US009270674B2

(12) **United States Patent**
Lang et al.

(10) **Patent No.: US 9,270,674 B2**
(45) **Date of Patent: Feb. 23, 2016**

(54) **VALIDATING THE IDENTITY OF A MOBILE APPLICATION FOR MOBILE APPLICATION MANAGEMENT**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 128 days.

(21) Appl. No.: **13/898,167**

(22) Filed: **May 20, 2013**

(65) **Prior Publication Data**

US 2014/0298420 A1 Oct. 2, 2014

Related U.S. Application Data

(60) Provisional application No. 61/806,577, filed on Mar. 29, 2013.

(51) **Int. Cl.**

G06F 21/00	(2013.01)
H04L 29/06	(2006.01)
G06F 21/44	(2013.01)
H04W 12/06	(2009.01)
H04W 12/08	(2009.01)

(52) **U.S. Cl.**

CPC ***H04L 63/10*** (2013.01); ***G06F 21/44*** (2013.01); ***H04W 12/06*** (2013.01); ***H04W 12/08*** (2013.01)

(58) **Field of Classification Search**

CPC G06F 21/44; G06F 21/445; G06F 21/45; G06F 21/51; G06F 21/64

USPC 726/26, 27; 713/192, 156, 159

See application file for complete search history.

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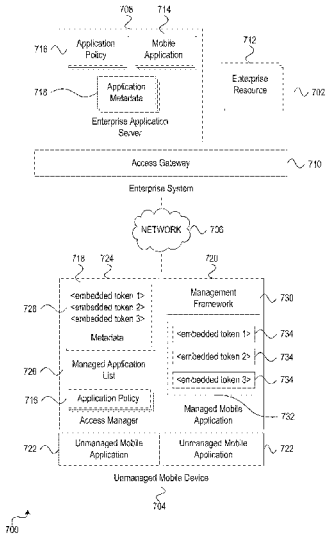
(57) **ABSTRACT**

A method of managing access to enterprise resources is provided. An access manager may operate at a mobile device to validate a mobile application installed at that mobile device. If the access manager does not successfully validate the mobile application, the access manager may prevent the mobile application from accessing computing resource. If the access manager does successfully validate the mobile application, then the access manager may identify the mobile application as a trusted mobile application. The access manager may thus permit the trusted mobile application to access the computing resource.

16 Claims, 14 Drawing Sheets



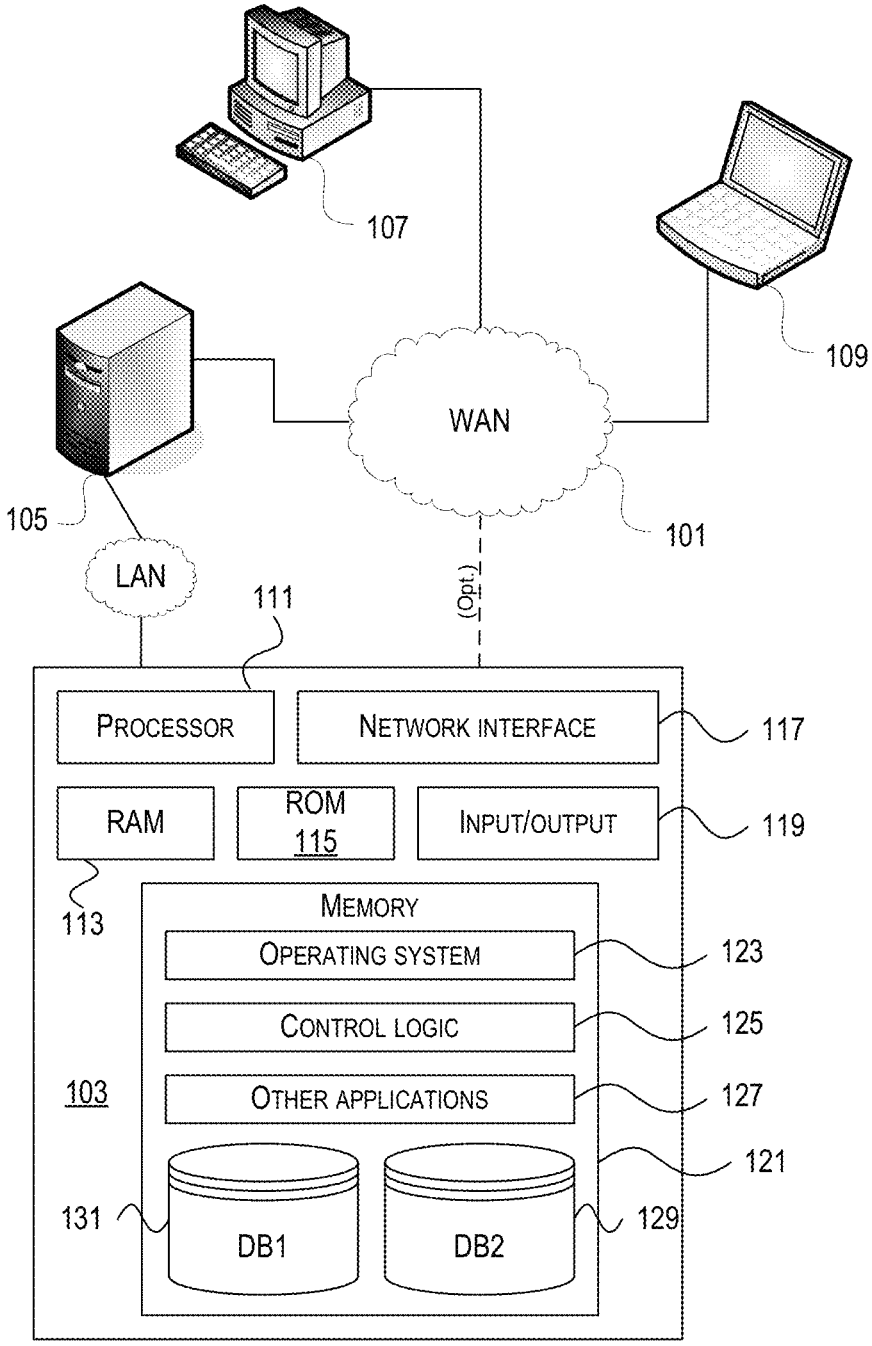

107
109
WAN
105
101
LAN
111
(Opt.)
PROCESSOR
NETWORK INTERFACE
117
RAM
ROM
115
INPUT/OUTPUT
119
113
MEMORY
OPERATING SYSTEM
123
CONTROL LOGIC
125
103
OTHER APPLICATIONS
127
121
131
DB1
DB2
129

FIG. 1

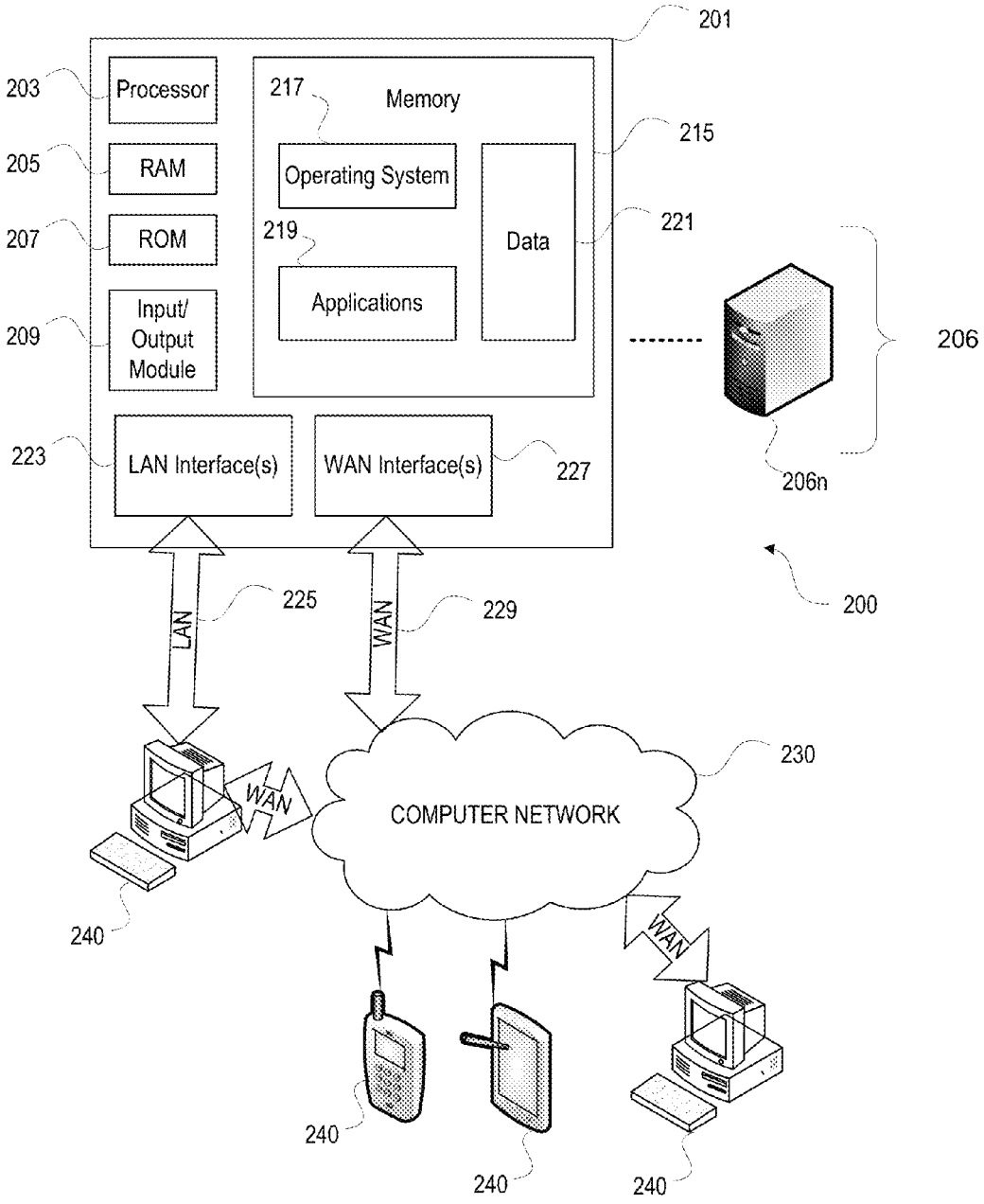

201
203
Processor
217
Memory
215
205
RAM
Operating System
207
ROM
219
Data
221
Applications
209
Input/
Output
Module
206
206n
223
LAN Interface(s)
WAN Interface(s)
227
200
LAN
225
WAN
229
230
COMPUTER NETWORK
WAN
WAN
240
240
240
240

FIG. 2

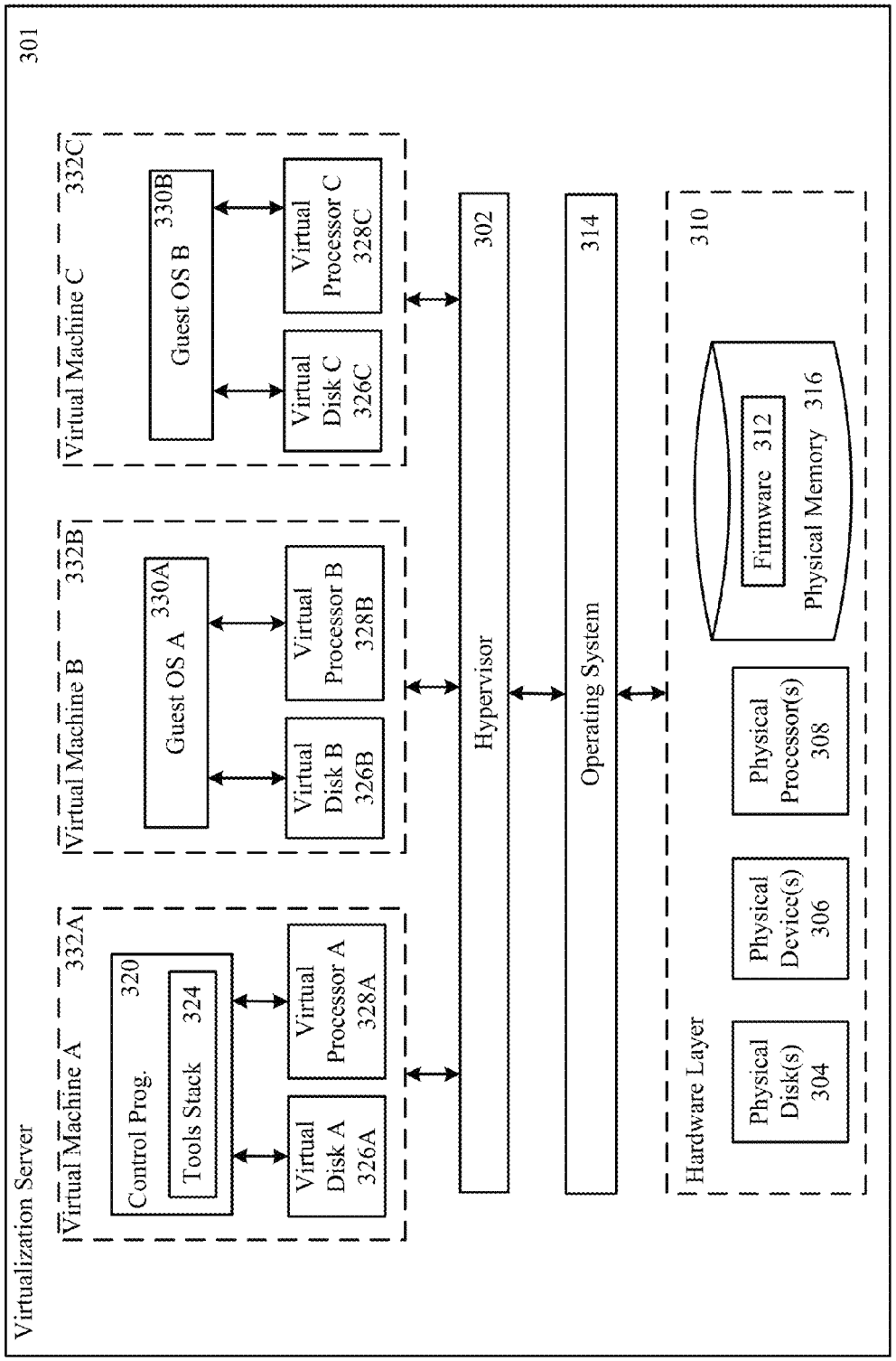

Virtualization Server
301
Virtual Machine A
332A
Control Prog.
320
Tools Stack
324
Virtual Disk A
326A
Virtual Processor A
328A
Virtual Machine B
332B
Guest OS A
330A
Virtual Disk B
326B
Virtual Processor B
328B
Virtual Machine C
332C
Guest OS B
330B
Virtual Disk C
326C
Virtual Processor C
328C
Hypervisor
302
Operating System
314
Hardware Layer
310
Physical Disk(s)
304
Physical Device(s)
306
Physical Processor(s)
308
Physical Memory
316
Firmware
312

FIG. 3

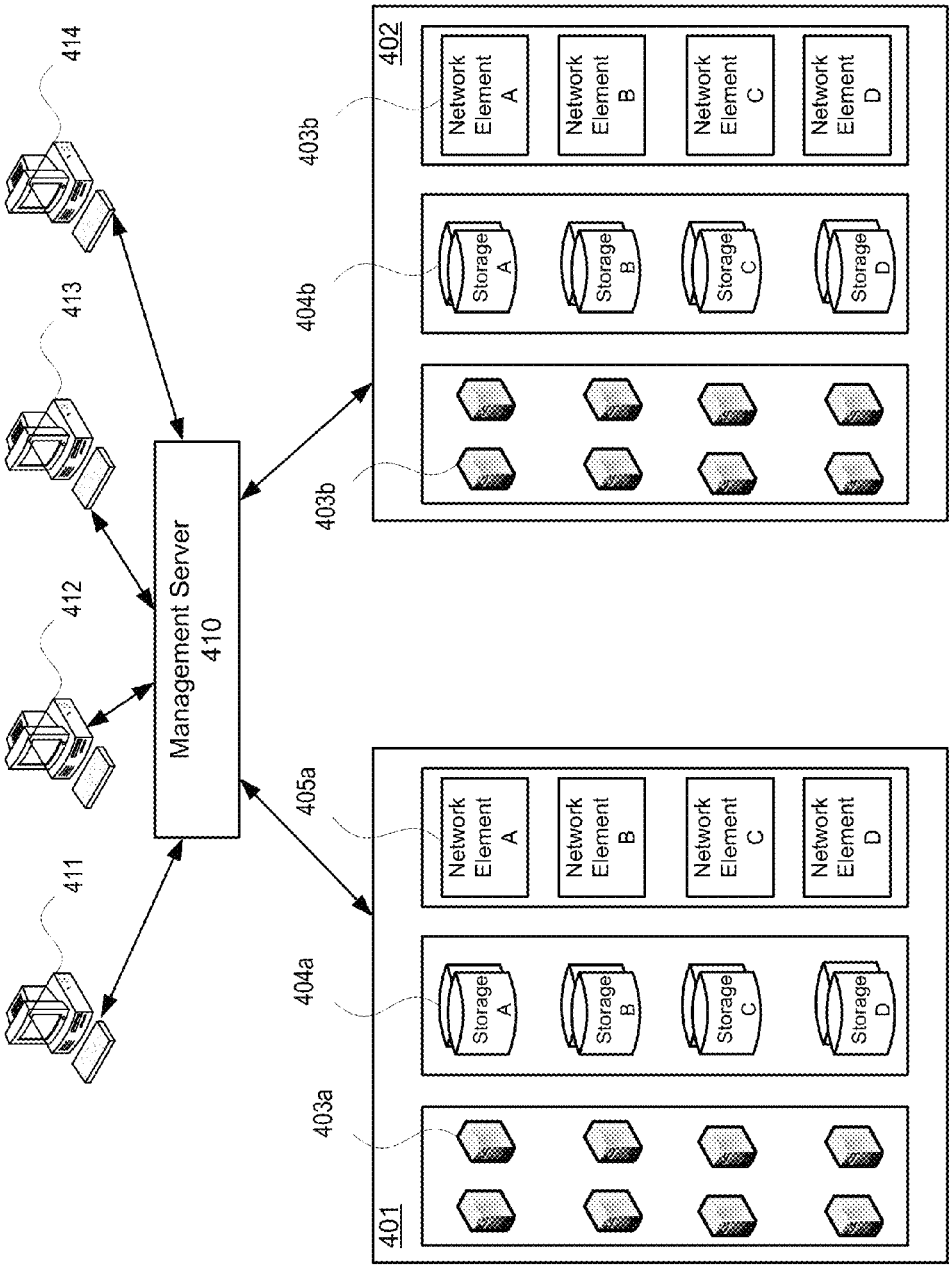

414
413
412
411
Management Server
410
403b
402
Network Element A
Network Element B
Network Element C
Network Element D
404b
Storage A
Storage B
Storage C
Storage D
403b
405a
Network Element A
Network Element B
Network Element C
Network Element D
404a
Storage A
Storage B
Storage C
Storage D
403a
401

