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(54) METHODS AND COMPUTER PROGRAM PRODUCTS FOR MONITORING AND REPORTING PERFORMANCE OF NETWORK APPLICATIONS EXECUTING IN OPERATING-SYSTEM-LEVEL VIRTUALIZATION CONTAINERS

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G06F 11/34	(2006.01)
G06F 9/455	(2006.01)

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

CPC ***G06F 11/3495*** (2013.01); ***G06F 9/45558*** (2013.01); ***G06F 11/3419*** (2013.01); *G06F 11/3409* (2013.01); *G06F 2009/45595* (2013.01); *G06F 2201/815* (2013.01)

USPC **709/224**; 709/202; 709/223; 700/9; 700/17; 718/1; 719/331

(58) **Field of Classification Search**

None

See application file for complete search history.

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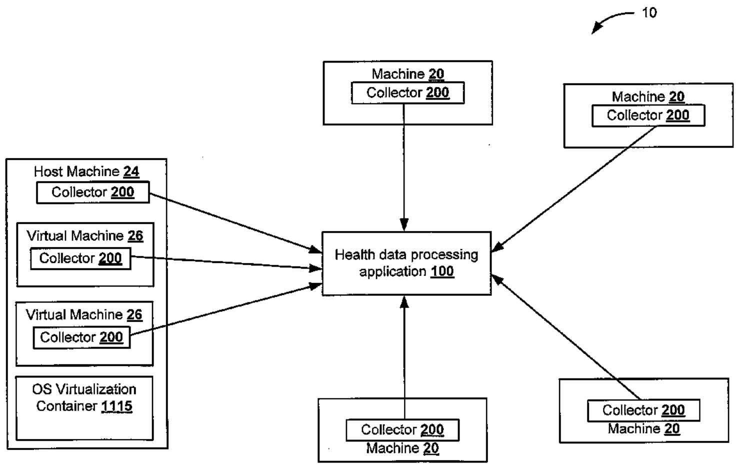
(57) **ABSTRACT**

Provided are methods and computer program products for monitoring the performance of network applications executing within operating-system-level virtualization containers. Methods may include enumerating operating-system-level virtualization containers on a networked device; creating a named pipe accessible by at least one application running in each operating-system-level virtualization container; retrieving, via the named pipe, performance data gathered by the at least one application, including an identification of each operating-system-level virtualization container; generating metrics based on the retrieved performance data; and generating an event incorporating the metrics, including operating-system-level virtualization container identifiers.

