White Paper

KVM – Open Source Virtualization for the Enterprise and OpenStack Clouds

Sponsored by: Open Virtualization Alliance (OVA)

Gary Chen
October 2014

IDC Opinion

Kernel-Based Virtual Machine (KVM) is a leading open source virtualization hypervisor that is an inherent part of Linux, enabling it to serve as a virtualization host. KVM makes its way into a virtualization market that is already mature, with virtual servers being the vast majority of logical server deployments today. Virtualization deployments have matured greatly beyond consolidation, today focusing on agility benefits such as faster provisioning. Virtualization also serves as the underpinning of cloud, which has begun to change the entire face of IT.

The cloud has been a boon for open source, with much of the public cloud being built on open source stacks that include the hypervisor, OS, infrastructure-as-a-service software, and application and middleware stacks. KVM plays a key role as the open source virtualization underpinning for both enterprise virtualization under traditional virtualization management, as well as in next-generation applications that are run on new cloud infrastructures such as OpenStack.

KVM will ride on the growth and success of Linux and OpenStack, both very large open source projects with bright futures. KVM has made many technical achievements over the years in the core hypervisor, but virtualization success today requires a holistic, end-to-end approach. For KVM to gain more traction, advanced management and tight integration and functionality with storage, networking, security, and other areas are required to round out a full KVM virtualization solution. This white paper examines the current state of KVM, identifies keys to future KVM success, and presents information on the progress the community has made in these areas.

Situation Overview

Server virtualization, in the span of a little more than a decade, has risen to become the default server deployment model, with 80% of all new logical server shipments virtualized in 2014 and forecasted to increase to 88% by 2017. Buyers were initially attracted to virtualization's consolidation benefits and flexibility for test and development. However, additional uses cases were developed, and today virtualization is used extensively for agility benefits such as faster provisioning, high availability, and disaster recovery. It is also the foundation underpinning private cloud initiatives.

VMware created the x86 server virtualization market and dominated the market for many years. However, competitors eventually shrunk the technology gap and now the virtualization market is more

competitive than ever, with offerings from Microsoft and various commercial implementations of open source projects Xen and KVM. KVM is the newest entrant into the market, having been merged into the mainline Linux kernel in 2007. It has drawn attention for its close ties to the Linux operating system and more recently, closely attached to OpenStack cloud deployments as the most popular hypervisor. The Linux server market is projected to show healthy growth in the coming years, with 5.2 million new license shipments expected in 2014 and increasing to 7.2 million by 2017, which leads to increased opportunity for KVM. According to IDC's Server Virtualization Tracker, new shipments of KVM are over 278,000 total units since 2011, representing a CAGR of nearly 42%.

As virtualization has matured, hypervisors have also become less of a standalone product and increasingly part of a larger stack. Many virtualization solutions are an integral part of an operating system or embedded into a larger bundle or "stack" of cloud software.

As more enterprise-ready hypervisors came to market, multi-hypervisor deployments began to be investigated by many customers. IDC's *Virtualization and the Cloud 2013* study found that 16% of customers had already deployed or were planning to deploy more than one hypervisor and an additional 45% were open to the idea in the future. Drivers for adopting a second hypervisor include compliance with multi-vendor sourcing strategies, cost reduction, increasing leverage with vendors, and software license optimization. However, the benefits of a multi-hypervisor environment have to be balanced with the cost and complexities of adding a second environment, making the decision complex and different for each customer. IDC has observed that migrating virtual machines (VMs) from one hypervisor to another isn't generally done for all but the simplest workloads due to the cost and effort involved, and most of the second hypervisor deployments will be used for new workloads being deployed.

Like Linux, KVM is cross-platform, which adds additional flexibility and choice. KVM has been ported to both ARM and IBM Power, with technical previews available for additional platforms including Linux on System z.

A Brief KVM Primer

Kernel-Based Virtual Machine (KVM) is an open source virtualization technology that enables the Linux operating system to serve as a hypervisor host. KVM is implemented as a loadable module in the Linux kernel that turns the Linux OS into a hypervisor for x86 and, more recently, Power and ARM systems.