FIG. 4

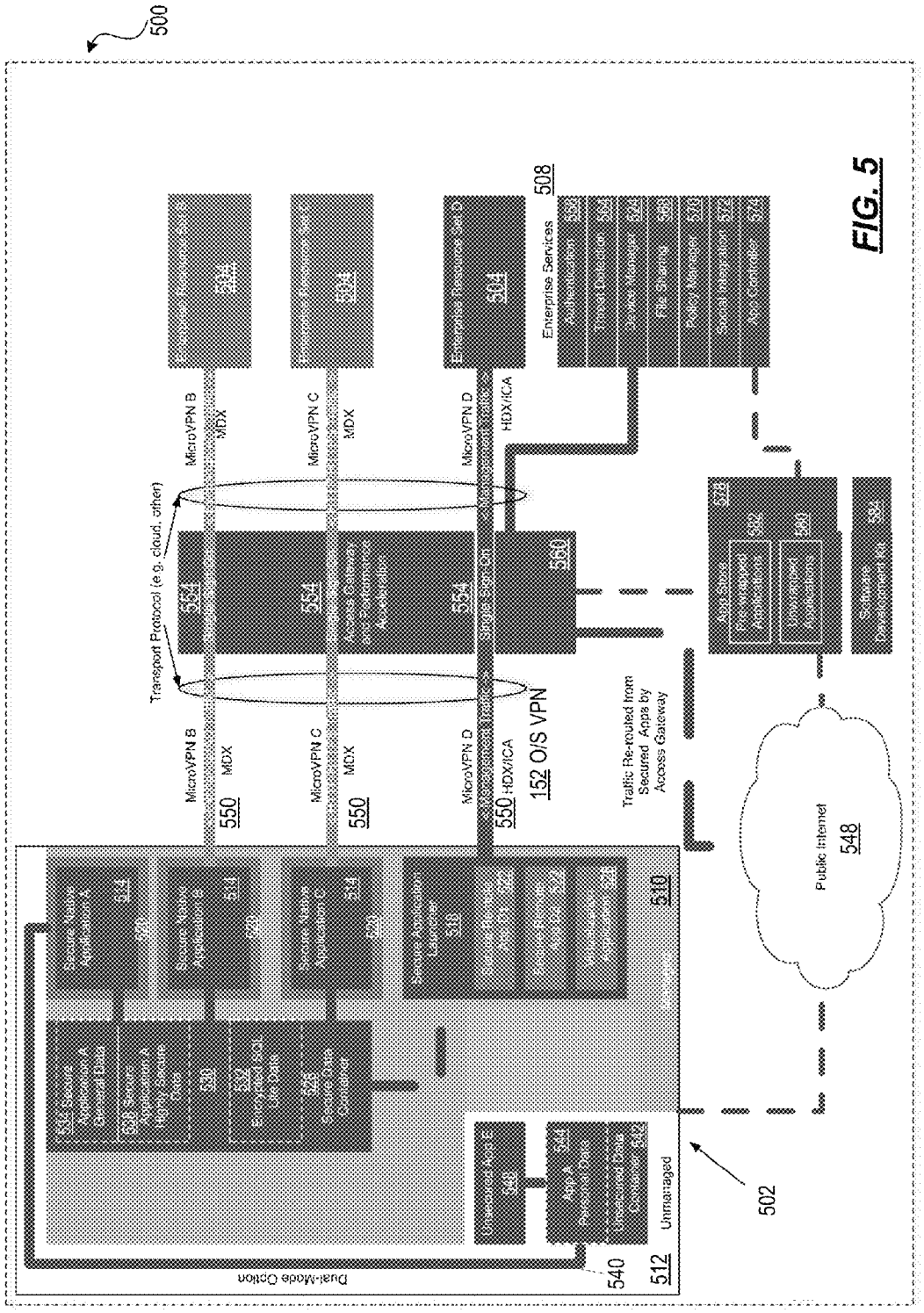

500
502
Dual-Mode Option
Unmanaged
512
540
Unsecured App E
548
App A Personal Data
Unsecured Data Container
542
Secure Application Launcher
518
Secure Application A General Data
Secure Application A Highly Secure Data
530
532
Encrypted SQL Lite Data
528
Secure Data Container
Secure Native Application A
Secure Native Application B
Secure Native Application C
Secure Native Application D
510
MicroVPN B
MDX
550
MicroVPN C
MDX
550
MicroVPN D
HDX/ICA
550
152 O/S VPN
Transport Protocol (e.g. cloud, other)
Single Sign-On
554
Access Gateway and Performance Acceleration
554
Single Sign-On
554
Management Traffic
560
Traffic Re-routed from Secured Apps by Access Gateway
Public Internet
548
Enterprise Resource Set D
504
Enterprise Resource Set C
504
Enterprise Resource Set D
504
Enterprise Services
508
Authentication
Threat Detection
Device Manager
File Sharing
Policy Manager
Social Integration
App Controller
App Store
Pre-wrapped Applications
Unwrapped Applications
Software Development Kit

FIG. 5

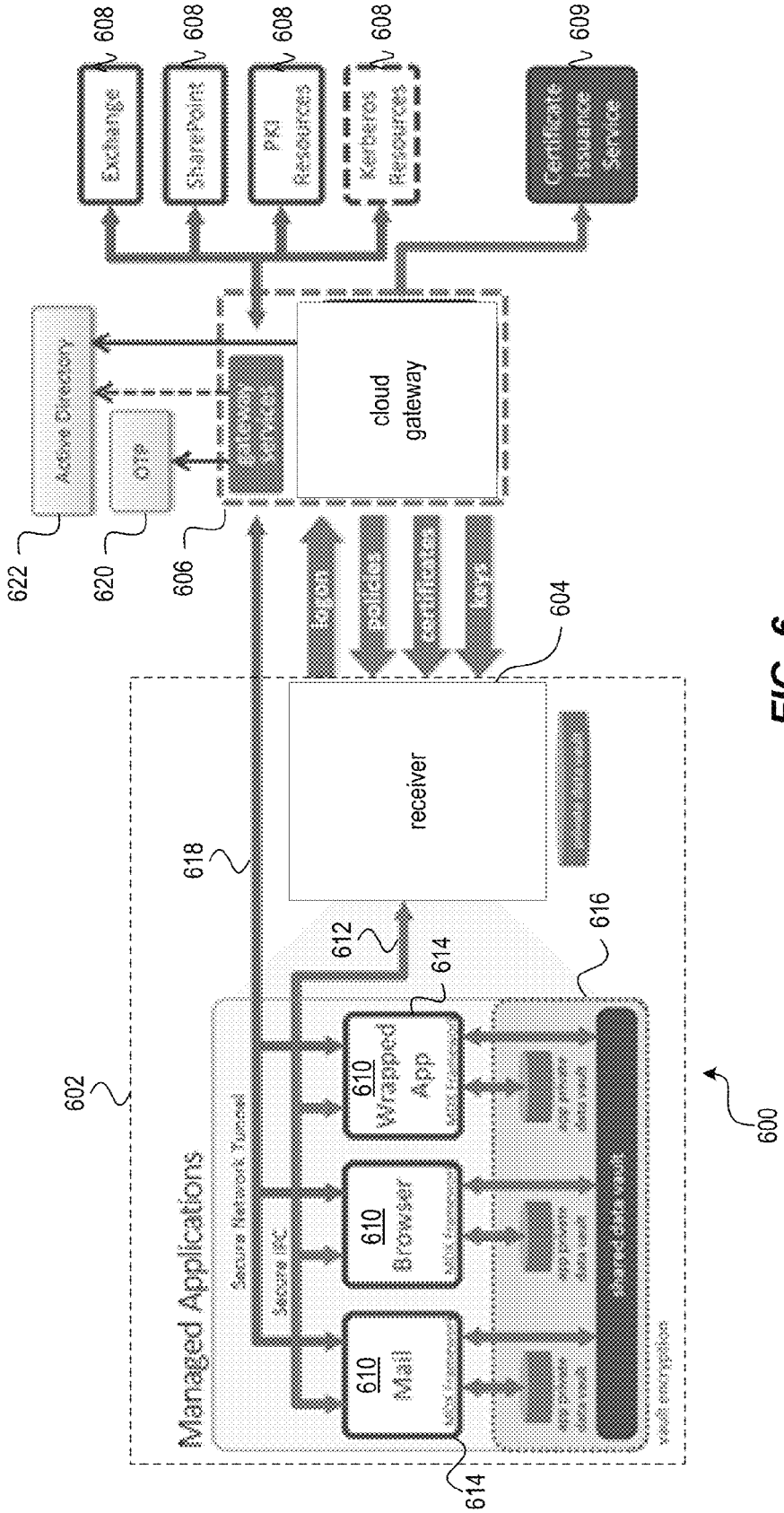

Exchange
SharePoint
PKI Resources
Kerberos Resources
Certificate Issuance Service
608
608
608
608
609
Active Directory
OTP
cloud gateway
622
620
606
logon
policies
certificates
keys
604
receiver
618
612
614
616
602
Managed Applications
Secure Network Tunnel
Secure IPC
610 Wrapped App
610 Browser
610 Mail
shared data vault
vault encryption
614
600

FIG. 6

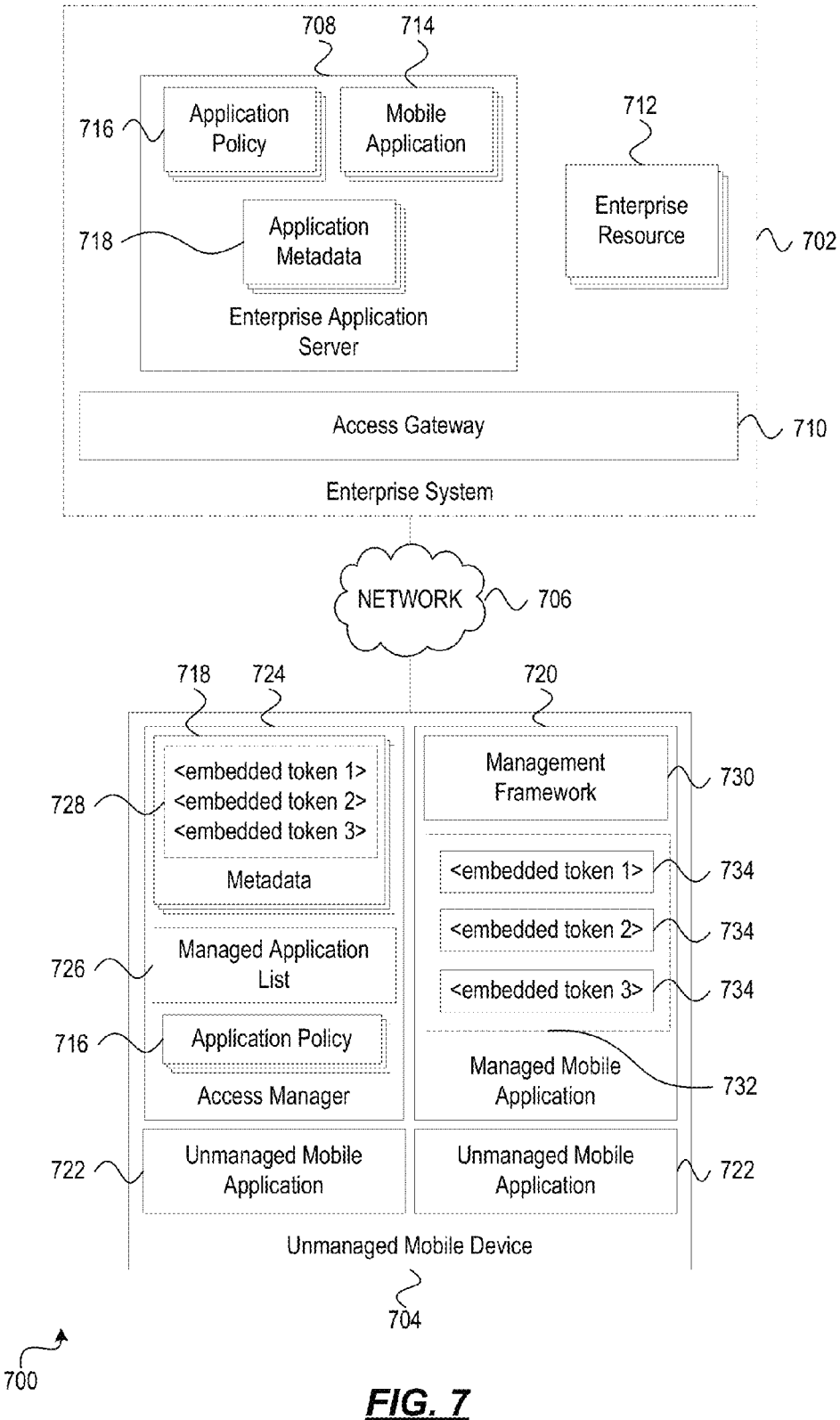

708
714
716
Application Policy
Mobile Application
712
Enterprise Resource
718
Application Metadata
Enterprise Application Server
702
Access Gateway
710
Enterprise System
NETWORK
706
718
724
720
728
<embedded token 1>
<embedded token 2>
<embedded token 3>
Metadata
Management Framework
730
<embedded token 1>
734
<embedded token 2>
734
<embedded token 3>
734
726
Managed Application List
716
Application Policy
Access Manager
Managed Mobile Application
732
722
Unmanaged Mobile Application
Unmanaged Mobile Application
722
Unmanaged Mobile Device
704
700

FIG. 7

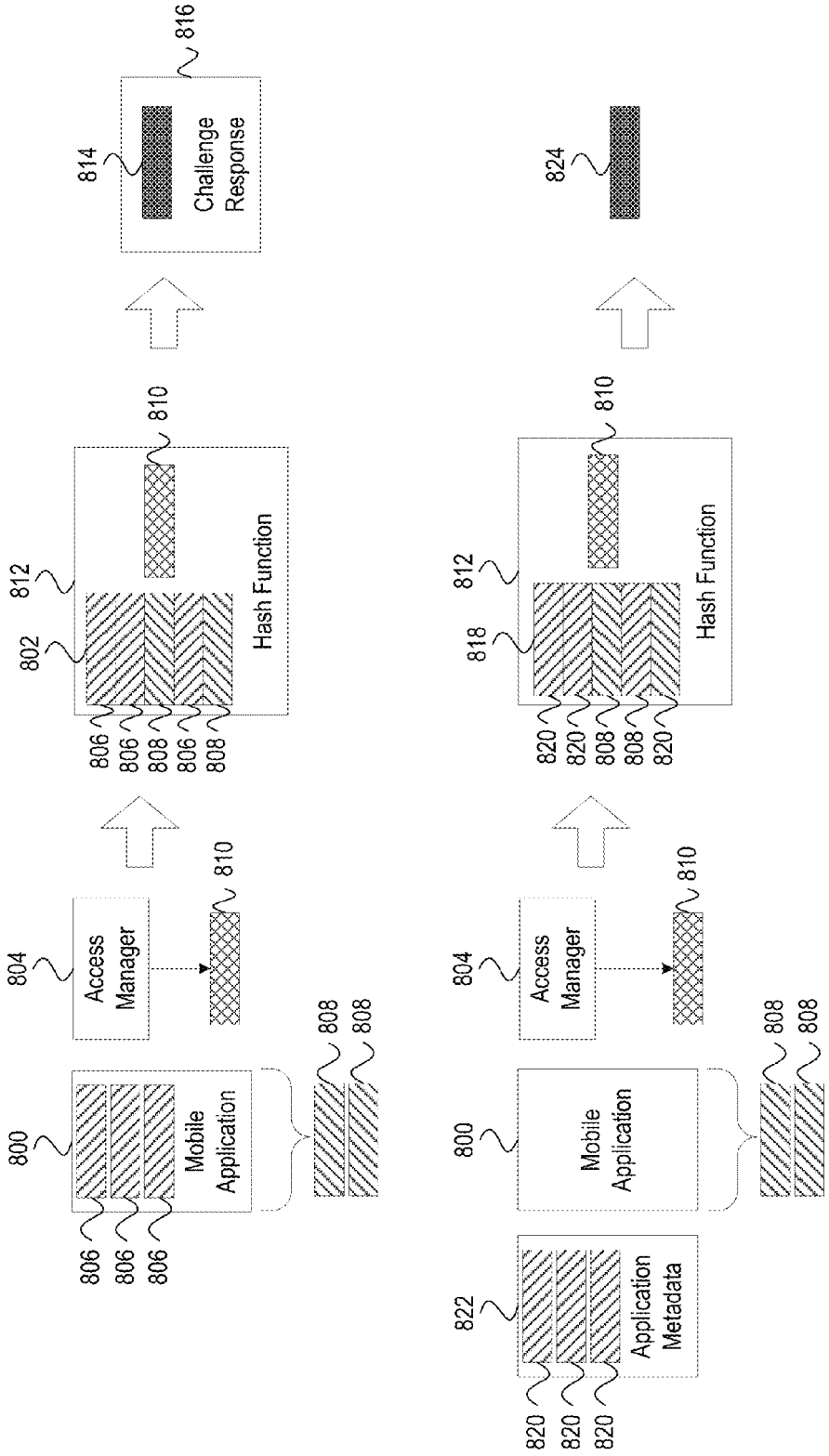

800
Mobile Application
806
806
806
804
Access Manager
810
808
808
812
802
Hash Function
810
806
806
808
806
808
814
Challenge Response
816
822
Application Metadata
820
820
820
818
820
820
808
808
820
824

FIG. 8

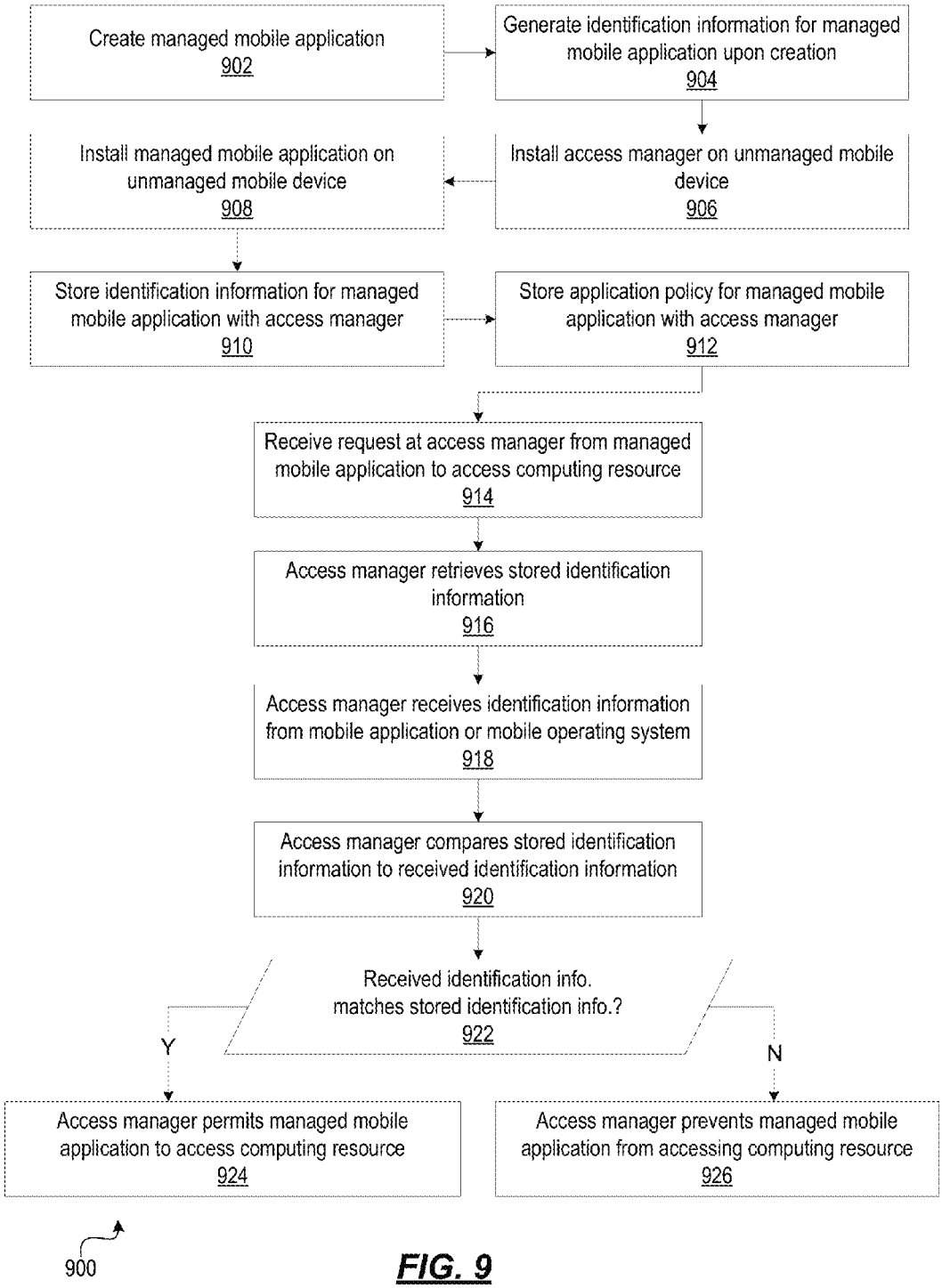

Create managed mobile application
902
Generate identification information for managed mobile application upon creation
904
Install access manager on unmanaged mobile device
906
Install managed mobile application on unmanaged mobile device
908
Store identification information for managed mobile application with access manager
910
Store application policy for managed mobile application with access manager
912
Receive request at access manager from managed mobile application to access computing resource
914
Access manager retrieves stored identification information
916
Access manager receives identification information from mobile application or mobile operating system
918
Access manager compares stored identification information to received identification information
920
Received identification info. matches stored identification info.?
922
Y
N
Access manager permits managed mobile application to access computing resource
924
Access manager prevents managed mobile application from accessing computing resource
926
900