20 Claims, 14 Drawing Sheets



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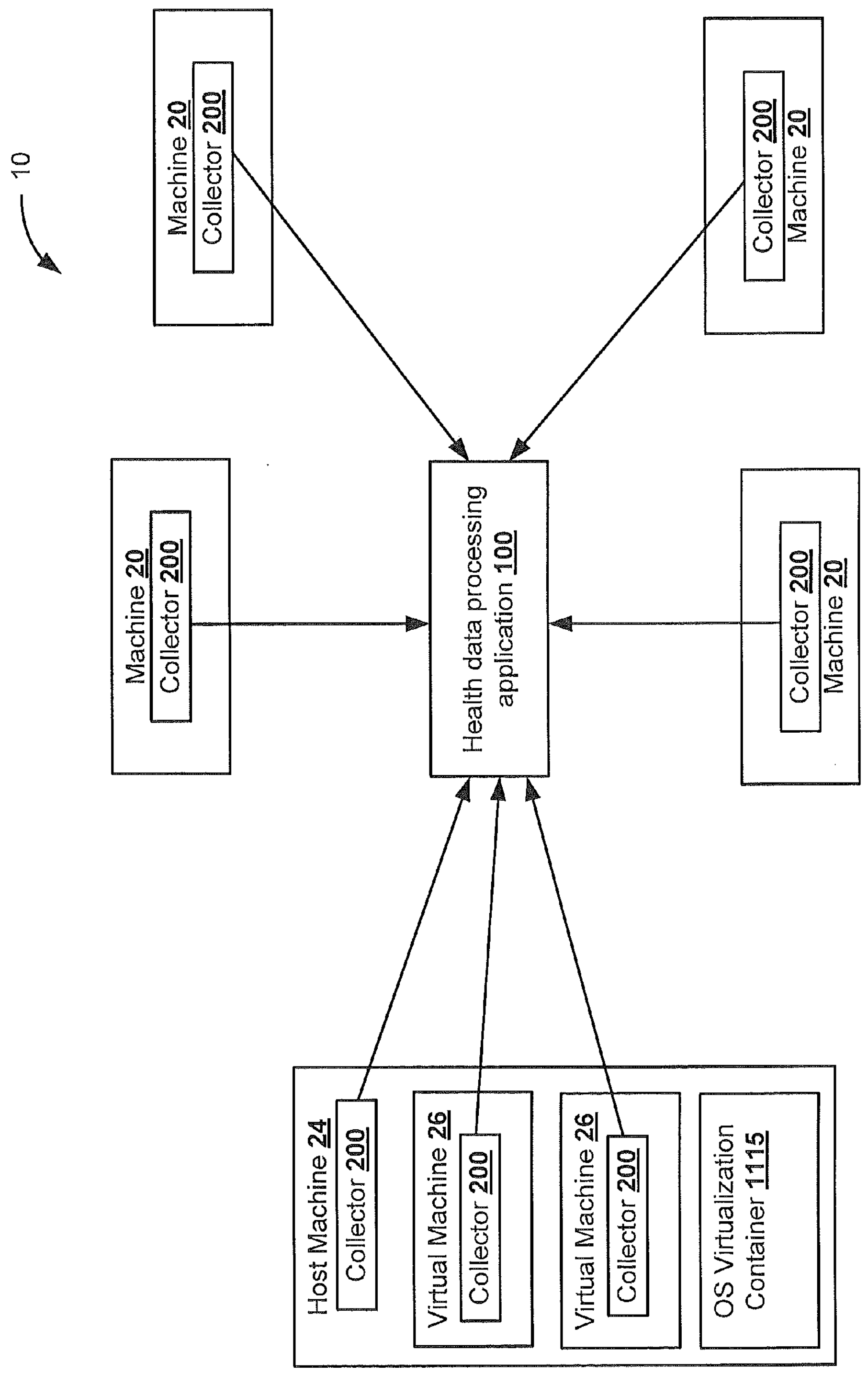

10
Machine 20
Collector 200
Machine 20
Collector 200
Collector 200
Machine 20
Health data processing application 100
Collector 200
Machine 20
Host Machine 24
Collector 200
Virtual Machine 26
Collector 200
Virtual Machine 26
Collector 200
OS Virtualization Container 1115

