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(54) **TECHNIQUES FOR DEVICE ENCRYPTION  
IN PREFAB REGION DATA CENTERS**

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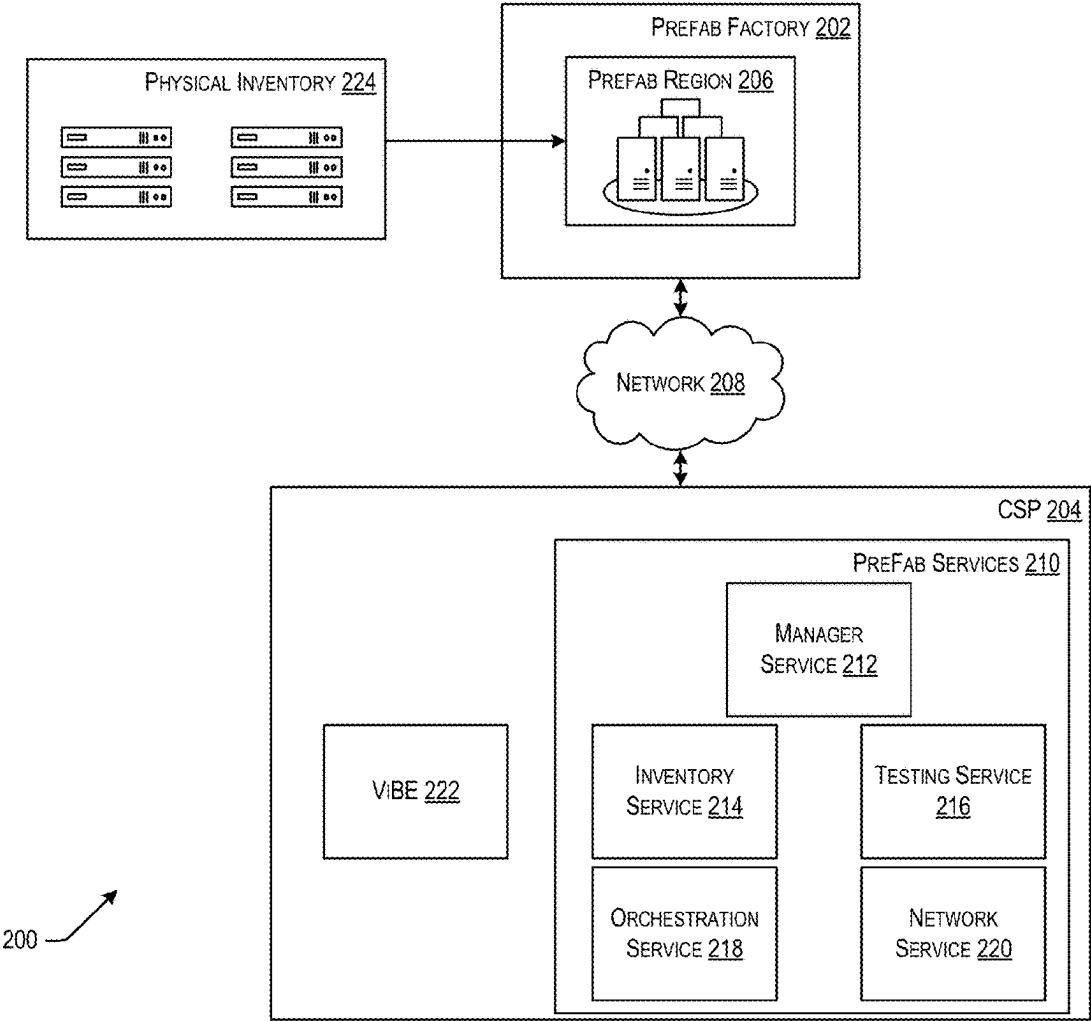
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(57) **ABSTRACT**

Techniques are disclosed for cryptographically securing data on devices of a region data center built in the first facility and installed at a data center. A plurality of server devices and a fleet of key server devices can be configured for transit by encrypting a storage device of each server device using a corresponding data encryption key, storing and encrypting each data encryption key at a corresponding key storage element of each server device using a key encryption key, and storing the key encryption key at the fleet of key server devices. After transit, the fleet of key server devices can be enabled and a server device booted using an initialization disk image stored at a boot volume of the first server device. The first server device can obtain the key encryption key, decrypt the encrypted data encryption key, and then decrypt the storage device.



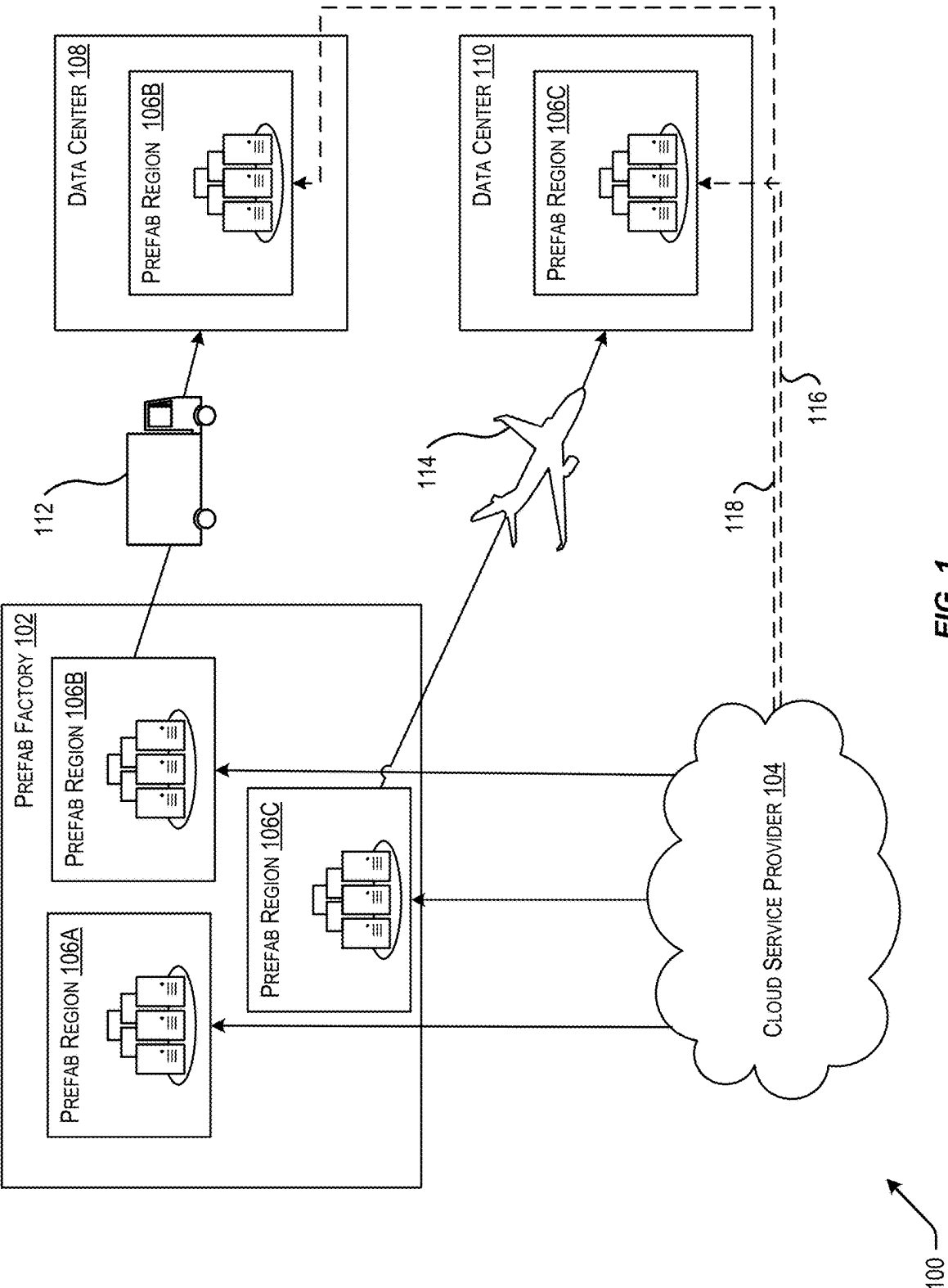
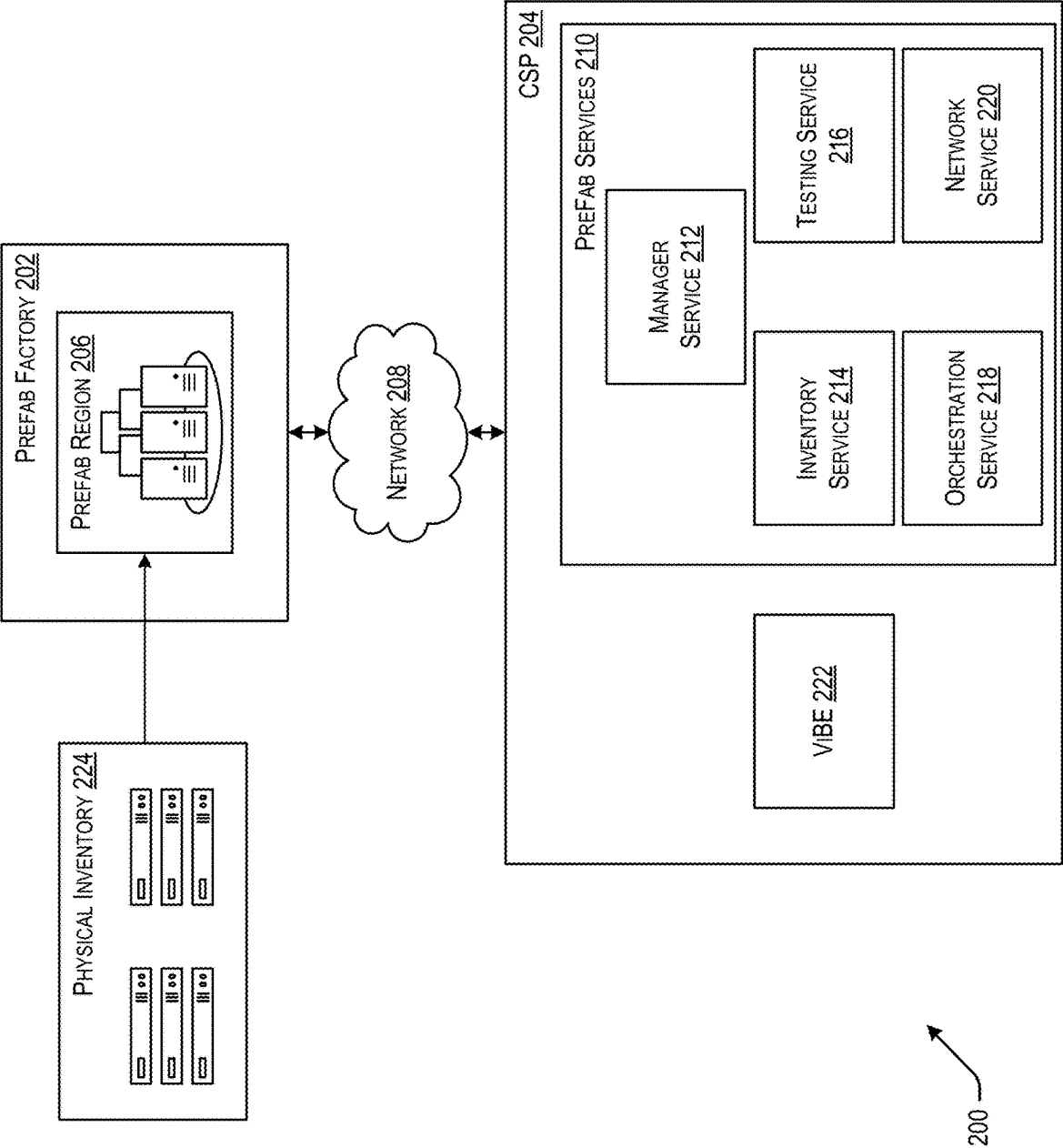


