US008327441B2

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

(10) **Patent No.: US 8,327,441 B2**
(45) **Date of Patent: Dec. 4, 2012**

(54) **SYSTEM AND METHOD FOR APPLICATION ATTESTATION**

(75) Inventors: **Srinivas Kumar**, Cupertino, CA (US); **Gurudatt Shashikumar**, Foster City, CA (US)

(73) Assignee: **Taasera, Inc.**, Erie, PA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/399,065**

(22) Filed: **Feb. 17, 2012**

(65) **Prior Publication Data**

US 2012/0216244 A1 Aug. 23, 2012

Related U.S. Application Data

(60) Provisional application No. 61/443,854, filed on Feb. 17, 2011.

(51) **Int. Cl.**
H04L 29/06 (2006.01)

(52) **U.S. Cl.** **726/22**

(58) **Field of Classification Search** 726/22, 726/23, 24, 25
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,091,835 A * 7/2000 Smithies et al. 382/115
6,507,904 B1 * 1/2003 Ellison et al. 712/229
6,760,441 B1 * 7/2004 Ellison et al. 380/45
6,990,579 B1 * 1/2006 Herbert et al. 713/164
6,996,710 B1 * 2/2006 Ellison et al. 713/156
7,013,481 B1 * 3/2006 Ellison et al. 726/4
7,194,759 B1 * 3/2007 Chess et al. 726/2
7,587,607 B2 * 9/2009 Brickell et al. 713/182
7,797,544 B2 * 9/2010 Dillaway et al. 713/179
7,882,221 B2 * 2/2011 Sailer et al. 709/224
7,979,696 B2 * 7/2011 Kim et al. 713/156
7,984,304 B1 * 7/2011 Waldspurger et al. 713/187
8,108,536 B1 * 1/2012 Hernacki et al. 709/231
2005/0033987 A1 * 2/2005 Yan et al. 713/201
2005/0132031 A1 * 6/2005 Sailer et al. 709/223
2005/0132202 A1 * 6/2005 Dillaway et al. 713/179
2005/0138384 A1 * 6/2005 Brickell et al. 713/182
2005/0221766 A1 * 10/2005 Brizek et al. 455/73
2005/0283660 A1 * 12/2005 McKeen et al. 714/11
2005/0289072 A1 12/2005 Sabharwal
(Continued)

OTHER PUBLICATIONS

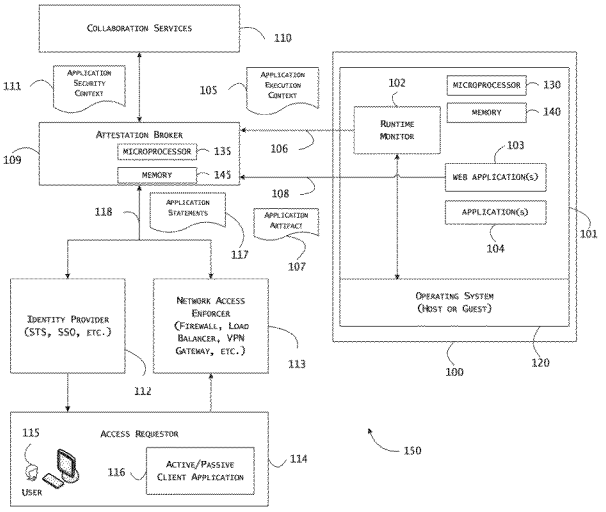
Notification of Transmittal of the International Search Report (Forms PCT/ISA/220 and PCT/ISA/210) and the Written Opinion of the International Searching Authority (Form PCT/ISA/237) dated Aug. 27, 2012, issued in corresponding International Application No. PCT/US2012/025551. (9 pages).

Primary Examiner — David Garcia Cervetti
(74) *Attorney, Agent, or Firm* — Buchanan Ingersoll & Rooney PC

(57) **ABSTRACT**

An instrumented machine or platform having a target application thereon is disclosed. An attestation service may generate an application artifact having associated therewith a name and an application statement having at least one of a plurality of attribute value assertions describing the examined runtime local execution and introspection based derived security context. The application statements may represent the level of contextual trustworthiness, at near real time, of a running application on the instrumented target platform. A runtime process and network monitor may examine the local runtime execution context of the target application, and an identity provider may authenticate a user to the web application based on a web services query for attestation of the target application. A physical or logical authorization service may control access of an authenticated user to the target application, based on a dynamic application statement and multi-factor application attestation issued by the attestation service.

26 Claims, 11 Drawing Sheets



U.S. PATENT DOCUMENTS

2006/0005009 A1* 1/2006 Ball et al. 713/155
2006/0200680 A1* 9/2006 Ellison et al. 713/190
2007/0005992 A1* 1/2007 Schluessler et al. 713/193
2007/0143474 A1 6/2007 Sheng et al.
2007/0174406 A1 7/2007 Morris et al.
2007/0185856 A1* 8/2007 Mittal et al. 707/5
2008/0015808 A1* 1/2008 Wilson et al. 702/123
2008/0083039 A1* 4/2008 Choi et al. 726/27
2008/0141027 A1* 6/2008 Kim et al. 713/156
2008/0235372 A1* 9/2008 Sailer et al. 709/224
2008/0289028 A1* 11/2008 Jansen et al. 726/11
2009/0094584 A1 4/2009 Dheap et al.
2009/0133110 A1 5/2009 Kumar et al.
2009/0138939 A1 5/2009 Kumar et al.
2009/0144818 A1 6/2009 Kumar et al.
2009/0172814 A1* 7/2009 Khosravi et al. 726/23
2009/0178138 A1* 7/2009 Weiss et al. 726/22
2009/0204806 A1* 8/2009 Kanemura et al. 713/155
2009/0204964 A1* 8/2009 Foley et al. 718/1
2009/0241170 A1 9/2009 Kumar et al.
2009/0276204 A1 11/2009 Kumar et al.
2009/0328186 A1 12/2009 Pollutro et al.
2010/0281273 A1* 11/2010 Lee et al. 713/190
2011/0035577 A1* 2/2011 Lin et al. 713/150
2011/0154500 A1* 6/2011 Sahita et al. 726/26
2011/0173643 A1* 7/2011 Nicolson et al. 719/328
2011/0179477 A1* 7/2011 Starnes et al. 726/9
2012/0084850 A1* 4/2012 Novak et al. 726/8
2012/0131334 A1* 5/2012 Haikney et al. 713/156

* cited by examiner

FIG. 1

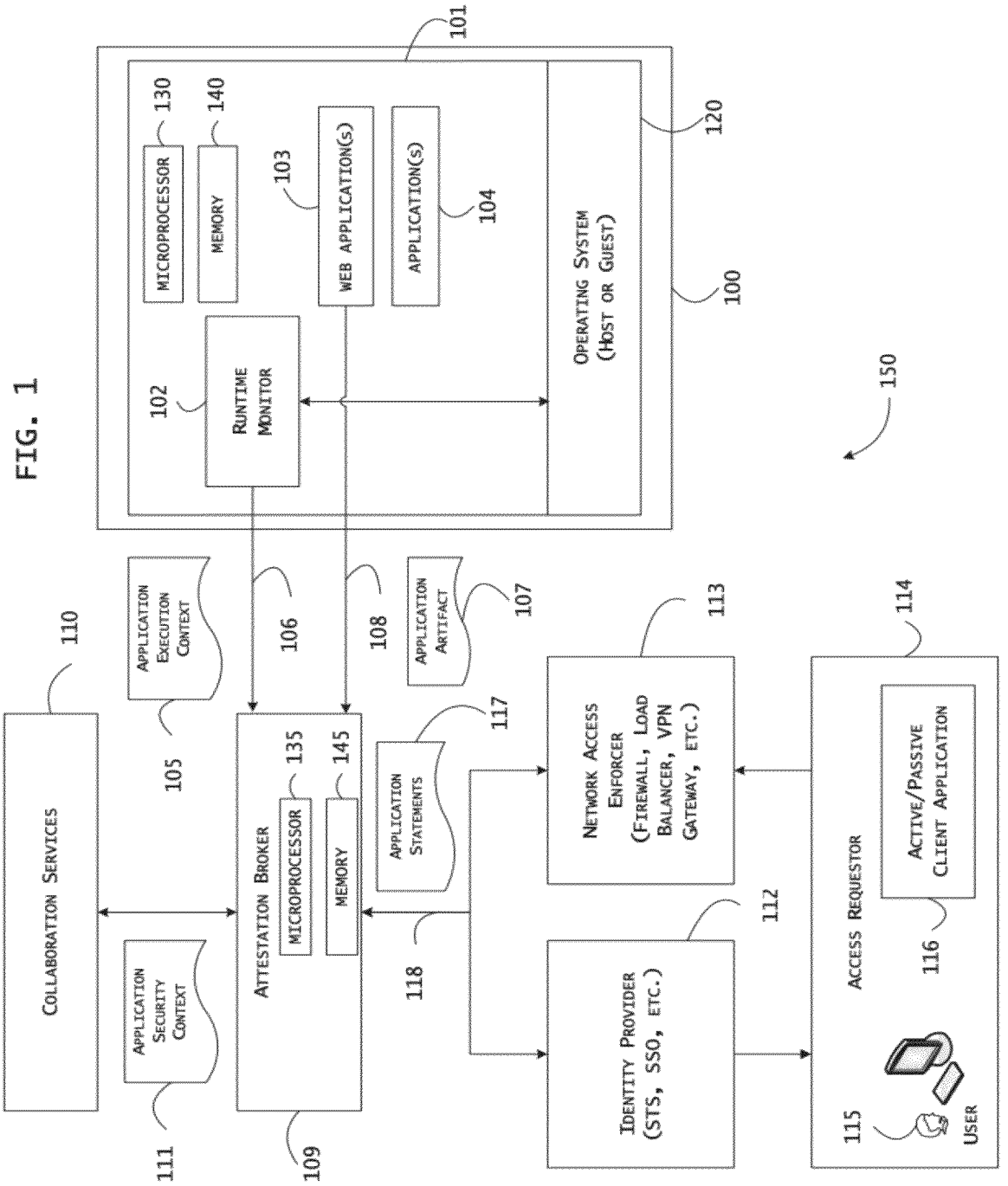

101
130
MICROPROCESSOR
140
MEMORY
103
WEB APPLICATION(S)
APPLICATION(S)
104
120
OPERATING SYSTEM (HOST OR GUEST)
100
102
RUNTIME MONITOR
150
APPLICATION EXECUTION CONTEXT
106
108
APPLICATION ARTIFACT
107
110
113
114
COLLABORATION SERVICES
105
ATTESTATION BROKER
135
MICROPROCESSOR
145
MEMORY
APPLICATION STATEMENTS
117
NETWORK ACCESS ENFORCER (FIREWALL, LOAD BALANCER, VPN GATEWAY, ETC.)
ACTIVE/PASSIVE CLIENT APPLICATION
ACCESS REQUESTOR
112
118
116
APPLICATION SECURITY CONTEXT
IDENTITY PROVIDER (STS, SSO, ETC.)
115
USER
111
109

FIG. 2

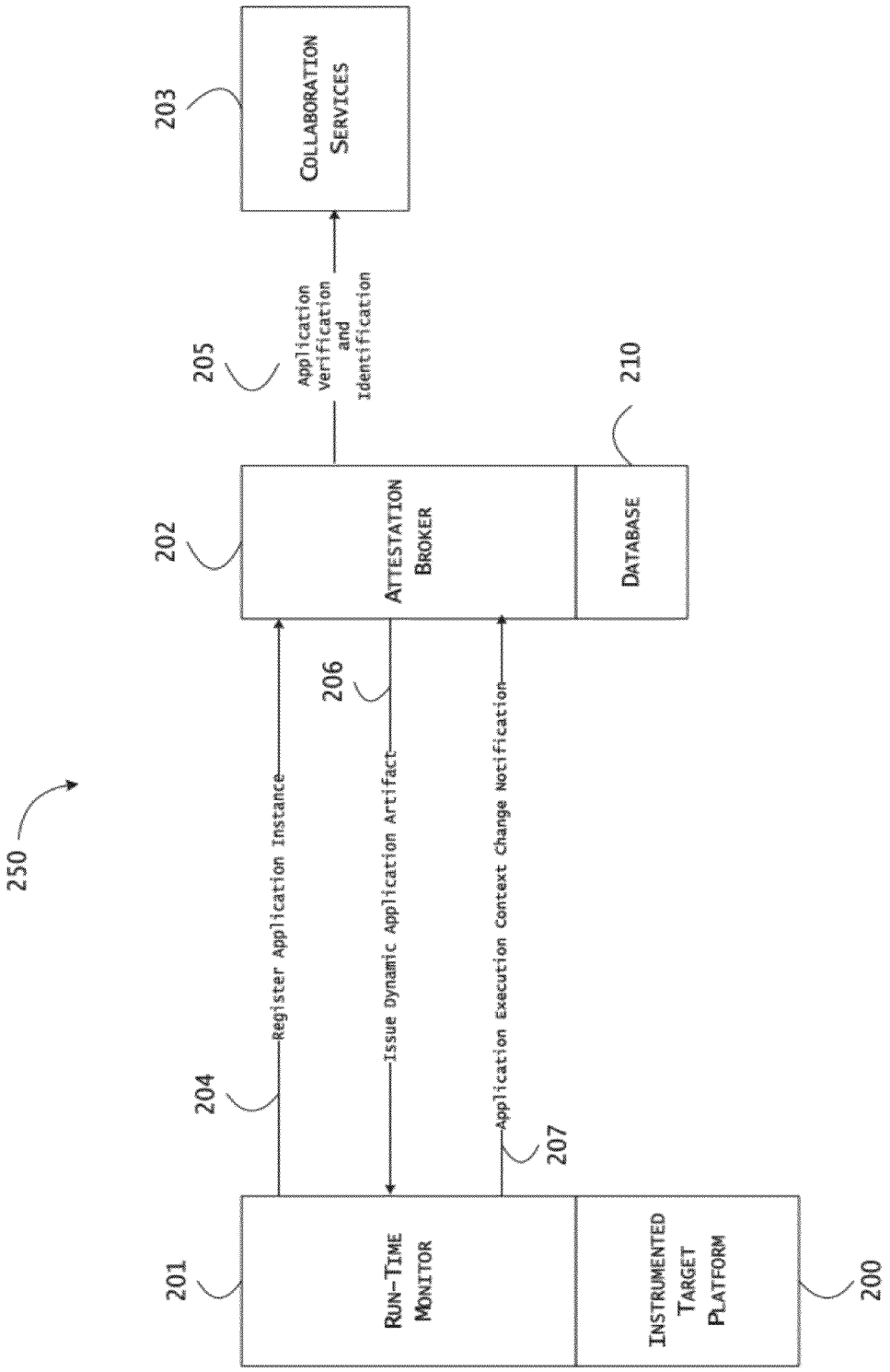

250
203
Collaboration Services
205
Application Verification and Identification
210
202
Attestation Broker
Database
206
Register Application Instance
Issue Dynamic Application Artifact
Application Execution Context Change Notification
204
207
201
Run-Time Monitor
Instrumented Target Platform
200