A hypervisor can be thought of in many ways as a very specialized operating system (OS) designed to run VMs instead of arbitrary applications. Besides the virtualization itself, the rest of a hypervisor really deals with standard OS tasks such as managing memory, scheduling processes, handling drivers, doing I/O, etc. The KVM module implements within Linux the essential capabilities for virtualization, but adopts the philosophy of not reinventing the wheel, and uses the established and proven Linux OS functions for the rest. By not having to rewrite basic functions, developers can focus their efforts on optimizing Linux for VM processes – not replicating those functions within the hypervisor code stack.

KVM has been a part of the mainline Linux kernel since 2007, and with it come certain advantages and implications:

- KVM is integrated and tested with Linux and included in nearly all Linux distributions.
- Though built on Linux, KVM can virtualize both Linux and other guests, for example Windows on x86 systems.
- Open source software offers many consumption models to customers. Some will take the raw open source code and deploy it, modify it, and support it themselves. Others will want a commercially tested and supported version, and the open nature of open source software means that any vendor can offer it commercially, which leads to customers being able to source from multiple vendors to reduce their risk.
- KVM is part of the Linux development community, so improvements to Linux generally benefit KVM. Open source software can mature very quickly if a large community forms and contributes resources. KVM, being part of Linux, can tap into one of the largest open source projects and has already shown remarkable maturation.
- KVM inherits the drivers and broad hardware compatibility of Linux, allowing it to run nearly anywhere Linux runs, and no unique effort is required to produce new drivers specifically for KVM.
- KVM reuses many of the mature and established Linux technologies such as process management, drivers, memory management, I/O, and Security Enhanced Linux (SELinux). SELinux is used to secure KVM by walling off processes, so if part of a system or VM is compromised, the problem is isolated and does not impact the entire system.

Containers and VMs

The recent interest in Linux container technology such as Docker has raised many questions about when to use containers and when to use VMs. Containers are a virtualization technology at the operating system level, essentially OS virtualization. Much of what is discussed today as "containers" is much more than the actual isolation container, which for Docker is LXC, a core part of the Linux kernel much like KVM. Much of the value of containers is from the management system, which orchestrates the containers around the datacenter and also packages items into the container. Operating at the OS level makes containers very efficient and performant, since they do not have to emulate a full physical server like a hypervisor. But containers also come with a very different set of characteristics:

- Applications written for a container will still be tied to an OS. For example, a Linux container would not be movable to a Solaris host, but only to another Linux host.
- The isolation model is not as strong as VMs for security. While containers can do a good job of resource isolation, security isolation is with a shared kernel and thus may not be enough for a multi-tenant environment or for highly sensitive applications. VMs and containers can be used together in this case to increase isolation – for example, putting each tenant onto a different container host, and then separating these container hosts into VMs.
- The application and use of containers are still evolving. While most Linux applications can be containerized today, the question is really for what workloads is containerization best, versus VMs and bare metal. Much of this will depend on the tooling that develops to manage containers, while VMs have had many years to mature their toolset. Today, containers are

developer-oriented, used primarily for new applications written for a container-and-cloud model. It's unlikely that the market will see a mass VM-to-container migration for existing virtualized applications, but it's not quite clear yet how much containers will vie as a virtualization technology for traditional workloads.

- Containers will greatly improve Linux distribution portability (moving an application between various Linux versions and distros), but it will likely not address all scenarios.

While containers are making an impact on the market, they're a very different tool than a hypervisor and can often be used in conjunction with VMs. VMs made their impact as an infrastructure tool, while containers have been developer-focused, often seen more as a packaging, revision control, and code repository tool than strictly a virtualization tool. These differing use cases likely mean containers and VMs will co-exist for the foreseeable future as tools with very different applications.

Keys for KVM Success in the Market

While the core KVM hypervisor has been maturing for quite awhile, the keys to KVM's survival and success in the market lie in several important supporting areas:

- **Management software**. This is key to enabling customers to adopt and deploy large and advanced deployments of virtualization.
- **Training and documentation**. Adopters need to be able to hire people with the skills to manage KVM, and seeding the IT workforce with these skills requires training programs and documentation.
- **Hardware and software ecosystem.** Virtualization is a heavily interconnected technology in the datacenter, with today's deployments being holistic, end-to-end approaches. A large, vibrant supporting ecosystem of complementary hardware and software solutions is key to creating a lasting platform.
- **Cloud**. Virtualization today is often a stepping-stone and a foundation for cloud, private or public. Cloud may well be the primary way to deploy virtualization in the future, and KVM will need a cloud platform to integrate with to stay relevant.