FIG. 1

FIG. 2



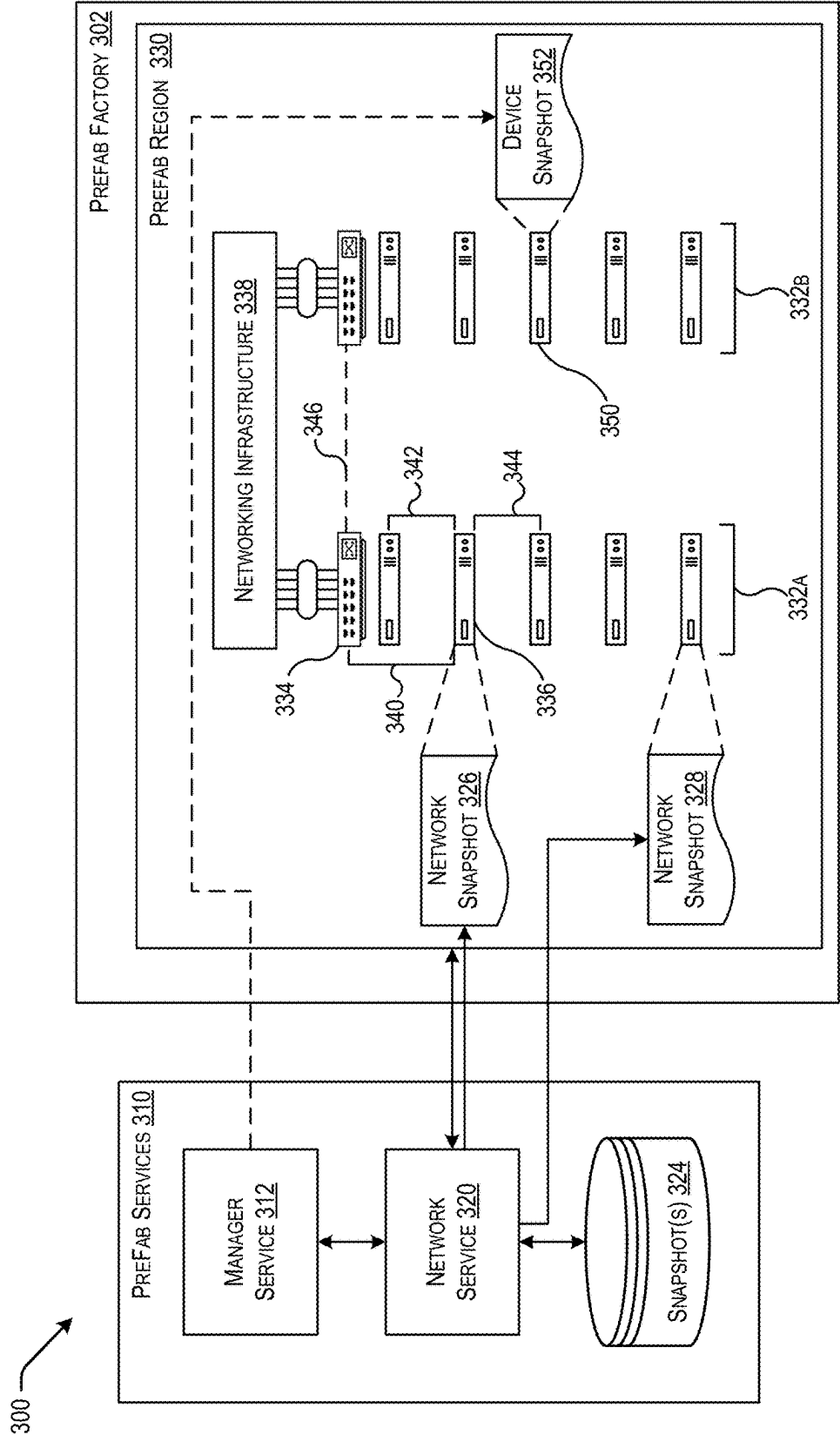


FIG. 3

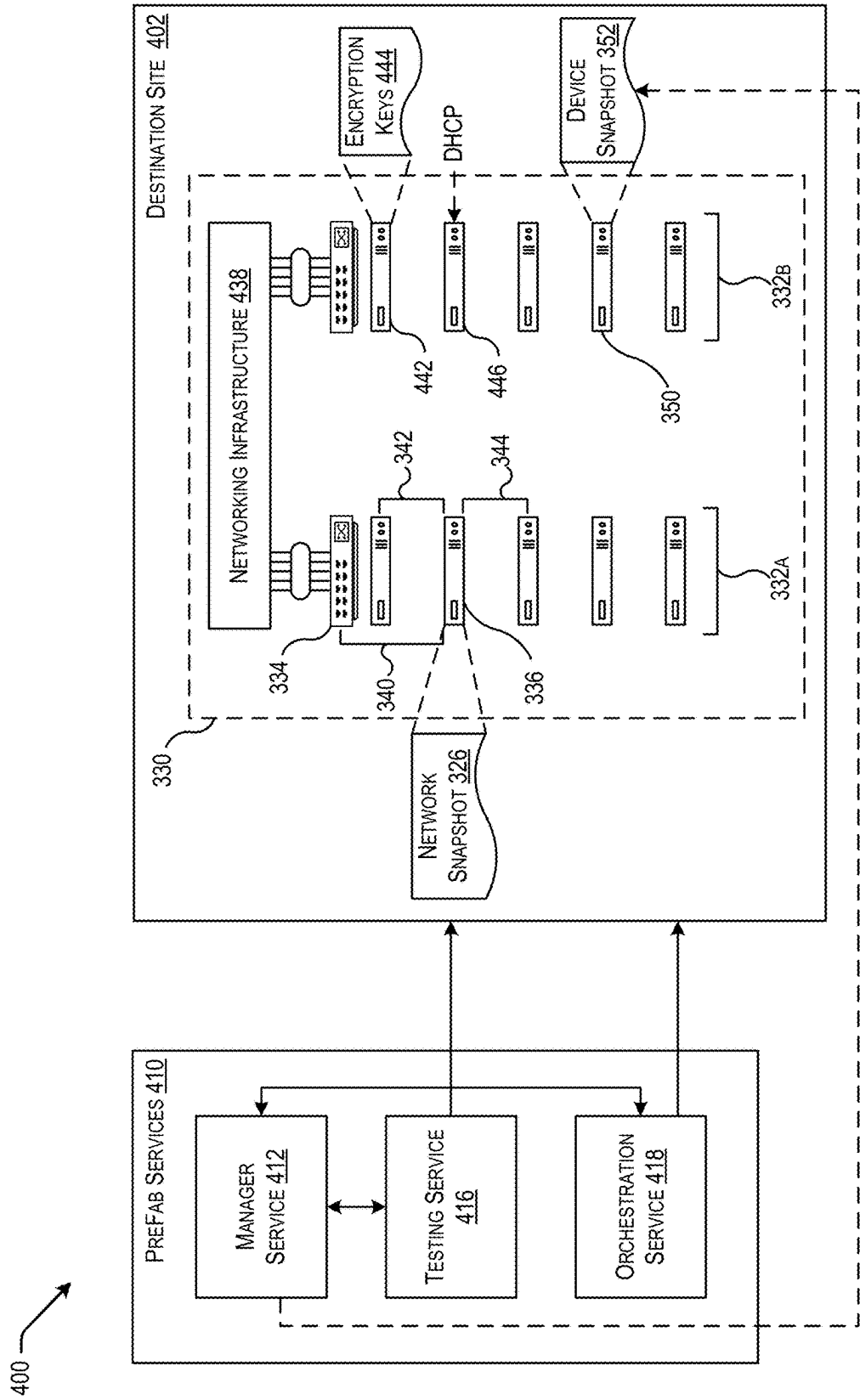


FIG. 4

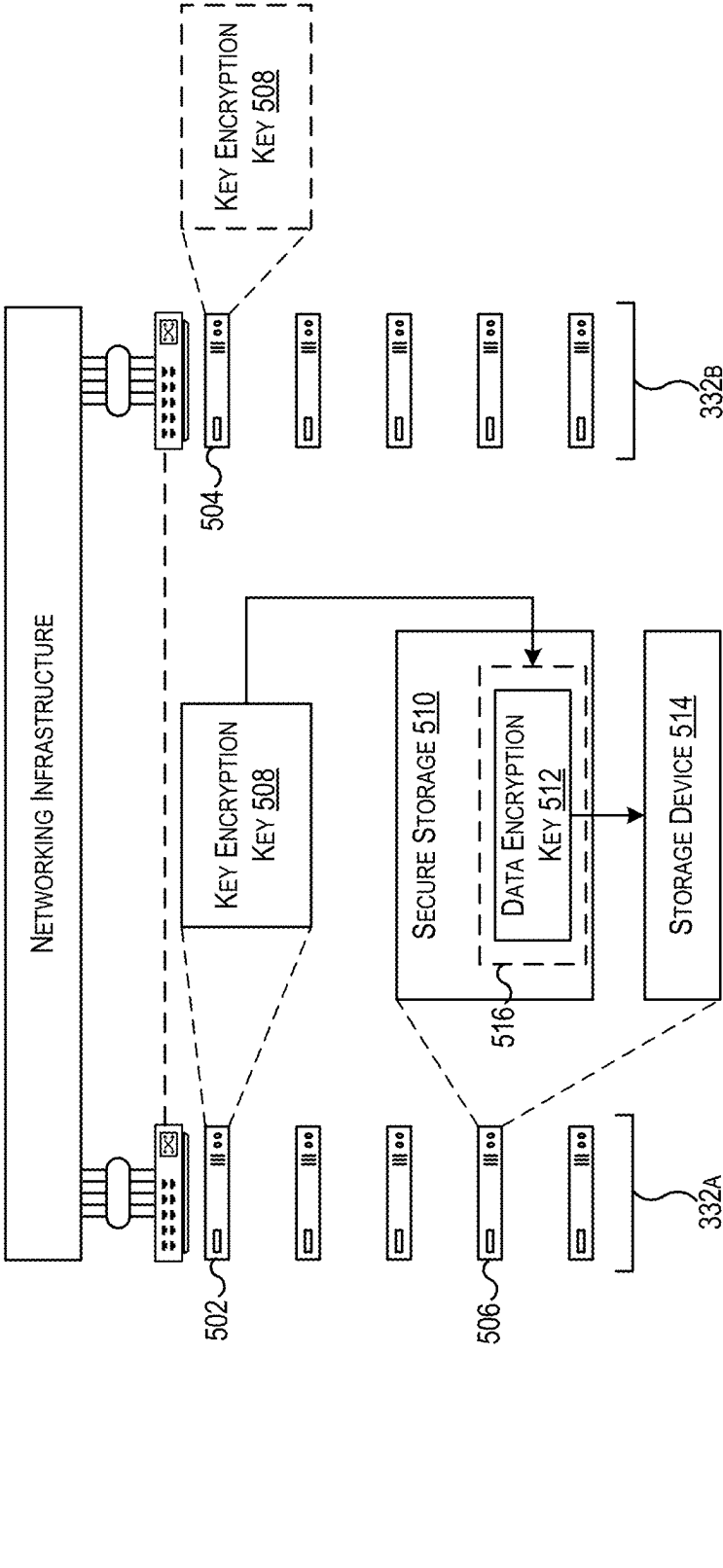


FIG. 5

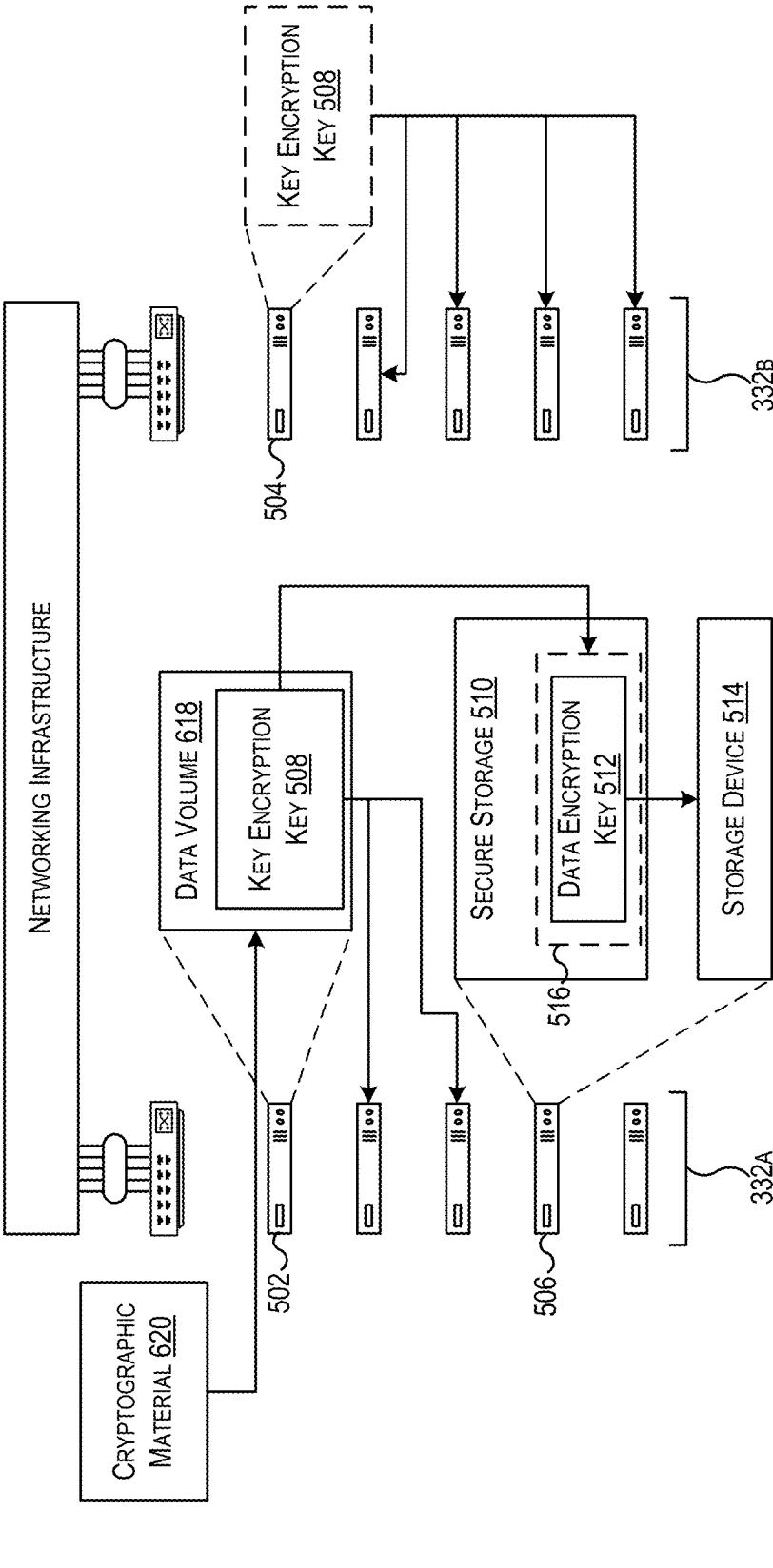


FIG. 6

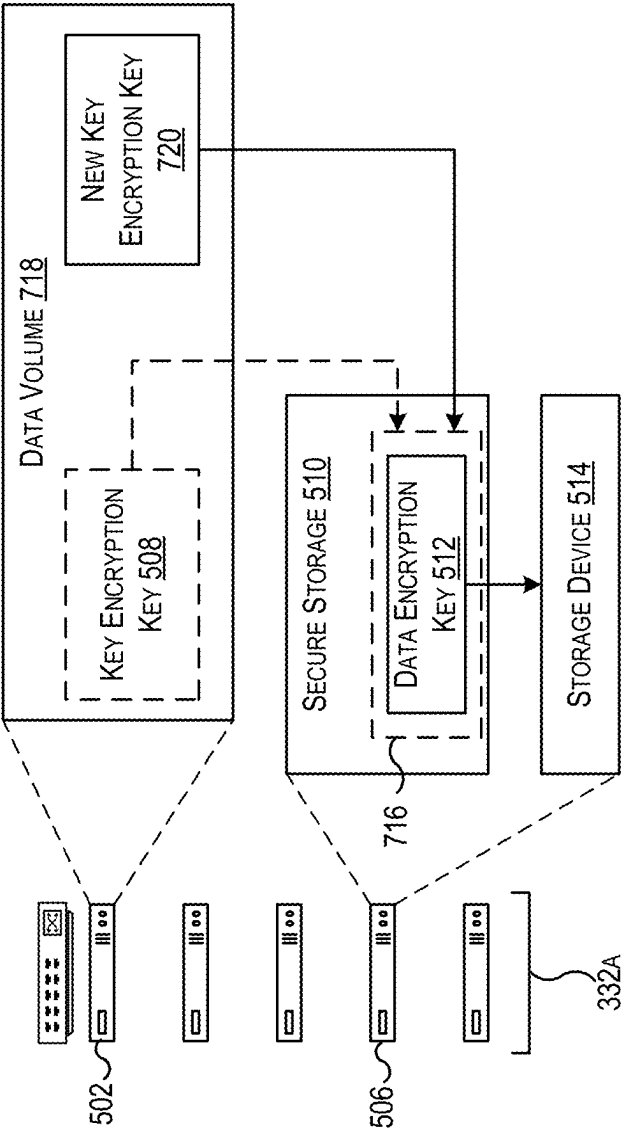


FIG. 7

700



800


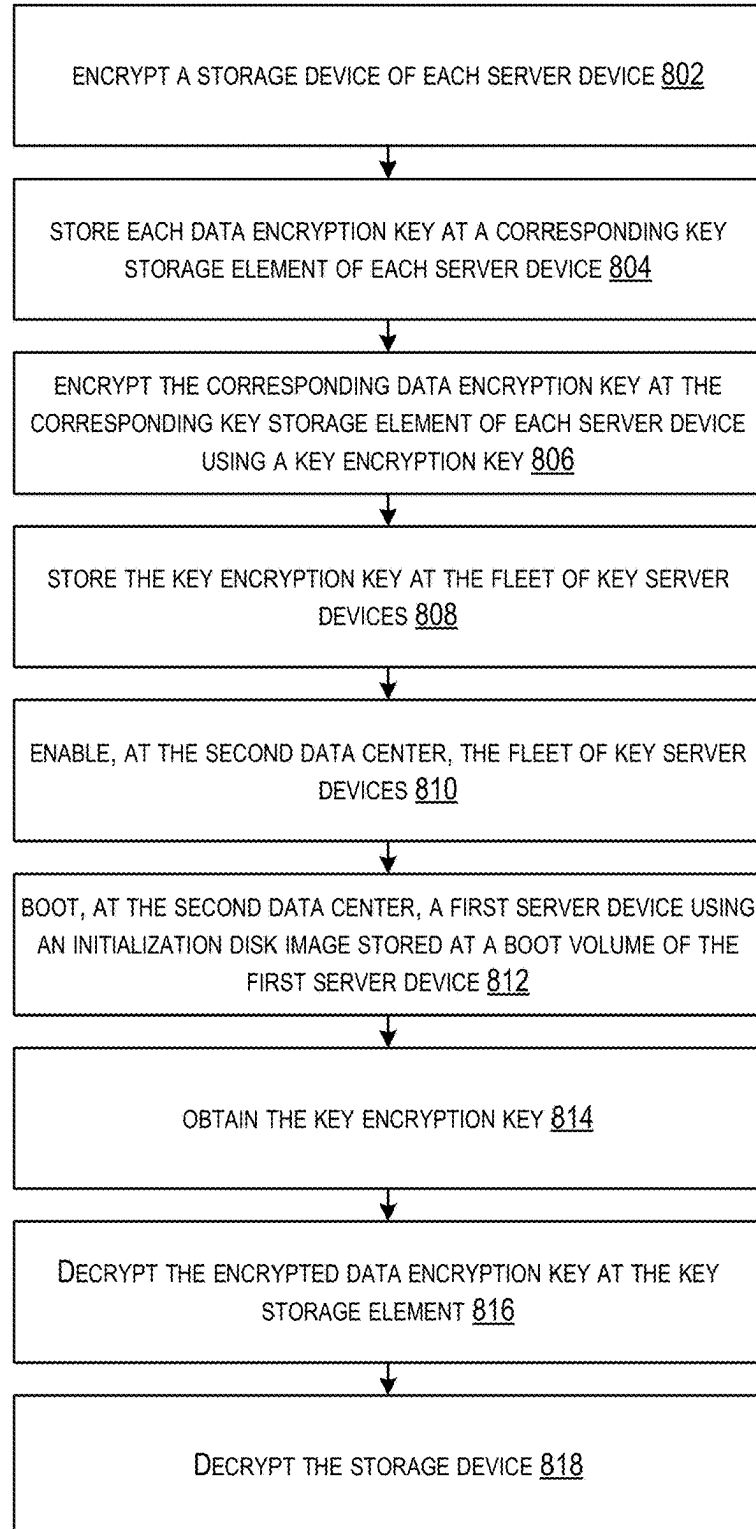



FIG. 8

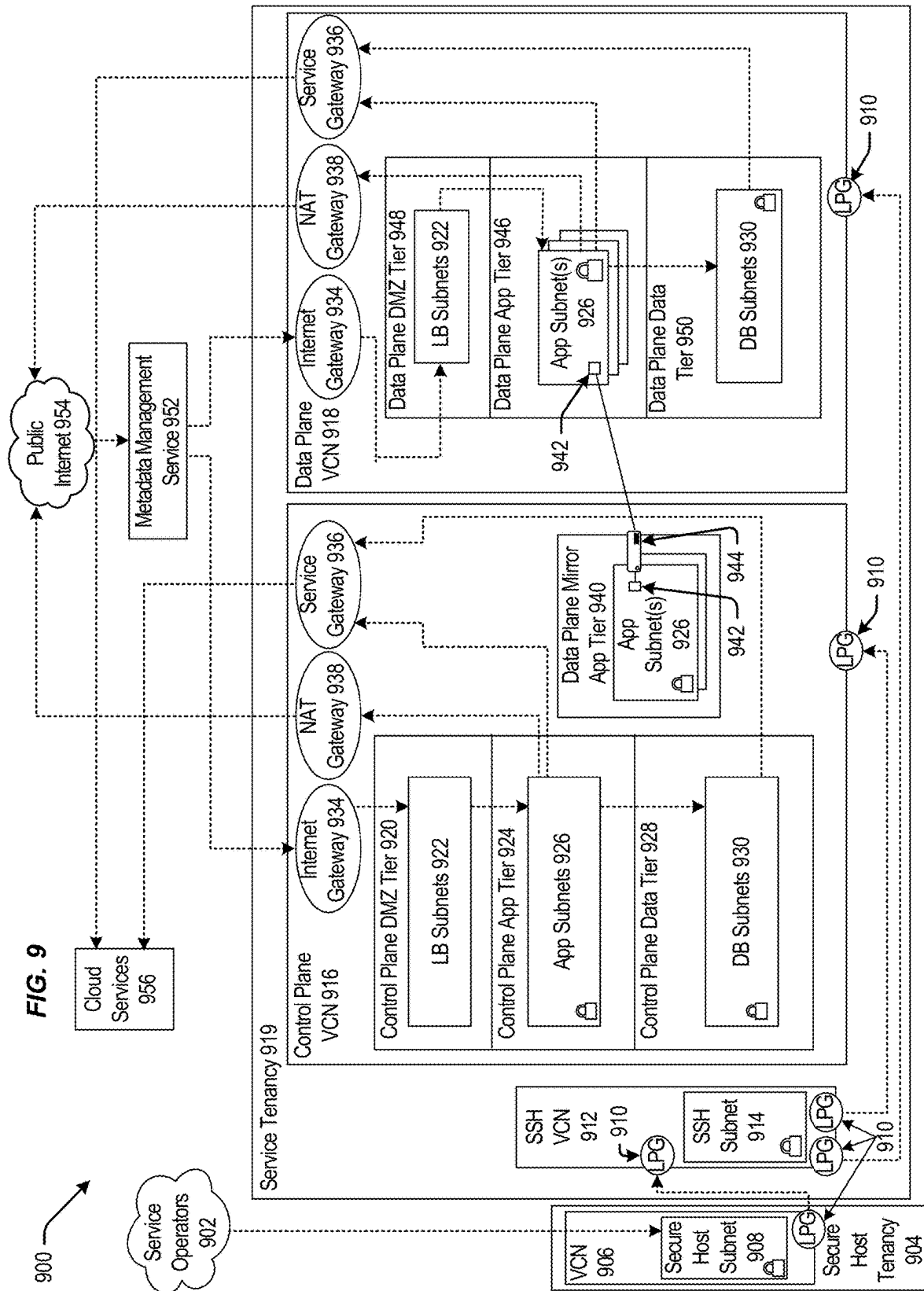
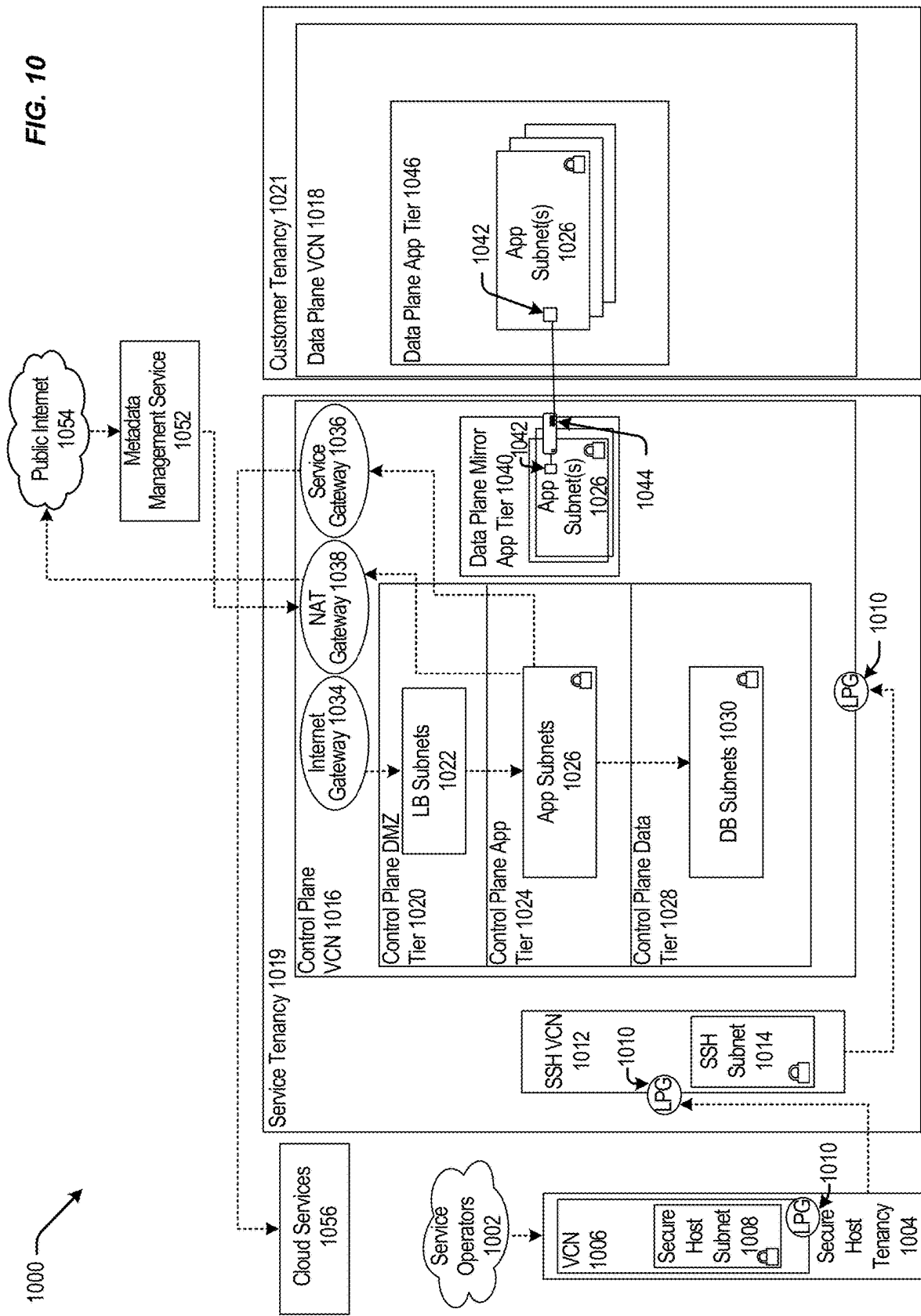
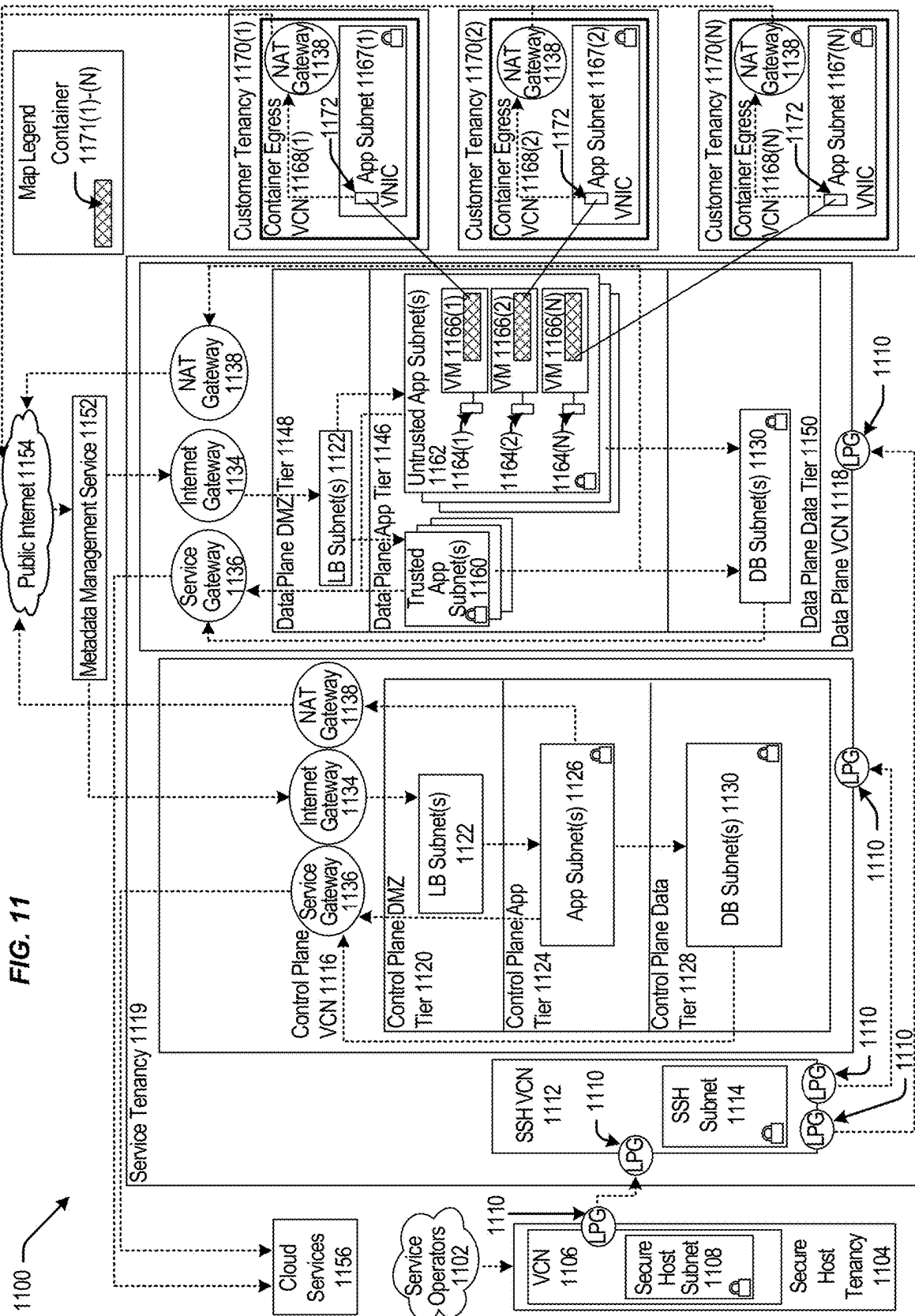
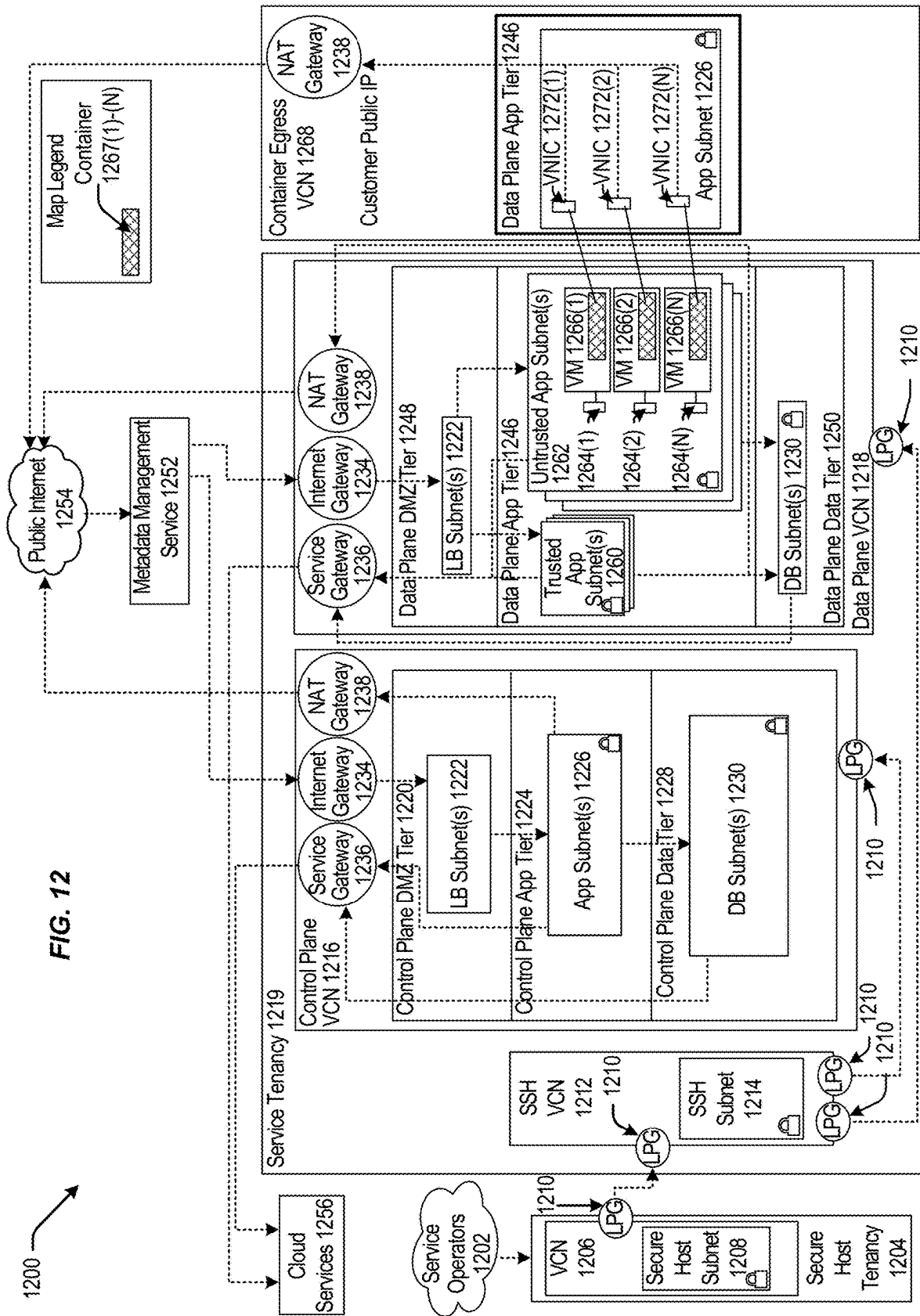