FIG. 3

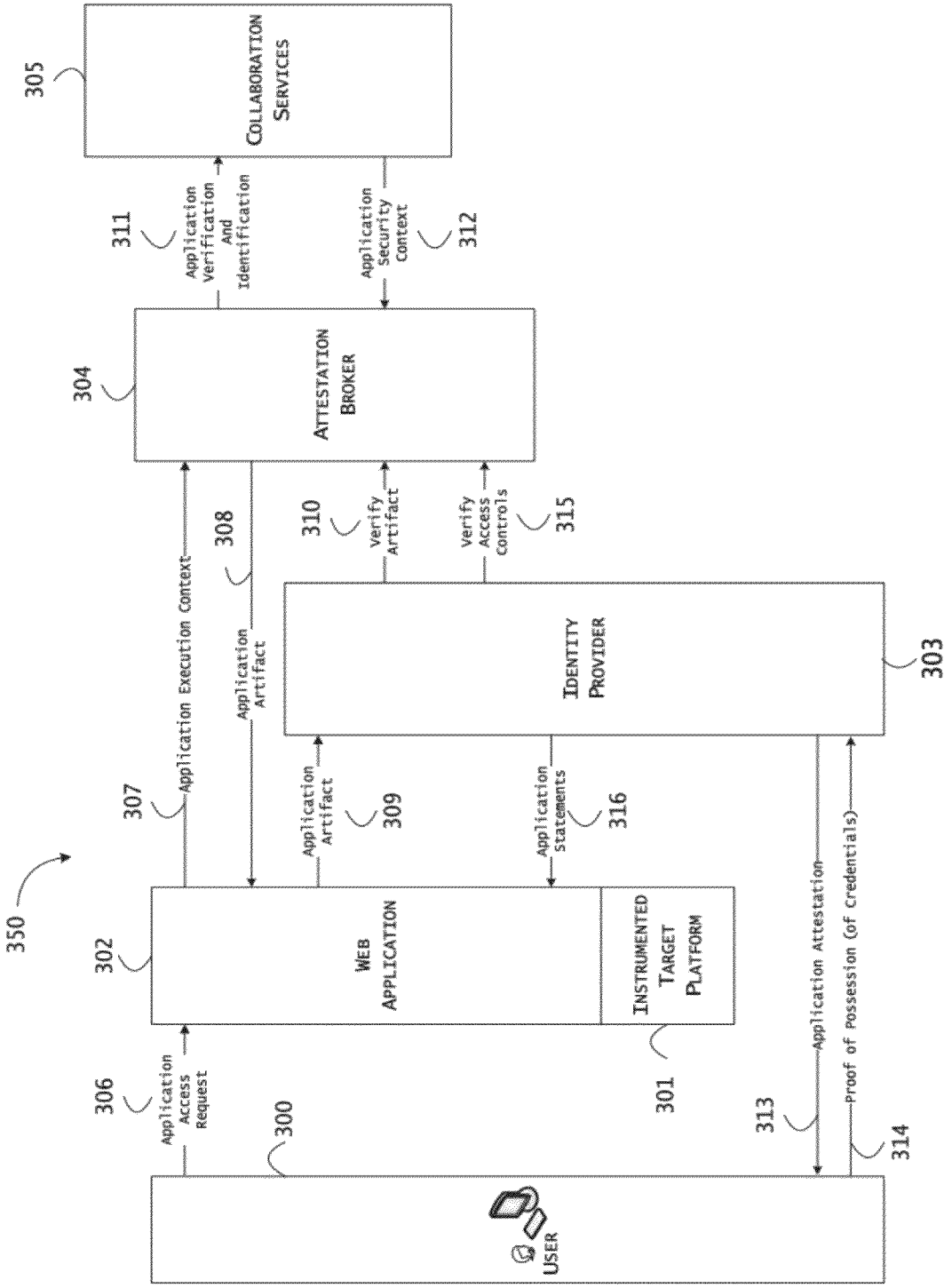

350
305
Collaboration Services
311
Application Verification And Identification
Application Security Context
312
304
Attestation Broker
308
Application Execution Context
Application Artifact
310
Verify Artifact
Verify Access Controls
315
Identity Provider
303
307
Application Artifact
309
Application Statements
316
302
Web Application
Instrumented Target Platform
301
306
Application Access Request
300
User
313
Application Attestation
Proof of Possession (of Credentials)
314

FIG. 4

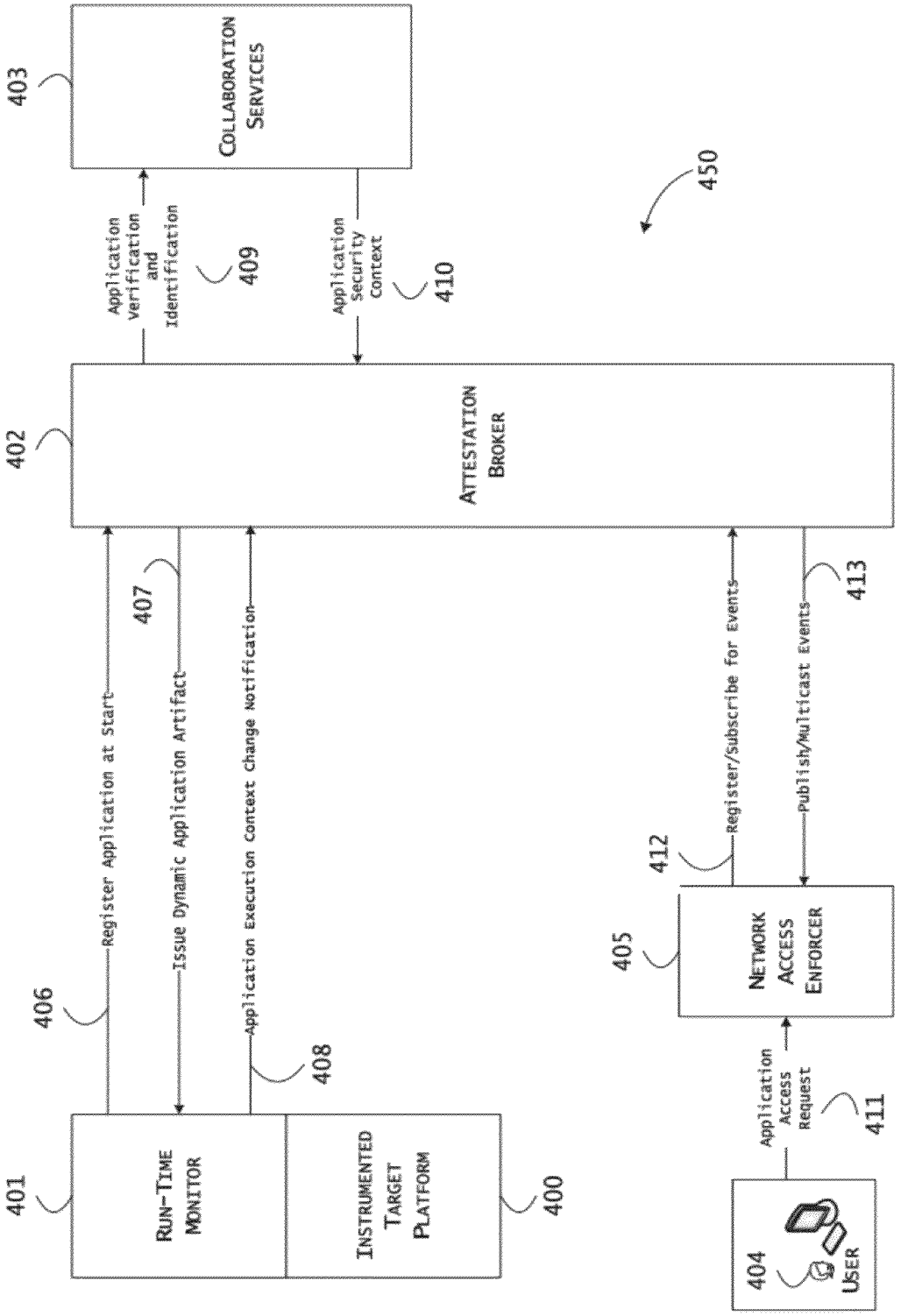

403
Collaboration Services
Application verification and Identification
409
Application Security Context
410
450
402
Attestation Broker
407
Register Application at Start
Issue Dynamic Application Artifact
Application Execution Context Change Notification
Register/Subscribe for Events
Publish/Multicast Events
413
412
405
Network Access Enforcer
406
408
Application Access Request
411
401
Run-Time Monitor
Instrumented Target Platform
400
404
User

FIG. 5

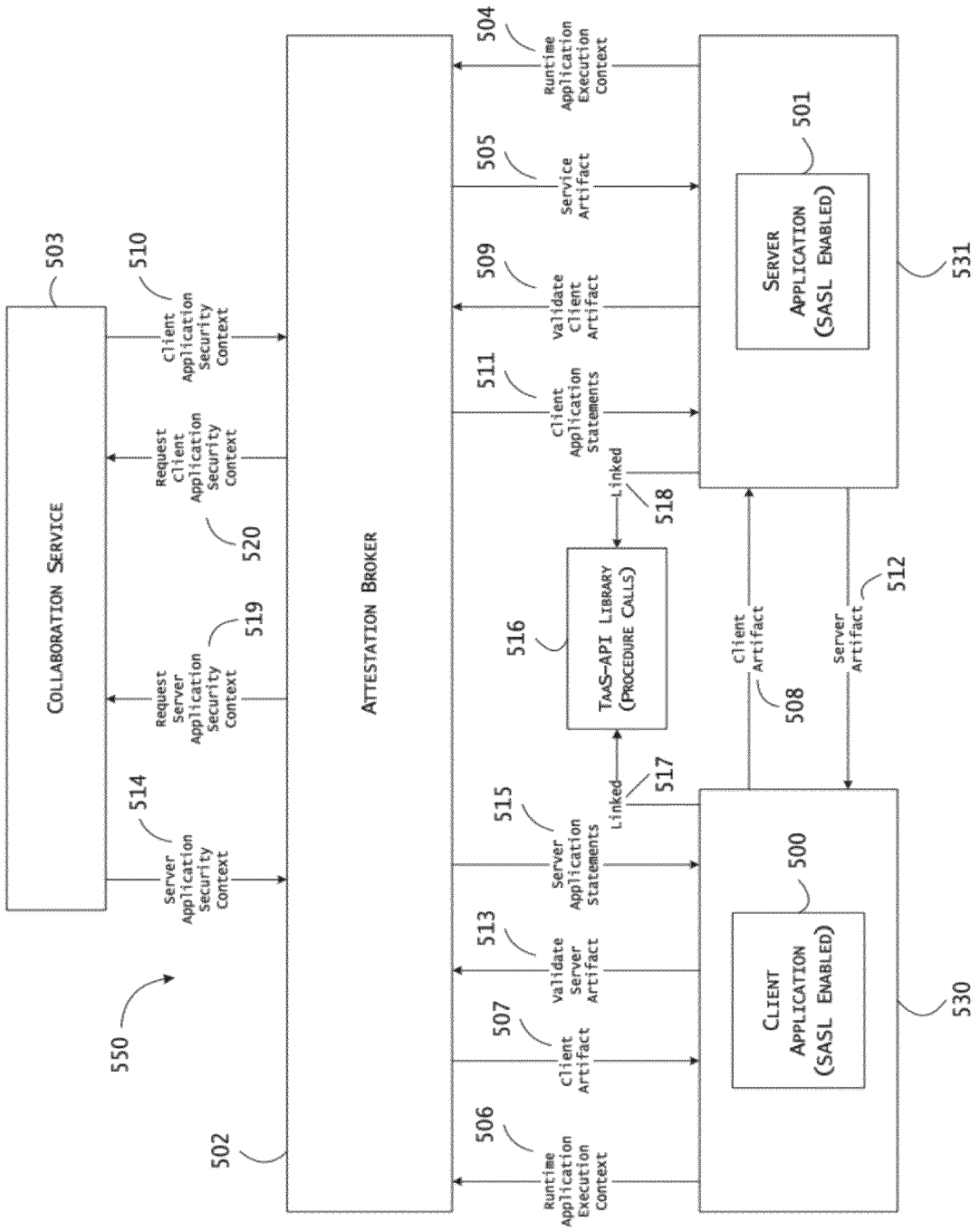

Collaboration Service
503
Attestation Broker
502
Client Application Security Context
510
Request Client Application Security Context
520
Request Server Application Security Context
519
Server Application Security Context
514
550
Runtime Application Execution Context
504
Service Artifact
505
Validate Client Artifact
509
Client Application Statements
511
Linked
518
TAAS-API Library (Procedure Calls)
516
Linked
517
Server Application Statements
515
Validate Server Artifact
513
Client Artifact
507
Runtime Application Execution Context
506
Client Artifact
508
Server Artifact
512
Server Application (SASL Enabled)
501
531
Client Application (SASL Enabled)
500
530

FIG. 6

650

TaaS Integrity Dashboard

Service Host (604)	Service Realm (603)	Service Name (602)	Version (606)	Vendor (605)	Metrics (608)	Ports (607)
EXG0003	eng.dba.com	SharePoint Server	2010	Microsoft Corporation	V/C/R/P	443
DEV0004	dev.eng.dba.com	Apache HTTP Server	2.2	GNU GPL	V/C/R/P	443
QA0005	qa.dba.com	FileZilla Server	0.9.37	GNU GPL	V/C/R/P	21
QA0007	qa.dba.com	Telnet Server	7.0	Microsoft Corporation	V/C/R/P	23
FD0008	finance.dba.com	OpenSSH Server	5.1	GNU GPL	V/C/R/P	22
FD0009	finance.dba.com	IIS Server	3.0	Microsoft Corporation	V/C/R/P	110; 443
TS0010	tech-support.dba.com	Tomcat Server	6.0.29	GNU GPL	V/C/R/P	443
TS0011	tech-support.dba.com	WebSphere Application Server	7.0	IBM	V/C/R/P	443
ELAB0012	lab.qa.dba.com	NetWeaver	7.3	SAP	V/C/R/P	443
ELAB0013	lab.qa.dba.com	WebLogic	10.3.1	Oracle	V/C/R/P	443
PS0014	proserv.dba.com	Microsoft Exchange Server	3.5	Microsoft Corporation	V/C/R/P	379; 443; 445; 993; 995
PM0015	proserv.dba.com	Active Directory	2.000.0	Microsoft Corporation	V/C/R/P	389, 636
BD0016	bizdev.dba.com	Zimbra	10.3.1	VMware, Inc.	V/C/R/P	25; 110; 143; 443

Monitor Date/Time: January 26, 2010 9:18 AM (PST) (601)