FIG. 9

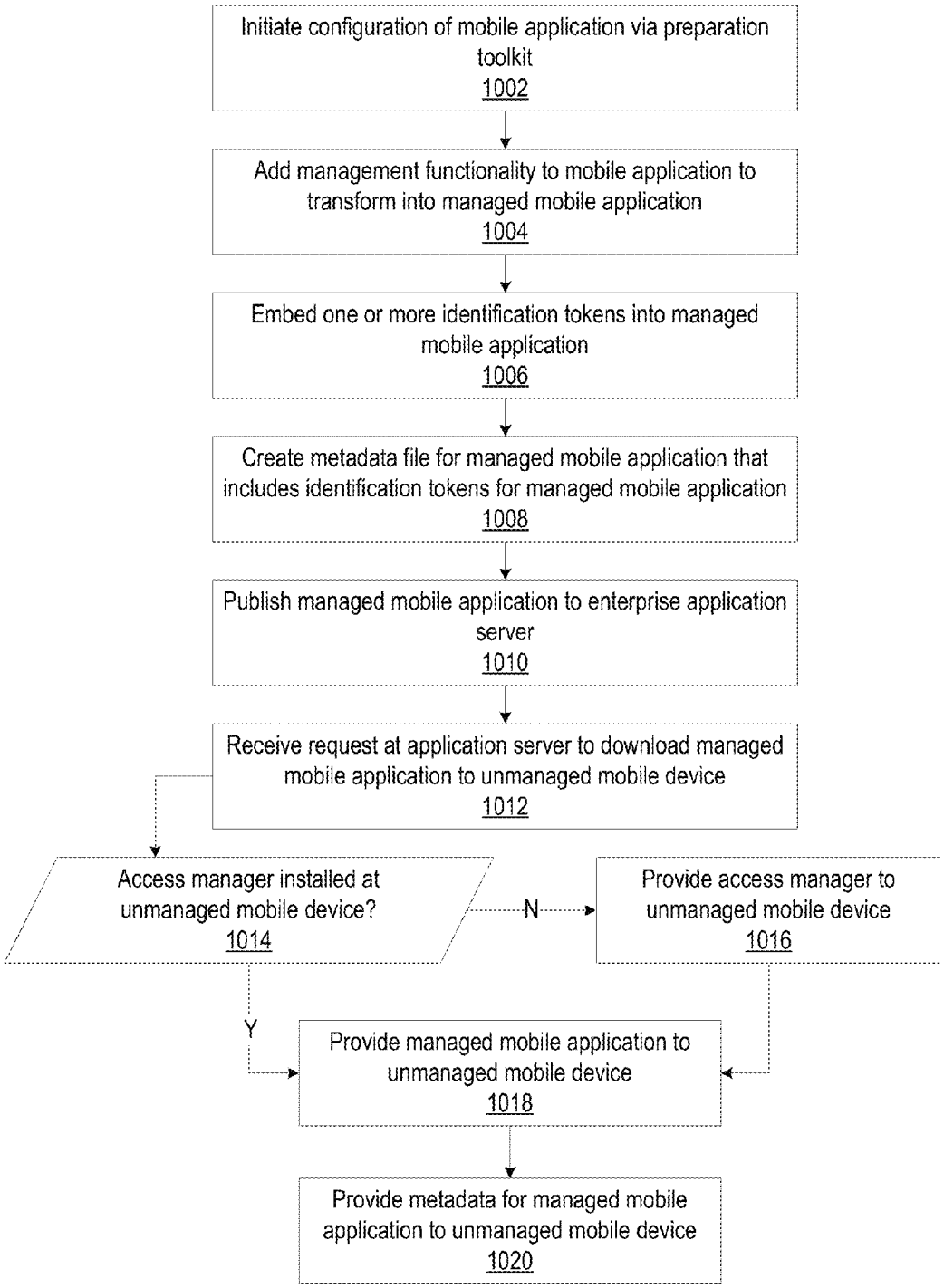

Initiate configuration of mobile application via preparation toolkit
1002
Add management functionality to mobile application to transform into managed mobile application
1004
Embed one or more identification tokens into managed mobile application
1006
Create metadata file for managed mobile application that includes identification tokens for managed mobile application
1008
Publish managed mobile application to enterprise application server
1010
Receive request at application server to download managed mobile application to unmanaged mobile device
1012
Access manager installed at unmanaged mobile device?
1014
N
Provide access manager to unmanaged mobile device
1016
Y
Provide managed mobile application to unmanaged mobile device
1018
Provide metadata for managed mobile application to unmanaged mobile device
1020
1000

FIG. 10

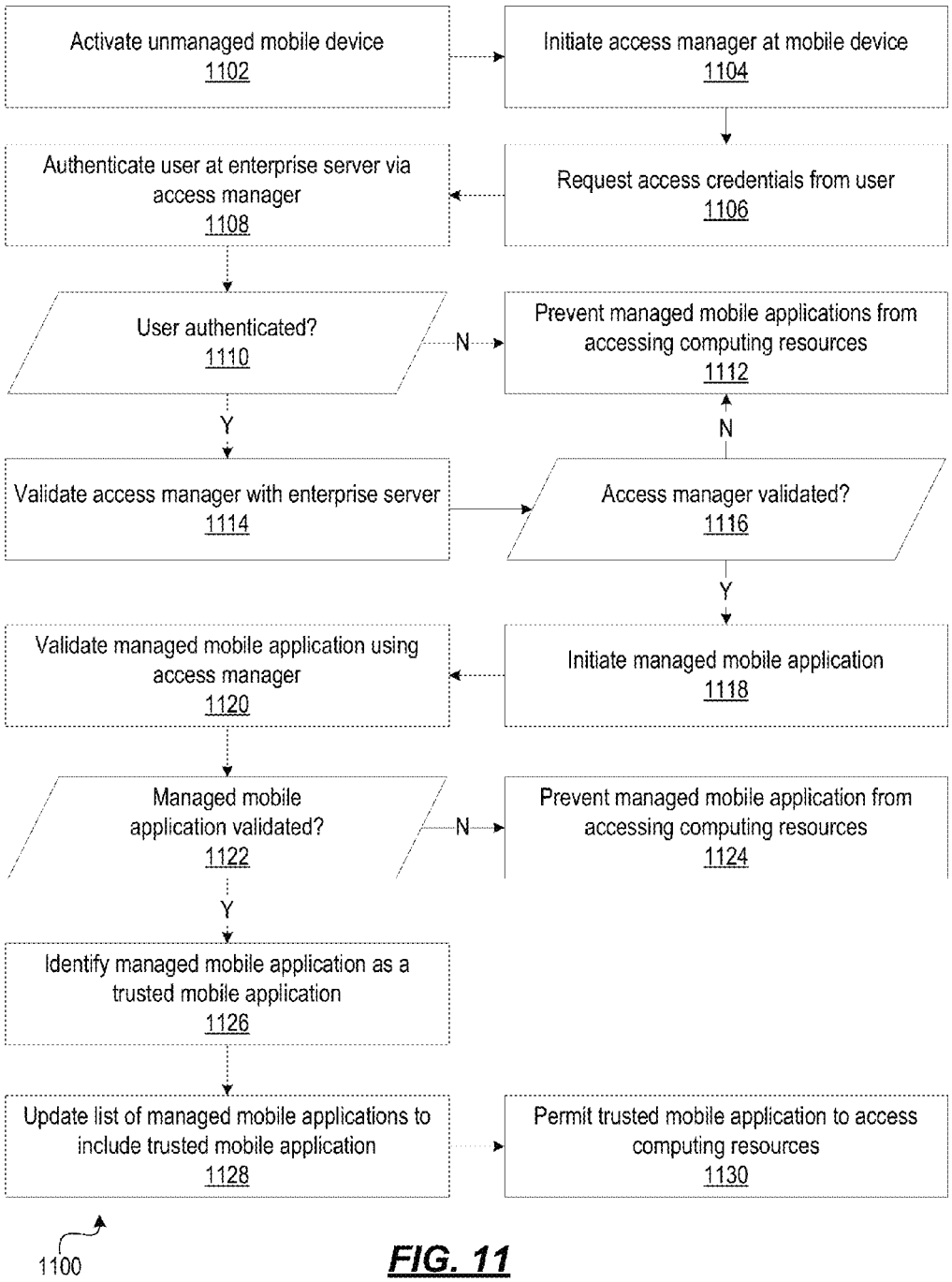

Activate unmanaged mobile device
1102
Initiate access manager at mobile device
1104
Request access credentials from user
1106
Authenticate user at enterprise server via access manager
1108
User authenticated?
1110
N
Prevent managed mobile applications from accessing computing resources
1112
Y
N
Validate access manager with enterprise server
1114
Access manager validated?
1116
Y
Validate managed mobile application using access manager
1120
Initiate managed mobile application
1118
Managed mobile application validated?
1122
N
Prevent managed mobile application from accessing computing resources
1124
Y
Identify managed mobile application as a trusted mobile application
1126
Update list of managed mobile applications to include trusted mobile application
1128
Permit trusted mobile application to access computing resources
1130
1100

FIG. 11

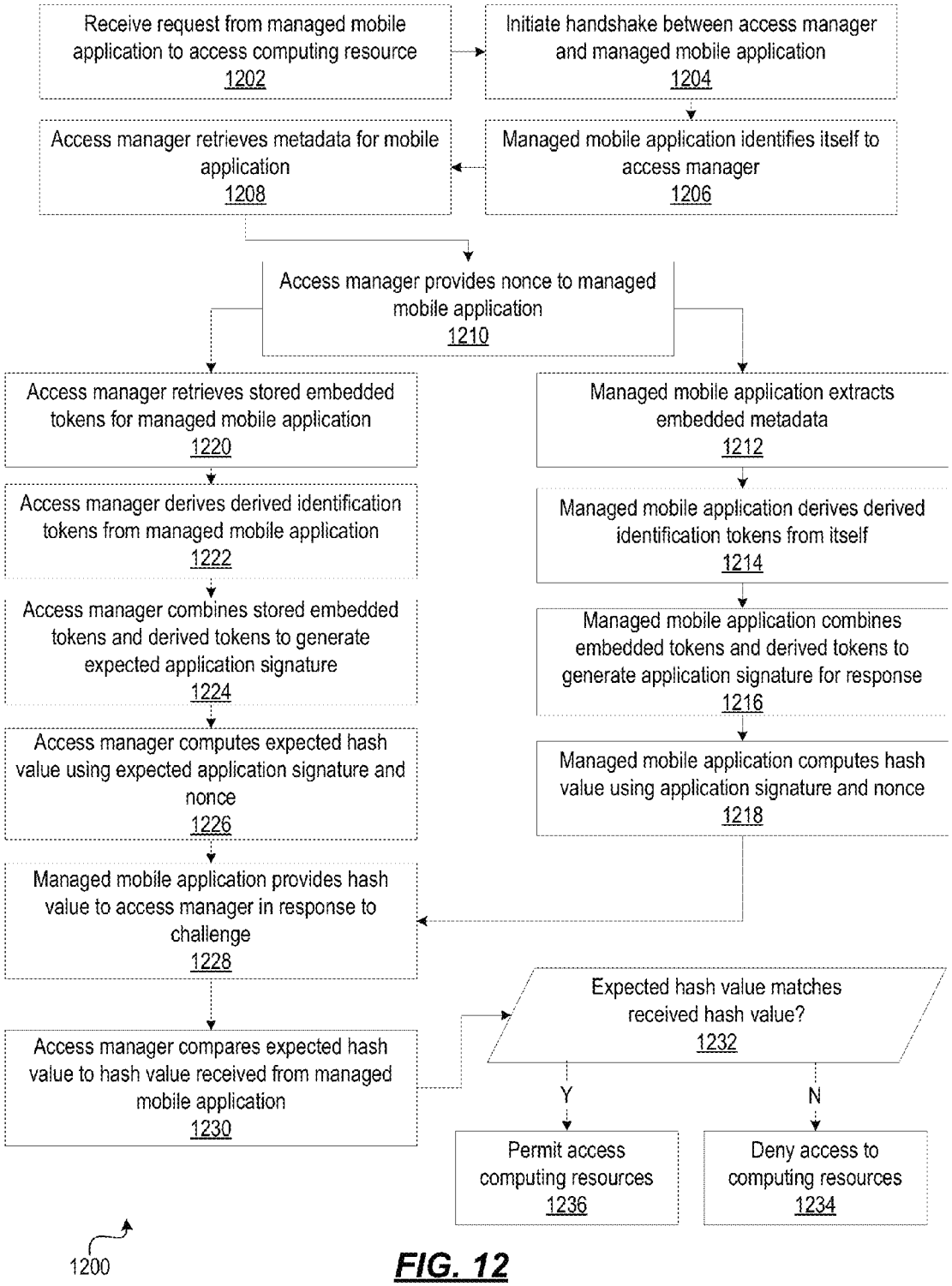

Receive request from managed mobile application to access computing resource 1202
Initiate handshake between access manager and managed mobile application 1204
Managed mobile application identifies itself to access manager 1206
Access manager retrieves metadata for mobile application 1208
Access manager provides nonce to managed mobile application 1210
Access manager retrieves stored embedded tokens for managed mobile application 1220
Access manager derives derived identification tokens from managed mobile application 1222
Access manager combines stored embedded tokens and derived tokens to generate expected application signature 1224
Access manager computes expected hash value using expected application signature and nonce 1226
Managed mobile application provides hash value to access manager in response to challenge 1228
Access manager compares expected hash value to hash value received from managed mobile application 1230
Managed mobile application extracts embedded metadata 1212
Managed mobile application derives derived identification tokens from itself 1214
Managed mobile application combines embedded tokens and derived tokens to generate application signature for response 1216
Managed mobile application computes hash value using application signature and nonce 1218
Expected hash value matches received hash value? 1232
Y
N
Permit access computing resources 1236
Deny access to computing resources 1234
1200

FIG. 12

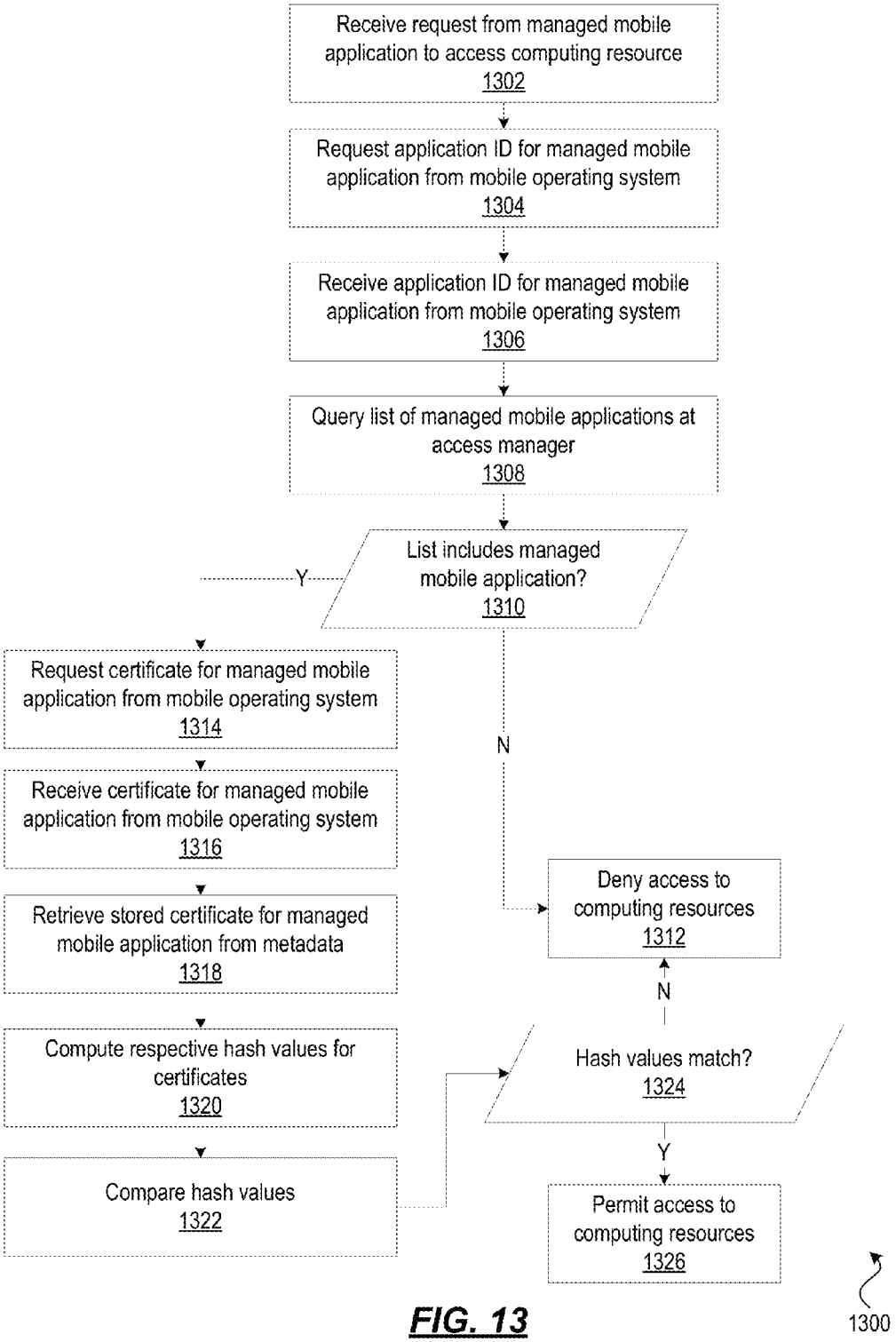

Receive request from managed mobile application to access computing resource 1302
Request application ID for managed mobile application from mobile operating system 1304
Receive application ID for managed mobile application from mobile operating system 1306
Query list of managed mobile applications at access manager 1308
List includes managed mobile application? 1310
Y
N
Request certificate for managed mobile application from mobile operating system 1314
Receive certificate for managed mobile application from mobile operating system 1316
Retrieve stored certificate for managed mobile application from metadata 1318
Compute respective hash values for certificates 1320
Compare hash values 1322
Hash values match? 1324
N
Y
Deny access to computing resources 1312
Permit access to computing resources 1326
1300

