only).

3 VDI density guidance

Density numbers given below are an extrapolation based on testing and validation work completed in the Dell Wyse Solutions Engineering labs on various PowerEdge Server platforms configured with identical CPU, memory and hard drive configurations. It is meant to be an estimate of VM density on the R730 platform for the workloads described in the table below.

Table 3 vSGA and vDGA user density extrapolations for the PowerEdge R730

Mode	Workload Type	NVIDIA GRID	Total GPUs	Maximum Concurrent Users
vSGA	Non-graphics	K1 (2 per server)	8	55
vDGA	Graphics-intensive	K2 (2 per server)	4	4

Table 4 vGPU user density values for the PowerEdge R730

Card	Physical GPUs	Virtual GPU	Intended User(s)	Frame Buffer (MB)	Virtual Display Heads	Maximum Resolution	Maximum vGPUs	
							Per GPU	Per Board
GRID K2	2	GRID K280Q	Designer	4096	4	2560x1600	1	2
		GRID K260Q	Designer	2048	4	2560x1600	2	4
		GRID K240Q	Power User	1024	2	2560x1600	4	8
		GRID K220Q	Power User	512	2	2560x1600	8	16
GRID K1	4	GRID K180Q	Power User	4096	4	2560x1600	1	4
		GRID K160Q	Power User	2048	4	2560x1600	2	8
		GRID K140Q	Knowledge Worker	1024	2	2560x1600	4	16
		GRID K120Q	Knowledge Worker	512	2	2560x1600	8	32

Table 5 Test environment specifications

Test Specifications
PowerEdge R730 2U Rack Server
2 x Intel Xeon E5-2660v3 processors @ 2.6GHz (10 cores)
256 GB Memory @ 2133MHz)
Min. 1.28 TB storage
Integrated Broadcom BCM57800 10G/GbE 2+2P [2x1Gb + 2x10Gb]
PERC H730P RAID Controller
2 x NVIDIA K2 or K1
Software: • VMware ESXi 6.0 • NVIDIA vGPU VIB 347.52 • vGPU driver for Win 8.1 64-bit client: 347.52 • Horizon agent x86_64_6.1 • Horizon agent direct connection-x86_64-6 • Win 8.1 64-bit clients

4 vDGA testing with NVIDIA GRID K2 adapters

The capability for 3D graphics and video in Horizon View further expands the use cases and target users to whom IT can deliver virtual desktops. vDGA gives IT departments the ability to deliver virtual desktops to users who traditionally would have required high-performance workstations in order to obtain the graphics performance required for running applications such as AutoCAD and eDrawings.

The following pages detail the tests and validation performed on a single R730 server with a single NVIDIA GRID K2 card. The validation is for workstation users and the GRID cards are operating in pass-through mode (i.e. vDGA mode). The GPU is not shared with any other VMs on the hypervisor. The results scale linearly by adding additional servers and GPUs.

For the validation described here, the Wyse P25 zero client endpoint was used, which is able to perform client side caching and can process PCoIP in embedded Teradici hardware . Also used, was the Wyse D10DP endpoint which is a dual core thin client which includes an enhanced graphics engine.

4.1 Graphics-specific performance analysis results

4.1.1 NVIDIA GRID K2 – Heaven Benchmark testing – Single VM

Heaven Benchmark (HB) is a GPU-intensive benchmark that significantly stresses graphics cards. This benchmark tool can be effectively used to determine the stability of a GPU under extremely stressful conditions, as well as validating the characteristics of the card's thermal subsystems.

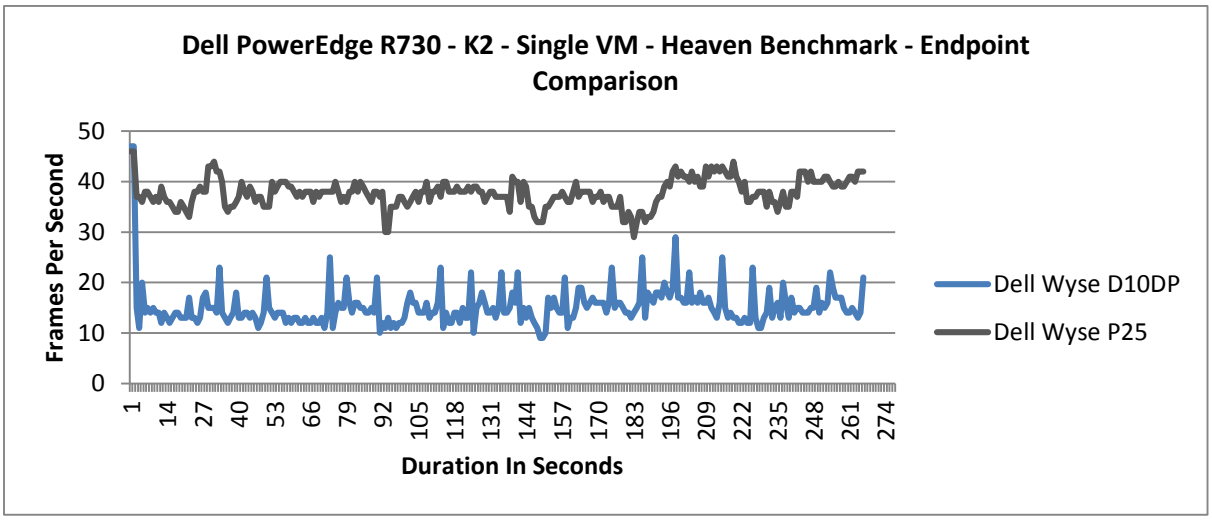


Figure 4 PowerEdge R730 – K2 – Single VM – HB – Endpoint comparison

As we can see in the above graph, the Wyse P25 is able to maintain a much higher frame rate than the Wyse D10DP – highlighting the fact that zero clients are a better candidate for high-end graphics workloads as they are able to process PCoIP frames in hardware. The Wyse D10DP, however, performs very well with lighter graphics workloads.

Note: Heaven benchmark produces a score after each benchmark test; however we found the scores to be unreliable so they are not included in this document

Note: Heaven benchmark was executed at high quality with a resolution of 1366 x 768 (not full screen)

4.1.2 NVIDIA GRID K2 – Heaven Benchmark testing – with companion workload

For the following test, we ran a companion workload on the other VMs on the host to establish whether or not it would have any negative impact on the test results of the benchmark VM. In theory, the companion workload should have little impact as each VM has access to its own dedicated GPU.

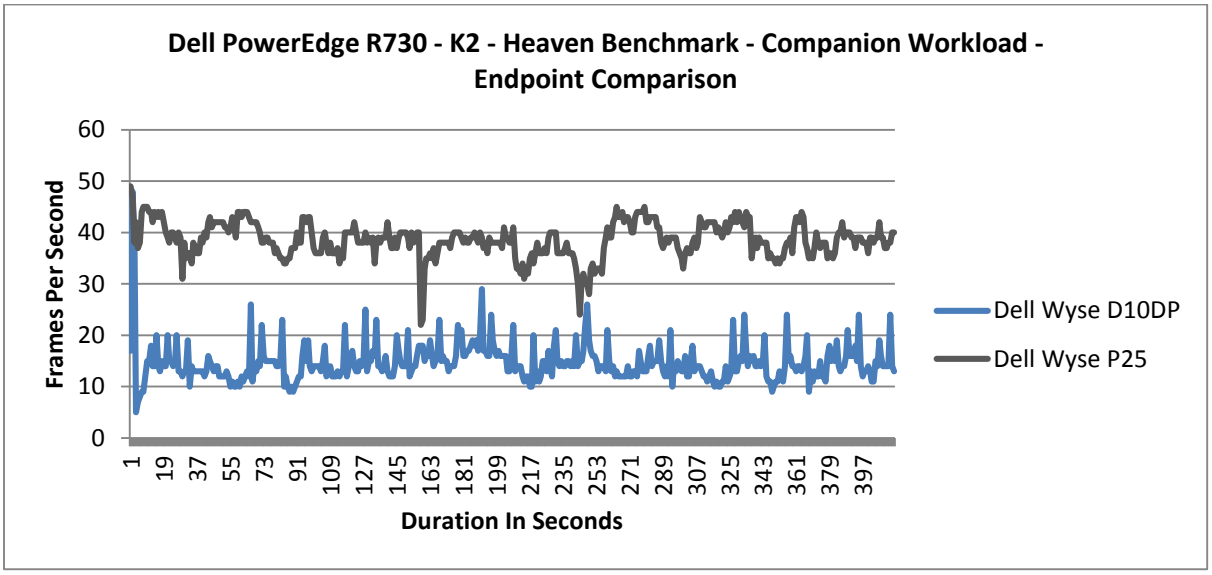


Figure 5 Dell PowerEdge R730 – K2 – HB with companion workload

As you can see, the graph in Figure 5 is almost identical to the graph in Figure 4 when just a single VM was used. This confirms that companion workloads on the other VMs do not impact the benchmark VM because the GPUs are assigned to each VM directly and there is little or no contention for resources.

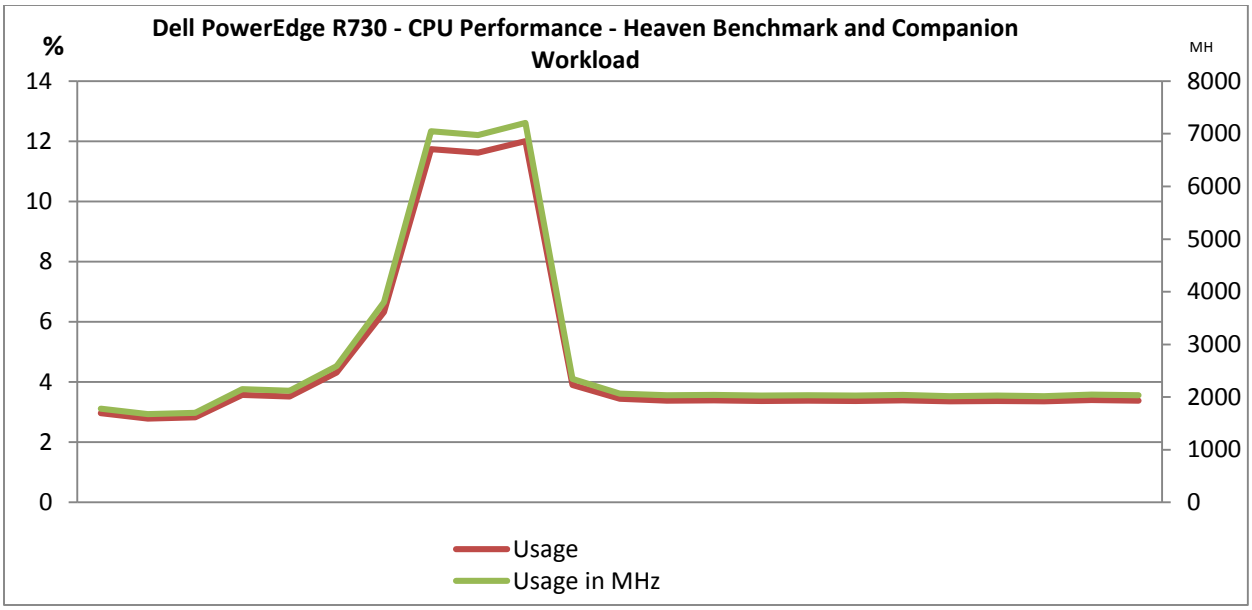


Figure 6 Dell PowerEdge R730 – CPU usage. Host CPU usage remained quite low while the HB and the companion workloads were running.

