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(54) **DEVICE AUTHORIZATION USING A DIRECTORY SYSTEM**

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H04L 9/32 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 9/3268*** (2013.01); ***H04L 9/3213*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 9/3268; H04L 9/3213
USPC 713/156
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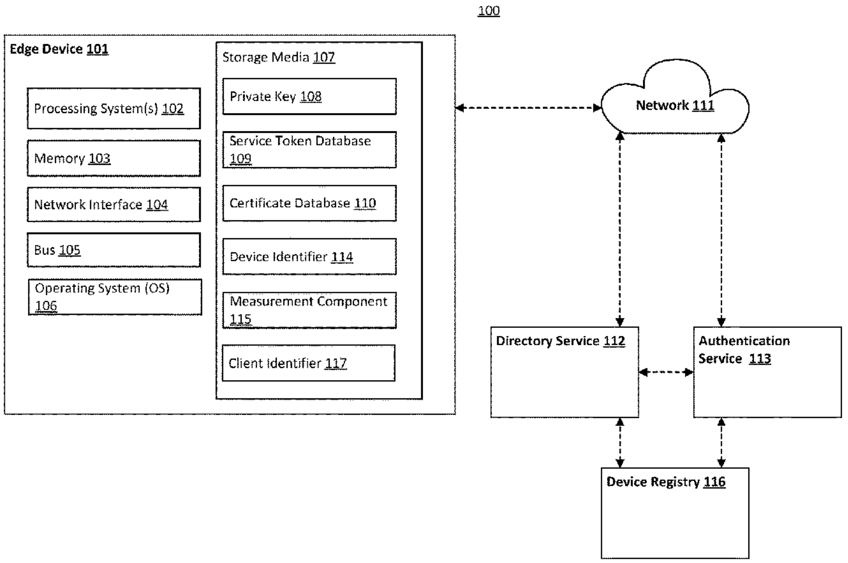
(57) **ABSTRACT**

Methods and systems are described which obtain a service token at an edge device. Embodiments obtain a device certificate from an authentication service based on a private key which is associated with a public key. The public key is further associated with a device identifier for the edge device at a directory service. Embodiments send a request for a service token to an authentication service from a directory service based on the private key where the directory service has identified the public key for the edge device. Other embodiments extract the device identifier from the device certificate and send a request for a service token to the directory service, where the request includes the device certificate and the device identifier. Embodiments receive the service token from the directory service and use the service token to access a service.