FIG. 7

750

700

702 703 704 705 706 707 708 709 710

TaaS Authorization Console								
Users	Roles	Auth Realm	Auth Type	Service Host	Service Realm	Service Name	Version	Vendor
Any	Business Development	dba-tp.com	OTP FOB	ENG0003	eng.dba.com	SharePoint Server	2010	Microsoft Corporation
Any	Sales; Support	dbasupplier.com	Password	DEV0004	dev.eng.dba.com	Apache HTTP Server	2.2	GNU GPL
Any	Product Management	dba-tp.com dba-ap.com	Smart Card	QA0005	qa.dba.com	FileZilla Server	0.9.37	GNU GPL
Any	Engineers	dba.com	Password	QA0007	qa.dba.com	Telnet Server	7.0	Microsoft Corporation
ajoe@dba.com asteve@dba.com		dba.com	OTP FOB	FD0008	finance.dba.com	OpenSSH Server	5.1	GNU GPL
Any	QA	dba.com	Password	FD0009	qa.dba.com	IIS Server	3.0	Microsoft Corporation
Any	Server Team	dba.com	Password	TS0010	tech-support.dba.com	Tomcat Server	6.0.29	GNU GPL
Any	Server Team	dba.com	Password	TS0011	tech-support.dba.com	WebSphere Application Server	7.0	IBM
Any	HelpDesk	dba.com	Password	ELAB0012	lab.qa.dba.com	NetWeaver	7.3	SAP
Any	Finance	dba.com	Password	ELAB0013	lab.qa.dba.com	WebLogic	10.3.1	Oracle
Any	Administrators	dba.com	Password	PS0014	proserv.dba.com	Microsoft Exchange Server	5.5	Microsoft Corporation
Any	Administrators	dba.com	OTP FOB	PM0015	proserv.dba.com	Active Directory	2,000.0	Microsoft Corporation
Any	Any	dba.com	Password	BD0016	bizdev.dba.com	Zimbra	10.3.1	VMware, Inc.
Any	Staff Engineer	dba.com	OTP FOB	HR0018	hr.dba.net	VisualSVN Server	2.1.4	VisualSVN
Cloud Client: DBA								

701

FIG. 9

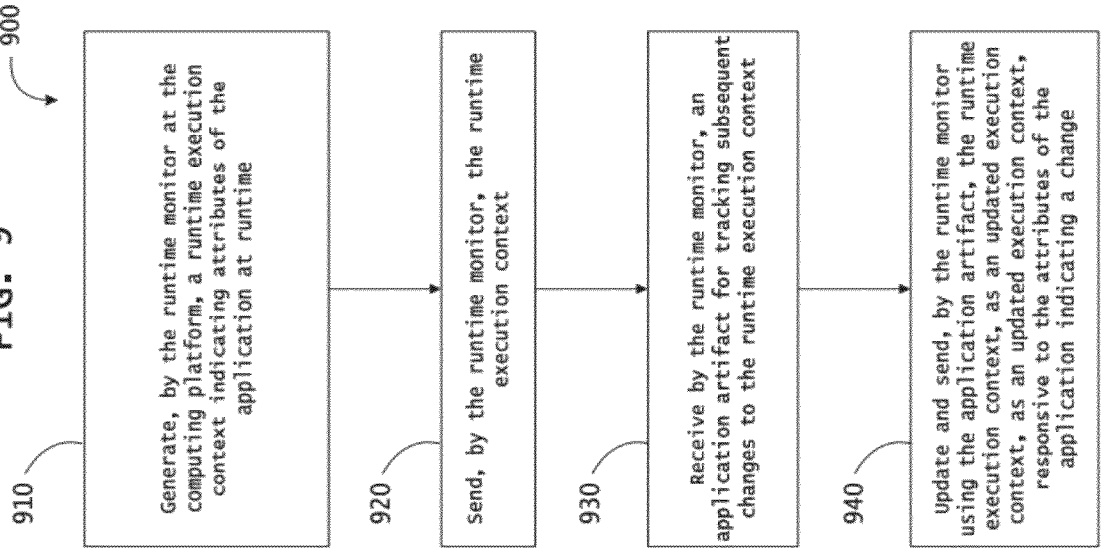

900
910
Generate, by the runtime monitor at the computing platform, a runtime execution context indicating attributes of the application at runtime
920
Send, by the runtime monitor, the runtime execution context
930
Receive by the runtime monitor, an application artifact for tracking subsequent changes to the runtime execution context
940
Update and send, by the runtime monitor using the application artifact, the runtime execution context, as an updated execution context, responsive to the attributes of the application indicating a change

FIG. 8

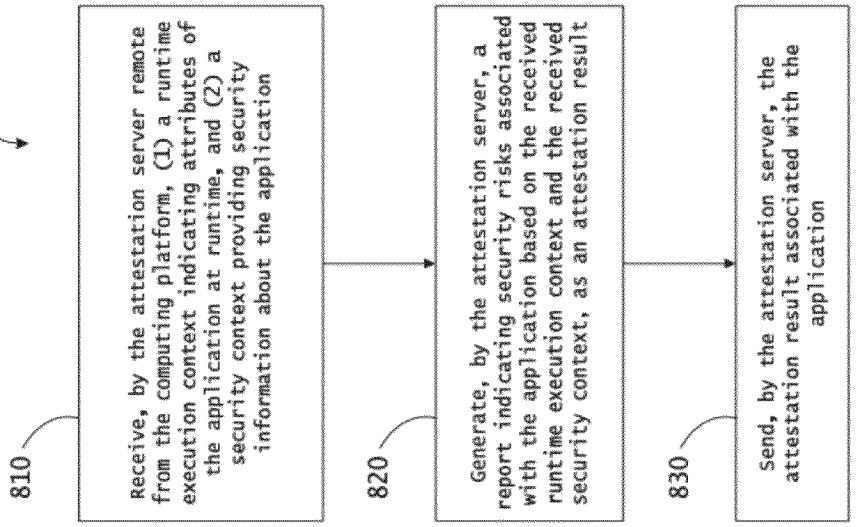

800
810
Receive, by the attestation server remote from the computing platform, (1) a runtime execution context indicating attributes of the application at runtime, and (2) a security context providing security information about the application
820
Generate, by the attestation server, a report indicating security risks associated with the application based on the received runtime execution context and the received security context, as an attestation result
830
Send, by the attestation server, the attestation result associated with the application

FIG. 11

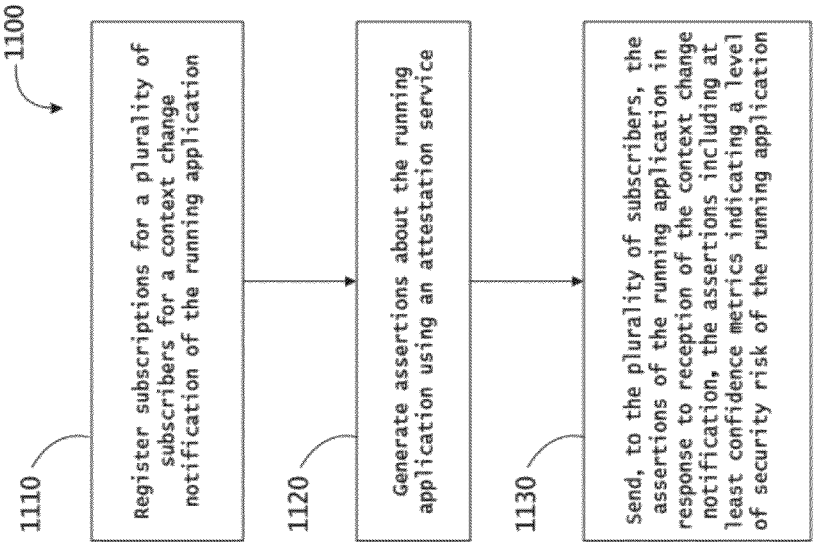

1100
1110
Register subscriptions for a plurality of subscribers for a context change notification of the running application
1120
Generate assertions about the running application using an attestation service
1130
Send, to the plurality of subscribers, the assertions of the running application in response to reception of the context change notification, the assertions including a least confidence metrics indicating a level of security risk of the running application

FIG. 10

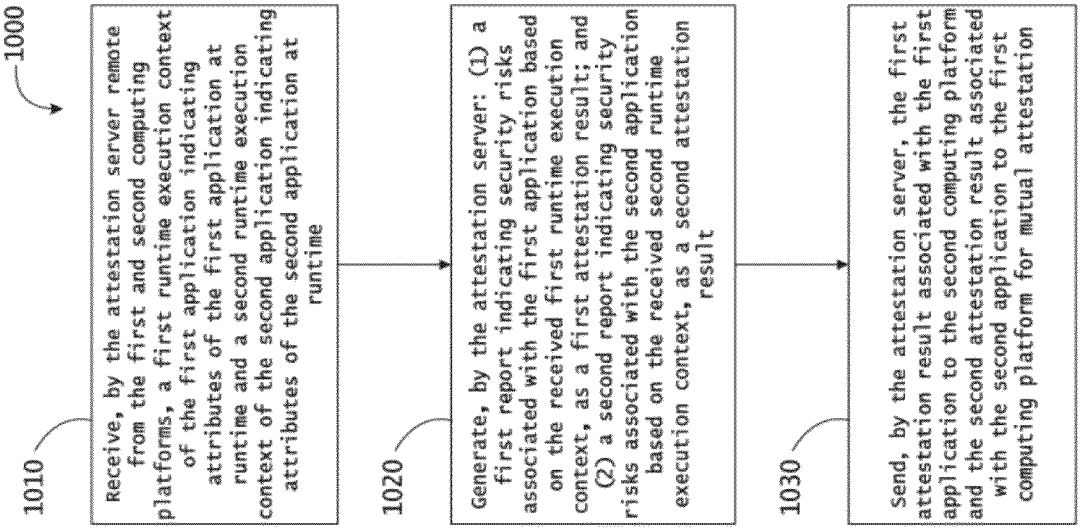

1000
1010
Receive, by the attestation server remote from the first and second computing platforms, a first runtime execution context of the first application indicating attributes of the first application at runtime and a second runtime execution context of the second application indicating attributes of the second application at runtime
1020
Generate, by the attestation server: (1) a first report indicating security risks associated with the first application based on the received first runtime execution context, as a first attestation result; and (2) a second report indicating security risks associated with the second application based on the received second runtime execution context, as a second attestation result
1030
Send, by the attestation server, the first attestation result associated with the first application to the second computing platform and the second attestation result associated with the second application to the first computing platform for mutual attestation

FIG. 12

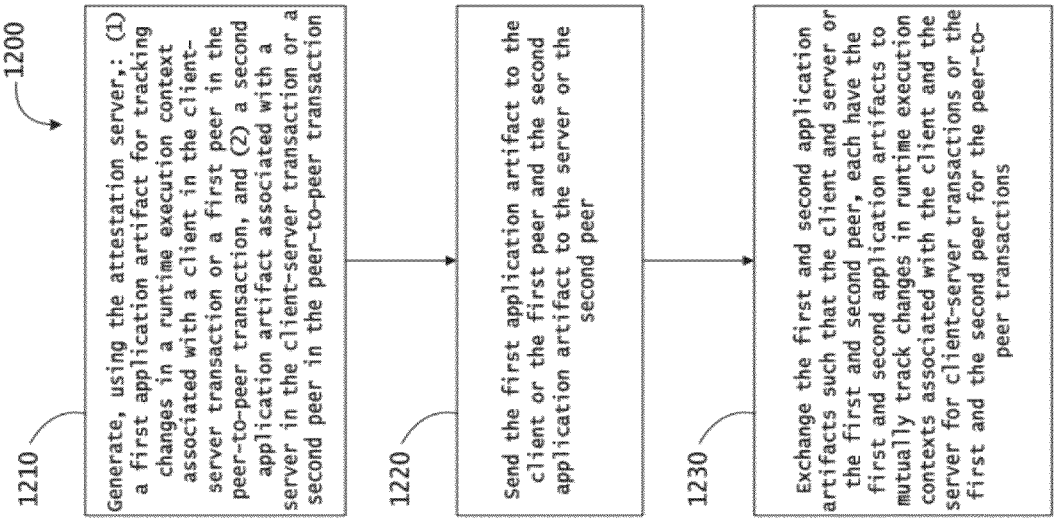

1200
1210
Generate, using the attestation server,: (1) a first application artifact for tracking changes in a runtime execution context associated with a client in the client-server transaction or a first peer in the peer-to-peer transaction, and (2) a second application artifact associated with a server in the client-server transaction or a second peer in the peer-to-peer transaction
1220
Send the first application artifact to the client or the first peer and the second application artifact to the server or the second peer
1230
Exchange the first and second application artifacts such that the client and server or the first and second peer, each have the first and second application artifacts to mutually track changes in runtime execution contexts associated with the client and the server for client-server transactions or the first and the second peer for the peer-to-peer transactions

