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Sharing ephemeral storage of a virtual machine for use as victim caches for use by virtual storage appliances in a cloud environment

Abstract

Systems and methods are provided for sharing ephemeral storage of a virtual machine (VM) for use as victim caches for virtual storage appliances running on the VM. According to one embodiment, a central service may run within the VM and be responsible for managing allocation and reclamation of ephemeral storage space of the VM to/from the virtual storage appliances. Responsive to startup of a new virtual storage appliance on the VM, the new virtual storage appliance may request space from the central service to inform creation of its victim cache. In connection with servicing the request, the central service may take into consideration various factors including one or more of the total aggregate size of multiple local ephemeral drives associated with the VM, remaining available ephemeral storage space, the number of active virtual storage appliances, and the SLO of the virtual storage appliance seeking to establish its victim cache.

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Background/Summary

RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 17/671,775, filed Feb. 15, 2022, which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND

Field

(1) Various embodiments of the present disclosure generally relate to data storage systems and networks. In particular, some embodiments relate to an approach for managing and sharing ephemeral storage in cloud storage environments for use as a victim cache for respective virtual storage appliances.

Description of the Related Art

(2) In storage networks, storage server computing devices may share a pool of data storage devices for persistent data storage. In a cloud environment, storage server computing devices host virtual storage appliances (e.g., implemented as containers or pods running on a virtual machine (VM)) that carry out functions relating to management of the storage network and the data stored on the data storage devices.

(3) Storage server computing devices may include a buffer cache that is an in-memory cache used by virtual storage appliances to cache data that is read from data storage devices. In this manner, in the event a subsequent access relates to data residing within the buffer cache, the data can be served from local, high performance, low latency storage, thereby improving overall performance of the virtual storage appliance.

(4) Cloud storage providers generally monetize the hosting of data by monitoring the amount of data exchanged between the storage server computing devices and the data storage devices of a persistent storage pool. Since servicing the subsequent access of data stored in a buffer cache does not require communication with a data storage device, costs may be reduced by using a hierarchy of caches including the buffer cache and a victim cache. While caching provides performance and cost advantages in storage networks, buffer caches are limited in size and victim caches that uses normal cloud storage resources count against limited disk input/output operations per second (IOPS) available to the VM machine at issue.

SUMMARY

(5) Systems and methods are described for sharing ephemeral storage of a virtual machine (VM) for use as victim caches for virtual storage appliances running on the VM. According to one embodiment, a first virtual storage appliance of multiple virtual storage appliances running on a virtual machine (VM) in a cloud environment requests a first storage space allocation within an ephemeral storage space of one or more local ephemeral storage devices that is managed by a central service. The first storage space allocation is for use by the first virtual storage appliance as a first victim cache. The first virtual storage appliance receives a first indication regarding an amount of the ephemeral storage space representing the first storage space allocation. A second virtual storage appliance of the multiple virtual storage appliances requests a second storage space allocation within the ephemeral storage space. The second storage space allocation is for use by the second virtual storage appliance as a second victim cache. The second virtual storage appliance receives a second indication regarding an amount of the ephemeral storage space representing the second storage space allocation.

(6) Other features of embodiments of the present disclosure will be apparent from accompanying drawings and detailed description that follows.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) In the Figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label with a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

(2) FIG. **1** is a block diagram of a network environment with exemplary storage server computing devices in accordance with an embodiment of the present disclosure.

(3) FIG. **2** is a block diagram of a storage server computing devices in accordance with an embodiment of the present disclosure.

(4) FIG. **3** is a block diagram conceptually illustrating an architecture of various functional units of a virtual machine in accordance with an embodiment of the present disclosure.

(5) FIG. **4** is a flow diagram illustrating operations for performing victim cache initialization an environment in accordance with an embodiment of the present disclosure.

(6) FIG. **5** is a flow diagram illustrating operations for usage of a victim cache in accordance with an embodiment of the present disclosure.

(7) FIG. **6** is a flow diagram illustrating operations for performing read request processing in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

(8) Systems and methods are described for sharing ephemeral storage of a virtual machine (VM) for use as victim caches for virtual storage appliances running on the VM. In a cloud environment, IOPS limits for an ephemeral drive, which exists only as long as the compute instance (e.g., VM) with which it is associated, are typically significantly higher than IOPS limits for persistent storage. As such, one potential approach to avoid usage of an external victim cache impacting disk IOPS limits may involve a compute instance that hosts a virtual storage appliance taking control of an ephemeral drive associated with the storage server computing device and allowing the virtual storage appliance to implement the external victim cache therein. This basic concept of using a local ephemeral storage device for a victim cache would likely be sufficient for lower end configurations or VM applications but is not readily extensible to more complicated cloud instances that may include multiple VMs on a given storage server computing device potentially having multiple local ephemeral storage devices and in which multiple virtual storage appliances may be running within a given VM that may each have a need for space for their respective victim caches. In such more complex cloud instances, a more thoughtful approach should be taken to appropriately share (e.g., allocate and reclaim) ephemeral storage for use by victim caches of multiple competing virtual storage appliances as they follow a defined lifecycle and are dynamically created and terminated.

(9) In various embodiments described herein, a central service may run within a VM and be responsible for managing assignment of ephemeral storage space allocated to the VM to multiple associated virtual storage systems. For example, responsive to startup of a virtual storage appliance, it may request space from the central service to inform creation of its victim cache. As described further below, in connection with acting on the request, the central service may take into consideration various factors including one or more of the total aggregate size of multiple local ephemeral drives of the storage server computing device, remaining available ephemeral storage space, the number of active virtual storage appliances, and the service level objective (SLO) (e.g., expressed in term of a number of IOPS per unit (e.g., terabyte (TB)) of persistent storage) of the virtual storage appliance seeking to establish its victim cache.