FIG. 10







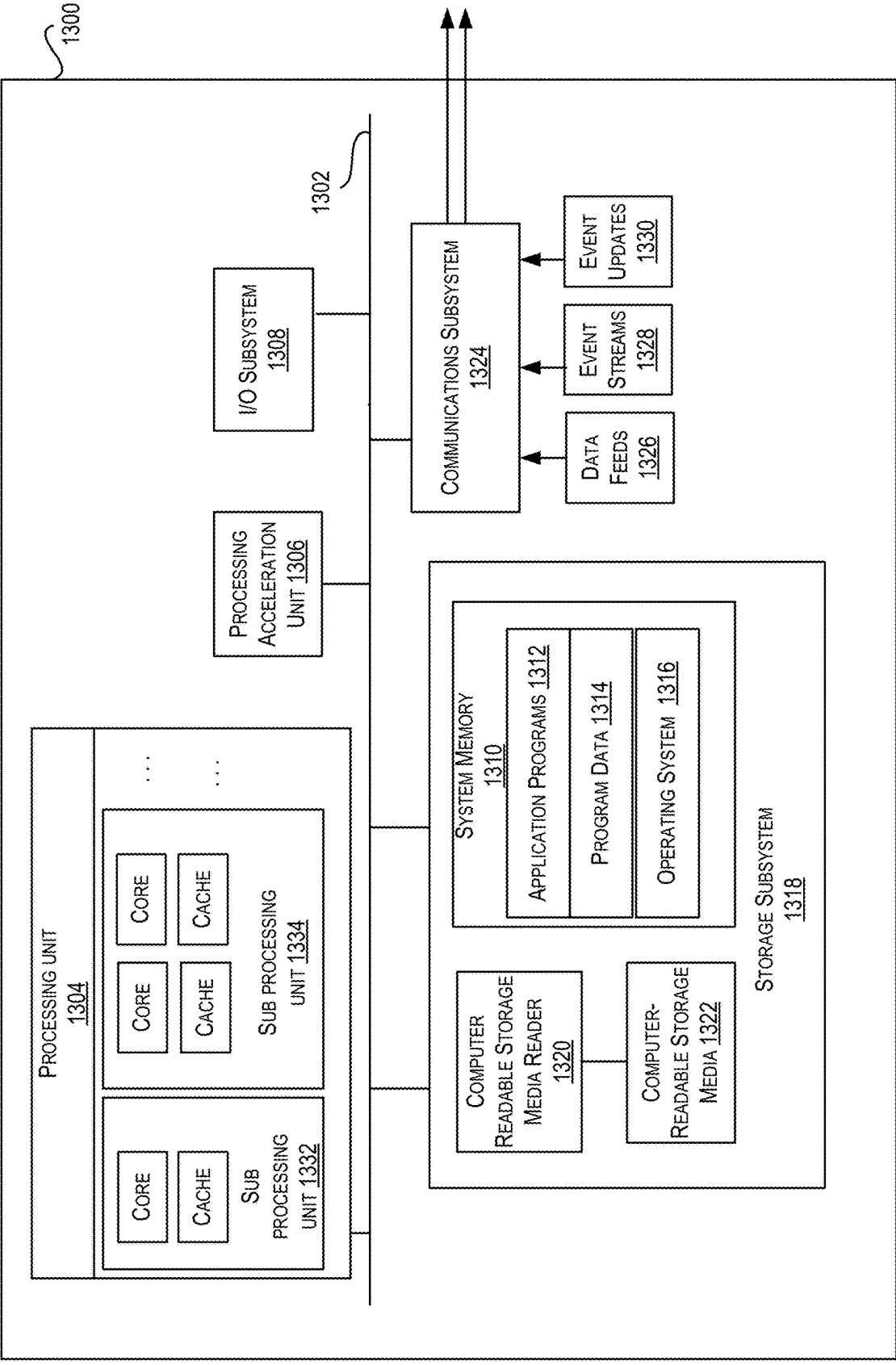


FIG. 13

## TECHNIQUES FOR DEVICE ENCRYPTION IN PREFAB REGION DATA CENTERS

### CROSS REFERENCES TO RELATED APPLICATIONS

[0001] The present application claims priority to and the benefit of U.S. Provisional Application No. 63/554,064, filed on Feb. 15, 2024, and entitled “TECHNIQUES FOR SECURE LIFT-AND-SHIFT ENCRYPTION WITH PREFAB REGIONS,” the entire contents of which are incorporated herein by reference for all purposes.

[0002] The present application is also related to the following applications, the entire contents of which are incorporated herein by reference for all purposes:

[0003] (1) U.S. Non-Provisional application Ser. No. 18/122,674 filed on Mar. 16, 2023, entitled “TECHNIQUES FOR BUILDING CLOUD REGIONS AT A PREFAB FACTORY,” Attorney Docket No. 088325-1307191 (344000US); and

[0004] (2) U.S. Non-Provisional application Ser. No. 18/122,675, filed on Mar. 16, 2023, entitled “TECHNIQUES FOR VALIDATING CLOUD REGIONS BUILT AT A PREFAB FACTORY,” Attorney Docket No. 088325-1373430 (344040US).

### BACKGROUND

[0005] A cloud infrastructure provider may operate one or more data centers in geographic areas around the world. A “region” is a logical abstraction around a collection of the computing, storage, and networking resources of the data centers of a given geographical area that are used to provide the cloud computing infrastructure. Building new regions can include provisioning the computing resources, configuring infrastructure, and deploying code to those resources, typically over network connections to the data centers. However, building regions with physical resources located at the final destination data center sites requires significant preparation work at the data centers that can complicate the logistics and scheduling of completing the building of a region.

### BRIEF SUMMARY

[0006] Embodiments of the present disclosure relate to automatically building a region using a prefab factory. A prefab factory may be a facility dedicated to configuring computing devices, networking devices, and other physical resources for delivery to a destination site (e.g., a destination region-one or more data centers in a geographic area, a customer facility, etc.). Operations for building a region can include bootstrapping (e.g., provisioning and/or deploying) resources (e.g., infrastructure components, artifacts, etc.) for any suitable number of services available from the region when delivered to the destination. Once the physical resources have been configured at the prefab factory, they may be shipped to the destination site, installed at the destination data center, and have final configurations and other software resources deployed to the physical resources. Resources used for bootstrapping (e.g., software artifacts, software images, etc.) may be provided in a bootstrapping environment in an existing region (e.g., one or more data centers of a host region). The host region can be selected based on network proximity to the prefab factory, and in a complimentary fashion, the prefab factory may be sited to

have high performance network connectivity to one or more host regions to support the bootstrapping environment. Building the region may be orchestrated by one or more cloud-based services that can manage the inventory of physical computing devices used to build regions in the prefab factory, generate and specify the configurations of regions to be built in the prefab factory, manage the bootstrapping of the regions, configure the regions for transmission to a destination site, and test and verify the physical resources after the physical resources have been installed at the destination site. A prefab region may be built to meet a specific customer’s configuration preferences (built-to-order) or built to a common specification that may be further customized during installation at a specific customer’s site (built-to-stock).

[0007] One embodiment is directed to a computer-implemented method for cryptographically securing data on the physical resources prior to transit to the destination site. The method can include configuring a plurality of server devices and a fleet of key server devices for transit to a data center. The configuration of the plurality of server devices and the fleet of key server devices can occur at the first facility. The configuration can include encrypting a storage device of each server device of the plurality of server devices using a corresponding data encryption key, storing each data encryption key at a corresponding key storage element of each server device of the plurality of server devices, encrypting the corresponding data encryption key at the corresponding key storage element of each server device using a key encryption key to produce an encrypted data encryption key, and storing the key encryption key at the fleet of key server devices. The method can also include enabling, at the data center, the fleet of key server devices. The method can also include initiating, at the data center, a boot sequence of a first server device using an initialization disk image stored at a boot volume of the first server device. Once the first server device has been booted, the first server device can obtain, from the fleet of key server devices, the key encryption key. The method can also include decrypting, by the first server device, the encrypted data encryption key at the key storage element to produce the corresponding data encryption key, and decrypting, by the first server device, the storage device.

[0008] Another embodiment is directed to a distributed computing system comprising one or more processors and instructions that, when executed by the one or more processors, cause the distributed computing system to perform the method described above.

[0009] Still another embodiment is directed to a non-transitory computer-readable medium storing computer-executable instructions that, when executed by one or more processors of a distributed computing system, cause the distributed computing system to perform the method described above.

### BRIEF DESCRIPTION OF DRAWINGS

[0010] To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced.

[0011] FIG. 1 is a block diagram illustrating a prefab factory for building regions and preparing the region computing devices for transmission to target data centers, according to at least one embodiment.

**[0012]** FIG. 2 is a block diagram illustrating a prefab factory connected to services provided by a CSP for building regions, according to at least one embodiment.

**[0013]** FIG. 3 is a diagram illustrating managing a network configuration of computing resources of a region being built in a prefab factory using a manager service and a network service, according to at least one embodiment.

**[0014]** FIG. 4 is a diagram illustrating a testing and evaluation of a region after delivery to a destination site using a manager service and a testing service, according to at least one embodiment.

**[0015]** FIG. 5 is a block diagram illustrating key servers within a region network, according to some embodiments.

**[0016]** FIG. 6 is a block diagram illustrating secured key servers in a region network, according to some embodiments.

**[0017]** FIG. 7 is a block diagram illustrating a rotation of key encryption keys used to secure data encryption keys in a region network, according to some embodiments.

**[0018]** FIG. 8 is a flow diagram of an example process for encrypting and decrypting storage volumes of a region network using a fleet of key servers, according to at least one embodiment.

**[0019]** FIG. 9 is a block diagram illustrating one pattern for implementing a cloud infrastructure as a service system, according to at least one embodiment.

**[0020]** FIG. 10 is a block diagram illustrating another pattern for implementing a cloud infrastructure as a service system, according to at least one embodiment.

**[0021]** FIG. 11 is a block diagram illustrating another pattern for implementing a cloud infrastructure as a service system, according to at least one embodiment.

**[0022]** FIG. 12 is a block diagram illustrating another pattern for implementing a cloud infrastructure as a service system, according to at least one embodiment.

**[0023]** FIG. 13 is a block diagram illustrating an example computer system, according to at least one embodiment.

#### DETAILED DESCRIPTION

##### Example Automated Data Center Build (Region Build) Infrastructure

**[0024]** The adoption of cloud services has seen a rapid uptick in recent times. Various types of cloud services are now provided by various different cloud service providers (CSPs). The term cloud service is generally used to refer to a service or functionality that is made available by a CSP to users or customers on demand (e.g., via a subscription model) using systems and infrastructure (cloud infrastructure) provided by the CSP. Typically, the servers and systems that make up the CSP's infrastructure, and which are used to provide a cloud service to a customer, are separate from the customer's own on-premises servers and systems. Customers can thus avail themselves of cloud services provided by the CSP without having to purchase separate hardware and software resources for the services. Cloud services are designed to provide a subscribing customer easy, scalable, and on-demand access to applications and computing resources without the customer having to invest in procuring the infrastructure that is used for providing the services or functions. Various different types or models of cloud services may be offered such as Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), Infrastructure-as-a-Service (IaaS), and others. A customer can subscribe to one or more

cloud services provided by a CSP. The customer can be any entity such as an individual, an organization, an enterprise, a government entity, and the like.

**[0025]** As indicated above, a CSP is responsible for providing the infrastructure and resources that are used for providing cloud services to subscribing customers. The resources provided by the CSP can include both hardware and software resources. These resources can include, for example, compute resources (e.g., virtual machines, containers, applications, processors, bare-metal computers), memory resources (e.g., databases, data stores), networking resources (e.g., routers, host machines, load balancers), identity, and other resources. In certain implementations, the resources provided by a CSP for providing a set of cloud services CSP are organized into data centers. A data center may be configured to provide a particular set of cloud services. The CSP is responsible for equipping the data center with infrastructure and resources that are used to provide that particular set of cloud services. A CSP may build one or more data centers.

**[0026]** Data centers provided by a CSP may be hosted in different regions. A region is a localized geographic area and may be identified by a region name. Regions are generally independent of each other and can be separated by vast distances, such as across countries or even continents. Regions are grouped into realms. Examples of regions for a CSP may include US West, US East, Australia East, Australia Southeast, and the like.

**[0027]** A region can include one or more data centers, where the data centers are located within a certain geographic area corresponding to the region. As an example, the data centers in a region may be located in a city within that region. For example, for a particular CSP, data centers in the US West region may be located in San Jose, California; data centers in the US East region may be located in Ashburn, Virginia; data centers in the Australia East region may be located in Sydney, Australia; data centers in the Australia Southeast region may be located in Melbourne, Australia; and the like.

**[0028]** Data centers within a region may be organized into one or more availability domains, which are used for high availability and disaster recovery purposes. An availability domain can include one or more data centers within a region. Availability domains within a region are isolated from each other, fault tolerant, and are architected in such a way that data centers in multiple availability domains are very unlikely to fail simultaneously. For example, the availability domains within a region may be structured in a manner such that a failure at one availability domain within the region is unlikely to impact the availability of data centers in other availability domains within the same region.

**[0029]** When a customer or subscriber subscribes to or signs up for one or more services provided by a CSP, the CSP creates a tenancy for the customer. The tenancy is like an account that is created for the customer. In certain implementations, a tenancy for a customer exists in a single realm and can access all regions that belong to that realm. The customer's users can then access the services subscribed to by the customer under this tenancy.

**[0030]** As indicated above, a CSP builds or deploys data centers to provide cloud services to its customers. As a CSP's customer base grows, the CSP typically builds new data centers in new regions or increases the capacity of existing data centers to service the customers' growing



demands and to better serve the customers. Preferably, a data center is built in close geographical proximity to the location of customers serviced by that data center. Geographical proximity between a data center and customers serviced by that data center leads to shorter latency resulting in more efficient use of resources and faster and more reliable services being provided to the customers. Accordingly, a CSP typically builds new data centers in new regions in geographical areas that are geographically proximal to the customers serviced by the data centers. For example, for a growing customer base in Germany, a CSP may build one or more data centers in a new region in Germany.

**[0031]** Building a data center (or multiple data centers)) and configuring it to provide cloud services in a region is sometimes also referred to as building a region. The term “region build” is used to refer to building one or more data centers in a region. Building a region involves provisioning or creating a set of new resources that are needed or used for providing a set of services that the data center is configured to provide. The end result of the region build process is the creation of a region, where the data center, together with the contained hardware and software resources, is capable of providing a set of services intended for that region and includes a set of resources that are used to provide the set of services.

**[0032]** Building a new region is a very complex activity requiring extensive coordination between various bootstrapping activities. At a high level, this involves the performance and coordination of various tasks such as: identifying the set of services to be provided by the data center; identifying various resources that are needed for providing the set of services; creating, provisioning, and deploying the identified resources; wiring the underlying hardware properly so that they can be used in an intended manner; and the like. Each of these tasks further have subtasks that need to be coordinated, further adding to the complexity. Due to this complexity, presently, the building of a region involves several manually initiated or manually controlled tasks that require careful manual coordination. As a result, the task of building a new region (i.e., building one or more data centers in a region and configuring the hardware and software in each data center to provide the requisite cloud services) is very time consuming. It can take time, for example many months, to build a region. Additionally, the process is very error prone, sometimes requiring several iterations before a desired configuration of the region is achieved, which further adds to the time taken to build a region (e.g., deploy hardware and software resources). These limitations and problems severely limit a CSP’s ability to grow computing resources in a timely manner responsive to increasing customer needs.

**[0033]** Recent innovations allow CSPs to reduce build time, reduce computing resource waste, and reduce risk related to building a region. A CSP may employ an orchestration service to bootstrap services into a new region. The orchestration service may be a cloud-based service hosted within a separate region (e.g., an orchestration region) from the target region. To bootstrap services into the target region, the orchestration service can create a bootstrapping environment to host instances of one or more cloud services. The orchestration service can then use the services in the bootstrapping environment to support the deployment of services into the target region.

**[0034]** Even more recent innovations allow CSPs to centralize the region build operations to one or more facilities that can act as “factories” to produce partially or fully configured physical infrastructure for subsequent delivery to a destination site. Instead of waiting for the construction of a target region data center and the installation of physical components (e.g., servers, network switches, power supply, etc.) at the data center before bootstrapping the services into the target region, a CSP can build regions in a prefab factory, ship the configured physical components, like racks, to the destination data center, and then finalize and verify the components of the region once the racks arrive at the destination site. The prefab factory is capable of building multiple regions simultaneously. Each region being built at the prefab factory can have separate configurations, network topologies, and services. By building the regions at a prefab factory, the complexity of scheduling and logistics related to preparing the destination facility, delivering physical components to the destination facility, and managing bootstrapping resources within the cloud services can be greatly reduced, since the regions can be built in advance and maintained until the destination site is ready.