20 Claims, 4 Drawing Sheets



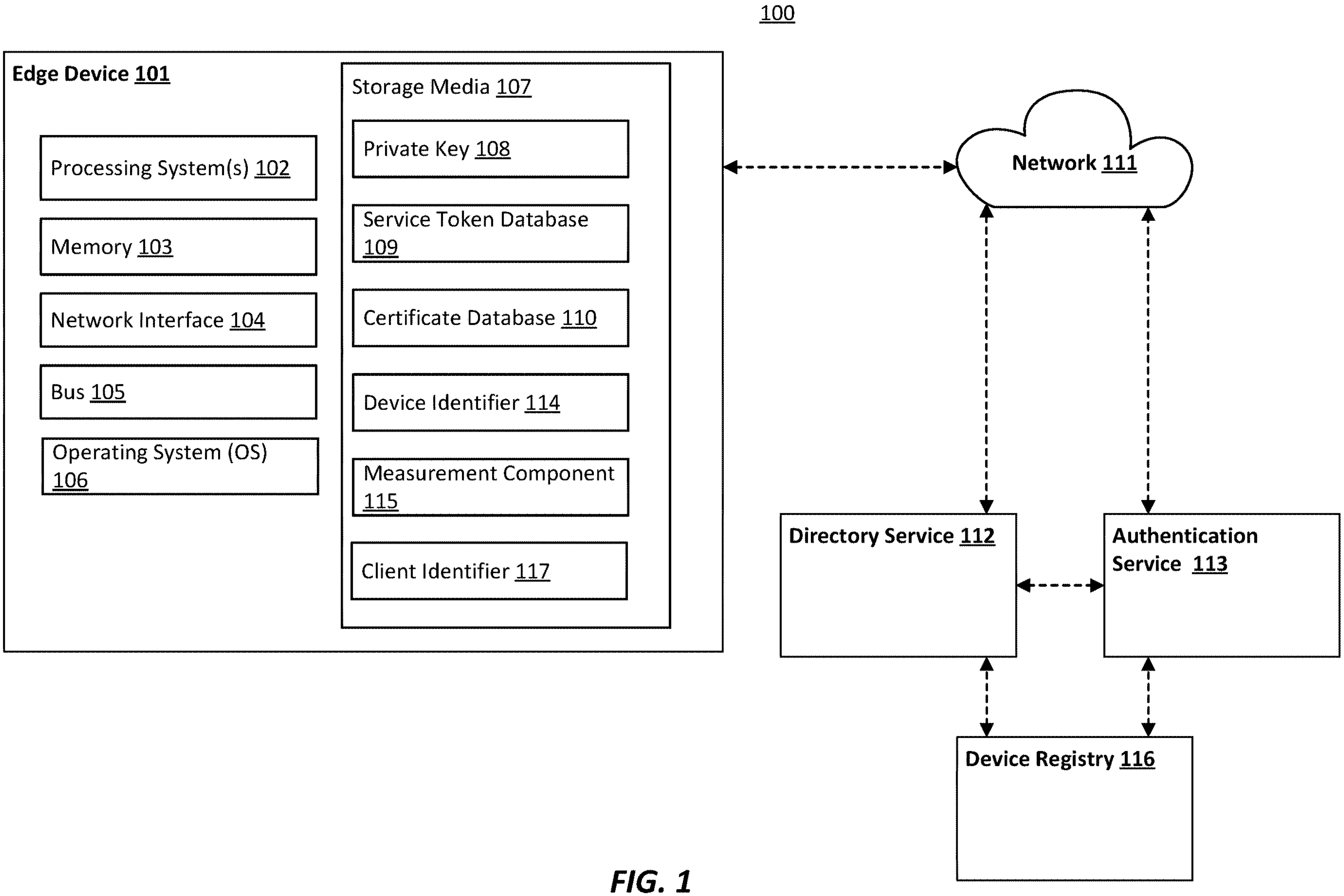

100
Edge Device 101
Processing System(s) 102
Memory 103
Network Interface 104
Bus 105
Operating System (OS) 106
Storage Media 107
Private Key 108
Service Token Database 109
Certificate Database 110
Device Identifier 114
Measurement Component 115
Client Identifier 117
Network 111
Directory Service 112
Authentication Service 113
Device Registry 116

FIG. 1

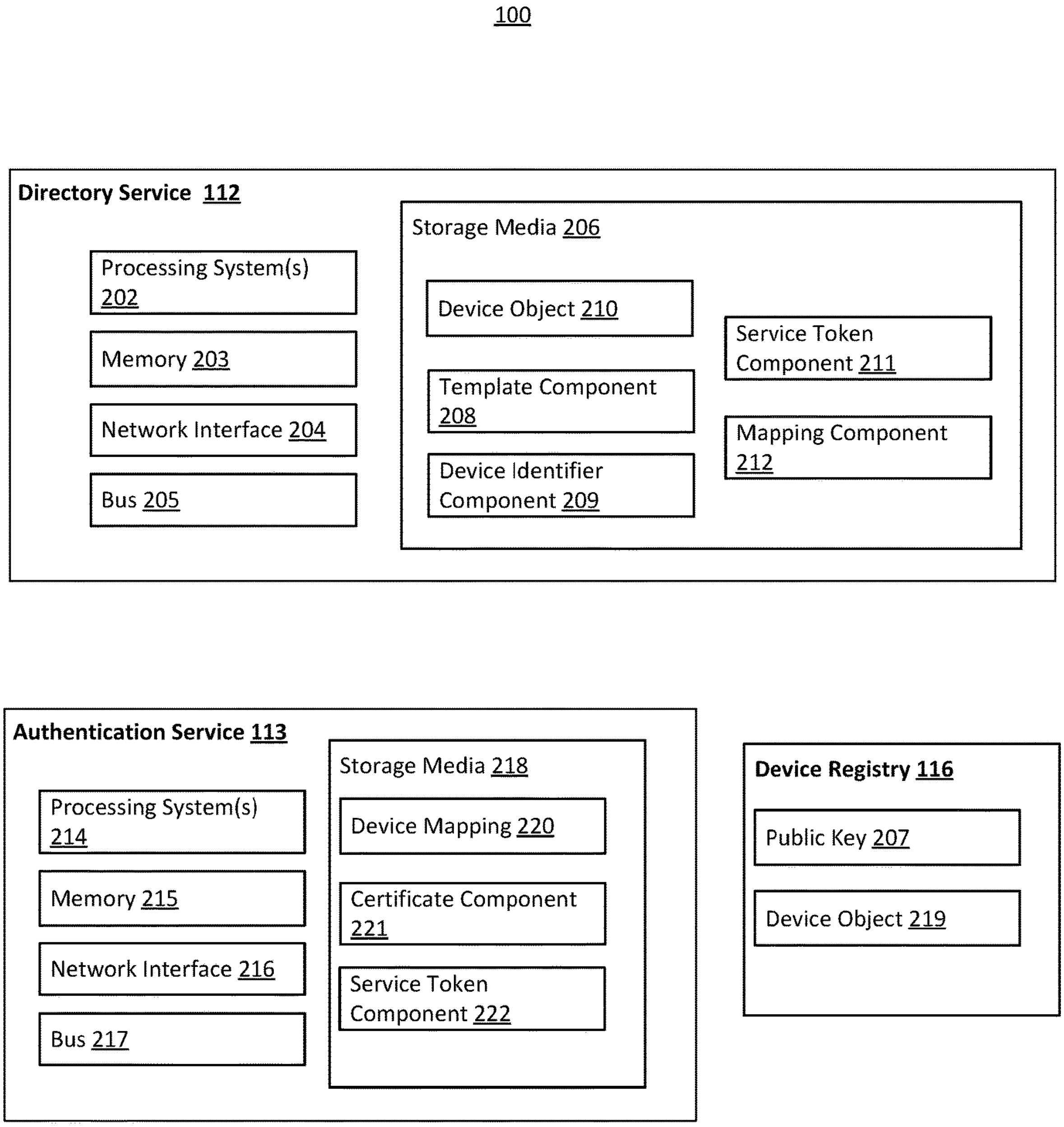

100
Directory Service 112
Processing System(s) 202
Memory 203
Network Interface 204
Bus 205
Storage Media 206
Device Object 210
Template Component 208
Device Identifier Component 209
Service Token Component 211
Mapping Component 212
Authentication Service 113
Processing System(s) 214
Memory 215
Network Interface 216
Bus 217
Storage Media 218
Device Mapping 220
Certificate Component 221
Service Token Component 222
Device Registry 116
Public Key 207
Device Object 219