(10) The methodologies described herein provide a number of advantages including methods, non-

transitory computer readable media, and devices that facilitate and improve the management of ephemeral storage devices for use as victim caches for virtual storage appliances implemented in complex cloud instances of a cloud environment, in which multiple VMs may be deployed on a given storage server computing device potentially having multiple local ephemeral storage devices and in which multiple virtual storage appliances may be running within a given VM.
(11) In the following description, numerous specific details are set forth in order to provide a thorough understanding of embodiments of the present disclosure. It will be apparent, however, to one skilled in the art that embodiments of the present disclosure may be practiced without some of these specific details. In other instances, well-known structures and devices are shown in block diagram form.
Terminology
(12) Brief definitions of terms used throughout this application are given below.
(13) A “computer” or “computer system” may be one or more physical computers, virtual computers, or computing devices. As an example, a computer may be one or more server computers, cloud-based computers, cloud-based cluster of computers, virtual machine instances or virtual machine computing elements such as virtual processors, storage and memory, data centers, storage devices, desktop computers, laptop computers, mobile devices, or any other special-purpose computing devices. Any reference to “a computer” or “a computer system” herein may mean one or more computers, unless expressly stated otherwise.
(14) The terms “connected” or “coupled” and related terms are used in an operational sense and are not necessarily limited to a direct connection or coupling. Thus, for example, two devices may be coupled directly, or via one or more intermediary media or devices. As another example, devices may be coupled in such a way that information can be passed there between, while not sharing any physical connection with one another. Based on the disclosure provided herein, one of ordinary skill in the art will appreciate a variety of ways in which connection or coupling exists in accordance with the aforementioned definition.
(15) If the specification states a component or feature “may”, “can”, “could”, or “might” be included or have a characteristic, that particular component or feature is not required to be included or have the characteristic.
(16) As used in the description herein and throughout the claims that follow, the meaning of “a,” “an,” and “the” includes plural reference unless the context clearly dictates otherwise. Also, as used in the description herein, the meaning of “in” includes “in” and “on” unless the context clearly dictates otherwise.
(17) The phrases “in an embodiment,” “according to one embodiment,” and the like generally mean the particular feature, structure, or characteristic following the phrase is included in at least one embodiment of the present disclosure and may be included in more than one embodiment of the present disclosure. Importantly, such phrases do not necessarily refer to the same embodiment.
(18) As used herein a “cloud” or “cloud environment” broadly and generally refers to a platform through which cloud computing may be delivered via a public network (e.g., the Internet) and/or a private network. The National Institute of Standards and Technology (NIST) defines cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” P. Mell, T. Grance, The NIST Definition of Cloud Computing, National Institute of Standards and Technology, USA, 2011. The infrastructure of a cloud may cloud may be deployed in accordance with various deployment models, including private cloud, community cloud, public cloud, and hybrid cloud. In the private cloud deployment model, the cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units), may be owned, managed, and operated by the organization, a third party, or some combination of them, and may exist on or off premises. In the community cloud

deployment model, the cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations), may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and may exist on or off premises. In the public cloud deployment model, the cloud infrastructure is provisioned for open use by the general public, may be owned, managed, and operated by a cloud provider (e.g., a business, academic, or government organization, or some combination of them), and exists on the premises of the cloud provider. The cloud service provider may offer a cloud-based platform, infrastructure, application, or storage services as-a-service, in accordance with a number of service models, including Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and/or Infrastructure-as-a-Service (IaaS). In the hybrid cloud deployment model, the cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

(19) Example Network Environment

(20) FIG. **1** is a block diagram of a network environment **100** with exemplary storage server computing devices in accordance with an embodiment of the present disclosure. In various examples described herein the network environment **100** represents a cloud storage network environment including client devices **114***a-n*, communication network(s) **116**, storage server computing devices **112***a-n*, a storage area network (SAN) **122**, and a persistent storage pool **120** including data storage devices **118***a-n*.

(21) Each of the client devices **114***a-n* may include a processor, a memory, a communication interface, and optionally an input device, and a display device, which are coupled together by a bus or other link, although each of the client devices **114***a-n* can have other types and numbers of components or other elements and other numbers and types of network devices could be used. The client devices **114***a-n* may run interface applications that provide an interface to make requests for and send content and/or data to storage server computing devices **112***a-b* via the communication network(s) **116**, for example. Each of the client devices **114***a-n* may be a conventional personal computer, a tablet computing device, a smart phone, a virtual machine running in a cloud, an application server hosting applications that utilize backend storage, or other processing and/or computing device, for example.

(22) By way of example only, the communication network(s) **116** and/or SAN **122** can use TCP/IP over Ethernet and industry-standard protocols, including NFS, CIFS, SOAP, XML, LDAP, and SNMP, although other types and numbers of communication networks, can be used. The communication network(s) **116** may employ any suitable interface mechanisms and network communication technologies including, for example, teletraffic in any suitable form (e.g., voice, modem, and the like), Public Switched Telephone Network (PSTNs), Ethernet-based Packet Data Networks (PDNs), combinations thereof, and the like. The communication network(s) **116** may also comprise any local area network and/or wide area network (e.g., Internet), although any other type of traffic network topologies may be used. The SAN **122** can also utilize a conventional high-performance, Fibre Channel serial link topology, SAS, SCSI, or SATA, in other examples.

(23) A non-limiting example of the storage server computing devices **112***a-n* is described further below with reference to FIG. **2**. The storage server computing devices **112***a-n* in this example are coupled to client devices **114***a-n* via communication network(s) **116** and data storage devices **118***a-n* in a persistent storage pool **120** via another communication network referred to in FIG. **1** as a storage area network (SAN) **122**.

