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CLOUD-BASED ZERO TRUST NETWORK ACCESS SERVICE

Abstract

A cloud-based platform for zero trust network access (ZTNA) services provides zero trust network access as a service for multiple customers in a multi-tenant architecture. In this context, the configuration for a new ZTNA application is validated with a service proxy in a sandbox or similar environment before release by the cloud-based platform for access through a public network. As a significant advantage, this approach mitigates inadvertent conflicts or instability in a service proxy that supports other applications and customers.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 18/089,930 filed on Dec. 28, 2022, which is a bypass continuation that claims priority to International Patent Application No. PCT/US22/54075 filed on Dec. 27, 2022, which claims priority to Indian Patent Application number 202211058975 filed on Oct. 15, 2022, where the entire content of each of the foregoing is hereby incorporated by reference.

BACKGROUND

[0002] There remains a need for improved techniques for deploying and managing zero trust network access applications with a cloud-based security infrastructure.

SUMMARY

[0003] A zero trust network access (ZTNA) system provides secure access to applications hosted on a customer premises. The ZTNA system is modified to facilitate distributed and/or cloud-based deployments of components for a control plane and a data plane, all collectively supporting a network-accessible front end for the customer's locally hosted applications.

[0004] Infrastructure for zero trust network access (ZTNA) is deployed as a cloud-based service remotely from a customer premises where user applications are hosted. By connecting an appliance on the customer premises to the cloud-based service through a secure tunnel or the like, an application hosted on the customer premises can then be accessed externally as a ZTNA application without the customer premises opening a firewall to public networks or otherwise exposing potential attack surfaces to the customer premises.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The foregoing and other objects, features, and advantages of the devices, systems, and methods described herein will be apparent from the following description of particular embodiments thereof, as illustrated in the accompanying drawings. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the devices, systems, and methods described herein.

[0006] FIG. 1 depicts a block diagram of a threat management system.

[0007] FIG. 2 depicts a block diagram of a threat management system.

[0008] FIG. 3 shows a system for enterprise network threat detection.

[0009] FIG. 4 illustrates a threat management system.

[0010] FIG. 5 shows a threat management facility in a zero trust network access (ZTNA) environment.

[0011] FIG. 6 shows a zero trust network access environment using a zero trust network access appliance.

[0012] FIG. 7 shows a method for validation of ZTNA configuration for a multi-tenant proxy environment.

[0013] FIG. 8 shows a method for domain ownership verification for a ZTNA service platform.

[0014] FIG. 9 shows a cloud computing platform with an abstraction layer that maps application domains to network load balancers.

[0015] FIG. **10** shows a method of using alias domains for accessing ZTNA applications.

[0016] FIG. **11** shows a hybrid appliance for zero trust network access to customer applications.

[0017] FIG. **12** shows a method for dynamic routing of application traffic to ZTNA connectors.

[0018] FIG. **13** shows a method for scaling tunnels for zero trust network access appliances.

DETAILED DESCRIPTION

[0019] Embodiments will now be described with reference to the accompanying figures. The foregoing may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein.

[0020] All documents mentioned herein are hereby incorporated by reference in their entirety. References to items in the singular should be understood to include items in the plural, and vice versa, unless explicitly stated otherwise or clear from the text. Grammatical conjunctions are intended to express any and all disjunctive and conjunctive combinations of conjoined clauses, sentences, words, and the like, unless otherwise stated or clear from the context. Thus, the term “or” should generally be understood to mean “and/or” and so forth.

[0021] Recitation of ranges of values herein are not intended to be limiting, referring instead individually to any and all values falling within the range, unless otherwise indicated herein, and each separate value within such a range is incorporated into the specification as if it were individually recited herein. The words “about,” “approximately” or the like, when accompanying a numerical value, are to be construed as indicating a deviation as would be appreciated by one of ordinary skill in the art to operate satisfactorily for an intended purpose. Similarly, words of approximation such as “approximately” or “substantially” when used in reference to physical characteristics, should be understood to contemplate a range of deviations that would be appreciated by one of ordinary skill in the art to operate satisfactorily for a corresponding use, function, purpose, or the like. Ranges of values and/or numeric values are provided herein as examples only, and do not constitute a limitation on the scope of the described embodiments. Where ranges of values are provided, they are also intended to include each value within the range as if set forth individually, unless expressly stated to the contrary. The use of any and all examples, or exemplary language (“e.g.,” “such as,” or the like) provided herein, is intended merely to better illuminate the embodiments and does not pose a limitation on the scope of the embodiments. No language in the specification should be construed as indicating any unclaimed element as essential to the practice of the embodiments.

[0022] In the following description, it is understood that terms such as “first,” “second,” “top,” “bottom,” “up,” “down,” and the like, are words of convenience and are not to be construed as limiting terms.

[0023] It should also be understood that endpoints, devices, compute instances, or the like that are referred to as “within” an enterprise network may also be “associated with” the enterprise network, e.g., where such assets are outside an enterprise gateway but nonetheless managed by or in communication with a threat management facility or other centralized security platform for the enterprise network. Thus, any description referring to an asset within the enterprise network should be understood to contemplate a similar asset associated with the enterprise network regardless of location in a network environment unless a different meaning is explicitly provided or otherwise clear from the context.

[0024] As described herein, a threat management system may use a Sensor, Events, Analytics, and Response (SEAR) approach to protect enterprises against cybersecurity threats.

[0025] FIG. **1** depicts a block diagram of a threat management system **101** providing protection against a plurality of threats, such as malware, viruses, spyware, cryptoware, adware, Trojans, spam, intrusion, policy abuse, improper configuration, vulnerabilities, improper access, uncontrolled access, and more. A threat management facility **100** may communicate with, coordinate, and control operation of security functionality at different control points, layers, and levels within the system **101**. A number of capabilities may be provided by a threat management

facility **100**, with an overall goal to intelligently use the breadth and depth of information that is available about the operation and activity of compute instances and networks as well as a variety of available controls. Another overall goal is to provide protection needed by an organization that is dynamic and able to adapt to changes in compute instances and new threats. In embodiments, the threat management facility **100** may provide protection from a variety of threats to a variety of compute instances in a variety of locations and network configurations.

[0026] Just as one example, users of the threat management facility **100** may define and enforce policies that control access to and use of compute instances, networks and data. Administrators may update policies such as by designating authorized users and conditions for use and access. The threat management facility **100** may update and enforce those policies at various levels of control that are available, such as by directing compute instances to control the network traffic that is allowed to traverse firewalls and wireless access points, applications, and data available from servers, applications and data permitted to be accessed by endpoints, and network resources and data permitted to be run and used by endpoints. The threat management facility **100** may provide many different services, and policy management may be offered as one of the services.

[0027] Turning to a description of certain capabilities and components of the threat management system **101**, an exemplary enterprise facility **102** may be or may include any networked computer-based infrastructure. For example, the enterprise facility **102** may be corporate, commercial, organizational, educational, governmental, or the like. As home networks get more complicated and include more compute instances at home and in the cloud, an enterprise facility **102** may also or instead include a personal network such as a home or a group of homes. The enterprise facility's **102** computer network may be distributed amongst a plurality of physical premises such as buildings on a campus and located in one or in a plurality of geographical locations. The configuration of the enterprise facility as shown is merely exemplary, and it will be understood that there may be any number of compute instances, less or more of each type of compute instances, and other types of compute instances. As shown, the exemplary enterprise facility includes a firewall **10**, a wireless access point **11**, an endpoint **12**, a server **14**, a mobile device **16**, an appliance or IoT device **18**, a cloud computing instance **19**, and a server **20**. Again, the compute instances **10-20** depicted are exemplary, and there may be any number or types of compute instances **10-20** in a given enterprise facility. For example, in addition to the elements depicted in the enterprise facility **102**, there may be one or more gateways, bridges, wired networks, wireless networks, virtual private networks, other compute instances, and so on.

[0028] The threat management facility **100** may include certain facilities, such as a policy management facility **112**, security management facility **122**, update facility **120**, definitions facility **114**, network access rules facility **124**, remedial action facility **128**, detection techniques facility **130**, application protection facility **150**, asset classification facility **160**, entity model facility **162**, event collection facility **164**, event logging facility **166**, analytics facility **168**, dynamic policy facility **170**, identity management facility **172**, and marketplace management facility **174**, as well as other facilities. For example, there may be a testing facility, a threat research facility, and other facilities. It should be understood that the threat management facility **100** may be implemented in whole or in part on a number of different compute instances, with some parts of the threat management facility on different compute instances in different locations. For example, the threat management facility **100** may include, or may be connected to a security agent **S** such as a local security agent deployed on one or more other entities within the threat management system **101**. The facilities of the threat management facility **100**, and/or a security agent **S** therefor, may be deployed on the same physical hardware or logical resource as a gateway for an enterprise facility **102**, a firewall **10**, or wireless access point **11**. Some or all of one or more of the facilities may be provided on one or more cloud servers that are operated by the enterprise or by a security service provider, such as the cloud computing instance **109**.

[0029] In embodiments, a marketplace provider **199** may make available one or more additional

facilities to the enterprise facility **102** via the threat management facility **100**. The marketplace provider may communicate with the threat management facility **100** via the marketplace interface facility **174** to provide additional functionality or capabilities to the threat management facility **100** and compute instances **10-26**. As non-limiting examples, the marketplace provider **199** may be a third-party information provider, such as a physical security event provider; the marketplace provider **199** may be a system provider, such as a human resources system provider or a fraud detection system provider; the marketplace provider may be a specialized analytics provider; and so on. The marketplace provider **199**, with appropriate permissions and authorization, may receive and send events, observations, inferences, controls, convictions, policy violations, or other information to the threat management facility. For example, the marketplace provider **199** may subscribe to and receive certain events, and in response, based on the received events and other events available to the marketplace provider **199**, send inferences to the marketplace interface, and in turn to the analytics facility **168**, which in turn may be used by the security management facility **122**.

[0030] The identity provider **158** may be any remote identity management system or the like configured to communicate with an identity management facility **172**, e.g., to confirm identity of a user as well as provide or receive other information about users that may be useful to protect against threats. In general, the identity provider may be any system or entity that creates, maintains, and manages identity information for principals while providing authentication services to relying party applications, e.g., within a federation or distributed network. The identity provider may, for example, offer user authentication as a service, where other applications, such as web applications, outsource the user authentication step to a trusted identity provider.

[0031] In embodiments, the identity provider **158** may provide user identity information, such as multi-factor authentication, to a SaaS application. Centralized identity providers such as Microsoft Azure, may be used by an enterprise facility instead of maintaining separate identity information for each application or group of applications, and as a centralized point for integrating multifactor authentication. In embodiments, the identity management facility **172** may communicate hygiene, or security risk information, to the identity provider **158**. The identity management facility **172** may determine a risk score for a user based on the events, observations, and inferences about that user and the compute instances associated with the user. If a user is perceived as risky, the identity management facility **172** can inform the identity provider **158**, and the identity provider **158** may take steps to address the potential risk, such as to confirm the identity of the user, confirm that the user has approved the SaaS application access, remediate the user's system, or such other steps as may be useful.

[0032] In embodiments, threat protection provided by the threat management facility **100** may extend beyond the network boundaries of the enterprise facility **102** to include clients (or client facilities) such as an endpoint **22** outside the enterprise facility **102**, a mobile device **26**, a cloud computing instance **109**, or any other devices, services or the like that use network connectivity not directly associated with or controlled by the enterprise facility **102**, such as a mobile network, a public cloud network, or a wireless network at a hotel or coffee shop. While threats may come from a variety of sources, such as from network threats, physical proximity threats, secondary location threats, the compute instances **10-26** may be protected from threats even when a compute instance **10-26** is not connected to the enterprise facility **102** network, such as when compute instances **22**, **26** use a network that is outside of the enterprise facility **102** and separated from the enterprise facility **102**, e.g., by a gateway, a public network, and so forth.

[0033] In some implementations, compute instances **10-26** may communicate with cloud applications, such as a SaaS application **156**. The SaaS application **156** may be an application that is used by but not operated by the enterprise facility **102**. Exemplary commercially available SaaS applications **156** include Salesforce, Amazon Web Services (AWS) applications, Google Apps applications, Microsoft Office **365** applications and so on. A given SaaS application **156** may

communicate with an identity provider **158** to verify user identity consistent with the requirements of the enterprise facility **102**. The compute instances **10-26** may communicate with an unprotected server (not shown) such as a web site or a third-party application through an internetwork **154** such as the Internet or any other public network, private network, or combination of these.

[0034] In embodiments, aspects of the threat management facility **100** may be provided as a stand-alone solution. In other embodiments, aspects of the threat management facility **100** may be integrated into a third-party product. An application programming interface (e.g., a source code interface) may be provided such that aspects of the threat management facility **100** may be integrated into or used by or with other applications. For instance, the threat management facility **100** may be stand-alone in that it provides direct threat protection to an enterprise or computer resource, where protection is subscribed to directly **100**. Alternatively, the threat management facility may offer protection indirectly, through a third-party product, where an enterprise may subscribe to services through the third-party product, and threat protection to the enterprise may be provided by the threat management facility **100** through the third-party product.

[0035] The security management facility **122** may provide protection from a variety of threats by providing, as non-limiting examples, endpoint security and control, email security and control, web security and control, reputation-based filtering, machine learning classification, control of unauthorized users, control of guest and non-compliant computers, and more.

[0036] The security management facility **122** may provide malicious code protection to a compute instance. The security management facility **122** may include functionality to scan applications, files, and data for malicious code, remove or quarantine applications and files, prevent certain actions, perform remedial actions, as well as other security measures. Scanning may use any of a variety of techniques, including without limitation signatures, identities, classifiers, and other suitable scanning techniques. In embodiments, the scanning may include scanning some or all files on a periodic basis, scanning an application when the application is executed, scanning data transmitted to or from a device, scanning in response to predetermined actions or combinations of actions, and so forth. The scanning of applications, files, and data may be performed to detect known or unknown malicious code or unwanted applications. Aspects of the malicious code protection may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of an application protection facility **150** provided by the cloud, and so on.

[0037] In an embodiment, the security management facility **122** may provide for email security and control, for example to target spam, viruses, spyware, and phishing, to control email content, and the like. Email security and control may protect against inbound and outbound threats, protect email infrastructure, prevent data leakage, provide spam filtering, and more. Aspects of the email security and control may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of the application protection facility **150** provided by the cloud, and so on.

[0038] In an embodiment, security management facility **122** may provide for web security and control, for example, to detect or block viruses, spyware, malware, unwanted applications, help control web browsing, and the like, which may provide comprehensive web access control enabling safe, productive web browsing. Web security and control may provide Internet use policies, reporting on suspect compute instances, security and content filtering, active monitoring of network traffic, URI filtering, and the like. Aspects of the web security and control may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of the application protection facility **150** provided by the cloud, and so on.

[0039] In an embodiment, the security management facility **122** may provide for network access control, which generally controls access to and use of network connections. Network control may stop unauthorized, guest, or non-compliant systems from accessing networks, and may control network traffic that is not otherwise controlled at the client level. In addition, network access

control may control access to virtual private networks (VPN), where VPNs may, for example, include communications networks tunneled through other networks and establishing logical connections acting as virtual networks. In embodiments, a VPN may be treated in the same manner as a physical network. Aspects of network access control may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of the application protection facility **150** provided by the cloud, e.g., from the threat management facility **100** or other network resource(s).