FIG. 2

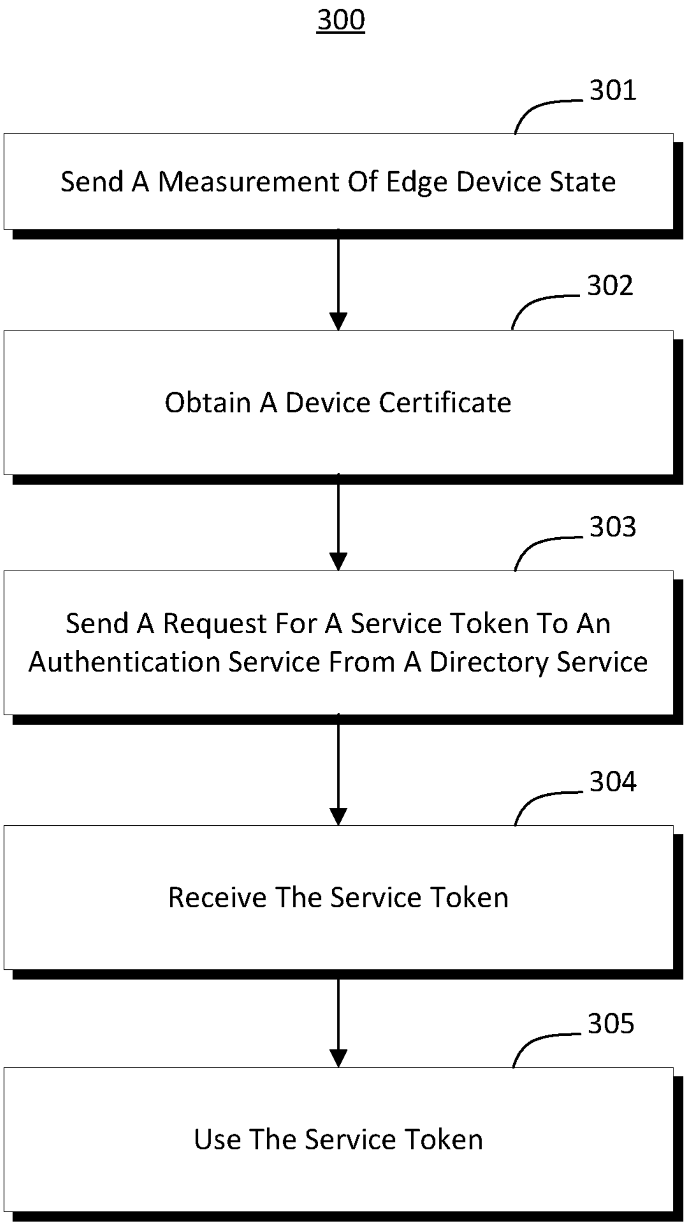

300
301
Send A Measurement Of Edge Device State
302
Obtain A Device Certificate
303
Send A Request For A Service Token To An Authentication Service From A Directory Service
304
Receive The Service Token
305
Use The Service Token