FIG. 13

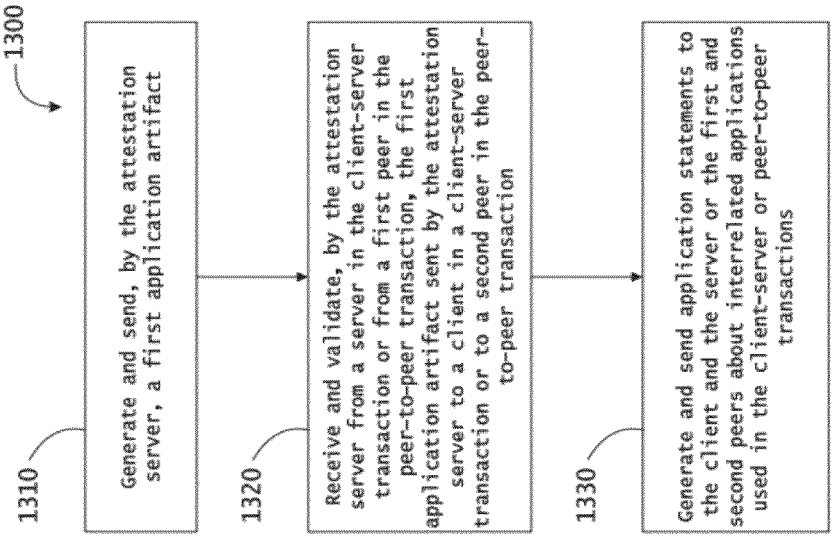
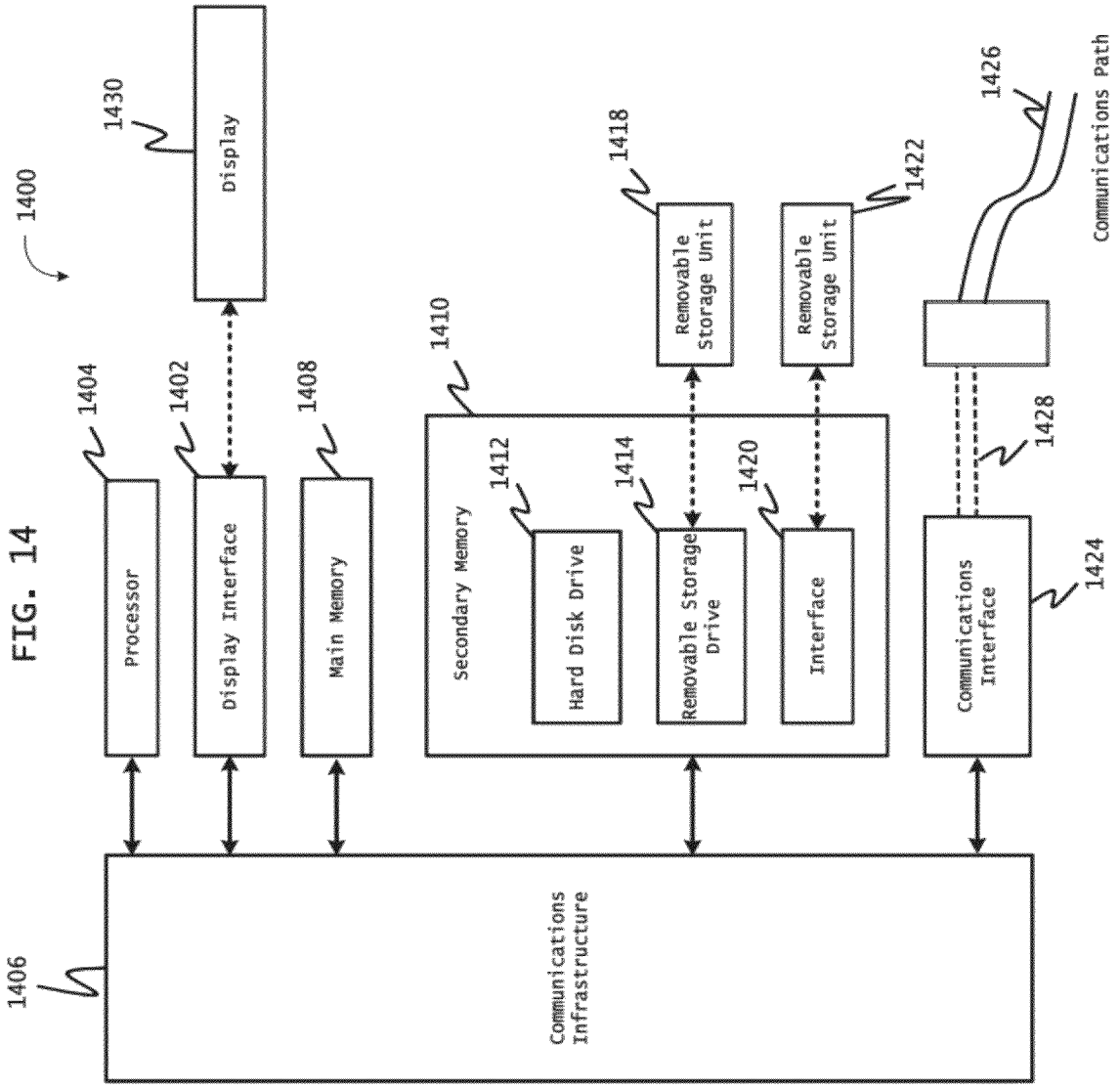

1300
1310
Generate and send, by the attestation server, a first application artifact
1320
Receive and validate, by the attestation server from a server in the client-server transaction or from a first peer in the peer-to-peer transaction, the first application artifact sent by the attestation server to a client in a client-server transaction or to a second peer in the peer-to-peer transaction
1330
Generate and send application statements to the client and the server or the first and second peers about interrelated applications used in the client-server or peer-to-peer transactions

FIG. 14


1400
1430
Display
1404
Processor
1402
Display Interface
1408
Main Memory
1410
Secondary Memory
1412
Hard Disk Drive
1414
Removable Storage Drive
1420
Interface
1418
Removable Storage Unit
1422
Removable Storage Unit
1426
Communications Path
1428
1424
Communications Interface
1406
Communications Infrastructure

SYSTEM AND METHOD FOR APPLICATION ATTESTATION

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Appl. No. 61/443,854 entitled "SYSTEM AND METHOD FOR APPLICATION ATTESTATION," filed Feb. 17, 2011, which is incorporated by reference herein in its entirety.

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

The present disclosure relates to the field of data center virtualization and, more particularly, to a system and method to provide attestation of applications at runtime.

2. Description of the Related Art

One recent trend in computing is the trend towards cloud computing in which, for example, enterprise software is no longer owned by the customer, but instead the Information Technology infrastructure can be provided by a third party and the software applications may be sold as service offerings.

SUMMARY OF THE DISCLOSURE

The presently disclosed technology may be embodied as a method, apparatus and/or system to discover one or more applications and/or to attest for the applications on an instrumented target platform at runtime using or based on a plurality of assertions (or statements).

The presently disclosed technology also may be embodied as a method, apparatus, and/or system for a plurality of services that enable visibility, control, and/or compliance in a cloud computing environment with dynamic application discovery, identification, monitoring and/or attestation based on a plurality of factors.

The presently disclosed technology also may be embodied as a further method, apparatus and/or system to establish user-to-application connections based on dynamic attestation of applications, and/or security controls provisioned based on context-aware business logic instead of, for example, topology based coordinates associated with encapsulation headers in network packets.

The presently disclosed technology also may be embodied as a yet further method, apparatus and/or system to authorize user-to-application transactions and/or data exchange in an established connection, during the authentication phase based on dynamic attestation of applications.

The presently disclosed technology also may be embodied as an additional method, apparatus and/or system for a runtime monitor to inspect web and non-web applications (e.g., all web and non-web applications) running on the instrumented target platform. The system may include an attestation service (or broker) using an attestation server and configured to generate application artifacts and/or to issue application statements or claims. The application artifact may represent an identified application instance (e.g., at runtime, globally unique, opaquely and/or in a time-sensitive manner, for example, using an application artifact having a specified or predetermined lifetime) on an instrumented platform (such as but not limited to a, Personal Digital Assistant (PDA), a tablet computing device, an iPhone ™, an iPod™, an iPad™, a device operating the Android operating system (OS) from Google Inc., a device running the Microsoft Windows® Mobile OS, a device running the Microsoft Windows® Phone OS, a device running the Symbian OS, a device running the webOS from Hewlett Packard, Inc., a mobile phone, a BlackBerry® device, a smartphone, a hand held computer, a netbook computer, a palmtop computer, a laptop computer, an ultra-mobile PC, a portable gaming system, a gaming console, or another similar type of computing device having a computer, microprocessor). The application statements may include at least one statement (or claim) about an inspected runtime execution context and/or an intelligence based security context.

The runtime monitor may be configured to inspect the execution context of the application after using a local attestation process. The execution context of each respective application may include associated files, processes, and/or network epochs (e.g., socket events). The system may include any type of identity provider configured to authenticate a user to web or non-web applications (for example, client-server or peer-to-peer applications) based on a request for attestation of and a security context of a target application on a computing platform (e.g., the instrumented target platform).

The presently disclosed technology also may be embodied as a method, apparatus and/or system that may include a network access enforcer for controlling the authenticated user's physical access to the target application on the instrumented target platform, responsive to one or more issued application statements (e.g., issued by the attestation service or another entity).

The presently disclosed technology also may be embodied as another method, apparatus and/or system to include an identity provider for controlling the authenticated user's authorization to commence transactions with a target application on the instrumented target platform, responsive to one or more issued application statements (e.g., issued by the attestation service).

The presently disclosed technology also may be embodied with an application artifact that may include at least a registered name (e.g., a registered globally unique security principal name) for the running application instance (e.g., a user program or a service program, among others). The attestation service may be configured to generate an artifact based on a runtime local execution context of the running application instance on the instrumented target platform.

The presently disclosed technology also may be embodied with one or more application statements or claims which may include at least one of: (1) a registered name (e.g., a registered globally unique security principal name) for the running application instance; (2) a digitally signed certificate; (3) creation and/or modification timestamps; (4) assertions of a security context from a plurality of collaboration services; (5) a list of active listening and/or open network ports (e.g., well-known and/or ephemeral); (6) network addresses used by the application; (7) a product publisher; (8) a product version; and/or (9) other runtime local execution context information.

The presently disclosed technology also may be embodied with one or more application statements or claims, which may include attribute value assertions about an introspected security context of one or more running applications. The introspected security context may be received from one (e.g., any one) of the plurality of collaboration services.

The presently disclosed technology may also be embodied with a plurality of collaboration services which may include: (1) an application whitelisting services (e.g., any application whitelisting services); (2) a vulnerability assessment service; (3) a patch management service; (4) an anti-virus service (5) a predictive and behavioral analytics engine; (6) and orches-

tration service; (7) a network intrusion detection or prevention service; (8) an open flow switch controller; and/or (9) a malware analysis system.

The presently disclosed technology may also be embodied with: (1) an identity provider that may include a single sign-on service or a brokered authentication service; (2) a network access enforcer, which may include devices such as for example network firewalls, load balancers, and/or VPN gateways, and which may be configured as a policy enforcement point to control access based on an application statement or claim.

The presently disclosed technology also may be embodied as a method, apparatus and/or system for evaluating authenticity of a web application (for example, a servlet in a container element). The method may include requesting a runtime application artifact for the web application from an attestation service, and requesting, based on the application artifact, an application statement from the attestation service. The method may further include requesting from a plurality of collaboration services, for example by the attestation service, a context (e.g., an introspection based security context) for the web application on the instrumented target platform. The method may also include establishing a communication channel (e.g., a secure communications channel) between the instrumented target platform and the server providing attestation service, and generating an application statement corresponding to at least one component of the web application. The method may include generating the statement about the application components, based on a parent/child association and/or a loader dependency, and transmitting the application statement to an identity provider. The method may further include generating a multi-factor confidence metric of the web application to be included with and rendered natively by a passive web client or browser.

The presently disclosed technology may be embodied as another method, apparatus and/or system for evaluating authenticity of a non-web client-server application and/or a peer-to-peer application. The method may include requesting an application artifact for the application from an attestation service, for example, by a runtime monitor, and requesting an application statement from the attestation service, for example, by network access enforcer(s). The method may further include requesting, by the attestation service from a plurality of collaboration services, a context (e.g., an introspection based security context) for the application on the instrumented target platform. The method may also include requesting a notification of or subscribing to a change (e.g., any change) in the execution context of the application on the instrumented target platform. The method may additionally include generating and publishing one or more application statements or claims about (regarding) the application based on at least one of a subscription request by a plurality of identity providers and/or network access enforcers. The method may further include receiving or generating, and publishing a multi-factor confidence metric of the application for a physical or logical access control decision.

The presently disclosed technology also may be embodied as a method, apparatus and/or system for client-server and/or peer-to-peer applications to evaluate the authenticity of peers prior to commencing a transaction or data exchange (e.g., any transaction or data exchange). The method may include a client-server application and/or a peer-to-peer application that may request an application artifact for each of the applications from an attestation service (or attestation server), and further may request, based on an artifact exchange, one or more application statements from the attestation service for each peer application. The method may further include requesting, by the attestation service from a plurality of collaboration services, a context (e.g., an introspection based security context) for these applications on the instrumented target platforms. The method may further include a secure exchange of the issued application artifacts between the applications, and a verification process (such as a back-channel verification of the exchanged artifacts with the attestation service). This method may further include requesting one or more application statements, based on (or responsive to) the exchanged application artifact, from the attestation service, and determining by the peer applications, or by the network access enforcer(s) receiving the one or more application statements, responsive to receiving the application statements, the authenticity of the other, or each application in the transaction.

The presently disclosed technology also may be embodied as a method, apparatus and/or system for displaying and continuously updating in real time or near real time (e.g., within a threshold period) the identity, attribution, and/or attestation information of executing or running (e.g., all running) applications hosted in the private an/or public virtual data centers in a cloud computing infrastructure. The method may include displaying one or more classification based confidence metrics and active listening and/or open network ports (e.g., well known and ephemeral) assigned on a plurality of instrumented target platforms.

The presently disclosed technology also may be embodied as a method, apparatus and/or system for establishing access control policies based on a user authentication method, a user role, a dynamically discovered and attested application running on an instrumented target platform via subscription based application statements from an attestation service. The method may also include decoupling of the business logic (role based access controls, authentication requirements, and/or line of business applications, among others) from the network topology based physical constraints in the network fabric (e.g. IP addresses, MAC addresses, VLAN identifiers, and/or subnet addresses, among others) and may include context-aware logical attributes (user identity and/or application identity among others) in policy grammar. The method may further include establishing access control rules that may leverage classification based dynamic confidence metrics, which may be included in an application statement used for authorization decisions.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

The invention is best understood from the following detailed description when read in connection with the accompanying drawings. According to common practice, various features/elements of the drawings may not be drawn to scale. Common numerical references represent like features/elements. The following figures are included in the drawings:

FIG. **1** is a schematic diagram illustrating an exemplary system/architecture in accordance with various exemplary embodiments;

FIG. **2** is a schematic diagram illustrating a method of monitoring and attesting applications in a cloud computing environment in accordance with various exemplary embodiments;

FIG. **3** is a schematic diagram illustrating another method of monitoring and attesting applications in the cloud computing environment in accordance with various exemplary embodiments;

FIG. **4** is a schematic diagram illustrating a further method of monitoring and attesting applications in a cloud computing environment in accordance with various exemplary embodiments;

FIG. **5** is a schematic diagram illustrating a method of monitoring and attesting a Simple Authentication and Security Layer (SASL) enabled client and server application in accordance with various exemplary embodiments;

FIG. **6** is a schematic diagram illustrating an exemplary security administration console including an integrity dashboard in accordance with various exemplary embodiments;

FIG. **7** is a schematic diagram illustrating another exemplary policy administration console including an authorization dashboard in accordance with various exemplary embodiments;

FIG. **8** is a flowchart illustrating a method in accordance with various exemplary embodiments of the presently disclosed technology;

FIG. **9** is a flowchart illustrating a method in accordance with various exemplary embodiments of the presently disclosed technology;

FIG. **10** is a flowchart illustrating a method in accordance with various exemplary embodiments of the presently disclosed technology;

FIG. **11** is a flowchart illustrating a method in accordance with various exemplary embodiments of the presently disclosed technology;

FIG. **12** is a flowchart illustrating a method in accordance with various exemplary embodiments of the presently disclosed technology; and

FIG. **13** is a flowchart illustrating a method in accordance with various exemplary embodiments of the presently disclosed technology.

FIG. **14** is a diagram of an example computer system in which embodiments can be implemented.

DETAILED DESCRIPTION

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

Many enterprises are moving there IT infrastructures to cloud computing environments (e.g., in which third parties may provide shared computing resources and applications running on those resources are offered as services to a plurality of customers) for various reasons including: (1) increased computing power; (2) increased storage capacity, and/or (3) increased network bandwidth, among others. Enterprise applications and mission critical applications may be executed in the cloud. Without adequate system and application security, the cloud can compromise these applications causing large financial losses. Data confidentiality, data integrity and data availability can be maintained in the cloud computing environment even when such applications may be controlled by these third parties. For example, enterprises are moving from self-managed on-premise data centers to service-provider managed outsourced virtual data centers (e.g., the cloud computing environments). The cloud may enable traditional information technology systems and applications to transparently execute from these service-providers managed outsourced virtual data centers. As newer technologies emerge, the cloud infrastructure may evolve transparent to and scalable with enterprise operations. Security in such environments may be an emerging challenge.