(24) The data storage devices **118***a-n* can be hard disk drives (e.g., solid-state drives (SSDs)), optical disk-based storage, or any other type of stable, non-volatile storage suitable for storing files or objects in storage volumes for short or long term retention, for example. The data storage

devices **118**_a-n_ optionally host one or more volumes based on a Redundant Array of Inexpensive Disks (RAID) architecture or other topology facilitating data persistency, although other types and numbers of volumes in other topologies can also be used.
(25) Depending on the particular implementation various portions (e.g., storage server computing devices **112**_a-n_, storage area network (SAN) **122**, and data storage devices **118**_a-n_) of the network environment **100** may be implemented within a cloud environment, such as a private cloud, a public cloud (e.g., Amazon Web Services (AWS), Microsoft Azure, or Google Cloud Platform (GCP)), a community cloud, or a hybrid cloud.
(26) While for sake of brevity, the network environment **100** is described at a high-level, it is to be appreciated the network environment **100** can include other numbers and types of systems, devices, components, and/or elements in other configurations. Additionally, as those skilled in the art will appreciate, the network environment **100** may include other network devices, such as one or more routers and/or switches, for example. This technology provides a number of advantages including methods, non-transitory computer readable media, and devices that facilitated utilization of an ephemeral storage device as a victim cache to improve virtual storage appliance performance in a cloud environment.
(27) Although examples of the storage server computing devices **112**_a-n_, client devices **114**_a-n_ and data storage devices **118**_a-n_ are described and illustrated herein, it is to be understood that the devices and systems of the examples described herein are for exemplary purposes, as many variations of the specific hardware and software used to implement the examples are possible, as will be appreciated by those skilled in the relevant art(s). In addition, two or more computing systems or devices can be substituted for any one of the systems in any embodiment of the examples.
(28) Example Storage Server Computing Device
(29) FIG. **2** is a block diagram of a storage server computing device **212** in accordance with an embodiment of the present disclosure. The storage server computing device **212** represents a non-limiting example of storage server computing devices **112**_a-n_ of FIG. **1**. In one embodiment, the storage server computing device **212** generally provides file services relating to the organization of information on data storage devices (e.g., data storage devices **118**_a-n_ of FIG. **1**) on behalf of clients (e.g., client devices **114**_a-n_ of FIG. **1**). In this example, the storage server computing device **212** includes processing resource(s) (e.g., processor(s) **224**), a memory **226**, a communication interface **228**, and one or more ephemeral storage devices **232**, which are coupled in communication via a bus **234** or other communication link.
(30) The processing resource(s) of the storage server computing device **212** may execute a program of stored instructions for one or more aspects of the technology, as described and illustrated by way of the embodiments herein, although the processing resource(s) could execute other numbers and types of programmed instructions. The processing resource(s) in the storage server computing device **212** may include one or more central processing units (CPUs) or general purpose processors with one or more processing cores, application-specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), and the like) and/or may be represented in the form of other types of electronic circuitry.
(31) The memory **226** of the storage server computing device **212** may include any of various forms of read only memory (ROM), random access memory (RAM), flash memory, non-volatile or volatile memory, or the like, or a combination of such devices, for example. In this example, the memory **226** includes an operating system **236**, a central service **237**, and one or more virtual storage appliances **238**_a-n_. As described further below, the central service **237** may be responsible for sharing the storage space within the ephemeral storage device(s) **232** for use as victim caches **248**_a-n_ by respective virtual storage appliances **238**_a-n_.
(32) In the context of the present example, each virtual storage appliance **238** is shown including respective ephemeral storage application programming interfaces (APIs) (e.g., APIs **246**_a-b_),

respective tables or tagstores **240***a-b*, respective buffer caches **242***a-b*, and respective insert queues **244***a-n*, although other types and/or numbers of applications or modules can also be included in other examples.

(33) The operating system **236** can be a host operating system such as FreeBSD, Linux or the like, for example, that can act effectively as a hypervisor for the virtual storage appliances **238***a-n*, which is a kernel module in some examples. The virtual storage appliances **238***a-n* may be operable to functionally organize stored data by invoking storage operations to facilitate file services. In particular, the virtual storage appliances **238***a-n* may implement a file system to logically organize information as a hierarchical structure of directories and files on the data storage devices. Accordingly, the virtual storage appliances **238***a-n* may cooperate with the communication interface **228** to access information requested by clients (e.g., client devices **114***a-n*) and stored on the data storage devices, among other functions.

(34) In one embodiment, the ephemeral storage device(s) **232** may include block-level flash memory that is local and accessible via the operating system **236**. In some examples, the hardware of the storage server computing device **212**, including the ephemeral storage devices **232** can be provided by a different entity than a provider of the virtual storage appliances **238***a-n*. In various embodiments described herein, the virtual storage appliances **238***a-n* may leverage the ephemeral storage devices **232** by utilizing the ephemeral storage API. In the context of the present example, the virtual storage appliances **238***a-n* may utilize the ephemeral storage devices **232** to host respective victim caches **248***a-n*, which store buffers that are evicted from respective buffer caches **242***a-n* of the virtual storage appliances **238***a-n*. Accordingly, the victim caches **248***a-n* effectively acts as an additional cache level, which facilitates improved performance of the virtual storage appliances **238***a-n*, as described and illustrated in more detail later. Depending upon the particular implementation, the ephemeral storage API may provide discover, read, and/or write functions/methods that expose the block-level ephemeral storage devices **232** to the virtual storage appliances **238***a-n* hosted by the storage server computing device **212** via the operating system **236** as described further below.

(35) The tagstores **240***a-n* in this example may store information regarding file system blocks of data including whether the file system blocks are stored in the corresponding buffer cache **242***a-n* or in the corresponding victim cache **248***a-n*. As those skilled in the art will appreciate serving data from the buffer caches **242***a-n* or victim caches **248***a-n* is quicker than serving the data from one of the data storage devices and advantageously does not count against the disk IOPS limits and does not incur a cost in many cloud storage networks. Accordingly, the tagstores **240***a-n* include identifying information (e.g., a physical volume block number (PVBN)) and the location one or more corresponding file system blocks in the respective buffer cache **242***a-n* or one or more corresponding data and/or context blocks in the respective victim cache **248***a-n*, as described and illustrated in more detail later.

(36) The buffer caches **242***a-n* in this example represent a repository for cached reads and writes associated with file system blocks of the data storage device(s) that are maintained in the form of buffers that can be used to service future reads to file system blocks more efficiently. Optionally, the buffer caches **242***a-n* may be stored in RAM memory that is faster than the medium (e.g., flash) of the ephemeral storage device(s) **232**. In various examples described herein, it is assumed both the buffer caches **242***a-n* and the ephemeral storage device(s) **232** are faster than the data storage devices, which may represent network attached cloud storage resources (e.g., disks).