FIG. 1a

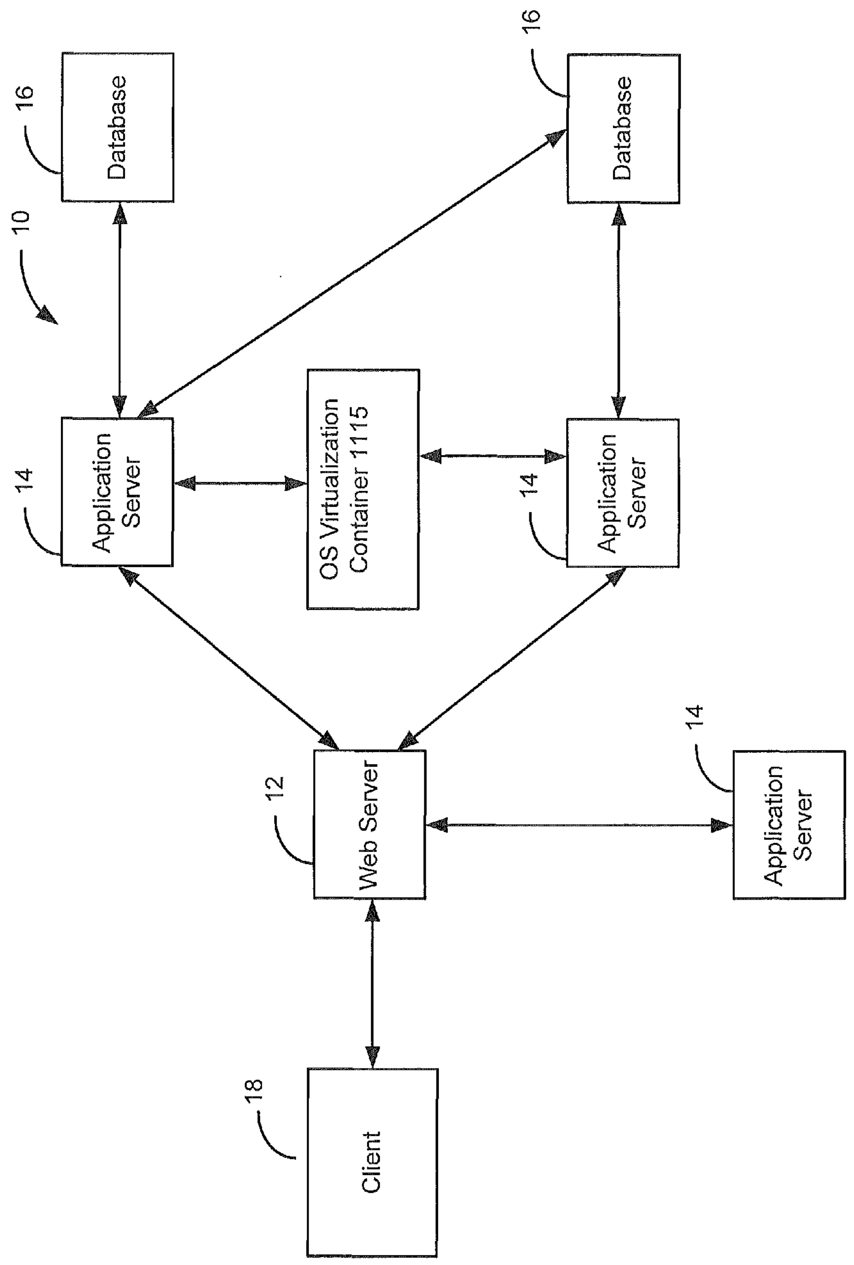

10
16
Database
16
Database
14
Application Server
OS Virtualization Container 1115
14
Application Server
12
Web Server
14
Application Server
18
Client