FIG. 13

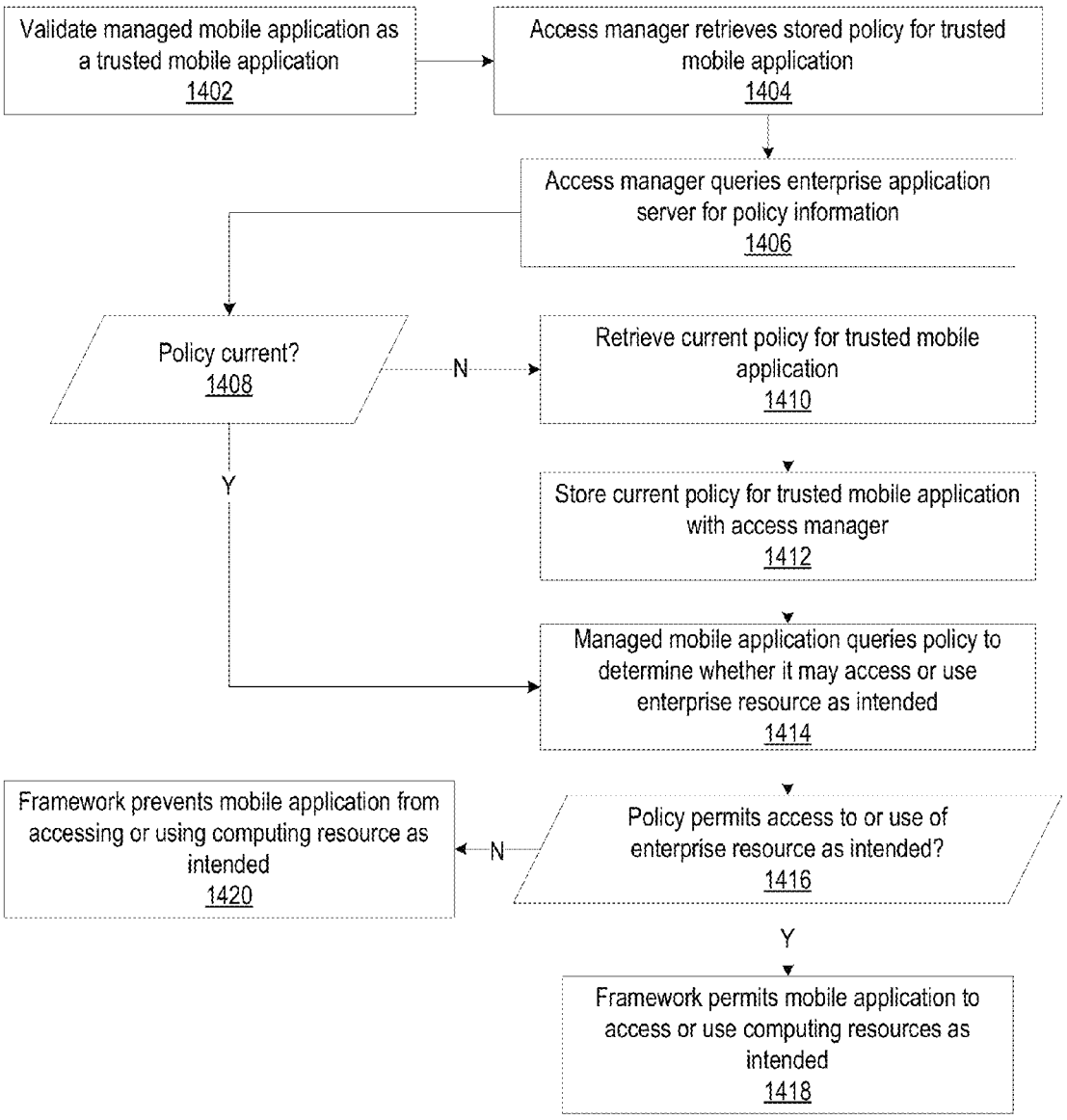

Validate managed mobile application as a trusted mobile application
1402
Access manager retrieves stored policy for trusted mobile application
1404
Access manager queries enterprise application server for policy information
1406
Policy current?
1408
N
Retrieve current policy for trusted mobile application
1410
Y
Store current policy for trusted mobile application with access manager
1412
Managed mobile application queries policy to determine whether it may access or use enterprise resource as intended
1414
Framework prevents mobile application from accessing or using computing resource as intended
1420
N
Policy permits access to or use of enterprise resource as intended?
1416
Y
Framework permits mobile application to access or use computing resources as intended
1418
1400

FIG. 14

VALIDATING THE IDENTITY OF A MOBILE APPLICATION FOR MOBILE APPLICATION MANAGEMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application Ser. No. 61/806,557, filed Mar. 29, 2013, and entitled "Systems and Methods for Enterprise Mobility Management," which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

Aspects described herein generally relate to management of mobile applications at mobile computing devices. More specifically, various aspects provide approaches to validating a mobile application operating at an unmanaged device and controlling execution of that mobile application.

BACKGROUND

The use of mobile computing devices continues to grow. In particular, business and other enterprises have come to rely on mobile computing devices to allow individuals to remotely access various computing resources. Such resources may include, for example, electronic mail services, file services, data, and other electronic resources provided by the computer systems of an enterprise or the mobile device itself.

Whether an individual is located locally or remotely relative to computing resources, an enterprise may seek to protect and control access to those resources. Accordingly, an enterprise may implement various technological mechanisms (e.g., gateways and firewalls) as well as access control mechanisms (e.g., user authentication and authorization) in order to ensure an individual can only access the resources that individual is authorized and entitled to access. Such mechanisms may also prevent unauthorized individuals from accessing any of the computing resources.

With respect to mobile devices, an enterprise may employ various approaches to control remote access to computing resources from those mobile devices. This endeavor may be referred to as mobile device management. In one approach, an enterprise may provide an individual with a company-owned and company-controlled mobile device. Such a device may be configured such that the enterprise has control over the configuration, functionality, operation, and data of the mobile device. In this regard, the company-controlled mobile device may be referred to as a managed device. The enterprise may remotely control the managed device via, e.g., a client-server architecture. An enterprise server may remotely issue commands to a client application residing at the managed device. Such commands may include, e.g., installing new applications or functionality, updating existing applications or functionality, updating configuration settings, providing data, and so forth. If the managed device is lost or stolen, the enterprise may issue commands to lock or wipe the device in order to prevent an unauthorized individual from gaining access to the device or from gaining access to the resources via the device.

Individuals, however, may find it inconvenient to maintain both a company-owned mobile device as well as a personal mobile device. Instead, individuals may prefer to access the resources from their personal mobile devices. This practice may be referred to as BYOD, bring-your-own-device. Because these personal devices may not be company-controlled, such personal devices may be referred to as unmanaged devices. To accommodate this preference, solutions to allow unmanaged devices to access these resources are currently in development.

For example, providing a company-controlled mobile application, a managed mobile application, that is configured to operate at an unmanaged device is one approach currently in development. However, challenges remain. For managed mobile applications operating on an unmanaged device to be a viable approach, mechanisms to prevent unauthorized access to or use of resources via the managed mobile application may be needed. In particular, there exists a need to validate the identity of a managed mobile application to ensure the managed mobile application has been altered to circumvent the security mechanisms that protect the resources. In addition, there exists a need to control the operation of the managed mobile application at the unmanaged mobile device.

BRIEF SUMMARY

The following presents a simplified summary of various aspects described herein. This summary is not an extensive overview, and is not intended to identify key or critical elements or to delineate the scope of the claims. The following summary merely presents some concepts in a simplified form as an introductory prelude to the more detailed description provided below.

To overcome limitations in the prior art described above, and to overcome other limitations that will be apparent upon reading and understanding the present specification, aspects described herein are directed towards controlling access to remote computing resources located at an enterprise computing system using managed mobile applications at mobile computing devices. In addition, aspects of the present disclosure are directed towards controlling access to local computing resources at the mobile computing devices themselves. An access manager may perform a validation process that determines whether a mobile application requesting access to computing resources has accurately identified itself and has not been subsequently altered after installation at the mobile computing device. In this way, the access manager may ensure the mobile application requesting access to the computing resource can be trusted and is not attempting to circumvent the security mechanisms used to protect those resources. As a result, individuals associated with the enterprise may advantageously utilize remote and local computing resources with their personal mobile devices.

A first aspect described herein provides a method of managing access to computing resources. An access manager may operate at a mobile device to validate a mobile application installed at that mobile device. If the access manager does not successfully validate the mobile application, the access manager may prevent the mobile application from accessing a computing resource. If the access manager does successfully validate the mobile application, then the access manager may identify the mobile application as a trusted mobile application. The access manager may thus permit the trusted mobile application to access the computing resource.

A second aspect described herein provides a mobile computing device. The mobile computing device may include a mobile application configured to access a computing resource, stored identification information associated with the mobile application, and an access manager. The access manager may be configured to validate the mobile application and prevent or permit access to the computing resource as described above.

A third aspect described herein provides an access manager configured to operate at a mobile device. The access manager may also be configured to validate a mobile application at the mobile device and prevent or permit access to a computing resource via the mobile application as described above. The access manager may further be configured to control operation of the mobile application based on an application policy stored at the mobile application.

Some aspects described herein provide that the stored identification information may be an original digital certificate associated and created along with the mobile application. The access manager may validate the mobile application by comparing the original digital certificate created for the mobile application with a digital certificate received from a mobile operating system at the mobile computing device. The computing resources may be located locally or remotely relative to the mobile computing device. Examples of computing resources include a software application operating at the mobile computing device or a remote computing system, a service provided by the mobile computing device or a remote computing system, data stored at the mobile computing device or the remote computing system, hardware at the mobile computing device or the remote computing system, and combinations of such.

The stored identification information may also be identification tokens embedded into the mobile application upon creation or derived from the mobile application. An application signature may be constructed based on an arrangement of the embedded and derive identification tokens. The access manager may also provide the mobile application with a nonce during validation, and use the nonce to compute an expected hash value using the application signature and the nonce. The access manager may generate an expected response, e.g., an expected hash value, and compare the expected response to a response received from the mobile application following a challenge from the access manager.

These and additional aspects will be appreciated with the benefit of the disclosures discussed in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of aspects described herein and the advantages thereof may be acquired by referring to the following description in consideration of the accompanying drawings, in which like reference numbers indicate like features, and wherein:

FIG. **1** depicts an illustrative computer system architecture that may be used in accordance with one or more illustrative aspects described herein.

FIG. **2** depicts an illustrative remote-access system architecture that may be used in accordance with one or more illustrative aspects described herein.

FIG. **3** depicts an illustrative virtualized (hypervisor) system architecture that may be used in accordance with one or more illustrative aspects described herein.

FIG. **4** depicts an illustrative cloud-based system architecture that may be used in accordance with one or more illustrative aspects described herein.

FIG. **5** depicts an illustrative enterprise mobility management system.

FIG. **6** depicts another illustrative enterprise mobility management system.

FIG. **7** depicts an illustrative mobile device management system.

FIG. **8** depicts a block diagram of an illustrative application signature and challenge response for a managed mobile application.

FIG. **9** is a flowchart of example method steps for managing a mobile application at an unmanaged mobile device.

FIG. **10** is a flowchart of example method steps for preparing a managed mobile application for managed operation at an unmanaged mobile device.

FIG. **11** is a flowchart of example method steps for initializing a managed mobile application at an unmanaged mobile device.

FIG. **12** is a flowchart of example method steps for validating a managed mobile application at an unmanaged mobile device having a first type of mobile operating system.

FIG. **13** is a flowchart of example method steps for validating a managed mobile application at an unmanaged mobile device having a second type of mobile operating system.

FIG. **14** is a flowchart of example method steps for enforcing application policies during operation of a managed mobile application.

DETAILED DESCRIPTION

In the following description of the various embodiments, reference is made to the accompanying drawings identified above and which form a part hereof, and in which is shown by way of illustration various embodiments in which aspects described herein may be practiced. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made without departing from the scope described herein. Various aspects are capable of other embodiments and of being practiced or being carried out in various different ways.

As a general introduction to the subject matter described in more detail below, aspects described herein are directed towards controlling remote and local access to computing resources at a remotely located enterprise computing system or at mobile computing devices themselves. An access manager may perform a validation process that determines whether a mobile application requesting access to computing resources has accurately identified itself and has not been subsequently altered after installation at the mobile computing device. In this way, the access manager may ensure the mobile application requesting access to the computing resource can be trusted and is not attempting to circumvent the security mechanisms used to protect those resources. As a result, individuals associated with the enterprise may advantageously utilize computing resources at their personal mobile devices. Computing resources may be located locally or remotely relative to the mobile computing device. Examples of computing resources include a software application operating at the mobile computing device or a remote computing system, a service provided by the mobile computing device or a remote computing system, data stored at the mobile computing device or the remote computing system, hardware at the mobile computing device or the remote computing system, and combinations of such. In the present disclosure, computing resources that are remotely located at a computing system of an enterprise are referred to as enterprise resources.

It is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. Rather, the phrases and terms used herein are to be given their broadest interpretation and meaning. The use of "including" and "comprising" and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items and equivalents thereof. The use of the terms "mounted," "connected," "coupled," "positioned," "engaged" and similar terms, is

meant to include both direct and indirect mounting, connecting, coupling, positioning and engaging.

Computing Architecture

Computer software, hardware, and networks may be utilized in a variety of different system environments, including standalone, networked, remote-access (aka, remote desktop), virtualized, and/or cloud-based environments, among others. FIG. **1** illustrates one example of a system architecture and data processing device that may be used to implement one or more illustrative aspects of the disclosure in a standalone and/or networked environment. Various network nodes **103**, **105**, **107**, and **109** may be interconnected via a wide area network (WAN) **101**, such as the Internet. Other networks may also or alternatively be used, including private intranets, corporate networks, LANs, metropolitan area networks (MAN) wireless networks, personal networks (PAN), and the like. Network **101** is for illustration purposes and may be replaced with fewer or additional computer networks. A local area network (LAN) may have one or more of any known LAN topology and may use one or more of a variety of different protocols, such as Ethernet. Devices **103**, **105**, **107**, **109** and other devices (not shown) may be connected to one or more of the networks via twisted pair wires, coaxial cable, fiber optics, radio waves or other communication media.

The term "network" as used herein and depicted in the drawings refers not only to systems in which remote storage devices are coupled together via one or more communication paths, but also to stand-alone devices that may be coupled, from time to time, to such systems that have storage capability. Consequently, the term "network" includes not only a "physical network" but also a "content network," which is comprised of the data—attributable to a single entity—which resides across all physical networks.

The components may include data server **103**, web server **105**, and client computers **107**, **109**. Data server **103** provides overall access, control and administration of databases and control software for performing one or more illustrative aspects of the disclosure as described herein. Data server **103** may be connected to web server **105** through which users interact with and obtain data as requested. Alternatively, data server **103** may act as a web server itself and be directly connected to the Internet. Data server **103** may be connected to web server **105** through the network **101** (e.g., the Internet), via direct or indirect connection, or via some other network. Users may interact with the data server **103** using remote computers **107**, **109**, e.g., using a web browser to connect to the data server **103** via one or more externally exposed web sites hosted by web server **105**. Client computers **107**, **109** may be used in concert with data server **103** to access data stored therein, or may be used for other purposes. For example, from client device **107** a user may access web server **105** using an Internet browser, as is known in the art, or by executing a software application that communicates with web server **105** and/or data server **103** over a computer network (such as the Internet).

Servers and applications may be combined on the same physical machines, and retain separate virtual or logical addresses, or may reside on separate physical machines. FIG. **1** illustrates just one example of a network architecture that may be used, and those of skill in the art will appreciate that the specific network architecture and data processing devices used may vary, and are secondary to the functionality that they provide, as further described herein. For example, services provided by web server **105** and data server **103** may be combined on a single server.

Each component **103**, **105**, **107**, **109** may be any type of known computer, server, or data processing device. Data server **103**, e.g., may include a processor **111** controlling overall operation of the rate server **103**. Data server **103** may further include RAM **113**, ROM **115**, network interface **117**, input/output interfaces **119** (e.g., keyboard, mouse, display, printer, etc.), and memory **121**. I/O **119** may include a variety of interface units and drives for reading, writing, displaying, and/or printing data or files. Memory **121** may further store operating system software **123** for controlling overall operation of the data processing device **103**, control logic **125** for instructing data server **103** to perform aspects of the disclosure as described herein, and other application software **127** providing secondary, support, and/or other functionality which may or may not be used in conjunction with aspects of the present disclosure. The control logic may also be referred to herein as the data server software **125**. Functionality of the data server software may refer to operations or decisions made automatically based on rules coded into the control logic, made manually by a user providing input into the system, and/or a combination of automatic processing based on user input (e.g., queries, data updates, etc.).

Memory **121** may also store data used in performance of one or more aspects of the disclosure, including a first database **129** and a second database **131**. In some embodiments, the first database may include the second database (e.g., as a separate table, report, etc.). That is, the information can be stored in a single database, or separated into different logical, virtual, or physical databases, depending on system design. Devices **105**, **107**, **109** may have similar or different architecture as described with respect to device **103**. Those of skill in the art will appreciate that the functionality of data processing device **103** (or device **105**, **107**, **109**) as described herein may be spread across multiple data processing devices, for example, to distribute processing load across multiple computers, to segregate transactions based on geographic location, user access level, quality of service (QoS), etc.

One or more aspects may be embodied in computer-usable or readable data and/or computer-executable instructions, such as in one or more program modules, executed by one or more computers or other devices as described herein. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types when executed by a processor in a computer or other device. The modules may be written in a source code programming language that is subsequently compiled for execution, or may be written in a scripting language such as (but not limited to) HTML or XML. The computer executable instructions may be stored on a computer readable medium such as a nonvolatile storage device. Any suitable computer readable storage media may be utilized, including hard disks, CD-ROMs, optical storage devices, magnetic storage devices, and/or any combination thereof. In addition, various transmission (non-storage) media representing data or events as described herein may be transferred between a source and a destination in the form of electromagnetic waves traveling through signal-conducting media such as metal wires, optical fibers, and/or wireless transmission media (e.g., air and/or space). Various aspects described herein may be embodied as a method, a data processing system, or a computer program product. Therefore, various functionality may be embodied in whole or in part in software, firmware and/or hardware or hardware equivalents such as integrated circuits, field programmable gate arrays (FPGA), and the like. Particular data structures may be used to more effectively implement one or more aspects of the disclosure, and such data structures are contemplated within the scope of computer executable instructions and computer-usable data described herein.

With further reference to FIG. **2**, one or more aspects described herein may be implemented in a remote-access environment. FIG. **2** depicts an example system architecture including a generic computing device **201** in an illustrative computing environment **200** that may be used according to one or more illustrative aspects described herein. Generic computing device **201** may be used as a server **206***a* in a single-server or multi-server desktop virtualization system (e.g., a remote access or cloud system) configured to provide virtual machines for client access devices. The generic computing device **201** may have a processor **203** for controlling overall operation of the server and its associated components, including random access memory (RAM) **205**, read-only memory (ROM) **207**, input/output (I/O) module **209**, and memory **215**.

I/O module **209** may include a mouse, keypad, touch screen, scanner, optical reader, and/or stylus (or other input device(s)) through which a user of generic computing device **201** may provide input, and may also include one or more of a speaker for providing audio output and a video display device for providing textual, audiovisual, and/or graphical output. Software may be stored within memory **215** and/or other storage to provide instructions to processor **203** for configuring generic computing device **201** into a special purpose computing device in order to perform various functions as described herein. For example, memory **215** may store software used by the computing device **201**, such as an operating system **217**, application programs **219**, and an associated database **221**.

Computing device **201** may operate in a networked environment supporting connections to one or more remote computers, such as terminals **240** (also referred to as client devices). The terminals **240** may be personal computers, mobile devices, laptop computers, tablets, or servers that include many or all of the elements described above with respect to the generic computing device **103** or **201**. The network connections depicted in FIG. **2** include a local area network (LAN) **225** and a wide area network (WAN) **229**, but may also include other networks. When used in a LAN networking environment, computing device **201** may be connected to the LAN **225** through a network interface or adapter **223**. When used in a WAN networking environment, computing device **201** may include a modem **227** or other wide area network interface for establishing communications over the WAN **229**, such as computer network **230** (e.g., the Internet). It will be appreciated that the network connections shown are illustrative and other means of establishing a communications link between the computers may be used. Computing device **201** and/or terminals **240** may also be mobile terminals (e.g., mobile phones, smartphones, PDAs, notebooks, etc.) including various other components, such as a battery, speaker, and antennas (not shown).