FIG. 3

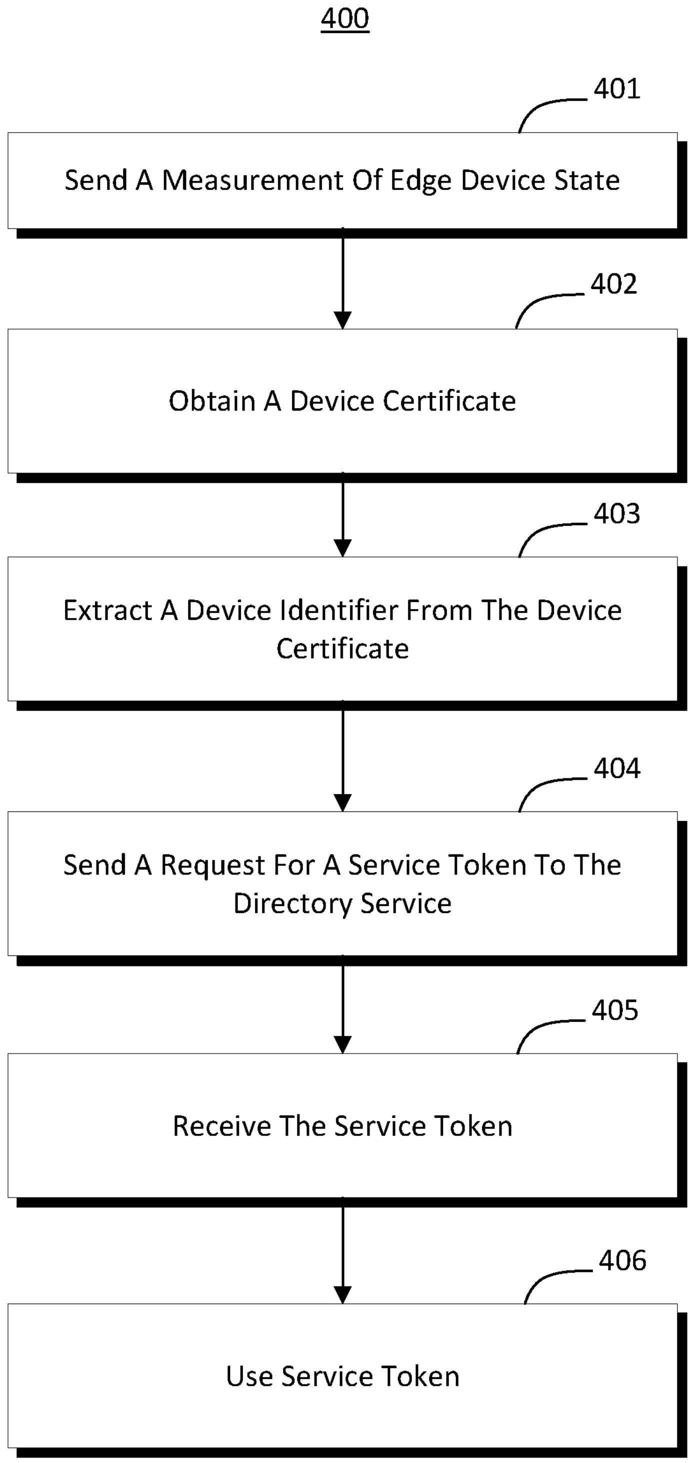

400
401
Send A Measurement Of Edge Device State
402
Obtain A Device Certificate
403
Extract A Device Identifier From The Device Certificate
404
Send A Request For A Service Token To The Directory Service
405
Receive The Service Token
406
Use Service Token

FIG. 4

DEVICE AUTHORIZATION USING A DIRECTORY SYSTEM

BACKGROUND

Internet of Things devices have the ability to connect to platforms to access services. These devices can connect to services based on certificates possessed by those devices.

The subject matter claimed herein is not limited to embodiments that solve any disadvantages or that operate only in environments such as those described above. Rather, this background is only provided to illustrate one example technology area where some embodiments described herein may be practiced.

BRIEF SUMMARY

In some aspects, the techniques described herein relate to a method for obtaining a service token at an edge device, implemented at a computer system that includes a processor, including: based on a private key at the edge device, obtaining a device certificate from an authentication service, wherein the private key is associated with a public key, the public key being associated with a device identifier for the edge device at a directory service; based on the private key, sending a request for a service token to the authentication service from a directory service, wherein the directory service has identified the public key for the edge device; receiving the service token from the authentication service; and using the service token to access a service.

In some aspects, the techniques described herein relate to a method for obtaining a service token at an edge device, implemented at a computer system that includes a processor, including: based on a private key at the edge device, obtaining a device certificate from an authentication service, wherein the private key is associated with a public key, the public key being associated with a device identifier for the edge device at a directory service; extracting the device identifier from the device certificate; sending a request for a service token to the directory service, wherein the request includes the device certificate and the device identifier; receiving the service token from the directory service based on the directory service identifying the public key for the edge device; and using the service token to access a service.

In some aspects, the techniques described herein relate to a computer system including: a processing system; and a computer storage media that stores computer-executable instructions that are executable by the processing system to at least: based on a private key at the edge device, obtain a device certificate from an authentication service, wherein the private key is associated with a public key, the public key being associated with a device identifier for the edge device at a directory service; derive a device identifier from the device certificate; send a request for a service token to the directory service, wherein the request includes the device certificate and the device identifier; receive the service token from the directory service based on the directory service identifying the public key for the edge device; and use the service token to access a service.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to describe the manner in which the advantages and features of the systems and methods described herein can be obtained, a more particular description of the embodiments briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the systems and methods described herein, and are not therefore to be considered to be limiting of their scope, certain systems and methods will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates an example computer architecture that facilitates an edge device obtaining a service token;

FIG. **2** illustrates an example computer architecture of a directory service and an authentication service;

FIG. **3** illustrates a flow chart of an example method for obtaining a service token from an authentication service; and

FIG. **4** illustrates a flow chart of an example method for obtaining a service token from a directory service.

DETAILED DESCRIPTION

Edge devices, such as Internet of Things devices, are capable of connecting to online services by utilizing authentication and attestation, resulting in the use of services provided by online service providers. For example, after an edge device boots up, it connects to an online service, such as a cloud service. Based on information provided by the edge device to the cloud service, such as a certificate, the cloud service determines whether the edge device is valid. However, in some instances, a counterfeit device may be authenticated using a counterfeit certificate. In these cases, the counterfeit device could fraudulently access the cloud service. Therefore, there is an ongoing need to provide secure device service tokens to authentic devices allowing the authentic devices to access the online services while avoiding providing counterfeit devices access to online services.

The embodiments described herein are directed to securely provisioning an edge device with a service token, which allows the edge device to securely access an online service provided by an online application platform. For example, an edge device may use a service token to request access to an online service found on an application platform such as AZURE SPHERE from MICROSOFT CORPORATION of Redmond, Washington. In embodiments, to access an online service, the edge device initially sends measurement data to a directory service. The directory service uses this measurement information to determine if the edge device is authentic or not. If the edge device is determined by the directory service to be authentic, the edge device is permitted to obtain a device certificate from an authentication service. The authentication service sends the device certificate to the edge device based on a private key stored in the edge device and a public key. The public key is associated with the edge device and is stored in the directory service. In one example, the public key is associated with the edge device at the directory service using a unique device identifier of the edge device. Once the edge device obtains the device certificate from the authentication service, the edge device uses the device certificate to request a service token for accessing an online service.

By securely obtaining service tokens at edge devices via the use of device certificates that are issued to the edge devices in the manner disclosed, the disclosed embodiments provide authentic devices access to online services while preventing counterfeit devices from accessing the online services.