In certain exemplary embodiments, applications may be secured by signing-on or authenticating applications onto the network using an attestation process (e.g., via a single factor or multi-factor attestation). In a multi-factor process, applications may be qualified based on at least two factors. A first factor may identify one or more attributes of the application (e.g., run time instance of the application) such as (1) a hash of the application, as an application fingerprint, (2) other applications/processes called by the application, (3) ports used by the application, (4) computing, storage, and network resource usage by the application, and/or (5) the platform executing the application, among others. Such information may be available locally (e.g., at the computing platform running the application) in the current execution context. A second factor may identify what is known about the application based on the attributes of the application from security intelligence external to the operating environment (e.g., a third party (e.g., trusted third party) separate from the computing platform running the application).

Applications that are hosted in self-managed and in-house enterprise data centers may be gradually migrating to outsourced service provider managed virtual data centers in private/public clouds. There may be a loss of visibility and direct control from this migration. Various exemplary embodiments include instrumentation to monitor the applications in process to increase visibility and enable attestation of applications executing in the outsourced service provider managed virtual data centers. As web and multi-tier applications proliferate in the cloud, secure connectivity, based on certificates issued by third party certificate authorities may be inadequate for security and compliance because a significant number of web-based threats originate from trusted web sites.

Generally, access control mechanisms are based on static context and physical constraints rather than logical attributes and dynamic local execution context and/or a holistic security context (e.g., based on both local execution context as well as security intelligence). Physical and logical access controls based on user-to-application bindings, as an operative element of business logic, and logical attributes in a virtualized and fluid network may be used in a cloud computing environment (for the utility based infrastructure, platform and/or software as a service model) to scale and/or be viable for multi-tenancy or shared resources with deterministic confidentiality between or among tenants.

The access control mechanism may include an instrumented target (hosting) computing platform, a policy statement (e.g., grammar) based on a runtime base of the particular application, a temporal and environmental context independent of physical constraints or enforcement methods, an attestation broker (service or server) for notifying interactive users, network access enforcers and identity providers.

The confluence of single-sign-on (SSO) mechanisms and multi-tier applications (for example, the web, application, database tiers) may introduce higher risks of non-compliance in outsourced multi-tenant cloud services infrastructures. In the absence of reliable application attestation methods, impersonation and delegation of user's credentials may pose serious security threats in, for example, multi-hop transitive chain of services, for both intra-cloud and inter-cloud computing environments, where inter-service transactions may be based on implied trust.

FIG. **1** is a schematic diagram illustrating an exemplary network **150** in accordance with various exemplary embodiments.

Referring to FIG. **1**, the exemplary network **150** may include a runtime monitor **102** that may discover and identify a web-based application **103** or non-web-based application

104 that may be executing or running on a computing platform (or an instrumented target platform) 100, an attestation broker 109 that may receive a request to attest to the identify of a running application and that may query one or more collaboration services 110 to request a context (e.g., a security context and/or an introspection based security context) of the running application. The application may be an application targeted for use by an access requestor 114 (e.g., another computing platform) that may be operated by a user (or end-user) 115 via, for example an active or passive client application 116, that may desire an assurance or an attestation that the application is appropriate to be used.

The attestation broker 109 (or the collaboration service 110) may be configured to generate application statements or reports 117, which may include assertions about the running target application, and may deliver the statements or reports 117 to the requestor, the third party, and/or end-user. The platform 100 may include any computing device 101 and/or virtual platform, for example, (e.g., a computer, microprocessor, Personal Digital Assistant (PDA), smartphone, notebook computer, and/or a virtual server running on hardware, among others). The computing device may include a microprocessor 130 for execution, for example, of computing platform software such as operating system software, applications, and runtime monitor software, among others and a memory 140 for data, metadata, and software storage.

The attestation broker 109 may issue application artifacts 107 (e.g., that may maintain a record of the state of the discovered or identified applications running on the instrumented platform 100) to the runtime monitor 102 for discovered or identified applications running on the instrumented platform 100. The runtime monitor 102 may use the application artifacts 107 to generate attribute value assertions (e.g., assertions regarding one or more attribute values associated with each respective running application) to describe the application execution context 105 of the applications.

For example, the attestation service or apparatus may include a processing unit 135 for: (1) receiving remote from the computing platform 101, a runtime execution context 105 indicating attributes of the application at runtime, and a security context 111 providing security information about the application; (2) generating a report 117 indicating security risks associated with the application based on the received runtime execution context 105 and the received security context 111, as an attestation result; and/or (3) sending the attestation result associated with the application; and a memory 145 for storing the generated report.

As a second example, the runtime monitor or monitoring apparatus may include: a processing unit 130 (e.g., a processor shared with the computing platform 101 or a separate processor) for: (1) generating a runtime execution context 105 indicating attributes of the application at runtime; (2) sending the runtime execution context 105 to the attestation service or server 109; (3) receiving an application artifact 107 for tracking subsequent changes to the runtime execution context 105; and/or (5) updating and sending using the application artifact 107, the runtime execution context 105, as an updated execution context, responsive to the attributes of the application indicating a change; and a memory 140 for storing the application artifact 107.

The application artifact may include previous assertions or may provide an identifier that associates the application to the previous assertions. The application execution context 105 may include at least a base (or static), temporal (or dynamic) and/or environmental aspects or attributes of the target application. A requestor (for example, a network access enforcer 113, such as a network firewall, a load balancer, a VPN gateway, and/or an identity provider 112, such as an Security Token Service (STS), Single Sign On (SSO) solution may subscribe for application statements or reports 117 from the attestation broker 109.

In certain exemplary embodiments, the generation of attribute value assertions for the application execution context 105 by the runtime monitor 102 on the instrumented platform 100 may include, for example, the collection of file hash digests and/or file attributes (e.g., file size, publisher details, creation and/or modification timestamps, digital signings, and product versions) for loaded (e.g., all loaded and/or in process) components of the running target application 103 or 104. The application execution context 105 may include parent-child process associations and/or loader dependencies, information about active listening and/or open network ports that are well known or ephemeral. The application execution context 105 may also include the executable file binaries. The runtime monitor 102 may generate and report the collection in a digitally-signed report to the attestation broker 109 in an application execution context notification.

In certain exemplary embodiments, as an outcome of (or based on) the evaluation of the running target application 103 or 104 on the target instrumented platform 100 using collaboration services 110, the attestation broker 109 may issue application statements or reports 117 via application statement notification 118. The issued application statements or reports 117 may be digitally-signed, and may include a name of the application instance (e.g., a globally unique security principal name of the application instance or other application identifier), as its application identifier. The application instance may be a user program or a service program. One example of such a name may be "service/hostname@realm".

The application statements or reports 117 may include attribute value assertions that may describe the runtime execution context 105 and application security context 111 of the application instance on the instrumented platform 100, as a machine identifier. The application identifier may be a publisher designated product name or a registered service principle name in a services directory. The machine identifier may be an IPv4/IPv6 address, a directory network services (DNS) hostname, a MAC address, a serial number (e.g., an IT or manufacturer issued serial number), an RFID, and/or other device identifiers, among others. The attestation broker 109 may provide to the requestor 112, 113 or 114, a confidence metric that may include one or more ratings (e.g., application confidence ratings for the targeted application).

The confidence metric may, for example, be classified based on: (1) the vulnerability of the application, (2) compliance of the application, (3) referential integrity of the application, and/or (4) patch level of the target application. These ratings may be determined by the attestation broker 109 based on communications or interactions with one or more of the plurality of collaboration services 110. The confidence metrics may include a value for each classification and/or an overall value, which is weighed by classification or averaged. The weighing may be predetermined, preset or determined based on user input. The confidence metrics may be a numerical representation of the evaluation of one or more of the collaborative services 110.

In certain exemplary embodiments, the application statements or reports 117 may be used by passive clients 116 (for example, a web browser) to render an icon or other indicator (either visual on the web page or audio indicator, for example, an icon at the bottom of the web page). The indicator may be an indicator (or an attestation) of the web application's authenticity to the user 115. For example, the user 115 may click on the attestation icon to view web application specific

information issued by the attestation broker **109** for the accessed web application. The attestation broker **109** may be a third party independent and trusted entity that provides such attestation services. The user **115** may confirm that the application attestation offered by the attestation broker **109** is current (e.g., that the lifetime of the application attestation has not expired).

The user **115** or access requestor **114** (e.g., the computing platform of the user) may ascertain from the attestation broker **109** that the application statements or reports (or claims **117** represent a recently (e.g., a most recent) verified contextual assessment of the accessed web application based on timestamps and/or message sequencing in the application statements **117**. The determination that the claims represent the most recent verified contextual assessment may be based on consolidating information collected via one or more of a plurality of collaboration services **110**.

The application statements or reports **117** may be received and may be interpreted by one or more network access enforcers **113** (e.g., network firewalls, load balancers, and/or VPN gateways, among others), one or more identity providers **112** (e.g., STS, and/or SSO services, among others) and/or active clients **116** (e.g., Simple Authentication and Security Layer (SASL) enabled client-server and/or peer-to-peer applications, among others) to leverage contextual information about the target application **103** or **104** on the instrumented platform **100**.

The runtime monitor **102** may discover, may identify and may track process starts (e.g., all process starts), process terminations (e.g., all process terminations) and network epochs (e.g., socket events) of applications on the operating system **120** of the instrumented platform **100**. The local execution context of the running application may be determined at runtime and may be reported as attribute value assertions over a communication channel **106** to the attestation broker service **109**.

In certain exemplary embodiment, the communication channel **106** may be a secure communication channel and/or the communication may be secured via known encryption/decryption methods. The attestation broker **109** may request introspection based security context (for example, evaluations and behavioral or predictive analytics based on historic state information and measurements sampled over a period of time using a variety of inspection methods) for the running application on the instrumented platform **100** from one or more of the plurality of collaboration services **110**.

In certain exemplary embodiments, the collaboration services **110** may perform just-in-time inspection (e.g., an assessment scan) of the target application and platform **100**. The collaboration service **110** may lookup the most recent inspection report based on, for example, an IT service management schedule and may return the requested attestations pertaining to the application execution context **105** to the requestor **112**, **113** or **114** or the user **115**.

The attestation broker **109** may generate and may return an application artifact **107** for the running application **103** or **104** to the runtime monitor **102**, as a reference for subsequent execution context change notifications **207** (see FIG. **2**) for the applications. Changes (e.g., any changes) in the running application's local execution context **105** may trigger an interaction with the attestation broker **109** (e.g., a communication by the runtime monitor **102** to the attestation broker **109**) to reissue the application statements or reports **117** for attestation of the targeted application having the changed local execution context. For example, when the hash of the targeted application changes or the file size of the targeted application changes, an updated attestation may be initiated by the runtime monitor **102** and provided by the attestation broker **109**. The attestation broker **109** may query one or more of the collaborative services **110** to determine the updated application statement or report **118** associated with the changed targeted application.

In certain exemplary embodiments, the attestation broker **109** may provide a single confidence value that represents the confidence (or risk) regarding the authenticity of the targeted application or a confidence metrics of a plurality of values based on different (e.g., independent) classifications. In other exemplary embodiments, the attestation broker **109** may provide the confidence metrics and other information in a standard format such that the requestors **112**, **113** and/or **114** or the runtime monitor **102** may analyze various attributes of the other information. For example, the runtime monitor **102** may store or may have access to application attestation policies and may compare the local execution context and application statement or report **117** with the attestation policies to determine whether the targeted application is authenticated for use by the requestor. The identity provider **112** may receive, for example, a web redirect from web application **103** to perform brokered authentication ceremonies to login a user (e.g., an interactive user) **115**.

In certain exemplary embodiments, the web application **103** may request via an application artifact request **106** an application artifact **107** from the attestation broker **109**. The web application **103** may include the received application artifact **107** in a web redirect to the identity provider **112**. The identity provider **112** may perform a back-channel query **118** to validate that the received application artifact **107** had been issued by the attestation broker **109** to ascertain the authenticity of the web application **103**. The identity provider **112** may then receive application statements or reports **117** for the web application **103**. A visual, audio or programmatic indication of application attestation may be provided to the access requestor **114** or user **115** via the access requestor **114**.

The interactive user **115** or requestor **114** may receive a visual or audio attestation of application authenticity, for example, in the form of a visual indicator or an icon on the login form. The attestation may be accepted or rejected before proceeding with any transaction with the web application **103** or the attestation may be automatically accepted after a predetermined or user specified time period, if not rejected by the user **115** or requestor **114**.

A network access enforcer **113** may subscribe with the attestation broker **109** for application statements or reports **117** and may discover a plurality of target applications **103** or **104** on a plurality of target machines or platforms **100**. The communication protocol for the communications **118** between the attestation broker **109** and the network access enforcer **113** may be any standards based protocol and message exchange data structures or schemas, such as for example: (1) Simple Object Access Protocol (SOAP); (2) Representational State Transfer (REST); or (3) Trusted Computing Group's (TCG's) Interface for Metadata Access Points (IF-MAP) specification, among others.

The attestation broker **109** may publish notifications with real time or near real-time application statements or reports **117** for the network access enforcer **113** to apply physical access controls (e.g., controls to physically enable access to or to block access to the targeted application). The determination to enable or disable physical access by the network access enforcer **113** may be based on attribute value assertions (e.g., in the transport layer) in application statements or records **117**. The attribute value assertions may include for

example, static (e.g., well known) and/or dynamic (e.g., ephemeral) network ports assigned to the target application **103** or **104**.

An active client application **116** and/or a server application **104** (e.g., using the Simple Authentication and Security layer (SASL) protocol) may request and/or use the received application statements or reports **117** programmatically for a mutual attestation handshake. For example, using SASL protocol such a mutual attestation handshake may be defined by an integrity exchange profile, before initiating an authentication handshake with proof of possession of credentials.

FIG. **2** is a schematic diagram illustrating a method of monitoring and attesting applications in a cloud computing environment in accordance with various exemplary embodiments.

Referring to FIG. **2**, an exemplary network **250** may include a runtime monitor **201**, an instrumented target platform **200**, an attestation broker **202**, a metadata database **210**, and/or a plurality of collaboration services **203**.

The runtime monitor **201** may discover, may inspect, may identify and/or may attest to the runtime execution of applications on the instrumented target platform **200**. The attestation broker **202** may issue application artifacts **206** based on a received application execution context (or application execution context change notification) **207** for registered application instances **204**. Responsive to the request from the runtime monitor **201**, or an access requestor **114** or user **115**, the attestation broker (or attestation server) **202** may initiate a query **205** of one or more of the plurality of collaboration services (or collaboration servers) **203**. The query **205** may include a search for a security context (e.g., an introspection based security context) for the target application.