**[0035]** A prefab factory can also be used to build computing components to be integrated into on-premises solutions for customers, for example, when the customer controls and manages its own data center environment.

**[0036]** The present disclosure is directed to a prefab factory in which automated region builds are performed using one or more prefab services. A prefab manager service can orchestrate the overall building of a region at the prefab factory. The manager service can work in conjunction with the one or more additional prefab services to manage the inventory of physical components used to construct the region at the prefab factory, configure the network (e.g., endpoints, network topology, addresses and/or other identifiers of the components within the region), bootstrapping services onto the region infrastructure, preparing the components for transmission of the region (including encrypting data volumes to provide security during transit), verifying the region after delivery to and installation at the destination site, and finalizing the configuration of the region, including performing any remaining bootstrapping or updating operations for the services deployed to the region infrastructure previously at the prefab factory.

**[0037]** In particular, the prefab services can perform operations to deploy the software resources to the physical components using device images. For example, a template region network can be built with individual infrastructure and software components deployed as orchestrated by a manager service. Once built, each device of the template region can be imaged to create an image set that corresponds to the network topology and hardware configuration of the template region. The manager service can orchestrate the creation of the image set and the deployment of image sets to target region networks, which may be built in a prefab factory or after installation at a destination site data center. Advantageously, deploying images to devices can occur significantly faster than deploying services to each node in a region network individually when the target hardware is compatible with the image set. Accordingly, a service provider offering region build operations according to the techniques described herein can substantially reduce the

expenditure of computational resources even beyond the improvements gained with an automated region build operation.

#### Certain Definitions

**[0038]** A “region” is a logical abstraction corresponding to a collection of computing, storage, and networking resources associated with a geographical location. A region can include any suitable number of one or more execution targets. A region may be associated with one or more data centers. A “prefab region” describes a region built in a prefab factory environment prior to delivery to the corresponding geographical location. In some embodiments, an execution target could correspond to the destination data center as opposed to the prefab factory data center.

**[0039]** An “execution target” refers to a smallest unit of change for executing a release. A “release” refers to a representation of an intent to orchestrate a specific change to a service (e.g., deploy version 8, “add an internal DNS record,” etc.). For most services, an execution target represents an “instance” of a service or an instance of change to be applied to a service. A single service can be bootstrapped to each of one or more execution targets. An execution target may be associated with a set of devices (e.g., a data center).

**[0040]** “Bootstrapping” a single service is intended to refer to the collective tasks associated with provisioning and deployment of any suitable number of resources (e.g., infrastructure components, artifacts, etc.) corresponding to a single service. Bootstrapping a region is intended to refer to the collective of tasks associated with each of the bootstrap of each of the services intended to be in the region.

**[0041]** A “service” refers to functionality provided by a set of resources, typically in the form of an API that customers can invoke to achieve some useful outcome. A set of resources for a service includes any suitable combination of infrastructure, platform, or software (e.g., an application) hosted by a cloud provider that can be configured to provide the functionality of a service. A service can be made available to users through the Internet.

**[0042]** An “artifact” refers to code being deployed to an infrastructure component or a Kubernetes engine cluster; this may include software (e.g., an application), configuration information (e.g., a configuration file), credentials, for an infrastructure component, or the like.

**[0043]** IaaS provisioning (or “provisioning”) refers to acquiring computers or virtual hosts for use, and even installing needed libraries or services on them. The phrase “provisioning a device” refers to evolving a device to a state in which it can be utilized by an end-user for their specific use. A device that has undergone the provisioning process may be referred to as a “provisioned device.” Preparing the provisioned device (installing libraries and daemons) may be part of provisioning; this preparation is different from deploying new applications or new versions of an application onto the prepared device. In most cases, deployment does not include provisioning, and the provisioning may need to be performed first. Once prepared, the device may be referred to as “an infrastructure component.”

**[0044]** IaaS deployment (or “deployment”) refers to the process of providing and/or installing a new application, or a new version of an application, onto a provisioned infrastructure component. Once the infrastructure component has been provisioned (e.g., acquired, assigned, prepared, etc.), additional software may be deployed (e.g., provided to and

installed on the infrastructure component). The infrastructure component can be referred to as a “resource” or “software resource” after provisioning and deployment has concluded. Examples of resources may include, but are not limited to, virtual machines, databases, object storage, block storage, load balancers, and the like.

**[0045]** A “virtual bootstrap environment” (ViBE) refers to a virtual cloud network that is provisioned in the overlay of an existing region (e.g., a “host region”). Once provisioned, a ViBE is connected to a new region using a communication channel (e.g., an IPSec Tunnel VPN). Certain essential core services (or “seed” services) like a deployment orchestrator, a public key infrastructure (PKI) service, a dynamic host configuration protocol service (DHCP), a domain name service (DNS), and the like can be provisioned in a ViBE. These services can provide the capabilities required to bring the hardware online, establish a chain of trust to the new region, and deploy the remaining services in the new region. Utilizing the virtual bootstrap environment can prevent circular dependencies between bootstrapping resources by utilizing resources of the host region. These services can be staged and tested in the ViBE prior to the prefab region (e.g., the target region) being available.

**[0046]** A “Manager Service” may refer to a service configured to manage provisioning and deployment operations for any suitable number of services as part of a prefab region build. A manager service may be used in conjunction with one or more additional prefab services to orchestrate a region build in a prefab factory as well as for managing how the prefabricated region is installed and configured at the destination data center after it is built and shipped over. The manager service and other prefab services may be hosted in an existing region of a CSP.

**[0047]** A “host region” refers to a region that hosts a virtual bootstrap environment (ViBE). A host region may be used to bootstrap a ViBE.

**[0048]** A “target region” refers to a region under build in the prefab factory. During a prefab region build, the target region is associated with physical space, power, and cooling provided by the prefab factory. After bootstrapping, once the prefabricated region has been shipped to the destination data center, the prefabricated region is associated with the destination data center into which it gets installed.

#### Prefab Region Build

**[0049]** In some examples, techniques for building a region at a prefab factory are described herein. Such techniques, as described briefly above, can include one or more prefab services (e.g., manager service, network service, inventory service, testing service, deployment orchestration system) hosted by a CSP that can manage bootstrapping (e.g., provisioning and deploying software to) infrastructure components for one or more regions within the prefab factory. The prefab factory may be configured to support multiple region builds simultaneously. For example, physical resources (e.g., server racks, network switches, etc.) of a first prefab region may be installed at one location in the prefab factory while physical resources of a second prefab region may be installed at a second location in the prefab factory. Each prefab region can be connected to a dedicated network fabric of the prefab factory to provide networking connections to each prefab region independently, so that each region can communicate with the prefab services and/or other cloud services to support the region build. Based on a

build request (a specification of the region, e.g., a number of server racks for the region, a number of computing devices, a number and type services to be hosted by the region, a network topology of the region, etc.), the prefab services can generate instructions to install (e.g., by factory personnel) the corresponding physical infrastructure in the prefab factory, which can include networking the physical devices together on their racks, positioning the racks at locations in the prefab factory, and connecting the devices to the static network fabric of the prefab factory. The manager service can then orchestrate the provisioning of the region infrastructure and deployment of software resources to the prefab region infrastructure, configure the prefab region for transmission, manage (e.g., schedule and monitor) the transmission of the prefab region, and perform testing and verification of the prefab region once it reaches its destination site.

**[0050]** The prefab factory can centralize the region build process to provide more efficient use of computing and networking resources that support region build. For example, the prefab factory may be sited “close” (e.g., with low-latency and high data rate networking connections) to a host region that includes the prefab services and/or a ViBE. Multiple regions may be built using the improved performance of the network connection to the host region, avoiding potential poor performance when performing a region build to a newly constructed data center site for typical region build. The prefab factory also provides improved physical and computational security for the devices during region build, as the CSP can control the prefab factory and the network connections therein.

**[0051]** In addition, the prefab factory improves the management of the inventory of physical components. The manager service can determine which computing devices are needed for a particular region build, which may be stored at or near the prefab factory. As regions are built and shipped, infrastructure for new regions can be quickly moved into the prefab factory and installed, increasing efficiency.

**[0052]** Turning now to the figures, FIG. 1 is a block diagram illustrating a prefab system 100 including a prefab factory 102 for building regions (e.g., Prefab Region 106A, Prefab Region 106B, Prefab Region 106C) and preparing the region computing devices for transmission to target data centers (e.g., data center 108, data center 110), according to at least one embodiment. Each region being built in the prefab factory 102 can include one or more devices that form the computing environment of a data center. The prefab factory 102 can be used to build multiple regions simultaneously. For example, prefab factory 102 can build all of Prefab Region 106A, Prefab Region 106B, and Prefab Region 106C at the same time. In some examples, the devices of a region may be installed and staged in the prefab factory 102 prior to beginning infrastructure provisioning and software deployment operations.

**[0053]** The prefab factory 102 can be a facility similar to a data center, including sufficient power, cooling, and networking infrastructure to support building one or more regions. The prefab factory 102 may be located in proximity to existing computing infrastructure of a CSP (e.g., CSP 104). For example, CSP 104 can operate existing data centers for one or more regions. The prefab factory 102 can be located close to or even adjacent to an existing data center of a host region to provide high data rate network connections between the cloud services of the CSP and the computing devices of the regions being built in the prefab factory

102. Additionally or alternatively, the prefab factory 102 can be located to improve logistical operations including shipping of regions to destination data centers.

**[0054]** A prefab region being built in the prefab factory 102 can include any suitable number of physical resources, including computing devices (e.g., servers, racks of multiple servers, etc.), storage (e.g., block storage devices, object storage devices, etc.), networking devices (e.g., switches, routers, gateways, etc.), and the like. Each region may have different physical resources according to the specific requirements of the destination region and data centers. For example, Prefab Region 106A may include 100 racks each having 40 computing devices, while Prefab Region 106B may include 20 racks each having 30 computing devices. Each rack of computing devices can include one or more networking devices communicatively connected to the server devices on the rack and configured to connect to networking infrastructure of the prefab factory 102 to form a network with other computing devices of the prefab region. Each rack can also include power supplies and cooling devices to support the operation of the computing devices on the racks.

**[0055]** The prefab factory 102 can include any suitable number of networking devices to support the installation and connection of the one or more computing devices of the prefab regions being built. For example, the prefab factory 102 can include any suitable number of leaf and spine switches to support the connection of computing devices on multiple racks to form the network of a prefab region. Similarly, the prefab factory 102 can include network cabling installed in the facility that can provide network connections to the networking infrastructure of the prefab factory 102. The network cabling may be positioned to terminate at locations within the prefab factory 102 where racks of computing devices for the prefab regions may be installed during region build operations. Additional details about the networking infrastructure and configuration of the prefab factory are provided below with respect to FIGS. 9-11.

**[0056]** The prefab factory 102 may be connected over one or more networks to services provided by CSP 104. During region build operations, CSP 104 can provision infrastructure components on the physical resources of the prefab regions and deploy software resources, configurations, and/or other artifacts to the provisioned infrastructure components. For example, CSP 104 can provision the computing devices of Prefab Region 106A to host one or more virtual machines, provide hostnames, network addresses, and other network configurations for the provisioned physical and virtual devices, and then deploy one or more services to be executed on the provisioned infrastructure. The prefab region may be brought to a state that is close to the final production state of the devices when they are installed at the destination facility.

**[0057]** Once the prefab region has been built, the physical resources may be configured for transmission/transportation to the destination facility. As used herein, the term “transmission” may be used synonymously with the term “transportation” within the context of moving the physical resources associated with the prefab region from the prefab factory to a destination site. Configuring the prefab region for transmission can include obtaining a “snapshot” of the current network configuration of the computing devices in the prefab region, storing the snapshot, providing a portion

of the snapshot to each computing device that includes identifiers for each device and its neighboring devices within the network, encrypting data volumes of the computing devices, and configuring the devices to boot into a test state when powered on after transmission. In addition to network snapshots, the prefab services of the CSP **104** may also capture device snapshots which are disk images taken of fully configured individual switches, compute devices, and smart NICs in the various racks to be shipped to the destination site. The device snapshots can enable rapid replacement of any device in the racks that get shipped if that device is non-functional after arrival and has to be replaced. Transportation to a destination facility may be by one or more methods, including shipment by truck **112** or shipment by aircraft **114**. For example, Prefab Region **106B** may be configured to be delivered by truck **112** to data center **108**, while Prefab Region **106C** may be configured to be delivered by aircraft **114** to data center **110**.

**[0058]** Once the computing devices of a prefab region arrive at the destination facility, they may be installed at the facility according to the configuration of the facility. The destination facilities can be data centers that have been built to host the prefab region devices, with networking, power, cooling, and other infrastructure provided according to the configuration of the prefab region. The data centers can have network connections to the CSP **104**. Installation of the prefab region can include manual operations for connecting racks and their computing devices to the network infrastructure of the data centers and other related tasks. Once the physical connections have been made, the devices of the prefab region can be powered on, which can initiate one or more testing operations by the devices based on the configuration that was performed at the prefab factory **102** prior to transmission. The prefab regions can also connect to the CSP **104** via one or more network connections to the data center to communicate with prefab services. For example, Prefab Region **106B** can connect to CSP **104** via connection **118**, while Prefab Region **106C** can connect to CSP **104** via connection **116**. The prefab services can deploy final configurations for the installed devices, deploy updates to software resources on the installed devices, and perform additional testing and verification operations for the prefab region at the destination data center.

**[0059]** FIG. 2 is a block diagram illustrating a prefab system **200** including a prefab factory **202** connected to prefab services **210** provided by a CSP **204** for building regions, according to at least one embodiment. The prefab factory **202** may be an example of prefab factory **102** of FIG. 1, and CSP **204** may be an example of CSP **104** of FIG. 1. The prefab factory **202** may interface with the CSP **204** via network **208**, which may be a public network like the Internet, a private network, or other network. The prefab services **210** can include manager service **212**, inventory service **214**, testing service **216**, orchestration service **218**, and network service **220**. The prefab services **210** can perform operations corresponding to building the prefab region **206** in the prefab factory **202**, including managing a bootstrapping environment (e.g., ViBE **222**), provisioning infrastructure components in the Prefab Region **206**, deploying software resources to the Prefab Region **206**, configuring the network of the Prefab Region **206**, testing the Prefab Region at various points during the build process, and managing the physical inventory (e.g., physical inventory

**224**) of computing devices used to build Prefab Region **206** and other prefab regions being built at prefab factory **202**.

**[0060]** The manager service **212** can perform tasks to coordinate the operations of the prefab services **210**, including scheduling prefab region build operations by other prefab services **210**, generating physical build requests and corresponding instructions, initiating shipping of the prefab region **206** to a destination site, and managing the provisioning and deployment of resources in the prefab region **206** both in the prefab factory **202** and at the destination site. A physical build request can specify the number and type of physical resources to be used in Prefab Region **206**. The physical build request can also include a set of instructions usable by personnel to install the corresponding physical resources in the prefab factory **202**. For example, the manager service **212** may generate a physical build request that specifies the number of racks and server devices for Prefab Region **206**, the number of networking devices usable to connect the server devices to form the network of Prefab Region **206**, and the connection plan that determines the networking connections between the specified server devices, networking devices, and the existing networking infrastructure of the prefab factory **202**. The physical build request can also include instructions for personnel to obtain physical devices from an associated location (e.g., physical inventory **224**) and instructions to install the devices in the prefab factory **202** at specified locations. In some embodiments, operations of the physical build request may be performed by automated systems under the control of the manager service **212**. For example, obtaining racks of server devices from physical inventory **224** and installing the racks at prefab factory **202** may be performed by a robotic system configured to move physical racks from site to site.

**[0061]** The inventory service **214** may be configured to track and monitor physical devices corresponding to one or more regions (e.g., one or more data centers of a region). The inventory service **214** can also track physical devices for one or more prefab regions (e.g., Prefab Region **206**) in the prefab factory **202**. Tracking and monitoring the physical devices can include maintaining an inventory of the devices according to an identifier of the device (e.g., serial number, device name, etc.) and the association of the devices with a data center. The inventory service **214** can provide inventory information to other prefab services **210**, including manager service **212**, for use in the prefab region build process. For example, inventory service **214** can determine if a physical device is located at prefab factory **202** or at a destination site. Inventory service **214** can query devices to determine their location and/or association with a region, prefab region, or data center via a network (e.g., network **208**). Inventory service **214** can also maintain a physical inventory (e.g., physical inventory **224**) of devices that are stored for use in prefab region build operations. For example, inventory service **214** can track physical devices as they are received at the physical inventory **224** and then retrieved from the physical inventory **224** to be used as part of a prefab region at prefab factory **202**. In some examples, inventory service **214** can provide inventory information to manager service **212** that is usable to generate a physical build request for Prefab Region **206** that includes instructions to obtain physical resources from physical inventory **224** and install the physical resources at the prefab factory **202**.

**[0062]** The physical inventory **224** may be a warehouse or storage facility for storing physical resources (e.g., comput-

ing devices) for use in prefab region build operations. The physical inventory **224** may be located near the prefab factory **202** to facilitate retrieval of physical resources according to a physical build request. For example, the physical inventory **224** may be a building adjacent to a building used for the prefab factory **202**. In some examples, the physical inventory **224** may be located within the prefab factory **202**. Physical resources may be placed into and retrieved from the physical inventory **224** by personnel associated with the CSP and the prefab factory **202**. In some instances, during prefab region build operations, the retrieval and installation of physical resources from physical inventory **224** may be done by robots, automated guided vehicles, or other similar autonomous or semi-autonomous systems using instructions provided by the physical build request.

**[0063]** The orchestration service **218** may be configured to perform bootstrapping operations to provision infrastructure components in the Prefab Region **206** and to deploy software resources to the Prefab Region **206**. The orchestration service **218** can also construct a bootstrapping environment (e.g., ViBE **222**) for use when bootstrapping resources into the Prefab Region **206**. The orchestration service **218** may be an example of a deployment orchestrator described above. In some examples, the orchestration service **218** may be configured to bootstrap (e.g., provision and deploy) services into a prefab region (e.g., Prefab Region **206**) based on predefined configuration files that identify the resources (e.g., infrastructure components and software to be deployed) for implementing a given change to the prefab region. The orchestration service **218** can parse and analyze configuration files to identify dependencies between resources. The orchestration service **218** may generate specific data structures from the analysis and may use these data structures to drive operations and to manage an order by which services are bootstrapped to a region. The orchestration service **218** may utilize these data structures to identify when it can bootstrap a service, when bootstrapping is blocked, and/or when bootstrapping operations associated with a previously blocked service can resume.

**[0064]** In some embodiments, the orchestration service **218** may include components configured to execute bootstrapping tasks that are associated with a single service of a prefab region. The orchestration service **218** can maintain current state data indicating any suitable aspect of the current state of the resources associated with a service. In some embodiments, desired state data may include a configuration that declares (e.g., via declarative statements) a desired state of resources associated with a service. In some embodiments, orchestration service **218** can identify, through a comparison of the desired state data and the current state data, that changes are needed to one or more resources. For example, orchestration service **218** can determine that one or more infrastructure components need to be provisioned, one or more artifacts deployed, or any suitable change needed to the resources of the service to bring the state of those resources in line with the desired state. Specific details about a particular implementation of orchestration service **218** is provided in U.S. patent application Ser. No. 17/016,754, entitled “Techniques for Deploying Infrastructure Resources with a Declarative Provisioning Tool,” the entire contents of which are incorporated in its entirety for all purposes.

**[0065]** The ViBE **222** may be an example of a bootstrapping environment that can be used to deploy resources to a prefab region in a prefab factory **202**. A ViBE can include a virtual cloud network (e.g., a network of cloud resources) implemented within a suitable region of a CSP (e.g., CSP **204**). The ViBE can have one or more nodes (e.g., compute nodes, storage nodes, load balancers, etc.) to support operations to host services deployed by orchestration service **218**. The ViBE services can in turn be used to support deployment of services into the Prefab Region **206**. For example, orchestration service **218** may deploy an instance of one or more constituent services of the orchestration service **218** into the bootstrapping environment (e.g., an instance of orchestration service **218**), which in turn may be used to deploy resources from the ViBE **222** to the Prefab Region **206**. Because a ViBE is implemented as a virtual cloud network in an existing region, any suitable amount of region infrastructure may be provisioned to support the deployed services within the ViBE (as compared to the fixed hardware resources of a seed server). The orchestration service **218** may be configured to provision infrastructure resources (e.g., virtual machines, compute instances, storage, etc.) for the ViBE **222** in addition to deploying software resources to the ViBE **222**. The ViBE **222** can support bootstrapping operations for more than one prefab region in the prefab factory **202** at the same time.

**[0066]** When the Prefab Region **206** is available to support bootstrapping operations, the ViBE **222** can be connected to the Prefab Region **206** so that services in the ViBE **222** can interact with the services and/or infrastructure components of the Prefab Region **206**. This can enable deployment of production level services, instead of self-contained seed services as in previous systems, and may require connectivity over the internet to the target region. Conventionally, a seed service was deployed as part of a container collection and used to bootstrap dependencies necessary to build out the region. Using infrastructure/tooling of an existing region, resources may be bootstrapped into the ViBE **222** and connected to the Prefab Region **206** in order to provision hardware and deploy services until the Prefab Region **206** reaches a self-sufficient state (e.g., self-sufficient with respect to services hosted within the Prefab Region **206**). Utilizing the ViBE **222** allows for standing up the dependencies and services needed to be able to provision/prepare infrastructure and deploy software while making use of the host region’s resources in order to break circular dependencies of core services.