[0040] In an embodiment, the security management facility **122** may provide for host intrusion prevention through behavioral monitoring and/or runtime monitoring, which may guard against unknown threats by analyzing application behavior before or as an application runs. This may include monitoring code behavior, application programming interface calls made to libraries or to the operating system, or otherwise monitoring application activities. Monitored activities may include, for example, reading and writing to memory, reading and writing to disk, network communication, process interaction, and so on. Behavior and runtime monitoring may intervene if code is deemed to be acting in a manner that is suspicious or malicious. Aspects of behavior and runtime monitoring may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of application protection **150** provided by the cloud, and so on.

[0041] In an embodiment, the security management facility **122** may provide for reputation filtering, which may target or identify sources of known malware. For instance, reputation filtering may include lists of URIs of known sources of malware or known suspicious IP addresses, code authors, code signers, or domains, that when detected may invoke an action by the threat management facility **100**. Based on reputation, potential threat sources may be blocked, quarantined, restricted, monitored, or some combination of these, before an exchange of data can be made. Aspects of reputation filtering may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of the application protection facility **150** provided by the cloud, and so on. In embodiments, some reputation information may be stored on a compute instance **10-26**, and other reputation data available through cloud lookups to an application protection lookup database, such as may be provided by the application protection facility **150**.

[0042] In embodiments, information may be sent from the enterprise facility **102** to a third party, such as a security vendor, or the like, which may lead to improved performance of the threat management facility **100**. In general, feedback may be useful for any aspect of threat detection. For example, the types, times, and number of virus interactions that an enterprise facility **102** experiences may provide useful information for the prevention of future virus threats. Feedback may also be associated with behaviors of individuals within the enterprise, such as being associated with most common violations of policy, network access, unauthorized application loading, unauthorized external device use, and the like. In embodiments, feedback may enable the evaluation or profiling of client actions that are violations of policy that may provide a predictive model for the improvement of enterprise policies.

[0043] An update management facility **90** may provide control over when updates are performed. The updates may be automatically transmitted, manually transmitted, or some combination of these. Updates may include software, definitions, reputations or other code or data that may be useful to the various facilities. For example, the update facility **120** may manage receiving updates from a provider, distribution of updates to enterprise facility **102** networks and compute instances, or the like. In embodiments, updates may be provided to the enterprise facility's **102** network, where one or more compute instances on the enterprise facility's **102** network may distribute updates to other compute instances.

[0044] The threat management facility **100** may include a policy management facility **112** that manages rules or policies for the enterprise facility **102**. Exemplary rules include access

permissions associated with networks, applications, compute instances, users, content, data, and the like. The policy management facility **112** may use a database, a text file, other data store, or a combination to store policies. In an embodiment, a policy database may include a block list, a blacklist, an allowed list, a whitelist, and more. As a few non-limiting examples, policies may include a list of enterprise facility **102** external network locations/applications that may or may not be accessed by compute instances, a list of types/classifications of network locations or applications that may or may not be accessed by compute instances, and contextual rules to evaluate whether the lists apply. For example, there may be a rule that does not permit access to sporting websites. When a website is requested by the client facility, a security management facility **122** may access the rules within a policy facility to determine if the requested access is related to a sporting website.

[0045] The policy management facility **112** may include access rules and policies that are distributed to maintain control of access by the compute instances **10-26** to network resources. Exemplary policies may be defined for an enterprise facility, application type, subset of application capabilities, organization hierarchy, compute instance type, user type, network location, time of day, connection type, or any other suitable definition. Policies may be maintained through the threat management facility **100**, in association with a third party, or the like. For example, a policy may restrict instant messaging (IM) activity by limiting such activity to support personnel when communicating with customers. More generally, this may allow communication for departments as necessary or helpful for department functions, but may otherwise preserve network bandwidth for other activities by restricting the use of IM to personnel that need access for a specific purpose. In an embodiment, the policy management facility **112** may be a stand-alone application, a part of the enterprise facility **102** network, a part of the threat management facility **100**, or any suitable combination of these.

[0046] The policy management facility **112** may include dynamic policies that use contextual or other information to make security decisions. As described herein, the dynamic policy facility **170** may generate policies dynamically based on observations and inferences made by the analytics facility. The dynamic policies generated by the dynamic policy facility **170** may be provided by the policy management facility **112** to the security management facility **122** for enforcement.

[0047] In embodiments, the threat management facility **100** may provide configuration management as an aspect of the policy management facility **112**, the security management facility **122**, or some combination. Configuration management may define acceptable or required configurations for the compute instances **10-26**, applications, operating systems, hardware, or other assets, and manage changes to these configurations. Assessment of a configuration may be made against standard configuration policies, detection of configuration changes, remediation of improper configurations, application of new configurations, and so on. An enterprise facility may have a set of standard configuration rules and policies for particular compute instances which may represent a desired state of the compute instance. For example, on a given compute instance **9, 14, 18**, a version of a client firewall may be required to be running and installed. If the required version is installed but in a disabled state, the policy violation may prevent access to data or network resources. A remediation may be to enable the firewall. In another example, a configuration policy may disallow the use of USB disks, and the policy management facility **112** may require a configuration that turns off USB drive access via a registry key of a compute instance. Aspects of configuration management may be provided, for example, in the security agent of an endpoint **12**, in a wireless access point **11** or firewall **10**, as part of the application protection facility **150** provided by the cloud, or any combination of these.

[0048] In embodiments, the threat management facility **100** may also provide for the isolation or removal of certain applications that are not desired or may interfere with the operation of a compute instance **10-26** or the threat management facility **100**, even if such application is not malware per se. The operation of such products may be considered a configuration violation. The

removal of such products may be initiated automatically whenever such products are detected, or access to data and network resources may be restricted when they are installed and running. In the case where such applications are services which are provided indirectly through a third-party product, the applicable application or processes may be suspended until action is taken to remove or disable the third-party product.

[0049] The policy management facility **112** may also require update management (e.g., as provided by the update facility **120**). Update management for the security facility **92** and policy management facility **112** may be provided directly by the threat management facility **100**, or, for example, by a hosted system. In embodiments, the threat management facility **100** may also provide for patch management, where a patch may be an update to an operating system, an application, a system tool, or the like, where one of the reasons for the patch is to reduce vulnerability to threats.

[0050] In embodiments, the security facility **92** and policy management facility **112** may push information to the enterprise facility **102** network and/or the compute instances **10-26**, the enterprise facility **102** network and/or compute instances **10-26** may pull information from the security facility **92** and policy management facility **112**, or there may be a combination of pushing and pulling of information. For example, the enterprise facility **102** network and/or compute instances **10-26** may pull update information from the security facility **92** and policy management facility **112** via the update facility **120**, an update request may be based on a time period, by a certain time, by a date, on demand, or the like. In another example, the security facility **92** and policy management facility **112** may push the information to the enterprise facility's **102** network and/or compute instances **10-26** by providing notification that there are updates available for download and/or transmitting the information. In an embodiment, the policy management facility **112** and the security facility **92** may work in concert with the update management facility **90** to provide information to the enterprise facility's **102** network and/or compute instances **10-26**. In various embodiments, policy updates, security updates and other updates may be provided by the same or different modules, which may be the same or separate from a security agent running on one of the compute instances **10-26**.

[0051] As threats are identified and characterized, the definitions facility **114** of the threat management facility **100** may manage definitions used to detect and remediate threats. For example, identity definitions may be used for scanning files, applications, data streams, etc. for the determination of malicious code. Identity definitions may include instructions and data that can be parsed and acted upon for recognizing features of known or potentially malicious code. Definitions also may include, for example, code or data to be used in a classifier, such as a neural network or other classifier that may be trained using machine learning. Updated code or data may be used by the classifier to classify threats. In embodiments, the threat management facility **100** and the compute instances **10-26** may be provided with new definitions periodically to include the most recent threats. Updating of definitions may be managed by the update facility **120**, and may be performed upon request from one of the compute instances **10-26**, upon a push, or some combination. Updates may be performed upon a time period, on demand from a device **10-26**, upon determination of an important new definition or a number of definitions, and so on.

[0052] A threat research facility (not shown) may provide a continuously ongoing effort to maintain the threat protection capabilities of the threat management facility **100** in light of continuous generation of new or evolved forms of malware. Threat research may be provided by researchers and analysts working on known threats, in the form of policies, definitions, remedial actions, and so on.

[0053] The security management facility **122** may scan an outgoing file and verify that the outgoing file is permitted to be transmitted according to policies. By checking outgoing files, the security management facility **122** may be able discover threats that were not detected on one of the compute instances **10-26**, or policy violation, such transmittal of information that should not be communicated unencrypted.

[0054] The threat management facility **100** may control access to the enterprise facility **102** networks. A network access facility **94** may restrict access to certain applications, networks, files, printers, servers, databases, and so on. In addition, the network access facility **94** may restrict user access under certain conditions, such as the user's location, usage history, need to know, job position, connection type, time of day, method of authentication, client-system configuration, or the like. Network access policies may be provided by the policy management facility **112**, and may be developed by the enterprise facility **102**, or pre-packaged by a supplier. Network access facility **94** may determine if a given compute instance **10-22** should be granted access to a requested network location, e.g., inside or outside of the enterprise facility **102**. Network access facility **94** may determine if a compute instance **22, 26** such as a device outside the enterprise facility **102** may access the enterprise facility **102**. For example, in some cases, the policies may require that when certain policy violations are detected, certain network access is denied. The network access facility **94** may communicate remedial actions that are necessary or helpful to bring a device back into compliance with policy as described below with respect to the remedial action facility **128**. Aspects of the network access facility **94** may be provided, for example, in the security agent of the endpoint **12**, in a wireless access point **11**, in a firewall **10**, as part of the application protection facility **150** provided by the cloud, and so on.

[0055] In an embodiment, the network access facility **94** may have access to policies that include one or more of a block list, an allowed list, an unacceptable network site database, an acceptable network site database, a network site reputation database, or the like of network access locations that may or may not be accessed by the client facility. Additionally, the network access facility **94** may use rule evaluation to parse network access requests and apply policies. The network access rule facility **94** may have a generic set of policies for all compute instances, such as denying access to certain types of websites, controlling instant messenger accesses, or the like. Rule evaluation may include regular expression rule evaluation, or other rule evaluation method(s) for interpreting the network access request and comparing the interpretation to established rules for network access. Classifiers may be used, such as neural network classifiers or other classifiers that may be trained by machine learning.

[0056] The threat management facility **100** may include an asset classification facility **160**. The asset classification facility will discover the assets present in the enterprise facility **102**. A compute instance such as any of the compute instances **10-26** described herein may be characterized as a stack of assets. The one level asset is an item of physical hardware. The compute instance may be, or may be implemented on physical hardware, and may have or may not have a hypervisor, or may be an asset managed by a hypervisor. The compute instance may have an operating system (e.g., Windows, MacOS, Linux, Android, IOS). The compute instance may have one or more layers of containers. The compute instance may have one or more applications, which may be native applications, e.g., for a physical asset or virtual machine, or running in containers within a computing environment on a physical asset or virtual machine, and those applications may link libraries or other code or the like, e.g., for a user interface, cryptography, communications, device drivers, mathematical or analytical functions and so forth. The stack may also interact with data. The stack may also or instead interact with users, and so users may be considered assets.

[0057] The threat management facility may include entity models stored in an entity model facility **162**. The entity models may be used, for example, to determine the events that are generated by assets. For example, some operating systems may provide useful information for detecting or identifying events. For example, operating systems may provide process and usage information that accessed through an API. As another example, it may be possible to instrument certain containers to monitor the activity of applications running on them. As another example, entity models for users may define roles, groups, permitted activities and other attributes.

[0058] The event collection facility **164** may be used to collect events from any of a wide variety of sensors that may provide relevant events from an asset, such as sensors on any of the compute

instances **10-26**, the application protection facility **150**, a cloud computing instance **109** and so on. The events that may be collected may be determined by the entity models. There may be a variety of events collected. Events may include, for example, events generated by the enterprise facility **102** or the compute instances **10-26**, such as by monitoring streaming data through a gateway such as firewall **10** and wireless access point **11**, monitoring activity of compute instances, monitoring stored files/data on the compute instances **10-26** such as desktop computers, laptop computers, other mobile computing devices, and cloud computing instances **19**, **109**. Events may range in granularity. An exemplary event may be communication of a specific packet over the network. Another exemplary event may be identification of an application that is communicating over a network.

[0059] The event logging facility **166** may be used to store events collected by the event collection facility **164**. The event logging facility **166** may store collected events so that they can be accessed and analyzed by the analytics facility **168**. Some events may be collected locally, and some events may be communicated to an event store in a central location or cloud facility. Events may be logged in any suitable format.

[0060] Events collected by the event logging facility **166** may be used by the analytics facility **168** to make inferences and observations about the events. These observations and inferences may be used as part of policies enforced by the security management facility. Observations or inferences about events may also be logged by the event logging facility **166**.

[0061] When a threat or other policy violation is detected by the security management facility **122**, the remedial action facility **128** may be used to remediate the threat. Remedial action may take a variety of forms, non-limiting examples including collecting additional data about the threat, terminating or modifying an ongoing process or interaction, sending a warning to a user or administrator, downloading a data file with commands, definitions, instructions, or the like to remediate the threat, requesting additional information from the requesting device, such as the application that initiated the activity of interest, executing a program or application to remediate against a threat or violation, increasing telemetry or recording interactions for subsequent evaluation, (continuing to) block requests to a particular network location or locations, scanning a requesting application or device, quarantine of a requesting application or the device, isolation of the requesting application or the device, deployment of a sandbox, blocking access to resources, e.g., a USB port, or other remedial actions. More generally, the remedial action facility **92** may take any steps or deploy any measures suitable for addressing a detection of a threat, potential threat, policy violation or other event, code or activity that might compromise security of a computing instance **10-26** or the enterprise facility **102**.

[0062] FIG. 2 depicts a block diagram of a threat management system **201** such as any of the threat management systems described herein, and including a cloud enterprise facility **280**. The cloud enterprise facility **280** may include servers **284**, **286**, and a firewall **282**. The servers **284**, **286** on the cloud enterprise facility **280** may run one or more enterprise applications and make them available to the enterprise facilities **102** compute instances **10-26**. It should be understood that there may be any number of servers **284**, **286** and firewalls **282**, as well as other compute instances in a given cloud enterprise facility **280**. It also should be understood that a given enterprise facility may use both SaaS applications **156** and cloud enterprise facilities **280**, or, for example, a SaaS application **156** may be deployed on a cloud enterprise facility **280**. As such, the configurations in FIG. 1 and FIG. 2 are shown by way of examples and not exclusive alternatives.

[0063] FIG. 3 shows a system **300** for enterprise network threat detection. The system **300** may use any of the various tools and techniques for threat management contemplated herein. In the system, a number of endpoints such as the endpoint **302** may log events in a data recorder **304**. A local agent on the endpoint **302** such as the security agent **306** may filter this data and feeds a filtered data stream to a threat management facility **308** such as a central threat management facility or any of the other threat management facilities described herein. The threat management facility **308** can

locally or globally tune filtering by local agents based on the current data stream and can query local event data recorders for additional information where necessary or helpful in threat detection or forensic analysis. The threat management facility **308** may also or instead store and deploys a number of security tools such as a web-based user interface that is supported by machine learning models to aid in the identification and assessment of potential threats by a human user. This may, for example, include machine learning analysis of new code samples, models to provide human-readable context for evaluating potential threats, and any of the other tools or techniques described herein. More generally, the threat management facility **308** may provide any of a variety of threat management tools **316** to aid in the detection, evaluation, and remediation of threats or potential threats.