FIG. **1** illustrates an example of a computer architecture **100** that facilitates obtaining a service token at an edge device. In FIG. **1**, the computer architecture **100** includes an edge device **101** comprising processing system(s) **102** (e.g., a single processor or a plurality of processors), memory **103** (e.g., system or main memory), operating system (OS) **106**, storage media **107** (e.g., a single computer-readable storage medium, or a plurality of computer-readable storage media), all interconnected by a bus **105**. In embodiments, edge device **101** also includes a network interface **104** (e.g., one or more network interface cards) for forming local or wide-area network connections via network **111**. Lastly, computer architecture **100** also includes a directory service **112** (e.g., AZURE ACTIVE DIRECTORY from MICROSOFT CORPORATION of Redmond, Washington; OKTA WORKFORCE IDENTITY from OKTA INCORPORATED of San Francisco, California), an authentication service **113**, and a device registry **116**, which are interconnected to one another and the edge device **101** via the network **111**.

The storage media **107** is illustrated as storing data. In some embodiments, the data includes a private key **108** (from an asymmetric public/private key pair) associated with the edge device **101**. In embodiments, the private key **108** is stored on the edge device **101** during manufacturing of the edge device **101**. In some embodiments, a public key **207** (see FIG. **2**) that corresponds to private key **108** is also stored on the edge device **101** during manufacturing of the edge device **101**.

The storage media **107** is also illustrated as storing a service token database **109** and a certificate database **110**. In embodiments, the service token database **109** stores one or more service tokens obtained by the edge device, while the certificate database **110** stores one or more certificates obtained by the edge device **101**. In embodiments, the edge device **101** obtains certificate(s) from the authentication service **113** and stores those certificate(s) in the certificate database **110**. In some embodiments, the edge device **101** receives service token(s) from the authentication service **113** and stores those service token(s) in the service token database **109**. In other embodiments, the edge device **101** receives service token(s) from the directory service **112** and stores those service token(s) in the service token database **109**.

In embodiments, storage media **107** also stores a device identifier **114**, which is unique to edge device **101** and a client identifier **117**, which is unique to the client with which the edge device **101** is associated. In embodiments, the device identifier **114** is extracted from a device certificate stored in the certificate database **110**. The device identifier **114** may be extracted, in some embodiments, by the OS **106** of the edge device **101**.

In embodiments, the edge device **101** obtains a device certificate based on using a measurement component **115** to measure a state of the edge device **101** and sends that measurement to the directory service **112**. In embodiments, the measured edge device state includes information about the OS **106** (e.g., a version of the OS **106**), information about other software operating at the edge device **101**, information about a bootup state of the edge device **101**, and the like.

FIG. **2** illustrates another example of the computer architecture **100** of FIG. **1**, with details regarding the directory service **112**, the authentication service **113**, and the device registry **116**. As shown in FIG. **2**, in embodiments, the directory service **112** comprises processing system(s) **202** (e.g., a single processor or a plurality of processors), memory **203** (e.g., system or main memory), storage media **206** (e.g., a single computer-readable storage medium, or a plurality of computer-readable storage media), all interconnected by a bus **205**. In embodiments, the directory service **112** also includes a network interface **204** (e.g., one or more network interface cards) for forming local or wide-area network connections via the network **111** (see FIG. **1**). Similarly, in embodiments, the authentication service **113** comprises processing system(s) **214** (e.g., a single processor or a plurality of processors), memory **215** (e.g., system or main memory), storage media **218** (e.g., a single computer-readable storage medium, or a plurality of computer-readable storage media), all interconnected by a bus **217**. In embodiments, the authentication service **113** also includes a network interface **216** (e.g., one or more network interface cards) for forming local or wide-area network connections via the network **111** (see FIG. **1**).

Referring to directory service **112**, storage media **206** is illustrated as storing computer-executable instructions implementing a template component **208**, a device identifier component **209**, a service token component **211**, and a mapping component **212**. Additionally, the storage media **206** is illustrated as storing data such as a device object **210** associated with the edge device **101**.

The device registry **116** is illustrated as storing data such as a public key **207**, which cryptographically corresponds to the private key **108** of the edge device **101**, and a device object **219** associated with the edge device **101**. In embodiments, the device object **219** associates the public key **207** with the device identifier **114** of the edge device **101**. In some embodiments, the directory service **112** obtains public key **207** from the device registry **116** or from the edge device **101** directly (e.g., during provisioning of edge device **101** within computer architecture **100**) or from a manufacturer of edge device **101**.

The authentication service **113** is also referred to as the device attestation and authentication service. In some embodiments, the authentication service **113** performs both authentication tasks as well as attestation tasks. The storage media **218** is illustrated as storing computer-executable instructions implementing at least a certificate component **221** and a service token component **222**. Storage media **218** is also illustrated as storing data such as a device mapping **220**. In embodiments, the authentication service **113** uses the certificate component **221** to generate a device certificate for the edge device **101**. In embodiments, the generated device certificate is based on the public key **207**, such that the generated device certificate is usable by edge device **101** based on its possession of private key **108**. In an embodiment, authentication service **113** obtains the public key **207** from one or more of the edge device **101**, the device registry **116**, or the directory service **112**. In embodiments, authentication service **113** generates the device certificate based on receiving confirmation from the directory service **112** that the public key **207** of edge device **101** corresponds to the device identifier **114** of the edge device **101** (e.g., based on device object **210**).

In embodiments, the directory service **112** associates the public key **207** stored in the device registry **116** with a device identifier **114** stored in the storage media **206**. In embodiments, the device identifier component **209** creates the device identifier **114** for the edge device **101**. While a variety of device identifier types can be used, in embodiments, the device identifier component **209** generates a globally-unique identifier (GUID) (e.g. a 128-bit or a 256-bit GUID). In embodiments, the device identifier component **209** stores the created device identifier **114** in the device certificate created by the certificate component **221** at the authentication service **113**. In embodiments, this enables the edge device **101** to obtain the device identifier **114** by extracting the device identifier **114** from the device certificate (e.g., using the OS **106** of the edge device **101**). In embodiments, a template component **208** creates a device template that specifies the general parameters of edge device **101**, such as manufacturer, model, OS, and the like.