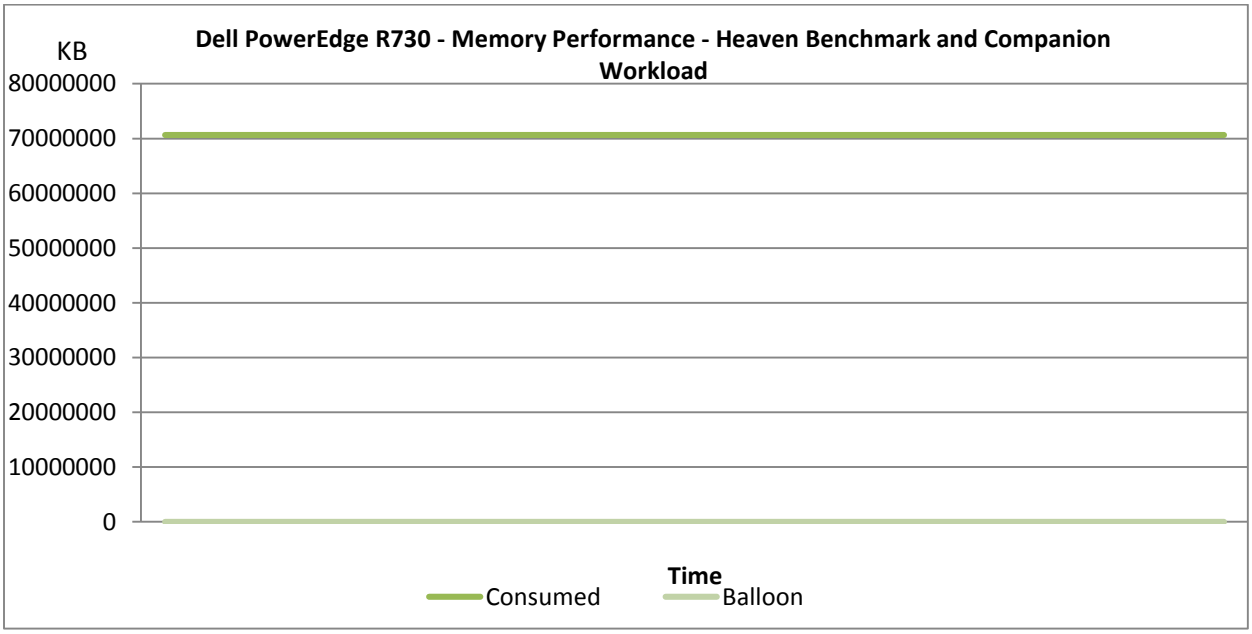


Figure 7 Dell PowerEdge R730 – Memory performance. Host memory usage during the HB while running the companion workloads showed no evidence of any memory ballooning.

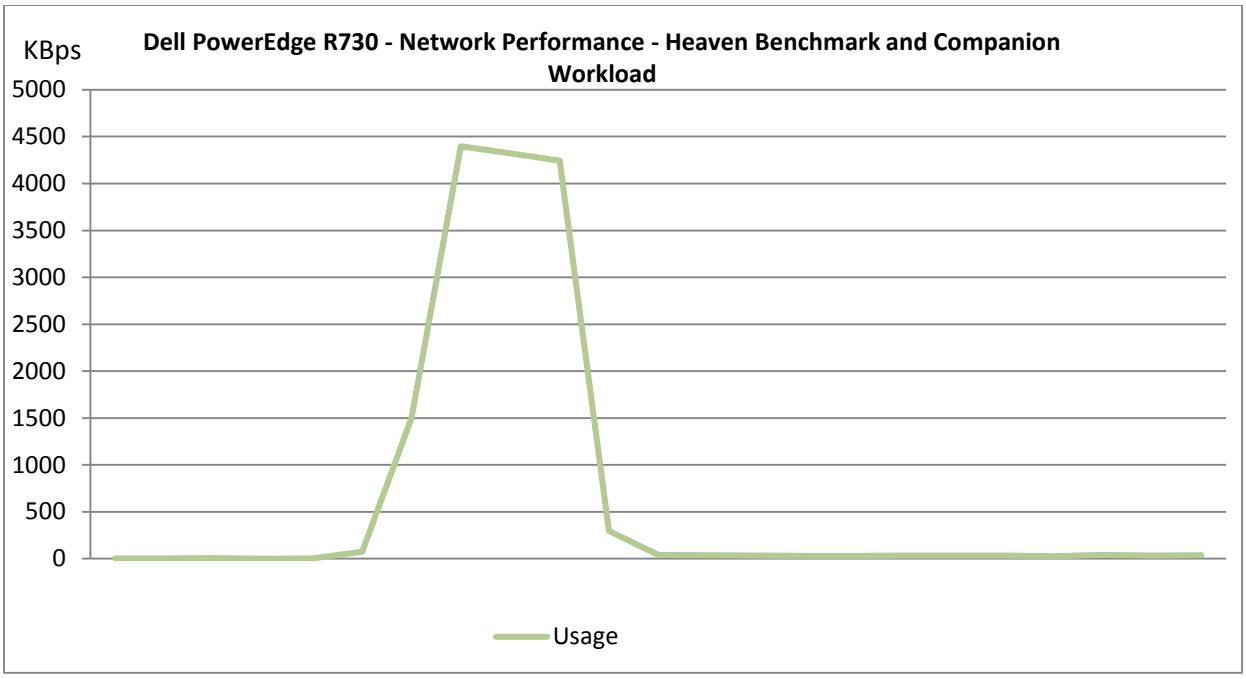


Figure 8 Dell PowerEdge R730 – Network performance. Host network usage metrics were well within acceptable thresholds while the HB and companion workloads were running.

4.1.3 NVIDIA GRID K2 – ViewPerf Benchmark testing – Single VM

ViewPerf is a portable OpenGL performance benchmark program. It runs on most implementations of Linux and Windows. ViewPerf provides a vast amount of flexibility in benchmarking OpenGL performance and is a widely used graphics benchmarking tool. It is made up of eight different view sets and each one provides a score at the end of the test.

The following graph shows the ViewPerf scores for both the Wyse P25 and the Dell Wyse D10DP using the NVIDIA GRID K2 card and a single VM test.

As you can see in Figure 10, the Wyse P25 zero client achieves slightly better scores than the Wyse D10DP thin client, again due to the fact that zero client endpoints process PCoIP in hardware. This represents the 'presentation' part of the graphics workloads as the rendering of the graphics is done by the K2 GPU.

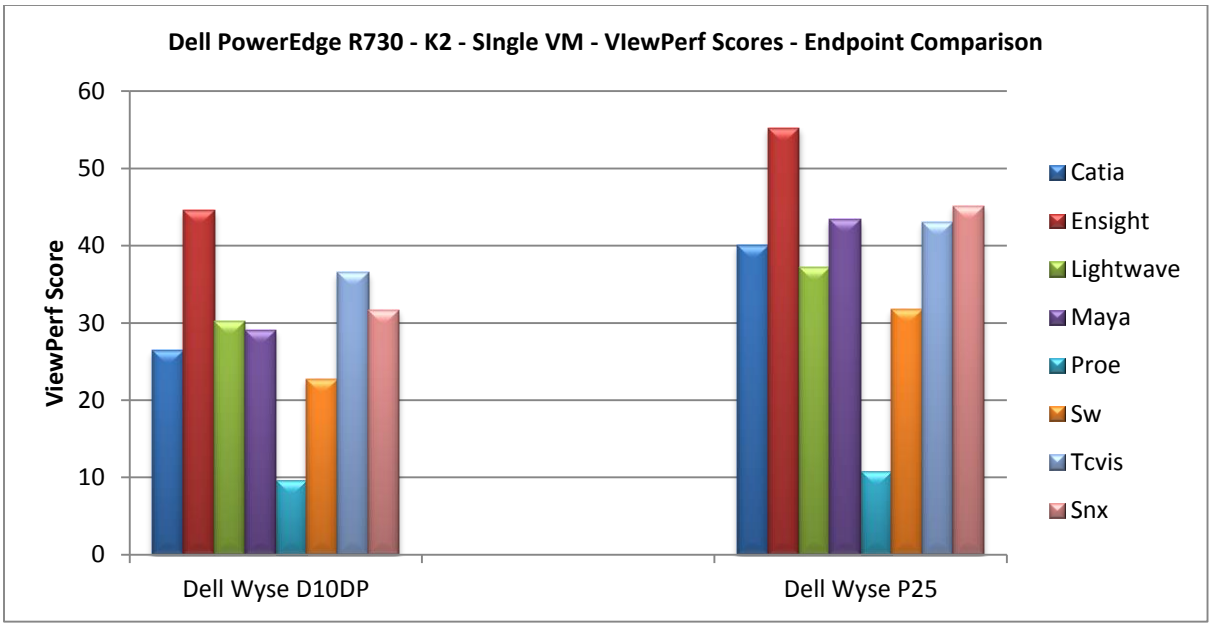


Figure 9 Dell PowerEdge R730 – K2 – Single VM – ViewPerf scores – Endpoint comparison

4.1.4 NVIDIA GRID K2 – ViewPerf Benchmark testing with companion workload

The following graphs show the ViewPerf scores of the Wyse P25 and the Wyse D10DP while a companion workload is running on a second virtual machine.