KVM Management

Libvirt is the primary virtualization library that KVM management applications use. It provides a virtual machine management API and basic management of virtual storage and networks. Management applications built on libvirt can be extremely basic, such as virsh, a command line interface to libvirt. However, enterprise customers today expect and need an advanced centralized virtualization management server with a slick GUI, which is provided by the oVirt open source project.

The oVirt project was started by Red Hat, and has since seen contributions from Intel who worked on TPM support, HP who improved NUMA intelligence, and IBM. Red Hat Enterprise Virtualization (RHEV) is a commercial distribution of oVirt, and the two have synchronized version numbers (e.g., RHEV 3.4 is based on oVirt 3.4). oVirt releases twice a year, with maintenance releases every 6 to 8 weeks in between releases. The corresponding RHEV release usually follows within one to two months, and the support life cycle has recently been extended from 3 to 5 years.

RHEV 3.4 released in June 2014 has the following key features and enhancements:

- Hot pluggable CPUs
- Ability to support multiple storage types (NFS, iSCSI, etc.)
- Integration with OpenStack Neutron, which allows the creation and management of networking services like Open vSwitch
- Integration with OpenStack Glance for VM images

oVirt 3.5 currently is aiming to implement the following improvements (subject to change):

- Better scale up/down with CPU and storage SLA support
- Enhanced NUMA support
- Improved networking support with advanced Linux networking capabilities exposed through oVirt

oVirt 3.6 is currently planned to be the last point release before 4.0, focusing on reliability, scalability, and cleaning up loose ends. It is tentatively planned to implement hot add memory, an improved update manager to upgrade the virtualization infrastructure, and improved scalability. Over time, the project intends to continue to integrate with various OpenStack modules such as Neutron (networking), Glance (image service), and Keystone (authentication) to provide more common backends for both traditional virtualized infrastructure and OpenStack cloud infrastructure. Version 4.0 and beyond will also continue major work on the UI to improve its functionality and responsiveness.

In addition to the datacenter and enterprise-focused oVirt/RHEV, several other management products are in the KVM ecosystem:

- Kimchi – Kimchi is an open source project focused on basic virtualization management, intended to be a very easy to deploy and use KVM manager for more simple and smaller environments, available for both x86 and Power systems.
- op5 Monitor – op5 is a developer of open source management software for enterprises to monitor and administer IT infrastructure including hardware, software, and cloud-based services. It can monitor virtual servers including KVM and is based on the open source Nagios project.
- ProxMox VE – This is a commercial open source virtualization management product that focuses on KVM management, which includes virtual machines, storage, virtualized networks, and HA Clustering.

The projects and products discussed above are primarily targeted at enterprises doing virtualization management for traditional enterprise applications with typical enterprise architectures. OpenStack is a newer way to manage KVM in cloud-style architecture, and today is primarily optimized for scale-out, cloud-native applications. OpenStack is discussed in further detail in a later section of this paper.

Training and Documentation

With KVM relying on existing Linux functions where possible, this makes Linux management skills very transferable to KVM. For example, KVM VMs are standard Linux processes and thus the usual

process management tools and techniques work to manage KVM guests. KVM VMs are standard Linux files, so file system skills apply to manage VM data files. And SELinux security can be applied to these processes and files like any other for security. However, most users will also want to leverage more advanced virtualization-specific tools like oVirt, and this is where training and documentation are crucial in order to enable customers to train or acquire IT staff to deploy KVM.

One major source of training programs that include both Linux and KVM is from the Linux Foundation, whose goal is to promote Linux in the marketplace. Commercial Linux vendors such as Red Hat, SUSE, and Canonical (all of whom distribute KVM) also offer training and certification, usually more specific to their distribution. These vendors also produce useful documentation for Linux, KVM, and management tools, expected of a commercial enterprise product. Transitiv, a UK based company, provides training as well on many open source subjects, including Linux and KVM. There is also the KVM Forum, an annual technical conference for KVM developers, along with users to discuss the technology, the infrastructure surrounding KVM, management tools, and the future of KVM.