**[0067]** The testing service **216** may be configured to perform one or more test operations or validation operations on the Prefab Region **206** following the provisioning and/or deployment of resources. The test operations may be part of a user-acceptance test usable to determine if the behavior of the built region conforms to a build specification. For example, testing service **216** may perform a test that interacts with an instance of a service deployed to the Prefab Region **206** to verify an expected operation of the queried service. As another example, testing service **216** may perform a networking test to obtain hostnames, networking addresses, and/or other identifiers of the components of the Prefab Region **206** to compare to the expected identifiers of the components as specified in a build request or other specification for the Prefab Region **206**. Testing service **216** may perform test operations both during the prefab region build process at prefab factory **202** and after delivery of the

Prefab Region 206 to a destination site. The testing operations performed at the prefab factory 202 may be the same or different from testing operations performed after the Prefab Region 206 is delivered to the destination site.

[0068] The manager service 212 can obtain inventory information from inventory service 214 for use when generating a physical build request. For example, the inventory information may be used by manager service 212 to determine which physical resources to install in the prefab factory 202 for a prefab region corresponding to the physical build request.

[0069] FIG. 3 is a diagram illustrating a CSP system 300 for managing a network configuration of computing resources of a Prefab Region 330 being built in a prefab factory 302 using a manager service 312 and a network service 320, according to at least one embodiment. The prefab factory 302 and Prefab Region 330 may be examples of other prefab factories and prefab regions described herein, including prefab factory 202 and Prefab Region 206 of FIG. 2. Prefab services 310 may be provided by the CSP and may be examples of prefab services 210 described above with respect to FIG. 2, including manager service 312 as an example of manager service 212 of FIG. 2 and network service 320 as an example of network service 220 of FIG. 2.

[0070] As described above with respect to FIG. 2, the manager service 312 can perform tasks to coordinate the operations of the prefab services 310, including scheduling prefab region build operations by other prefab services 310, generating physical build requests and corresponding instructions, and configuring Prefab Region 206 for shipping to a destination site. A physical build request can specify the number and type of physical resources to be used in Prefab Region 206. The network service 320 can use configuration information from a build request to determine a network topology of the devices (e.g., servers, networking devices, racks of servers and networking devices, etc.). The network service 320 can also determine the network configuration of devices of the Prefab Region 330 after the provisioning of infrastructure components in the Prefab Region 330.

[0071] In some examples, the network service 320 can store a snapshot of the network configuration of a prefab region (e.g., Prefab Region 330). A snapshot can include information about the network topology of the prefab region at a specific point in time, including network identifiers (e.g., network addresses, hostnames, etc.) for the devices in the prefab region, the current network connections between the devices, the physical networking interfaces between the devices and the networking infrastructure 338 of the prefab factory 302, and network settings for the devices (e.g., port configurations, gateway configurations, etc.). As an example, server device 336 may be a computing device in server rack 332A of Prefab Region 330. Server device 336 may have a networking connection 340 to switch 334 of server rack 332. The network configuration of Prefab Region 330 can then include information associating server device 336 to switch 334, including information specifying the type of network connection 340, the port of switch 334 to which server device 336 is connected, and the settings of both server device 336 and switch 334 that correspond to the networking connection 340 between them. In addition, the network configuration can include information that associates server device 336 with “neighboring” devices in Prefab Region 330 that have networking connections 342, 344 between them. The networking connections 342 and 344

may be via switch 334, so that server device 336 may be communicatively connected to other devices in server rack 332A via network connections 342, 344. In some examples, “neighboring” devices of a given device in Prefab Region 330 can include each computing device on the same server rack. In addition, switch 334 may have network connections to one or more other switches within Prefab Region 330 (e.g., network connection 346 to a switch of server rack 332B).

[0072] The network snapshot may be used to validate the physical installation (e.g., physical networking connections) of Prefab Region 330 after the devices are installed at the destination site. For example, network service 320 can provide the network snapshot (or a portion of the snapshot) to each device in the Prefab Region 330 as part of configuring the Prefab Region 330 for transportation to a destination site. For example, network service 320 may provide network snapshot 326 to server device 336 for storage at server device 336.

[0073] Network snapshot 326 may be a portion of the network snapshot corresponding to the network configuration of the entire Prefab Region 330. Network snapshot 326 can include an identifier (e.g., network address, hostname, etc.) for server device 336 and information associating server device 336 with one or more other devices in Prefab Region 330. The information associating server device 336 with a neighboring device can include an identifier for the neighboring device and information about the network connection between them. For example, server device 336 can use network snapshot 326 to identify neighboring devices and communicate with the neighboring devices over the network connection.

[0074] The network service 320 may also maintain a network configuration for the network fabric of the prefab factory 302. For example, the prefab factory 302 can have networking infrastructure to support multiple, separate prefab regions being built at the same time. The prefab factory 302 can have multiple dedicated locations for placing server racks for the prefab regions being built. Each location may have a set of networking cables of the networking infrastructure that terminate at the location that can be connected to the server racks. Based on the devices placed at the location, specific cables from the set of networking cables can be connected to the devices (e.g., to a top-of-rack switch) to connect the devices to other devices in the prefab region using a portion of the network fabric of the prefab factory 302. For example, server rack 332A may be placed at a location within the prefab factory 302 and connected to networking infrastructure 338 using switch 334, while server rack 332B may be placed at a second location and connected to networking infrastructure 338.

[0075] In addition to operations for preserving the network configuration of the Prefab Region 330, configuring Prefab Region 330 for transportation to a destination site can also include the manager service 312 configuring each device to enter a testing state during a subsequent power-on of the device, encrypting data volumes of the devices with encryption keys, storing the encryption keys at a device that can act as a key server for the Prefab Region 330 during initialization at the destination site, and configuring one of the devices to act as dynamic host configuration protocol (DHCP) server during initialization of the Prefab Region 330 at the destination site. Manager service 312 may also generate instructions usable by personnel or robotic systems

associated with the prefab factory 302 for packing the devices for transmission. Manager service 312 may also generate instructions usable by personnel associated with the destination facility for installing and connecting the devices at the destination facility.

[0076] In some embodiments, configuring the devices of Prefab Region 330 can also include operations to capture device snapshots of each device. A device snapshot can include a software image of one or more disk drives or other memory of a computing device, which can be used to duplicate the software configuration of the device onto a replacement device. The manager service 312 can generate the device snapshots in conjunction with one or more of the prefab service 310. The device snapshots may be stored along with the network snapshot(s) in a database or datastore (e.g., snapshot(s) 324). As a particular example, manager service 312 can generate device snapshot 352 of server device 350 of Prefab Region 330 at the prefab factory 302. The device snapshot 352 may be used to image another physical device that has the same or similar physical configuration as server device 350 in order to create a duplicate server device in the event that server device 350 fails (e.g., damaged or lost during transit to the destination site).

[0077] FIG. 4 is a diagram illustrating a CSP system 400 for testing and evaluation of a Prefab Region 330 after delivery to a destination site 402 using a manager service 412 and a testing service 416, according to at least one embodiment. The destination site 402 may be a data center facility at a location corresponding to new region to be deployed for the CSP using the computing resources of Prefab Region 330. Prefab services 410 may be provided by the CSP and may be similar to prefab services 210 of FIG. 2, including manager service 412 as an example of manager service 212, testing service 416 as an example of testing service 216, and orchestration service 418 as an example of orchestration service 218 of FIG. 2.

[0078] Shipping Prefab Region 330 to the destination site 402 can include powering down each device, disconnecting the devices from the networking infrastructure of the prefab factory, and packing the devices as appropriate for transit. Server racks (e.g., server racks 332A, 332B) may be shipped intact, without disconnecting individual devices of the server rack. Once delivered to the destination site 402, the server racks may be positioned in the destination site 402 per the physical layout of the resulting data center and connected to the networking infrastructure 438 of the destination site. For example, networking connections may be made between the networking infrastructure 438 and the switches of the server racks 332A, 332B by connecting one or more networking cables to the switches (e.g., switch 334).

[0079] As described above, the devices in Prefab Region 330 may have been configured to boot into a test mode when first powered on at the destination site 402. In some embodiments, the devices may have a dedicated boot volume to support the test mode during initialization at the destination site 402. In other embodiments, the boot volume may be configured on an external device connected to each device in the Prefab Region 330. For example, each server device (e.g., server device 336) may be connected to a smart network interface card (SmartNIC) that provides a low-overhead boot volume that can be used to boot the server device into a test mode. Because the boot volume may only

be used to support the test mode, the data on the boot volume may not need to be encrypted as with data volumes on the server devices.

[0080] The test mode may be configured to cause each computing device to validate its connection to other devices in the Prefab Region 330. The validation can determine if the physical network connections of the devices to the networking infrastructure 438 at the destination site 402 were made correctly. To validate a connection, a device in the test mode may use a stored network configuration or portion of the network configuration that was determined by a network service (e.g., network service 320 of FIG. 3) and stored at each device. For example, server device 336 can use network snapshot 326 to determine a neighboring computing device that is communicatively connected to server device 336 by network connection 342. To validate the network connection 342, server device 336 may send a validation request to the neighboring computing device. If the network connection 342 is intact, then server device may receive a validation indication from the neighboring computing device that indicates that the validation request was successfully received at the neighboring computing device. The server device 336 may validate all of the connections specified in network snapshot 326. Similarly, devices on one server rack (e.g., server rack 332A) may validate a connection to each other server rack (e.g., server rack 332B) in the Prefab Region 330.

[0081] In some embodiment, one device of Prefab Region 330 may be configured to act as a DHCP server (e.g., DHCP server 446). The DHCP server 446 may provide network addresses or other identifiers to the devices in Prefab Region 330 during initialization. For example, during test mode, each device may validate a connection to the DHCP server 446 and then receive an address, identifier, or other network configuration information from the DHCP server 446. The device may compare the received identifier to an identifier included in the network configuration that was generated by the network service during prefab region build operations at the prefab factory. For example, server device 336 can receive an identifier from DHCP server 446 and then compare the received identifier to an identifier in network snapshot 326. Because the Prefab Region 330 should not have undergone any component changes during transit, the network configuration of the Prefab Region 330 at the destination site 402 should be unchanged, including configuration information from DHCP server 446. That is to say, server devices in the Prefab Region should receive the same network addresses from DHCP server 446 after installation of the devices at the destination site 402. If the network configuration changes, then the server devices can indicate that the network configuration of Prefab Region 330 may be incorrect.

[0082] In some embodiments, if any device was damaged in transit and no longer works, operators at the destination site may replace the broken device with a new replacement device and configure the new device with the device snapshot taken prior to shipping thus allowing the on-site post-install validation to complete successfully even if there was hardware failure in transit. For example, server device 350 may be damaged during transportation to the destination site 402. Discovery of the non-functional state of server device 350 may occur during testing operations to validate the network configuration of the Prefab Region 330. To recover, the manager service 412 can generate instructions to replace



server device 350 with an identical physical device at the same location on server rack 332B. Once the replacement device is installed, the manager service 412 can deploy the device snapshot 352 that was generated during prefab region build operations in the prefab factory 302. Deploying the device snapshot 352 can include imaging one or more disk drives or other memories of the replacement server device to bring the replacement server device to the same software configuration as server device 350 in the Prefab Region 330 prior to transportation to the destination site 402. Other devices, including networking devices like switch 334, may be similarly replaced and restored using the captured device snapshots.

[0083] The DHCP server 446 can perform test mode validation operations similar to other devices within Prefab Region 330. If DHCP server 446 can successfully validate the network connections between neighboring devices and itself, DHCP server 446 can exit test mode and begin operating as a DHCP server to other devices in the Prefab Region 330. In some embodiments, DHCP server 446 may complete its test mode validation operations prior to other devices in Prefab Region 330 completing their test mode validation operations. For example, server device 336 may boot into test mode and attempt to validate a network connection to DHCP server 446 before validating network connection 342 or network connection 344 between itself and neighboring computing devices. DHCP server 446 may not send a validation indication to server device 336 until DHCP server 446 has completed its own test mode validation operations. Server device 336 can then wait a predetermined amount of time and retry the validation request to DHCP server 446. Similarly, other computing devices performing test mode validation operations may wait and retry validation requests until DHCP server 446 is operational.

[0084] As described above, data volumes of the devices in Prefab Region 330 may be encrypted prior to transportation to the destination site 402. The encryption keys used to encrypt the data volumes of each device may be associated with that specific device. The encryption keys 444 may be stored at one of the computing devices in Prefab Region 330 configured to act as a key server for the Prefab Region 330 during initialization (e.g., stored at key server 442). As described in detail below with respect to FIGS. 5-8, implementations of a device encryption for securing data volumes during region build and transit can include a single key server 442 or a fleet of key servers that are configured to correctly decrypt each data volume or other secured storage on the server devices in the Prefab Region 330.

[0085] Once the Prefab Region 330 has been installed and initialized at destination site 402 (e.g., devices boot into a normal operating mode, data volumes decrypted, services deployed during prefab region build operations at the prefab factory are executing), testing service 416 can perform one or more acceptance tests. An acceptance test can include verifying that all services are functioning as expected. For example, testing service 416 can interact with a service executing at Prefab Region 330 to verify that the service is operating according to the requirements that define the acceptance test. Testing service 416 can provide results of an acceptance test to manager service 412 indicating that Prefab Region build is complete.

[0086] During transportation of Prefab Region 330 to destination site 402, updates or other changes may be specified for one or more infrastructure components and/or

software resources that had been provisioned at and/or deployed to Prefab Region 330 at the prefab factory. For example, a service may have been updated to a newer version during the transit time. Before the prefab region build operation is complete, orchestration service 418 can deploy updated software resources to Prefab Region 330 at destination site 402. Deploying an updated software resource may occur similar to deployment of software resources to the Prefab Region 330 at the prefab factory.

#### Device Encryption Techniques

[0087] The provisioning of infrastructure components and deployment of software resources within a prefab region using a prefab factory allow for great flexibility and customization of each individual prefab region that is built. In particular, orchestrating the deployment of services, virtual machines, databases, object storage, compute instances, load balancers, and the like using a manager service ensures the correct dependencies and networking integrity of the deployed resources as the region is built. However, the physical resources of the prefab region may then contain software resources, including proprietary data of the CSP and potentially confidential data of the customer, that may be vulnerable during transit to the destination site. Typically, encrypting the data volumes of the server devices would be sufficient to ensure data protection in the event that any of the server devices were lost or stolen during transit. However, encrypted volumes on the server devices presents challenges when configuring the data center at the destination site, since device decryption can require additional operations, including manual operations, to deliver cryptographic material securely to the destination site and/or configure on-site network resources to manage cryptographic operations (e.g., key vending, authorization/authentication of key requesting services, etc.). Such operations can inhibit the streamlined process of configuring the prefab region at the destination site using the manager service.

[0088] Instead, the CSP can use network-bound encryption of the storage volumes of the server devices with one or more key servers in the prefab region configured as a fleet and capable of managing the decryption operations of the prefab region after installation at the destination site. Each storage volume can be encrypted (at the prefab factory) with a corresponding data encryption key, which can then be stored in a secure storage element of the server device. The data encryption key can itself be encrypted with a second key, a key encryption key, that is stored on a separate key server of the prefab region. Prior to transit from the prefab factory, each server device of the prefab region can be configured to boot into a state that allows the server device to verify its network connectivity in the prefab region and communicate with the key server to retrieve the key encryption key. The key server can vend the key encryption key to the server device, after which the data encryption key can be decrypted and used to decrypt the storage volumes of the server device.

[0089] In general, the prefab region built in the prefab factory can make use of a plurality of key servers to vend the key encryption keys to each server device. This plurality of key servers can be referred to as a fleet of key servers. In embodiments described below, the fleet of key servers can either be server devices included in the prefab region (and therefore configured similarly to other physical resources of the prefab region) or a fleet of universal key servers that are



managed by the CSP and communicatively connected to the prefab region at the destination site via one or more network connections (e.g., the internet). For example, each server rack of the prefab region can have one device configured as a key server, so that the collection of key servers on the several server racks constitute the fleet of key servers. In other embodiments, the fleet of key servers can be delivered to the destination site separately from the other physical resources and connected to the prefab region.

**[0090]** In embodiments where the key servers are components of the prefab region, several methods can be employed to keep the key servers themselves secure during transit to the destination site. The key servers may be secured via cryptographic materials that are not provided in the prefab region. For example, the cryptographic material to decrypt the fleet of key servers can be stored on a separate hardware component like a hardware security module (HSM) or a device, like a smart network interface card (SmartNIC) that has a trusted platform module (TPM) that can be connected to the prefab region server devices after installation at the destination site. Under this approach, one or more agents of the customer can receive the key servers or their critical cryptographic components and physically install them in the prefab region (in the case of the fleet of key servers) or inside/connected to the key servers (in the case of separate cryptographic hardware) at the destination site. Shipping by different means and routes means an attacker needs to know the itinerary of all the parts to be able to gain possession of the cryptographic components and the key servers to be able to access the key servers.

**[0091]** In other cases, the fleet of key servers can be configured to be decrypted or made accessible within the prefab region using credentials provided to the customer. An agent of the CSP (or the customer onsite) can login to a trusted network to download the appropriate cryptographic material needed by the key servers to boot and then load those credentials onto the key servers. For added security, the CSP may require multiple agents to load separate cryptographic materials into the prefab region before the key servers will boot so that a bad actor would have to compromise multiple agents to gain the ability to access the prefab region.

**[0092]** In still other cases, the CSP can maintain control over a fleet of universal key servers as part of a cloud network (e.g., Prefab Service 310) that can connect to the prefab region at the destination site. Under this approach, the fleet of key servers may be a universal fleet of key servers that can support the decryption and key encryption key rotation for multiple prefab regions. The key servers within the prefab region in this case can boot into an initialization ramdisk, connect to the cloud-based universal key servers, and perform authorization and authentication operations with the universal key servers. To prevent compromised physical resources of the prefab regions from gaining cryptographic boot materials, one or more agents of the CSP or the customer must first login to confirm that the Prefab hardware was received and in good hands.

**[0093]** The device encryption techniques described herein can provide numerous advantages over a typical encryption process for device storage volumes. As one example, network bound encryption using the fleet of key servers allows for automated boot and startup processes for the server devices in the prefab region. By reducing the number of manual operations needed for decrypting the storage vol-

umes, the final steps of prefab region build at the destination site can be completed more quickly and with fewer errors. In addition, by employing key servers that vend key encryption keys to each corresponding server device in the prefab region, the cryptographic materials can be rotated without the need to decrypt and re-encrypt the entire storage volumes. For example, the key encryption keys can be rotated by deploying new key encryption keys, decrypting the data encryption keys, and then re-encrypting the data encryption keys with the new key encryption keys. In doing so, substantial computing resources are saved by not requiring the decryption of the storage volumes, which are much larger than the secure storage used for the data encryption keys.

**[0094]** FIG. 5 is a block diagram illustrating key servers 502, 504 within a prefab region 500, according to some embodiments. The prefab region 500 can be an example of Prefab Region 330 described above with respect to FIGS. 3 & 4. The Prefab Region 500 may be installed at a destination site (e.g., destination site 402 of FIG. 4). The Prefab Region 500 can include server racks 332A, 332B, which can include a plurality of server devices.

**[0095]** As depicted in FIG. 5, the Prefab Region 500 can include a fleet of key servers, with each of the server racks 332A, 332B having a key server. For example, server rack 332A can have a key server 502, while server rack 332B can have a key server 504. The key servers 502, 504 can be computing devices similar to other server devices on the server racks. The key servers can be configured to vend encryption keys to computing devices within the Prefab Region 500. For example, key server 502 may be configured to vend encryption keys to server devices of server rack 332A, while key server 504 may be configured to vend encryption keys to server devices of server rack 332B.

**[0096]** As described briefly above, each server device on the server racks of the Prefab Region 500 may include one or more storage volumes or storage devices on which data is stored after the provisioning and deployment operations in the Prefab Factory. For example, server device 506 of server rack 332A can include a storage device 514 that persists service and application data that was created on server device 506 at the Prefab Factory. The storage device 514 can include one or more storage volumes. To protect this data during transit to the destination site, the storage device 514 can be encrypted using a data encryption key 512. The data encryption key 512 can be specific to the server device 506. For example, the data encryption key 512 may only be used to encrypt and decrypt data on the server device 506, including data on storage device 514.

**[0097]** The server device 506 can also include a secure storage 510. The secure storage 510 may be a dedicated storage component for cryptographically sensitive information like keys and credentials used for the encrypting and decrypting data on the server device 506. As one example, the secure storage 510 can be a trusted platform module (TPM). In other examples, the secure storage 510 can be a hardware security module (HSM) connected to the server device 506. Each server device of the server racks 332A, 332B of the Prefab Region 500 can include a secure storage similar to secure storage 510. The data encryption key 512 can be stored on the secure storage 510.

**[0098]** The data encryption key 512 may itself be encrypted when stored on the secure storage 510 of server device 506. The encrypted data encryption key 516 can be encrypted using key encryption key 508. The encryption of

the storage device **514** using data encryption key **512** and the encryption of the data encryption key **512** to produce encrypted data encryption key **516** may be done at the Prefab Factory as part of preparing and configuring the Prefab Region **500** for transit to the destination site.

[0099] As shown in FIG. 5, the key encryption key **508** can be stored on the key server **502**. The key server **502** may itself be secured and/or encrypted so that the cryptographic material on the key server **502** may be protected during transit to the destination site. In some embodiments, the fleet of key servers including key server **502** and key server **504** can be transported separately from the other components of the Prefab Region **500** to the destination site. The key server **504** for the server rack **332B** may be configured with a copy of the key encryption key **508** that is usable to encrypt and/or decrypt data encryption keys on the server devices of server rack **332B**. In some embodiments, the key encryption key on server device **504** may be different from key encryption key **508**. In some embodiments, the fleet of key servers including key server **502** and key server **504** may store more than one key encryption key that can be used to encrypt the data encryption keys for the corresponding server devices.