Embodiments create device object **210** associated with the edge device **101** and store that device object **210** in the storage media **206** of the directory service **112**. Embodiments also create device object **219** associated with the edge device **101** and store that device object **219** in the device registry **116**. A mapping component **212** at the directory service **112** maps the device object **210** and the device object **219** and stores that mapping in a device mapping **220** at the authentication service **113**. In embodiments, the mapping component **212** maps the device identifier **114** with a device certificate and sends the device mapping **220** to the authentication service **113**. The authentication service **113**, in turn, stores the device mapping **220** in the storage media **218**.

In some embodiments, the edge device **101** sends a request to the authentication service **113** for a service token that is used to access an online service. In these embodiments, the request is based on the device certificate generated by the authentication service **113**. Once the authentication service **113** receives the request for the service token, the service token component **222** creates the service token and sends the service token to the edge device **101**. The edge device **101** receives the service token and stores the service token in the service token database **109**. The edge device **101** then uses the service token stored in the service token database **109** to access an online service (e.g., an AZURE SPHERE application).

Embodiments are now described in connection with FIGS. **3** and **4**, which illustrate flow charts of example methods **300** and **400** for obtaining a service token at an edge device. In embodiments, instructions for implementing methods **300** and **400** are encoded as computer-executable instructions (e.g., device identifier component **209**, service token component **211**, and certificate component **221**) stored on a computer storage media (e.g., storage media **107**, **206**, and **218**) that are executable by a processing system (e.g., processing system(s) **102**, **202**, and **214**) to cause a computer system (e.g., edge device **101**, directory service **112**, authentication service **113**) to perform the method.

The following discussion now refers to a number of methods and method acts. Although the method acts may be discussed in certain orders, or may be illustrated in a flow chart as occurring in a particular order, no particular ordering is required unless specifically stated, or required because an act is dependent on another act being completed prior to the act being performed.

Referring to FIG. **3**, method **300** illustrates an embodiment in which the edge device **101** obtains a service token from the directory service **112** directly. In some embodiments, method **300** comprises act **301** of sending a measurement of edge device state. In some embodiments, act **301** comprises sending a measurement of edge device state to a directory service. For example, the measurement component **115** at the edge device **101** measures edge device state of the edge device **101**. In embodiments, the measured edge device state includes information about the OS **106** of the edge device **101** (e.g., OS version information), information about other software operating at the edge device **101**, information about a bootup state of the edge device **101**, and the like. In embodiments, the edge device **101** sends this measurement of the edge device state to the directory service **112**. In embodiments, the directory service **112** uses this measurement to determine whether the edge device **101** is an authentic device or a counterfeit device.

Method **300** also comprises an act **302** of obtaining a device certificate. In some embodiments, act **302** comprises, based on the possession of a private key at the edge device, obtaining a device certificate from an authentication service. For example, the edge device **101** obtains a device certificate from authentication service **113** and stores that certificate in the certificate database **110**. In embodiments, the authentication service **113** uses the certificate component **221** to generate the device certificate for the edge device **101**.

In embodiments, the private key is associated with the public key, and the public key is associated with a device identifier for the edge device at the device registry. For example, the private key **108** and the public key **207** form an asymmetric cryptographic key pair that was created during the manufacturing of edge device **101**. In embodiments, the private key **108** (and, potentially, public key **207**) is stored on the edge device **101** during manufacturing of the edge device **101**. In embodiments, the directory service **112** receives the public key **207** (e.g., from the edge device **101**, from a manufacturer of edge device **101**), and the directory service **112** creates the device identifier **114** for the edge device **101** (device identifier component **209**). The directory service **112** further maps the identity of the edge device **101** with the public key **207** using the mapping component **212**. The mapping component also maps the device object **210** with a device object **219** stored in the device registry **116** and sends a device mapping **220** to the authentication service **113**.

Method **300** also comprises act **303** of sending a request for a service token to an authentication service from a directory service. In some embodiments, act **303** comprises, based on the private key, sending a request for a service token to the authentication service from a directory service, wherein the directory service has identified the public key for the edge device.

Method **300** also comprises act **304** of receiving the service token. In some embodiments, act **304** comprises receiving the service token from the authentication service. In embodiments, the service token component **222** creates the service token after receiving a request and sends the service token to the edge device **101**. The edge device **101** then stores the service token in the service token database **109**.

Method **300** also comprises act **305** of using the service token. In some embodiments, act **304** comprises using the service token to access a service. In embodiments, once the edge device **101** has stored the service token in the service token database **109**, the edge device **101** uses the service token to access services (e.g., applications found in AZURE SPHERE or similar application platforms).

Referring to FIG. **4**, method **400** illustrates an embodiment in which the edge device **101** obtains a service token from the directory service **112** via the authentication service **113**. In embodiments, method **400** comprises act **401** of sending a measurement of edge device state. In some embodiments, act **401** comprises sending a measurement of edge device state to the directory service. For example, the measurement component **115** at the edge device **101** measures the edge device state the edge device **101**. The measured edge device state includes information about the OS **106** of the edge device **101** (e.g., OS version information), information about other software operating at the edge device **101**, information about a bootup state of the edge device **101**, and the like. In embodiments, the edge device

101 sends this measurement of the edge device state to the directory service **112**. In embodiments, the directory service **112** uses this measurement to determine whether the edge device **101** is an authentic device or a counterfeit device.