The KVM Ecosystem

Intel is the leading vendor of x86 processors, which is the most popular architecture for Linux and KVM. Intel also plays a major role in KVM software development, enabling and optimizing KVM to use hardware features in Intel processors. Each revision of Intel processors includes new and improved virtualization hardware functionality, and the goal is to ideally have this enabled when the processor launches.

Intel may begin developing KVM code during processor development, either through a simulator or on pre-release hardware. When the processor launches or sometime thereafter, Intel releases the code into the KVM project repository, which then eventually makes its way into the various KVM and Linux distributions. Through Intel's efforts, the current KVM code takes advantage of all the hardware virtualization features of Intel processors. Some interesting areas of work in progress include APIC virtualization for improved performance, VMSC shadowing to improve nested virtualization performance, and cache QoS monitoring for better scheduling and SLA performance.

AMD also makes similar contributions to Linux and KVM for its x86 processors. AMD participates in several key KVM related initiatives, including the Linux Foundation, Open Virtualization Alliance, and the OpenStack Foundation. AMD also is working on a 64-bit ARM server processor.

While x86 is the most popular Linux and KVM architecture today, work is being done to port to other architectures. IBM is making Power more open with the OpenPOWER Foundation, an initiative to develop Power with partners. IBM has led the efforts to port Linux and KVM to the Power platform, and has been working upstream on KVM for System z, with SUSE releasing a tech preview of KVM for Linux on System z

ARM, already popular in mobile client devices, is also targeting servers. Linaro is an industry consortium composed of major IT suppliers whose goal is to bring open source software to the ARM platform. As part of this goal, Linaro and its members have been working on porting key system software for ARM servers such as Linux, KVM, and OpenStack, to bring key virtualization and cloud functionality to this burgeoning server platform

On the storage side – a key supporting element of virtualization – NetApp has developed storage integration for KVM. NetApp was an early supporter of virtualization and invested significant resources into optimizing and integrating with virtualization as a market differentiator. NetApp was also an early supporter of integration with KVM via the ovirt.org open source program. It develops an oVirt/RHEV plug-in to manage virtual storage through the oVirt/RHEV interface and enable NetApp-specific features in KVM.

Other notable ecosystem products that integrate with KVM include:

- BlueCat, which provides IP Address Management (IPAM) solutions that power core network services to make it easier to deploy virtual infrastructure and clouds.
- Bloombase, which develops information security products designed to protect a wide range of data through cryptography. Its solution integrates with KVM to protect virtual machine data.
- Mellanox Technologies, which provides InfiniBand and Ethernet interconnect solutions and services for servers and storage and enables these in Linux and KVM.

Much of the KVM ecosystem is organized by the Open Virtualization Alliance, designed to promote and market KVM. Many vendors have joined the OVA – currently more than 200 members representing users and providers of virtualization, datacenter, and cloud solutions. The governing members of the OVA include HP, IBM, Intel, NetApp, and Red Hat. OVA concentrates on four initiatives: 1) educate the marketplace about KVM, 2) increase awareness and credibility of KVM-based products and services, 3) publish design patterns, blueprints, and design architectures to foster best practices, and 4) facilitate the delivery of KVM solutions to the marketplace.

OpenStack Key to KVM's Future

OpenStack is an open source project aimed at developing cloud software to build and operate infrastructure-as-a-service clouds. The project has tremendous community momentum behind it, with most major IT vendors participating. The project is run by the independent OpenStack Foundation, charged with promoting the development, distribution, and adoption of OpenStack.

OpenStack is developed in a modular fashion, with modules for compute, block storage, object software, software-defined networking, authentication, etc. More modules are proposed and developed constantly, expanding the functionality of OpenStack.

OpenStack in many ways is a framework that provides consistent API-driven access to infrastructure. However, for certain functions, OpenStack requires a backend to plug into, as is the case with Nova, OpenStack's compute function. OpenStack does not include a hypervisor or virtualization functionality, requiring an existing hypervisor to be integrated through a driver. While OpenStack has drivers for most major hypervisors, KVM plays a special role in OpenStack, being the most popular hypervisor for OpenStack deployments.