[0100] FIG. 6 is a block diagram illustrating secured key servers **502**, **504** in a Prefab Region **600**, according to some embodiments. The Prefab Region **600** may be an example of Prefab Region **500** described above with respect to FIG. 5.

[0101] In the embodiment of FIG. 6, the Prefab Region **600** can include a fleet of key servers including key server **502** and key server **504**. The key servers can store key encryption keys (e.g., key encryption key **508**) on a local data volume that is itself encrypted or secured to prevent access or tampering by unauthorized entities during the transit of the Prefab Region **600** to the destination site. In this embodiment, the fleet of key servers can be shipped with the other physical components of Prefab Region **600**. Because the key servers **502**, **504** are not transported separately from the server racks **332A**, **332B**, the key server **502**, **504** can be secured with separate cryptographic material **620** that is delivered to the destination site separately.

[0102] The key server **502** can include a data volume **618** in which the key encryption key **508** is stored. In some embodiments, the data volume **618** can be encrypted. Cryptographic material **620** can be delivered to the destination site separately and used to access the data volume **618** containing key encryption key **508**. For example, cryptographic material **620** can be provided to operations personnel at the destination site to access the key server **502**. The cryptographic material **620** can include credentials usable to decrypt data volume **618** on the key server **502**.

[0103] In some embodiments, the cryptographic material **620** may include the key encryption key **508** and may be delivered to the destination site separately. The cryptographic material **620**, including the key encryption key **508**, may be placed into the data volume **618** on the key server **502** (and other key servers of the fleet of key servers like key server **504**). Once the fleet of key servers have been provisioned with the key encryption key **508**, the key servers can vend the key encryption key **508** to the server devices to decrypt the encrypted data encryption keys (e.g., encrypted data encryption key **516**) to produce the data encryption keys to decrypt the storage volumes at each server device.

[0104] FIG. 7 is a block diagram illustrating a rotation of key encryption keys used to secure data encryption keys in a prefab region **700**, according to some embodiments. The

Prefab Region **700** may be an example of a portion of the Prefab Region **600** described above with respect to FIG. 6. As depicted in FIG. 7, the Prefab Region **600** includes server rack **332A** having key server **502** and server device **506**.

[0105] An advantage of using a fleet of key servers with key encryption keys within the Prefab Region **700** is that key encryption keys can be rotated (changed) more easily and with less computational operations than rotating data encryption keys. For instance, during the build of the Prefab Region in the Prefab Factory and the configuration for transporting the Prefab Region to the destination site, one set of key encryption keys can be used to encrypt the data encryption keys. Due to the time needed to transport the Prefab Region to the destination site or with the physical components in storage prior to shipment to the destination site, the key encryption keys may need to be rotated to comply with security policies. Rather than decrypt all of the encrypted storage volumes within the Prefab Region and re-encrypt with a new data encryption key, only the encrypted data encryption keys are decrypted and re-encrypted with a new key encryption key.

[0106] As shown in FIG. 7, data encryption key **512** stored on server device **506** may be used to encrypt the data on storage device **514**. Device encryption key **512** may be encrypted with key encryption key **508** to produce an encrypted data encryption key. To rotate the key encryption key **508**, the data encryption key **512** can be decrypted and a new key encryption key **720** can be provided by the key server **502**. For example, key server **502** can generate a new key encryption key **720** for the key rotation operation. The key server **502** can then instruct the server device **506** to encrypt data encryption key **512** using new key encryption key **720** to produce new encrypted data encryption key **716**. The new encrypted data encryption key **716** can be stored in the secure storage **510** of server device **502**.

[0107] FIG. 8 is a flow diagram of an example process for encrypting and decrypting storage volumes of a prefab region using a fleet of key servers, according to at least one embodiment. The method **800** may be performed by one or more components of a distributed computing system, including one or more components of a distributed computing system of a prefab region (e.g., prefab region **330** of FIG. 3), including server devices of server racks (e.g., server racks **332A** and **332B** of FIGS. 3-7). The operations of method **800** may be performed in any suitable order, and method **800** may include more or fewer operations than those depicted in FIG. 8.

[0108] Some or all of the method **800** (or any other processes and/or methods described herein, or variations, and/or combinations thereof) may be performed under the control of one or more computer systems configured with executable instructions and may be implemented as code (e.g., executable instructions, one or more computer programs, or one or more applications) executing collectively on one or more processors, by hardware or combinations thereof. The code may be stored on a computer-readable storage medium, for example, in the form of a computer program comprising a plurality of instructions executable by one or more processors. The computer-readable storage medium may be non-transitory.

[0109] The method **800** can begin at block **802** with configuring a plurality of server devices and a fleet of key server devices for transit to a data center. The operations of blocks **802-810** of method **800** can be included in the

configuration of the plurality of server devices and the fleet of key server device. The configuration of the server devices for transit can include encrypting a storage device (e.g., storage device **514** of FIG. **5**) of each server device (e.g., server device **502**) of the plurality of server devices using a corresponding data encryption key (e.g., data encryption key **512**). In some embodiments, the plurality of server devices can be configured to transit to the data center separately from the fleet of key server devices.

[**0110**] At block **804**, each data encryption key can be stored at a corresponding key storage element of each server device of the plurality of server devices. The key storage element may be secure storage **510** described above with respect to FIGS. **5-7**.

[**0111**] At block **806**, the corresponding data encryption keys can be encrypted using a key encryption key. The resulting encrypted data encryption key can be stored at the key storage element of each server device.

[**0112**] At block **808**, the key encryption key can be stored at the fleet of key server devices. In some embodiments, the fleet of key server devices can include one or more key server devices. In some embodiments, each key server of the fleet of key server device can store a copy of the key encryption key. In some embodiments, a different key encryption key may be used to encrypt a portion of the server devices and stored on a different key server.

[**0113**] At block **810**, the fleet of key server devices can be enabled at the data center. Enabling the key server devices can include powering on and booting the key server devices. In addition, in some embodiments, enabling the key server devices can include authentication, authorization, and/or decryption operations for the key server device to access the stored key encryption key on the key server device. In some embodiments, enabling the fleet of key server devices can include communicatively connecting the fleet of key server devices to the plurality of server devices. For example, the plurality of server devices can be connected via network connections to the fleet of key server devices.

[**0114**] At block **812**, a boot sequence of the first server device can be initiated using an initialization disk image. The initialization disk image can be stored at a boot volume of the first server device. For example, the initialization disk image may be software including an operating system and sufficient applications and services to allow the server device to perform boot operations, network connectivity checks, and data access operations with attached storage devices. In particular, the initialization disk image may be unencrypted, so that access to the data encryption key is not necessary to perform the boot operations.

[**0115**] At block **814** the first server device can obtain the key encryption key from the fleet of key server devices. The first server device can be communicatively connected to the fleet of key server devices and can send a request to the fleet of key server devices to obtain the key encryption key. For example, the first server device may be connected to a key server (e.g., key server **502**) on the same rack of server devices in the Prefab Region. The first server device can request the key encryption key from the key server. In some embodiments, first server device can request the key encryption key from the fleet of key server devices that are part of a cloud computing environment and connected to the Prefab Region via a public network connection (e.g., the internet).

[**0116**] At block **816**, the first server device can use the key encryption key to decrypt the encrypted data encryption key

to retrieve the corresponding data encryption key. The encrypted data encryption key may be stored at the key storage element. The decryption operations may occur in memory so that the unencrypted device encryption key is not stored in the key storage element.

[**0117**] At block **818**, the first server device can use the data encryption key to decrypt the storage device.

[**0118**] In some embodiments, configuring the plurality of server devices and the fleet of key server devices for transit to the data center can include encrypting, at the first facility, data volumes of the fleet of key server devices. Once the fleet of key server devices with encrypted data volumes have been transported to the data center, the fleet of key server devices can be enabled by providing cryptographic material usable to decrypt the data volumes of the fleet of key server devices. The cryptographic material can include credentials and/or encryption keys that are provided by operations personnel. In some embodiments, the cryptographic material can be obtained from a cloud service provider. For example, a CSP can transmit cryptographic material to the fleet of key server devices at the data center via a network connection. The fleet of key server devices can use the cryptographic material to decrypt the data volumes. Once the data volumes of the fleet of key server devices is decrypted, the key server devices can retrieve key encryption keys and vend them to server devices in the data center.

[**0119**] In some embodiments, prior to the transit of the plurality of server devices and the fleet of key server devices from the first facility to the data center, the key encryption key can be changed (rotated) for a new key encryption key. To perform the rotation of the key encryption key, the encrypted data encryption key at the storage element of each server device of the plurality of server devices can be decrypted using the key encryption key. Once the corresponding data encryption keys have been decrypted, a new key encryption key can be generated and used to encrypt the corresponding data encryption keys at the corresponding key storage element of each server device. The resulting new encrypted data encryption key can be stored at the storage element of each server device. The new key encryption key can be stored at the fleet of key server devices.

#### Example Infrastructure as a Service Architectures

[**0120**] As noted above, infrastructure as a service (IaaS) is one particular type of cloud computing. IaaS can be configured to provide virtualized computing resources over a public network (e.g., the Internet). In an IaaS model, a cloud computing provider can host the infrastructure components (e.g., servers, storage devices, network nodes (e.g., hardware), deployment software, platform virtualization (e.g., a hypervisor layer), or the like). In some cases, an IaaS provider may also supply a variety of services to accompany those infrastructure components (example services include billing software, monitoring software, logging software, load balancing software, clustering software, etc.). Thus, as these services may be policy-driven, IaaS users may be able to implement policies to drive load balancing to maintain application availability and performance.

[**0121**] In some instances, IaaS customers may access resources and services through a wide area network (WAN), such as the Internet, and can use the cloud provider's services to install the remaining elements of an application stack. For example, the user can log in to the IaaS platform to create virtual machines (VMs), install operating systems

(OSs) on each VM, deploy middleware such as databases, create storage buckets for workloads and backups, and even install enterprise software into that VM. Customers can then use the provider's services to perform various functions, including balancing network traffic, troubleshooting application issues, monitoring performance, managing disaster recovery, etc.

**[0122]** In most cases, a cloud computing model may require the participation of a cloud provider. The cloud provider may, but need not be, a third-party service that specializes in providing (e.g., offering, renting, selling) IaaS. An entity might also opt to deploy a private cloud, becoming its own provider of infrastructure services.

**[0123]** In some examples, IaaS deployment is the process of putting a new application, or a new version of an application, onto a prepared application server or the like. It may also include the process of preparing the server (e.g., installing libraries, daemons, etc.). This is often managed by the cloud provider, below the hypervisor layer (e.g., the servers, storage, network hardware, and virtualization). Thus, the customer may be responsible for handling (OS), middleware, and/or application deployment (e.g., on self-service virtual machines (e.g., that can be spun up on demand)) or the like.

**[0124]** In some examples, IaaS provisioning may refer to acquiring computers or virtual hosts for use, and even installing needed libraries or services on them. In most cases, deployment does not include provisioning, and the provisioning may need to be performed first.

**[0125]** In some cases, there are two different challenges for IaaS provisioning. First, there is the initial challenge of provisioning the initial set of infrastructure before anything is running. Second, there is the challenge of evolving the existing infrastructure (e.g., adding new services, changing services, removing services, etc.) once everything has been provisioned. In some cases, these two challenges may be addressed by enabling the configuration of the infrastructure to be defined declaratively. In other words, the infrastructure (e.g., what components are needed and how they interact) can be defined by one or more configuration files. Thus, the overall topology of the infrastructure (e.g., what resources depend on which, and how they each work together) can be described declaratively. In some instances, once the topology is defined, a workflow can be generated that creates and/or manages the different components described in the configuration files.

**[0126]** In some examples, an infrastructure may have many interconnected elements. For example, there may be one or more virtual private clouds (VPCs) (e.g., a potentially on-demand pool of configurable and/or shared computing resources), also known as a core network. In some examples, there may also be one or more inbound/outbound traffic group rules provisioned to define how the inbound and/or outbound traffic of the network will be set up and one or more virtual machines (VMs). Other infrastructure elements may also be provisioned, such as a load balancer, a database, or the like. As more and more infrastructure elements are desired and/or added, the infrastructure may incrementally evolve.

**[0127]** In some instances, continuous deployment techniques may be employed to enable deployment of infrastructure code across various virtual computing environments. Additionally, the described techniques can enable infrastructure management within these environments. In

some examples, service teams can write code that is desired to be deployed to one or more, but often many, different production environments (e.g., across various different geographic locations, sometimes spanning the entire world). However, in some examples, the infrastructure on which the code will be deployed may need to first be set up. In some instances, the provisioning can be done manually, a provisioning tool may be utilized to provision the resources, and/or deployment tools may be utilized to deploy the code once the infrastructure is provisioned.

**[0128]** FIG. 9 is a block diagram 900 illustrating an example pattern of an IaaS architecture, according to at least one embodiment. Service operators 902 can be communicatively coupled to a secure host tenancy 904 that can include a virtual cloud network (VCN) 906 and a secure host subnet 908. In some examples, the service operators 902 may be using one or more client computing devices, which may be portable handheld devices (e.g., an iPhone®, cellular telephone, an iPad®, computing tablet, a personal digital assistant (PDA)) or wearable devices (e.g., a Google Glass® head mounted display), running software such as Microsoft Windows Mobile®, and/or a variety of mobile operating systems such as iOS, Windows Phone, Android, BlackBerry 8, Palm OS, and the like, and being Internet, e-mail, short message service (SMS), BlackBerry®, or other communication protocol enabled. Alternatively, the client computing devices can be general purpose personal computers including, by way of example, personal computers and/or laptop computers running various versions of Microsoft Windows®, Apple Macintosh®, and/or Linux operating systems. The client computing devices can be workstation computers running any of a variety of commercially-available UNIX® or UNIX-like operating systems, including without limitation the variety of GNU/Linux operating systems, such as for example, Google Chrome OS. Alternatively, or in addition, client computing devices may be any other electronic device, such as a thin-client computer, an Internet-enabled gaming system (e.g., a Microsoft Xbox gaming console with or without a Kinect® gesture input device), and/or a personal messaging device, capable of communicating over a network that can access the VCN 906 and/or the Internet.

**[0129]** The VCN 906 can include a local peering gateway (LPG) 910 that can be communicatively coupled to a secure shell (SSH) VCN 912 via an LPG 910 contained in the SSH VCN 912. The SSH VCN 912 can include an SSH subnet 914, and the SSH VCN 912 can be communicatively coupled to a control plane VCN 916 via the LPG 910 contained in the control plane VCN 916. Also, the SSH VCN 912 can be communicatively coupled to a data plane VCN 918 via an LPG 910. The control plane VCN 916 and the data plane VCN 918 can be contained in a service tenancy 919 that can be owned and/or operated by the IaaS provider.

**[0130]** The control plane VCN 916 can include a control plane demilitarized zone (DMZ) tier 920 that acts as a perimeter network (e.g., portions of a corporate network between the corporate intranet and external networks). The DMZ-based servers may have restricted responsibilities and help keep breaches contained. Additionally, the DMZ tier 920 can include one or more load balancer (LB) subnet(s) 922, a control plane app tier 924 that can include app subnet(s) 926, a control plane data tier 928 that can include database (DB) subnet(s) 930 (e.g., frontend DB subnet(s) and/or backend DB subnet(s)). The LB subnet(s) 922 con-

tained in the control plane DMZ tier **920** can be communicatively coupled to the app subnet(s) **926** contained in the control plane app tier **924** and an Internet gateway **934** that can be contained in the control plane VCN **916**, and the app subnet(s) **926** can be communicatively coupled to the DB subnet(s) **930** contained in the control plane data tier **928** and a service gateway **936** and a network address translation (NAT) gateway **938**. The control plane VCN **916** can include the service gateway **936** and the NAT gateway **938**.

**[0131]** The control plane VCN **916** can include a data plane mirror app tier **940** that can include app subnet(s) **926**. The app subnet(s) **926** contained in the data plane mirror app tier **940** can include a virtual network interface controller (VNIC) **942** that can execute a compute instance **944**. The compute instance **944** can communicatively couple the app subnet(s) **926** of the data plane mirror app tier **940** to app subnet(s) **926** that can be contained in a data plane app tier **946**.

**[0132]** The data plane VCN **918** can include the data plane app tier **946**, a data plane DMZ tier **948**, and a data plane data tier **950**. The data plane DMZ tier **948** can include LB subnet(s) **922** that can be communicatively coupled to the app subnet(s) **926** of the data plane app tier **946** and the Internet gateway **934** of the data plane VCN **918**. The app subnet(s) **926** can be communicatively coupled to the service gateway **936** of the data plane VCN **918** and the NAT gateway **938** of the data plane VCN **918**. The data plane data tier **950** can also include the DB subnet(s) **930** that can be communicatively coupled to the app subnet(s) **926** of the data plane app tier **946**.

**[0133]** The Internet gateway **934** of the control plane VCN **916** and of the data plane VCN **918** can be communicatively coupled to a metadata management service **952** that can be communicatively coupled to public Internet **954**. Public Internet **954** can be communicatively coupled to the NAT gateway **938** of the control plane VCN **916** and of the data plane VCN **918**. The service gateway **936** of the control plane VCN **916** and of the data plane VCN **918** can be communicatively coupled to cloud services **956**.

**[0134]** In some examples, the service gateway **936** of the control plane VCN **916** or of the data plane VCN **918** can make application programming interface (API) calls to cloud services **956** without going through public Internet **954**. The API calls to cloud services **956** from the service gateway **936** can be one-way: the service gateway **936** can make API calls to cloud services **956**, and cloud services **956** can send requested data to the service gateway **936**. But, cloud services **956** may not initiate API calls to the service gateway **936**.

**[0135]** In some examples, the secure host tenancy **904** can be directly connected to the service tenancy **919**, which may be otherwise isolated. The secure host subnet **908** can communicate with the SSH subnet **914** through an LPG **910** that may enable two-way communication over an otherwise isolated system. Connecting the secure host subnet **908** to the SSH subnet **914** may give the secure host subnet **908** access to other entities within the service tenancy **919**.

**[0136]** The control plane VCN **916** may allow users of the service tenancy **919** to set up or otherwise provision desired resources. Desired resources provisioned in the control plane VCN **916** may be deployed or otherwise used in the data plane VCN **918**. In some examples, the control plane VCN **916** can be isolated from the data plane VCN **918**, and the data plane mirror app tier **940** of the control plane VCN

**916** can communicate with the data plane app tier **946** of the data plane VCN **918** via VNICs **942** that can be contained in the data plane mirror app tier **940** and the data plane app tier **946**.

**[0137]** In some examples, users of the system, or customers, can make requests, for example create, read, update, or delete (CRUD) operations, through public Internet **954** that can communicate the requests to the metadata management service **952**. The metadata management service **952** can communicate the request to the control plane VCN **916** through the Internet gateway **934**. The request can be received by the LB subnet(s) **922** contained in the control plane DMZ tier **920**. The LB subnet(s) **922** may determine that the request is valid, and in response to this determination, the LB subnet(s) **922** can transmit the request to app subnet(s) **926** contained in the control plane app tier **924**. If the request is validated and requires a call to public Internet **954**, the call to public Internet **954** may be transmitted to the NAT gateway **938** that can make the call to public Internet **954**. Metadata that may be desired to be stored by the request can be stored in the DB subnet(s) **930**.

**[0138]** In some examples, the data plane mirror app tier **940** can facilitate direct communication between the control plane VCN **916** and the data plane VCN **918**. For example, changes, updates, or other suitable modifications to configuration may be desired to be applied to the resources contained in the data plane VCN **918**. Via a VNIC **942**, the control plane VCN **916** can directly communicate with, and can thereby execute the changes, updates, or other suitable modifications to configuration to, resources contained in the data plane VCN **918**.

**[0139]** In some embodiments, the control plane VCN **916** and the data plane VCN **918** can be contained in the service tenancy **919**. In this case, the user, or the customer, of the system may not own or operate either the control plane VCN **916** or the data plane VCN **918**. Instead, the IaaS provider may own or operate the control plane VCN **916** and the data plane VCN **918**, both of which may be contained in the service tenancy **919**. This embodiment can enable isolation of networks that may prevent users or customers from interacting with other users', or other customers', resources. Also, this embodiment may allow users or customers of the system to store databases privately without needing to rely on public Internet **954**, which may not have a desired level of threat prevention, for storage.

**[0140]** In other embodiments, the LB subnet(s) **922** contained in the control plane VCN **916** can be configured to receive a signal from the service gateway **936**. In this embodiment, the control plane VCN **916** and the data plane VCN **918** may be configured to be called by a customer of the IaaS provider without calling public Internet **954**. Customers of the IaaS provider may desire this embodiment since database(s) that the customers use may be controlled by the IaaS provider and may be stored on the service tenancy **919**, which may be isolated from public Internet **954**.