(37) The optional insert queues **244***a-n* may be used by respective virtual storage appliances **238***a-n* to store buffers evicted from respective buffer caches **242***a-n* that have been identified as qualifying for insertion into respective victim caches **248***a-n*. The buffers evicted from a given buffer cache (e.g., buffer cache **242***a*) can be queued in the corresponding insert queue (e.g., insert queue **244***a*) and more efficiently stored, by the virtual storage appliance (e.g., virtual storage appliance **238***a*) using its ephemeral storage API, in the corresponding victim cache (e.g., victim cache **248***a*) as a

batch, although evicted buffers can also be inserted directly into the victim cache in other examples.

(38) The communication interface **228** of the storage server computing device **212** can include one or more network interface controllers (NICs) for operatively coupling and communicating between the storage server computing device **212** and clients, which may be coupled in communication via communication network(s) (e.g., communication network(s) **116** of FIG. **1**), and the data storage devices, which may be coupled together by another network (e.g., SAN **122** of FIG. **1**), although other types and numbers of communication networks or systems with other types and numbers of connections and configurations to other devices and elements also can be used.

(39) Example Virtual Machine Architecture

(40) FIG. **3** is a block diagram conceptually illustrating an architecture **300** of various functional units of a virtual machine in accordance with an embodiment of the present disclosure. In the context of the present example, a central service **310** is used to manage and share ephemeral storage (e.g., ephemeral storage devices **340***a-x*) allocated to a virtual machine to facilitate use of the ephemeral storage by one or more virtual storage appliances (e.g., data pods **320***a-n*) as respective external victim caches **325***a-n*. Depending upon the particular implementation, the ephemeral storage devices **340***a-x* may be arranged as desired, such as RAID0 or individually.

(41) The central service **310** may be responsible for managing the ephemeral storage devices **340***a-x* and the availability of the ephemeral storage devices **340***a-x* to the data pods **320***a-n* acting as the virtual storage appliances (e.g., virtual storage appliances **238***a-n*). For example, the central service **310** may allocate and reclaim ephemeral storage space for use by data pods **320***a-n* as victim caches **325***a-n* responsive to requests received by the data pods **320***a-n* and termination of the data pods **320***a-n*, respectively. The central service **310** may implement a heartbeat mechanism to determine whether any data pod to which is has allocated ephemeral space has gone down or otherwise been terminated. For example, each data pod may periodically send a heartbeat message to the central service **310** to notify the central service **310** that it is alive (e.g., remains active). In this manner, the central service **310** may reclaim ephemeral storage space allocated to a data pod that is no longer alive (e.g., as indicated by failure to receive a heartbeat message from a given data pod for a predetermined or configurable amount of time). Depending upon the particular implementation, the reclaimed ephemeral storage space may be retained for subsequent allocation to new data pods and/or may be redistributed among those data pods remaining active.

(42) In one embodiment, the central service **310** may run in the same VM as the data pods **320***a-n* and be part of a daemon set. In one embodiment, when a VM/node comes up, the central service **310** may be the first pod that runs on it. Responsive to starting up, the central service **310** may discover the various ephemeral storage devices (e.g., ephemeral storage devices **140***a-x*) that are present and may format them with a file system **330** (e.g., a journaling file system, such as extended file system version 4 (ext4)). Thereafter, the central service **310** may maintain various metadata to facilitate management of the ephemeral storage. For example, the central service **310** may maintain information regarding one or more of the following: the total amount of ephemeral drive space; the amount of space of the total that has been allocated to the data pods **320***a-n;* the remaining space available of the total; the total number of data pods that have been created and that remain active; a table that defines the SLOs and the percentage of ephemeral space that should be allotted to a particular data pod based on the SLO or a static mapping for each SLO (e.g., how much ephemeral space to allot). a table that maintains a list of current data pods (e.g., based on their respective pod identifiers) and how much ephemeral space has been allocated to each of the data pods **320***a-n* as well as a timestamp indicating when the central service received the last heartbeat message from each of the data pods **320***a-n.*

(43) In the context of the present example and as described further below, upon startup of a given data pod (e.g., data pod **320***a*), the given data pod may initialize and configure its victim cache (e.g., victim cache **325***a*) by making a request to the central service **310** and providing its SLO

(e.g., SLO **321***a*). In response, the central service **310** returns the amount of space (e.g., space **322***a*) the data pod may use for its victim cache. There are various approaches for determining appropriate allocations of total available ephemeral storage space among the data pods. For example, the central service **310** may perform a table lookup into a prepopulated table based on the SLO and the number of data pods to arrive at a percentage of the total available ephemeral storage space to be allocated to the given data pod. Alternatively, the central service **310** may dynamically calculate the amount of ephemeral storage space to be allocated to the given data pod based on a predefined or configurable ratio (e.g., 10-to-1, 20-to-1, or the like) of persistent disk storage associated with the given data pod to ephemeral storage space.

(44) Example Victim Cache Initialization

(45) FIG. **4** is a flow diagram illustrating operations for performing victim cache initialization in an environment in accordance with an embodiment of the present disclosure. In the context of the present example, it is assumed a VM of potentially multiple VMs has been created on a storage server computing device (e.g., storage server computing device **212**) and the VM is being configured to host one or more virtual storage appliances (e.g., virtual storage appliances **238***a-n*). The storage server computing device may include one or more local and non-persistent block-level ephemeral storage devices (e.g., ephemeral storage device(s) **232**) that are accessible via an operating system (e.g., operating system **236**) of the storage server computing device. As will be appreciated by those skilled in the art, such non-persistent storage media is not something that can be incorporated into an aggregate maintained by persistent data storage devices (e.g., data storage devices **118***a-n*). As such, in the event of a failure, the virtual storage appliance at issue may be rebooted on a different one of the storage server computing devices (e.g., storage server computing devices **112***a-n*). Since the ephemeral storage device(s) are local storage media, the virtual storage appliance would no longer have access to that data stored in the ephemeral storage device(s) in such a scenario.