FIG. 1b

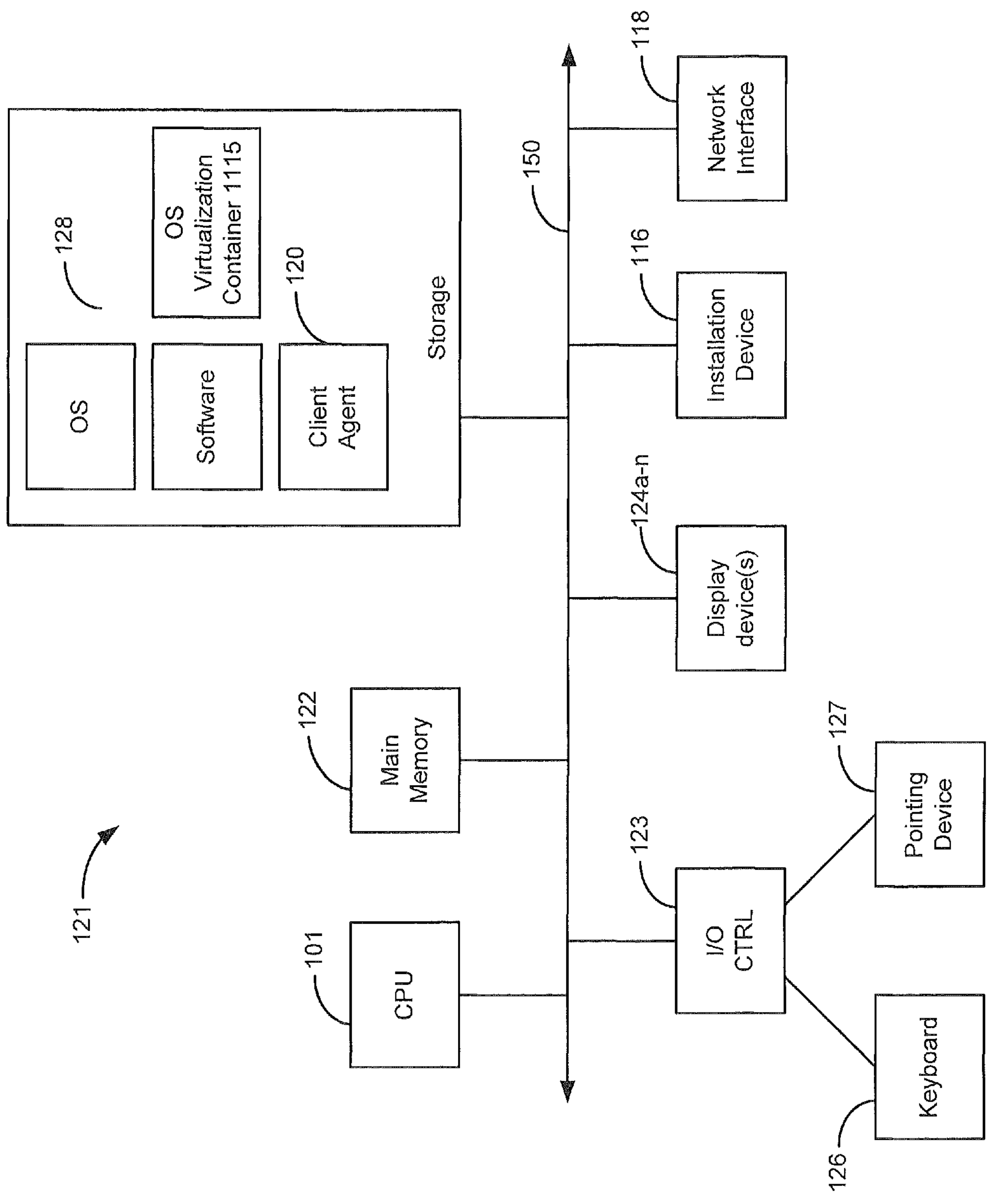

121
OS
Software
Client Agent
120
OS Virtualization Container 1115
128
Storage
150
CPU
101
Main Memory
122
I/O CTRL
123
Display device(s)
124a-n
Installation Device
116
Network Interface
118
Pointing Device
127
Keyboard
126

FIG. 1c

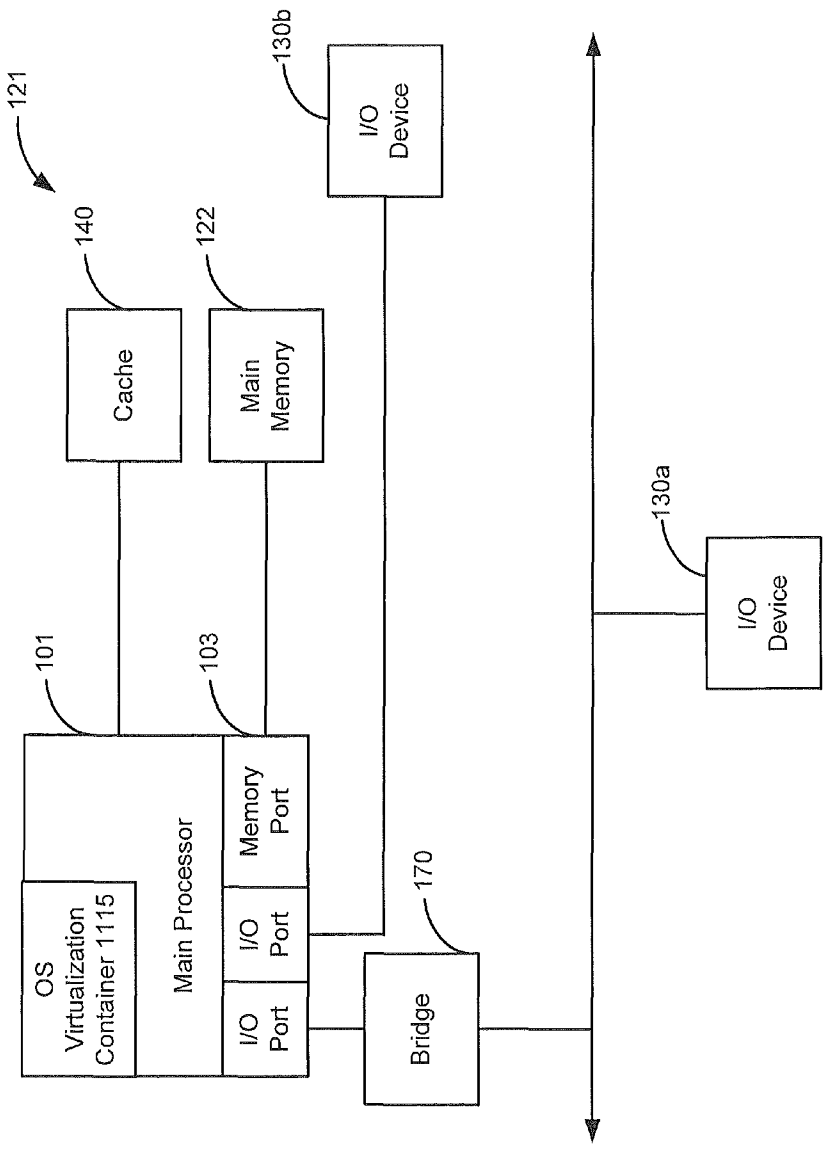

121
140
Cache
122
Main Memory
130b
I/O Device
101
103
OS Virtualization Container 1115
Main Processor
Memory Port
I/O Port
I/O Port
170
Bridge
130a
I/O Device