**[0141]** FIG. 10 is a block diagram 1000 illustrating another example pattern of an IaaS architecture, according to at least one embodiment. Service operators **1002** (e.g., service operators **902** of FIG. 9) can be communicatively coupled to a secure host tenancy **1004** (e.g., the secure host tenancy **904** of FIG. 9) that can include a virtual cloud network (VCN) **1006** (e.g., the VCN **906** of FIG. 9) and a secure host subnet **1008** (e.g., the secure host subnet **908** of

FIG. 9). The VCN 1006 can include a local peering gateway (LPG) 1010 (e.g., the LPG 910 of FIG. 9) that can be communicatively coupled to a secure shell (SSH) VCN 1012 (e.g., the SSH VCN 912 of FIG. 9) via an LPG 910 contained in the SSH VCN 1012. The SSH VCN 1012 can include an SSH subnet 1014 (e.g., the SSH subnet 914 of FIG. 9), and the SSH VCN 1012 can be communicatively coupled to a control plane VCN 1016 (e.g., the control plane VCN 916 of FIG. 9) via an LPG 1010 contained in the control plane VCN 1016. The control plane VCN 1016 can be contained in a service tenancy 1019 (e.g., the service tenancy 919 of FIG. 9), and the data plane VCN 1018 (e.g., the data plane VCN 918 of FIG. 9) can be contained in a customer tenancy 1021 that may be owned or operated by users, or customers, of the system.

[0142] The control plane VCN 1016 can include a control plane DMZ tier 1020 (e.g., the control plane DMZ tier 920 of FIG. 9) that can include LB subnet(s) 1022 (e.g., LB subnet(s) 922 of FIG. 9), a control plane app tier 1024 (e.g., the control plane app tier 924 of FIG. 9) that can include app subnet(s) 1026 (e.g., app subnet(s) 926 of FIG. 9), a control plane data tier 1028 (e.g., the control plane data tier 928 of FIG. 9) that can include database (DB) subnet(s) 1030 (e.g., similar to DB subnet(s) 930 of FIG. 9). The LB subnet(s) 1022 contained in the control plane DMZ tier 1020 can be communicatively coupled to the app subnet(s) 1026 contained in the control plane app tier 1024 and an Internet gateway 1034 (e.g., the Internet gateway 934 of FIG. 9) that can be contained in the control plane VCN 1016, and the app subnet(s) 1026 can be communicatively coupled to the DB subnet(s) 1030 contained in the control plane data tier 1028 and a service gateway 1036 (e.g., the service gateway 936 of FIG. 9) and a network address translation (NAT) gateway 1038 (e.g., the NAT gateway 938 of FIG. 9). The control plane VCN 1016 can include the service gateway 1036 and the NAT gateway 1038.

[0143] The control plane VCN 1016 can include a data plane mirror app tier 1040 (e.g., the data plane mirror app tier 940 of FIG. 9) that can include app subnet(s) 1026. The app subnet(s) 1026 contained in the data plane mirror app tier 1040 can include a virtual network interface controller (VNIC) 1042 (e.g., the VNIC of 942) that can execute a compute instance 1044 (e.g., similar to the compute instance 944 of FIG. 9). The compute instance 1044 can facilitate communication between the app subnet(s) 1026 of the data plane mirror app tier 1040 and the app subnet(s) 1026 that can be contained in a data plane app tier 1046 (e.g., the data plane app tier 946 of FIG. 9) via the VNIC 1042 contained in the data plane mirror app tier 1040 and the VNIC 1042 contained in the data plane app tier 1046.

[0144] The Internet gateway 1034 contained in the control plane VCN 1016 can be communicatively coupled to a metadata management service 1052 (e.g., the metadata management service 952 of FIG. 9) that can be communicatively coupled to public Internet 1054 (e.g., public Internet 954 of FIG. 9). Public Internet 1054 can be communicatively coupled to the NAT gateway 1038 contained in the control plane VCN 1016. The service gateway 1036 contained in the control plane VCN 1016 can be communicatively coupled to cloud services 1056 (e.g., cloud services 956 of FIG. 9).

[0145] In some examples, the data plane VCN 1018 can be contained in the customer tenancy 1021. In this case, the IaaS provider may provide the control plane VCN 1016 for each customer, and the IaaS provider may, for each cus-

tomers, set up a unique compute instance 1044 that is contained in the service tenancy 1019. Each compute instance 1044 may allow communication between the control plane VCN 1016, contained in the service tenancy 1019, and the data plane VCN 1018 that is contained in the customer tenancy 1021. The compute instance 1044 may allow resources, that are provisioned in the control plane VCN 1016 that is contained in the service tenancy 1019, to be deployed or otherwise used in the data plane VCN 1018 that is contained in the customer tenancy 1021.

[0146] In other examples, the customer of the IaaS provider may have databases that live in the customer tenancy 1021. In this example, the control plane VCN 1016 can include the data plane mirror app tier 1040 that can include app subnet(s) 1026. The data plane mirror app tier 1040 can reside in the data plane VCN 1018, but the data plane mirror app tier 1040 may not live in the data plane VCN 1018. That is, the data plane mirror app tier 1040 may have access to the customer tenancy 1021, but the data plane mirror app tier 1040 may not exist in the data plane VCN 1018 or be owned or operated by the customer of the IaaS provider. The data plane mirror app tier 1040 may be configured to make calls to the data plane VCN 1018 but may not be configured to make calls to any entity contained in the control plane VCN 1016. The customer may desire to deploy or otherwise use resources in the data plane VCN 1018 that are provisioned in the control plane VCN 1016, and the data plane mirror app tier 1040 can facilitate the desired deployment, or other usage of resources, of the customer.

[0147] In some embodiments, the customer of the IaaS provider can apply filters to the data plane VCN 1018. In this embodiment, the customer can determine what the data plane VCN 1018 can access, and the customer may restrict access to public Internet 1054 from the data plane VCN 1018. The IaaS provider may not be able to apply filters or otherwise control access of the data plane VCN 1018 to any outside networks or databases. Applying filters and controls by the customer onto the data plane VCN 1018, contained in the customer tenancy 1021, can help isolate the data plane VCN 1018 from other customers and from public Internet 1054.

[0148] In some embodiments, cloud services 1056 can be called by the service gateway 1036 to access services that may not exist on public Internet 1054, on the control plane VCN 1016, or on the data plane VCN 1018. The connection between cloud services 1056 and the control plane VCN 1016 or the data plane VCN 1018 may not be live or continuous. Cloud services 1056 may exist on a different network owned or operated by the IaaS provider. Cloud services 1056 may be configured to receive calls from the service gateway 1036 and may be configured to not receive calls from public Internet 1054. Some cloud services 1056 may be isolated from other cloud services 1056, and the control plane VCN 1016 may be isolated from cloud services 1056 that may not be in the same region as the control plane VCN 1016. For example, the control plane VCN 1016 may be located in "Region 1," and cloud service "Deployment 9," may be located in Region 1 and in "Region 2." If a call to Deployment 9 is made by the service gateway 1036 contained in the control plane VCN 1016 located in Region 1, the call may be transmitted to Deployment 9 in Region 1. In this example, the control plane VCN 1016, or Deploy-

ment 9 in Region 1, may not be communicatively coupled to, or otherwise in communication with, Deployment 9 in Region 2.

[0149] FIG. 11 is a block diagram 1100 illustrating another example pattern of an IaaS architecture, according to at least one embodiment. Service operators 1102 (e.g., service operators 902 of FIG. 9) can be communicatively coupled to a secure host tenancy 1104 (e.g., the secure host tenancy 904 of FIG. 9) that can include a virtual cloud network (VCN) 1106 (e.g., the VCN 906 of FIG. 9) and a secure host subnet 1108 (e.g., the secure host subnet 908 of FIG. 9). The VCN 1106 can include an LPG 1110 (e.g., the LPG 910 of FIG. 9) that can be communicatively coupled to an SSH VCN 1112 (e.g., the SSH VCN 912 of FIG. 9) via an LPG 1110 contained in the SSH VCN 1112. The SSH VCN 1112 can include an SSH subnet 1114 (e.g., the SSH subnet 914 of FIG. 9), and the SSH VCN 1112 can be communicatively coupled to a control plane VCN 1116 (e.g., the control plane VCN 916 of FIG. 9) via an LPG 1110 contained in the control plane VCN 1116 and to a data plane VCN 1118 (e.g., the data plane 918 of FIG. 9) via an LPG 1110 contained in the data plane VCN 1118. The control plane VCN 1116 and the data plane VCN 1118 can be contained in a service tenancy 1119 (e.g., the service tenancy 919 of FIG. 9).

[0150] The control plane VCN 1116 can include a control plane DMZ tier 1120 (e.g., the control plane DMZ tier 920 of FIG. 9) that can include load balancer (LB) subnet(s) 1122 (e.g., LB subnet(s) 922 of FIG. 9), a control plane app tier 1124 (e.g., the control plane app tier 924 of FIG. 9) that can include app subnet(s) 1126 (e.g., similar to app subnet(s) 926 of FIG. 9), a control plane data tier 1128 (e.g., the control plane data tier 928 of FIG. 9) that can include DB subnet(s) 1130. The LB subnet(s) 1122 contained in the control plane DMZ tier 1120 can be communicatively coupled to the app subnet(s) 1126 contained in the control plane app tier 1124 and to an Internet gateway 1134 (e.g., the Internet gateway 934 of FIG. 9) that can be contained in the control plane VCN 1116, and the app subnet(s) 1126 can be communicatively coupled to the DB subnet(s) 1130 contained in the control plane data tier 1128 and to a service gateway 1136 (e.g., the service gateway of FIG. 9) and a network address translation (NAT) gateway 1138 (e.g., the NAT gateway 938 of FIG. 9). The control plane VCN 1116 can include the service gateway 1136 and the NAT gateway 1138.

[0151] The data plane VCN 1118 can include a data plane app tier 1146 (e.g., the data plane app tier 946 of FIG. 9), a data plane DMZ tier 1148 (e.g., the data plane DMZ tier 948 of FIG. 9), and a data plane data tier 1150 (e.g., the data plane data tier 950 of FIG. 9). The data plane DMZ tier 1148 can include LB subnet(s) 1122 that can be communicatively coupled to trusted app subnet(s) 1160 and untrusted app subnet(s) 1162 of the data plane app tier 1146 and the Internet gateway 1134 contained in the data plane VCN 1118. The trusted app subnet(s) 1160 can be communicatively coupled to the service gateway 1136 contained in the data plane VCN 1118, the NAT gateway 1138 contained in the data plane VCN 1118, and DB subnet(s) 1130 contained in the data plane data tier 1150. The untrusted app subnet(s) 1162 can be communicatively coupled to the service gateway 1136 contained in the data plane VCN 1118 and DB subnet(s) 1130 contained in the data plane data tier 1150. The data plane data tier 1150 can include DB subnet(s) 1130

that can be communicatively coupled to the service gateway 1136 contained in the data plane VCN 1118.

[0152] The untrusted app subnet(s) 1162 can include one or more primary VNICS 1164(1)-(N) that can be communicatively coupled to tenant virtual machines (VMs) 1166(1)-(N). Each tenant VM 1166(1)-(N) can be communicatively coupled to a respective app subnet 1167(1)-(N) that can be contained in respective container egress VCNs 1168(1)-(N) that can be contained in respective customer tenancies 1170(1)-(N). Respective secondary VNICS 1172(1)-(N) can facilitate communication between the untrusted app subnet(s) 1162 contained in the data plane VCN 1118 and the app subnet contained in the container egress VCNs 1168(1)-(N). Each container egress VCNs 1168(1)-(N) can include a NAT gateway 1138 that can be communicatively coupled to public Internet 1154 (e.g., public Internet 954 of FIG. 9).

[0153] The Internet gateway 1134 contained in the control plane VCN 1116 and contained in the data plane VCN 1118 can be communicatively coupled to a metadata management service 1152 (e.g., the metadata management system 952 of FIG. 9) that can be communicatively coupled to public Internet 1154. Public Internet 1154 can be communicatively coupled to the NAT gateway 1138 contained in the control plane VCN 1116 and contained in the data plane VCN 1118. The service gateway 1136 contained in the control plane VCN 1116 and contained in the data plane VCN 1118 can be communicatively coupled to cloud services 1156.

[0154] In some embodiments, the data plane VCN 1118 can be integrated with customer tenancies 1170. This integration can be useful or desirable for customers of the IaaS provider in some cases such as a case that may desire support when executing code. The customer may provide code to run that may be destructive, may communicate with other customer resources, or may otherwise cause undesirable effects. In response to this, the IaaS provider may determine whether to run code given to the IaaS provider by the customer.

[0155] In some examples, the customer of the IaaS provider may grant temporary network access to the IaaS provider and request a function to be attached to the data plane app tier 1146. Code to run the function may be executed in the VMs 1166(1)-(N), and the code may not be configured to run anywhere else on the data plane VCN 1118. Each VM 1166(1)-(N) may be connected to one customer tenancy 1170. Respective containers 1171(1)-(N) contained in the VMs 1166(1)-(N) may be configured to run the code. In this case, there can be a dual isolation (e.g., the containers 1171(1)-(N) running code, where the containers 1171(1)-(N) may be contained in at least the VM 1166(1)-(N) that are contained in the untrusted app subnet(s) 1162), which may help prevent incorrect or otherwise undesirable code from damaging the network of the IaaS provider or from damaging a network of a different customer. The containers 1171(1)-(N) may be communicatively coupled to the customer tenancy 1170 and may be configured to transmit or receive data from the customer tenancy 1170. The containers 1171(1)-(N) may not be configured to transmit or receive data from any other entity in the data plane VCN 1118. Upon completion of running the code, the IaaS provider may kill or otherwise dispose of the containers 1171(1)-(N).

[0156] In some embodiments, the trusted app subnet(s) 1160 may run code that may be owned or operated by the IaaS provider. In this embodiment, the trusted app subnet(s)



**1160** may be communicatively coupled to the DB subnet(s) **1130** and be configured to execute CRUD operations in the DB subnet(s) **1130**. The untrusted app subnet(s) **1162** may be communicatively coupled to the DB subnet(s) **1130**, but in this embodiment, the untrusted app subnet(s) may be configured to execute read operations in the DB subnet(s) **1130**. The containers **1171(1)-(N)** that can be contained in the VM **1166(1)-(N)** of each customer and that may run code from the customer may not be communicatively coupled with the DB subnet(s) **1130**.

[0157] In other embodiments, the control plane VCN **1116** and the data plane VCN **1118** may not be directly communicatively coupled. In this embodiment, there may be no direct communication between the control plane VCN **1116** and the data plane VCN **1118**. However, communication can occur indirectly through at least one method. An LPG **1110** may be established by the IaaS provider that can facilitate communication between the control plane VCN **1116** and the data plane VCN **1118**. In another example, the control plane VCN **1116** or the data plane VCN **1118** can make a call to cloud services **1156** via the service gateway **1136**. For example, a call to cloud services **1156** from the control plane VCN **1116** can include a request for a service that can communicate with the data plane VCN **1118**.

[0158] FIG. 12 is a block diagram **1200** illustrating another example pattern of an IaaS architecture, according to at least one embodiment. Service operators **1202** (e.g., service operators **902** of FIG. 9) can be communicatively coupled to a secure host tenancy **1204** (e.g., the secure host tenancy **904** of FIG. 9) that can include a virtual cloud network (VCN) **1206** (e.g., the VCN **906** of FIG. 9) and a secure host subnet **1208** (e.g., the secure host subnet **908** of FIG. 9). The VCN **1206** can include an LPG **1210** (e.g., the LPG **910** of FIG. 9) that can be communicatively coupled to an SSH VCN **1212** (e.g., the SSH VCN **912** of FIG. 9) via an LPG **1210** contained in the SSH VCN **1212**. The SSH VCN **1212** can include an SSH subnet **1214** (e.g., the SSH subnet **914** of FIG. 9), and the SSH VCN **1212** can be communicatively coupled to a control plane VCN **1216** (e.g., the control plane VCN **916** of FIG. 9) via an LPG **1210** contained in the control plane VCN **1216** and to a data plane VCN **1218** (e.g., the data plane **918** of FIG. 9) via an LPG **1210** contained in the data plane VCN **1218**. The control plane VCN **1216** and the data plane VCN **1218** can be contained in a service tenancy **1219** (e.g., the service tenancy **919** of FIG. 9).

[0159] The control plane VCN **1216** can include a control plane DMZ tier **1220** (e.g., the control plane DMZ tier **920** of FIG. 9) that can include LB subnet(s) **1222** (e.g., LB subnet(s) **922** of FIG. 9), a control plane app tier **1224** (e.g., the control plane app tier **924** of FIG. 9) that can include app subnet(s) **1226** (e.g., app subnet(s) **926** of FIG. 9), a control plane data tier **1228** (e.g., the control plane data tier **928** of FIG. 9) that can include DB subnet(s) **1230** (e.g., DB subnet(s) **1130** of FIG. 11). The LB subnet(s) **1222** contained in the control plane DMZ tier **1220** can be communicatively coupled to the app subnet(s) **1226** contained in the control plane app tier **1224** and to an Internet gateway **1234** (e.g., the Internet gateway **934** of FIG. 9) that can be contained in the control plane VCN **1216**, and the app subnet(s) **1226** can be communicatively coupled to the DB subnet(s) **1230** contained in the control plane data tier **1228** and to a service gateway **1236** (e.g., the service gateway of FIG. 9) and a network address translation (NAT) gateway **1238** (e.g., the

NAT gateway **938** of FIG. 9). The control plane VCN **1216** can include the service gateway **1236** and the NAT gateway **1238**.

[0160] The data plane VCN **1218** can include a data plane app tier **1246** (e.g., the data plane app tier **946** of FIG. 9), a data plane DMZ tier **1248** (e.g., the data plane DMZ tier **948** of FIG. 9), and a data plane data tier **1250** (e.g., the data plane data tier **950** of FIG. 9). The data plane DMZ tier **1248** can include LB subnet(s) **1222** that can be communicatively coupled to trusted app subnet(s) **1260** (e.g., trusted app subnet(s) **1160** of FIG. 11) and untrusted app subnet(s) **1262** (e.g., untrusted app subnet(s) **1162** of FIG. 11) of the data plane app tier **1246** and the Internet gateway **1234** contained in the data plane VCN **1218**. The trusted app subnet(s) **1260** can be communicatively coupled to the service gateway **1236** contained in the data plane VCN **1218**, the NAT gateway **1238** contained in the data plane VCN **1218**, and DB subnet(s) **1230** contained in the data plane data tier **1250**. The untrusted app subnet(s) **1262** can be communicatively coupled to the service gateway **1236** contained in the data plane VCN **1218** and DB subnet(s) **1230** contained in the data plane data tier **1250**. The data plane data tier **1250** can include DB subnet(s) **1230** that can be communicatively coupled to the service gateway **1236** contained in the data plane VCN **1218**.

[0161] The untrusted app subnet(s) **1262** can include primary VNICS **1264(1)-(N)** that can be communicatively coupled to tenant virtual machines (VMs) **1266(1)-(N)** residing within the untrusted app subnet(s) **1262**. Each tenant VM **1266(1)-(N)** can run code in a respective container **1267(1)-(N)**, and be communicatively coupled to an app subnet **1226** that can be contained in a data plane app tier **1246** that can be contained in a container egress VCN **1268**. Respective secondary VNICS **1272(1)-(N)** can facilitate communication between the untrusted app subnet(s) **1262** contained in the data plane VCN **1218** and the app subnet contained in the container egress VCN **1268**. The container egress VCN can include a NAT gateway **1238** that can be communicatively coupled to public Internet **1254** (e.g., public Internet **954** of FIG. 9).

[0162] The Internet gateway **1234** contained in the control plane VCN **1216** and contained in the data plane VCN **1218** can be communicatively coupled to a metadata management service **1252** (e.g., the metadata management system **952** of FIG. 9) that can be communicatively coupled to public Internet **1254**. Public Internet **1254** can be communicatively coupled to the NAT gateway **1238** contained in the control plane VCN **1216** and contained in the data plane VCN **1218**. The service gateway **1236** contained in the control plane VCN **1216** and contained in the data plane VCN **1218** can be communicatively coupled to cloud services **1256**.

[0163] In some examples, the pattern illustrated by the architecture of block diagram **1200** of FIG. 12 may be considered an exception to the pattern illustrated by the architecture of block diagram **1100** of FIG. 11 and may be desirable for a customer of the IaaS provider if the IaaS provider cannot directly communicate with the customer (e.g., a disconnected region). The respective containers **1267(1)-(N)** that are contained in the VMs **1266(1)-(N)** for each customer can be accessed in real-time by the customer. The containers **1267(1)-(N)** may be configured to make calls to respective secondary VNICS **1272(1)-(N)** contained in app subnet(s) **1226** of the data plane app tier **1246** that can be contained in the container egress VCN **1268**. The sec-



ondary VNICs **1272(1)-(N)** can transmit the calls to the NAT gateway **1238** that may transmit the calls to public Internet **1254**. In this example, the containers **1267(1)-(N)** that can be accessed in real-time by the customer can be isolated from the control plane VCN **1216** and can be isolated from other entities contained in the data plane VCN **1218**. The containers **1267(1)-(N)** may also be isolated from resources from other customers.

[0164] In other examples, the customer can use the containers **1267(1)-(N)** to call cloud services **1256**. In this example, the customer may run code in the containers **1267(1)-(N)** that requests a service from cloud services **1256**. The containers **1267(1)-(N)** can transmit this request to the secondary VNICs **1272(1)-(N)** that can transmit the request to the NAT gateway that can transmit the request to public Internet **1254**. Public Internet **1254** can transmit the request to LB subnet(s) **1222** contained in the control plane VCN **1216** via the Internet gateway **1234**. In response to determining the request is valid, the LB subnet(s) can transmit the request to app subnet(s) **1226** that can transmit the request to cloud services **1256** via the service gateway **1236**.