(46) As noted above, in one embodiment, when a VM/node comes up, the central service may be the first pod that runs on it. At block **410**, a central service (e.g., central service **310**) may initialize ephemeral storage (e.g., the portion of the total aggregate ephemeral storage space of ephemeral storage devices **340***a-x* that is available for use by the VM) for the VM or node at issue. In one embodiment, the central service (e.g., hosted by a VM of potentially multiple VMs running on the storage server computing device) initializes and configures utilization of one or more ephemeral storage devices by discovering the one or more ephemeral storage devices that are present and then formatting them with a file system (e.g., file system **330**) appropriate for the operating system (e.g., operating system **236**). At this point, one or more data pods (e.g., data pods **320***a-n*) representing the one or more virtual storage systems may come up. Accordingly, the ephemeral storage device(s) are ideally suited for use as an external cache in which corresponding data is persistently stored on the data storage devices. In this particular example, the file system created on the ephemeral storage device(s) is used to store one or more victim caches (e.g., victim cache **325***a*) for use by respective data pods (e.g., data pods **320***a-n*) acting as the virtual storage appliances.

(47) At decision block **420**, it is determined whether a new data pod (e.g., data pod **320***a*) has been created. If so, processing continues with block **430**; otherwise, processing loops back to decision block **420**.

(48) At block **430**, the new data pod requests its allocation of ephemeral storage for use as a victim cache (e.g., victim cache **325***a*) from the central service. In one embodiment, the request to the central service contains information regarding the SLO (e.g., SLO **321***a*) of the data pod and the central service returns an indication or success or failure and an amount of space (e.g., space **322***a*) the data pod may employ for the victim cache.

(49) Assuming the request for ephemeral storage space is successful, at block **440**, the data pod initializes and configures the victim cache based on the ephemeral storage allocation via an ephemeral storage API (e.g., one of APIs **246***a-n*). In one embodiment, the ephemeral storage API

exposes the block-level ephemeral storage devices to the data pod via the operating system. In one embodiment, the ephemeral storage API provides a create function that can be invoked by the virtual storage appliance. The create function may be configured to use the operating system to create one or more files for use as the victim cache within the space allotted.

(50) Example Usage of a Victim Cache

(51) FIG. **5** is a flow diagram illustrating operations for usage of a victim cache in accordance with an embodiment of the present disclosure. In the context of the present example, it is assumed a victim cache has been created for use by a data pod (e.g., one of data pods **320***a*-*n*) acting as a virtual storage appliance (e.g., virtual storage appliance **238***a*) and the virtual storage appliance is now operational and servicing various read and write requests received from clients (e.g., client devices **114***a*-*n*) relating to data maintained by persistent data storage devices (e.g., data storage devices **118***a*-*n*). In one embodiment, read data can be maintained in a buffer cache (e.g., buffer cache **242***a*) to facilitate relatively quick responses for subsequent requests for the data. In this example, the buffer cache eventually reaches capacity and a buffer is evicted based on the application of a policy (e.g., an age-based policy).

(52) At decision block **510**, the virtual storage appliance determines whether a buffer has been evicted from the buffer cache. If so, processing continues with decision block **520**; otherwise processing loops back to decision block **510** and effectively waits for a buffer to be evicted from the buffer cache in this example.

(53) At decision block **520**, a determination is made by the virtual storage appliance regarding whether the file system block associated with the evicted buffer should be inserted into the victim cache. If so, processing continues with block **530**; otherwise, processing branches to decision block **510** and subsequent requests for the file system block at issue will be directed to one of the data storage devices as the file system block will no longer be cached. This determination may be made based on the application of an established policy that prioritizes certain buffers over others for insertion in the victim cache. Accordingly, the policy can be based on hit count, type of data in the file system block, or likelihood of a future access by one of the clients, for example, although any other criteria can also be used to determine whether to insert an evicted buffer into the victim cache.

(54) At block **530**, the virtual storage appliance optionally inserts the file system block into an insert queue (e.g., insert queue **244***a*) in this example. The insert queue may be used to batch file system block insertions into the victim cache for efficiency purposes, although depending upon the particular implementation, file system blocks may also be inserted directly into the victim cache without being batched as well.

(55) At decision block **540**, it is determined by the virtual storage appliance whether a threshold capacity (e.g., a predetermined or configurable batch size of buffers) of the insert queue has been exceeded in the insert queue. If so, processing continues with block **550**; otherwise, processing branches back to decision block **510**.

(56) At block **550**, the virtual storage appliance dequeues a file system block from the insert queue, retrieves an identifier (e.g., a PVBN) (e.g., from metadata of the file system block), and stores the identifier in an entry in a tagstore (e.g., tagstore **240***a*). The entry can be identified based on the application of a hash algorithm, for example, although any other type of method for determining locations for insertions into the tagstore can also be used.

(57) At block **560**, the virtual storage appliance inserts the file system block into the victim cache using a method exposed by the ephemeral storage API. For example, the ephemeral storage API may include a write function that can be invoked by the virtual storage appliance. The write function may be configured to use the operating system to store the file system block in the victim cache and return the location(s) in the victim cache that were used to store the file system block. While outside the scope of the present disclosure, it is noted that the storage of file system blocks that include metadata (e.g., for error-checking purposes) may be striped across multiple sectors in

which one represents a context block storing the metadata so as to avoid dedicating an entire block to context as described in US Pub. No. 2017/0344575, which is hereby incorporated by referenced in its entirety for all purposes.

(58) At block **570**, the virtual storage appliance **3** updates the entry in the tagstore that is associated with the file system block corresponding to the buffer evicted from the buffer cache to include the location(s) within the victim cache (e.g., as returned in block **560**).

(59) At decision block **580**, the virtual storage appliance determines whether there are more evicted buffers or corresponding file system blocks in the insert queue. If so, processing continues with block **550**; otherwise, processing branches back to decision block **510**.

(60) Example Read Request Processing

(61) FIG. **6** is a flow diagram illustrating operations for performing read request processing in accordance with an embodiment of the present disclosure. As above, in the context of the present example, it is assumed a victim cache has been created for use by a data pod (e.g., one of data pods **320***a-n*) acting as a virtual storage appliance (e.g., virtual storage appliance **238***a*) and the virtual storage appliance is now operational and servicing various read and write requests received from clients (e.g., client devices **114***a-n*) relating to data maintained by persistent data storage devices (e.g., data storage devices **118***a-n*). In one embodiment, read data can be maintained in a buffer cache (e.g., buffer cache **242***a*) to facilitate relatively quick responses for subsequent requests for the data.