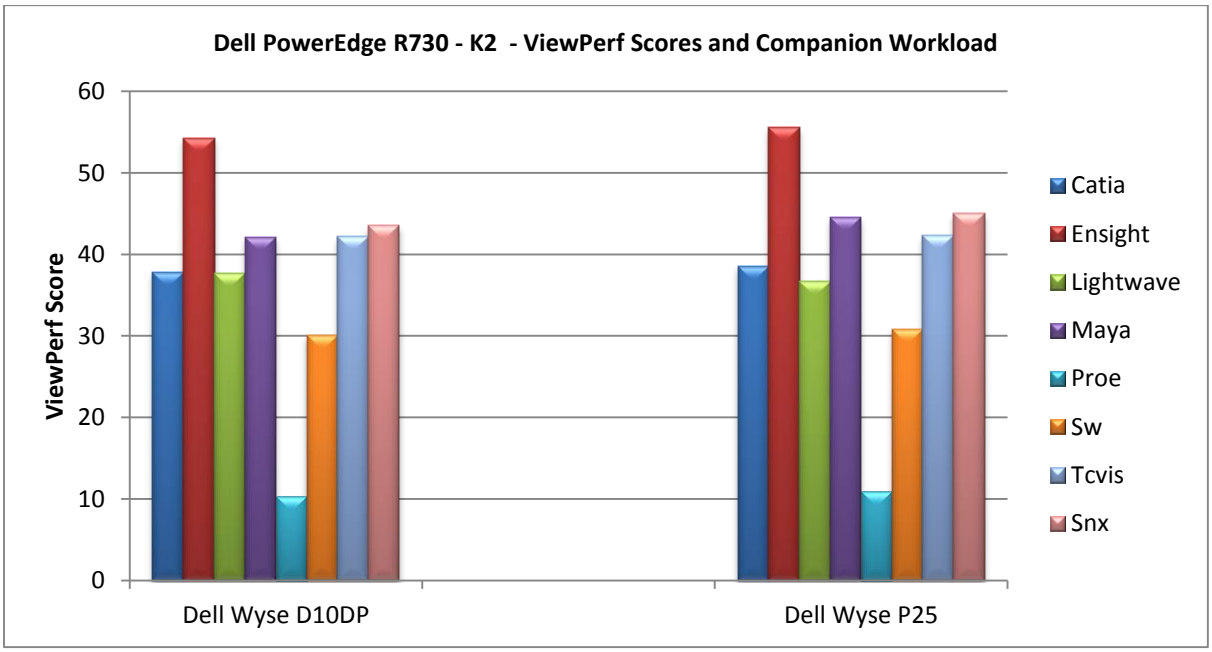


Figure 10 ViewPerf scores with companion workload

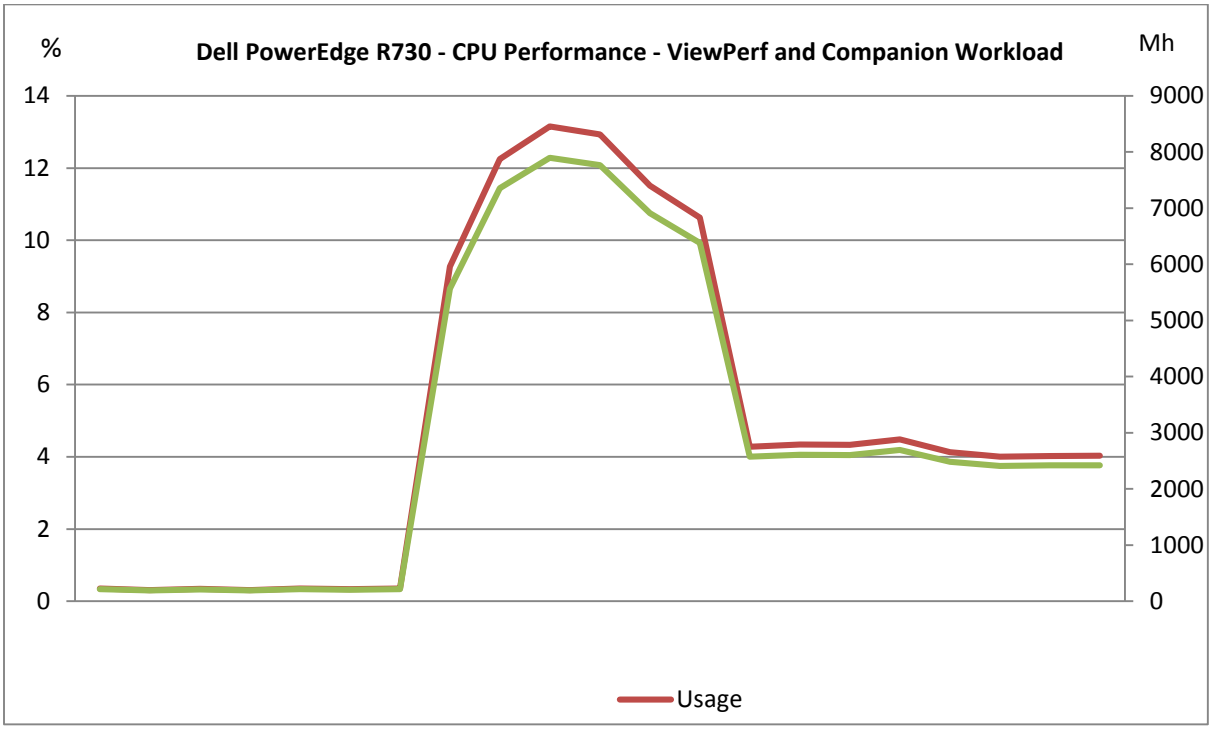


Figure 11 Host CPU usage remained quite low while the HB and the companion workloads were running.

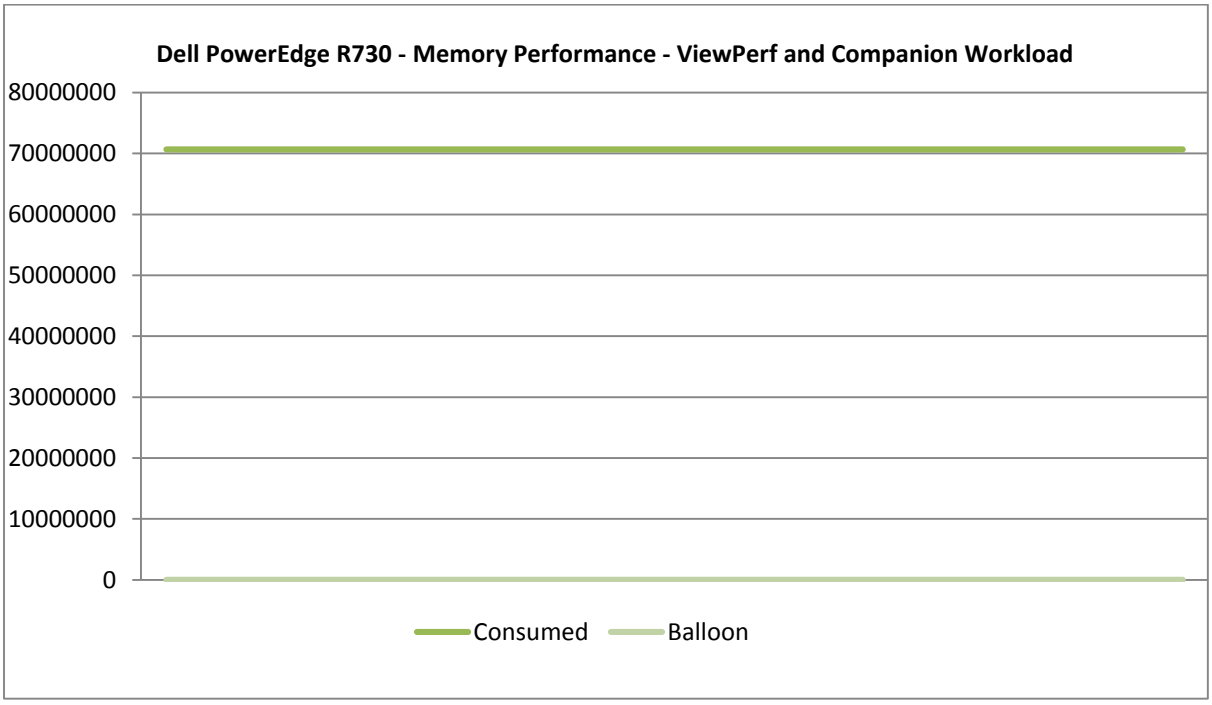


Figure 12 Host memory usage while the HB and the companion workloads were running showed no evidence of any memory ballooning.

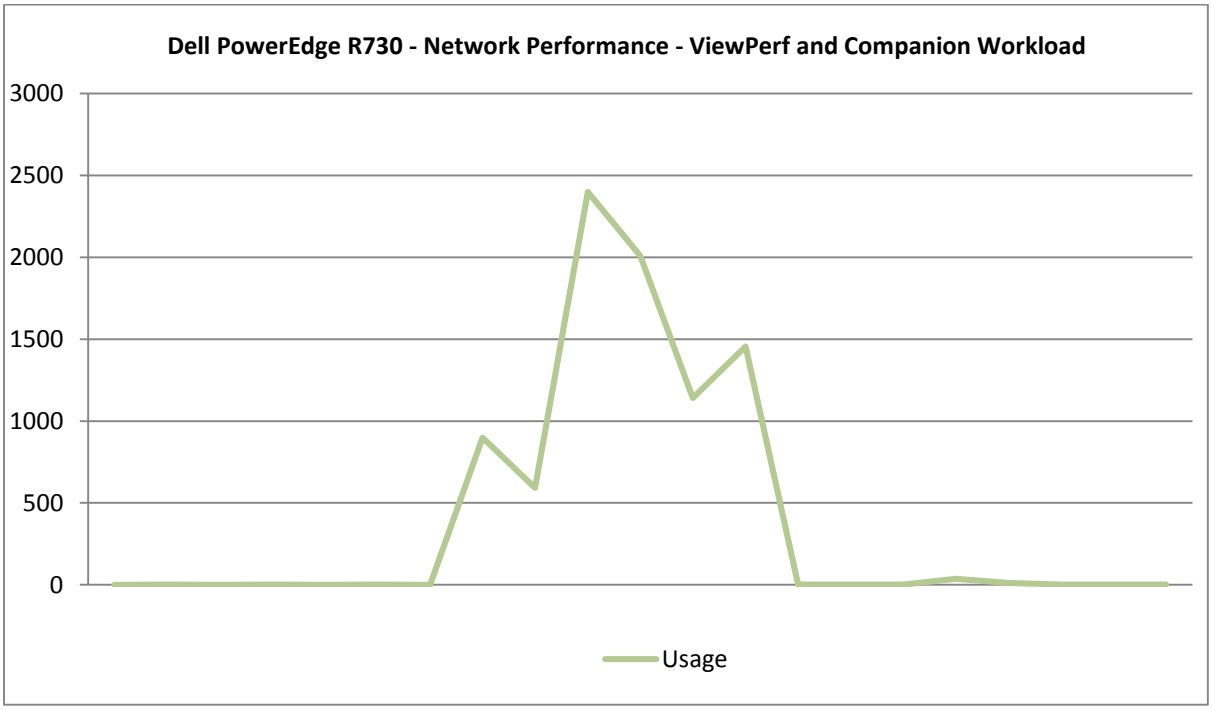


Figure 13 Host network utilization remained well within acceptable thresholds.