Method **400** also comprises an act **402** of obtaining a device certificate. In some embodiments, act **402** comprises, based on a private key at the edge device, obtaining a device certificate from an authentication service. For example, the edge device **101** obtains a device certificate from authentication service **113** and stores that certificate in the certificate database **110**. In embodiments, the authentication service **113** uses the certificate component **221** to generate the device certificate for the edge device **101**.

In embodiments, the private key is associated with the public key, and the public key is associated with a device identifier for the edge device at the directory service. For example, the private key **108** and the public key **207** form an asymmetric cryptographic key pair that was created during the manufacturing of edge device **101**. In embodiments, the private key **108** (and, potentially, public key **207**) is stored on the edge device **101** during manufacturing of the edge device **101**. In embodiments, the directory service **112** receives the public key **207** (e.g., from the edge device **101**, from a manufacturer of edge device **101**), and the directory service **112** creates the device identifier **114** for the edge device **101** (device identifier component **209**). The directory service **112** further maps the identity of the edge device **101** with the public key **207** using the mapping component **212**. The mapping component also maps the device object **210** with a device object **219** stored in the device registry **116** and sends a device mapping **220** to the authentication service **113**.

Method **400** also comprises act **403** of extracting a device identifier from the device certificate. In some embodiments, act **403** comprises extracting the device identifier from the device certificate. In embodiments, the device identifier **114** is stored in the device certificate using the device identifier component **209**. The edge device **101** receives this device certificate and stores the certificate in the certificate database **110**. The edge device **101** then extracts the device identifier **114** from the device certificate (e.g., using the OS **106** of the edge device **101**). The edge device **101** stores the device identifier **114** in the storage media **107**.

Method **400** also comprises act **404** of sending a request for a service token to the directory service. In some embodiments, act **404** comprises sending a request for a service token to the directory service where the request includes the device certificate and the device identifier. In some embodiments, the request includes the client identifier as well as the device certificate and the device identifier.

Method **400** also comprises act **405** of receiving the service token. In some embodiments, act **405** comprises receiving the service token from the directory service based on the directory service identifying the public key for the edge device. In embodiments, the directory service **112** receives the request from the edge device **101** for a service token and identifies the public key **207**, which corresponds to the edge device **101**. The service token component **211** creates the service token and sends the service token to the edge device. The edge device **101** stores the service token in the service token database **109**.

Method **400** also comprises act **406** of using the service token. In some embodiments, act **406** comprises using the service token to access a service. In embodiments, once the edge device **101** has stored the service token in the service token database **109**, the edge device **101** may use the service token to access services (e.g., applications found in AZURE SPHERE or similar application platforms).

Embodiments of the disclosure may comprise or utilize a special-purpose or general-purpose computer system (e.g., edge device **101**, directory service **112**, and authentication service **113**) that includes computer hardware, such as, for example, a processing system (e.g., processing system(s) **102**, **202**, and **214**) and system memory (e.g., memory **103**, **203**, and **215**), as discussed in greater detail below. Embodiments within the scope of the present disclosure also include physical and other computer-readable media for carrying or storing computer-executable instructions and/or data structures. Such computer-readable media can be any available media that can be accessed by a general-purpose or special-purpose computer system. Computer-readable media that store computer-executable instructions and/or data structures are computer storage media (e.g., storage media **107**, **206**, and **218**). Computer-readable media that carry computer-executable instructions and/or data structures are transmission media. Thus, by way of example, embodiments of the disclosure can comprise at least two distinctly different kinds of computer-readable media: computer storage media and transmission media.

Computer storage media are physical storage media that store computer-executable instructions and/or data structures. Physical storage media include computer hardware, such as random access memory (RAM), read-only memory (ROM), electrically erasable programmable ROM (EEPROM), solid state drives (SSDs), flash memory, phase-change memory (PCM), optical disk storage, magnetic disk storage or other magnetic storage devices, or any other hardware storage device(s) which can be used to store program code in the form of computer-executable instructions or data structures, which can be accessed and executed by a general-purpose or special-purpose computer system to implement the disclosed functionality.

Transmission media can include a network and/or data links that can be used to carry program code in the form of computer-executable instructions or data structures and which can be accessed by a general-purpose or special-purpose computer system. A "network" is defined as one or more data links that enable the transport of electronic data between computer systems and/or modules and/or other electronic devices. When information is transferred or provided over a network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a computer system, the computer system may view the connection as transmission media. Combinations of the above should also be included within the scope of computer-readable media.

Further, upon reaching various computer system components, program code in the form of computer-executable instructions or data structures can be transferred automatically from transmission media to computer storage media (or vice versa). For example, computer-executable instructions or data structures received over a network or data link can be buffered in RAM within a network interface module (e.g., network interface **104**), and then eventually transferred to computer system RAM and/or to less volatile computer storage media at a computer system. Thus, it should be understood that computer storage media can be included in computer system components that also (or even primarily) utilize transmission media.

Computer-executable instructions comprise, for example, instructions and data which, when executed at one or more processors, cause a general-purpose computer system, special-purpose computer system, or special-purpose processing device to perform a certain function or group of functions. Computer-executable instructions may be, for example, binaries, intermediate format instructions such as assembly language, or even source code.