In certain exemplary embodiments, the applications running on the instrumented target platform **200** may be verified using one or more of the collaboration services **203** for identification, based on an application execution context received from the runtime monitor **201** either directly or via the attestation broker **202**.

The runtime monitor **201** may inspect the execution context of processes on the instrumented target platform **200** for application epochs (e.g., process and/or socket events). Responsive to or after detection of application process start, a runtime application execution context (e.g., metadata) may be generated. The metadata may include: (1) the file hash digest, (2) file attributes (for example, the file size, the publisher details, the creation and/or the modification timestamps, the digital signing, and/or the product version) for loaded components of the running target application, (3) parent-child process associations, (4) loader dependencies, and/or (5) information about active listening and/or open network ports that may be well-known and/or ephemeral; and/or executable file binaries. The running application may be registered **204** by providing the generated application execution context to the attestation broker **202**.

In certain exemplary embodiments, the attestation broker **202** may verify the authenticity of the running application on the instrumented target platform **200** with the query **205**. The query **205** that may include the metadata collected from the runtime monitor **201** may be sent from the attestation broker **202** and received by one or more collaboration services **203**. The query **205** may request a security context for the running application that may indicate the level of risk (of confidence) associated with running the target application on the instrumented platform **200**.

The attestation broker **202** may generate a dynamically changing application artifact **206** which may be time sensitive and may be globally unique. The application artifact **206** may be based on the received application execution context and the attestation broker **202** may return the generated application artifact to the runtime monitor **201**. The runtime monitor **201** may inspect each of the running applications for state changes including, for example, active listening and open network ports (e.g., well-known and ephemeral) and/or terminations of the applications. These inspections may occur, for example, at the transport layer of the open systems interconnection (OSI) stack.

In certain exemplary embodiments, other types of state changes may be inspected, such as elements related to the execution context. Any contextual (state) changes may be notified in real time or near real time by an application execution context change notification **207** from the runtime monitor **201** to the attestation broker **202**. The attestation broker **202** may store persistent and/or transient state information (e.g., including metadata) in a local database or remote repository **210**, such as an IF-MAP Server, for example) for registered applications (e.g., each registered running application) on one or more of the plurality of instrumented target platforms **200**.

FIG. **3** is a schematic diagram illustrating another method of monitoring and attesting applications in the cloud computing environment in accordance with various exemplary embodiments.

Referring to FIG. **3**, an exemplary network **350** may include an interactive user **300**, an instrumented target platform **301**, a web application **302**, an identity provider **303**, an attestation broker **304** and collaboration services **305**. The web application **302** may interact with the attestation broker **304** for runtime multi-factor attestation of the web application **302**. The operational flow may enable a mechanism to apply, for example, at a post-connect phase of a session for authorization control on an intermediate node element in the control path.

The interactive user **300** may establish a physical connection over a network and may initiate an application access request **306** to commence or initiate a transaction with a web application **302** hosted on the instrumented target platform **301**.

In certain exemplary embodiments, the web application **302** may execute a code element (such as for example, a web servlet or other processing element) that may generate a runtime application execution context (e.g., metadata) and may automatically initiate a query **307** to the attestation broker **304** by sending the generated metadata of the runtime application execution context.

In certain exemplary embodiments, the attestation broker **304**, may verify the authenticity of the running web application **302** on the instrumented target platform **301** by sending a verification query **311** (e.g., real time or near-real time) of the received metadata to one or more of the collaboration services **305** and receiving from the queried collaboration services **305** an application security context **312**. The attestation broker **304** may generate an application artifact **308** and may send the application artifact to the web application **302**.

The web application **302** may include (for example, may embed, as a markup) the received application artifact **309** as an assertion (e.g., in a security assertion markup language (SAML or other common form of markup)) to the identity provider **303** which may use back-channel communications **310** with the attestation broker **304** to verify the application artifact **309**.

In certain exemplary embodiments, the attestation broker (or attestation server) **304** may request a collaboration service **305** for an introspection based security context for the running application.

In various exemplary embodiments, the identity provider **303** may initiate a direct interactive authentication sequence with an interactive user **300** in the associated domain (e.g., realm). The login form (or web page) displayed to the user **300** may include an application attestation **313**. The application attestation **313** may be in any perceivable indicator including an attestation icon for the accessed web application. For example, the attestation icon may include information about the web application **302**, such as, for example, the identity, the product version, the publisher, the modification timestamp, and/or the confidence metrics. The user **300** may determine whether the information including the confidence metrics information is acceptable to continue with the transaction (e.g., to use of the running target application) and may provide proof of possession of credentials **314** to authenticate the user **300** to the identity provider **303**.

Although user authentication is disclosed as occurring after the determination whether to continue the transaction to use the running application, it is contemplated that user authentication may occur at any stage of the login process and may occur prior to such a determination whether to use the running application.

In certain exemplary embodiments, values associated with the confidence metrics may be provided on a common scale (e.g., a scale of 1 to 10) and may be presented to the user **300** with a common visual scheme such as green to indicate a low risk for use of the target application, yellow to indicate a intermediate risk for use of the target application, and red to indicate a high risk for use of the target application.

In certain exemplary embodiments, the identity provider **303** may query **315** the attestation broker **304** to determine whether access to the web application **302**, based on an authorization profile configured for the attestation broker **304**, can be granted for the authenticated user **300** to transact data exchanges with the web application **302**.

In various exemplary embodiments, the identity provider **303** may return standards based authentication, attribute and/or authorization statements or reports **316** to the web application **302**. The web application **302** may selectively grant access to the user **300** for the target application on the instrumented platform **301** or may selectively block access by the user **300** to the target application on the instrumented platform **301** based on the application statements or reports **316** received from the attestation broker **304** and pre-established or system administrator established access or attestation policies.

The application statements or reports **316** may include, for example, information about the user's identity, one or more authentication factors such as password, PIN, smart card, among others, and preexisting roles in a user directory (for example, Active Directory, among others), a role based management system (for example, Oracle or SAP, among others) and/or a relational database (for example, MS-SQL, MySQL, or Oracle DB, among others). Access may also be granted or denied (blocked) based on a plurality of factors.

For example, the identity provider **303** may deny access to an authenticated user **300** based on the level of concern (e.g., high) in the confidence metrics for a specific classification (e.g., compliance). The level of concern for a classification of the confidence metrics may be expressed in user-to-application policy bindings provisioned for the attestation broker **304**. The outcome of the policy decision logic, at or external to the attestation broker **304**, may be returned to the web application **302**, as one or more application statements or reports.

The identity provider **303** may represent an intermediate single sign-on (SSO) entity (or function) that may use identity stores (or caches) to manage passwords and may perform authentication ceremonies on behalf of the user **300**. The authentication may be performed such that it is transparent to the user **300**.

FIG. **4** is a schematic diagram illustrating a further method of monitoring and attesting applications in a cloud computing environment in accordance with various exemplary embodiments.

Referring to FIG. **4**, an exemplary network **450** may include an instrumented target platform **400**, a runtime monitor **401**, an attestation broker **402**, collaboration services **403**, an interactive user **404**, and/or a network access enforcer **405**. The user **404** may establish a physical connection over network **450** and may initiate an application access request **411** to commence or initiate a transaction with a target application hosted on the instrumented target platform **401**.

Applications running on the instrumented target platform **400** may be inspected by the runtime monitor **401** for application execution context and state changes. The operational flow may be an exemplary mechanism to apply, during or at the connection establishment phase of a session (e.g., an Internet Protocol (IP) or non-IP session), authorization controls at an intermediate system or apparatus in the data path.

The runtime monitor **401** may inspect the instrumented target platform **400** for application epochs (e.g., process and/or socket events). Responsive to detection of an application process start by the run-time monitor **401**, the runtime monitor may generate a runtime application execution context (e.g., metadata), which may include, for example, the file hash digests and/or file attributes for loaded components of the running target application. The running target application may be registered by the runtime monitor **401** with the attestation broker **402** via a start notification **406** and the runtime application execution context (e.g., that may include the metadata) may be sent by the runtime monitor **401** to the attestation broker **402** via an application execution context change notification **408**. In certain exemplary embodiments, the notifications **406** and **408** may occur together.

In certain exemplary embodiments, the attestation broker **402** may verify the authenticity of the running application on the instrumented target platform **400** with a real time or near real time exchange **409** of the received metadata with one or more collaboration services **403** and the return of the application security context **410** based on the exchanged metadata. The attestation broker **402** may also request on or more collaboration services **403** to perform a static, dynamic and/or virtual execution analysis of the executable file binary, for example, by a malware analysis system.

In certain exemplary embodiments, the attestation broker **402** may remediate an instrumented target platform **400**, using manual or automated methods, in response to a requested analysis performed by one or more collaboration services **403**.

The attestation broker **402** may generate a dynamic application artifact (e.g., that may be globally unique and may be time-sensitive) **407** and may issue the application artifact **407** to the runtime monitor **401**. The runtime monitor **401** may inspect running applications on the instrumented target platform **400** for contextual (state) changes, including, for example, active listening and/or open network ports, (e.g., at the transport layer of the OSI stack), and terminations of applications.

In certain exemplary embodiments, other types of state changes may be inspected, such as elements related to the execution context. Contextual (or state) changes **408** (e.g., any contextual changes) may be notified in real time or near real time to the attestation broker **402**. The attestation broker

402 may store persistent and transient state information in a local database or remote repository 210 (see FIG. 2) for registered running applications on a plurality of instrumented target platforms 400.

A network access enforcer 405 may register or subscribe with the attestation broker 402 as a web service over a web services protocol interface 412:413 for notifications (e.g., publications) of application statements or reports (e.g., claims) for running applications (e.g., all running applications) on a plurality of instrumented target platforms 400. The attestation broker 402 may publish in real time or near real time, up-to-date application statements or reports 413 to a plurality of subscribers 405 or users 404. The application statements or reports may include (1) an application identifier such as a registered name (e.g., a globally unique service principle name), (2) a machine identifier, (3) a product identifier, (4) a product version, (5) active listening and/or open network ports, (6) network addresses used by the target application, and/or (7) confidence metrics based on security context assessments 410 performed by one or more collaboration services 403. The confidence metrics may be based on: (1) recent (e.g., the most recent) security context assessments performed by one of the collaboration services 403, (2) correlated data from different collaboration services 403, and/or (3) weighed averages associated with each security context assessment, among others.

The network access enforcer 405 may query the attestation broker 402 for user specific application bindings configured for the attestation broker 402 to determine authorization controls based on dynamic multi-factor application attestation, and real time (or near real time) confidence metrics based on the local execution context 408 and assessed security context 410. For example, the network access enforcer 405, such as a virtual or physical network firewall appliance, may deny access to an authenticated user based on the level of concern ("high") (for example, from a three level ranking system of "high", "medium" and "low") in the confidence metrics for a specific classification (e.g., patch level) as expressed in the user-to-application policy bindings provisioned for the attestation broker 402. Although a three level ranking system is illustrated, it is contemplated that ranking systems with more or less levels are possible.

FIG. 5 is a schematic diagram illustrating a method of monitoring and attesting a Simple Authentication and Security Layer (SASL) enabled client and server application in accordance with various exemplary embodiments.

Referring to FIG. 5, an exemplary network 550 may include a client application 500, a server application 501, an attestation broker 502, a collaboration service 503, and/or an application programming interface (API) library 516.

Although a Simple Authentication Security Layer (SASL) protocol is illustrated, it is contemplated that any application layer protocol between client-server and peer-to-peer applications, or network security protocols, for example IPSec Authenticated Internet Protocol (AuthIP) or Internet Key Exchange (IKE), may be extended and/or used to provide the functions of the client application 500 and the server application 501.

In certain exemplary embodiments, the client application 501 and the server application 501 may be statically or dynamically linked to the API library 516 (e.g., a Trust-as-a-Service (TAAS) API library). The API library 516 may implement a set of procedure calls for applications to exchange messages (e.g., opaque and/or secure messages) with an attestation service or broker 502 that may hide the implementation details from the higher level application.

Although one exemplary embodiment is illustrated for the API library 516, it is contemplated that any application framework may be extended to implement the set of procedure calls provided by the API library 516.

The server application 501 may send a runtime server application execution context 504, may request a server application artifact 505, and may receive the server application artifact 505 from the attestation service (e.g., the attestation broker or the attestation server) 502. The application execution context 504 may include the file hash digests and file attributes of components of the running server application 501 including parent-child process associations and loader dependencies.

The client application 500 may establish a network connection to the server application 501 and may initiate a profile exchange for authentication.

Subsequent to completing an authentication exchange (for example to authenticate the user associated with the client application 500), the client application 500 may send a runtime client application execution context 506 and may request a client application artifact 507 from the attestation broker or service or server 502. The client application execution context 506 may include the file hash digests and file attributes of components of the running client application 500 including parent-child process associations and loader dependencies. Responsive to or after receiving a client application artifact 507, the client application 500 may transmit the received application artifact (indicated as 508) to the server application 501. The server application 501 may send the received client application artifact 507 to the attestation server 502 for client artifact validation 509 and may request a client application statement or report 511 for the client application 500.

In certain exemplary embodiments, the attestation broker 502 may initiate a request 520 for an introspection based security context 510 for the client application 500 from one or more of the collaboration services 503. The requested collaboration services 503 may collect and may generate the client application security context 510 and may send the client application security context 510 to the attestation broker 502. The client application statement or report 511 may be generated by the attestation broker 502 from the client application security context 510 and may include assertions about the runtime execution context 504 and intelligence based security context 510 for the client application 500. Responsive to receiving the client application statement or report 511 from the attestation server 502, the server application 501 may determine whether the attestation of the client application 500 is adequate.

In certain exemplary embodiments, the confidence metrics may be included in the client application statements or reports 511 and may be analyzed, for example by the server application 501, to determine whether to transact data exchanges with the client application 500.

Upon or after receiving the client application statements 511 and determining to transact data exchanges with the client application 500, the server application 501 may transmit the received server application artifact (indicated as 512) to the client application 500. The client application 500 may send the received server application artifact 512 to the attestation server 502 for validation of the server artifact 513 and may request an application statement or report 515 for the server application 501.

In certain exemplary embodiments, the attestation broker 502 may initiate a request 519 for an introspection based security context 514 for the server application 501 from one or more of the collaboration services 503. The requested collaboration services 503 may collect and may generate the

server application security context **514** and may send the server application security context **514** to the attestation broker **502**. The server application statement or report **515** generated by the attestation broker **502** may include assertions about the runtime execution context and intelligence based security context for the server application **501**. Responsive to or after receiving the server application statement or report **515** from the attestation broker or service **502**, the client application **500** may determine whether the attestation of the server application **501** is adequate. In certain exemplary embodiments, the confidence metrics included in the server application statement may be analyzed, for example by the client application, to determine whether to transact data exchanges with the server application **501**.