4.1.5 Subjective tests

As part of the validation work performed in the Wyse Solutions Engineering labs, our technicians were able to login to the Wyse D10DP and Wyse P25 successfully and execute many subjective tests while the companion workloads were running on the host.

They performed multiple concurrent activities while the workloads were running on the desktops. Examples include opening Microsoft Office applications, Adobe Reader documents, Internet Explorer and browsing through folders using Windows Explorer.

Subjective user experience on both endpoints was more than satisfactory.

5 Conclusions

vDGA works well and offers very good graphics performance in virtualized environments. Setup and installation are straight forward and easily accomplished by the average VDI administrator.

While the NVIDIA GRID K1 GPU is best suited to entry-level or shared graphics usage, the K2 GPU is capable of much greater performance when working with intensive, high-end graphics applications such as Heaven Benchmark. K2 GPU usage was much lower than the K1 GPU usage when running the more demanding applications. The K1 card was capable of running Heaven Benchmark at the lowest resolution and the lowest quality setting available in the application; whereas the K2 was able to display many more FPS when running Heaven at a higher resolution and quality. These test results clearly demonstrate that the K2 GPU is much better suited to handling more graphically-intensive workloads.

Endpoint selection is very important when designing an infrastructure for heavy graphics workloads. The endpoint needs to be capable of decoding the PCoIP frames quickly in order to display smooth, graphically rich images. This is why we selected the Wyse P25 and Wyse D10DP for our testing as both are capable of delivering a great graphical experience to the end user.

As expected, performance of the VMs running in vDGA mode were unaffected by added workloads that were placed on co-hosted VMs. The data collected in each of these tests confirm that when GPUs are dedicated to VMs using the vDGA technology present in Horizon View, performance was maintained at a high level as measured by frame rates and host metrics.

vGPU test data can be found in the Appendix of this document and clearly demonstrates that server resource utilization levels were very low throughout the 4 client tests. Additional testing is underway to identify the maximum number of vGPU cliens

A Configuration details

Table 6 Configuration details

Solution Configuration – Hardware Components		Description
Virtual desktops	Windows 8.1 64-bit 4 x CPU 32 GB RAM	Configuration of VMs for vDGA testing
VMware compute host	1 x Dell PowerEdge R730 Server VMware ESXi 6.0 (on Micro SD) Intel Xeon E5-2660 v3 2.6 GHz 256 GB RAM @ 2133 MHz 10 x 146GB 15K SAS HDDs Broadcom BCM57800 PERC H730P RAID controller 2 x NVIDIA GRID K1 2 x NVIDIA GRID K2 APEX 2800 PCoIP card	For VMware ESXi environment 10 x 146GB drives were configured in a RAID-10 array
VMware management host	1 x Dell PowerEdge R720 Server ESXi 6.0 Intel Xeon E5-2690 @ 2.7 GHZ 128 GB RAM @ 1600 MHZ 10 x 146GB 15K SAS HDDs Broadcom BCM5720 1GbE NIC PERC H710P RAID Controller	For VMware ESXi environment 10 x 146 GB drives were configured in a RAID-10 array. Each VM hosted the following workloads on Windows Server 2008 R2: VMware vCenter VMware Horizon View Connection Server Microsoft SQL Server (View Connection Server and vCenter databases) File server
Network	1 x Dell PowerConnect 6248 1GbE 48-port switch	Mainstream network 1GbE ToR switch
Performance monitoring	VMware vSphere Virtual Center 6.0 NVIDIA SMI Utility	
Software components	VMware vCenter Server 6.0 VMware Horizon View 6.0 VMware ESXi 6.0 MS SQL Server 2008 Ent. Ed. Windows Server 2008 R2 SP1	
Other configuration notes	PCoIP GPU was applied to enable 120 maximum FPS. Build to lossless was disabled. Heaven Benchmark was not run in full screen mode. Dell U2713 display @ 1920x1200	

B Test results – 12 June 2015

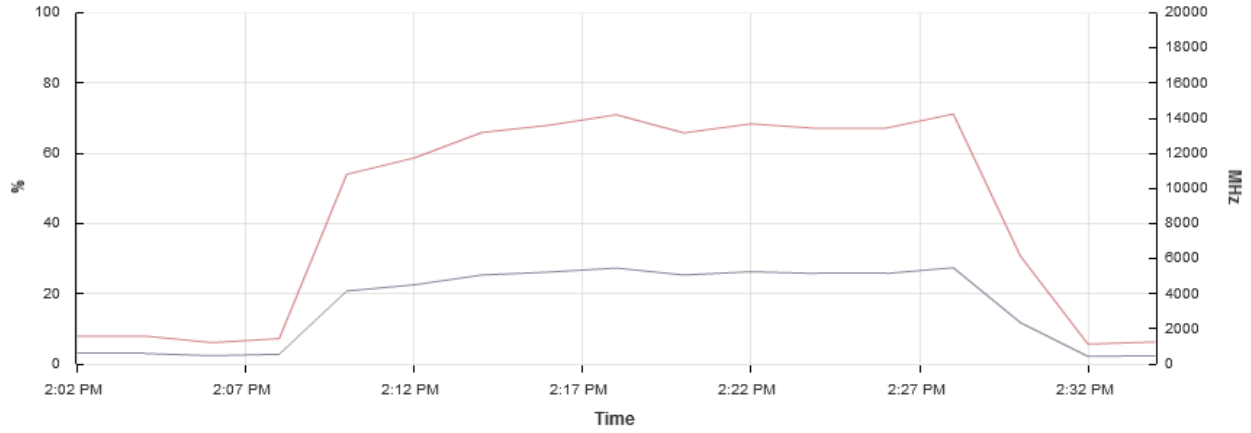
All resolutions set to 1920x1200.

Test configurations: R730 ESXi 6 and View client VMs:

- R730 with two K2 cards and
  - A.1 vDGA configuration and 4 client VMs
  - A.2 vGPU configuration with K280q and 4 client VMs
  - A.3 vGPU configuration with K220q and 4 client VMs

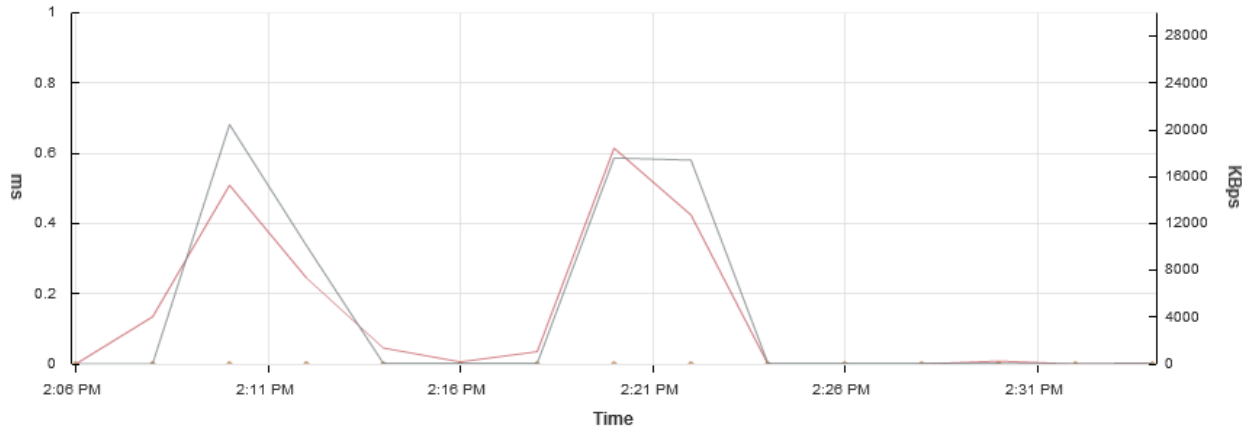
B.1 ESXi performance graphs

B.1.1 CPU



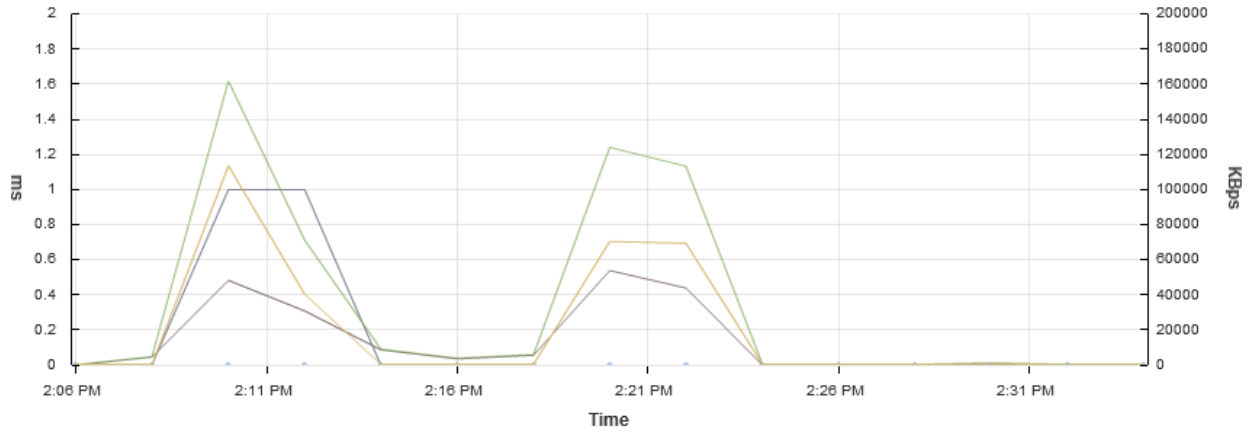
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	10.50.176.56	Usage	Average	%	2.42	27.39	2.19	16.495
	10.50.176.56	Usage in MHz	Average	MHz	1263	14245	1144	8580...