(62) At block **605**, the virtual storage appliance receives a request to read a file from a client. The read request can be received via communication network(s) (e.g., communication network(s) **116**). At block **610**, responsive to receipt of the read request, the virtual storage appliance resolves one or more identifiers (e.g., one or more PVBNs) of file system blocks associated with the file.

(63) At decision block **615**, the virtual storage appliance determines whether the file system blocks are in the buffer cache. If so, processing branches to block **620**; otherwise, processing continues with decision block **625**. The determination can be made based on an indication or location in the entries in the tagstore (e.g., tagstore **240***a*) for the file system blocks, for example, although other methods of determining whether the file system blocks are stored in the buffer cache can also be used.

(64) At block **620**, the virtual storage appliance retrieves the file system blocks from the buffer cache using the locations in the corresponding entries in the tagstore for the file system blocks. Since the file system blocks are retrieved from the buffer cache maintained in local memory (e.g., memory **226**), no charge is incurred for the virtual storage appliance to obtain the file in this example. Similarly, such retrieval from local memory has no impact on disk IOPS limits. At this point in the present example, processing skips to decision block **640**.

(65) At decision block **625**, the virtual storage appliance determines whether the file system blocks are in the victim cache. If so, processing branches to block **635**; otherwise, processing continues with block **630**. The determination can be made based on an indication or location in the entries in the tagstore for the file system blocks, for example, although other methods of determining whether the file system blocks are stored in the victim cache can also be used. Optionally, a hash function can be utilized to identify entries in the tagstore, for example. The tagstore can be populated as described above with reference to FIG. **5**.

(66) At block **630**, the virtual storage appliance retrieves the file system blocks corresponding to the file from one or more of the data storage devices. Accordingly, when the requested file is not cached, the virtual storage appliance resolves the location of the file system blocks in the file system and uses a SAN (e.g., SAN **122**) to obtain the file from one or more of the data storage devices. An associated charge is incurred for the transfer of the file across the SAN Similarly, such access to the data storage devices counts against disk IOPS limits. At this point in the present example, processing skips to decision block **640**.

(67) At block **635**, the virtual storage appliance retrieves the file system blocks from the victim

cache using the locations included in the entries in the tagstore for the file system blocks and using the ephemeral storage API. Since, in this example, there was a hit in the tagstore for all of the file system blocks corresponding to the file, and the file system blocks were not stored in the buffer cache, the file system blocks are presumed to be stored in the victim cache. For example, the file system blocks were previously stored in the buffer cache and were subsequently evicted due to storage constraints of the buffer cache and as a result inserted into the victim cache, for example, as described above with reference to FIG. **5**. As in the context of the present example, the victim cache is in local ephemeral storage, retrieval of the file will count against applicable ephemeral storage IOPS limits; however, no charge or disk IOPS are incurred for the virtual storage appliance to obtain the file in this example.

(68) The virtual storage appliance in this example is configured to invoke a read method exposed by the ephemeral storage API, optionally passing one or more of the locations of the file system blocks retrieved from the tagstore. The read method may be configured to use the operating system to access the locations in the victim cache in order to obtain the file system blocks corresponding to the file. For each requested file system block, the read method may be configured to obtain multiple data blocks and one context block (e.g., containing metadata) that were inserted into the victim cache.

(69) Optionally, the virtual storage appliance may also increment a hit count in the entries of the tagstore for each of the file system blocks to indicate that the file system blocks have been accessed by a client. The hit count can be used to evaluate an eviction policy for the victim cache, although age-based and other eviction policies can also be used to manage the victim cache.

(70) At decision block **640**, the virtual storage appliance determines whether the retrieved file system blocks are verified. With respect to file system blocks retrieved from the victim cache, a retrieved context block storing metadata can be used to verify that the data contained in corresponding data blocks, retrieved from the victim cache for each of the file system blocks, is valid, although other methods for verifying the retrieved file system blocks can also be used. If the virtual storage appliance determines the retrieved file system blocks are verified, then the file is returned to the requesting client at block **650** (e.g., via the communication network(s)); otherwise, processing branches to block **645**.

(71) At block **645**, the virtual storage appliance generates and returns an error to the requesting client, drops the request received at block **605**, and/or initiates a mitigation action to determine or correct the error, for example.

(72) While in the context of the various flow diagrams described herein, a number of enumerated blocks are included, it is to be understood that examples may include additional blocks before, after, and/or in between the enumerated blocks. Similarly, in some examples, one or more of the enumerated blocks may be omitted and/or performed in a different order.

(73) Embodiments of the present disclosure include various steps, which have been described above. The steps may be performed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a processing resource (e.g., a general-purpose or special-purpose processor) programmed with the instructions to perform the steps. Alternatively, depending upon the particular implementation, various steps may be performed by a combination of hardware, software, firmware and/or by human operators.

(74) Embodiments of the present disclosure may be provided as a computer program product, which may include a non-transitory machine-readable storage medium embodying thereon instructions, which may be used to program a computer (e.g., storage server computing device **212**) or other electronic devices to perform a process. The machine-readable medium may include, but is not limited to, fixed (hard) drives, magnetic tape, floppy diskettes, optical disks, compact disc read-only memories (CD-ROMs), and magneto-optical disks, semiconductor memories, such as ROMs, PROMs, random access memories (RAMs), programmable read-only memories (PROMs), erasable PROMs (EPROMs), electrically erasable PROMs (EEPROMs), flash memory, magnetic or optical

cards, or other type of media/machine-readable medium suitable for storing electronic instructions (e.g., computer programming code, such as software or firmware).

(75) Various methods described herein may be practiced by combining one or more non-transitory machine-readable storage media containing the code according to embodiments of the present disclosure with appropriate special purpose or standard computer hardware to execute the code contained therein. An apparatus for practicing various embodiments of the present disclosure may involve one or more computers (e.g., physical and/or virtual servers) (or one or more processors within a single computer) and storage systems containing or having network access to computer program(s) coded in accordance with various methods described herein, and the method steps associated with embodiments of the present disclosure may be accomplished by modules, routines, subroutines, or subparts of a computer program product.