Although confidence metrics included in the application statements may be analyzed by the requesting application, in certain exemplary embodiments, the API library **516** may provide standard and/or custom pluggable filters to normalize the classifications based confidence metrics such that a standard rating scale may be provided to each requesting application and the requesting application may predetermine settings for denying access to an application with a particular rating exceeding a risk threshold and/or granting access to the application with the particular rating equal to or not-exceeding the risk threshold. In certain exemplary embodiments, application at or near the risk threshold may be temporarily denied access pending further analysis based on additional collaborative services **503** or based on user of system administrator input granting or denying such access.

FIG. **6** is a schematic diagram illustrating an exemplary security administration console **650** including an integrity dashboard **600** in accordance with various exemplary embodiments of the invention.

Referring to FIG. **6**, the exemplary security administration console **650** may visually display the integrity dashboard or display window **600**. The integrity dashboard or display window **600** may include information fields including a dashboard clock **601**, discovered and identified applications **602**, service realms **603**, instrumented target platforms **604**, product vendors **605**, product versions **606**, active network service ports **607**, and confidence metrics **608**.

The information fields may be displayed and/or updated in real time or near real time. For example, the identified and attested application **602** running on the instrumented target platform **604**, service realms **603**, product vendors **605**, product versions **606**, current classifications based confidence metrics **608** and currently active network service ports **607** for the application may be displayed on an integrity dashboard **600** in near real time as indicated by the dashboard clock **601**. The dashboard **600** may include administrative controls (not shown) to create filters for perspective views, and issue security alerts based on a plurality of defined criteria and/or provide companion reporting services.

Although the integrity dashboard is shown with specific information fields and in a particular arrangement, it is contemplated that other information fields and arrangements are possible. For example, additional attributes included in the application statements or reports or other network management information available from network management systems may also be displayed.

FIG. **7** is a schematic diagram illustrating another exemplary policy administration console **750** including an authorization dashboard **700** in accordance with various exemplary embodiments of the invention.

Referring to FIG. **7**, the authorization dashboard or controls window **700** may include information fields provisioned and parsed by for example a cloud client (or tenant) **701** and may include users **702**, roles **703**, authentication realms **704**, authentication types **705**, instrumented service hosts (or target platforms) **706**, service realms **707**, identified and attested applications **708**, product versions **709** and/or product vendors **710**.

The authorization dashboard **700** for each cloud client **701** may include a plurality of policy components (or rules) for defining a policy (or rule set) for the user **702**, a plurality of users, roles **703** or a plurality of roles and an attested application instance **707**:**708**. The dashboard **700** may include administrative controls (not shown) to create filters for perspective views, and issue security alerts based on a plurality of defined criteria and/or provide companion reporting services. The filters may enable, for example, filtering of an authenticated user by an authentication type (or authentication method) **705** for a runtime access control decision. Each row of the illustrated authorization dashboard **700** includes information fields (e.g., contents) that may represent (or correspond to) a statement of policy created by the system administrator for the cloud client **701**.

In certain exemplary embodiments, federation of services across different hosting realms may be displayed such that a user authenticated in one authentication domain (or realm) may be provisioned with policy based access to an application hosted in a different target services domain (or realm).

In certain exemplary embodiments, the attestation broker **102**, for example, may be configured to service requests for application artifacts and application statements across a plurality of hosting realms.

Although the integrity and authorization dashboard is shown with specific information fields and in a particular arrangement, it is contemplated that other information fields and arrangements are possible and that these dashboards may be parsed using any one of the information fields to generate a different perspective view.

The access control policies created by the system administrator of the cloud client using the authorization dashboard (or console) may be based on runtime context-aware logical attributes pertaining to an attested running application instance such that the contextual information for the attestation may include the runtime local execution context and an introspected security context. There are no physical constraints wherein rules may require network topology based static attributes, including at least one of: an IPv4/IPv6 address, a port number, a MAC address, a network identifier, a subnet, a VLAN identifier, or combinations or variants thereof.

Although various embodiments have been described in terms of creating context-aware policies in a cloud environment, it is not limited thereto. The methods may be carried out, for example, between any numbers of computer systems maintaining secure transactions among themselves.

FIG. **8** is a flowchart illustrating a method **800** in accordance with various exemplary embodiments.

Referring to FIG. **8**, the method **800** may provide an attestation service or broker **109** for an application at runtime executing on a computing platform **101** using an attestation server **109**. At block **810**, the attestation server **109** remote from the computing platform **101** may receive: (1) a runtime execution context **105** indicating attributes of the application at runtime, and (2) a security context **111** providing security information about the application. At block **820**, the attestation server **109** may generate a report **117** indicating security risks associated with the application based on the received runtime execution context **105** and the received security con-

text **111**, as an attestation result. At block **830**, the attestation server **109** may send the attestation result associated with the application.

In certain exemplary embodiments, at block **830**, the attestation server **109** may also send an automated remediation request to a collaboration service **110** (for example, an orchestration service) to initiate operations on an instrumented platform **100** (for example, to reimage, snapshot or quarantine the instrumented platform) based on the attestation result associated with one or more applications (**103**, **104**).

In certain exemplary embodiments, the attestation server **109** may generate an application artifact **108** as a reference for changes in a subsequent execution context **105** and may send the generated application artifact **108** such that subsequent changes to the runtime execution context **105** are tracked based on the generated application artifact **108**.

In certain exemplary embodiments, the attestation results and the application artifact **108** may be digitally signed.

In certain exemplary embodiments, the received security context **111** may be an introspective security context and the attestation server **109** may generate one or more security assertions that pertain to the received runtime execution context **105** and the received introspective security context **111**.

In certain exemplary embodiments, a user's transaction with the application may be controlled by applying a set of authorization rules in accordance with the attestation results. In these and other exemplary embodiments, a user's network access to the application may be controlled based on the set of authorization rules and the attestation results.

In certain exemplary embodiments, confidence metrics in the attestation results may be provided which indicate a level of security risk by different classifications such that a restriction on a user's transaction with the application may be applied based on the level of security risk indicated by the confidence metrics in the attestation results.

In certain exemplary embodiments, the restriction on the user's transaction may include the application of routing decisions and the redirection of the user to an alternate computer platform.

FIG. **9** is a flowchart illustrating a method **900** in accordance with various exemplary embodiments.

Referring to FIG. **9**, the method **900** may provide an attestation service for an application at runtime executing on a computing platform **101** using a runtime monitor **102**. At block **910**, the runtime monitor **102** at the computing platform **101** may generate a runtime execution context **105** indicating attributes of the application at runtime. At block **920**, the runtime monitor **102** may send the runtime execution context **105** to the attestation server **109**. At block **930**, the runtime monitor may receive an application artifact **107** for tracking subsequent changes to the runtime execution context **105**. At block **940**, the runtime monitor **102** using an application artifact **107** may update and may send the runtime execution context **105**, as an updated execution context, responsive to the attributes of the application indicating a change.

In certain exemplary embodiments, the generation of the runtime execution context **105** may include the runtime monitor **102** inspecting running application processes on the computing platform **101** and generating metadata that includes at least a local runtime execution context.

FIG. **10** is a flowchart illustrating a method **1000** in accordance with various exemplary embodiments.

Referring to FIG. **10**, the method **1000** may provide mutual attestation for first and second interrelated applications **500** and **501** at runtime using an attestation server **502**. The first application **500** may run on a first computing platform **530** and the second application **501** may run on a second computing platform **531**. At block **1010**, the attestation server **502** remote from the first and second computing platforms **530** and **531** may receive a first runtime execution context **506** of the first application **500** indicating attributes of the first application **500** at runtime and a second runtime execution context **504** of the second application **501** indicating attributes of the second application **501** at runtime. At block **1020**, the attestation server **502** may generate: (1) a first report **515** indicating security risks associated with the first application **500** based on the received first runtime execution context **506**, as a first attestation result; and (2) a second report **511** indicating security risks associated with the second application **501** based on the received second runtime execution context **504**, as a second attestation result. At block **1030**, the attestation server **502** may send the first attestation result associated with the first application **500** to the second computing platform **531** and the second attestation result associated with the second application **501** to the first computing platform **530** for mutual attestation.

In certain exemplary embodiments, a web browser may render an icon indicating that the first attestation result has been sent and responsive to user selection of the icon, may render the attestation result about the first application which is a web application accessed via the web browser.

In certain exemplary embodiments, the attestation server **502** may generate a first application artifact **507** as a reference for changes in a subsequent execution context of the first application **500** and a second application artifact **505** as a reference for changes in a subsequent execution context of the second application **501**; and may send the generated application artifacts **507** and **505** such that subsequent changes to the first and second runtime execution contexts **506** and **504** may be tracked in the first and second interrelated applications **500** and **501** based on the generated first and second application artifacts **507** and **505**, respectively.

In certain exemplary embodiments, access by a requestor, for example a user **115**, to the first application **500** may be controlled based on the first attestation results and independently based on the second attestation results.

FIG. **11** is a flowchart illustrating a method of providing attestation of a running application in accordance with various exemplary embodiments.

Referring to FIG. **11**, the method **1100** may provide attestation of a running application (e.g., web or non-web applications). At block **1110**, the attestation server **402** may register subscriptions for a plurality of subscribers **412** or users **300** for context change notifications **408** of the running application. At block **1120**, the attestation service or server **402** may generate assertions about the running application. At block **1130**, the attestation service or server **402** may send to the plurality of subscribers **412** or users **300**, the assertions of the running application in response to reception of the context change notification **408**. The assertions may include at least confidence metrics indicating a level of security risk of the running application.

FIG. **12** is a flowchart illustrating a method **1200** in accordance with various exemplary embodiments.

Referring to FIG. **12**, the method **1200** may provide mutual attestation of applications in client-server or peer-to-peer transactions using an attestation server. At block **1210**, the attestation server **502** may generate (1) a first application artifact **507** for tracking changes in a runtime execution context **506** associated with a client **530** in the client-server transaction, and (2) a second application artifact **505** associated with a server **531** in the client-server transaction. At block **1220**, the attestation server **502** may send the first

application artifact **507** to the client **530** and the second application artifact **505** to the server **531**. At block **1230**, the first and second application artifacts **507** and **505** may be exchanged such that the client **530** and the server **531** each have the first and second application artifacts **507** and **505** to mutually track changes in runtime execution contexts **506** and **504** associated with the client **530** and the server **531** for client server transactions.

Although a client-server transaction between a client and a server is shown, it is contemplated that mutual attestation may be provided by an attestation server between first and second peers or among first, second and/or further peers in a peer-to-peer environment.

FIG. **13** is a flowchart illustrating a method **1300** in accordance with various exemplary embodiments.

Referring to FIG. **13**, the method **1300** may provide mutual attestation of applications in client-server or peer-to-peer transactions using an attestation server. At block **1310**, the attestation server **502** may generate and send a first application artifact **507**. At block **1320**, the attestation server **502** may receive and validate from a server **531** in the client-server transaction, the first application artifact **507** sent by the attestation server **502** to a client **530** in a client server transaction. At block **1330**, the attestation server **502** may generate and send application statements **511** and **515** to the client **530** and the server **531** about interrelated applications **500** and **501** used in the client-server transaction. For example, the sending of the application statements **511** and **515** to the client **530** and the server **531** may include: sending by the attestation server **502**: (1) the application statement **511** regarding a client application **500** of the interrelated applications **500**:**501** to the server **531** of the client-server transaction and the application statement **515** regarding a server application **501** of the interrelated applications **500**:**501** to the client **530** of the client-server transaction.

In certain exemplary embodiments, the attestation server **502** may generate and send a second application artifact **505**, may receive the second application artifact **505** from a client **530** in the client server transaction and may validate the second application artifact **505** sent by the attestation server **502** to a server **531** in a client server transaction.

In certain exemplary embodiments, a method of providing attestation services for applications at runtime may include one or more of the following steps: hosting, by an instrumented target platform, a target user or service program; generating, by an application attestation service: (1) a globally unique, opaque, time-sensitive application artifact; and (2) at least one application statement including a plurality of assertions pertaining to an inspection based runtime local execution context and an introspection based security context; inspecting, by a runtime monitor, running application processes on the instrumented target platform; generating, by the runtime monitor, metadata that includes at least the runtime local execution context; authenticating, by an identity provider, a user to a web application; providing an attestation of the local execution and introspected security context of the web application based on a web services request; controlling, by a network access enforcer, access of an authenticated user to a target application using a subscription based application attestation service; and/or providing, by a collaboration service, the introspected based security context for the target application running on the instrumented target platform.

In certain exemplary embodiments, a method for providing attestation of the authenticity of a running web application or web servlet may include one or more of the following steps: requesting an application artifact for a running web application or servlet instance; establishing a secure channel between the web server and the attestation server; generating at least one hash file digest corresponding to the execution context of the web application or servlet instance; determining at least one file attribute corresponding to at least one element or the execution context of the web application or web servlet instance; sending an application report to an identity provider; generating assertions based on a received security context and a received local execution context; transmitting confidence metrics in the report to the identity provider; and/or providing attestation of the running web application or web servlet as a digital icon for rendering by a web browser.

In certain exemplary embodiments, the attestation may be provided prior to (1) commencing any data exchange in an established connection with a user; and/or (2) establishing a network connection with a user.

In certain exemplary embodiments, the rendering of attestation information about a web application to be accessed may be responsive to user input.

In certain exemplary embodiments, a system for continuously monitoring running applications hosted on self-managed and on-premise, or on outsourced service provider managed infrastructure may include one or more of the following: an instrumented target platform for hosting a target user or service program; an application attestation service for generating a globally unique, opaque, and time-sensitive application artifact and application statements including a plurality of assertions pertaining to inspection based runtime local execution context and introspection based security context; a runtime monitor for discovering, identifying and inspecting running application processes on the instrumented target platform and for generating metadata that includes at least the runtime local execution context; a collaboration service to provide introspected security context for a target application running on the instrumented target platform; and/or a graphical user interface for: (1) requesting and receiving dynamic assertions from a metadata repository of the attestation service, the dynamic assertions pertaining to the local execution context the introspected security context of running application instances on instrumented target platforms; (2) for continuously displaying the dynamic assertions to a system administrator; and for provisioning and dispatching alerts based on the dynamic assertions and predefined criteria.

In certain exemplary embodiments, the network access enforcer may subscribe for and receives dynamic application statements from the attestation service to analyze the contextual assertions and to determine whether an authenticated user is permitted or denied network access to an attested application instance.

In certain exemplary embodiments, the graphical user interface may display the applications running on instrumented target platform on a client specific dashboard or portal, and may present for each associated application execution context at least one of: (1) a service hostname; (2) a service realm; (3) a service principal name; (4) a product version; (5) product vendor; (6) one or more classifications based confidence metrics; or (7) an active network service port.

In certain exemplary embodiments, the identity provider may query for dynamic application statements from the attestation server to analyze the contextual assertions and to determine whether an authenticated user is permitted or denied authorization to transact data exchanges with an attested application instance in an established connection.

In certain exemplary embodiments, the network access enforcer may analyze classifications based confidence metrics included in received dynamic application statements, based on a subscription, from the attestation service to deter-

mine whether an authenticated user is permitted or denied network access to an attested application instance.