B.1.2 Datastore



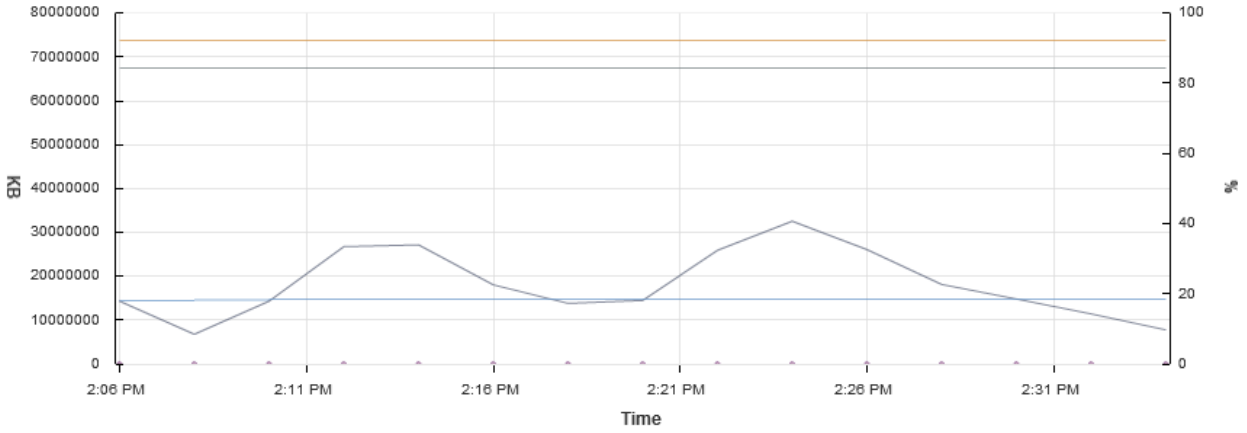
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxmayadatastore	Read latency	Average	ms	0	0	0	0
	kbgxmayadatastore	Read rate	Average	KBps	50	18459	0	4052.8
	kbgxmayadatastore	Write latency	Average	ms	0	0	0	0
	kbgxmayadatastore	Write rate	Average	KBps	90	20479	6	4409...

B.1.3 Disk



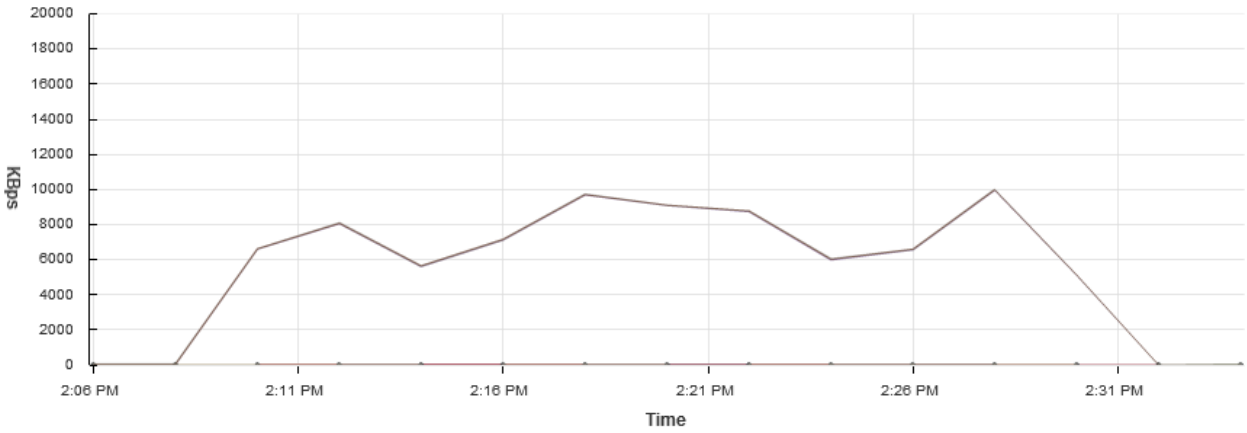
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	10.50.176.56	Highest latency	Latest	ms	0	1	0	0.133
	10.50.176.56	Read rate	Average	KBps	86	53772	23	1333...
	/vmfs/devices/disks/mp...	Read rate	Average	KBps	15	15	0	6
	/vmfs/devices/disks/na...	Read rate	Average	KBps	71	53772	8	1333...
	10.50.176.56	Usage	Average	KBps	423	1617...	225	3319...
	10.50.176.56	Write rate	Average	KBps	336	1134...	170	1985...

B.1.4 Memory



K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	10.50.176.56	Balloon	Average	KB	0	0	0	0
	10.50.176.56	Consumed	Average	KB	7362...	7362...	7358...	7361...
	10.50.176.56	Granted	Average	KB	6734...	6734...	6734...	6734...
	10.50.176.56	Shared common	Average	KB	12	12	12	12
	10.50.176.56	Swap used	Average	KB	0	0	0	0
	10.50.176.56	Usage	Average	%	18.28	18.28	18.27	18.2...

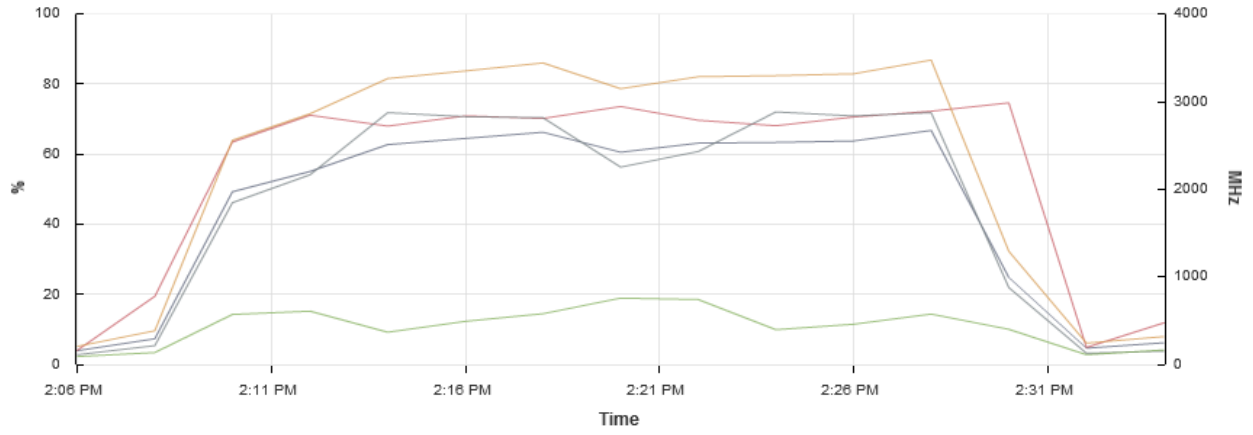
B.1.5 Network



K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	10.50.176.56	Data receive rate	Average	KBps	7	44	4	27.7...
	vmnic0	Data receive rate	Average	KBps	4	42	2	25.2...
	vmnic2	Data receive rate	Average	KBps	0	0	0	0
	vmnic3	Data receive rate	Average	KBps	0	0	0	0
	10.50.176.56	Data transmit rate	Average	KBps	54	9980	5	5520...
	vmnic0	Data transmit rate	Average	KBps	24	9950	1	5507...

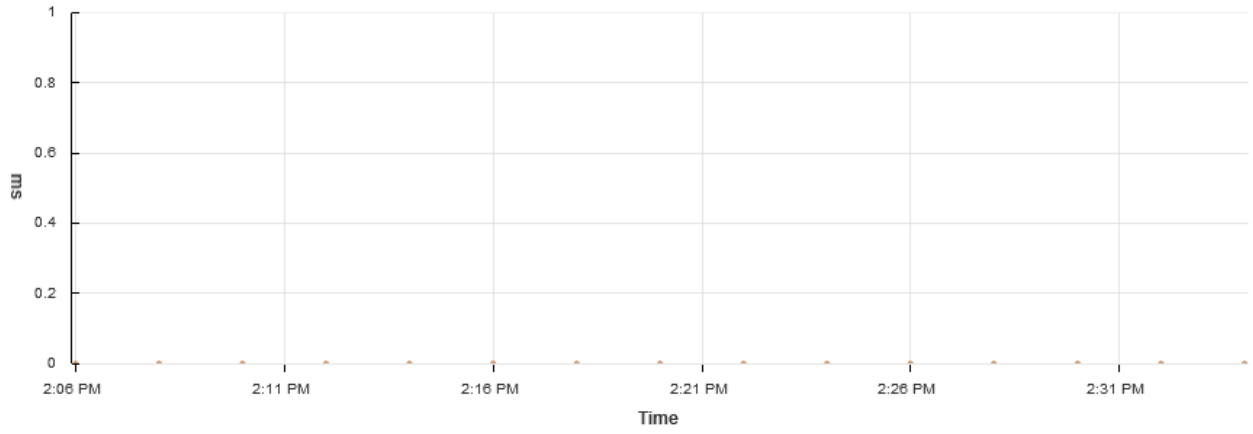
B.2 Client VM performance graphs – A.1 vDGA – 4 clients