[0165] It should be appreciated that IaaS architectures **900**, **1000**, **1100**, **1200** depicted in the figures may have other components than those depicted. Further, the embodiments shown in the figures are only some examples of a cloud infrastructure system that may incorporate an embodiment of the disclosure. In some other embodiments, the IaaS systems may have more or fewer components than shown in the figures, may combine two or more components, or may have a different configuration or arrangement of components.

[0166] In certain embodiments, the IaaS systems described herein may include a suite of applications, middleware, and database service offerings that are delivered to a customer in a self-service, subscription-based, elastically scalable, reliable, highly available, and secure manner. An example of such an IaaS system is the Oracle Cloud Infrastructure (OCI) provided by the present assignee.

[0167] FIG. 13 illustrates an example computer system **1300**, in which various embodiments may be implemented. The system **1300** may be used to implement any of the computer systems described above. As shown in the figure, computer system **1300** includes a processing unit **1304** that communicates with a number of peripheral subsystems via a bus subsystem **1302**. These peripheral subsystems may include a processing acceleration unit **1306**, an I/O subsystem **1308**, a storage subsystem **1318** and a communications subsystem **1324**. Storage subsystem **1318** includes tangible computer-readable storage media **1322** and a system memory **1310**.

[0168] Bus subsystem **1302** provides a mechanism for letting the various components and subsystems of computer system **1300** communicate with each other as intended. Although bus subsystem **1302** is shown schematically as a single bus, alternative embodiments of the bus subsystem may utilize multiple buses. Bus subsystem **1302** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. For example, such architectures may include an Industry Standard Architecture (ISA) bus, Micro Channel Architecture (MCA) bus, Enhanced ISA (EISA) bus, Video Electronics Standards Association (VESA) local bus, and Peripheral Component

Interconnect (PCI) bus, which can be implemented as a Mezzanine bus manufactured to the IEEE P1386.1 standard.

[0169] Processing unit **1304**, which can be implemented as one or more integrated circuits (e.g., a conventional microprocessor or microcontroller), controls the operation of computer system **1300**. One or more processors may be included in processing unit **1304**. These processors may include single core or multicore processors. In certain embodiments, processing unit **1304** may be implemented as one or more independent processing units **1332** and/or **1334** with single or multicore processors included in each processing unit. In other embodiments, processing unit **1304** may also be implemented as a quad-core processing unit formed by integrating two dual-core processors into a single chip.

[0170] In various embodiments, processing unit **1304** can execute a variety of programs in response to program code and can maintain multiple concurrently executing programs or processes. At any given time, some or all of the program code to be executed can be resident in processor(s) **1304** and/or in storage subsystem **1318**. Through suitable programming, processor(s) **1304** can provide various functionalities described above. Computer system **1300** may additionally include a processing acceleration unit **1306**, which can include a digital signal processor (DSP), a special-purpose processor, and/or the like.

[0171] I/O subsystem **1308** may include user interface input devices and user interface output devices. User interface input devices may include a keyboard, pointing devices such as a mouse or trackball, a touchpad or touch screen incorporated into a display, a scroll wheel, a click wheel, a dial, a button, a switch, a keypad, audio input devices with voice command recognition systems, microphones, and other types of input devices. User interface input devices may include, for example, motion sensing and/or gesture recognition devices such as the Microsoft Kinect® motion sensor that enables users to control and interact with an input device, such as the Microsoft Xbox® 360 game controller, through a natural user interface using gestures and spoken commands. User interface input devices may also include eye gesture recognition devices such as the Google Glass® blink detector that detects eye activity (e.g., ‘blinking’ while taking pictures and/or making a menu selection) from users and transforms the eye gestures as input into an input device (e.g., Google Glass®). Additionally, user interface input devices may include voice recognition sensing devices that enable users to interact with voice recognition systems (e.g., Siri® navigator), through voice commands.

[0172] User interface input devices may also include, without limitation, three dimensional (3D) mice, joysticks or pointing sticks, gamepads and graphic tablets, and audio/visual devices such as speakers, digital cameras, digital camcorders, portable media players, webcams, image scanners, fingerprint scanners, barcode reader 3D scanners, 3D printers, laser rangefinders, and eye gaze tracking devices. Additionally, user interface input devices may include, for example, medical imaging input devices such as computed tomography, magnetic resonance imaging, position emission tomography, medical ultrasonography devices. User interface input devices may also include, for example, audio input devices such as MIDI keyboards, digital musical instruments and the like.

[0173] User interface output devices may include a display subsystem, indicator lights, or non-visual displays such as

audio output devices, etc. The display subsystem may be a cathode ray tube (CRT), a flat-panel device, such as that using a liquid crystal display (LCD) or plasma display, a projection device, a touch screen, and the like. In general, use of the term “output device” is intended to include all possible types of devices and mechanisms for outputting information from computer system 1300 to a user or other computer. For example, user interface output devices may include, without limitation, a variety of display devices that visually convey text, graphics and audio/video information such as monitors, printers, speakers, headphones, automotive navigation systems, plotters, voice output devices, and modems.

[0174] Computer system 1300 may comprise a storage subsystem 1318 that provides a tangible non-transitory computer-readable storage medium for storing software and data constructs that provide the functionality of the embodiments described in this disclosure. The software can include programs, code, instructions, scripts, etc., that when executed by one or more cores or processors of processing unit 1304 provide the functionality described above. Storage subsystem 1318 may also provide a repository for storing data used in accordance with the present disclosure.

[0175] As depicted in the example in FIG. 13, storage subsystem 1318 can include various components including a system memory 1310, computer-readable storage media 1322, and a computer readable storage media reader 1320. System memory 1310 may store program instructions that are loadable and executable by processing unit 1304. System memory 1310 may also store data that is used during the execution of the instructions and/or data that is generated during the execution of the program instructions. Various different kinds of programs may be loaded into system memory 1310 including but not limited to client applications, Web browsers, mid-tier applications, relational database management systems (RDBMS), virtual machines, containers, etc.

[0176] System memory 1310 may also store an operating system 1316. Examples of operating system 1316 may include various versions of Microsoft Windows®, Apple Macintosh®, and/or Linux operating systems, a variety of commercially-available UNIX® or UNIX-like operating systems (including without limitation the variety of GNU/Linux operating systems, the Google Chrome® OS, and the like) and/or mobile operating systems such as iOS, Windows® Phone, Android® OS, BlackBerry® OS, and Palm® OS operating systems. In certain implementations where computer system 1300 executes one or more virtual machines, the virtual machines along with their guest operating systems (GOSs) may be loaded into system memory 1310 and executed by one or more processors or cores of processing unit 1304.

[0177] System memory 1310 can come in different configurations depending upon the type of computer system 1300. For example, system memory 1310 may be volatile memory (such as random access memory (RAM)) and/or non-volatile memory (such as read-only memory (ROM), flash memory, etc.) Different types of RAM configurations may be provided including a static random access memory (SRAM), a dynamic random access memory (DRAM), and others. In some implementations, system memory 1310 may include a basic input/output system (BIOS) containing basic routines that help to transfer information between elements within computer system 1300, such as during start-up.

[0178] Computer-readable storage media 1322 may represent remote, local, fixed, and/or removable storage devices plus storage media for temporarily and/or more permanently containing, storing, computer-readable information for use by computer system 1300 including instructions executable by processing unit 1304 of computer system 1300.

[0179] Computer-readable storage media 1322 can include any appropriate media known or used in the art, including storage media and communication media, such as but not limited to, volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage and/or transmission of information. This can include tangible computer-readable storage media such as RAM, ROM, electronically erasable programmable ROM (EEPROM), flash memory or other memory technology, CD-ROM, digital versatile disk (DVD), or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or other tangible computer readable media.

[0180] By way of example, computer-readable storage media 1322 may include a hard disk drive that reads from or writes to non-removable, nonvolatile magnetic media, a magnetic disk drive that reads from or writes to a removable, nonvolatile magnetic disk, and an optical disk drive that reads from or writes to a removable, nonvolatile optical disk such as a CD ROM, DVD, and Blu-Ray® disk, or other optical media. Computer-readable storage media 1322 may include, but is not limited to, Zip® drives, flash memory cards, universal serial bus (USB) flash drives, secure digital (SD) cards, DVD disks, digital video tape, and the like. Computer-readable storage media 1322 may also include, solid-state drives (SSD) based on non-volatile memory such as flash-memory based SSDs, enterprise flash drives, solid state ROM, and the like, SSDs based on volatile memory such as solid state RAM, dynamic RAM, static RAM, DRAM-based SSDs, magnetoresistive RAM (MRAM) SSDs, and hybrid SSDs that use a combination of DRAM and flash memory based SSDs. The disk drives and their associated computer-readable media may provide non-volatile storage of computer-readable instructions, data structures, program services, and other data for computer system 1300.

[0181] Machine-readable instructions executable by one or more processors or cores of processing unit 1304 may be stored on a non-transitory computer-readable storage medium. A non-transitory computer-readable storage medium can include physically tangible memory or storage devices that include volatile memory storage devices and/or non-volatile storage devices. Examples of non-transitory computer-readable storage medium include magnetic storage media (e.g., disk or tapes), optical storage media (e.g., DVDs, CDs), various types of RAM, ROM, or flash memory, hard drives, floppy drives, detachable memory drives (e.g., USB drives), or other type of storage device.

[0182] Communications subsystem 1324 provides an interface to other computer systems and networks. Communications subsystem 1324 serves as an interface for receiving data from and transmitting data to other systems from computer system 1300. For example, communications subsystem 1324 may enable computer system 1300 to connect to one or more devices via the Internet. In some embodiments communications subsystem 1324 can include radio frequency (RF) transceiver components for accessing wireless voice and/or data networks (e.g., using cellular tele-

phone technology, advanced data network technology, such as 3G, 4G or EDGE (enhanced data rates for global evolution), WiFi (IEEE 802.11 family standards, or other mobile communication technologies, or any combination thereof), global positioning system (GPS) receiver components, and/or other components. In some embodiments communications subsystem 1324 can provide wired network connectivity (e.g., Ethernet) in addition to or instead of a wireless interface.

[0183] In some embodiments, communications subsystem 1324 may also receive input communication in the form of structured and/or unstructured data feeds 1326, event streams 1328, event updates 1330, and the like on behalf of one or more users who may use computer system 1300.

[0184] By way of example, communications subsystem 1324 may be configured to receive data feeds 1326 in real-time from users of social networks and/or other communication services such as Twitter® feeds, Facebook® updates, web feeds such as Rich Site Summary (RSS) feeds, and/or real-time updates from one or more third party information sources.

[0185] Additionally, communications subsystem 1324 may also be configured to receive data in the form of continuous data streams, which may include event streams 1328 of real-time events and/or event updates 1330, that may be continuous or unbounded in nature with no explicit end. Examples of applications that generate continuous data may include, for example, sensor data applications, financial tickers, network performance measuring tools (e.g., network monitoring and traffic management applications), click-stream analysis tools, automobile traffic monitoring, and the like.

[0186] Communications subsystem 1324 may also be configured to output the structured and/or unstructured data feeds 1326, event streams 1328, event updates 1330, and the like to one or more databases that may be in communication with one or more streaming data source computers coupled to computer system 1300.

[0187] Computer system 1300 can be one of various types, including a handheld portable device (e.g., an iPhone® cellular phone, an iPad® computing tablet, a PDA), a wearable device (e.g., a Google Glass® head mounted display), a PC, a workstation, a mainframe, a kiosk, a server rack, or any other data processing system.

[0188] Due to the ever-changing nature of computers and networks, the description of computer system 1300 depicted in the figure is intended only as a specific example. Many other configurations having more or fewer components than the system depicted in the figure are possible. For example, customized hardware might also be used and/or particular elements might be implemented in hardware, firmware, software (including applets), or a combination. Further, connection to other computing devices, such as network input/output devices, may be employed. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will appreciate other ways and/or methods to implement the various embodiments.

[0189] Although specific embodiments have been described, various modifications, alterations, alternative constructions, and equivalents are also encompassed within the scope of the disclosure. Embodiments are not restricted to operation within certain specific data processing environments, but are free to operate within a plurality of data processing environments. Additionally, although embodi-

ments have been described using a particular series of transactions and steps, it should be apparent to those skilled in the art that the scope of the present disclosure is not limited to the described series of transactions and steps. Various features and aspects of the above-described embodiments may be used individually or jointly.

[0190] Further, while embodiments have been described using a particular combination of hardware and software, it should be recognized that other combinations of hardware and software are also within the scope of the present disclosure. Embodiments may be implemented only in hardware, or only in software, or using combinations thereof. The various processes described herein can be implemented on the same processor or different processors in any combination. Accordingly, where components or services are described as being configured to perform certain operations, such configuration can be accomplished, e.g., by designing electronic circuits to perform the operation, by programming programmable electronic circuits (such as microprocessors) to perform the operation, or any combination thereof. Processes can communicate using a variety of techniques including but not limited to conventional techniques for inter process communication, and different pairs of processes may use different techniques, or the same pair of processes may use different techniques at different times.

[0191] The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. It will, however, be evident that additions, subtractions, deletions, and other modifications and changes may be made thereto without departing from the broader spirit and scope as set forth in the claims. Thus, although specific disclosure embodiments have been described, these are not intended to be limiting. Various modifications and equivalents are within the scope of the following claims.

[0192] The use of the terms “a” and “an” and “the” and similar referents in the context of describing the disclosed embodiments (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. The term “connected” is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate embodiments and does not pose a limitation on the scope of the disclosure unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the disclosure.

[0193] Disjunctive language such as the phrase “at least one of X, Y, or Z,” unless specifically stated otherwise, is intended to be understood within the context as used in general to present that an item, term, etc., may be either X, Y, or Z, or any combination thereof (e.g., X, Y, and/or Z).

Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y, or at least one of Z to each be present.

**[0194]** Preferred embodiments of this disclosure are described herein, including the best mode known for carrying out the disclosure. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. Those of ordinary skill should be able to employ such variations as appropriate and the disclosure may be practiced otherwise than as specifically described herein. Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein.

**[0195]** All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

**[0196]** In the foregoing specification, aspects of the disclosure are described with reference to specific embodiments thereof, but those skilled in the art will recognize that the disclosure is not limited thereto. Various features and aspects of the above-described disclosure may be used individually or jointly. Further, embodiments can be utilized in any number of environments and applications beyond those described herein without departing from the broader spirit and scope of the specification. The specification and drawings are, accordingly, to be regarded as illustrative rather than restrictive.

What is claimed is:

**1.** A method, comprising:

configuring, at a first facility, a plurality of server devices and a fleet of key server devices for transit to a data center by at least:

encrypting a storage device of each server device of the plurality of server devices using a corresponding data encryption key;

storing each data encryption key at a corresponding key storage element of each server device of the plurality of server devices;

encrypting the corresponding data encryption key at the corresponding key storage element of each server device using a key encryption key to produce an encrypted data encryption key; and

storing the key encryption key at the fleet of key server devices;

enabling, at the data center, the fleet of key server devices; initiating, at the data center, a boot sequence for a first server device using an initialization disk image stored at a boot volume of the first server device;

obtaining, by the first server device from the fleet of key server devices, the key encryption key;

decrypting, by the first server device, the encrypted data encryption key at the key storage element to produce the corresponding data encryption key; and

decrypting, by the first server device, the storage device.

**2.** The method of claim 1, wherein enabling the fleet of key server devices comprises communicatively connecting the fleet of key server devices to the plurality of server devices.

**3.** The method of claim 1, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises configuring the fleet of key server devices to transit to the data center separately from the plurality of server devices.

**4.** The method of claim 1, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises encrypting, at the first facility, data volumes of the fleet of key server devices, and wherein enabling the fleet of key server devices comprises:

providing, to the fleet of key server devices at the data center, cryptographic material usable to decrypt the data volumes; and

decrypting the data volumes of the fleet of key server devices.

**5.** The method of claim 1, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises encrypting, at the first facility, data volumes of the fleet of key server devices, and wherein enabling the fleet of key server devices comprises:

communicatively connecting the fleet of key server devices with a key service of a cloud service provider; obtaining, from the key service, cryptographic material usable to decrypt the data volumes; and decrypting the data volumes of the fleet of key server devices.

**6.** The method of claim 1, further comprising, prior to the transit of the plurality of server devices and the fleet of key server devices from the first facility to the data center:

decrypting, using the key encryption key, the encrypted data encryption key at the storage element of each server device of the plurality of server devices to produce the corresponding data encryption keys;

encrypting the corresponding data encryption keys at the corresponding key storage element of each server device using a new key encryption key to produce a new encrypted data encryption key; and

storing the new key encryption key at the fleet of key server devices.

**7.** The method of claim 1, wherein the fleet of key server devices comprises one or more key server devices.

**8.** A computer system, comprising:

one or more processors; and

one or more memories storing computer-executable instructions that, when executed by the one or more processors, cause the computer system to:

configure, at a first facility, a plurality of server devices and a fleet of key server devices for transit to a data center by at least:

encrypting a storage device of each server device of the plurality of server devices using a corresponding data encryption key;

storing each data encryption key at a corresponding key storage element of each server device of the plurality of server devices;

encrypting the corresponding data encryption key at the corresponding key storage element of each

server device using a key encryption key to produce an encrypted data encryption key; and storing the key encryption key at the fleet of key server devices;

enable, at the data center, the fleet of key server devices;

initiate, at the data center, a boot sequence of a first server device using an initialization disk image stored at a boot volume of the first server device;

obtain, by the first server device from the fleet of key server devices, the key encryption key;

decrypt, by the first server device, the encrypted data encryption key at the key storage element to produce the corresponding data encryption key; and

decrypt, by the first server device, the storage device.

9. The computer system of claim 8, wherein enabling the fleet of key server devices comprises communicatively connecting the fleet of key server devices to the plurality of server devices.

10. The computer system of claim 8, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises configuring the fleet of key server devices to transit to the data center separately from the plurality of server devices.

11. The computer system of claim 8, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises encrypting, at the first facility, data volumes of the fleet of key server devices, and wherein enabling the fleet of key server devices comprises:

providing, to the fleet of key server devices at the data center, cryptographic material usable to decrypt the data volumes; and

decrypting the data volumes of the fleet of key server devices.

12. The computer system of claim 8, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises encrypting, at the first facility, data volumes of the fleet of key server devices, and wherein enabling the fleet of key server devices comprises:

communicatively connecting the fleet of key server devices with a key service of a cloud service provider;

obtaining, from the key service, cryptographic material usable to decrypt the data volumes; and

decrypting the data volumes of the fleet of key server devices.

13. The computer system of claim 8, wherein the one or more memories store additional computer-executable instructions that, when executed by the one or more processors, cause the computer system to further, prior to the transit of the plurality of server devices and the fleet of key server devices from the first facility to the data center:

decrypt, using the key encryption key, the encrypted data encryption key at the storage element of each server device of the plurality of server devices to produce the corresponding data encryption keys;

encrypt the corresponding data encryption keys at the corresponding key storage element of each server device using a new key encryption key to produce a new encrypted data encryption key; and

store the new key encryption key at the fleet of key server devices.

14. The computer system of claim 8, wherein the fleet of key server devices comprises one or more key server devices.

15. A non-transitory computer-readable medium storing computer-executable instructions that, when executed by one or more processors of a computer system, cause the computer system to at least:

configure, at a first facility, a plurality of server devices and a fleet of key server devices for transit to a data center by at least:

encrypting a storage device of each server device of the plurality of server devices using a corresponding data encryption key;

storing each data encryption key at a corresponding key storage element of each server device of the plurality of server devices;

encrypting the corresponding data encryption key at the corresponding key storage element of each server device using a key encryption key to produce an encrypted data encryption key; and

storing the key encryption key at the fleet of key server devices;

enable, at the data center, the fleet of key server devices;

initiate, at the data center, a boot sequence of a first server device using an initialization disk image stored at a boot volume of the first server device;

obtain, by the first server device from the fleet of key server devices, the key encryption key;

decrypt, by the first server device, the encrypted data encryption key at the key storage element to produce the corresponding data encryption key; and

decrypt, by the first server device, the storage device.

16. The non-transitory computer-readable medium of claim 15, wherein enabling the fleet of key server devices comprises communicatively connecting the fleet of key server devices to the plurality of server devices.

17. The non-transitory computer-readable medium of claim 15, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises configuring the fleet of key server devices to transit to the data center separately from the plurality of server devices.

18. The non-transitory computer-readable medium of claim 15, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises encrypting, at the first facility, data volumes of the fleet of key server devices, and wherein enabling the fleet of key server devices comprises:

providing, to the fleet of key server devices at the data center, cryptographic material usable to decrypt the data volumes; and

decrypting the data volumes of the fleet of key server devices.

19. The non-transitory computer-readable medium of claim 15, wherein configuring the plurality of server devices and the fleet of key server devices for transit to the data center further comprises encrypting, at the first facility, data volumes of the fleet of key server devices, and wherein enabling the fleet of key server devices comprises:

communicatively connecting the fleet of key server devices with a key service of a cloud service provider;

obtaining, from the key service, cryptographic material usable to decrypt the data volumes; and

decrypting the data volumes of the fleet of key server devices.

**20.** The non-transitory computer-readable medium of claim **15**, storing additional computer-executable instructions that, when executed by the one or more processors of the computer system, cause the computer system to further, prior to the transit of the plurality of server devices and the fleet of key server devices from the first facility to the data center:

decrypt, using the key encryption key, the encrypted data encryption key at the storage element of each server device of the plurality of server devices to produce the corresponding data encryption keys;

encrypt the corresponding data encryption keys at the corresponding key storage element of each server device using a new key encryption key to produce a new encrypted data encryption key; and

store the new key encryption key at the fleet of key server devices.

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