In certain exemplary embodiments, the identity provider may analyze classifications based confidence metrics included in received dynamic application statements, based on a subscription, from the attestation service to determine whether an authenticated user is permitted or denied authorization to transact data exchanges with an attested application instance in an established connection.

In certain exemplary embodiments, a method for creating context-aware policies for network connections or data exchange transactions between authenticated users and attested running applications hosted on self-managed and on-premise, or on outsourced service provider managed infrastructures may include one or more of the following steps: hosting, by an instrumented target platform, a target user or service program; generating, by an application attestation service, a globally unique, opaque, and time-sensitive application artifact and application statements comprising of a plurality of assertions pertaining to inspection based runtime local execution context and introspection based security context; discovering, identifying and inspecting, by a runtime monitor, running application processes on the instrumented target platform generate, by a runtime monitor, metadata that includes at least the runtime local execution context; authenticating, by an identity provider, a user to a web application based on a web services request to provide attestation of the local execution and introspected security context of the web application; controlling, by a network access enforcer, access of an authenticated user to a target application using the application attestation service that is subscription based; providing, by a collaboration service, an introspected security context for the target application running on the instrumented target platform; and/or creating, using a graphical user interface, access control rules for users annotated by a distinguished name in a user directory or database, and applications annotated by a registered globally unique security principal name.

In certain exemplary embodiments, context-aware access control policies may be created that stipulate acceptable thresholds for authorizations on the basis of dynamic classifications based confidence metrics.

Although exemplary embodiments have been described in terms of a computing device or instrumented platform, it is contemplated that it may be implemented in software on microprocessors/general purpose computers such as the computer system **1400** illustrated in FIG. **14**. In various embodiments, one or more of the functions of the various components may be implemented in software that controls a computing device, such as computer system **1400**, which is described below with reference to FIG. **14**.

Aspects of the present invention shown in FIGS. **1-13**, or any part(s) or function(s) thereof, may be implemented using hardware, software modules, firmware, non-transitory computer readable media having instructions stored thereon, or a combination thereof and may be implemented in one or more computer systems or other processing systems.

FIG. **14** illustrates an example computer system **1400** in which embodiments of the present invention, or portions thereof, may be implemented as computer-readable code. For example, network systems **150**, **250**, **340**, **450** and **550** of FIGS. **1-5**, can be implemented in computer system **1400** using hardware, software, firmware, non-transitory computer readable media having instructions stored thereon, or a combination thereof and may be implemented in one or more computer systems or other processing systems. Hardware, software, or any combination of such may embody any of the modules and components used to implement the network systems of FIGS. **1-5**.

If programmable logic is used, such logic may execute on a commercially available processing platform or a special purpose device. One of ordinary skill in the art may appreciate that embodiments of the disclosed subject matter can be practiced with various computer system configurations, including multi-core multiprocessor systems, minicomputers, mainframe computers, computers linked or clustered with distributed functions, as well as pervasive or miniature computers that may be embedded into virtually any device.

For instance, at least one processor device and a memory may be used to implement the above described embodiments. A processor device may be a single processor, a plurality of processors, or combinations thereof. Processor devices may have one or more processor "cores."

Various embodiments of the invention are described in terms of this example computer system **1400**. After reading this description, it will become apparent to a person skilled in the relevant art how to implement the invention using other computer systems and/or computer architectures. Although operations may be described as a sequential process, some of the operations may in fact be performed in parallel, concurrently, and/or in a distributed environment, and with program code stored locally or remotely for access by single or multiprocessor machines. In addition, in some embodiments the order of operations may be rearranged without departing from the spirit of the disclosed subject matter.

Processor device **1404** may be a special purpose or a general purpose processor device. As will be appreciated by persons skilled in the relevant art, processor device **1404** may also be a single processor in a multi-core/multiprocessor system, such system operating alone, or in a cluster of computing devices operating in a cluster or server farm. Processor device **1404** is connected to a communication infrastructure **1406**, for example, a bus, message queue, network, or multi-core message-passing scheme.

Computer system **1400** also includes a main memory **1408**, for example, random access memory (RAM), and may also include a secondary memory **1410**. Secondary memory **1410** may include, for example, a hard disk drive **1412**, removable storage drive **1414**. Removable storage drive **1414** may comprise a floppy disk drive, a magnetic tape drive, an optical disk drive, a flash memory, or the like.

The removable storage drive **1414** reads from and/or writes to a removable storage unit **1418** in a well known manner. Removable storage unit **1418** may comprise a floppy disk, magnetic tape, optical disk, etc. which is read by and written to by removable storage drive **1414**. As will be appreciated by persons skilled in the relevant art, removable storage unit **1418** includes a non-transitory computer usable storage medium having stored therein computer software and/or data.

In alternative implementations, secondary memory **1410** may include other similar means for allowing computer programs or other instructions to be loaded into computer system **1400**. Such means may include, for example, a removable storage unit **1422** and an interface **1420**. Examples of such means may include a program cartridge and cartridge interface (such as that found in video game devices), a removable memory chip (such as an EPROM, or PROM) and associated socket, and other removable storage units **1422** and interfaces **1420** which allow software and data to be transferred from the removable storage unit **1422** to computer system **1400**.

Computer system **1400** may also include a communications interface **1424**. Communications interface **1424** allows software and data to be transferred between computer system

1400 and external devices. Communications interface 1424 may include a modem, a network interface (such as an Ethernet card), a communications port, a PCMCIA slot and card, or the like. Software and data transferred via communications interface 1424 may be in the form of signals, which may be electronic, electromagnetic, optical, or other signals capable of being received by communications interface 1424. These signals may be provided to communications interface 1424 via a communications path 1426. Communications path 1426 carries signals and may be implemented using wire or cable, fiber optics, a phone line, a cellular phone link, an RF link or other communications channels.

In this document, the terms "computer program medium," "non-transitory computer readable medium," and "computer usable medium" are used to generally refer to media such as removable storage unit 1418, removable storage unit 1422, and a hard disk installed in hard disk drive 1412. Signals carried over communications path 1426 can also embody the logic described herein. Computer program medium and computer usable medium can also refer to memories, such as main memory 1408 and secondary memory 1410, which can be memory semiconductors (e.g. DRAMs, etc.). These computer program products are means for providing software to computer system 1400.

Computer programs (also called computer control logic) are stored in main memory 1408 and/or secondary memory 1410. Computer programs may also be received via communications interface 1424. Such computer programs, when executed, enable computer system 1400 to implement the present invention as discussed herein. In particular, the computer programs, when executed, enable processor device 1404 to implement the processes of the present invention, such as the stages in the methods illustrated by the flowcharts 800, 900, 1000, 1100, 1200 and 1300 of FIGS. 8-13, discussed above. Accordingly, such computer programs represent controllers of the computer system 1400. Where the invention is implemented using software, the software may be stored in a computer program product and loaded into computer system 1400 using removable storage drive 1414, interface 1420, and hard disk drive 1412, or communications interface 1424.

Embodiments of the invention also may be directed to computer program products comprising software stored on any computer useable medium. Such software, when executed in one or more data processing device, causes a data processing device(s) to operate as described herein. Embodiments of the invention employ any computer useable or readable medium. Examples of computer useable mediums include, but are not limited to, primary storage devices (e.g., any type of random access memory), secondary storage devices (e.g., hard drives, floppy disks, CD ROMS, ZIP disks, tapes, magnetic storage devices, and optical storage devices, MEMS, nanotechnological storage device, etc.), and communication mediums (e.g., wired and wireless communications networks, local area networks, wide area networks, intranets, etc.).

It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections, is intended to be used to interpret the claims. The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present invention as contemplated by the inventor(s), and thus, are not intended to limit the present invention and the appended claims in any way.

Embodiments of the present invention have been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range equivalents of the claims and without departing from the invention.

What is claimed is:

1. A method of providing an attestation service for an application at runtime executing on a computing platform using an attestation server, comprising:

receiving, by the attestation server remote from the computing platform:

a runtime execution context indicating attributes of the application at runtime, wherein the attributes comprise one or more executable file binaries of the application and loaded components of the application; and

a security context providing security information about the application, wherein the security information comprises an execution analysis of the one or more executable file binaries and the loaded components;

generating, by the attestation server, a report indicating security risks associated with the application based on the received runtime execution context and the received security context, as an attestation result; and

sending, by the attestation server, the attestation result associated with the application.

2. The method of claim 1, further comprising:

generating, by the attestation server, an application artifact as a reference for changes in a subsequent execution context; and

sending the generated application artifact such that subsequent changes to the runtime execution context are tracked based on the generated application artifact.

3. The method according to claim 2, further comprising digitally signing the attestation results,

wherein the attributes further comprise parent-child process associations of the application.

4. The method of claim 1, wherein the received security context is an introspective security context, and wherein the execution analysis is a static, dynamic, or virtual analysis of the one or more executable file binaries and the loaded components.

5. The method of claim 4, wherein the generating of the report indicating security risks associated with the application includes generating, by the attestation server, one or more security assertions that pertain to the received runtime execution context and the received introspective security context.

6. The method according to claim 1, further comprising authenticating the application using a plurality of collaboration services.

7. The method according to claim 1, further comprising controlling a user's transaction with the application by applying a set of authorization rules in accordance with the attestation results.

8. The method according to claim 1, further comprising controlling a user's network access to the application by applying a set of authorization rules in accordance with the attestation results.

9. The method according to claim 1, further comprising providing confidence metrics in the attestation results indicating a level of security risk by different classifications such that a restriction on a user's transaction with the application are applied based on the level of security risk indicated by the confidence metrics in the attestation results.

10. The method according to claim 9, wherein the application of the restriction on the user's transaction includes applying the restriction on the user's network access to the application.

11. The method according to claim 1, wherein the application of the restriction on the user's transaction includes applying routing decisions and redirecting the user to an alternate computer platform.

12. The method according to claim 1, further comprising controlling, by a network access enforcer, access of a user to the application based on the attestation result.

13. A non-transitory computer readable medium having instructions stored thereon that, if executed by a computing device, cause the computing device to perform operations for providing mutual attestation of applications in client-server or peer-to-peer transactions using an attestation server, the operations comprising:

generating and sending, by the attestation server, a first application artifact that dynamically and opaquely identifies:

an instance of a first application; and

a record of a current execution state of the first application;

receiving and validating, by the attestation server, from a server in the client server transaction or from a first peer in the peer-to-peer transaction, the first application artifact sent by the attestation server to a client in a client server transaction or to a second peer in the peer-to-peer transaction;

generating and sending application statements to the client and the server or the first and second peers about interrelated applications used in the client-server or peer-to-peer transactions.

14. The computer readable medium of claim 13, the operations further comprising:

generating and sending, by the attestation server, a second application artifact that dynamically and opaquely identifies:

an instance of a second application; and

a record of a current execution state of the second application;

receiving and validating, by the attestation server, from a client in the client server transaction or from a second peer in the peer-to-peer transaction, the second application artifact sent by the attestation server to a server in a client server transaction or to a first peer in the peer-to-peer transaction.

15. The computer readable medium of claim 14, wherein:

sending the application statements comprises the following operations:

sending, by the attestation server:

an application statement regarding a client application of the interrelated applications to the server of the client-server transaction and the application statement regarding a server application of the interrelated applications to the client of the client-server transaction; or

an application statement regarding a first peer application of the interrelated applications to the second peer of the peer-to-peer transaction and the application statement regarding a second peer application of the interrelated applications to the first peer of the peer-to-peer transaction; and

determining, based at least in part upon the sent application statements, whether or not to exchange data with associated applications.

16. The computer readable medium of claim 15, wherein:

generating the application statements comprises including confidence metrics and contextual assertions in the application statements; and

determining includes:

comparing respective confidence metrics to a set of rules; and

determining whether or not to exchange data based on the comparison.

17. A method for providing attestation of the authenticity of a running web application or web servlet using an attestation server, comprising:

requesting an application artifact that is a dynamic, opaque reference to a running web application or servlet instance;

establishing a secure channel between the web server and the attestation server;

generating at least one digital signature corresponding to the execution context of the web application or servlet instance;

determining at least one parent-child process association corresponding to the execution context of the web application or web servlet instance;

sending an application report to an identity provider;

generating assertions based on a received security context and a received local execution context;

transmitting confidence metrics in the report to the identity provider; and

providing attestation of the running web application or web servlet as a digital icon for rendering by a web browser.

18. The method according to claim 17, wherein the providing is prior to commencing any data exchange in an established connection with a user.

19. The method according to claim 17, wherein the providing is prior to establishing a network connection with a user.

20. The method according to claim 19, further comprising rendering attestation information about the web application to be accessed responsive to user input.

21. A system for continuously monitoring running applications hosted on self-managed and on-premise, or on outsourced service provider managed infrastructure comprising:

an instrumented target platform for hosting target, running applications;

an application attestation service for:

generating globally unique, opaque, and time-sensitive application artifacts identifying records of current execution states and application statements for the target, running applications including a plurality of assertions pertaining to inspection based runtime local execution context and introspection based security context; and

remediating the instrumented target platform, wherein the remediating includes one or more of: a reimage, a snapshot, or a quarantine of the instrumented target platform;

a runtime monitor for;

discovering, identifying and inspecting running application processes on the instrumented target platform, wherein the discovering includes analysis of executable file binaries of the target, running applications; and

generating metadata that includes at least the runtime local execution context;

a collaboration service configured to:

provide introspected security context for the target, running applications on the instrumented target platform; and

analyze executable file binaries for the target application running on the instrumented target platform; and

a graphical user interface configured to:

request and receive dynamic assertions from a metadata repository of the attestation service, the dynamic assertions pertaining to the local execution context or the introspected security context of running application instances on the instrumented target platform;

continuously display the dynamic assertions; and

provision and dispatch alerts based on the dynamic assertions and predefined criteria.

22. The system according to claim **21**, further comprising a network access enforcer configured to:

subscribe to and receive dynamic application statements including contextual assertions from an attestation service;

analyze the contextual assertions; and

determine whether or not an authenticated user is permitted to access an attested application instance via a network.

23. The system according to claim **21**, wherein the graphical user interface is further configured to:

display the applications running on the instrumented target platform in a client specific dashboard or portal, and

present, for each associated application execution context, at least one of:

a service hostname;

a service realm;

a service principal name;

a product version;

a product vendor;

one or more classification-based confidence metrics;

an active network service port; or

executable file binaries.

24. The system according to claim **21**, further comprising an identity provider configured to:

query for dynamic application statements from the attestation server including contextual assertions;

analyze the contextual assertions; and

determine whether or not an authenticated user is authorized to exchange data with an attested application instance via an established connection.

25. The system according to claim **21**, further comprising a network access enforcer configured to:

analyze classifications based confidence metrics included in received dynamic application statements, based on a subscription, from an attestation service; and

determine whether or not an authenticated user is permitted to access an attested application instance via a network.

26. The system according to claim **21**, further comprising an identity provider configured to:

analyze classification-based confidence metrics included in received dynamic application statements, based on a subscription, from an attestation service; and

determine whether or not an authenticated user is authorized to exchange data with an attested application instance via an established connection.

* * * * *