(76) For example, a computer system (e.g., storage server computing device **212** of FIG. **2**) may implement the techniques described herein using customized hard-wired logic, one or more ASICs or FPGAs, firmware or program logic which in combination with the computer system causes or programs the computer system to be a special-purpose machine. According to one embodiment, the techniques herein may be performed by storage server computing device **212** in response to one or more processing resource(s) (e.g., processors **224**) executing one or more sequences of one or more instructions contained in main memory (e.g., memory **226**). Such instructions may be read into main memory from another storage medium. Execution of the sequences of instructions contained in main memory may cause the one or more processing resource(s) to perform the process steps described herein. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions.

(77) The term “storage media” as used herein refers to any non-transitory media that store data or instructions that cause a machine to operation in a specific fashion. Such storage media may comprise non-volatile media or volatile media. Non-volatile media includes, for example, optical, magnetic or flash disks. Volatile media includes dynamic memory, such as main memory. Common forms of storage media include, for example, a flexible disk, a hard disk, a solid state drive, a magnetic tape, or any other magnetic data storage medium, a CD-ROM, any other optical data storage medium, any physical medium with patterns of holes, a RAM, a PROM, and EPROM, a FLASH-EPROM, NVRAM, any other memory chip or cartridge.

(78) Storage media is distinct from but may be used in conjunction with transmission media. Transmission media may participate in transferring information between storage media. For example, transmission media may include coaxial cables, copper wire and fiber optics, including the wires that comprise bus **234**. Transmission media can also take the form of acoustic or light waves, such as those generated during radio-wave and infra-red data communications.

(79) Various forms of media may be involved in carrying one or more sequences of one or more instructions to the one or more processing resource(s) for execution. For example, the instructions may initially be carried on a magnetic disk or solid state drive of a remote computer. The remote computer can load the instructions into its dynamic memory and send the instructions over a telephone line using a modem. A modem local to the computer system can receive the data on the telephone line and use an infra-red transmitter to convert the data to an infra-red signal. An infra-red detector can receive the data carried in the infra-red signal and appropriate circuitry can place the data on bus **234**. Bus **234** may then carry the data to main memory, from which the one or more processing resource(s) may retrieve and execute the instructions.

Alternative Embodiments

(80) A central service is described in various embodiments as performing ephemeral storage space management using files (e.g., providing a file system in which victim caches of respective virtual storage appliances may be stored); however, it is to be appreciated in alternative embodiments, such space management may be performed using blocks. For example, the central service may manage all the blocks of ephemeral storage and allocate them to the virtual storage appliances in

chunks. As those skilled in the art will appreciate, this block-based approach has no need for installation of a file system on top of the raw ephemeral drives but would involve the central service maintaining additional data structures for garbage collection as well block management. While involving extra work to be performed by both the central service and the individual data pods and the additional communications between the central service and the individual data pods, this block-based approach may be a reasonable alternative depending upon the various tradeoffs associated with the particular implementation.

(81) While in the context of the various embodiments described herein, a central service may be implemented on a per VM basis for managing ephemeral storage available to a particular VM and sharing it among multiple virtual storage appliances hosted by the particular VM, it is to be appreciated in alternative embodiments, the central service may be implemented on a per cluster basis for managing ephemeral storage on behalf a cluster of nodes (e.g., a group of storage server computing devices).

Comparative Example

(82) Without limitation and solely for purposes of providing a concrete example of the benefits of a distributed ephemeral cache implemented in accordance with various embodiments described herein, first consider a cloud VM/compute-instance (e.g., a GCP standard N1-16 VM with an SSD persistent disk) that comes with a 25K read/write disk IOPS limit and running a single 3 TB virtual storage appliance (e.g., a single data pod or container) having 3 TB of provisioned backing storage (e.g., persistent storage provided by data storage devices **118***a*-*n*) but with no local ephemeral storage. Assuming the service provider and consumer/end-user have agreed to an SLO of 4K IOPS/TB on the frontend side (e.g., frontend end-user data read or write requests), support can be provided for 12K IOPS on the frontend for this virtual storage appliance. Meanwhile, assuming a data amplification of 2 (e.g., due to indirects and metadata), the backend IOPS (e.g., from the perspective of the data storage devices **118***a*-*n*) would be 24K. As this is close to the limit of 25K, this system is not scalable. For instance, if it was desired to increase the size of the provisioned persistent storage to 4 TB, in this example, that would require 4 TB*4K=16K frontend IOPS and 32K backend IOPS, which exceeds the disk IOPS limit of 25K.

(83) Now, consider the same scenario as above, but with local ephemeral storage present that is being intelligently shared by two 3 TB virtual storage appliances in accordance with the various embodiments described herein. In this example, each virtual storage appliance would need 12K frontend IOPS and 24K backend IOPS for a total requirement of 48K backend IOPS. For purposes of this example, assume a local ephemeral drive is 375G in size and has an NVME interface that offers 170,000 read or 90,000 write IOPS. As noted above, the IOs done from the local ephemeral drive aren't counted against the IOs done from the VM. If up to 8 local drives can be added for a VM and the local drive IOs scale up to 4 ephemeral drives, the maximum IOs that can be achieved using the ephemeral drive in this example are 170,000*4 read IOPS=680,000 or 90,000*4=360,000 write IOPS. Since the ephemeral drives support much more than the needed 48K backend IOPS, assuming most of the data is coming from the ephemeral drives, these two example virtual storage appliances can easily both scale to 4 TB and beyond by adding ephemeral storage that is shared between the two virtual storage appliances.

(84) All examples and illustrative references are non-limiting and should not be used to limit the applicability of the proposed approach to specific implementations and examples described herein and their equivalents. For simplicity, reference numbers may be repeated between various examples. This repetition is for clarity only and does not dictate a relationship between the respective examples. Finally, in view of this disclosure, particular features described in relation to one aspect or example may be applied to other disclosed aspects or examples of the disclosure, even though not specifically shown in the drawings or described in the text.