B.2.1 CPU



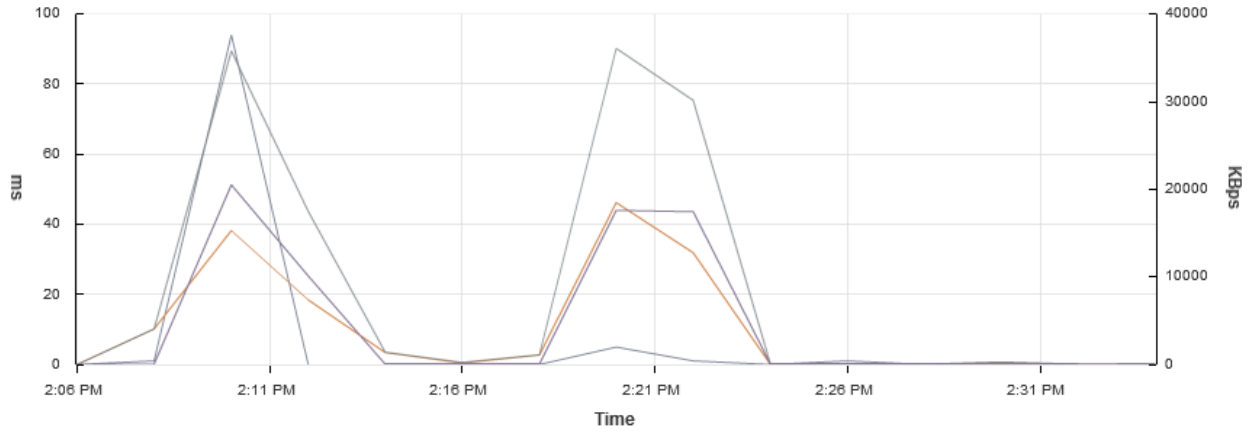
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM9_1	Usage	Average	%	6.16	66.81	3.97	44.165
	kbgxVM9_1	Usage	Maximum	%	11.87	74.65	4.03	54.193
	kbgxVM9_1	Usage in MHz	Average	MHz	320	3473	206	2296
	0	Usage in MHz	Average	MHz	152	2880	113	1819...
	1	Usage in MHz	Average	MHz	164	759	91	430....

B.2.2 Datastore



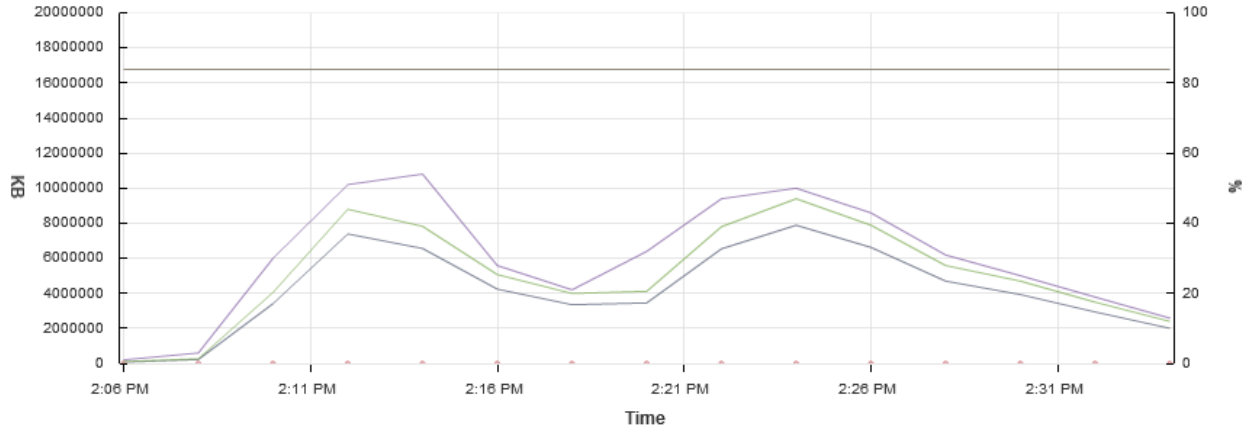
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM9_1	Highest latency	Latest	ms	0	0	0	0
	kbgxmayadatastore	Read latency	Average	ms	0	0	0	0
	kbgxmayadatastore	Write latency	Average	ms	0	0	0	0

B.2.3 Disk



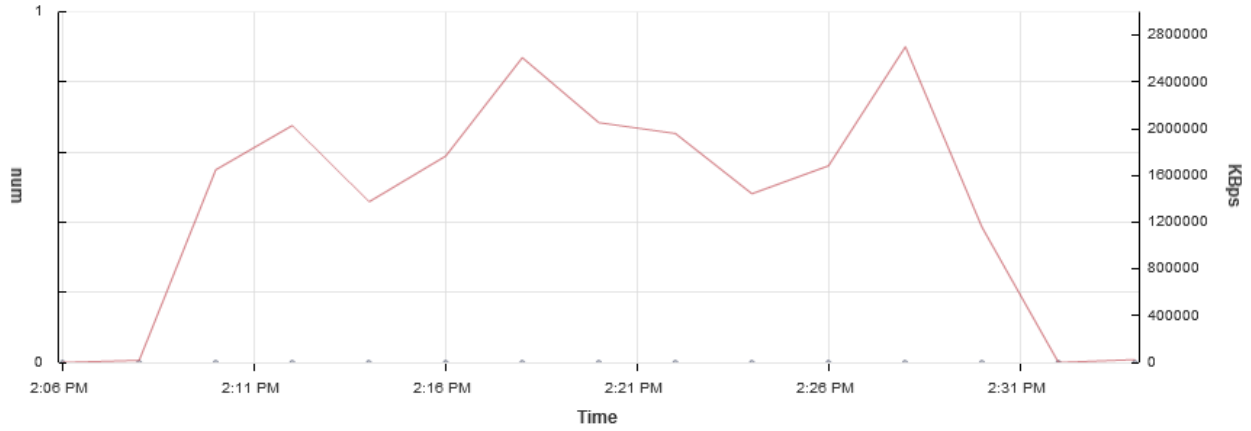
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM9_1	Highest latency	Latest	ms	0	94	0	6.8
	kbgxVM9_1	Read rate	Average	KBps	50	18459	0	4052...
	/vmfs/devices/disks/naa...	Read rate	Average	KBps	50	18459	0	4052...
	kbgxVM9_1	Usage	Average	KBps	141	36079	6	8463
	kbgxVM9_1	Write rate	Average	KBps	90	20478	6	4409.6
	/vmfs/devices/disks/naa...	Write rate	Average	KBps	90	20478	6	4409.6

B.2.4 Memory



K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM9_1	Active	Average	KB	2013...	7885...	83886	4225...
	kbgxVM9_1	Balloon	Average	KB	0	0	0	0
	kbgxVM9_1	Consumed	Average	KB	1677...	1677...	1677...	1677...
	kbgxVM9_1	Granted	Average	KB	1677...	1677...	1677...	1677...
	kbgxVM9_1	Usage	Average	%	11.99	46.99	0.49	25.177
	kbgxVM9_1	Usage	Maximum	%	12.99	53.99	0.99	29.858

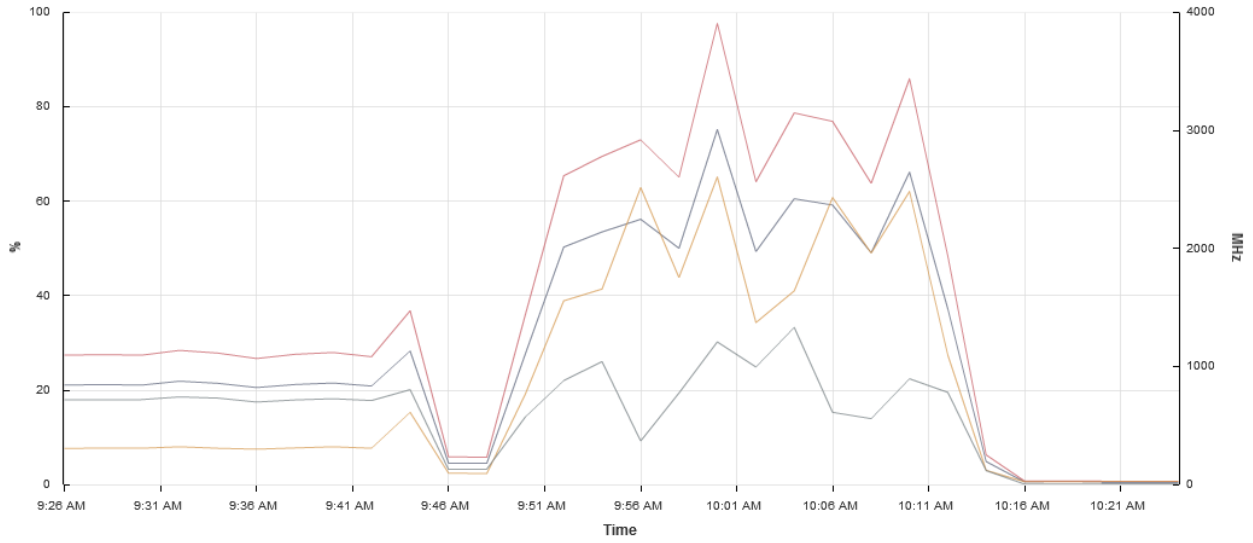
B.2.5 Network



K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM9_1	Net Throughput Content...	Summation	num	0	0	0	0
	kbgxVM9_1	Net Throughput Usage	Average	KBps	24956	2703...	290	1364...