Aspects described herein may also be operational with numerous other general purpose or special purpose computing system environments or configurations. Examples of other computing systems, environments, and/or configurations that may be suitable for use with aspects described herein include, but are not limited to, personal computers, server computers, hand-held or laptop devices, multiprocessor systems, microprocessor-based systems, set top boxes, programmable consumer electronics, network PCs, minicomputers, mainframe computers, distributed computing environments that include any of the above systems or devices, and the like.

As shown in FIG. **2**, one or more client devices **240** may be in communication with one or more servers **206***a*-**206***n* (generally referred to herein as "server(s) **206**"). In one embodiment, the computing environment **200** may include a network appliance installed between the server(s) **206** and client machine(s) **240**. The network appliance may manage client/server connections, and in some cases can load balance client connections amongst a plurality of backend servers **206**.

The client machine(s) **240** may in some embodiments be referred to as a single client machine **240** or a single group of client machines **240**, while server(s) **206** may be referred to as a single server **206** or a single group of servers **206**. In one embodiment a single client machine **240** communicates with more than one server **206**, while in another embodiment a single server **206** communicates with more than one client machine **240**. In yet another embodiment, a single client machine **240** communicates with a single server **206**.

A client machine **240** can, in some embodiments, be referenced by any one of the following non-exhaustive terms: client machine(s); client(s); client computer(s); client device(s); client computing device(s); local machine; remote machine; client node(s); endpoint(s); or endpoint node(s). The server **206**, in some embodiments, may be referenced by any one of the following non-exhaustive terms: server(s), local machine; remote machine; server farm(s), or host computing device(s).

In one embodiment, the client machine **240** may be a virtual machine. The virtual machine may be any virtual machine, while in some embodiments the virtual machine may be any virtual machine managed by a Type 1 or Type 2 hypervisor, for example, a hypervisor developed by Citrix Systems, IBM, VMware, or any other hypervisor. In some aspects, the virtual machine may be managed by a hypervisor, while in aspects the virtual machine may be managed by a hypervisor executing on a server **206** or a hypervisor executing on a client **240**.

Some embodiments include a client device **240** that displays application output generated by an application remotely executing on a server **206** or other remotely located machine. In these embodiments, the client device **240** may execute a virtual machine receiver program or application to display the output in an application window, a browser, or other output window. In one example, the application is a desktop, while in other examples the application is an application that generates or presents a desktop. A desktop may include a graphical shell providing a user interface for an instance of an operating system in which local and/or remote applications can be integrated. Applications, as used herein, are programs that execute after an instance of an operating system (and, optionally, also the desktop) has been loaded.

The server **206**, in some embodiments, uses a remote presentation protocol or other program to send data to a thin-client or remote-display application executing on the client to present display output generated by an application executing on the server **206**. The thin-client or remote-display protocol can be any one of the following non-exhaustive list of protocols: the Independent Computing Architecture (ICA) protocol developed by Citrix Systems, Inc. of Ft. Lauderdale, Fla.; or the Remote Desktop Protocol (RDP) manufactured by the Microsoft Corporation of Redmond, Wash.

A remote computing environment may include more than one server **206***a*-**206***n* such that the servers **206***a*-**206***n* are logically grouped together into a server farm **206**, for example, in a cloud computing environment. The server farm **206** may include servers **206** that are geographically dispersed while and logically grouped together, or servers **206** that are located proximate to each other while logically grouped together. Geographically dispersed servers **206***a*-**206***n* within a server farm **206** can, in some embodiments, communicate using a WAN (wide), MAN (metropolitan), or

LAN (local), where different geographic regions can be characterized as: different continents; different regions of a continent; different countries; different states; different cities; different campuses; different rooms; or any combination of the preceding geographical locations. In some embodiments the server farm **206** may be administered as a single entity, while in other embodiments the server farm **206** can include multiple server farms.

In some embodiments, a server farm may include servers **206** that execute a substantially similar type of operating system platform (e.g., WINDOWS, UNIX, LINUX, iOS, ANDROID, SYMBIAN, etc.) In other embodiments, server farm **206** may include a first group of one or more servers that execute a first type of operating system platform, and a second group of one or more servers that execute a second type of operating system platform.

Server **206** may be configured as any type of server, as needed, e.g., a file server, an application server, a web server, a proxy server, an appliance, a network appliance, a gateway, an application gateway, a gateway server, a virtualization server, a deployment server, an SSL VPN server, a firewall, a web server, an application server or as a master application server, a server executing an active directory, or a server executing an application acceleration program that provides firewall functionality, application functionality, or load balancing functionality. Other server types may also be used.

Some embodiments include a first server **106***a* that receives requests from a client machine **240**, forwards the request to a second server **106***b*, and responds to the request generated by the client machine **240** with a response from the second server **106***b*. First server **106***a* may acquire an enumeration of applications available to the client machine **240** as well as address information associated with an application server **206** hosting an application identified within the enumeration of applications. First server **106***a* can then present a response to the client's request using a web interface, and communicate directly with the client **240** to provide the client **240** with access to an identified application. One or more clients **240** and/or one or more servers **206** may transmit data over network **230**, e.g., network **101**.

FIG. **2** shows a high-level architecture of an illustrative desktop virtualization system. As shown, the desktop virtualization system may be single-server or multi-server system, or cloud system, including at least one virtualization server **206** configured to provide virtual desktops and/or virtual applications to one or more client access devices **240**. As used herein, a desktop refers to a graphical environment or space in which one or more applications may be hosted and/or executed. A desktop may include a graphical shell providing a user interface for an instance of an operating system in which local and/or remote applications can be integrated. Applications may include programs that execute after an instance of an operating system (and, optionally, also the desktop) has been loaded. Each instance of the operating system may be physical (e.g., one operating system per device) or virtual (e.g., many instances of an OS running on a single device). Each application may be executed on a local device, or executed on a remotely located device (e.g., remoted).

With further reference to FIG. **3**, a computer device **301** may be configured as a virtualization server in a virtualization environment, for example, a single-server, multi-server, or cloud computing environment. Virtualization server **301** illustrated in FIG. **3** can be deployed as and/or implemented by one or more embodiments of the server **206** illustrated in FIG. **2** or by other known computing devices. Included in virtualization server **301** is a hardware layer that can include one or more physical disks **304**, one or more physical devices **306**, one or more physical processors **308** and one or more physical memories **316**. In some embodiments, firmware **312** can be stored within a memory element in the physical memory **316** and can be executed by one or more of the physical processors **308**. Virtualization server **301** may further include an operating system **314** that may be stored in a memory element in the physical memory **316** and executed by one or more of the physical processors **308**. Still further, a hypervisor **302** may be stored in a memory element in the physical memory **316** and can be executed by one or more of the physical processors **308**.

Executing on one or more of the physical processors **308** may be one or more virtual machines **332**A-C (generally **332**). Each virtual machine **332** may have a virtual disk **326**A-C and a virtual processor **328**A-C. In some embodiments, a first virtual machine **332**A may execute, using a virtual processor **328**A, a control program **320** that includes a tools stack **324**. Control program **320** may be referred to as a control virtual machine, Dom0, Domain 0, or other virtual machine used for system administration and/or control. In some embodiments, one or more virtual machines **332**B-C can execute, using a virtual processor **328**B-C, a guest operating system **330**A-B.

Virtualization server **301** may include a hardware layer **310** with one or more pieces of hardware that communicate with the virtualization server **301**. In some embodiments, the hardware layer **310** can include one or more physical disks **304**, one or more physical devices **306**, one or more physical processors **308**, and one or more memory **316**. Physical components **304**, **306**, **308**, and **316** may include, for example, any of the components described above. Physical devices **306** may include, for example, a network interface card, a video card, a keyboard, a mouse, an input device, a monitor, a display device, speakers, an optical drive, a storage device, a universal serial bus connection, a printer, a scanner, a network element (e.g., router, firewall, network address translator, load balancer, virtual private network (VPN) gateway, Dynamic Host Configuration Protocol (DHCP) router, etc.), or any device connected to or communicating with virtualization server **301**. Physical memory **316** in the hardware layer **310** may include any type of memory. Physical memory **316** may store data, and in some embodiments may store one or more programs, or set of executable instructions. FIG. **3** illustrates an embodiment where firmware **312** is stored within the physical memory **316** of virtualization server **301**. Programs or executable instructions stored in the physical memory **316** can be executed by the one or more processors **308** of virtualization server **301**.

Virtualization server **301** may also include a hypervisor **302**. In some embodiments, hypervisor **302** may be a program executed by processors **308** on virtualization server **301** to create and manage any number of virtual machines **332**. Hypervisor **302** may be referred to as a virtual machine monitor, or platform virtualization software. In some embodiments, hypervisor **302** can be any combination of executable instructions and hardware that monitors virtual machines executing on a computing machine. Hypervisor **302** may be Type 2 hypervisor, where the hypervisor that executes within an operating system **314** executing on the virtualization server **301**. Virtual machines then execute at a level above the hypervisor. In some embodiments, the Type 2 hypervisor executes within the context of a user's operating system such that the Type 2 hypervisor interacts with the user's operating system. In other embodiments, one or more virtualization servers **301** in a virtualization environment may instead include a Type 1 hypervisor (not shown). A Type 1 hypervisor

may execute on the virtualization server **301** by directly accessing the hardware and resources within the hardware layer **310**. That is, while a Type 2 hypervisor **302** accesses system resources through a host operating system **314**, as shown, a Type 1 hypervisor may directly access all system resources without the host operating system **314**. A Type 1 hypervisor may execute directly on one or more physical processors **308** of virtualization server **301**, and may include program data stored in the physical memory **316**.

Hypervisor **302**, in some embodiments, can provide virtual resources to operating systems **330** or control programs **320** executing on virtual machines **332** in any manner that simulates the operating systems **330** or control programs **320** having direct access to system resources. System resources can include, but are not limited to, physical devices **306**, physical disks **304**, physical processors **308**, physical memory **316** and any other component included in virtualization server **301** hardware layer **310**. Hypervisor **302** may be used to emulate virtual hardware, partition physical hardware, virtualize physical hardware, and/or execute virtual machines that provide access to computing environments. In still other embodiments, hypervisor **302** controls processor scheduling and memory partitioning for a virtual machine **332** executing on virtualization server **301**. Hypervisor **302** may include those manufactured by VMWare, Inc., of Palo Alto, Calif.; the XEN hypervisor, an open source product whose development is overseen by the open source Xen.org community; HyperV, VirtualServer or virtual PC hypervisors provided by Microsoft, or others. In some embodiments, virtualization server **301** executes a hypervisor **302** that creates a virtual machine platform on which guest operating systems may execute. In these embodiments, the virtualization server **301** may be referred to as a host server. An example of such a virtualization server is the XEN SERVER provided by Citrix Systems, Inc., of Fort Lauderdale, Fla.

Hypervisor **302** may create one or more virtual machines **332**B-C (generally **332**) in which guest operating systems **330** execute. In some embodiments, hypervisor **302** may load a virtual machine image to create a virtual machine **332**. In other embodiments, the hypervisor **302** may executes a guest operating system **330** within virtual machine **332**. In still other embodiments, virtual machine **332** may execute guest operating system **330**.

In addition to creating virtual machines **332**, hypervisor **302** may control the execution of at least one virtual machine **332**. In other embodiments, hypervisor **302** may presents at least one virtual machine **332** with an abstraction of at least one hardware resource provided by the virtualization server **301** (e.g., any hardware resource available within the hardware layer **310**). In other embodiments, hypervisor **302** may control the manner in which virtual machines **332** access physical processors **308** available in virtualization server **301**. Controlling access to physical processors **308** may include determining whether a virtual machine **332** should have access to a processor **308**, and how physical processor capabilities are presented to the virtual machine **332**.

As shown in FIG. **3**, virtualization server **301** may host or execute one or more virtual machines **332**. A virtual machine **332** is a set of executable instructions that, when executed by a processor **308**, imitate the operation of a physical computer such that the virtual machine **332** can execute programs and processes much like a physical computing device. While FIG. **3** illustrates an embodiment where a virtualization server **301** hosts three virtual machines **332**, in other embodiments virtualization server **301** can host any number of virtual machines **332**. Hypervisor **302**, in some embodiments, provides each virtual machine **332** with a unique virtual view of the physical hardware, memory, processor and other system resources available to that virtual machine **332**. In some embodiments, the unique virtual view can be based on one or more of virtual machine permissions, application of a policy engine to one or more virtual machine identifiers, a user accessing a virtual machine, the applications executing on a virtual machine, networks accessed by a virtual machine, or any other desired criteria. For instance, hypervisor **302** may create one or more unsecure virtual machines **332** and one or more secure virtual machines **332**. Unsecure virtual machines **332** may be prevented from accessing resources, hardware, memory locations, and programs that secure virtual machines **332** may be permitted to access. In other embodiments, hypervisor **302** may provide each virtual machine **332** with a substantially similar virtual view of the physical hardware, memory, processor and other system resources available to the virtual machines **332**.

Each virtual machine **332** may include a virtual disk **326**A-C (generally **326**) and a virtual processor **328**A-C (generally **328**.) The virtual disk **326**, in some embodiments, is a virtualized view of one or more physical disks **304** of the virtualization server **301**, or a portion of one or more physical disks **304** of the virtualization server **301**. The virtualized view of the physical disks **304** can be generated, provided and managed by the hypervisor **302**. In some embodiments, hypervisor **302** provides each virtual machine **332** with a unique view of the physical disks **304**. Thus, in these embodiments, the particular virtual disk **326** included in each virtual machine **332** can be unique when compared with the other virtual disks **326**.

A virtual processor **328** can be a virtualized view of one or more physical processors **308** of the virtualization server **301**. In some embodiments, the virtualized view of the physical processors **308** can be generated, provided and managed by hypervisor **302**. In some embodiments, virtual processor **328** has substantially all of the same characteristics of at least one physical processor **308**. In other embodiments, virtual processor **308** provides a modified view of physical processors **308** such that at least some of the characteristics of the virtual processor **328** are different than the characteristics of the corresponding physical processor **308**.

With further reference to FIG. **4**, some aspects described herein may be implemented in a cloud-based environment. FIG. **4** illustrates an example of a cloud computing environment (or cloud system) **400**. As seen in FIG. **4**, client computers **411-414** may communicate with a cloud management server **410** to access the computing resources (e.g., host servers **403**, storage resources **404**, and network resources **405**) of the cloud system.

Management server **410** may be implemented on one or more physical servers. The management server **410** may run, for example, CLOUDSTACK by Citrix Systems, Inc. of Ft. Lauderdale, Fla., or OPENSTACK, among others. Management server **410** may manage various computing resources, including cloud hardware and software resources, for example, host computers **403**, data storage devices **404**, and networking devices **405**. The cloud hardware and software resources may include private and/or public components. For example, a cloud may be configured as a private cloud to be used by one or more particular customers or client computers **411-414** and/or over a private network. In other embodiments, public clouds or hybrid public-private clouds may be used by other customers over an open or hybrid networks.

Management server **410** may be configured to provide user interfaces through which cloud operators and cloud customers may interact with the cloud system. For example, the management server **410** may provide a set of APIs and/or one

or more cloud operator console applications (e.g., web-based on standalone applications) with user interfaces to allow cloud operators to manage the cloud resources, configure the virtualization layer, manage customer accounts, and perform other cloud administration tasks. The management server **410** also may include a set of APIs and/or one or more customer console applications with user interfaces configured to receive cloud computing requests from end users via client computers **411-414**, for example, requests to create, modify, or destroy virtual machines within the cloud. Client computers **411-414** may connect to management server **410** via the Internet or other communication network, and may request access to one or more of the computing resources managed by management server **410**. In response to client requests, the management server **410** may include a resource manager configured to select and provision physical resources in the hardware layer of the cloud system based on the client requests. For example, the management server **410** and additional components of the cloud system may be configured to provision, create, and manage virtual machines and their operating environments (e.g., hypervisors, storage resources, services offered by the network elements, etc.) for customers at client computers **411-414**, over a network (e.g., the Internet), providing customers with computational resources, data storage services, networking capabilities, and computer platform and application support. Cloud systems also may be configured to provide various specific services, including security systems, development environments, user interfaces, and the like.

Certain clients **411-414** may be related, for example, different client computers creating virtual machines on behalf of the same end user, or different users affiliated with the same company or organization. In other examples, certain clients **411-414** may be unrelated, such as users affiliated with different companies or organizations. For unrelated clients, information on the virtual machines or storage of any one user may be hidden from other users.

Referring now to the physical hardware layer of a cloud computing environment, availability zones **401-402** (or zones) may refer to a collocated set of physical computing resources. Zones may be geographically separated from other zones in the overall cloud of computing resources. For example, zone **401** may be a first cloud datacenter located in California, and zone **402** may be a second cloud datacenter located in Florida. Management sever **410** may be located at one of the availability zones, or at a separate location. Each zone may include an internal network that interfaces with devices that are outside of the zone, such as the management server **410**, through a gateway. End users of the cloud (e.g., clients **411-414**) might or might not be aware of the distinctions between zones. For example, an end user may request the creation of a virtual machine having a specified amount of memory, processing power, and network capabilities. The management server **410** may respond to the user's request and may allocate the resources to create the virtual machine without the user knowing whether the virtual machine was created using resources from zone **401** or zone **402**. In other examples, the cloud system may allow end users to request that virtual machines (or other cloud resources) are allocated in a specific zone or on specific resources **403-405** within a zone.

In this example, each zone **401-402** may include an arrangement of various physical hardware components (or computing resources) **403-405**, for example, physical hosting resources (or processing resources), physical network resources, physical storage resources, switches, and additional hardware resources that may be used to provide cloud computing services to customers. The physical hosting resources in a cloud zone **401-402** may include one or more computer servers **403**, such as the virtualization servers **301** described above, which may be configured to create and host virtual machine instances. The physical network resources in a cloud zone **401** or **402** may include one or more network elements **405** (e.g., network service providers) comprising hardware and/or software configured to provide a network service to cloud customers, such as firewalls, network address translators, load balancers, virtual private network (VPN) gateways, Dynamic Host Configuration Protocol (DHCP) routers, and the like. The storage resources in the cloud zone **401-402** may include storage disks (e.g., solid state drives (SSDs), magnetic hard disks, etc.) and other storage devices.

The example cloud computing environment shown in FIG. **4** also may include a virtualization layer (e.g., as shown in FIGS. **1-3**) with additional hardware and/or software resources configured to create and manage virtual machines and provide other services to customers using the physical resources in the cloud. The virtualization layer may include hypervisors, as described above in FIG. **3**, along with other components to provide network virtualizations, storage virtualizations, etc. The virtualization layer may be as a separate layer from the physical resource layer, or may share some or all of the same hardware and/or software resources with the physical resource layer. For example, the virtualization layer may include a hypervisor installed in each of the virtualization servers **403** with the physical computing resources. Known cloud systems may alternatively be used, e.g., WINDOWS AZURE (Microsoft Corporation of Redmond Wash.), AMAZON EC2 (Amazon.com Inc. of Seattle, Wash.), IBM BLUE CLOUD (IBM Corporation of Armonk, N.Y.), or others.

Enterprise Mobility Management Architecture

FIG. **5** represents an enterprise mobility technical architecture **500** for use in a BYOD environment. The architecture enables a user of a mobile device **502** to both access enterprise or personal resources from a mobile device **502** and use the mobile device **502** for personal use. The user may access such enterprise resources **504** or enterprise services **508** using a mobile device **502** that is purchased by the user or a mobile device **502** that is provided by the enterprise to user. The user may utilize the mobile device **502** for business use only or for business and personal use. The mobile device may run an iOS operating system, and Android operating system, or the like. The enterprise may choose to implement policies to manage the mobile device **504**. The policies may be implanted through a firewall or gateway in such a way that the mobile device may be identified, secured or security verified, and provided selective or full access to the enterprise resources. The policies may be mobile device management policies, mobile application management policies, mobile data management policies, or some combination of mobile device, application, and data management policies. A mobile device **504** that is managed through the application of mobile device management policies may be referred to as an enrolled device.