(85) The foregoing outlines features of several examples so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they

may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the examples introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

1. A method comprising: requesting, by a first virtual storage appliance of a plurality of virtual storage appliances running on a virtual machine (VM) in a cloud environment, a first storage space allocation within an ephemeral storage space of one or more local ephemeral storage devices that is managed by a central service, wherein the first storage space allocation is for use by the first virtual storage appliance as a first victim cache; receiving, by the first virtual storage appliance, a first indication regarding an amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the first storage space allocation; requesting, by a second virtual storage appliance of the plurality of virtual storage appliances, a second storage space allocation within the ephemeral storage space of the one or more local ephemeral storage devices, wherein the second storage space allocation is for use by the second virtual storage appliance as a second victim cache; and receiving, by the second virtual storage appliance, a second indication regarding an amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the second storage space allocation.
2. The method of claim 1, further comprising causing by the first virtual storage appliance, the first victim cache to be initialized and configured.
3. The method of claim 1, wherein the amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the first storage space allocation is determined based on one or more of a total amount of ephemeral storage space represented by the one or more local ephemeral storage devices, a total number of the plurality of virtual storage appliances, a total amount of persistent storage associated with the first virtual storage appliance, and a service-level objective (SLO) of the first virtual storage appliance.
4. The method of claim 3, wherein the SLO is expressed in terms of a number of input/output operations per second (IOPS) per unit of the persistent storage.
5. The method of claim 1, wherein the ephemeral storage space of one or more local ephemeral storage devices is shared by the plurality of virtual storage appliances using a file-based approach within a file system established by the central service on the one or more local ephemeral storage devices.
6. The method of claim 1, wherein the ephemeral storage space of the one or more local ephemeral storage devices is shared by the plurality of virtual storage appliances using a block-based approach within block ranges allocated to respective virtual storage appliances of the plurality of virtual storage appliances.
7. A non-transitory machine readable medium storing instructions, which when executed by one or more processors of one or more computer systems, cause the one or more processors to perform a method comprising: requesting, by a first virtual storage appliance of a plurality of virtual storage appliances running on a virtual machine (VM) in a cloud environment, a first storage space allocation within an ephemeral storage space of one or more local ephemeral storage devices that is managed by a central service, wherein the first storage space allocation is for use by the first virtual storage appliance as a first victim cache; receiving, by the first virtual storage appliance, a first indication regarding an amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the first storage space allocation; requesting, by a second virtual storage appliance of the plurality of virtual storage appliances, a second storage space allocation

within the ephemeral storage space of the one or more local ephemeral storage devices, wherein the second storage space allocation is for use by the second virtual storage appliance as a second victim cache; and receiving, by the second virtual storage appliance, a second indication regarding an amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the second storage space allocation.
8. The non-transitory machine readable medium of claim 7, wherein the method further comprises causing by the first virtual storage appliance, the first victim cache to be initialized and configured.
9. The non-transitory machine readable medium of claim 7, wherein the amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the first storage space allocation is determined based on one or more of a total amount of ephemeral storage space represented by the one or more local ephemeral storage devices, a total number of the plurality of virtual storage appliances, a total amount of persistent storage associated with the first virtual storage appliance, and a service-level objective (SLO) of the first virtual storage appliance.
10. The non-transitory machine readable medium of claim 9, wherein the SLO is expressed in terms of a number of input/output operations per second (IOPS) per unit of the persistent storage.
11. The non-transitory machine readable medium of claim 7, wherein the ephemeral storage space of the one or more local ephemeral storage devices is shared by the plurality of virtual storage appliances using a file-based approach within a file system established by the central service on the one or more local ephemeral storage devices.
12. The non-transitory machine readable medium of claim 7, wherein the ephemeral storage space of the one or more local ephemeral storage devices is shared by the plurality of virtual storage appliances using a block-based approach within block ranges allocated to respective virtual storage appliances of the plurality of virtual storage appliances.
13. A system comprising: one or more processors; and a non-transitory computer-readable medium, coupled to the one or more processors, having stored therein instructions that when executed by the one or more processors cause the one or more processors to perform a method comprising: requesting, by a first virtual storage appliance of a plurality of virtual storage appliances running on a virtual machine (VM) in a cloud environment, a first storage space allocation within an ephemeral storage space of one or more local ephemeral storage devices that is managed by a central service, wherein the first storage space allocation is for use by the first virtual storage appliance as a first victim cache; receiving, by the first virtual storage appliance, a first indication regarding an amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the first storage space allocation; requesting, by a second virtual storage appliance of the plurality of virtual storage appliances, a second storage space allocation within the ephemeral storage space of the one or more local ephemeral storage devices, wherein the second storage space allocation is for use by the second virtual storage appliance as a second victim cache; and receiving, by the second virtual storage appliance, a second indication regarding an amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the second storage space allocation.
14. The system of claim 13, wherein the method further comprises causing by the first virtual storage appliance, the first victim cache to be initialized and configured.
15. The system of claim 13, wherein the amount of the ephemeral storage space of the one or more local ephemeral storage devices representing the first storage space allocation is determined based on one or more of a total amount of ephemeral storage space represented by the one or more local ephemeral storage devices, a total number of the plurality of virtual storage appliances, a total amount of persistent storage associated with the first virtual storage appliance, and a service-level objective (SLO) of the first virtual storage appliance.
16. The system of claim 15, wherein the SLO is expressed in terms of a number of input/output operations per second (IOPS) per unit of the persistent storage.
17. The system of claim 13, wherein the ephemeral storage space of the one or more local

ephemeral storage devices is shared by the plurality of virtual storage appliances using a file-based approach within a file system established by the central service on the one or more local ephemeral storage devices.

18. The system of claim 13, wherein the ephemeral storage space of the one or more local ephemeral storage devices is shared by the plurality of virtual storage appliances using a block-based approach within block ranges allocated to respective virtual storage appliances of the plurality of virtual storage appliances.

19. The system of claim 13, wherein the system hosts the VM and the central service runs on the VM.

20. The system of claim 13, wherein the plurality of virtual storage appliances are implemented as containers or pods.