FIG. 1d

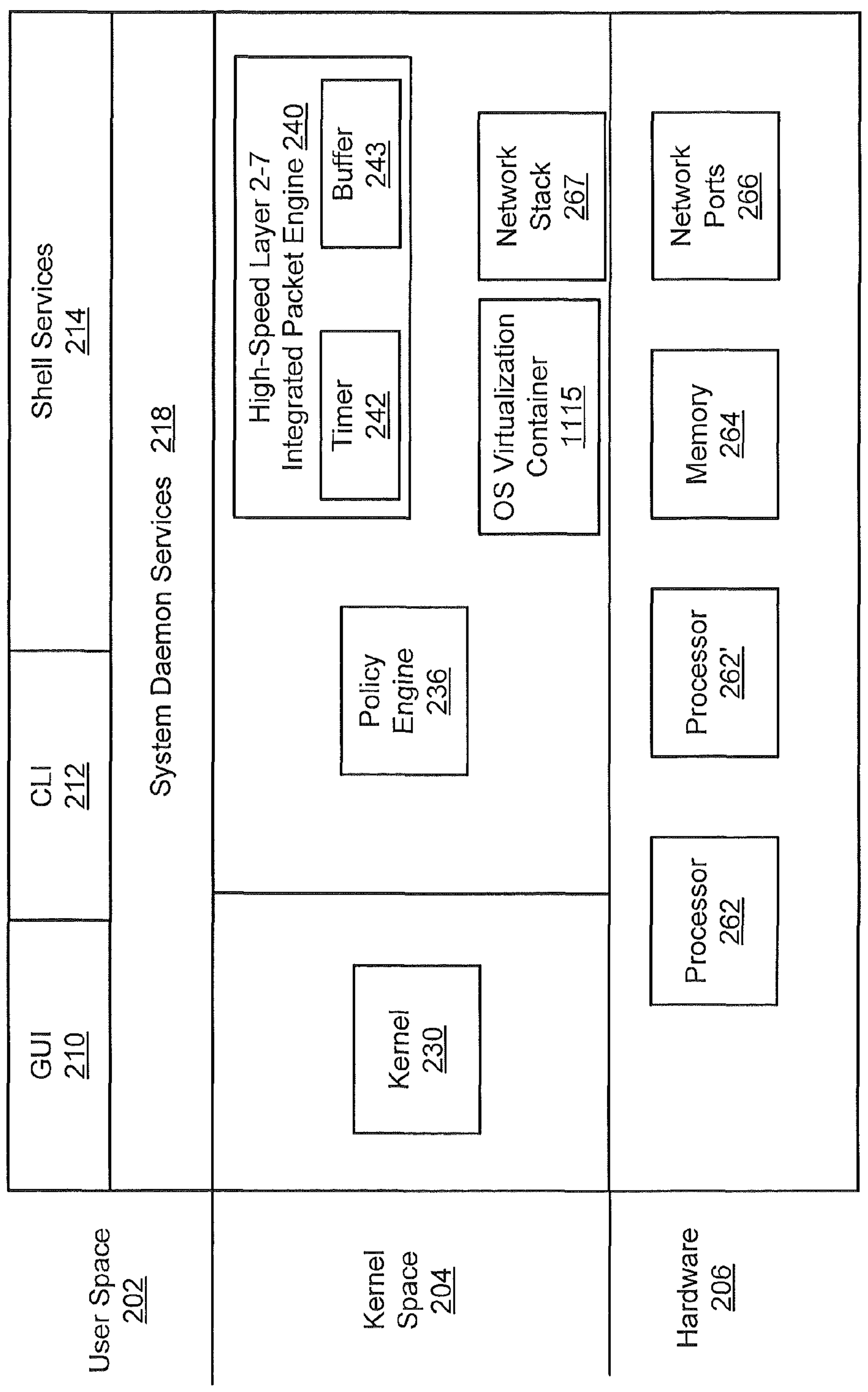

User Space 202
Kernel Space 204
Hardware 206
GUI 210
CLI 212
Shell Services 214
System Daemon Services 218
Kernel 230
Policy Engine 236
High-Speed Layer 2-7 Integrated Packet Engine 240
Timer 242
Buffer 243
OS Virtualization Container 1115
Network Stack 267
Processor 262
Processor 262'
Memory 264
Network Ports 266