[0064] The threat management facility **308** may perform a range of threat management functions such as any of those described herein. The threat management facility **308** may generally include an application programming interface **310** to third party services **320**, a user interface **312** for access to threat management and network administration functions, and a number of threat detection tools **314**.

[0065] In general, the application programming interface **310** may support programmatic connections with third party services **320**. The application programming interface **310** may, for example, connect to Active Directory or other customer information about files, data storage, identities and user profiles, roles, access privileges and so forth. More generally the application programming interface **310** may provide a programmatic interface for customer or other third party context, information, administration and security tools, and so forth. The application programming interface **310** may also or instead provide a programmatic interface for hosted applications, identity provider integration tools or services, and so forth.

[0066] The user interface **312** may include a website or other graphical interface or the like, and may generally provide an interface for user interaction with the threat management facility **308**, e.g., for threat detection, network administration, audit, configuration and so forth. This user interface **312** may generally facilitate human curation of intermediate threats as contemplated herein, e.g., by presenting intermediate threats along with other supplemental information, and providing controls for user to dispose of such intermediate threats as desired, e.g., by permitting execution or access, by denying execution or access, or by engaging in remedial measures such as sandboxing, quarantining, vaccinating, and so forth.

[0067] The threat detection tools **314** may be any of the threat detection tools, algorithms, techniques or the like described herein, or any other tools or the like useful for detecting threats or potential threats within an enterprise network. This may, for example, include signature based tools, behavioral tools, machine learning models, and so forth. In general, the threat detection tools **314** may use event data provided by endpoints within the enterprise network, as well as any other available context such as network activity, heartbeats, and so forth to detect malicious software or potentially unsafe conditions for a network or endpoints connected to the network. In one aspect, the threat detection tools **314** may usefully integrate event data from a number of endpoints (including, e.g., network components such as gateways, routers, and firewalls) for improved threat detection in the context of complex or distributed threats. The threat detection tools **314** may also or instead include tools for reporting to a separate modeling and analysis platform **318**, e.g., to support further investigation of security issues, creation or refinement of threat detection models or algorithms, review and analysis of security breaches, and so forth.

[0068] The threat management tools **316** may generally be used to manage or remediate threats to the enterprise network that have been identified with the threat detection tools **314** or otherwise. Threat management tools **316** may, for example, include tools for sandboxing, quarantining, removing, or otherwise remediating or managing malicious code or malicious activity, e.g., using any of the techniques described herein.

[0069] The endpoint **302** may be any of the endpoints or other compute instances or the like

described herein. This may, for example, include end-user computing devices, mobile devices, firewalls, gateways, servers, routers and any other computing devices or instances that might connect to an enterprise network. As described above, the endpoint **302** may generally include a security agent **306** that locally supports threat management on the endpoint **302**, such as by monitoring for malicious activity, managing security components on the endpoint **302**, maintaining policy compliance, and communicating with the threat management facility **308** to support integrated security protection as contemplated herein. The security agent **306** may, for example, coordinate instrumentation of the endpoint **302** to detect various event types involving various computing objects on the endpoint **302**, and supervise logging of events in a data recorder **304**. The security agent **306** may also or instead scan computing objects such as electronic communications or files, monitor behavior of computing objects such as executables, and so forth. The security agent **306** may, for example, apply signature-based or behavioral threat detection techniques, machine learning models (e.g., models developed by the modeling and analysis platform), or any other tools or the like suitable for detecting malware or potential malware on the endpoint **302**.

[0070] The data recorder **304** may log events occurring on or related to the endpoint. This may, for example, include events associated with computing objects on the endpoint **302** such as file manipulations, software installations, and so forth. This may also or instead include activities directed from the endpoint **302**, such as requests for content from Uniform Resource Locators or other network activity involving remote resources. The data recorder **304** may record data at any frequency and any level of granularity consistent with proper operation of the endpoint **302** in an intended or desired manner.

[0071] The endpoint **302** may include a filter **322** to manage a flow of information from the data recorder **304** to a remote resource such as the threat detection tools **314** of the threat management facility **308**. In this manner, a detailed log of events may be maintained locally on each endpoint, while network resources can be conserved for reporting of a filtered event stream that contains information believed to be most relevant to threat detection. The filter **322** may also or instead be configured to report causal information that causally relates collections of events to one another. In general, the filter **322** may be configurable so that, for example, the threat management facility **308** can increase or decrease the level of reporting based on a current security status of the endpoint, a group of endpoints, the enterprise network, and the like. The level of reporting may also or instead be based on currently available network and computing resources, or any other appropriate context.

[0072] In another aspect, the endpoint **302** may include a query interface **324** so that remote resources such as the threat management facility **308** can query the data recorder **304** remotely for additional information. This may include a request for specific events, activity for specific computing objects, or events over a specific time frame, or some combination of these. Thus, for example, the threat management facility **308** may request all changes to the registry of system information for the past forty eight hours, all files opened by system processes in the past day, all network connections or network communications within the past hour, or any other parametrized request for activities monitored by the data recorder **304**. In another aspect, the entire data log, or the entire log over some predetermined window of time, may be requested for further analysis at a remote resource.

[0073] It will be appreciated that communications among third party services **320**, a threat management facility **308**, and one or more endpoints such as the endpoint **302** may be facilitated by using consistent naming conventions across products and machines. For example, the system **300** may usefully implement globally unique device identifiers, user identifiers, application identifiers, data identifiers, Uniform Resource Locators, network flows, and files. The system may also or instead use tuples to uniquely identify communications or network connections based on, e.g., source and destination addresses and so forth.

[0074] According to the foregoing, a system disclosed herein includes an enterprise network, and endpoint coupled to the enterprise network, and a threat management facility coupled in a

communicating relationship with the endpoint and a plurality of other endpoints through the enterprise network. The endpoint may have a data recorder that stores an event stream of event data for computing objects, a filter for creating a filtered event stream with a subset of event data from the event stream, and a query interface for receiving queries to the data recorder from a remote resource, the endpoint further including a local security agent configured to detect malware on the endpoint based on event data stored by the data recorder, and further configured to communicate the filtered event stream over the enterprise network. The threat management facility may be configured to receive the filtered event stream from the endpoint, detect malware on the endpoint based on the filtered event stream, and remediate the endpoint when malware is detected, the threat management facility further configured to modify security functions within the enterprise network based on a security state of the endpoint.

[0075] The threat management facility may be configured to adjust reporting of event data through the filter in response to a change in the filtered event stream received from the endpoint. The threat management facility may be configured to adjust reporting of event data through the filter when the filtered event stream indicates a compromised security state of the endpoint. The threat management facility may be configured to adjust reporting of event data from one or more other endpoints in response to a change in the filtered event stream received from the endpoint. The threat management facility may be configured to adjust reporting of event data through the filter when the filtered event stream indicates a compromised security state of the endpoint. The threat management facility may be configured to request additional data from the data recorder when the filtered event stream indicates a compromised security state of the endpoint. The threat management facility may be configured to request additional data from the data recorder when a security agent of the endpoint reports a security compromise independently from the filtered event stream. The threat management facility may be configured to adjust handling of network traffic at a gateway to the enterprise network in response to a predetermined change in the filtered event stream. The threat management facility may include a machine learning model for identifying potentially malicious activity on the endpoint based on the filtered event stream. The threat management facility may be configured to detect potentially malicious activity based on a plurality of filtered event streams from a plurality of endpoints. The threat management facility may be configured to detect malware on the endpoint based on the filtered event stream and additional context for the endpoint.

[0076] The data recorder may record one or more events from a kernel driver. The data recorder may record at least one change to a registry of system settings for the endpoint. The endpoints may include a server, a firewall for the enterprise network, a gateway for the enterprise network, or any combination of these. The endpoint may be coupled to the enterprise network through a virtual private network or a wireless network. The endpoint may be configured to periodically transmit a snapshot of aggregated, unfiltered data from the data recorder to the threat management facility for remote storage. The data recorder may be configured to delete records in the data recorder corresponding to the snapshot in order to free memory on the endpoint for additional recording.

[0077] FIG. 4 illustrates a threat management system. In general, the system may include an endpoint **402**, a firewall **404**, a server **406** and a threat management facility **408** coupled to one another directly or indirectly through a data network **405**, all as generally described above. Each of the entities depicted in FIG. 4 may, for example, be implemented on one or more computing devices such as the computing device described herein. A number of systems may be distributed across these various components to support threat detection, such as a coloring system **410**, a key management system **412** and a heartbeat system **414**, each of which may include software components executing on any of the foregoing system components, and each of which may communicate with the threat management facility **408** and an endpoint threat detection agent **420** executing on the endpoint **402** to support improved threat detection and remediation.

[0078] The coloring system **410** may be used to label or color software objects for improved

tracking and detection of potentially harmful activity. The coloring system **410** may, for example, label files, executables, processes, network communications, data sources and so forth with any suitable information. A variety of techniques may be used to select static and/or dynamic labels for any of these various software objects, and to manage the mechanics of applying and propagating coloring information as appropriate. For example, a process may inherit a color from an application that launches the process. Similarly, a file may inherit a color from a process when it is created or opened by a process, and/or a process may inherit a color from a file that the process has opened. More generally, any type of labeling, as well as rules for propagating, inheriting, changing, or otherwise manipulating such labels, may be used by the coloring system **410** as contemplated herein.

[0079] The key management system **412** may support management of keys for the endpoint **402** in order to selectively permit or prevent access to content on the endpoint **402** on a file-specific basis, a process-specific basis, an application-specific basis, a user-specific basis, or any other suitable basis in order to prevent data leakage, and in order to support more fine-grained and immediate control over access to content on the endpoint **402** when a security compromise is detected. Thus, for example, if a particular process executing on the endpoint is compromised, or potentially compromised or otherwise under suspicion, keys to that process may be revoked in order to prevent, e.g., data leakage or other malicious activity.

[0080] The heartbeat system **414** may be used to provide periodic or aperiodic information from the endpoint **402** or other system components about system health, security, status, and so forth. A heartbeat may be encrypted or plaintext, or some combination of these, and may be communicated unidirectionally (e.g., from the endpoint **402** to the threat management facility **408**) or bidirectionally (e.g., between the endpoint **402** and the server **406**, or any other pair of system components) on any useful schedule.

[0081] In general, these various monitoring and management systems may cooperate to provide improved threat detection and response. For example, the coloring system **410** may be used to evaluate when a particular process is potentially opening inappropriate files based on an inconsistency or mismatch in colors, and a potential threat may be confirmed based on an interrupted heartbeat from the heartbeat system **414**. The key management system **412** may then be deployed to revoke keys to the process so that no further files can be opened, deleted, or otherwise modified. More generally, the cooperation of these systems enables a wide variety of reactive measures that can improve detection and remediation of potential threats to an endpoint.

[0082] FIG. 5 shows an enterprise network. In the enterprise network **500**, an endpoint **502** may access an enterprise resource **504** through a network device **506**, with security for the enterprise network managed by a threat management facility **508**. In general, the enterprise network **500**, the endpoint **402**, the enterprise resource **504**, the network device **506**, and the threat management facility **508** may be any of those described herein.

[0083] The endpoint **502** may include any of the endpoints, endpoint devices, compute instances, or other physical or virtual computing devices described herein. In one aspect, a user of the endpoint **502** may request or seek to use the enterprise resource **504**. The endpoint **502** may execute a local security agent **510**, also as described herein, that locally manages security of the endpoint **502** in cooperation with the threat management facility **508**. The endpoint **502** may also execute a local application such as a web browser or other application that accesses (or requests access to) the enterprise resource **504** through the network device **506**.

[0084] The enterprise resource **504** may generally include any application, database, data store, file server, web server, mail server, or other resource supported by an enterprise, including an application or the like locally hosted on customer premises, one or more remote resources, or any combination of these. In one aspect, the enterprise resource may include a protected resource such as an application secured by password access, and/or a zero trust network access resource accessible through a zero trust network access gateway for the enterprise network.

[0085] The network device **506** may include any network device such as a firewall, switch, wireless access point, gateway, and so forth. In general, services operating on the network device **506** may support network connectivity among other devices (including access to the enterprise resource **504**), and may support enterprise threat management through a connection to the threat management facility **508** and the local security agent **510** executing on the endpoint **502**. The network device **506** may advantageously incorporate a hardware security system **514** such as a dedicated chip or circuit that stores data for authenticating the network device **506** to other devices, or otherwise securing operation of the network device **506** or verifiably asserting an identity of the network device **506**. For example, Trusted Platform Module (TPM) is an international standard for a dedicated hardware cryptoprocessor that specifies an architecture, security algorithms, cryptographic primitives, root keys, authorization standards, and so forth that can be used for authentication. A TPM cryptoprocessor securely stores device-specific key material that is bound to a device at manufacture. The cryptoprocessor may also support various cryptographic functions (e.g., encryption, decryption, hashing, key generation, random number generation, etc.) for remote attestation, so that the cryptoprocessor can reliably authenticate the device to other entities on demand. In the context of a secure enterprise network, the hardware security system **514** permits the network device **506** to authenticate to the threat management facility **508** automatically or semi-automatically when the network device **506** is physically connected to a customer's enterprise network. While the Trusted Platform Module standard provides a useful and highly secure, hardware-based security system, any other standardized, proprietary, and/or commercial hardware-based security system may also or instead be used as the hardware security system **514**, provided the system offers suitable security, and, where applicable, provided the system supports remote authentication of the network device **506**, e.g., from the threat management facility **508**. For example, Platform Trust Technology from Intel™ and PSP fTPM from AMD™ provide similar functions and security to the TPM standard, and may be used to provide a hardware security system **514** as contemplated herein.

[0086] In one aspect, the network device **506** may include a zero trust network access (ZTNA) gateway that provides secure connectivity for user devices, such as the endpoint **502**, to a protected resource such as the enterprise resource **504**. The zero trust network access gateway, may, for example, support client access via a WebSocket service, and/or agentless access using a reverse proxy. The zero trust network access gateway may facilitate establishing and maintaining a connection with an endpoint-deployed local security agent **510** that is adapted for operation in a ZTNA environment. In general, the zero trust network access gateway may require authentication of endpoints **502** on a resource-by-resource basis. To this end, the system **100** may include an identity provider **516** that supports, e.g., secure, credential-based authentication of entities within the enterprise network **500**.

[0087] The threat management facility **508** may include any of the threat management facilities or other security resources described herein. The threat management facility **508** may generally support security of the enterprise network **500**, including a range of administrative services such as configuring gateways, managing protected resources, configuring the identity provider **516**, monitoring ZTNA appliances, creating notifications, generating reports, managing users, and the like. In one aspect, the threat management facility **508** may support security by detecting new network hardware such as the network device **506** when it is added to the enterprise network **500**, and by authenticating the new network hardware, such as the network device **506**, before permitting network traffic through the network device **506**.

[0088] In one aspect, the network device **506** may itself be an endpoint **502** that is managed by the threat management facility **508**. It should also be noted that an endpoint **502** other than a network device, such as a client device or other end user device, may also include a hardware security system **514** that can be used to authenticate an end user or an end user device to the threat management facility **508** (e.g., for delivery of security services or for entry into a managed

enterprise network), or to authenticate to a ZTNA gateway or the enterprise resource **504** (e.g., for zero trust network access to the enterprise resource **504** by a user of the device). Thus, notwithstanding specific embodiments described herein, the hardware security system **514** may generally be used to authenticate new hardware securely and reliably when it is added to the enterprise network **500**, or to authenticate a device or device user when requesting access to network resources, or any combination of these.