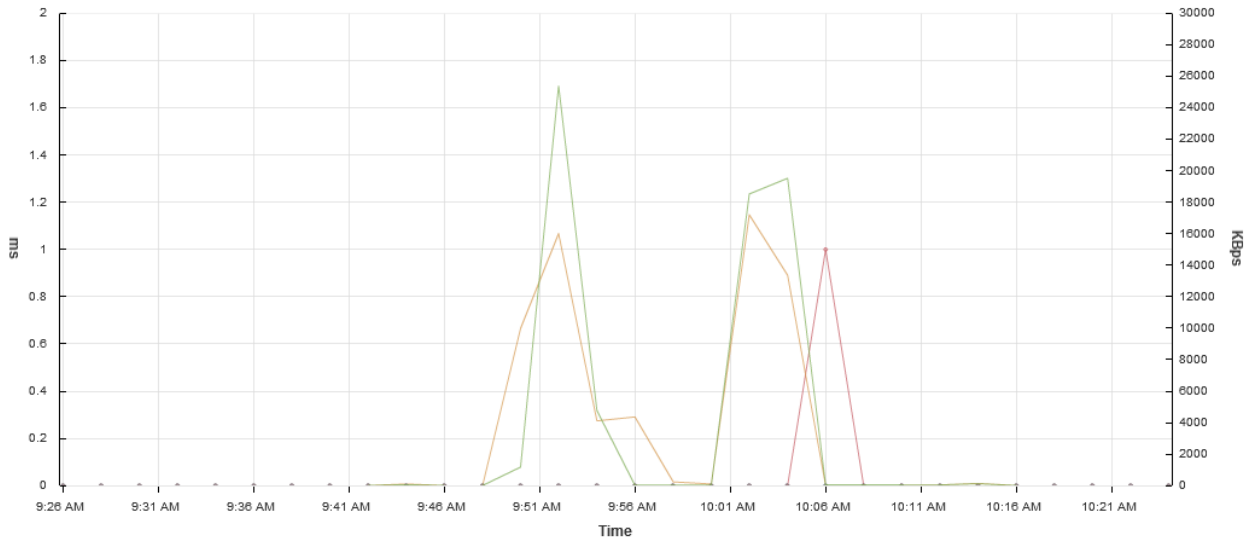
B.3 Client VM performance graphs – A.2 vGPU K280q – 4 clients

B.3.1 CPU



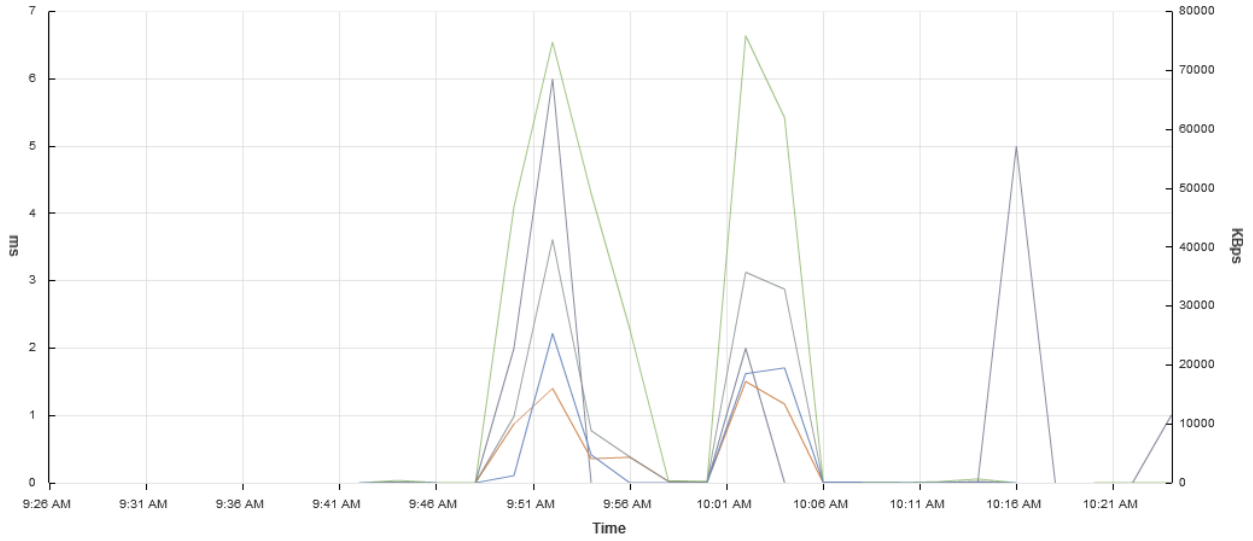
Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
	kbgxVM7_4	Usage	Average	%	0.52	75.22	0.52	29.016
	kbgxVM7_4	Usage in MHz	Average	MHz	27	3911	27	1508.3...
	0	Usage in MHz	Average	MHz	23	2608	23	856.067
	1	Usage in MHz	Average	MHz	2	1332	2	590.1

B.3.2 Datastore



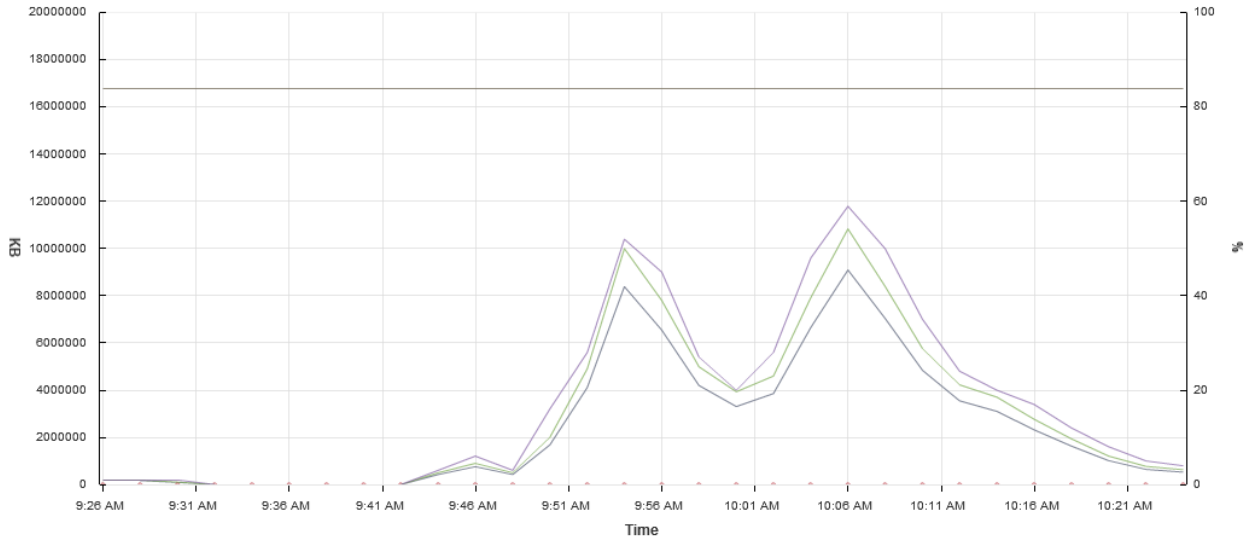
Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
	kbgxVM7_4	Highest latency	Latest	ms	0	0	0	0
	kbgxmayadatastore	Read latency	Average	ms	0	1	0	0.033
	kbgxmayadatastore	Read rate	Average	KBps	0	17205	0	2188.0...
	kbgxmayadatastore	Write latency	Average	ms	0	0	0	0
	kbgxmayadatastore	Write rate	Average	KBps	2	25410	1	2327.4...

B.3.3 Disk



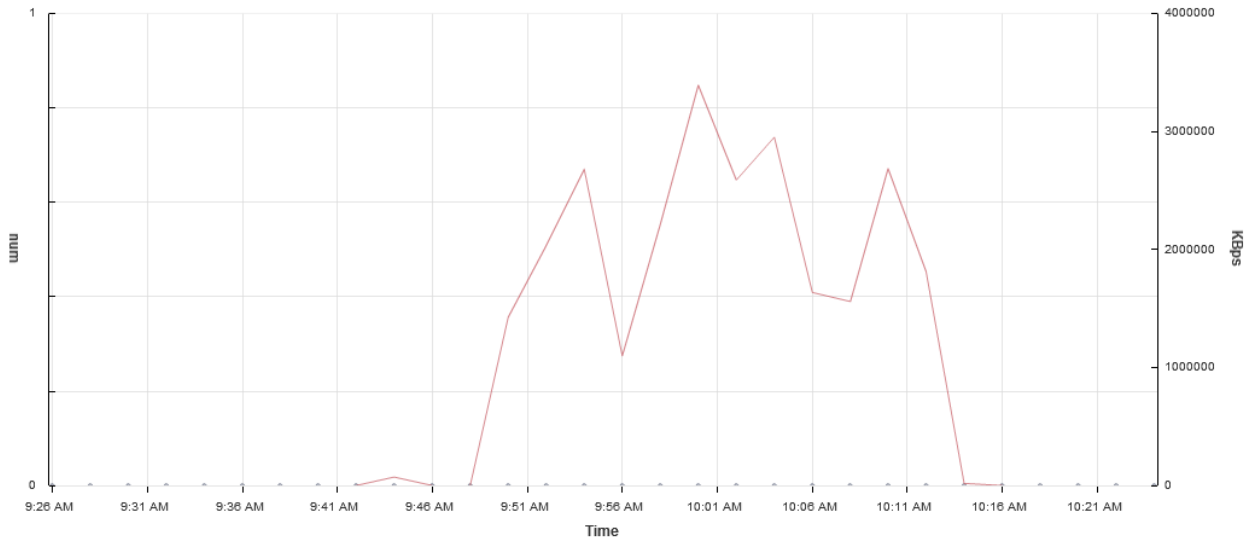
Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
	kbgxVM7_4	Highest latency	Latest	ms	1	6	0	0.533
	kbgxVM7_4	Read rate	Average	KBps	0	17205	0	2188.0...
	/vmfs/devices/disks/naa.6b0...	Read rate	Average	KBps	0	17205	0	2188.0...
	kbgxVM7_4	Usage	Average	KBps	2	41351	1	4515.6...
	kbgxVM7_4	Usage	Maximum	KBps	5	75881	3	11230....
	kbgxVM7_4	Write rate	Average	KBps	2	25336	1	2327.4...