FIG. 2

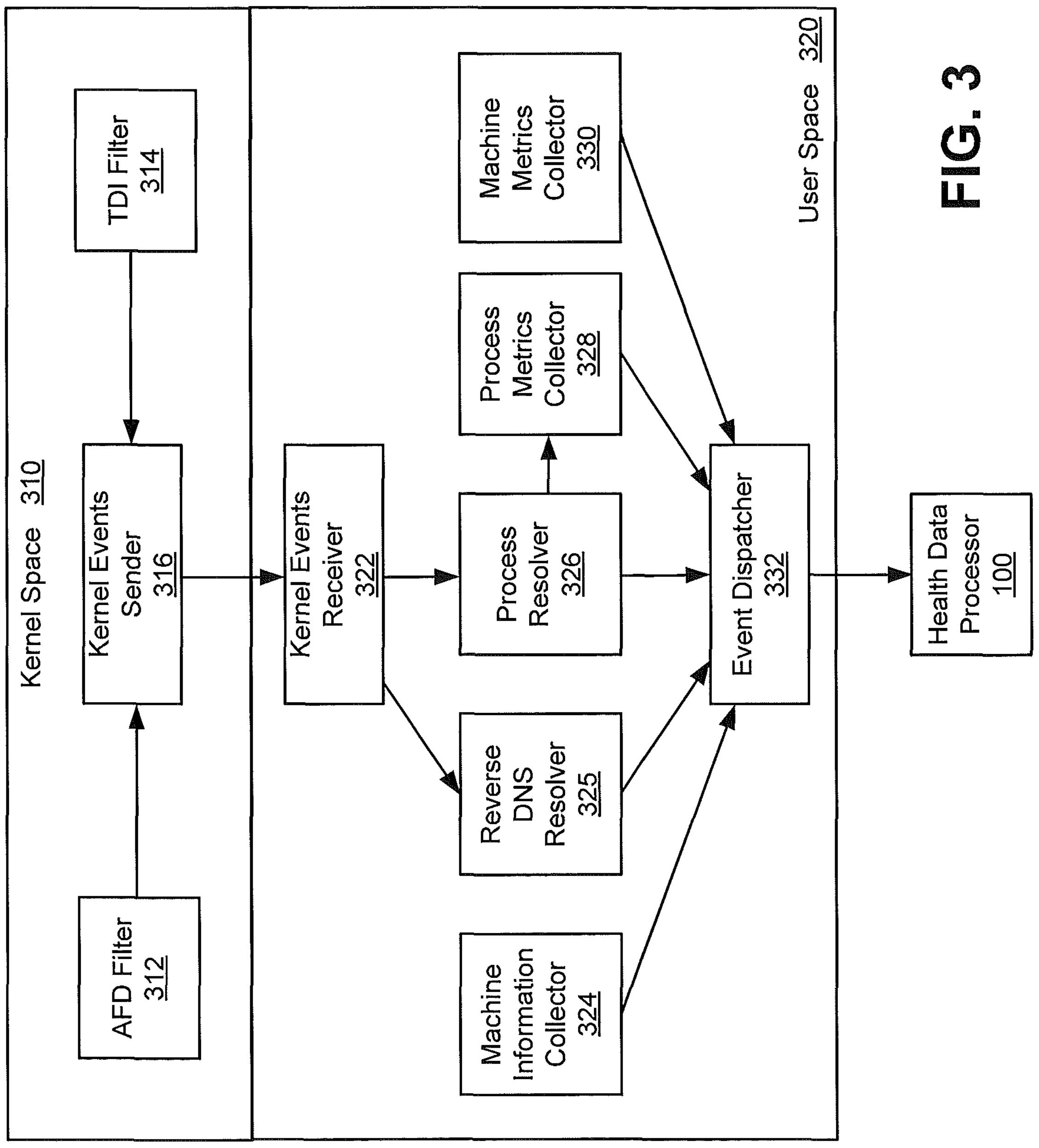

Kernel Space 310
AFD Filter 312
Kernel Events Sender 316
TDI Filter 314
User Space 320
Kernel Events Receiver 322
Machine Information Collector 324
Reverse DNS Resolver 325
Process Resolver 326
Process Metrics Collector 328
Machine Metrics Collector 330
Event Dispatcher 332
Health Data Processor 100