[0089] In one aspect, the local security agent **510** may provide a secure heartbeat, such as any of the secure heartbeats described herein. In the context of network access, the secure heartbeat may be used to assert an identity of a device, a device user, or a security posture of the endpoint **502** in order to facilitate access to the enterprise resource **504**, security services of the threat management facility **508**, or other network resources associated with the enterprise network **500**.

[0090] FIG. **6** shows a zero trust network access environment using a zero trust network access (ZTNA) appliance. In general, a portion of the infrastructure for zero trust network to an application may be deployed as a cloud-based service remotely from the customer premises where an application is hosted. By connecting this cloud-based infrastructure to a ZTNA appliance on the customer premises through a secure tunnel or the like, the application hosted behind the ZTNA appliance on the customer premises can then be accessed externally as a ZTNA application via the cloud-based service without the customer premises opening a firewall to public networks or otherwise exposing potential attack surfaces to the customer premises.

[0091] In general, a system **600** supporting the zero trust network access environment may include an application **602** hosted on a customer premises **604**, along with a ZTNA appliance **608** hosted on the customer premises **604**. The system **600** may include any of the ZTNA gateways, ZTNA applications, endpoints, and threat management facilities described herein, as well as any of the subcomponents or modules thereof. The ZTNA appliance **608** may be configured to provide zero trust network access to the application **602**.

[0092] In the system **600**, a cloud computing platform **614** hosted remotely from the customer premises **604** may be configured to provide a point of access to a device such as the user device **606** operated by a user who is associated with the customer premises **604**. To this end, the cloud computing platform **614** may host a zero trust network as a service (ZTNAaaS) platform **616** managed by the threat management facility **628** and configured to provide a network access point for ZTNA applications remotely hosted on the customer premises **604**. The ZTNAaaS platform **616** may, for example, include a reverse proxy server **612** for securely connecting to the customer premises **604** and a service proxy **618** providing a network access point. The ZTNAaaS platform **616** may also include an authentication server **620**, a configuration service **622**, and control plane services **624**. The cloud computing platform **614** hosting the ZTNAaaS platform **616** may also include other services and resources, such as an interface to external Domain name system resources, domain hosting resources, data caches (e.g., for customer configuration information), cloud computing resources (e.g., for managing compute instances, monitoring the ZTNAaaS platform **616**, and so forth), and network resources. For example, the cloud computing platform **614** may include a number of network load balancers such as a first network load balancer **626** and a second network load balancer **627** that distribute traffic (with the user device **606** and/or the customer premises **604**) across multiple targets, such as different compute instances hosted on the cloud computing platform **614**.

[0093] A threat management facility **628**, such as any of the threat management facilities described herein, may host a number of ZTNA services **630** for configuring and managing resources of the ZTNAaaS platform **616**, thus providing a control plane for zero trust network access to the application **602** hosted on the customer premises **604**. The ZTNA services **630** may be deployed, e.g., using any suitable microservices architecture or other environment suitable for scalable deployment or the like. In one aspect, the ZTNA services **630** may store configuration information such as application information, gateway information, security and use policies, identity and access

management information (including identity providers, if/as appropriate), and so forth. The ZTNA services **630** may also support many of the functions described herein, such as creating alias fully qualified domain names for connectors and agentless applications, validating domain ownership, and so forth. The threat management facility **628** may be hosted remotely from the cloud computing platform **614** and/or customer premises **604**, and may be coupled in a secure communicating relationship with the cloud computing platform **614** and/or customer premises **604**. In general, the threat management facility **628** may provide security services for the customer premises **604** (and external enterprise users) as described herein. The threat management facility **628** may also provide a user interface **634**, such as an administrative interface for administrative configuration of the ZTNA appliance **608**, or more generally for use in configuring the ZTNA environment as further described herein. The user interface **634** may also support management of any of the other security and ZTNA services described herein.

[0094] The cloud computing platform **614** may generally provide a configurable data plane for managing ZTNA connections from a user device **606** to the application **602**. To provide a network-facing access point, the service proxy **618** on the ZTNAaaS platform **616** may generally be configured to couple the user device **606** to the application **602** hosted on the customer premises **604**, e.g., by directing an incoming request from the user device **606** via the reverse proxy server **612** to a secure tunnel coupled to the reverse proxy client **610** at the customer premises **604**, where a second service proxy **632** on the ZTNA appliance **608** can authenticate a user at the user device **606** for access to the application **602** using any suitable authentication protocols, authentication factors, procedures, credentials, and so forth. In one aspect, a secure heartbeat from the user device **606**, such as any of the heartbeats described herein, may be used as an authentication factor for authenticating to the ZTNA appliance **608**, or otherwise asserting an identity of the user or security posture of the user device **606** to support the use of secure services, connections, and so forth.

[0095] In one aspect, the cloud computing platform **614** provides a data plane for zero trust network access to the application **602** hosted on the customer premises **604**. To this end, the cloud computing platform **614** may support an addressable access point at the service proxy **618**, which is connected by a data path through the reverse proxy server **612** to the reverse proxy client **610** on the customer premises **604**, and from there to the application **602**. In one aspect, the administrative interface of the threat management facility **628** may be configured to receive a Domain name system record identifying an address for the cloud computing platform **614**, e.g., for accessing an associated application **602**. Based on address information provided through the administrative interface, or where appropriate, information that is automatically generated, the cloud computing platform **614** may then provide a network address available from a public network for zero trust network access to the application **602**. The cloud computing platform **614** may also or instead provide a fully qualified domain name for zero trust network access to the application.

[0096] Returning to the customer premises **604**, the ZTNA appliance **608** may generally be configured, e.g., by a service proxy **632** managed by the ZTNA services **630**, to support ZTNA access to the application **602**. In this capacity, the ZTNA appliance **608** may authenticate users who request access to the application **602** from the user device **606**. Users may be authenticated using any suitable authentication techniques or protocols. For example, the ZTNA appliance **608** may authenticate users for access to the application **602** with a username and password, such as a username and password managed by the customer premises **604** or an identity management platform **640** such as a third party identity management platform external to the customer premises **604**, or an identity management platform hosted by the threat management facility **628** (which may also be a third party relative to the customer). In one aspect, the ZTNA appliance **608** may be configured to authenticate the user with two or more authentication factors including, by way of non-limiting examples, a biometric authentication factor, a hardware token authentication factor, an identifier such as an electronic mail or instant messaging address, a heartbeat from the user device **606** (e.g., a heartbeat from a security agent executing on the user device **606**), or any other

authentication factor associated with a user that the user can employ to assert identity to the ZTNA appliance **608**. The authentication factors and supporting credentials may in general be managed by the customer premises **604**, the threat management facility **628**, the identity management platform **640**, or any combination of these.

[0097] In order to securely couple the customer premises **604** to the cloud computing platform **614** for ZTNA delivery of the application **602**, the ZTNA appliance **608** may include a reverse proxy client **610**, and may be configured to initiate a secure connection to a reverse proxy server **612** on the cloud computing platform **614** in order to operatively couple the application **602** hosted on the customer premises **604** through the cloud computing platform **614** to the user device **606** operated by the user. In general, the reverse proxy server **612** and the reverse proxy client **610** may be any client-server modules suitable for establishing a secure tunnel between the ZTNA appliance **608** on the customer premises **604** and the cloud computing platform **614** where a front end of the ZTNA data plane is hosted. For example, the reverse proxy server **612** and reverse proxy client may be a Fast Reverse Proxy Server and Fast Reverse Proxy Client based on an open source project for exposing a local resource behind a firewall or Network Address Translation device to the Internet by port forwarding, or any other server/client architecture for securely connecting resources across a public data network.

[0098] In operation, the reverse proxy client **610** may initiate outbound TLS connections or the like to the reverse proxy server **612**, and then the reverse proxy server **612** can allocate a free port dynamically where the reverse proxy server **612** can listen for new connections from the ZTNA appliance **608**. In one aspect, the reverse proxy server **612** can be configured to authenticate connections from the reverse proxy client **610**, e.g., using the authentication server **620** of the ZTNAaaS platform **616**. For example, when the reverse proxy client **610** makes an initial connection to the reverse proxy server **612**, the reverse proxy server **612** may take a token supplied by the reverse proxy client **610**, and request that the authentication server **620** validate the token. This may include a token from the threat management facility **628**, a token from the identity management platform **640**, a token from a hardware security system on the ZTNA appliance **608**, or any other token or other secure, identifying information for verifiably asserting the identity of the ZTNA appliance **608**, or a user of the ZTNA appliance **608**, to the ZTNAaaS platform **616**. The reverse proxy client **610** may also provide additional details, such as gateway details for the application **602**, so that this information can be used to configure the ZTNAaaS platform **616**. If the authentication token is validated by the authentication server **620**, then a secure tunnel may be established. Otherwise, the connection may be terminated.

[0099] When a new connection is created, the reverse proxy server **612** may request configuration information from the configuration service **622**, which can store Internet Protocol (IP) address information, port details, and other information for the reverse proxy server **612** and the ZTNA appliance **608** (including, e.g., a name of the application **602** being supported by the connection), and provide an OK response (HTTP 200) to the reverse proxy server **612** upon proper configuration. The service proxy **618** may then be configured through the control plane service **624**, e.g., with data from the configuration service **622**, to respond to requests for the application **602** received from a device such as the user device **606**. In response to the OK response from the configuration service **622**, the reverse proxy server **612** may initiate listening for new connections to the application **602** on a port for the service proxy **618** in the ZTNAaaS platform **616**. If no OK response is received from the configuration service **622**, the connection to the reverse proxy client **610** may be terminated.

[0100] In general, the configuration service **622** may manage configuration information for the ZTNAaaS platform **616**, e.g., by synchronizing data on the ZTNAaaS platform **616** as customers or administrators make changes at the threat management facility **628**, and by notifying the control plane service **624** of changes. The configuration service **622** may monitor the ZTNA services **630** for configuration changes, e.g., by subscribing to an Amazon™ SNS Topic in an AWS

environment, or otherwise subscribing to a communication channel, listening for corresponding events, or otherwise communicating with the ZTNA services **630** to receive updates to configuration information. The configuration service **622** may, for example, be configured as a server plugin for the reverse proxy server **612** so that the reverse proxy server **612** issues a request to the configuration service **622** when a reverse proxy client **610** makes a connection. As a part of this request, the reverse proxy server **612** may provide information to the configuration service **622** about the connection to the reverse proxy client **610** such as the Internet Protocol address, port, gateway identifier, and tenant (e.g., customer) identifier. Using these details, the configuration service **622** may fetch information for the connection and cache the data in a suitable data store on the cloud computing platform **614**. For example, the configuration service **622** may fetch tenant (or customer) information, gateway information, information for applications configured for the gateway, customer uploaded certificates, heartbeat certificates, endpoint certificate and/or fingerprint lists, domain ownership details, and so forth.

[0101] The application **602** may be any application hosted on the customer premises **604** or any of the other enterprise resources described herein including without limitation databases, data management software, media players, connectivity applications or browsers, security programs, office productivity tools, games, or other general or business-specific applications. The application **602** may, for example, be an agentless application, e.g., an application that does not require services or processes running in the background on a user device **606**, and that typically requires an account for access to data and other local resources. The application **602** may also or instead include an agent-based application. For agentless applications, the service proxy **618** may differentiate customers using domain names for gateways and applications (where the same domain name cannot be used by two different customers). In this case, Mutual Transport Layer Security (mTLS) authentication, or any other suitably secure authentication, may be performed by the service proxy **618**. For agent-based applications, the service proxy **618** may be provided with customer certificates, which can be sent to a user's browser/agent for use, along with other certifying material such as a heartbeat, a fingerprint, user credentials, certificates and the like, as appropriate, in connecting to the service proxy **618**, which may be configured with corresponding routes to forward associated requests to tunnels that have been established for specific services/applications.

[0102] The user device **606** may generally include any of the endpoints or other compute instances or computing devices described herein. In one aspect, the user device **606** may include a local security agent, such as any of the local security agents described herein, configured to locally manage security of the user device **606**, connect to the threat management facility for remote management of device security, generate a heartbeat indicating a security state or other information about the user device **606**, and so forth.

[0103] The service proxies, such as the service proxy **618** for the ZTNAaaS platform **616** or the service proxy **632** for the ZTNA appliance **608**, may be any suitably configurable agents, modules, code segments, containers, computing objects, or the like. In a microservices architecture, a service proxy may more specifically operate as an intermediary between microservices application components, and provide a connection for clients to request various services. For example, Envoy is an open source edge and service proxy designed for use in cloud computing environments. Envoy provides a high performance distributed proxy for use in single services/applications, as well as large microservice architectures, and offers features such as API's for dynamic configuration, a small memory footprint, load balancing, and good observability, that make Envoy a good choice for use in the service proxies described herein. However, any other edge proxy or service proxy architecture, or other distributed computing framework suitable for scalable use and remote management in a cloud computing environment may also or instead be used to deploy and manage service proxies (and other resources) as described herein.

[0104] In one aspect, the ZTNA appliance **608** may be user-configurable to select between a

gateway mode and a cloud mode. In the cloud mode, the ZTNA appliance **608** may be configured as a ZTNA connector that provides access to the application **602** through the cloud computing platform **614** as generally described herein. That is, the ZTNA appliance **608** may be configured to make an outbound connection to the reverse proxy server **612** of the cloud computing platform, authenticate to the reverse proxy server **612** with the authentication server **620**, establish a secure tunnel between the ZTNA appliance **608** (at the customer premises **604**) and the reverse proxy server **612** (at the cloud computing platform **614**), and use the secure tunnel to provide zero trust network access to the application **602** hosted on the customer premises **604** by the user of the user device **606**. In this mode, the ZTNA connector may authenticate a user that accesses the application **602** through the secure tunnel to the cloud computing platform **614**, e.g., by using authentication services of the cloud computing platform **614**, the identity management platform **640**, the threat management facility **628**, or any other source(s) of trusted authentication services for the customer premises **604**.

[0105] A user-configurable ZTNA appliance **608** may also be configured or reconfigured, e.g., by a setting controlled through the user interface **634** of the threat management facility **628**, to operate in a gateway mode. In this gateway mode, the ZTNA appliance **608** may be configured as a ZTNA gateway to provide access to the application **602** through a firewall **650** hosted on the customer premises **604**, or connected between the customer premises **604** and an external data network. In this latter configuration, the gateway mode, the user device **606** would access the application **602** through the firewall **650** at the customer premises **604**, and through the ZTNA appliance **608**, which will operate as a ZTNA gateway to authenticate the user of the user device **606** for zero trust network access. Thus more generally, the ZTNA appliance **608** may be user-configurable by the customer (e.g., using the user interface **634** of the threat management facility **628**) to operate as either (a) a zero trust network access gateway exposed to a public network through a firewall **650** for the customer premises **604**, or (b) a zero trust network access connector coupled through a secure tunnel to a data plane hosted on the cloud computing platform **614**, and accessible via a service proxy **618** exposed to the public network (or other network used by the user device **606**). This approach advantageously permits a customer who is managing the customer premises **604** to select whether and when to use a firewall rather than a cloud-based data plane, and/or to deploy different applications using any combination of the foregoing. This also permits the customer to choose between access protocols, e.g., where the ZTNA gateway uses a Session Description Protocol (SDP) interface and the ZTNA connector uses a Software-as-a-Service (SaaS) interface.