Most OpenStack development and deployment uses Linux as the host OS for its cloud controllers. KVM, being part of Linux, was a natural choice for the hypervisor. Linux and KVM being open source was key As a fully open stack, they allowed fully open development and transparent test and debug across the entire cloud stack. This led to KVM being best supported, easiest to deploy, and the most

full-featured driver in OpenStack. With KVM playing a key role in OpenStack, success for OpenStack will also mean success for KVM.

Notable commercial implementations of OpenStack include:

- **HP Helion** – In May 2014, HP introduced a major HP Helion cloud strategy and a plan to invest $1 billion over the next two years in OpenStack-based products and services. The objective is to offer customers a unified HP hybrid cloud stack and operational expertise that works for on-premises private clouds, HP public cloud, HP managed cloud, or a third-party service provider's cloud. The HP Helion program includes a free, community-version OpenStack available as of May 2014 and a more robust commercial version for enterprises and service providers by the end of 2014; Cloud Foundry-based application development platform or platform as a service; indemnification against intellectual property infringement claims to reduce the risk for enterprise adoption of OpenStack; and, a new professional services practice to deliver HP OpenStack life-cycle assistance.
- **IBM** – IBM is a major contributor to OpenStack and is basing all its cloud products on OpenStack. IBM offers a number of OpenStack-based products. IBM Cloud Manager with OpenStack is an entry-level product, designed to quickly and easily get a basic cloud infrastructure up and running. IBM Cloud Orchestrator builds on the previous products by adding orchestration for complex multi-tier applications, service catalogs, and service management. IBM supports and integrates other IBM products such as PowerVM, PowerKVM, z/VM, IBM SVC, XIV, and GPFS storage, DB2 database, and Platform Computing EGO scheduler. IBM also develops Platform Resource Scheduler, an enhanced replacement for the default OpenStack compute scheduler.
- **Red Hat** – Red Hat joined the OpenStack movement three years ago and has invested in a large engineering team that is a key contributor to OpenStack code. Red Hat, best known for its enterprise Linux business, has built its OpenStack product (Red Hat Enterprise Linux OpenStack Platform aka RHEL OSP) upon its established enterprise Linux and enterprise virtualization product. Red Hat's Cloud Infrastructure (RHCI) product includes traditional virtualization based on KVM and oVirt, cloud infrastructure based on OpenStack, and CloudForms hybrid cloud management. This enables customers to move from traditional server virtualization to private and hybrid cloud operations at their own speed while continuing to use existing infrastructure. Red Hat is stimulating the move to OpenStack by encouraging its large network of existing partners (software, hardware, and service providers) to develop and test products for OpenStack.
- In addition to the highlighted distributions above, there is also a vibrant ecosystem of OpenStack distributions. Other notable vendors include Canonical and SUSE, who are also major Linux distributors. Piston Cloud Computing creates a secure OpenStack distribution for the enterprise. Oracle has OpenStack for both Oracle Linux and Oracle Solaris, and is focusing on enabling traditional enterprise applications such as its database to run on OpenStack. Nebula manufactures the Nebula One, a turnkey, appliance-based approach to OpenStack. Mirantis, which started out as an OpenStack professional services firm, now also produces its own OpenStack distribution focusing on openness and interoperability. RackSpace operates a public cloud based on OpenStack, and also has an on-premises private cloud OpenStack offering. CloudScaling's distribution focuses on Amazon and Google public cloud compatibility.

NTT Com's OpenStack Deployment

NTT Com, a leading global carrier headquartered in Japan, is an early adopter of OpenStack and is basing one of its Cloud^{n} public cloud offerings on OpenStack and the KVM hypervisor. NTT has been actively involved with the OpenStack and KVM community since its inception and continues to contribute to the development of both projects, with an emphasis on the cloud service provider use case.

As a carrier, one of the main benefits of OpenStack to NTT Com is the flexible plug-in infrastructure that lends itself to being used as a unified orchestrator of both computing and networking resources. NTT Com used OpenStack to integrate its existing software-defined-networking (SDN)-powered enterprise VPN service (Arcstar Universal One), which allows its customers to create virtual datacenters that can span two or more physical ones. The combination of OpenStack and SDN offers a lot of flexibility when designing a virtual datacenter and its accompanying virtual network. NTT Com also developed a GUI portal for its cloud services, which uses OpenStack native APIs underneath the covers, letting customers provision and manage virtual machines, networks, and storage without having to know the OpenStack APIs.