The operating system of the mobile device may be separated into a managed partition **510** and an unmanaged partition **512**. The managed partition **510** may have policies applied to it to secure the applications running on and data stored in the managed partition. The applications running on the managed partition may be secure applications. The secure applications may be email applications, web browsing applications, software-as-a-service (SaaS) access applications, Windows Application access applications, and the like. The secure applications may be secure native applications **514**,

secure remote applications **522** executed by a secure application launcher **518**, virtualization applications **526** executed by a secure application launcher **518**, and the like. The secure native applications **514** may be wrapped by a secure application wrapper **520**. The secure application wrapper **520** may include integrated policies that are executed on the mobile device **502** when the secure native application is executed on the device. The secure application wrapper **520** may include meta-data that points the secure native application **514** running on the mobile device **502** to the resources hosted at the enterprise that the secure native application **514** may require to complete the task requested upon execution of the secure native application **514**. The secure remote applications **522** executed by a secure application launcher **518** may be executed within the secure application launcher application **518**. The virtualization applications **526** executed by a secure application launcher **518** may utilize resources on the mobile device **502**, at the enterprise resources **504**, and the like. The resources used on the mobile device **502** by the virtualization applications **526** executed by a secure application launcher **518** may include user interaction resources, processing resources, and the like. The user interaction resources may be used to collect and transmit keyboard input, mouse input, camera input, tactile input, audio input, visual input, gesture input, and the like. The processing resources may be used to present a user interface, process data received from the enterprise resources **504**, and the like. The resources used at the enterprise resources **504** by the virtualization applications **526** executed by a secure application launcher **518** may include user interface generation resources, processing resources, and the like. The user interface generation resources may be used to assemble a user interface, modify a user interface, refresh a user interface, and the like. The processing resources may be used to create information, read information, update information, delete information, and the like. For example, the virtualization application may record user interactions associated with a GUI and communicate them to a server application where the server application may use the user interaction data as an input to the application operating on the server. In this arrangement, an enterprise may elect to maintain the application on the server side as well as data, files, etc. associated with the application. While an enterprise may elect to "mobilize" some applications in accordance with the principles herein by securing them for deployment on the mobile device, this arrangement may also be elected for certain applications. For example, while some applications may be secured for use on the mobile device, others may not be prepared or appropriate for deployment on the mobile device so the enterprise may elect to provide the mobile user access to the unprepared applications through virtualization techniques. As another example, the enterprise may have large complex applications with large and complex data sets (e.g. material resource planning applications) where it would be very difficult, or otherwise undesirable, to customize the application for the mobile device so the enterprise may elect to provide access to the application through virtualization techniques. As yet another example, the enterprise may have an application that maintains highly secured data (e.g. human resources data, customer data, engineering data) that may be deemed by the enterprise as too sensitive for even the secured mobile environment so the enterprise may elect to use virtualization techniques to permit mobile access to such applications and data. An enterprise may elect to provide both fully secured and fully functional applications on the mobile device as well as a virtualization application to allow access to applications that are deemed more properly operated on the server side. In an embodiment, the virtualization application may store some data, files, etc. on the mobile phone in one of the secure storage locations. An enterprise, for example, may elect to allow certain information to be stored on the phone while not permitting other information.

In connection with the virtualization application, as described herein, the mobile device may have a virtualization application that is designed to present GUIs and then record user interactions with the GUI. The application may communicate the user interactions to the server side to be used by the server side application as user interactions with the application. In response, the application on the server side may transmit back to the mobile device a new GUI. For example, the new GUI may be a static page, a dynamic page, an animation, or the like.

The applications running on the managed partition may be stabilized applications. The stabilized applications may be managed by a device manager **524**. The device manager **524** may monitor the stabilized applications and utilize techniques for detecting and remedying problems that would result in a destabilized application if such techniques were not utilized to detect and remedy the problems.

The secure applications may access data stored in a secure data container **528** in the managed partition **510** of the mobile device. The data secured in the secure data container may be accessed by the secure wrapped applications **514**, applications executed by a secure application launcher **518**, virtualization applications **526** executed by a secure application launcher **518**, and the like. The data stored in the secure data container **528** may include files, databases, and the like. The data stored in the secure data container **528** may include data restricted to a specific secure application **530**, shared among secure applications **532**, and the like. Data restricted to a secure application may include secure general data **534** and highly secure data **538**. Secure general data may use a strong form of encryption such as AES 128-bit encryption or the like, while highly secure data **538** may use a very strong form of encryption such as AES 254-bit encryption. Data stored in the secure data container **528** may be deleted from the device upon receipt of a command from the device manager **524**. The secure applications may have a dual-mode option **540**. The dual mode option **540** may present the user with an option to operate the secured application in an unsecured mode. In an unsecured mode, the secure applications may access data stored in an unsecured data container **542** on the unmanaged partition **512** of the mobile device **502**. The data stored in an unsecured data container may be personal data **544**. The data stored in an unsecured data container **542** may also be accessed by unsecured applications **548** that are running on the unmanaged partition **512** of the mobile device **502**. The data stored in an unsecured data container **542** may remain on the mobile device **502** when the data stored in the secure data container **528** is deleted from the mobile device **502**. An enterprise may want to delete from the mobile device selected or all data, files, and/or applications owned, licensed or controlled by the enterprise (enterprise data) while leaving or otherwise preserving personal data, files, and/or applications owned, licensed or controlled by the user (personal data). This operation may be referred to as a selective wipe. With the enterprise and personal data arranged in accordance to the examples described herein, an enterprise may perform a selective wipe.

The mobile device may connect to enterprise resources **504** and enterprise services **508** at an enterprise, to the public Internet **548**, and the like. The mobile device may connect to enterprise resources **504** and enterprise services **508** through virtual private network connections. The virtual private network connections may be specific to particular applications

550, particular devices, particular secured areas on the mobile device, and the like 552. For example, each of the wrapped applications in the secured area of the phone may access enterprise resources through an application specific VPN such that access to the VPN would be granted based on attributes associated with the application, possibly in conjunction with user or device attribute information. The virtual private network connections may carry Microsoft Exchange traffic, Microsoft Active Directory traffic, HTTP traffic, HTTPS traffic, application management traffic, and the like. The virtual private network connections may support and enable single-sign-on authentication processes 554. The single-sign-on processes may allow a user to provide a single set of authentication credentials, which are then verified by an authentication service 558. The authentication service 558 may then grant to the user access to multiple enterprise resources 504, without requiring the user to provide authentication credentials to each individual enterprise resource 504.

The virtual private network connections may be established and managed by an access gateway 560. The access gateway 560 may include performance enhancement features that manage, accelerate, and improve the delivery of enterprise resources 504 to the mobile device 502. The access gateway may also re-route traffic from the mobile device 502 to the public Internet 548, enabling the mobile device 502 to access publicly available and unsecured applications that run on the public Internet 548. The mobile device may connect to the access gateway via a transport network. The transport network may be a wired network, wireless network, cloud network, local area network, metropolitan area network, wide area network, public network, private network, and the like.

The enterprise resources 504 may include email servers, file sharing servers, SaaS applications, Web application servers, Windows application servers, and the like. Email servers may include Exchange servers, Lotus Notes servers, and the like. File sharing servers may include ShareFile servers, and the like. SaaS applications may include Salesforce, and the like. Windows application servers may include any application server that is built to provide applications that are intended to run on a local Windows operating system, and the like. The enterprise resources 504 may be premise-based resources, cloud based resources, and the like. The enterprise resources 504 may be accessed by the mobile device 502 directly or through the access gateway 560. The enterprise resources 504 may be accessed by the mobile device 502 via a transport network. The transport network may be a wired network, wireless network, cloud network, local area network, metropolitan area network, wide area network, public network, private network, and the like.

The enterprise services 508 may include authentication services 558, threat detection services 564, device manager services 524, file sharing services 568, policy manager services 570, social integration services 572, application controller services 574, and the like. Authentication services 558 may include user authentication services, device authentication services, application authentication services, data authentication services and the like. Authentication services 558 may use certificates. The certificates may be stored on the mobile device 502, by the enterprise resources 504, and the like. The certificates stored on the mobile device 502 may be stored in an encrypted location on the mobile device, the certificate may be temporarily stored on the mobile device 502 for use at the time of authentication, and the like. Threat detection services 564 may include intrusion detection services, unauthorized access attempt detection services, and the like. Unauthorized access attempt detection services may include unauthorized attempts to access devices, applications, data, and the like. Device management services 524 may include configuration, provisioning, security, support, monitoring, reporting, and decommissioning services. File sharing services 568 may include file management services, file storage services, file collaboration services, and the like. Policy manager services 570 may include device policy manager services, application policy manager services, data policy manager services, and the like. Social integration services 572 may include contact integration services, collaboration services, integration with social networks such as Facebook, Twitter, and LinkedIn, and the like. Application controller services 574 may include management services, provisioning services, deployment services, assignment services, revocation services, wrapping services, and the like.

The enterprise mobility technical architecture 500 may include an application store 578. The application store 578 may include unwrapped applications 580, pre-wrapped applications 582, and the like. Applications may be populated in the application store 578 from the application controller 574. The application store 578 may be accessed by the mobile device 502 through the access gateway 560, through the public Internet 548, or the like. The application store may be provided with an intuitive and easy to use User Interface. The application store 578 may provide access to a software development kit 584. The software development kit 584 may provide a user the capability to secure applications selected by the user by wrapping the application as described previously in this description. An application that has been wrapped using the software development kit 584 may then be made available to the mobile device 502 by populating it in the application store 578 using the application controller 574.

The enterprise mobility technical architecture 500 may include a management and analytics capability 588. The management and analytics capability 588 may provide information related to how resources are used, how often resources are used, and the like. Resources may include devices, applications, data, and the like. How resources are used may include which devices download which applications, which applications access which data, and the like. How often resources are used may include how often an application has been downloaded, how many times a specific set of data has been accessed by an application, and the like.

FIG. 6 is another illustrative enterprise mobility management system 600. Some of the components of the mobility management system 500 described above with reference to FIG. 5 have been omitted for the sake of simplicity. The architecture of the system 600 depicted in FIG. 6 is similar in many respects to the architecture of the system 500 described above with reference to FIG. 5 and may include additional features not mentioned above.

In this case, the left hand side represents an enrolled mobile device 602 with a receiver 604, which interacts with a gateway 606 to cloud-based services (a "cloud gateway") and to access various enterprise resources 608 and services 609 such as Exchange, Sharepoint, PKI Resources, Kerberos Resources, Certificate Issuance service, as shown on the right hand side above. The cloud gateway 606 may also include access gateway and application controller functionality. Although not specifically shown, the mobile device 602 may also interact with an enterprise application store (a "store front") for the selection and downloading of applications.

The receiver 604 acts as the UI (user interface) intermediary for Windows apps/desktops hosted in an enterprise data center, which are accessed using a display remoting protocol such as, e.g., the HDX/ICA protocol available from Citrix. The receiver 604 also supports the installation and manage-

ment of native applications on the mobile device **602**, such as native iOS or Android applications. For example, the managed applications **610** (mail, browser, wrapped application) shown in the figure above are all native applications that execute locally on the device. The receiver **604** and the mobile application management protocol of this architecture act to provide policy driven management capabilities and features such as connectivity and SSO (single sign on) to enterprise resources/services **608**. One example of a mobile application management protocol is the MDX (mobile experience technology) protocol available from Citrix. The receiver **604** handles primary user authentication to the enterprise, normally to an access gateway (AG) with SSO to other cloud gateway components. The receiver **604** obtains policies from the cloud gateway **606** to control the behavior of the managed applications **610** on the mobile device **602**.

The secure inter-process communication (IPC) links **612** between the native applications **610** and receiver **604** represent a management channel, which allows the receiver to supply policies to be enforced by the management framework **614** "wrapping" each application. The management framework **614** may be, for example, the MDX framework available from Citrix. The IPC link **612** also allows receiver **604** to supply credential and authentication information that enables connectivity and SSO to enterprise resources **608**. Finally the IPC link **612** allows the management framework **614** to invoke user interface functions implemented by receiver **604**, such as online and offline authentication.

Communications between the receiver **604** and cloud gateway **606** are essentially an extension of the management channel from the management framework **614** wrapping each native managed application **610**. The management framework **614** requests policy information from receiver **604**, which in turn requests it from cloud gateway **606**. The management framework **614** requests authentication, and receiver **604** logs into the gateway services part of the cloud gateway **606**, which may be, e.g., a NetScaler Access Gateway available from Citrix. The receiver **604** may also call supporting services on the cloud gateway **606**, which may produce input material to derive encryption keys for the local data vaults **616**, or provide client certificates which may enable direct authentication to PKI protected resources, as more fully explained below.

In more detail, the management framework **614** "wraps" each managed application **610**. This may be incorporated via an explicit build step, or via a post-build processing step. The management framework **614** may "pair" with receiver **604** on first launch of an application **610** to initialize the secure IPC link **612** and obtain the policy for that application. The management framework **614** may enforce relevant portions of the policy that apply locally, such as the receiver login dependencies and some of the containment policies that restrict how local OS services may be used, or how they may interact with the application **610**.

The management framework **614** may use services provided by receiver **604** over the secure IPC link **612** to facilitate authentication and internal network access. Key management for the private and shared data vaults **616** (containers) may be also managed by appropriate interactions between the managed applications **610** and receiver **604**. Vaults **616** may be available only after online authentication, or may be made available after offline authentication if allowed by policy. First use of vaults **616** may require online authentication, and offline access may be limited to at most the policy refresh period before online authentication is again required.

Network access to internal resources may occur directly from individual managed applications **610** through the access gateway functionality of the cloud gateway **606**. The management framework **614** is responsible for orchestrating the network access on behalf of each application **610**. The receiver **604** may facilitate these network connections by providing suitable time limited secondary credentials obtained following online authentication. Multiple modes of network connection may be used, such as reverse web proxy connections and end-to-end VPN-style tunnels **618**.

The mail and browser managed applications **610** have special status and may make use of facilities that might not be generally available to arbitrary wrapped applications. For example, the mail application may use a special background network access mechanism that allows it to access a mail server (e.g., Exchange) over an extended period of time without requiring a full AG logon. The browser application may use multiple private data vaults to segregate different kinds of data.

This architecture supports the incorporation of various other security features. For example, the cloud gateway **606** (including its gateway services) in some cases may not need to validate directory service passwords, e.g., Active Directory (AD) passwords. It can be left to the discretion of an enterprise whether directory service password is used as an authentication factor for some users in some situations. Different authentication methods may be used if a user is online or offline (e.g., connected or not connected to a network).

Step up authentication is a feature wherein the cloud gateway **606** may identify managed native applications **610** that are allowed to have access to highly classified data requiring strong authentication, and ensure that access to these applications is only permitted after performing appropriate authentication, even if this means a re-authentication is required by the user after a prior weaker level of login.

Another security feature of this solution is the encryption of the data vaults **616** (containers) on the mobile device **602**. The vaults **616** may be encrypted so that all on-device data including files, databases, and configurations are protected. For on-line vaults, the keys may be stored on the server (e.g., the cloud gateway), and for off-line vaults, a local copy of the keys may be protected by a user password. When data is stored locally on the device **602** in the secure container **616**, it is preferred that a minimum of AES 256 encryption algorithm be utilized.

Other secure container features may also be implemented. For example, a logging feature may be included, wherein all security events happening inside an application **610** are logged and reported to the backend. Data wiping may be supported, such as if the application **610** detects tampering, associated encryption keys may be written over with random data, leaving no hint on the file system that user data was destroyed. Screenshot protection is another feature, where an application may prevent any data from being stored in screenshots. For example, the key window's hidden property may be set to YES. This may cause whatever content is currently displayed on the screen to be hidden, resulting in a blank screenshot where any content would normally reside.

Local data transfer may be prevented, such as by preventing any data from being locally transferred outside the application container, e.g., by copying it or sending it to an external application. A keyboard cache feature may operate to disable the autocorrect functionality for sensitive text fields. SSL certificate validation may be operable so the application specifically validates the server SSL certificate instead of it being stored in the keychain. An encryption key generation feature may be used such that the key used to encrypt data on the device is generated using a passphrase supplied by the user (if offline access is required). It may be XORed with another key

randomly generated and stored on the server side if offline access is not required. Key Derivation functions may operate such that keys generated from the user password use KDFs (key derivation functions, notably PBKDF2) rather than creating a cryptographic hash of it. The latter makes a key susceptible to brute force or dictionary attacks.

Further, one or more initialization vectors may be used in encryption methods. An initialization vector may cause multiple copies of the same encrypted data to yield different cipher text output, preventing both replay and cryptanalytic attacks. This may also prevent an attacker from decrypting any data even with a stolen encryption key if the specific initialization vector used to encrypt the data is not known. Further, authentication then decryption may be used, wherein application data is decrypted only after the user has authenticated within the application. Another feature may relate to sensitive data in memory, which may be kept in memory (and not in disk) only when it's needed. For example, login credentials may be wiped from memory after login, and encryption keys and other data inside objective-C instance variables are not stored, as they may be easily referenced. Instead, memory may be manually allocated for these.

An inactivity timeout may be implemented, wherein after a policy-defined period of inactivity, a user session is terminated.

Data leakage from the management framework **614** may be prevented in other ways. For example, when an application **610** is put in the background, the memory may be cleared after a predetermined (configurable) time period. When backgrounded, a snapshot may be taken of the last displayed screen of the application to fasten the foregrounding process. The screenshot may contain confidential data and hence should be cleared.

Another security feature relates to the use of an OTP (one time password) **620** without the use of directory service **622** password for access to one or more applications. In some cases, some users do not know (or are not permitted to know) their directory service password, so these users may authenticate using an OTP **620** such as by using a hardware OTP system like SecurID (OTPs may be provided by different vendors also, such as Entrust or Gemalto). In some cases, after a user authenticates with a user ID, a text is sent to the user with an OTP **620**. In some cases, this may be implemented only for online use, with a prompt being a single field.

An offline password may be implemented for offline authentication for those applications **610** for which offline use is permitted via enterprise policy. For example, an enterprise may want the store front to be accessed in this manner. In this case, the receiver **604** may require the user to set a custom offline password and the directory service password is not used. Cloud gateway **606** may provide policies to control and enforce password standards with respect to the minimum length, character class composition, and age of passwords, such as described by the standard Windows Server password complexity requirements, although these requirements may be modified.

Another feature relates to the enablement of a client side certificate for certain applications **610** as secondary credentials (for the purpose of accessing PKI protected web resources via the management framework micro VPN feature). For example, an email application may utilize such a certificate. In this case, certificate-based authentication using a mobile data synchronization protocol (e.g., the protocol employed by ActiveSync) may be supported, wherein a certificate from the receiver **604** may be retrieved by the cloud gateway **606** and used in a keychain. Each managed application may have one associated client certificate, identified by a label that is defined in the cloud gateway.

The cloud gateway **606** may interact with an enterprise special purpose web service to support the issuance of client certificates to allow relevant managed applications to authenticate to internal PKI protected resources.

The receiver **604** and the management framework **614** may be enhanced to support obtaining and using client certificates for authentication to internal PKI protected network resources. More than one certificate may be supported, such as to match various levels of security and/or separation requirements. The certificates may be used by the mail and browser managed applications, and ultimately by arbitrary wrapped applications (provided those applications use web service style communication patterns where it is reasonable for the management framework to mediate https requests).

Management framework client certificate support on iOS may rely on importing a PKCS 12 BLOB (Binary Large Object) into the iOS keychain in each managed application for each period of use. Management framework client certificate support may use a HTTPS implementation with private in-memory key storage. The client certificate may not be present in the iOS keychain and may not be persisted except potentially in "online-only" data value that is strongly protected.

Mutual SSL may also be implemented to provide additional security by requiring that a mobile device **602** is authenticated to the enterprise, and vice versa. Virtual smart cards for authentication to cloud gateway **606** may also be implemented.