[0106] According to the foregoing, a system for zero trust network access to a customer application, as described herein, may include an application hosted on a customer premises; a threat management facility configured to manage security for the customer premises; a cloud computing platform hosted remotely from the customer premises, the cloud computing platform configured to provide a point of access to a device operated by a user associated with the customer premises, and a zero trust network access appliance hosted on the customer premises. The cloud computing platform may include a service proxy configured to couple the device to the application hosted on the customer premises, a reverse proxy server connected to the service proxy, the reverse proxy server configured to securely connect to the customer premises, and an authentication server securely coupled to the threat management facility and configured to create a secure tunnel to the customer premises by authenticating a secure connection to the reverse proxy server. The zero trust network access appliance may be configured to initiate the secure connection to the reverse proxy server, and the zero trust network access appliance configured to operatively couple the application hosted on the customer premises through the cloud computing platform to the device operated by the user.

[0107] In another aspect, a system for zero trust network access to a customer application, as described herein, may include an application hosted on a customer premises; a cloud computing platform remote from the customer premises, the cloud computing platform providing a cloud-

based data plane for zero trust network access to the application; a zero trust network access appliance hosted on the customer premises, the zero trust network access appliance locally coupled to the application and remotely coupled to the cloud computing platform; and a secure tunnel between the cloud computing platform and the zero trust network access appliance, the zero trust network access appliance configured to provide zero trust network access to the application from the cloud computing platform through the secure tunnel.

[0108] The system **600** may include a sandbox **660** for testing components such as service proxies. As described herein, service proxies that provide an access point for applications through a data network may become increasingly complex as additional customers and applications are added. In order to ensure that a service proxy will function properly before deployment, a newly configured service proxy may advantageously be tested in a sandbox environment. In general, this may include any programming environment that simulates usage on the ZTNAaaS platform **616** and cloud computing platform **614** and permits testing and validation in that environment before the service proxy is deployed live. While the sandbox is depicted as residing on the threat management facility **628**, it will be understood that the sandbox may also or instead execute on the cloud computing platform **614** or some other separate environment configured for isolated testing of cloud computing components.

[0109] It will be understood that, while FIG. **6** depicts single entities such as a single user device **606**, a single application, **602**, a single ZTNA appliance **608**, a single reverse proxy server/client, and so forth, any number of users, applications, ZTNA appliances, and so forth, may be supported by the architecture described herein. This includes multiple instances of the same application, e.g., to scale access to an application, or multiple different applications hosted by a customer. This may also or instead include multiple, unaffiliated customer premises and customers using the cloud computing platform as a multi-tenant resource, as well as multiple cloud computing platforms collectively supporting a data plane for one or more customers or applications. Thus, any number of entities, connections, devices, servers, appliances, and the like may be used consistent with this disclosure, unless a specific number is explicitly provided or otherwise clear from the context. A number of additional features, configurations, and uses of the ZTNA environment are now provided.

[0110] FIG. **7** shows a method for validation of ZTNA configuration for a multi-tenant proxy environment. In general, a cloud-based platform for zero trust network access services provides zero trust network access as a service for multiple customers in a multi-tenant architecture. As a service proxy or the like becomes increasingly complex with the addition of new customers and applications, it becomes increasingly possible for programming conflicts, inconsistencies, or the like to impair operation of the service proxy, particularly where configuration information from one source (e.g., a user interface of a threat management facility) is being converted into an executable form for use by a service proxy or the like. In this context, the configuration for a new ZTNA application may advantageously be validated as an update to a preexisting service proxy that has a known, good configuration before release of the new ZTNA application for access through a public network by the cloud-based platform. As a significant advantage, this approach mitigates inadvertent conflicts or instability in a service proxy that supports other applications and customers. In general, the cloud-based platform, customers, customer premises, service proxies, applications, and other components discussed below may be any as described herein.

[0111] As shown in step **702**, the method **700** may begin with providing configuration information for a service proxy, e.g., by configuring a service proxy in an administrative interface or other user interface, or otherwise receiving a customer configuration for a service proxy for deployment on a cloud computing platform to provide zero trust network access to an application hosted on a customer premises. This may include providing the configuration information, e.g., through a user interface of a threat management facility that hosts a control plane for managing the zero trust network access through the ZTNA services described herein. This may also or instead include

providing configuration information for the service proxy such as a fully qualified domain name for the application or any other suitable network address information for accessing the application through a data network. The configuration information may also or instead include a fully qualified domain name for a zero trust network access appliance that provides access to the application. In another aspect, the configuration information may include a digital certificate, a digitally signed certificate, or other key material for authenticating the application to a user, or otherwise securely managing the application and access thereto.

[0112] As shown in step **704**, the method **700** may include launching a first instance of the service proxy in a sandbox environment such as any of the sandboxes described herein. In one aspect, the service proxy may include an edge proxy positioned on an edge of the cloud computing platform and coupled to a public network such as the Internet or any other data network that might be used by a user device to access a ZTNA application.

[0113] As shown in step **706**, the method **700** may include loading validated configuration information into the first instance of the service proxy for one or more other applications previously validated in the sandbox environment. This provides a known, working configuration of a service proxy for testing. This may, for example, include a configuration for one or more other applications, such as at least one application hosted by a different tenant of the cloud computing platform than a customer who is configuring the service proxy. As a significant advantage, this facilitates the identification and resolution of addressing or routing conflicts where multiple tenants are using a single cloud computing platform **614** for cloud-based ZTNA access.

[0114] As shown in step **708**, the method **700** may include loading new configuration information, such as by loading the configuration information for the application from step **702** into the first instance of the service proxy. In this manner, the service proxy may be incrementally updated from a known, working configuration to a new configuration that supports one or more new applications that a customer wishes to deploy as ZTNA applications through the ZTNAaaS platform.

[0115] As shown in step **710**, the method **700** may include validating proper operation of the service proxy with the new configuration information, e.g., by testing the first instance of the service proxy for proper operation in the sandbox environment. Testing may, for example, include at least confirming that the first instance of the service proxy is executing and responsive. Testing may also or instead include confirming that the first instance of the service proxy correctly responds to a request for the application for which new configuration information was provided. Any number and type of tests may also or instead be performed. For example, testing the first instance of the service proxy for proper operation may include requesting the configuration information for the application from the first instance of the service proxy, or requesting configuration information for one or more other applications supported by the first instance of the service proxy. Other testing may, for example, including testing that the first instance of the service proxy responds to a request for access to each one of the applications supported by the first instance of the service proxy, or otherwise confirming responsiveness and proper operation thereof. In one aspect, this may include presenting a request to the service proxy in the testing environment, such as a request for an application, e.g., using a fully qualified domain name for the application or any other suitably addressed request in the testing environment.

[0116] As shown in step **712**, it may be determined if the validation is successful. If the validation is successful, the method **700** may proceed to step **714** where, in response to validating proper operation of the first instance of the service proxy in the sandbox environment, the method **700** may include loading the configuration information for the application into a second instance of the service proxy executing on the cloud computing platform and coupled to a public network. This may, for example include updating the second instance of the service proxy using the ZTNA services of a threat management facility and the configuration services of a ZTNAaaS platform as described herein.

[0117] The second instance of the service proxy may be coupled to other components of a system

to support ZTNA access as described herein. For example, the second instance of the service proxy may be coupled to a zero trust network access appliance hosted on a customer premises in order to access an application hosted on the customer premises. In one aspect, the service proxy may be coupled to the zero trust network access appliance through a secure tunnel. The second instance of the service proxy may also or instead be coupled to the zero trust network access appliance through a reverse proxy server. In one aspect, the second instance of the service proxy may execute on a cloud computing platform to provide service proxies for the application according to the validated configuration information. The second instance of the service proxy may support multiple applications, customers, and users. For example, the second instance of the service proxy may be coupled to a public network, such as the Internet or any other data network, through a network load balancer to provide a scalable network front end. The second instance of the service proxy may also or instead support one or more other applications associated with one or more other tenants of the cloud computing platform. More generally, the second instance of the service proxy (and/or the first instance of the service proxy) may be configured to support access to any number of different applications, including multiple applications for a single customer, applications for two or more different customers, or any combination of these.

[0118] As shown in step **716**, where the validation is not successful, the method **700** may include initiating remedial action. This may include notifying an administrator, preventing deployment of the configuration, or any other suitable remediation. Where testing information is available from the sandbox, this may also include notifying a recipient of the specific nature of the failure, and where available, suggesting reconfigurations to address the failure.

[0119] In another aspect, a system described herein includes a customer premises hosting an application; a threat management facility configured to provide a user interface for receiving configuration information for zero trust network access to the application; a testing environment configured to test a service proxy for proper operation when loaded with the configuration information; and a cloud computing platform configured to host the service proxy, the cloud computing platform further configured to receive the configuration information for the application upon validation in the testing environment, and to provide zero trust network access to the application based on the configuration information.

[0120] The system may include a zero trust network access appliance hosted on the customer premises. The zero trust network access appliance may be configured to authenticate a user connecting to the application through the service proxy executing on the cloud computing platform. The system may test the service proxy in the testing environment by presenting a request for access to the application using a fully qualified domain name for the application.

[0121] FIG. **8** shows a method for domain ownership verification for a ZTNA service platform. In general, a cloud computing platform may provide zero trust network access as a service to a customer that maintains an application on-premises, as generally described herein. In this context, the customer may be required to demonstrate ownership of a domain before the cloud computing platform will provide access to the customer's on-premises application via the domain, thus preventing accidental addressing conflicts or intentional misuse of domains that are owned by other parties. In general, the cloud computing platform, customers, customer premises, applications, and other components discussed below may be any as described herein.

[0122] As shown in step **802**, the method **800** may include initiating registration of an application on a ZTNAaaS platform, such as any of the ZTNAaaS platforms or supporting infrastructure described herein, e.g., by submitting a registration request to a user interface of a threat management facility.

[0123] As shown in step **804**, the method **800** may include receiving a request from a customer to register a domain for zero trust network access to an application hosted on a customer premises. Receiving the request may, for example, include receiving the request at a user interface of a threat management facility or other console or management point for the ZTNAaaS platform. Receiving

the request may more specifically include receiving a request from a customer that is hosting an application on a customer premises to register a domain for zero trust network access to the application through a service hosted on a cloud computing platform. The cloud computing platform may, for example, include a cloud-based zero trust network access platform providing zero trust network access as a service to one or more customers, such as any of the ZTNAaaS platforms and related infrastructure described herein, or any other cloud-based system suitable for supporting a ZTNA data plane external to a customer premises as described herein. Where the application is to be accessed by an agentless application on a user device, access may require a domain name (e.g., a fully qualified domain name) to locate the application on the network. In order to facilitate such access, and to reliably configure service proxies and other infrastructure in the ZTNAaaS platform to support proper addressing of incoming application requests, the ownership of each domain name used to route application requests may advantageously be verified as described herein.

[0124] The domain name specified by the request may include a top level domain or sub-domain that the customer provides for network access to an application. In one aspect, verification of a domain (e.g., foo.com), may include verification of sub-domains for the domain (e.g., abc.foo.com), but not sub-sub-domains (e.g., 123.abc.foo.com). This convention can advantageously provide a greater address space for the verifier, while avoiding conflicts with other authorized users of sub-domains (who might otherwise allocate conflicting sub-sub domain names).

[0125] As shown in step **806**, the method **800** may include generating a token. This may include, for example, generating, at a threat management facility or other location associated with the ZTNAaaS platform and infrastructure, a random string or the like for use as the token in response to the customer request for verification. Information may be encoded into the token such as a time stamp, source identifier, digital signature, or other information. However, this information is not generally required for purposes of domain ownership verification as described herein, e.g., where the token can be securely stored, tamper-free, by the threat management facility until it is needed for comparison to a text record maintained by a Domain Name System host for the domain, e.g., in a DNS record **808**.

[0126] As shown in step **810**, the method **800** may include providing the token to the customer. The token may be provided by transmitting the token for display in a user interface such as a user interface of the threat management facility where the customer is registering the domain. The token may also or instead be provided by transmitting the token to a predetermined address associated with the customer, such as an electronic mail address, an instant messaging address, a telephone number, or the like. Operationally, once a token has been provided to the user, the threat management facility may prompt the user for verification with a “verify” button. This provides the customer with an opportunity to update the DNS record **808** before continuing with the verification process.

[0127] As shown in step **812**, the method **800** may include receiving the token, e.g., using any of the techniques described above. For example, the token may be displayed to the customer in a user interface such as the user interface for the threat management facility (e.g., in a location near the “verify” button), or the token may be provided in an instant message, electronic mail or the like.

[0128] As shown in step **814**, the method **800** may include updating the DNS record **808** for the domain from a customer account with the DNS host. This may, for example, include logging into the DNS host as an administrator, launching a management console, selecting the appropriate domain name, and then adding a new record. In particular, DNS provides a DNS TXT record for storing owner-configurable, publicly accessible text associated a domain name. The DNS TEXT record thus provides a convenient medium for adding user-selected data, such as the token, without altering functional DNS server data for the domain name, such as corresponding IP addresses.

[0129] As shown in step **816**, the method **800** may include checking for a presence of the token in the DNS record **808**, such as a Domain Name System text record (“DNS TXT record”) stored for

the domain at a DNS host. In general, DNS data is made publicly available by the DNS host, so the threat management facility (or other resource) may query this information, e.g., using a Linux dig command, nslookup, or other technique to access DNS records, and more specifically to check whether the token sent to the customer can be located in the DNS TXT record. This verification may be deferred, e.g., until a customer selects a “verify” button or the like, in order to provide the customer with an opportunity to update the DNS record **808**. Thus in one aspect, the method **800** may include receiving an explicit request to verify the domain from the customer before checking for the presence of the token in the domain name system text record. The method may also or instead include automatically checking for the presence of the token in the domain name system text record after providing the token to the customer, e.g., by waiting a predetermined time and, if the user has not manually requested verification, proceeding with an automatic verification. If the ownership cannot be verified (by presence of the token in the DNS record **808**) after a predetermined time, then the verification process may be terminated or expired, requiring the customer to initiate a new registration request, e.g., by returning to step **802**.

[0130] As shown in step **818**, the method **800** may include registering the domain to the customer, e.g., for accessing ZTNA applications hosted on the customer premises through the ZTNAaaS data plane. This step may advantageously be deferred until the verification is completed as described above, however, the method **800** may also or instead include registering the domain while imposing other safeguards on use of the registered domain while verification is pending. In one aspect, registering the domain may include configuring a service proxy on the cloud computing platform to provide access to the application on the customer premises, e.g., by updating configuration information for the service proxy and reverse proxy server in the ZTNAaaS platform to direct requests received at the cloud computing platform to an appropriate ZTNA appliance at the customer premises, e.g., a ZTNA appliance that is providing access to the target application.

[0131] This may also include additional configuration steps at the ZTNAaaS platform, such as creating a secure tunnel from the cloud computing platform to the application on the customer premises, e.g., through a ZTNA appliance. Creating the secure tunnel may include coupling the secure tunnel with the reverse proxy server at the cloud computing platform. Creating the secure tunnel may also or instead include coupling the secure tunnel with a zero trust network access appliance at the customer premises.

[0132] Registering the domain to the customer may also or instead include supporting use of the ZTNA application according to the configuration. For example, registering the domain may include, in response to a request from a client to the domain, providing zero trust network access for the client to the application through the cloud computing platform.

[0133] Registering the domain to the customer may also or instead include additional administrative steps after verification. For example, if a verified domain was previously registered to a different user, the method **800** may include invalidating or revoking this conflicting claimed ownership, e.g., in any conflicting components throughout the control and data plane including, e.g., any conflicting configuration information in service proxies, ZTNA appliances, threat management facilities, and so forth.