Challenges and Opportunities

Challenges

- Enterprise virtualization is a tough market for any competitor, as VMware was the first to market in recent years and established dominating market share. While competitors have been closing the gap from a technology point of view, VMware has established a large, entrenched installed base that will take a long time to wear away. Microsoft also has a very large system software installed base with Windows, and is VMware's largest competitor. While Linux is also a major operating system, KVM is the newest entrant to virtualization and may struggle to find a niche in traditional enterprise virtualization, as giants VMware and Microsoft battle it out and continue to leverage their large installed bases.
- While KVM has matured rapidly and developed a robust core hypervisor, success in the market will depend on carrying that over to the management software and building a vibrant ecosystem of complementary hardware and software solutions. In the system software space, platforms that can attract a large ecosystem are the winners. The OVA has worked to begin to build this ecosystem, but the IT market must also divide its attention among other large, established ecosystems around platforms such as VMware and Windows. KVM will have to compete with these ecosystems as it tries to gather partners to build solutions around KVM.

Opportunities

- As virtualization options grow and improve, IDC research shows that customers are receptive to adopting multiple hypervisors. While the core virtualization platforms are greatly improved, the key to successful multi-hypervisor adoption is being able to master and manage the additional complexity that comes with it. If that can be done with emerging management software or cloud software, multi-hypervisor adoption could increase and benefit KVM.
- OpenStack is one of the fastest evolving open source projects today, and many large vendors have bet big on OpenStack. The OpenStack Foundation has attracted an impressive roster of vendors, service providers, and users. KVM is tightly linked to OpenStack as a preferred

hypervisor, so as OpenStack adoption increases, so will KVM adoption. While traditional enterprise virtualization is an established market, the cloud market is an adjacency. Some clouds will extend existing virtual infrastructure and others will be built "greenfield" – an opportunity for KVM.

- Linux continues to gain share in the server market, leading to more opportunities for attached technologies like KVM. Linux servers also faced less early sprawl issues than did Windows servers, leading to Linux servers being less virtualized than Windows, which gives KVM an opportunity to tap into.

Essential Guidance

KVM is a key open source technology providing virtualization capabilities to Linux. As customers continue on their virtualization journey and into cloud, KVM has the opportunity for increased adoption. Customers are beginning to adopt multiple hypervisors, and interest in these deployments is growing. However, the challenge lies not with the capabilities of the virtualization platform itself, but in how to manage the cost and complexities of multiple environments. Keys to KVM's future success include:

- Continued improvement to KVM management, primarily centered on oVirt. oVirt continues to gain contributors and to improve rapidly with an aggressive roadmap in place. As the hypervisors begin to commoditize, the differentiation begins to move to higher layers of the stack, such as advanced management.
- KVM is widely distributed and available in most Linux distributions. Bringing users to KVM will include bringing them to Linux. Linux skills are highly applicable to KVM, and training and documentation for Linux and KVM will be required to expand the skills base and availability in the IT workforce.
- The OVA continues to foster the KVM ecosystem, and important work has been done by its over 200 members and supporting organizations. A key metric for system platform success today is the size and strength of its ecosystem and KVM has made important progress in this area. Continued ecosystem momentum will be key for KVM customers to get more value out of KVM and critical for the future of KVM.
- OpenStack is one of the brightest spots for KVM. As cloud deployments gain in adoption, OpenStack is the leading open source option and has tremendous community momentum behind it. KVM is the most popular hypervisor for OpenStack deployments, so as OpenStack succeeds, so will KVM. OpenStack will bring KVM into new cloud environments, beyond the traditional enterprise virtualization market.

KVM continues to grow its share rapidly in the virtualization market and innovative projects like OpenStack continue to open more doors for KVM. The KVM community continues to grow and members have made key contributions in various areas to improve KVM and related technologies. As enterprises consider new hypervisors like KVM and cloud technologies like OpenStack, these new developments and progressions are encouraging signs of KVM's momentum.

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Global Headquarters

5 Speen Street
Framingham, MA 01701
USA
508.872.8200
Twitter: @IDC
idc-insights-community.com
www.idc.com