Both limited and full Kerberos support may be additional features. The full support feature relates to an ability to do full Kerberos login to directory service **622**, using a directory service password or trusted client certificate, and obtain Kerberos service tickets to respond to HTTP Negotiate authentication challenges. The limited support feature relates to constrained delegation in AFEE, where AFEE supports invoking Kerberos protocol transition so it can obtain and use Kerberos service tickets (subject to constrained delegation) in response to HTTP Negotiate authentication challenges. This mechanism works in reverse web proxy (aka CVPN) mode, and when http (but not https) connections are proxied in VPN and MicroVPN mode.

Another feature relates to application container locking and wiping, which may automatically occur upon jail-break or rooting detections, and occur as a pushed command from administration console, and may include a remote wipe functionality even when an application **610** is not running.

A multi-site architecture or configuration of the store front and application controller may be supported that allows users to be service from one of several different locations in case of failure.

In some cases, managed applications **610** may be allowed to access a certificate and private key via an API (example OpenSSL). Trusted managed applications **610** of an enterprise may be allowed to perform specific Public Key operations with an application's client certificate and private key. Various use cases may be identified and treated accordingly, such as when an application behaves like a browser and no certificate access is required, when an application reads a certificate for "who am I," when an application uses the certificate to build a secure session token, and when an application uses private keys for digital signing of important data (e.g. transaction log) or for temporary data encryption.

Identification of Managed Mobile Applications

In FIG. **7**, an illustrative mobile device management system **700** is shown. The system **700** may be similar in many

respects to the systems **500** and **600** described above with reference to FIG. **5** and FIG. **6** respectively. The system **700** may also omit certain components described above for the sake of simplicity and may include additional features not mentioned above.

The mobile device management system **700** may include an enterprise system **702** in signal communication with one or more mobile devices **704** via a network **706**. The enterprise system may include an enterprise application server **708**, an access gateway **710**, and one or more computing resources such as enterprise resources **712**.

The enterprise application server **708** may be similar in many respects to the application store **578** discussed above with reference to FIG. **5**. The enterprise application server **708** may provide access to mobile applications **714** available for installation at a mobile device, e.g., the mobile device **704**. As noted above, the mobile applications **714** may include both secured and unsecured mobile applications. Accordingly, the mobile applications **714** may correspond to the unwrapped applications **180** and the pre-wrapped applications **182** described above with reference to FIG. **5**. As also noted above, a secured mobile application may be wrapped with a secure application wrapper that enables the management of and control over the execution of the secured mobile application. In this regard, a secured mobile application, wrapped mobile application, or enrolled mobile application may also be referred to as a managed mobile application.

The enterprise application server **708** may also provide access to application policies **716** and application metadata **718** respectively associated with the mobile applications **714**. An application policy **716** may represent one of the mechanisms through which management of a mobile application is achieved. As noted above, an application policy **716** may define rights and entitlements with respect to which users may utilize a managed mobile application, which computing resources a managed mobile application may access, the features available at a managed mobile application when executing at a mobile device, and combinations of the same.

Application metadata **718** refers to information that describes and/or identifies a mobile application. Application metadata **718** may be generated during the build process of a new mobile application and made available via the enterprise application server **708** when the new mobile application is published to the enterprise application server Application metadata **718** may include, for example, the name of the mobile application, the size of the mobile application, a unique identifier for the mobile application, the version of the mobile application, and so forth. As discussed further below application metadata **718** may also include information useful to validate the identity of a mobile application.

The access gateway **710** may facilitate access to the enterprise resources **712** from a managed mobile application operating at a mobile device, e.g., the mobile device **704**. The access gateway **710** may be similar in many respects to the access gateway **160** and the cloud gateway **606** described above with reference to FIG. **5** and FIG. **6** respectively. The enterprise resources **712** may correspond to the enterprise resources **504** and **608** as well as the enterprise services **508** and **609** as also described above with reference to FIG. **5** and FIG. **6** respectively. Once validated, authenticated, and authorized, mobile applications may access the enterprise resources **712** via the access gateway **710** as described above.

Both managed mobile applications **720** as well as unmanaged mobile applications **722** may reside at the mobile device **704**. An access manager application **724** may also reside at the mobile device **704** and manage execution of the managed mobile applications **720** on the mobile device. A mobile device that includes both managed and unmanaged mobile applications may be referred to as an unmanaged mobile device as an enterprise may only be equipped to exercise control over the managed mobile applications at that mobile device and may not be equipped to exercise control over other aspects of the mobile device, e.g., the unmanaged applications. Because the mobile device **704** includes a managed mobile application **720** and unmanaged mobile applications **722**, the mobile device shown by way of example in FIG. **7** may be referred to as an unmanaged mobile device and may represent the personal mobile device of an individual.

The access manager application **724** ("access manager") may be similar in many respects to the Receiver **604** discussed above with reference to FIG. **6**. As discussed further below, the access manager **724** may manage user authentication, validation of mobile application identity, and enforcement of mobile application policies. A user may access the enterprise application server **708** (e.g., via a web browser) to initially download and install the access manager **724** at the mobile device **704**. As noted above, the access manager **724** may also serve as the interface to the enterprise application server **708** enabling a user to browse, download, and install the mobile applications available from the enterprise system **702**.

When the user downloads a managed mobile application **720** to the mobile device **704**, the access manager **724** may also download the application metadata **718** associated with the managed mobile application **720** as well as any application policies **716** associated with the managed mobile application. As noted above, the access manager **724** may receive the application metadata **718** for a mobile application **720** from the enterprise application server **708**. In some example implementations, the access manager **724** may store the application metadata **718** and the application policies **716** at a secure location of the mobile device **704**, e.g., the secure data container **528** of FIG. **5** and/or the secure data vaults **616** of FIG. **6**.

The access manager **724** may also maintain a list **726** of managed mobile applications currently installed at the mobile device **704** and under management of the access manager. Upon installation of a new managed mobile application, the access manager **724** may add a new entry to the managed mobile application list **726**. The new entry in the list **726** may correspond to the new managed mobile application installed at the mobile device **704**.

As noted above, the access manager **724** may be configured to validate the identity of the managed mobile application **720**, e.g., to ensure that the managed mobile application has accurately identified itself and/or to ensure that the managed mobile application has not been altered after installation at the mobile device **704**. The access manager may rely on identification information **728** included in the application metadata **718** to validate the identity of the managed mobile application **720**. In some example embodiments, the access manager **724** may rely on the mobile platform on which the managed mobile application **720** is operating in order to validate the identity of the managed mobile application. The operating system of the mobile platform may produce identification information that the access manager **724** may compare to stored identification information for the managed mobile application. If the stored identification information matches the identification information received from the operating system, then the access manager **724** may identify the managed mobile application **720** as a trusted mobile application and grant access to the enterprise resources **712**. If the stored identification information for the managed mobile application does not match the identification information received from the operating system, then the access manager

724 may identify the managed mobile application 720 as a suspicious or untrustworthy mobile application and deny access to the enterprise resources 712. As noted above, the access manager 724 may also grant or deny access to local computing resources at the mobile device 704 itself. Local computing resources at the mobile device 704 may include, for example, a camera or other recording hardware; location services such as GPS, network services such as cellular or internet services, communication services such as Bluetooth, interface commands such as the cut-and-paste and screenshot features.

In other example embodiments, the access manager 724 may challenge the managed mobile application 720 to identify itself. The access manager 724 may issue a challenge request to the managed mobile application 720 and determine an expected challenge response. The expected challenge response is a response that is expected to be received from a managed mobile application that has accurately identified itself and that has not been altered. As explained further below, only a mobile application that has accurately identified itself and has not been altered may be able to produce the expected challenged response. If the response received from the managed mobile application 720 matches the expected response, then the access manager 724 may identify the managed mobile application 720 as a trusted mobile application. Having identified the managed mobile application 720 as a trusted mobile application, the access manager may provide the managed mobile application with the credentials necessary to access the enterprise resources 712. If the response received from the managed mobile application 720 does not match the expected response, then the access manager may identify the managed mobile application as a suspicious or untrustworthy mobile application and deny access to the enterprise resources 712. Again, the access manager 724 may grant or deny access to local computing resources at the mobile device 704 depending on whether the response received from the managed mobile application 720 matches the expected response.

The expected response may be based, at least in part, on the identification information 728 included in the application metadata 718 that is associated with the managed mobile application 720. The identification information may be created when the mobile application itself is created. The identification information may be, for example, an original digital certificate or original information that may be used to generate an application signature. The expected response may thus include or otherwise correspond to the identification information 728. As explained further below, a mobile application that submits a false identity or a mobile application that has been subsequently altered is unable to generate the expected response and thus unable to gain access to the computing resources.

Various approaches may be selectively employed to validate the identity of a managed mobile application. The particular approach ultimately implemented may depend on the mobile platform and operating system of the mobile device 704. For example, the Android operating system available from Google Inc. of Mountain View, Calif. may include mechanisms through which the access manager may strongly identify a mobile application requesting access to computing resources. Those skilled in the art will recognize that the Android operating system may include built-in mechanisms for requesting the signing certificate of an application, which the access manager 724 may utilize to validate the identity of a managed mobile application requesting access to the computing resources such as enterprise resources 712. It will also be recognized that the Android operating system may prevent an application from being altered after installation and may prevent a mobile application from using a signing certificate created for a different mobile application. In this way, the access manager 724 may rely on the signing certificates provided by the operating system of the mobile platform in order to validate the identity of a managed mobile application. Validation of application identity using signing certificates will be discussed in further detail below.

Other operating systems, however, may not include built-in mechanisms the access manager 724 may rely on to validate the identity of a managed mobile application requesting access to the computing resources. For example, the iOS operating system available from Apple Inc. of Cupertino, Calif. may not include mechanisms to request a signing certificate for the managed mobile application. In addition, the methods available for inter-process communication in iOS, may not include mechanisms to validate the identity of the mobile applications at each end of the communication. Mobile applications operating on the iOS platform may exchange communications, for example, via a copy-and-paste procedure, via an agreed to URL scheme, or via the network.

In some example implementations, the access manager 724 and the managed mobile application 720 may be configured to communicate via the network, e.g., via the transmission control protocol (TCP). In this example, the access manager 724 may open a TCP socket and wait to receive a connection request from the managed mobile application 720. It will be appreciated, however, that TCP does not include a mechanism to identify the managed mobile application requesting the connection to the access manager 724. Because the iOS platform may not include a mechanism to obtain a signing certificate for the mobile application making the request, additional steps may be employed to validate the identity of the requesting mobile application. Instead of relying on a signing certificate, the access manager 724 in this example, may rely, at least in part, on identification information 732 embedded in and/or derived from the managed mobile application 720 as set forth below.

The wrapping process discussed above may configure a mobile application to operate as a managed mobile application. In this regard, the wrapping process may include (e.g., insert, embed, wrap, etc.) a management framework 730 in the managed mobile application 720. The management framework 730 may correspond to the secure application wrapper 120 and the management framework 614 discussed above with reference to FIG. 5 and FIG. 6 respectively. The management framework 730 enables the access manager 724 to manage the operation of the mobile application 720 as discussed above with reference to FIG. 6.

The managed mobile application 720 may also employ the management framework 730 to identify itself to the access manager 724. In particular, the management framework 730 may generate the response to the challenge posed by the access manager 724 during the identity validation procedure.

In some example implementations, the management framework 730 of the managed mobile application 720 may be configured to generate an application signature. The management framework 730 may also be configured to provide a challenge response that is based, at least in part, on this application signature. The application signature may in turn be based on identification information 732 embedded in and/or derived from the managed mobile application 720. Stated differently, the management framework 730 may generate an application signature based on static information and dynamic information associated with the managed mobile application 720.

The static information may be secret information that is embedded into the managed mobile application **720** during the wrapping process described above. For example, the secret information may include one or more identification tokens **734** embedded into the application during the wrapping process. The identification tokens **734** may be, e.g., randomized alphanumeric strings embedded into the binary of the managed mobile application **720**. The management framework **730** may be configured to extract the identification tokens **734** when constructing the application signature in order to respond to the challenge received from the access manager **724**.

The dynamic information may be identification tokens derived from the managed mobile application **720**. For example, the derived identification tokens may be hash values obtained using selective hash functions on the various components of the mobile application bundle, e.g., the mobile application binary, application icon, application frameworks, and the like. The access manager **724** may derive this dynamic identification information in an ad hoc fashion during the identity validation procedure. One or more selective hash functions may be used to generate one or more selective hash values that represent the derived identification tokens. The access manager may utilize the management framework **730** to help derive the dynamic identification information from the managed mobile application **720** as needed.

The management framework **730** may also be configured to construct the application signature used in the response to the challenge received from the access manager **724**. The application signature may comprise a combination of the static information extracted from the managed mobile application **720** as well as the dynamic information derived from the managed mobile application. The management framework **730** may further be configured to arrange the static information and the dynamic information within the application signature in a particular way. Thus, strong identification of the managed mobile application **720** may be achieved through the static information embedded in the managed mobile application, the dynamic information derived from the mobile application, and the arrangement of the static and dynamic information within the application signature.

As noted above, the access manager **724** may be configured to generate an expected response when challenging the managed mobile application **720**. Accordingly, the access manager **724** may likewise be configured to construct an expected application signature. The access manager **724** may construct the expected application signature based on the identification information **728** included in the application metadata **718** for the managed mobile application **720**. The access manager may also be configured to dynamically derive the dynamic information from the managed mobile application **720**. Furthermore, the access manager **724** may likewise be configured to arrange the static and dynamic information within the expected application signature in a particular way.

In order to guard against replay attacks, the access manager **724** may provide a nonce (e.g., an arbitrary and random number) to the managed mobile application **720** for use in the response to the challenge. The access manager **724** may hash the nonce with the expected application signature to obtain an expected hash value. Similarly, the management framework **730** of the managed mobile application may hash the application signature with the received nonce to obtain a response hash value. In response to the challenge from the access manager **724**, the managed mobile application **720** may thus provide the access manager with the computed hash value obtained from the application signature and the nonce received from the access manager. The access manager may thus compare the expected hash value to the received hash value. The access manager **724** may thus identify the managed mobile application **720** as a trusted mobile application when the expected hash value matches the received hash value.

With reference to FIG. **8** a block diagram of an illustrative application signature and challenge response is shown. As noted above, a managed mobile application **800** may generate an application signature **802** in response to a challenge from an access manager **804**. The application signature **802** may include identification tokens **806** embedded in the managed mobile application **800** as well as identification tokens **808** derived from the managed mobile application. As seen in FIG. **8**, the managed mobile application **800** may arrange the embedded identification tokens **806** and the derived identification tokens **808** in a particular way within the application signature **802**. As an example, the managed mobile application **800** may concatenate the embedded identification tokens **806** and the derived identification tokens **808** in a particular order to construct the application signature. In another example, the managed mobile application **800** may concatenate portions of the embedded identification tokens **806** and portions of the derived identification tokens **808** to construct the application signature. It will be appreciated that various approaches to constructing the application signature may be selectively employed. As also noted above, the access manager **804** may provide a nonce **810** to the managed mobile application **800**. The managed mobile application **800** may employ a hash function **812** to generate a hash value **814** based on the application signature **802** and the nonce **810**. The managed mobile application **800** may provide the hash value **814** to the access manager **802** in the response **816** to the challenge received.

To validate the identity of the managed mobile application **800**, the access manager **804** may construct an expected application signature **818** based on the identification tokens **820** stored with the application metadata **822** and identification tokens **808** derived from the managed mobile application. The access manager **804** may also employ the hash function **812** to generate an expected hash value **824** based on the identification tokens **820** from the application metadata **822** and the nonce **810**. In response to the challenge, the access manager **804** may receive the challenge response **816** and compare the hash value **814** in the challenge response with the expected hash value **824**.

With the benefit of the present disclosure, it will be appreciated that only an unaltered mobile application received from the enterprise application server (**708** in FIG. **7**) may generate the expected hash value **824**. It will also be appreciated that the expected application signature **818** may not be stored persistently at the mobile device, but rather reconstructed as needed to verify the identity of the mobile application **800** requesting access to computing resources. The approach set forth above thus represents a mechanism to strongly identify a mobile application in order to determine whether to grant or deny the mobile application access to computing resources.

FIGS. **9-14** depict example methods steps related to aspects of validating the identity of a managed mobile application, enforcing application policies once validated, and controlling operation of the managed mobile applications.

In FIG. **9**, a flowchart **900** of example method steps for managing a mobile application at an unmanaged mobile device is shown. An enterprise may create a managed mobile application configured to operate at a mobile device (e.g., an unmanaged mobile device) and configured to access computing resources from the mobile device (block **902**). The enter-

prise may also configure the managed mobile application to be managed by an access manager application at the mobile device. As noted above, the enterprise may wrap or otherwise include a management framework (e.g., the MDX framework) that enables the access manager to validate the identity of the managed mobile application and control operation of the managed mobile application.

Upon creation of the managed mobile application, the enterprise may also create identification information associated with the managed mobile application (block **904**). The identification information may be, for example, a signed application certificate and/or application metadata that includes identification tokens. The identification tokens may be embedded into the managed mobile application (e.g., into the application binary) in some example implementations. A user may download and install the access manager at a mobile device (block **906**). The access manager may provide the user with an interface from which to browse the enterprise application server (e.g., the enterprise application store) and select various managed mobile applications to download to the mobile device. The access manager may require the user to provide access credentials in order to logon to the enterprise application server. The user may be associated with a user profile, and the user profile may be associated with various rights and entitlements. In this way, the managed mobile applications presented to the user as available to download depend upon the rights and entitlements assigned to the user, e.g., the enterprise application server may only present managed mobile applications that the user is entitled to use.

Having selected a managed mobile application, the user may download the mobile application via the access managed and install the mobile application at the mobile device (block **908**). The enterprise application server may also provide the identification information associated with the mobile application as well as an access policy associated with the mobile application. Accordingly, when the user downloads and installs a managed mobile application, the access manager may also download and store the identification information (block **910**) and the application policy (block **912**) associated with the mobile application.

Having installed the mobile application at the mobile device, the user may utilize the mobile application to access a computing resource. When the mobile application seeks to access the computing resource, the mobile application may check-in with the access manager and request access to the resource (block **914**). Upon receipt of the request to access the computing resource, the access manager may retrieve the identification information received from the enterprise application server and stored at the mobile device (block **916**). The access manager may also receive identification information from the mobile operating system, e.g., a signed application certification, or from the mobile application itself, e.g., a hash value based, at least in part, on an application signature (block **918**).

The access manager may then compare the stored identification information to the received identification information (block **920**). If the received identification information matches the stored identification information (block **922**:Y), then the access manager may determine that the mobile application is valid and identify the mobile application as a trusted mobile application. Accordingly, the access manager may permit the managed mobile application to access the computing resource (block **924**). The access manager may, for example, provide the mobile application with the access credentials, certificates, keys, and the like necessary to establish a connection with and access an enterprise resource. In some example implementations, the application policy associated with the mobile application may determine the manner in which the mobile application accesses and uses the computing resource. If the received identification information does not match the stored identification information (block **924**:N), then the access manager may determine that the mobile application is invalid and not identify the mobile application as a trust mobile application and thus prevent the mobile application from accessing the computing resource (block **926**).

In FIG. **10** is a flowchart **1000** of example method steps for preparing a managed mobile application for managed operation at an unmanaged mobile device. As noted above, some mobile operating systems may not provide built-in mechanisms the access manager may employ to validate the identity of the mobile application. Accordingly, the mobile application may be configured such that it can strongly identify itself. The enterprise may use a toolkit to prepare a mobile application as a managed mobile application (block **1002**). The toolkit may add functionality (e.g., the MDX framework) that transforms the mobile application into a managed mobile application (block **1004**). The toolkit may also generate and embed identification tokens (e.g., randomized strings) into the managed mobile application (block **1006**). The functionality added to the managed mobile application may include functionality that enables the managed mobile application to extract, arrange, and combine the embedded identification tokens in order to construct an application signature. The functionality added to the managed mobile application may also include functionality that enables the managed mobile application to derive identification tokens dynamically as well as to arrange and combine the derived identification tokens with the embedded identification tokens when constructing the application signature. Furthermore, the functionality added to the managed mobile application may additionally include functionality that enables the managed mobile application to generate a hash value based, at least in part, on the application signature.