[0134] As shown in step **820**, the method **800** may also include configuring the ZTNA appliance for access to the application at the registered domain name. This may include any necessary configuration of the ZTNA appliance, which may be performed locally at the customer premises and/or through an administrative interface at the threat management facility, as well as ensuring that instances of the application are executing on the customer premises and connected to the ZTNA appliance in a manner suitable for remote access. After the ZTNAaaS platform, ZTNA appliance, and application have been configured, a request from a client to the domain, if received at the cloud computing platform, may be responded to by providing zero trust network access for the client to the application through the cloud computing platform.

[0135] According to the foregoing, there is also disclosed herein a system including a customer

premises hosting an application; a cloud computing platform coupled to the customer premises through a secure tunnel, the cloud computing platform configured to provide zero trust network access to the application through the secure tunnel; a threat management facility providing a control plane for the zero trust network access, the threat management facility configured to: receive a request from the customer to register a domain for zero trust network access to the application; provide a token to the customer; locate the token in a record stored at a domain name system host for the domain; and register the domain for access to the application through the zero trust network access provided by the cloud computing platform.

[0136] The system may include a reverse proxy server executing on the cloud computing platform and coupled to the secure tunnel for secure communications with the customer premises. The system may include a zero trust network access appliance at the customer premises and coupled to the secure tunnel for secure communications with the cloud computing platform. The zero trust network access appliance may include at least one of a hardware appliance and a virtual appliance. [0137] FIG. 9 shows a cloud computing platform with an abstraction layer that maps application domains to network load balancers. In general, a system **900** may connect a user device **902** to an application **904** hosted on customer premises **906** through the customer's ZTNA appliance **908**, which connects, via a secure tunnel **910** between a reverse proxy server **912** and a reverse proxy client **914**, through a network load balancer **916** to a ZTNAaaS platform **918** that includes a service proxy **920** that is configurable to resolve requests and direct them to the correct secure tunnel for a corresponding application. The service proxy **920** may be positioned behind a second network load balancer **922** in order to support scalability by managing the distribution of incoming requests for ZTNA applications among available resources. In general, each service proxy **920** may be configured to support multiple applications for a single customer, as well as applications for two or more different customers at different customer premises. Thus, the service proxies **920** may be arranged into clusters of service proxies **920**, each associated with one of the network load balancers **922**, and each associated with one or more specific ones of the applications **904**. The user device **902**, application **904**, customer premises **906**, ZTNA appliance **908**, secure tunnel **910**, reverse proxy server **912**, reverse proxy client **914**, network load balancer **916**, ZTNAaaS platform **918**, service proxies **920**, network load balancers **922** and other components may all be any such components described herein, or the like.

[0138] The cloud computing platform **924** hosting the ZTNAaaS platforms **918** may include an abstraction layer **930** interposed between the user device **902** and the network load balancers **922** for the cloud computing platform **924**. The abstraction layer **930** may be configurable, e.g., by a threat management facility (not shown), to map requests for a particular domain (e.g., a domain associated with a specific one of the applications **904**) to a specific one of the network load balancers **922**. This permits administrative control, e.g., through the threat management facility or other administrative components, over which application requests (and/or domain names) are directed to which network load balancers **922**. By providing this abstraction layer **930**, each service proxy **920** may advantageously be assigned to a predetermined subset of applications **904**, and each network load balancer **922** may, in turn, be assigned to a predetermined subset of service proxies **920**. Network load balancer **922** may be assigned to a predetermined group of applications **904**. This approach advantageously simplifies the configuration of service proxies **920** at the cloud computing platform **924** by permitting dedicated relationships among network load balancers **922** facing a public network, specific service proxies **920** in the cloud computing platform **924**, and specific applications **904** on customer premises **906**, while concurrently reducing or avoiding the administrative burden on customers of updating network pointers when clusters of service proxies allocated to a specific application **904** are periodically reconfigured to adjust to varying user traffic. [0139] According to the foregoing, in one aspect there is disclosed herein a system including a customer premises hosting an application, the customer premises including a zero trust network access appliance configured to provide zero trust network access to the application through a secure

tunnel. The system may also include a cloud computing platform coupled to the zero trust network access appliance through the secure tunnel, the cloud computing platform comprising one or more processors and memory storing code that, when executing on the one or more processors, performs the steps of: hosting a cluster of service proxies, the cluster of service proxies configured to provide access to the application, providing a network load balancer associated with the cluster of service proxies, and providing an abstraction layer that maps requests for a domain to the network load balancer for the cluster of service proxies associated with the corresponding application. The system may generally include any of the customer premises, applications, zero trust network access appliances, secure tunnels, cloud computing platforms, service proxies, network load balancers, and abstraction layers described herein.

[0140] The system may also include a threat management facility, such as any of the threat management facilities described herein. The threat management facility may be configured to provide a control plane for zero trust network access to the application, and to manage network security for the customer premises. In order to facilitate the use of an abstraction layer, the threat management facility may be further configured to generate an alias domain for the application and transmit the alias domain to the cloud computing platform for use as the domain (for accessing the application) in the abstraction layer. In one aspect, the cloud computing platform hosts a plurality of clusters of proxies, each one of the plurality of clusters of proxies associated with a predetermined one or more applications in a group of applications that is different from each other one of the plurality of clusters of proxies. In another aspect, the cloud computing platform may be configured to add a service proxy to the cluster of service proxies or remove a service proxy from the cluster of service proxies based on a demand for use of the application. In this manner, access to applications may be organized and scaled as needed according to, e.g., network traffic or other performance metrics.

[0141] FIG. **10** shows a method of using alias domains for accessing ZTNA applications. Where a cloud computing platform provides zero trust network access as a service to customers that maintain applications on-premises, the cloud computing platform may advantageously associate customers and/or applications with specific service proxies. An abstraction layer for network access may then be added that maps an alias domain for each customer and/or application to a network load balancer associated with the specific service proxies associated with the corresponding application(s). In general, the method **1000** may be performed using the systems, computing devices, and other methods described herein. For example, a cloud computing platform may be configured to provide a data plane for zero trust network access to an application hosted on a customer premises, as described herein, and the cloud computing platform may include a cloud-based zero trust network access platform configured to provide zero trust network access as a service to a plurality of customers associated with a plurality of customer premises (including the customer premises where the application is hosted).

[0142] As shown in step **1002**, the method **1000** may include creating a cluster of service proxies and hosting the cluster of service proxies on a cloud computing platform. In general, the cluster of proxy servers may be a dedicated cluster servicing one or more predetermined applications, which may include one or more predetermined applications for a specific customer, or one or more applications associated two or more different customers having different customer premises. This may, for example, include independent corporations or other business or organizational entities. This may also or instead include independent divisions or the like within such entities. The nature of these independently operated customers is not important, except to illustrate that there need not be any preexisting operational or legal relationship among different customers in order for them to share a cloud computing platform and/or cluster of proxy servers as contemplated herein.

[0143] The cluster of service proxies may be configured to provide access to at least one application on at least one customer premises, e.g., by configuring each of the service proxies to respond to requests for the at least one application, or more generally, to a specific and

predetermined sub-group of the applications and/or customers supported by the cloud computing platform. While the cloud computing platform might otherwise be required to configure each service proxy to respond to all managed applications, associating specific clusters of service proxies with specific subsets of applications advantageously permits the cloud computing platform to independently manage a group of service proxies (e.g., in the cluster) that is responsible for the specific subset of applications. This may include a group of applications related to a specific customer premises, or a group of applications spanning two or more different customer premises. In one aspect, each service proxy in a cluster may be identically configured so that a network load balancer can make allocations based on quantity of connections, or other traffic or performance metrics, rather than whether a particular service proxy can access a particular application. However, the advantages of the technique disclosed herein may also be achieved for a group of differently configured service proxies, e.g., where each service proxy in the cluster is configured for traffic to at least one set of applications that is common among all of the service proxies in the cluster.

[0144] As shown in step **1004**, the method **1000** may include coupling the cluster of service proxies to a specific one of the network load balancers in the cloud computing platform. It will be appreciated that in one aspect, a cluster of service proxies may be associated with two or more of the network load balancers, and in another aspect, one of the network load balancers may be associated with two or more different clusters of service proxies associated with different groups of applications. In general, these allocations may depend on the volume of traffic for each application or customer, provided that a predetermined relationship between network load balancers and clusters of service proxies is maintained in a manner that facilitates the use of an abstraction layer to couple an external network request with an appropriate service proxy for a requested application. When arranged in this manner, the use of the abstraction layer can advantageously relieve the customer from identifying and configuring specific service proxies that are responsible for the customer's ZTNA applications deployed through the cloud computing platform.

[0145] In general, coupling to a specific load balancer, and the other administrative steps described herein (e.g., excluding operation of the ZTNA application and other unmanaged customer premises components), may be managed with a threat management facility such as any of those described herein. In one aspect, the threat management facility may be hosted remotely from the customer premises, and may provide security services for the customer premises. The threat management facility may also be configured to provides a control plane for zero trust network access to the application hosted on the customer premises.

[0146] As shown in step **1006**, the method **1000** may include creating an alias domain for zero trust network access to one of the applications. This may include a preliminary check of whether a domain is owned by the customer who is creating a new ZTNA appliance or ZTNA application. For example, a preliminary check of domain ownership (or control) may be performed using domain ownership verification as described herein. If ownership (or control) is sufficiently verified, then creating the alias domain may include creating a fully qualified domain name (FQDN) for each ZTNA appliance configured for the application. The FQDN may, for example, include a Universal Unique Identifier (UUID), a gateway/application name, or other identifier to uniquely identify the application in a network environment, along with other zone information, region information, or other domain name identifiers or the like providing a unique path specifying a location where the application can be accessed. Creating the alias domain will also generally include updating DNS records so that the DNS record (or CNAME record, as appropriate) for the alias domain points to an address, such as an IP address, where a network load balancer for the application can be reached.

[0147] In one aspect, the alias domain may be managed by the threat management facility and communicated to the cloud computing platform, e.g., by providing a configuration service role that can create and delete zone records for a domain that is stored in the cloud computing platform, e.g.,

using a cross-account trust relationship between the threat management facility and the cloud computing platform. Whenever a gateway or application is created (or updated or deleted), the service may create (or update or delete) the corresponding alias domain in the cloud computing platform, or a Domain Name System web service or the like used by the cloud computing platform to manage addressing for applications. Thus in one aspect creating the alias domain may include creating the alias domain at the threat management facility and transmitting the alias domain to the cloud computing facility. In general, a DNS zone may be limited to a certain number of records. Thus in one aspect, once this quota has been reached with alias domains, a new zone may be created with corresponding sub-domains for additional applications.

[0148] More generally, any suitable techniques for generating a functioning domain name and mapping it at a DNS host to an address for a specific load balancer (e.g., a load balancer allocated to a cluster of service proxies for an associated application) may be used to create alias domains as described herein.

[0149] As shown in step **1008**, the method **1000** may include providing an abstraction layer for the cloud computing platform that maps the alias domain to the network load balancer. In general, this may include any programmatic technique for associating alias domains with applications (or service proxies, or load balancers) in a manner that permits incoming requests for applications to be coupled to a specific one or more of the load balancers. For example, this may include a database or other data store or the like storing records that map domain and/or path information associated with an application to one or more predetermined load balancers that are coupled, in turn, to a cluster of service proxies configured to service requests for the corresponding application(s). The abstraction layer may also or instead include code to route or otherwise couple network requests received from an external network (e.g., from the user device **902** illustrated in FIG. **9**) to the appropriate load balancer(s) and service proxy clusters based on this mapping. In general, the abstraction layer may be updated as needed to reflect changes in the allocation of applications and ZTNA appliances to different clusters of service proxies.

[0150] As shown in step **1010**, the method **1000** may include receiving a request from a client at the cloud computing platform for an application serviced by a predetermined cluster of service proxies. In general, the application may include any of the ZTNA applications or other enterprise resources described herein, and the client may be any of the user devices or other computing devices described herein.

[0151] As shown in step **1012**, the method **1000** may include connecting the request to a network load balancer with the abstraction layer. This may include identifying, based on data stored in the abstraction layer, or accessible to the abstraction layer, a cluster of service proxies associated with the requested application, and connecting the requested through the abstraction layer to the appropriate network load balancer. In another aspect, this may include directly identifying one or more predetermined network load balancers associated with the corresponding cluster of service proxies, and routing communicating the request to the network load balancer. In this case, the request will be communicated by the network load balancer to one of the service proxies in the dedicated cluster, each of which have been preconfigured to handle requests for the associated application.

[0152] As shown in step **1014**, the method **1000** may include selecting a selected one of the service proxies from the cluster of service proxies with the network load balancer. In general, a network load balancer automatically distributes network traffic across multiple targets such as links, machines, virtual machines, compute instances, containers, IP addresses, or the like. The network load balancer may thus select a target for an incoming request using any suitable algorithm based on, e.g., the communication protocol, the source address and port, the destination address and port, a Transmission Control Protocol (TCP) sequence number, and so forth, and/or based on the health or responsiveness of available targets. These techniques may be used to efficiently distribute incoming requests for an application among the number of service proxies in a manner that

balances use of each of the service proxies in the cluster. Each service proxy may, in turn distribute requests to one or more specific application instances associated with that service proxy in order to similarly balance use of application instances hosted on customer premises.

[0153] As shown in step **1016**, the method **1000** may include connecting the request to the selected one of the service proxies from the cluster of service proxies with the network load balancer.

[0154] As shown in step **1018**, the method **1000** may include connecting the request to the application hosted on the customer premises (e.g., with a ZTNA appliance as described herein) using the selected one service proxies from the cluster of service proxies, or more generally, transmitting the request to the application. This may include authenticating the client, or the user of the client, for zero trust network access to the at least one application, e.g., by requesting suitable credentials or other authentication factor(s) with the ZTNA appliance and authenticating the received credentials/factors with an identity management platform, such as any described herein, or any other trusted identity management infrastructure.

[0155] In general, the method **1000** described herein may be used with any of the other systems and methods described herein. Thus for example, transmitting the request to the application may include authenticating a client to the application for zero trust network access to the application, and or authenticating the application (or ZTNA appliance or the like) to the cloud platform when creating a secure tunnel therebetween. Transmitting the request to the application may also or instead include transmitting the request through a zero trust network access appliance hosted on the customer premises. In another aspect, transmitting the request to the application may include transmitting the request through a reverse proxy server hosted on the cloud computing platform, such as a reverse proxy server securely coupled to the zero trust network access appliance hosted on the customer premises. As further described herein, the reverse proxy server may be coupled to the zero trust network access appliance through a second network load balancer, and a reverse proxy client on the zero trust network access may authenticate to the reverse proxy server when establishing a secure tunnel between the customer premises and a cloud computing platform for the ZTNA data plane.

[0156] Using this technique, the infrastructure details for the network load balancer(s) handling application traffic may be abstracted, facilitating easier migration of application traffic from one network load balancer to another. This can also facilitate, where necessary or helpful, explicit partitioning of customer traffic, e.g., for improved performance.

[0157] FIG. **11** shows a hybrid appliance for zero trust network access to customer applications. In general, a zero trust network access appliance deployed at a customer premises can support a gateway mode and a cloud mode. In the gateway mode, the appliance may operate as a zero trust network access gateway and provide zero trust network access to applications hosted at the customer premises using a firewall at the customer premises for network security. In the cloud mode, the appliance may initiate a secure connection with a remote, cloud computing platform that provides a front end for zero trust network access. A threat management facility for the customer may provide a control plane for managing zero trust network access provided through the cloud computing platform, and for selecting between the cloud mode and the gateway mode for the appliance. In general, the applications, appliances, gateways, customer premises, firewalls, cloud computing platforms, threat management facilities, and other components may be any as described herein.