It will be appreciated that the disclosed systems and methods may be practiced in network computing environments with many types of computer system configurations, including, personal computers, desktop computers, laptop computers, message processors, hand-held devices, multiprocessor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, mobile telephones, PDAs, tablets, pagers, routers, switches, and the like. Embodiments of the disclosure may also be practiced in distributed system environments where local and remote computer systems, which are linked (either by hardwired data links, wireless data links, or by a combination of hardwired and wireless data links) through a network, both perform tasks. As such, in a distributed system environment, a computer system may include a plurality of constituent computer systems. In a distributed system environment, program modules may be located in both local and remote memory storage devices.

It will also be appreciated that the embodiments of the disclosure may be practiced in a cloud computing environment. Cloud computing environments may be distributed, although this is not required. When distributed, cloud computing environments may be distributed internationally within an organization and/or have components possessed across multiple organizations. In this description and the following claims, "cloud computing" is defined as a model for enabling on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services). A cloud computing model can be composed of various characteristics, such as on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service, and so forth. A cloud computing model may also come in the form of various service models such as, for example, Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). The cloud computing model may also be deployed using different deployment models such as private cloud, community cloud, public cloud, hybrid cloud, and so forth.

Some embodiments, such as a cloud computing environment, may comprise a system that includes one or more hosts that are each capable of running one or more virtual machines. During operation, virtual machines emulate an operational computing system, supporting an OS and perhaps one or more other applications as well. In some embodiments, each host includes a hypervisor that emulates virtual resources for the virtual machines using physical resources that are abstracted from the view of the virtual machines. The hypervisor also provides proper isolation between the virtual machines. Thus, from the perspective of any given virtual machine, the hypervisor provides the illusion that the virtual machine is interfacing with a physical resource, even though the virtual machine only interfaces with the appearance (e.g., a virtual resource) of a physical resource. Examples of physical resources including processing capacity, memory, disk space, network bandwidth, media drives, and so forth.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the described features or acts described above, or the order of the acts described above. Rather, the described features and acts are disclosed as example forms of implementing the claims.

The present disclosure may be embodied in other specific forms without departing from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

When introducing elements in the appended claims, the articles "a," "an," "the," and "said" are intended to mean there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Unless otherwise specified, the terms "set," "superset," and "subset" are intended to exclude an empty set, and thus "set" is defined as a non-empty set, "superset" is defined as a non-empty superset, and "subset" is defined as a non-empty subset. Unless otherwise specified, the term "subset" excludes the entirety of its superset (i.e., the superset contains at least one item not included in the subset). Unless otherwise specified, a "superset" can include at least one additional element, and a "subset" can exclude at least one element.

What is claimed:

1. A method implemented at an edge device computer system that includes a processing system, comprising:

based on a private key at the edge device, obtaining a device certificate from an authentication service, wherein the private key is associated with a public key, the public key being associated with a device identifier for the edge device at a directory service;

based on the private key, sending a request for a service token to the authentication service from the directory service, wherein the directory service has identified the public key for the edge device;

receiving the service token from the authentication service; and

using the service token to access a service.

2. The method of claim **1**, further comprising sending a measurement of edge device state to the authentication service.

3. The method of claim **1**, wherein the device identifier for the edge device is mapped with the public key for the edge device.

4. The method of claim **1**, wherein the device identifier for the edge device is created by the directory service.

5. The method of claim **1**, wherein a first object of the edge device stored in the directory service is mapped with a second object of the edge device stored in a device registry.

6. The method of claim **1**, wherein the private key is stored on the edge device during manufacturing, and wherein the public key is stored in a device registry.

7. A method implemented at a computer system that includes a processing system, comprising:

based on a private key at an edge device, obtaining a device certificate from an authentication service, wherein the private key is associated with a public key, the public key being associated with a device identifier for the edge device at a directory service;

extracting the device identifier from the device certificate;

sending a request for a service token to the directory service, wherein the request includes the device certificate, a client identifier, and the device identifier;

receiving the service token from the directory service based on the directory service identifying the public key for the edge device; and

using the service token to access a service.

8. The method of claim **7**, wherein an operating system on the edge device extracts the device identifier from the device certificate.

9. The method of claim **7**, further comprising sending a measurement of edge device state to the authentication service.

10. The method of claim **7**, wherein the device identifier for the edge device is mapped with the public key for the edge device.

11. The method of claim **7**, wherein the device identifier for the edge device is created by the directory service.

12. The method of claim **7**, wherein a first object of the edge device stored in the directory service is mapped with a second object of the edge device stored in a device registry.

13. The method of claim **7**, wherein the private key is stored on the edge device during manufacturing, and wherein the public key is stored in a device registry.

14. A computer system comprising:

a processing system; and

a computer storage media that stores computer-executable instructions that are executable by the processing system to at least:

based on a private key at an edge device, obtain a device certificate from an authentication service, wherein the private key is associated with a public key, the public key being associated with a device identifier for the edge device at a directory service;

extract the device identifier from the device certificate;

send a request for a service token to the directory service, wherein the request includes the device certificate and the device identifier;

receive the service token from the directory service based on the directory service identifying the public key for the edge device; and

use the service token to access a service.

15. The computer system of claim **14**, wherein an operating system on the edge device extracts the device identifier from the device certificate.

16. The computer system of claim **14**, the computer-executable instructions also executable by the processing system to send a measurement of edge device state to the authentication service.

17. The computer system of claim **14**, wherein the device identifier for the edge device is mapped with the public key for the edge device.

18. The computer system of claim **14**, wherein the device identifier for the edge device is created by the directory service.

19. The computer system of claim **14**, wherein a first object of the edge device stored in the directory service is mapped with a second object of the edge device stored in a device registry.

20. The computer system of claim **14**, wherein the private key is stored on the edge device during manufacturing, and wherein the public key is stored in a device registry.

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