The toolkit may also generate application metadata for the managed mobile application that includes the identification tokens embedded into the mobile application (block **1008**). The enterprise may then publish the managed mobile application to the enterprise application server along with the application metadata and any application policies associated with the mobile application (block **1010**). The enterprise application server may receive a request from a mobile device to download a selected mobile application (block **1012**). If the access manager has not yet been installed at the mobile device (block **1014**:N), then the enterprise application server may first download the access manager application to the mobile device (block **1016**). Once the access manager is installed at the mobile application (block **1014**:Y), the enterprise application server may download the selected mobile application to the mobile device in response to receipt of the request (**1018**). As noted above, the enterprise application server may also download to the mobile device the application metadata associated with the selected mobile application for storage at the mobile device. The access manager may have access to the application metadata thereby enabling the access manager to validate the identity of the mobile application associated with the application metadata.

In FIG. **11**, a flowchart **1100** of example method steps for initializing a managed mobile application at an unmanaged mobile device is shown. When the mobile device is first activated and initialized (block **1102**), the access manager application may be one of the first mobile applications launched (block **1104**). The access manager may, for example, launch automatically as part of the startup process

of the mobile device and/or in response to user input received at the mobile device. When the access manager application launches, the access manager may request access credentials (e.g., a username and password) from the user (block **1106**). The access manager may then provide the access credentials to the enterprise server for authentication (block **1108**). If the enterprise server does not authenticate the user (block **1110**:N), then the access manager may prevent any managed mobile applications at the mobile device from accessing the computing resources (block **1112**). For example, the access manager may refrain from providing mobile applications the access credentials necessary to establish connections with the enterprise resources.

If the enterprise server does authenticate the user (block **1110**:Y), then the enterprise server may validate the identity of the access manager itself (block **1114**) in order to ensure that the access manager application has not been altered. The enterprise server may validate the identity of the access manager in the same manner as the managed mobile application. As an example, a signing certificate used to sign the access manager may be employed to validate the access manager application. For example, the enterprise system may validate the managed mobile application. If the access manager is not validated (block **1116**:N), then the management framework of the managed mobile applications may treat the access manager as missing from the mobile device, and the managed mobile applications may thus be prevented from accessing the computing resources (block **1112**).

If the enterprise server does validate the identity of the access manager application (block **1116**:Y), then a managed mobile application may be initiated (block **1118**). Upon launch as well as during operation, the mobile application may check-in with the access manager so that the access manager may validate the identity of the managed mobile application (block **1120**). If the access manager cannot validate the identity of the managed mobile application (block **1122**:N), then the access manager may prevent the managed mobile application from accessing the computing resources (block **1124**). If the access manager successfully validates the identity of the managed mobile application (block **1122**:Y), then the access manager may identify the managed mobile application as a trusted mobile application (block **1126**). If the managed mobile application has just launched at the mobile device, then the access manager may update the list of mobile applications managed by the access manager to include the trusted mobile application (block **1128**). Having validated the identity of the managed mobile application, the access manager may also permit the trusted mobile application to access the computing resources (block **1130**).

In FIG. **12**, is a flowchart **1200** of example method steps for validating a managed mobile application at an unmanaged mobile device having a first type of mobile operating system is shown. The mobile operating system, in this example, may not include built-in mechanisms the access manager may utilize to validate the identity of a mobile application. The access manager may receive a request from a managed mobile application seeking to access a computing resource (block **1202**). Upon receipt of the request, the access manager may initiate a handshake with the managed mobile application to start the identity validation process (block **1204**). The managed mobile application may identify itself to the access manager, e.g., by providing a unique application identifier to the access manager (block **1206**). In turn, the access manager may utilize the application identifier to retrieve the application metadata associated with the mobile application (block **1208**). The access manager may also generate a nonce and provide the nonce to the mobile application (block **1210**).

The access manager and the managed mobile application may then begin the process of constructing the application signature and corresponding hash value used to validate the identity of the mobile application and determine whether the mobile application is a trusted mobile application. The mobile application may extract the embedded identification tokens (block **1212**) and derive the derived identification tokens (block **1214**) used to construct the application signature. The mobile application may then arrange and combine the embedded identification tokens extracted and the derived identification tokens to obtain the application signature (block **1216**). The mobile application may then compute a hash value using the application signature and the nonce received from the access manager (block **1218**).

Having provided the nonce to the mobile application, the access manager may retrieve the embedded identification tokens from the application metadata associated with the mobile application (block **1220**). The access manager may similarly derive the derived identification tokens from the mobile application (block **1222**) used to construct the expected application signature. The access manager may then arrange and combine the embedded identification tokens retrieved from the application metadata and the derived identification tokens to obtain the expected application signature (block **1224**). The access manager may then compute an expected hash value using the expected application signature and the nonce provided to the mobile application (block **1226**).

It will be appreciated that the hash value computed by the access manager should be the same as the hash value computed by the mobile application if the embedded identification tokens retrieved from the application metadata are the same as the embedded identification tokens extracted from the mobile application; if the identification tokens derived by the access manager are the same as the identification tokens derived by the mobile; if the expected application signature constructed by the access manager is the same as the application signature constructed by the mobile application; and if the mobile application uses the nonce provided by the access manager to compute the hash value. Accordingly, the mobile application may provide the hash value in a response to the access manager (block **1228**), and the access manager may compare the expected hash value to the value received from the mobile application (block **1230**). If the expected hash value does not match the received hash value (block **1232**:N), then the access manager may determine that the mobile application has falsely identified itself, has been altered after installation at the mobile device, and so forth. As a result, the access manager may deny the mobile application access to the computing resources (block **1234**). If the expected hash value matches the received hash value (block **1232**:Y), then the access manager may identify the mobile application as a trusted mobile application and permit the trusted mobile application to access the computing resources (block **1236**).

In FIG. **13**, a flowchart **1300** of example method steps for validating a managed mobile application at an unmanaged mobile device having a second type of mobile operating system is shown. The mobile operating system, in this example, may include built-in mechanisms the access manager may utilize to validate the identity of a mobile application. The access manager may receive a request from the managed mobile application to access a computing resource (block **1302**). The access manager may request from the mobile operating system a unique application identifier for the mobile application (block **1304**) and receive the application identifier in response (block **1306**).

Based on the application identifier for the mobile application, the access manager may query the list of managed mobile applications (**1308**). If the list of managed mobile applications does not include the mobile application requesting access to the computing resource (block **1310**:N), then the access manager may deny the mobile application access to the resource (block **1312**). If, however, the list of managed mobile applications does include the mobile application requesting access to the computing resource (block **1310**:Y), the access manager may then request from the mobile operating system the application certificate for mobile application (block **1314**).

As noted above, the enterprise application server may provide application certificates for the mobile applications installed at mobile devices. The application certificates may be stored at a secure storage location at the mobile device that is accessible by the access manager. Accordingly, the access manager may receive the requested application certificate from the mobile operating system (block **1316**) and retrieve the stored application certificate provided by the enterprise application server (block **1318**). In some example implementations, the access manager may compute respective hash values for each of the certificates (step **1320**), e.g., using the SHA-1 hash function. The access manager may compare the hash value of the stored certificate to the hash value of the certificate received from the mobile operating system. (block **1322**). If the hash values match (block **1324**:Y), then the access manager may determine that the mobile application is a trusted mobile application and permit the mobile application to access the computing resources (block **1326**). If the hash values do not match (block **1324**:N), then the access manager may determine that the mobile application is an untrusted mobile application and deny the mobile application access to the computing resources (block **1312**).

In FIG. **14**. a flowchart **1400** of example method steps for enforcing application policies during operation of a managed mobile application is shown. As noted above, the enterprise application server may provide application policies associated with the managed mobile applications installed at mobile devices. An enterprise may periodically update the application policies, and the access manager may thus be configured to ensure the most recent and up-to-date application policies are stored at a mobile device before permitting a managed mobile application from accessing the computing resources. In this way, the enterprise may grant or revoke entitlements to applications and application functionalities.

After the access manager validates the identity of a managed mobile application (block **1402**), the access manager may retrieve the application policy associated with the managed mobile application and stored at the mobile device (block **1404**). The access manager may then query the enterprise application server for policy information associated with the application policy (block **1406**), e.g., a policy date, a policy version number, and the like. Based on the policy information received from the enterprise application server, the access manager may determine whether the application policy stored at the mobile device is current (block **1408**). As an example, the access manager may compare the policy date or policy version received from the enterprise application server to the policy date or policy version of the application policy stored at the mobile device. If the policy date or policy version do not match, then the access manager may determine that the application policy stored at the mobile device is not current (block **1408**:N). If the policy date or policy version do match, then the access manager may determine that the application policy stored at the mobile device is current (block **1408**:Y).

If the application policy is not current (block **1408**:N), then the access manager may retrieve the current policy associated with the mobile application from the enterprise system, e.g., the enterprise application store (block **1410**). The access manager may download the current application policy and store the current application policy at a secure storage location at the mobile device (block **1412**). Once the access manager has obtained the current policy for the mobile application, the managed mobile application may refer to the application policy to determine whether it may access or use the computing resource as intended (block **1414**).

The management framework, for example, may configure the managed mobile application to query the policy before accessing or using a computing resource. As an example, the framework may configure the managed mobile application to query the application policy in order to determine whether data may be copied to another mobile application at the mobile device. In some example implementations, the managed mobile application may only copy the data to other managed mobile applications at the mobile device. As another example, the framework may configure the managed mobile application to query the application policy in order to determine whether the mobile device may capture a screenshot of the managed mobile application. These and other examples will be appreciated with the benefit of this disclosure.

If the application policy permits the managed mobile application to access or use computing resource as intended (block **1416**:Y), then the framework may permit the managed mobile application to carry out the intended action (block **1418**). If, however, the application policy does not permit the managed mobile application to access or use the computing resource as intended (block **1418**:N), then the framework may prevent the managed mobile application from carrying out the intended action (block **1420**).

Mobile Application Management with Mobile Device Management

Although mobile application management (MAM) has been discussed in the context of an unmanaged device, aspects of the present disclosure may also be employed with respect to managed devices as well. An enterprise may utilize mobile device management (MDM) in conjunction with mobile application management to further control the operation of the mobile device. In particular, the mobile device may enroll with an MDM system to establish a managed relationship between the MDM system and the mobile device. Once the mobile device is enrolled, the MDM system may leverage the managed relationship to enforce policies, monitor the mobile device, push information to the mobile device, and the like.

In sum, the MDM system may obtain information about the mobile device that would otherwise be unavailable absent the managed relationship. Such information may correspond to device-level settings that are not discoverable or readable through applications at the mobile device. Such device-level settings may include PIN or password settings, encryption settings, network-related settings, and the like. Such information may also include information regarding the processes currently running at the mobile device and the mobile applications installed at the mobile device (e.g., the application inventory). The MDM system may further obtain additional or alternative types of information pertaining to the managed mobile device. The MDM system may compare the information obtained from the managed mobile device against various policies and take various actions in response.

With respect to a device PIN/password, the MDM system may obtain information that indicates whether the device is

secured via a PIN/password, the complexity of the PIN/password, and the age of the PIN/password. Through the managed relationship, the MDM system may obtain information regarding the PIN/password settings of the device. The MDM system may compare this information to policies governing the use of device PINs/passwords. As an example, if a security policy indicates that the mobile device must be secured by a PIN/password and the information obtained from the mobile device indicates that the device PIN/password setting is not enabled, then the MDM system may push notifications to the managed mobile device indicating the security policy regarding device PINs/passwords. As another example, if the MDM system determines that the device PIN/password does not meet the complexity requirements of the security policy, then the MDM system may likewise push a notification to the managed mobile device indicating that a new, more complex PIN/password is required to comply with the security policy. As a further example, if the security policy indicates that device PINs/passwords must be changed periodically, then the MDM system may push a notification to the managed mobile device indicating the need to change the device PIN/password upon determining that the current device PIN/password has expired.

With respect to encryption settings, the MDM system may also obtain information that indicates whether the device has hardware encryption enabled. Through the managed relationship, the MDM system may enable hardware encryption at the managed mobile device upon determining that a security policy requires hardware encryption and that hardware encryption is not currently enabled at the mobile device. The MDM system may also set network-related settings at the managed mobile device through the managed relationship.

The MDM system may additionally obtain information regarding the processes currently running at the managed mobile device. The MDM system may compare the running processes against a list of malicious applications, programs, or processes in order to identify, e.g., malware at the managed mobile device. Through the managed relationship, the MDM system may kill any processes identified as malware or potentially malicious. The MDM system may also remove the corresponding malicious applications or programs through the managed relationship with the mobile device.

Similarly, the MDM system may obtain a list of applications installed at the managed mobile device. The MDM system may compare the list of installed applications to, e.g., an application whitelist or an application blacklist. The application whitelist may be a list of mobile applications permitted to be installed at the mobile device. If the list of installed applications includes an application that does not appear on the mobile application whitelist, then the MDM system may leverage the managed relationship to remove the application. The application blacklist may be a list of mobile applications prohibited from being installed at the mobile device. If the list of installed applications includes an application that appears on the mobile application blacklist, then the MDM system may similarly leverage the managed relationship to remove the application. It will be appreciated that the MDM system may additionally leverage the managed relationship to push mobile applications to the managed mobile device in order to control which mobile applications are installed at the mobile device. In view of this disclosure, it will also be appreciated that the MDM system may exert more robust control over the mobile applications installed at the mobile device. As described above, MAM may disable a mobile application installed at the mobile device upon determination that the application violates a policy. When MDM is used in conjunction with MAM, however, the mobile application may not only be disabled, it may be removed entirely from the mobile device. The MDM system may push other types of information to the managed mobile device. For example, the MDM system may leverage the managed relationship to push application updates or certificates to the mobile device. The certificates may be, e.g., X.509 device certificates.

The disclosures provided in this disclosure provide a number of technical advantages. In general, the approaches set forth above enable an enterprise to securely and strongly identify a mobile application regardless of mobile platform. The approaches set forth above also provide an automated way to verify the identity of mobile applications accessing potentially sensitive data such as authentication credentials, digital certificates, enterprise data, and the like. An enterprise implementing the approaches set forth above may also reduce the number of physical devices under its management by allowing individuals to use their personal devices to access enterprise resources. In this regard, an enterprise may avoid having to enroll an entire device into a mobile device management system, and may instead only enroll various mobile applications at a mobile device in a mobile application management system. These and other advantages will be appreciated with the benefit of the disclosures provided above.

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 specific features or acts described above. Rather, the specific features and acts described above are described as example implementations of the following claims.

What is claimed is:

1. A method of managing access to enterprise resources comprising:

operating an access manager at a mobile computing device;

storing, at the mobile computing device, identification information corresponding to an identification token embedded in a mobile application installed at the mobile computing device;

validating, using the access manager, the mobile application based, at least in part, on the identification token and the identification information stored wherein validating the mobile application comprises

challenging the mobile application to provide a response that is based, at least in part, on the identification token,

generating an expected response based, at least in part, on the identification information stored,

comparing the expected response to the response provided by the mobile application, and

determining that the mobile application is either valid or invalid based on whether the expected response matches the response provided by the mobile application;

preventing the mobile application from accessing a computing resource upon unsuccessful validation of the mobile application by the access manager;

identifying the mobile application as a trusted mobile application upon successful validation of the mobile application by the access manager; and

permitting the trusted mobile application to access the computing resource.

2. The method of claim **1** wherein:

the identification token is embedded into the mobile application before the mobile application is installed at the mobile computing device;

the mobile application is configured to extract the identification token embedded in the mobile application; and

the response provided by the mobile application is based further on the identification token extracted from the mobile application.

3. The method of claim **2** wherein validating the mobile application further includes:

deriving one or more identification tokens from the mobile application using the access manager;

generating an expected application signature based on an arrangement of the one or more identification tokens derived from the mobile application and the identification information stored that corresponds to the identification token embedded in the mobile application; and

generating the expected response based further on the expected application signature.

4. The method of claim **3** wherein validating the mobile application further includes:

providing a nonce to the mobile application;

computing an expected hash value using the expected application signature and the nonce; and

wherein the expected response is the expected hash value.

5. The method of claim **1** further comprising:

opening a Transmission Control Protocol (TCP) socket at the mobile computing device using the access manager;

waiting for the mobile application to establish a connection with the access manager at the TCP socket; and

wherein the access manager initiates validation of the mobile application when the mobile application establishes a connection with the access manager at the TCP socket.

6. The method of claim **1** further comprising:

obtaining an application policy associated with the trusted mobile application;

storing the application policy at the mobile computing device; and

controlling operation of the trusted mobile application using the access manager and based on the application policy.

7. A mobile computing device comprising:

a mobile application configured to access a computing resource;

a data store storing identification information corresponding to an identification token embedded in the mobile application;

an access manager configured to validate the mobile application based on the stored identification information by

challenging the mobile application to provide a response that is based, at least in part, on the identification token,

generating an expected response based, at least in part, on the identification information stored,

comparing the expected response to the response provided by the mobile application, and

determining that the mobile application is either valid or invalid based on whether the expected response matches the response provided by the mobile application; and

wherein the access manager is further configured to

prevent the mobile application from accessing the computing resource upon unsuccessful validation of the mobile application,

identify the mobile application as a trusted mobile application upon successful validation of the mobile application, and

permit the trusted mobile application to access the computing resource.

8. The mobile computing device of claim **7** wherein:

the mobile application is configured to extract the identification token embedded in the mobile application; and

the response provided by the mobile application is further based on the embedded identification token extracted from the mobile application.

9. The mobile computing device of claim **8** wherein the access manager is further configured to:

derive one or more identification tokens from the mobile application;

generate an expected application signature based on an arrangement of the one or more identification tokens derived from the mobile application and the identification information stored that corresponds to the identification token embedded in the mobile application; and

generate the expected response based further on the expected application signature.

10. The mobile computing device of claim **9** wherein the access manager is further configured to:

provide a nonce to the mobile application;

compute an expected hash value using the expected application signature and the nonce; and

wherein the expected response comprises the expected hash value.

11. The mobile computing device of claim **7** wherein the computing resource is at least one of:

i) a software application operating at the mobile computing device or a remote computing system;

ii) a service provided by the mobile computing device or the remote computing system;

iii) data stored at the mobile computing device or the remote computing system;

iv) hardware at the mobile computing device or the remote computing system; and

v) combinations thereof.

12. The mobile computing device of claim **7** further comprising:

an application policy associated with the mobile computing device; and

wherein the access manager is configured to control operation of the trusted mobile application based on the application policy.

13. A non-transitory computer-readable storage medium having instructions stored thereon that, when executed at a mobile computing device, cause the mobile computing device to:

validate a mobile application installed at the mobile computing device based on identification information stored at the mobile computing device wherein the identification information stored corresponds to an identification token embedded in the mobile application and wherein validating the mobile application comprises

challenging the mobile application to provide a response that is based, at least in part, on the identification token,

generating an expected response based, at least in part, on the identification information stored,

comparing the expected response to the response provided by the mobile application, and

determining that the mobile application is either valid or invalid based on whether the expected response matches the response provided by the mobile application; and

prevent the mobile application from accessing a computing resource upon unsuccessful validation of the mobile application;

identify the mobile application as a trusted mobile application upon successful validation of the mobile application and

permit the trusted mobile application to access the computing resource.

14. The non-transitory computer-readable storage medium of claim **13** wherein the instructions, when executed, further cause the mobile computing device to:

derive an identification token from the mobile application;

generate an application signature comprising an arrangement of the derived identification token and the identification information stored that corresponds to the identification token embedded in the mobile application; and

wherein the expected response is based further on the application signature.

15. The non-transitory computer-readable storage medium of claim **14** wherein:

the challenge includes a nonce; and

the expected response is based further on the nonce.

16. The non-transitory computer readable storage medium of claim **15** wherein the instructions, when executed,further cause the mobile computing device to:

hash the nonce provided to the mobile application in the challenge with the application signature to generate an expected hash value; and

wherein the expected response comprises the expected hash value.

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