[0158] As shown in FIG. **11**, the system **1100** may include a customer premises **1102** hosting an application **1104** through a ZTNA appliance **1106**. The ZTNA appliance **1106** may be managed by a threat management facility **1108**, all as generally described herein. A cloud computing platform **1110** may host a ZTNAaaS service that provides a configurable data plane for ZTNA access to the application **1104**, e.g., by a user device **1112**. The ZTNA appliance **1106** may be a hybrid appliance configured to operate in either a cloud mode or a gateway mode. In the cloud mode, the hybrid appliance may provide a first data path **1114** for the application **1104** through the cloud computing

platform **1110** (via a local reverse proxy client **1116**). In the gateway mode, the hybrid appliance may provide a second data path **1118** through a firewall **1120** on the customer premises **1102**. The ZTNA appliance **1106** may generally include a service proxy **1122**, such as any of the service proxies described herein, configured to manage ZTNA functions of the ZTNA application, and further configured to switch between the cloud mode and the gateway mode, e.g., under control of a cloud agent **1124** securely coupled to the threat management facility **1108**.

[0159] According to the foregoing, there is disclosed herein a system **1100** including an application **1104** hosted on a customer premises **1102**. The system **1100** may also include a firewall **1120** between the customer premises **1102** and a public data network (not shown), and a threat management facility **1108** configured to manage security for the customer premises **1102**. The system **1100** may also include a cloud computing platform **1110** hosted remotely from the customer premises **1102**, and the cloud computing platform **1110** may be configured to provide zero trust network access to the application **1104** by a user device **1112** operated by a user associated with the customer premises **1102**. The system **1100** may also include a zero trust network access appliance **1106** hosted on the customer premises **1102**.

[0160] As described herein, the zero trust network access appliance **1106** may be a hybrid appliance configured to respond to a user input (e.g., from an administrative console of the threat management facility **1108**) by selecting between operating in a gateway mode and operating in a cloud mode. In the gateway mode, the zero trust network access appliance **1106** may operate as a zero trust network access gateway to provide zero trust network access from the public data network to the application **1104** through the firewall for the customer premises **1102**. In the cloud mode, the zero trust network access appliance **1106** may act as a zero trust network access connector coupling the application **1104** hosted on the customer premises **1102** to the cloud computing platform through a secure tunnel to provide zero trust network access from the public data network to the application **1104** through the cloud computing platform **1110**. The threat management facility **1108** may generally provide a control plane for configuring the zero trust network access appliance to operate in the cloud mode or the gateway mode, e.g., by accessing the zero trust network access appliance **1106** through the cloud agent **1124**.

[0161] As also generally described herein, the zero trust network access appliance **1106** may be configured to authenticate a user on the user device **1112** (or in some instances, the user device **1112** itself) for zero trust network access to the application **1104**, e.g., with user credentials, one or more other authentication factors, or any combination of these or the like. For example, the zero trust network appliance **1106** may authenticate using biometric authentication factors, hardware-based tokens or authentication factors, software-based tokens or authentication factors, user credentials, and so forth. In one aspect, a heartbeat from a user device, such as any of the heartbeats described herein, may include a secure (e.g., encrypted or signed) assertion of a health status of the user device, which may be used as an authentication factor when controlling access to the application **1104** through the zero trust network access appliance. In one aspect, the zero trust network appliance **1106** may authenticate the user using a third party identity management platform external to the customer premises **1102**, or using any other source of trust and/or identity information. In another aspect, the cloud computing platform **1110** may be configured to authenticate the user for zero trust network access to the application **1104**, e.g., by providing an authentication server or other authentication infrastructure through the secure tunnel provided by the reverse proxy client **1116**, and/or using a secure connection to the threat management facility **1108** or a separate, trusted source of authentication services.

[0162] As also generally described herein, the cloud computing platform may provide a data plane for zero trust network access to the application **1104** hosted on the customer premises **1102**. The system **1100** may also include a reverse proxy server **1126** on the cloud computing platform **1110**, which may be configured to create the secure tunnel with the zero trust network access appliance **1106** hosted on the customer premises **1102**. In one aspect, the zero trust network access appliance

1106 may be configured to make an outbound connection to the reverse proxy server **1126** of the cloud computing platform **1110**, authenticate to the reverse proxy server **1126** with an authentication server (not shown) hosted on the cloud computing platform **1110**, establish a secure tunnel between the zero trust network access appliance **1106** and the reverse proxy server **1126**, and use the secure tunnel to provide zero trust network access by the user of the user device **1112** to the application **1104** that is hosted on the customer premises **1102**.

[0163] In one aspect, the threat management facility **1108** may be configured to provide a user interface for administrative configuration of the zero trust network access appliance **1106** and the cloud computing platform **1110**. For example, the user interface may facilitate user selection between the gateway mode and the cloud mode for the zero trust network access appliance **1106**.

[0164] More generally, there is disclosed herein a system for zero trust network access to a customer application comprising an application **1104** hosted on a customer premises **1102** and a zero trust network access appliance **1106** hosted on the customer premises **1102**, where the zero trust network access appliance **1106** is configured to respond to a user input by selecting between a gateway mode and a cloud mode. In the gateway mode, the zero trust network access appliance **1106** may operate as a zero trust network access gateway to provide zero trust network access to the application **1104** at the customer premises **1102**. In the cloud mode, the zero trust network access appliance **1106** may act as a zero trust network access connector coupling the application **1104** hosted on the customer premises **1102** to a cloud computing platform **1110** to provide zero trust network access to the application **1104** at the cloud computing platform **1110**. When operating as the zero trust network access gateway, the ZTNA appliance **1106** may generally expose the application **1104** to a data network through a firewall **1120** of the customer premises **1102**, which may perform any suitable firewall functions for securing the customer premises **1102** against malicious activity. When operating as a zero trust network access connector, the ZTNA appliance **1106** may expose the application **1104** to the data network through a secure tunnel, e.g., a secure tunnel between the zero trust network access appliance **1106** and a reverse proxy server **1126** on the cloud computing platform **1110**.

[0165] The system **1100** may also use any of the other cloud computing or other components described herein. For example, the system **1100** may include a service proxy on the cloud computing platform **1110**, the service proxy coupled to the reverse proxy server **1126** and configured to expose the application **1104** to a data network for access by remote users. The system **1100** may also or instead include a network load balancer coupling the service proxy to the data network. The network load balancer facing the data network may, for example, be configured to select a service proxy at the cloud computing platform for responding to a request for the application **1104**, and/or may be configured to select a service proxy from cluster of service proxies for responding to a request from the data network for the application **1104**. The system **1100** may also or instead include a network load balancer between the cloud computing platform **1110** and the customer premises **1102**, which may be configured to select a reverse proxy server from among a number of reverse proxy servers for handling a connection between the zero trust network access connector and the cloud computing platform **1110**.

[0166] FIG. 12 shows a method for dynamic routing of application traffic to ZTNA connectors. In general, a cloud computing platform may provide zero trust network access as a service to customers that maintain applications on-premises, and a zero trust network access appliance at the customer premises may operate in a cloud mode as a ZTNA connector to couple the on-premises applications to the cloud computing platform, all as described herein. A customer may host multiple instances of the appliance in order to support scalable access, and each instance may create a separate secure tunnel to the cloud computing platform. In this context, when a new appliance authenticates a new secure tunnel, information such as a connector name, customer, and port for the tunnel may be shared on a control plane for the computing platform to facilitate programmatic load balancing within the cloud computing platform. Based on this information, each

instance of the application may be individually selected, and/or traffic may be managed among the different instances, by addressing each instance of the application through its corresponding secure tunnel. In the method **1200** described below, the ZTNA connectors, cloud computing platforms, customer premises, applications, secure tunnels, and other components may be any as described herein.

[0167] As shown in step **1202**, a method **1200** for dynamic routing of application traffic to ZTNA connectors (or appliances) may include receiving a request to configure a ZTNA application. This may, for example, include a request to provide zero trust network access to an application hosted on a customer premises, or more specifically, receiving, at an administrative console of a threat management facility, a request to provide access to an application hosted on a customer premises through a zero trust network access appliance. The request may contain, e.g., information for identifying the application and network location, and/or any other information necessary or helpful for initiating managed ZTNA access to the application.

[0168] As shown in step **1204**, the method **1200** may include configuring the zero trust network access appliance at the customer premises, for example, by specifying first configuration information. For example, the first configuration information may include a name of the application, a certificate for authenticated access the application, and/or a fully qualified domain name for accessing the application on a network. The configuration may include providing any necessary information to the threat management facility, and then transmitting this information and other automatically generated configuration information to a ZTNA appliance on the customer premises, for example using a secure connection from a threat management facility to a cloud agent or other resource on the customer premises that is coupled to the ZTNA appliance.

[0169] As shown in step **1206**, the method **1200** may include receiving second configuration information for the application. For example, deploying the ZTNA application may include creating a secure tunnel between the customer premises and a cloud computing platform as described herein. When a reverse proxy client on the ZTNA appliance creates the secure tunnel to a reverse proxy server on the cloud computing platform (which will provide a cloud-based data plane for the application), the reverse proxy server may share this information, via the control plane, with the threat management facility and other components of the cloud computing platform to facilitate configuration of the data plane components for provisioning of the application through the cloud computing platform. By way of non-limiting example, this second configuration information may include a port or other network identifier of a reverse proxy server at the cloud computing platform that is connected to a reverse proxy client of the zero trust network access appliance (e.g., through a secure tunnel between the client and server).

[0170] As shown in step **1208**, the method **1200** may include configuring a service proxy at the cloud computing platform to provide access to the application based on the first configuration information and the second configuration information. For example, user configuration information such as the application name, authentication certificates, and FQDN(s) may be provided through the administrative interface when initiating configuration of the ZTNA application, and results of successful provisioning, such as the application port number, may be obtained through the control plane after the connection to the ZTNA appliance is created and assigned to a port on the reverse proxy server. This data may collectively be pushed out from the threat management facility or other control locus to configure a service proxy in the cloud computing platform to respond to requests for the application, and more specifically, requests for the application directed to the FQDN(s).

[0171] As shown in step **1210**, the method **1200** may include instantiating additional instances of the ZTNA application. For example, this may be based on a performance test for a particular application, for a particular ZTNA appliance, or for a particular customer premises, and may include performance evaluations based on latency, bandwidth, service levels, and so forth.

However measured, the results of performance testing may be used as the basis for automatically or manually controlling the addition or removal of ZTNA appliances to ensure a desired level of

service or access. Thus in one aspect, the method **1200** may include instantiating a plurality of instances of a ZTNA appliances for applications on the customer premises. Each ZTNA appliance may have its own reverse proxy client forming a secure tunnel to the cloud computing platform. However, each ZTNA appliance may also have local access to, and responsibility for, multiple applications hosted on the customer premises.

[0172] In order to facilitate dynamic scaling of ZTNA appliances in this context, the configuration process may be used to ensure that a list of applications associated with a ZTNA appliance on the customer premises is pushed to the control plane so that service proxies executing on the cloud computing platform can be correspondingly configured to forward specific application traffic to specific secure tunnels. This information can more generally be used, e.g., to support load balancing in the data plane. For example, where the service proxies within the cloud computing platform have access to unencrypted data traffic, this advantageously permits programmatic load balancing of traffic within the cloud computing platform based on, e.g., request payloads, request parameters, the name or type of a requested application, and so forth, in addition to any network-layer and/or traffic-based load balancing using network load balancers as described herein.

[0173] As shown in step **1212**, the method **1200** may include configuring a cluster of service proxies at the cloud computing platform to provide access to the application. This may, for example, include configuring service proxies for use in the data plane for the ZTNA appliance, and identifying a set of similarly or identically configured service proxies for use with one or more predetermined network load balancers, such as with any of the abstraction layers described herein.

[0174] As shown in step **1214**, the method **1200** may include load balancing for the cluster, e.g., by dynamically routing requests for the application among the plurality of zero trust network access appliances at the cloud computing platform to balance a load associated with use of the application among the plurality of zero trust network access appliances. In addition to connecting specific application traffic to specific secure tunnels to managed traffic flows as described herein, this may also, for example, include causing a network load balancer, such as any of the network load balancers described herein, to manage demand for the application among a plurality of secure tunnels for a plurality of zero trust network access appliances known to have connectivity to the application, or more generally, to manage connections between the cloud computing platform and secure tunnels coupled to instances of the ZTNA appliance and ZTNA applications. Load balancing may also or instead include causing a second network load balancer to manage network traffic between a public data network and the cluster of service proxies configured to provide access to the application. In this manner, incoming traffic to the service proxies may advantageously be load balanced independently from traffic with ZTNA appliances for a particular application. In a multi-tenant environment or the like, where a particular service proxy or cluster of service proxies may have traffic for many different customers, this can advantageously help to ensure that public facing service proxies scale appropriately to aggregated traffic, while customer facing reverse proxy servers scale appropriately to customer-specific or application-specific traffic, all without explicitly sorting or analyzing traffic that is received from the public data network.

[0175] According to the foregoing, in one aspect, there is described herein a multi-layered load balancing system for a cloud-based ZTNA data plane. This may include a first layer of network load balancers facing a data network external to a ZTNA application. This layer may include an abstraction layer that allocates specific application requests to suitably configured clusters of service proxies. The service proxies in a cluster may also programmatically support load balancing by allocating specific application traffic to specific secure tunnels based on configuration information provided to the service proxies as new ZTNA appliances are provisioned. Finally, a second layer of network load balancers may be positioned between the service proxies and one or more ZTNA appliances. In this manner, the second layer of network load balancers can automatically manage traffic across a number of ZTNA appliances for a customer on a tunnel-by-tunnel basis independently of application-specific traffic.

[0176] As described herein, the threat management facility may provide a control plane for managing zero trust network access to the application through the cloud computing platform. Thus, the method **1200** may include, with the threat management facility, configuring a plurality of ZTNA appliances at the customer premises for an application, and/or configuring a plurality of instances of a ZTNA application for use with a ZTNA appliance.

[0177] According to the foregoing, there is also disclosed herein a system for dynamically routing zero trust network access to a customer application. In general, the system may include a customer premises, a cloud computing platform, and a threat management facility. The customer premises may include an application and a zero trust network access appliance configured to authenticate users for access to the application. The zero trust network access appliance may include a reverse proxy client for creating secure tunnels to the cloud computing platform. The cloud computing platform may be remote from the customer premises, and may include a plurality of service proxies providing a network access point for the application, a network load balancer for distributing access requests to the plurality of service proxies, and a reverse proxy server configured to establish a secure tunnel to the reverse proxy client of the zero trust network access appliance. The threat management facility may be remote from the customer premises and the cloud computing platform, and may be configured to provide security services for the customer premises and a control plane for zero trust network access to the application through the cloud computing platform. The threat management facility may also be configured to managed the ZTNA infrastructure, e.g., by performing the steps of receiving configuration information for the application from the cloud computing platform, the configuration information including a name of the application and a port of the reverse proxy server for the secure tunnel, and configuring one or more of the plurality of service proxies to forward a request from a client for the application to the reverse proxy server and the port for the secure tunnel.

[0178] The plurality of service proxies may include a cluster of service proxies accessed through a network load balancer as described herein. The threat management facility may be further configured to scale the application by performing the steps of, in response to detecting a degradation in performance of the application: configuring a second zero trust network access appliance at the customer premises, connecting the second zero trust network access appliance to the cloud computing platform through a second secure tunnel; and configuring the one or more of the plurality of service proxies to forward the request from the client for the application to either of the secure tunnel or the second secure tunnel. The cloud computing platform may also include a second network load balancer for managing traffic relating to the application between the secure tunnel and the second secure tunnel.