B.3.4 Memory



Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
	kbgxVM7_4	Active	Average	KB	531278	90876...	0	24830...
	kbgxVM7_4	Balloon	Average	KB	0	0	0	0
	kbgxVM7_4	Consumed	Average	KB	16777...	16777...	16777...	16777...
	kbgxVM7_4	Granted	Average	KB	16777...	16777...	16777...	16777...
	kbgxVM7_4	Usage	Average	%	3.15	54.16	0	14.791
	kbgxVM7_4	Usage	Maximum	%	3.99	58.99	0	17.092

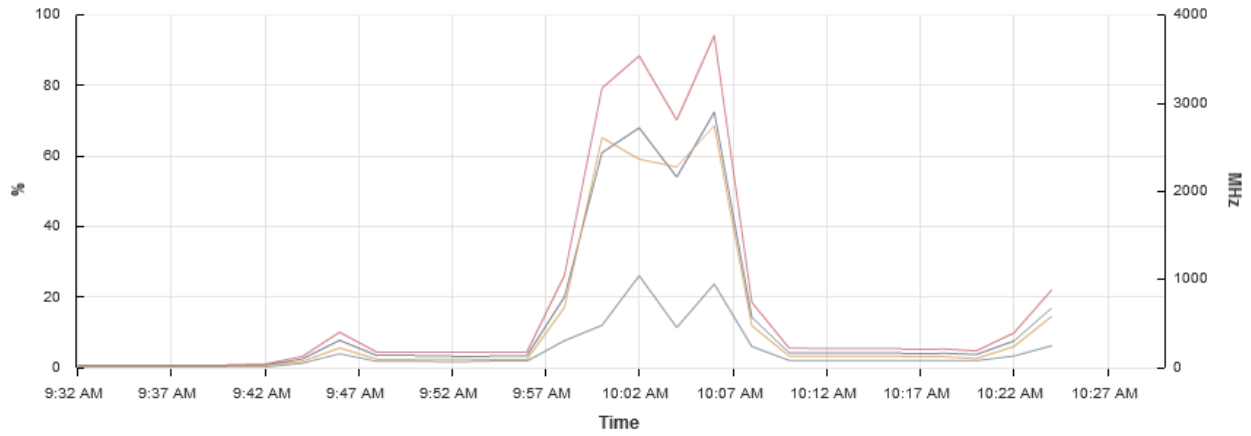
B.3.5 Network



Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
	kbgxVM7_4	Net Throughput Contention	Summation	num	0	0	0	0
	kbgxVM7_4	Net Throughput Usage	Average	KBps	108	33935...	49	87237...

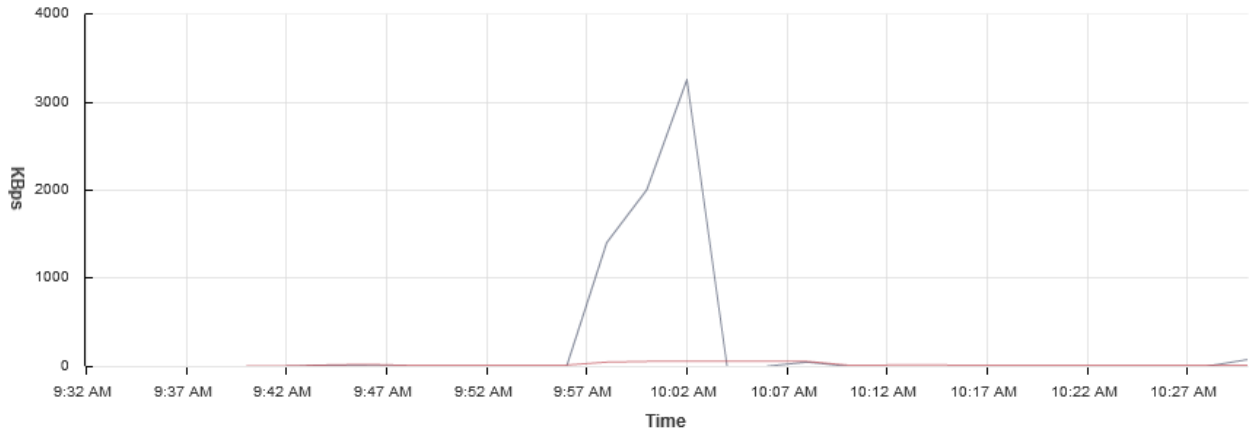
B.4 Client VM performance graphs – A.3 vGPU K220q – 4 clients

B.4.1 CPU



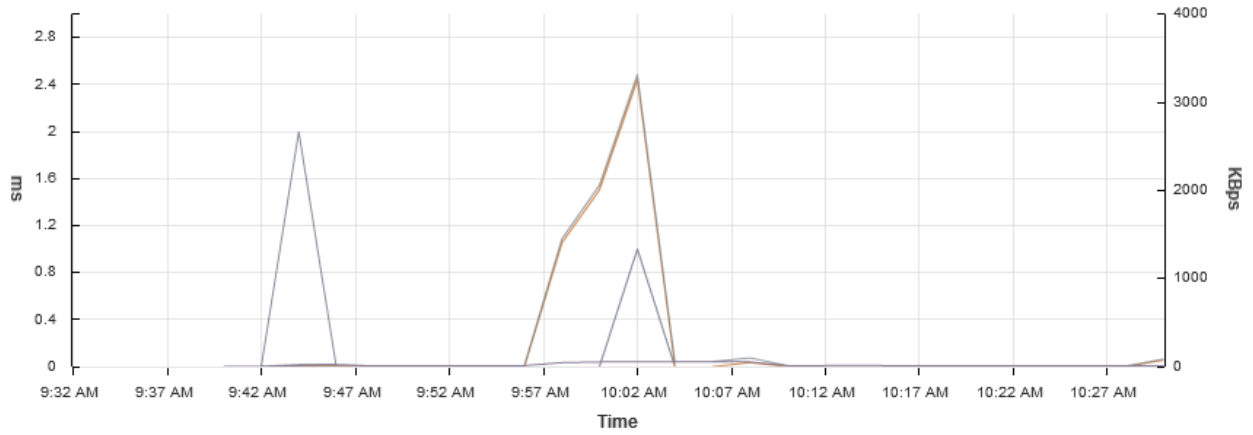
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM8_1	Usage	Average	%	16.9	72.47	0.62	13.706
	kbgxVM8_1	Usage in MHz	Average	MHz	878	3768	32	712....
	0	Usage in MHz	Average	MHz	579	2745	26	505....
	1	Usage in MHz	Average	MHz	250	1043	3	182....

B.4.2 Datastore



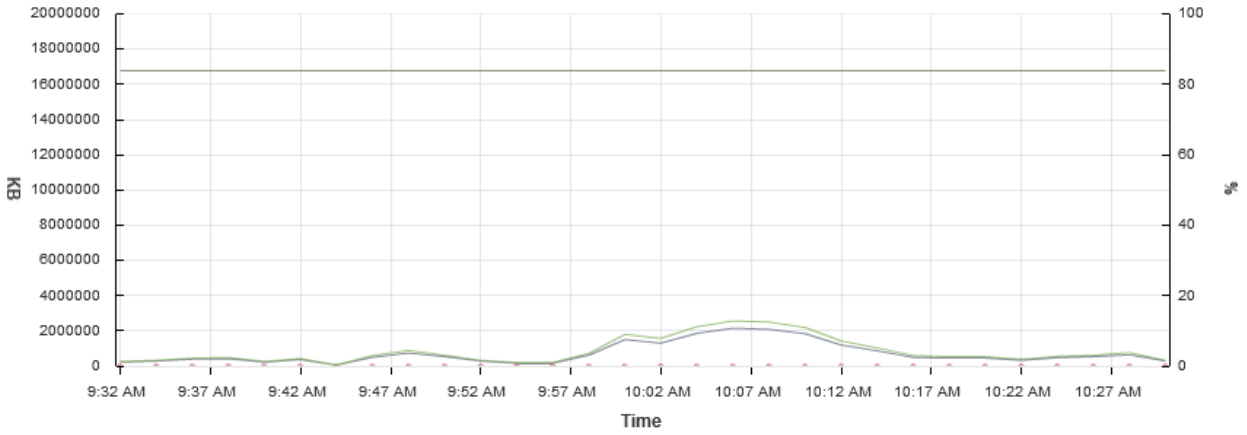
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxmayadatastore	Read rate	Average	KBps	74	3254	0	226.5
	kbgxmayadatastore	Write rate	Average	KBps	14	58	0	17.8

B.4.3 Disk



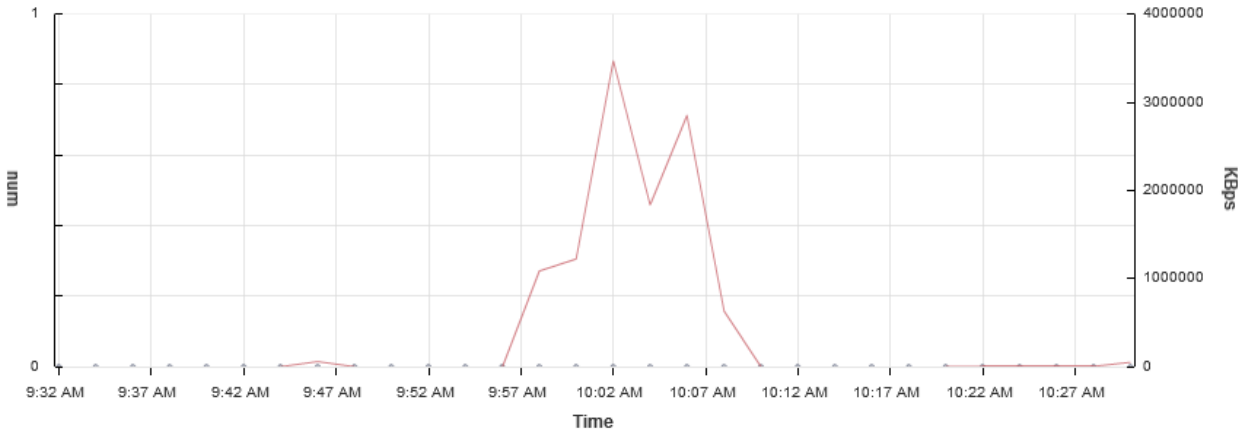
K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM8_1	Highest latency	Latest	ms	0	2	0	0.1
	kbgxVM8_1	Read rate	Average	KBps	74	3254	0	226.5
	/vmfs/devices/disks/na...	Read rate	Average	KBps	74	3254	0	226.5
	kbgxVM8_1	Usage	Average	KBps	89	3313	0	244....
	kbgxVM8_1	Write rate	Average	KBps	14	58	0	17.8
	/vmfs/devices/disks/naa...	Write rate	Average	KBps	14	58	0	17.8

B.4.4 Memory



K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM8_1	Active	Average	KB	2796...	2153...	55924	7167...
	kbgxVM8_1	Balloon	Average	KB	0	0	0	0
	kbgxVM8_1	Consumed	Average	KB	1677...	1677...	1677...	1677...
	kbgxVM8_1	Granted	Average	KB	1677...	1677...	1677...	1677...
	kbgxVM8_1	Usage	Average	%	1.65	12.82	0.33	4.259

B.4.5 Network



K...	Object	Measurement	Rollup	Units	Latest	Maxim...	Minim...	Average
	kbgxVM8_1	Net Throughput Content...	Summation	num	0	0	0	0
	kbgxVM8_1	Net Throughput Usage	Average	KBps	51737	3469...	68	3741...