[0179] The configuration information may include any information useful for configuring the data plane or other components of the ZTNA infrastructure. For example, the configuration information may include a certificate for the application, or any other keys or other information useful for authenticating the application with reference to a trusted third party. The configuration information may also or instead include a fully qualified domain name for accessing the application. The configuration information may also or instead include a name of a customer associated with the customer premises hosting the application, or any other information for identifying the customer, the application, or the application location. In another aspect, the configuration information may include a name of the zero trust network access appliance providing access to the application.

[0180] FIG. **13** shows a method for scaling tunnels for zero trust network access (ZTNA) appliances. In general, a cloud computing platform provides zero trust network access as a service to a customer that maintain applications on-premises, and a ZTNA appliance at the customer premises couples the on-premises applications to the cloud computing platform. In this context, the number of secure tunnels maintained for an application between the customer premises and the cloud computing platform may be dynamically managed to support variations in user demand for the application. The cloud computing platform, ZTNA appliance, customer premises, applications,

and other components may be any as described herein.

[0181] As shown in step **1302**, the method **1300** may include providing a first reverse proxy server on a cloud computing platform. The first reverse proxy server may be any of the reverse proxy servers described herein, and may have a first secure tunnel to a first zero trust network access appliance executing on a customer premises and managing zero trust network access to an application hosted on the customer premises.

[0182] As shown in step **1304**, the method **1300** may include monitoring resource usage of the first reverse proxy server. This may generally include any resource usage that can be monitored for the reverse proxy server and that can might usefully provide a benchmark for evaluating whether to add or remove reverse proxy servers for an application such as a ZTNA application (or ZTNA appliance) managed through a cloud computing platform as described herein. For example, the resource usage may include central processing unit utilization for a physical or virtual machine executing the first reverse proxy server. The resource usage may also or instead include a memory usage for the machine. In another aspect, the resource usage may include a measure of network performance such as bandwidth used by the application or latency of responses to requests for the application. Metrics such as latency may usefully be measured end to end, e.g., from when a service proxy receives a request to when the service proxy transmits a response from the application, or over any other physical or logical interval that can be monitored by the cloud computing platform. Where instrumentation of the customer premises is available, this may also or instead include latency, delays, or processing/memory usage by appliances, applications, or other components executing on the customer premises.

[0183] As shown in step **1306**, the method **1300** may include responding to a threshold, such as a predetermined threshold for any of the resource usages described herein.

[0184] When the resource usage for the first reverse proxy meets a predetermined threshold such as a utilization or latency limit, responding to the threshold may include causing the one or more computing devices to perform the steps of: instantiating a second reverse proxy server on the cloud computing platform, instantiating a second reverse proxy client on the customer premises, and coupling the second reverse proxy client to the second reverse proxy server to establish a second secure tunnel. In this manner, additional secure tunnels (and associated computing components) may be added dynamically as needed in response to an increase in usage demands that exceeds a monitored resource usage limit.

[0185] This dynamic scaling may be performed by adding tunnels (e.g., reverse proxy clients) on a single ZTNA appliance, or by adding ZTNA appliances, or some combination of these. For example, instantiating the second reverse proxy client may include configuring a second zero trust network access appliance on the customer premises and instantiating the second reverse proxy client on the second zero trust network access appliance. In another aspect, instantiating the second reverse proxy client may include instantiating the second reverse proxy client on the first zero trust network access appliance. In either case, a complementary reverse proxy server may be instantiated on the cloud computing platform if/as necessary to handle a new connection to the new reverse proxy client, along with a corresponding service proxy if/as needed. In some embodiments, only one of these techniques may be used to dynamically scale the number of available tunnels. In other embodiments, dynamic scaling may include selecting between these and/or other response techniques based on contextual information such as whether the resource usage is network related (suggesting the use of additional tunnels to expand network capacity) or processor/memory related (suggesting the use of additional appliances to expand processing capacity). In another aspect, the number of tunnels for an appliance may be increased until some quota or other limit on tunnels for a ZTNA appliance is reached, after which a new ZTNA appliance will be instantiated on the customer premises (or requested, where the threat management facility does not independently control provisioning of ZTNA appliances for the customer). It will also be appreciated that this step may be performed iteratively, e.g., by adding an additional zero trust network access appliance,

adding an additional secure tunnel, and allocating requests for the application among available secure tunnels until the resource usage for each available reverse proxy server is below the predetermined threshold.

[0186] When the resource usage for the first reverse proxy falls below a second predetermined threshold, which may be the same as or different than the predetermined threshold above, responding to the threshold may include unprovisioning ZTNA resources, e.g., by closing tunnels or terminating appliances. For example, this may include removing at least one of the first reverse proxy server and the second reverse proxy server when remaining reverse proxy servers for the application at the cloud computing platform can each handle traffic for the application while operating below the second predetermined threshold for resource usage. This step may also be performed iteratively, e.g., by de-provisioning resources as long as the remaining resources have sufficient processing capacity to operate below the first threshold that would otherwise trigger additional provisioning.

[0187] As shown in step **1308**, the method **1300** may include allocating requests among the current resources, as adjusted in step **1306**. For an increase in the number of tunnels, this may, for example, including allocating requests among the first secure tunnel and the second secure tunnel in order reduce the resource usage for the first reverse proxy server. For a decrease in the number of tunnels, this may include allocating requests among remaining tunnels unless and until the resource usage once again meets or exceeds the predetermined threshold. In general, this allocation may be performed automatically for the currently available tunnels, e.g., by using a network load balancer or other similar network resource disposed between reverse proxy servers and reverse proxy clients to balance usage of secure tunnels therebetween. In another aspect, this allocation may be performed by reconfiguring service proxies in the cloud computing platform to programmatically allocate application traffic in any desired manner.

[0188] In general, this process may be repeated substantially continuously as long as dynamic tunnel scaling adjustments are desired. As such, the method **1300** may return to step **1304** to continue monitoring resource usage according to any suitable metrics or parameters until another adjustment is required. In this manner, the method **1300** may continuously and dynamically adapt available tunnels/appliances by increasing or decreasing the available resources according to current demand.

[0189] According to the foregoing, a system for routing zero trust network access to a customer application, as described herein, may include a customer premises, a cloud computing platform, and a threat management facility. The customer premises may include an application, and a first zero trust network access appliance configured to authenticate users for access to the application. The first zero trust network access appliance may include a first reverse proxy client. The cloud computing platform may be remote from the customer premises, and may include a service proxy providing a network access point for the application, and a first reverse proxy server configured to establish a first secure tunnel to the first reverse proxy client of the first zero trust network access appliance. The threat management facility may be remote from the customer premises and the cloud computing platform, and may be configured to monitor a resource usage for the first reverse proxy server. The threat management facility may further be configured to respond to changes in the resource usage by, when the resource usage for the first reverse proxy server meets a predetermined threshold, performing the steps of instantiating a second reverse proxy server on the cloud computing platform, configuring a second zero trust network access appliance on the customer premises, and coupling the second zero trust network access appliance to the second reverse proxy server to establish a second secure tunnel. The system may also include a network load balancer configured to allocate requests among the first secure tunnel and the second secure tunnel, thereby reducing the resource usage by the first reverse proxy server.

[0190] The predetermined threshold may, for example, include one or more of a central processing unit usage limit for a machine executing the first reverse proxy server, a memory usage limit for a

machine executing the first reverse proxy server, a bandwidth limit for the first secure tunnel, or a latency for the application. In one aspect, allocating requests may include directing traffic for the application through two or more network load balancers. Allocating requests may also or instead include allocating traffic for the application among two or more service proxies on the cloud computing platform, e.g., using a second network load balancer between the service proxies and a data network. In one aspect, the threat management facility may be configured to dynamically scale resources by adding one or more additional reverse proxy servers, adding one or more additional zero trust network access appliances, adding one or more secure tunnels, and allocating requests among available secure tunnels until the resource usage for each reverse proxy server is below the predetermined threshold. The threat management facility may also or instead be configured to dynamically scale resources by removing at least one of the first reverse proxy server and the second reverse proxy server when remaining reverse proxy servers for the application can each handle application traffic while operating below the predetermined threshold for resource usage. More generally, the threat management facility may continuously and dynamically scale the number of ZTNA applications based on any suitable resource metrics to avoid under-provisioning or over-provisioning based on current demand.

[0191] It will be appreciated that all of the foregoing methods and systems may be used along or in any suitable combination(s). Thus, for example, an abstraction layer may be used on the network front end for a cloud-based data plane, and dynamic tunnel scaling may be used on the customer premises back end. At the same time, new proxy configurations may be prevalidated and the ownership/control of domain names may be checked before permitting access to an application through the data plane with a user-specified fully qualified domain name. All such combinations are intended to fall within the scope of this disclosure unless specifically stated otherwise.

[0192] The above systems, devices, methods, processes, and the like may be realized in hardware, software, or any combination of these suitable for a particular application. The hardware may include a general-purpose computer and/or dedicated computing device. This includes realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable devices or processing circuitry, along with internal and/or external memory. This may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization of the processes or devices described above may include computer-executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. In another aspect, the methods may be embodied in systems that perform the steps thereof, and may be distributed across devices in a number of ways. At the same time, processing may be distributed across devices such as the various systems described above, or all of the functionality may be integrated into a dedicated, standalone device or other hardware. In another aspect, means for performing the steps associated with the processes described above may include any of the hardware and/or software described above. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[0193] Embodiments disclosed herein may include computer program products comprising computer-executable code or computer-usable code that, when executing on one or more computing devices, performs any and/or all of the steps thereof. The code may be stored in a non-transitory fashion in a computer memory, which may be a memory from which the program executes (such as random-access memory associated with a processor), or a storage device such as a disk drive, flash memory or any other optical, electromagnetic, magnetic, infrared, or other

device or combination of devices. In another aspect, any of the systems and methods described above may be embodied in any suitable transmission or propagation medium carrying computer-executable code and/or any inputs or outputs from same.

[0194] It will be appreciated that the devices, systems, and methods described above are set forth by way of example and not of limitation. Absent an explicit indication to the contrary, the disclosed steps may be modified, supplemented, omitted, and/or re-ordered without departing from the scope of this disclosure. Numerous variations, additions, omissions, and other modifications will be apparent to one of ordinary skill in the art. In addition, the order or presentation of method steps in the description and drawings above is not intended to require this order of performing the recited steps unless a particular order is expressly required or otherwise clear from the context.

[0195] The method steps of the implementations described herein are intended to include any suitable method of causing such method steps to be performed, consistent with the patentability of the following claims, unless a different meaning is expressly provided or otherwise clear from the context. So, for example, performing the step of X includes any suitable method for causing another party such as a remote user, a remote processing resource (e.g., a server or cloud computer) or a machine to perform the step of X. Similarly, performing steps X, Y, and Z may include any method of directing or controlling any combination of such other individuals or resources to perform steps X, Y, and Z to obtain the benefit of such steps. Thus, method steps of the implementations described herein are intended to include any suitable method of causing one or more other parties or entities to perform the steps, consistent with the patentability of the following claims, unless a different meaning is expressly provided or otherwise clear from the context. Such parties or entities need not be under the direction or control of any other party or entity, and need not be located within a particular jurisdiction.

[0196] It should further be appreciated that the methods above are provided by way of example. Absent an explicit indication to the contrary, the disclosed steps may be modified, supplemented, omitted, and/or re-ordered without departing from the scope of this disclosure.

[0197] It will be appreciated that the methods and systems described above are set forth by way of example and not of limitation. Numerous variations, additions, omissions, and other modifications will be apparent to one of ordinary skill in the art. In addition, the order or presentation of method steps in the description and drawings above is not intended to require this order of performing the recited steps unless a particular order is expressly required or otherwise clear from the context. Thus, while particular embodiments have been shown and described, it will be apparent to those skilled in the art that various changes and modifications in form and details may be made therein without departing from the spirit and scope of this disclosure and are intended to form a part of the invention as defined by the following claims, which are to be interpreted in the broadest sense allowable by law.

Claims

1. A system for zero trust network access to a customer application comprising: an application remotely accessible through an enterprise network; a threat management facility configured to manage security for the enterprise network; a cloud computing platform hosted remotely from the application, the cloud computing platform configured to provide a cloud-based data plane for zero trust network access to the application by a device, the cloud computing platform including: a service proxy configured to receive a request from the device to connect to the application, a reverse proxy server connected to the service proxy, the reverse proxy server configured to securely connect to the application, and an authentication server configured to authenticate a secure connection between the application and the reverse proxy server; and a zero trust network access appliance for the enterprise network, the zero trust network access appliance configured to couple the application through the cloud-based data plane to the device.

2. The system of claim 1, wherein the zero trust network access appliance is configured to authenticate a user of the device for access to the application.
 3. The system of claim 2, wherein the zero trust network access appliance is configured to authenticate the user of the device with a username and a password managed by a customer premises hosting the application.
 4. The system of claim 2, wherein the zero trust network access appliance is configured to authenticate the user of the device with two or more authentication factors.
 5. The system of claim 2, wherein the zero trust network access appliance authenticates the user of the device with a third party identity management platform external to a customer premises hosting the application.
 6. The system of claim 1, wherein the threat management facility is hosted remotely from a cloud resource hosting the application and coupled in a secure communicating relationship with the cloud resource hosting the application.
 7. The system of claim 1, wherein the threat management facility provides a control plane for zero trust network access to the application through the cloud computing platform.
 8. The system of claim 1, wherein the zero trust network access appliance is configured to: make an outbound connection to the reverse proxy server of the cloud computing platform; authenticate to the reverse proxy server with the authentication server; establish a secure tunnel between the zero trust network access appliance and the reverse proxy server; and use the secure tunnel to provide zero trust network access to the application by a user of the device.
 9. The system of claim 1, wherein the threat management facility is configured to provide a user interface for administrative configuration of the zero trust network access appliance.
 10. The system of claim 9, wherein the user interface for administrative configuration is configured to receive a Domain name system record identifying an address for the cloud computing platform.
 11. The system of claim 9, wherein the zero trust network access appliance is user-configurable through the threat management facility to operate as either (a) a zero trust network access gateway exposed to a public network through a firewall for a customer premises hosting the application or (b) a zero trust network access connector coupled through a secure tunnel to the cloud-based data plane hosted on the cloud computing platform.
 12. The system of claim 1, wherein the application is an agentless application.
 13. The system of claim 1, wherein the application is an agent-based application.
 14. The system of claim 1, wherein the cloud computing platform provides a network address for zero trust network access to the application from a public network.
 15. The system of claim 1, wherein the cloud computing platform provides a fully qualified domain name for zero trust network access to the application.
 16. The system of claim 1, further comprising a connector configured to selectively couple the application to external users through a firewall for a customer premises hosting the application and a secure tunnel coupling the application to the cloud-based data plane.
 17. The system of claim 16, wherein the connector authenticates a user of the device accessing the application through the secure tunnel.
 18. The system of claim 1, wherein the zero trust network access appliance is configured to authenticate a user of the device for zero trust network access to the application with at least one of a biometric authentication factor, a hardware-based authentication factor, or a software-based authentication factor.
 19. The system of claim 1, wherein the zero trust network access appliance is configured to authenticate a user of the device for zero trust network access to the application with a heartbeat from a user device.
 20. The system of claim 1, wherein the cloud computing platform is configured to authenticate a user of the device for zero trust network access to the application.
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