FIG. 3

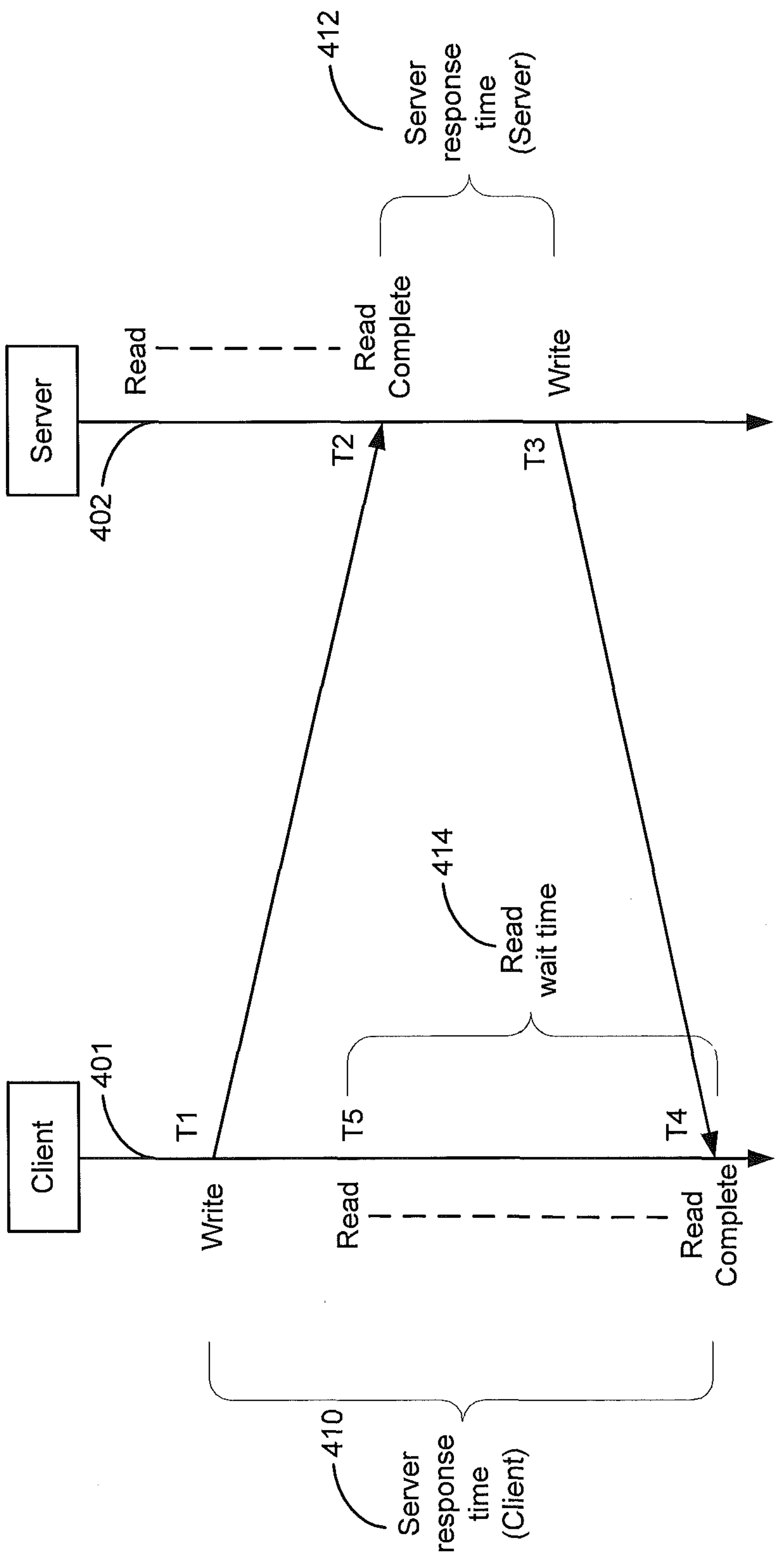

Server
402
Read
Read Complete
Write
T2
T3
412
Server response time (Server)
Client
401
T1
T5
T4
Write
Read
Read Complete
414
Read wait time
410
Server response time (Client)

FIG. 4

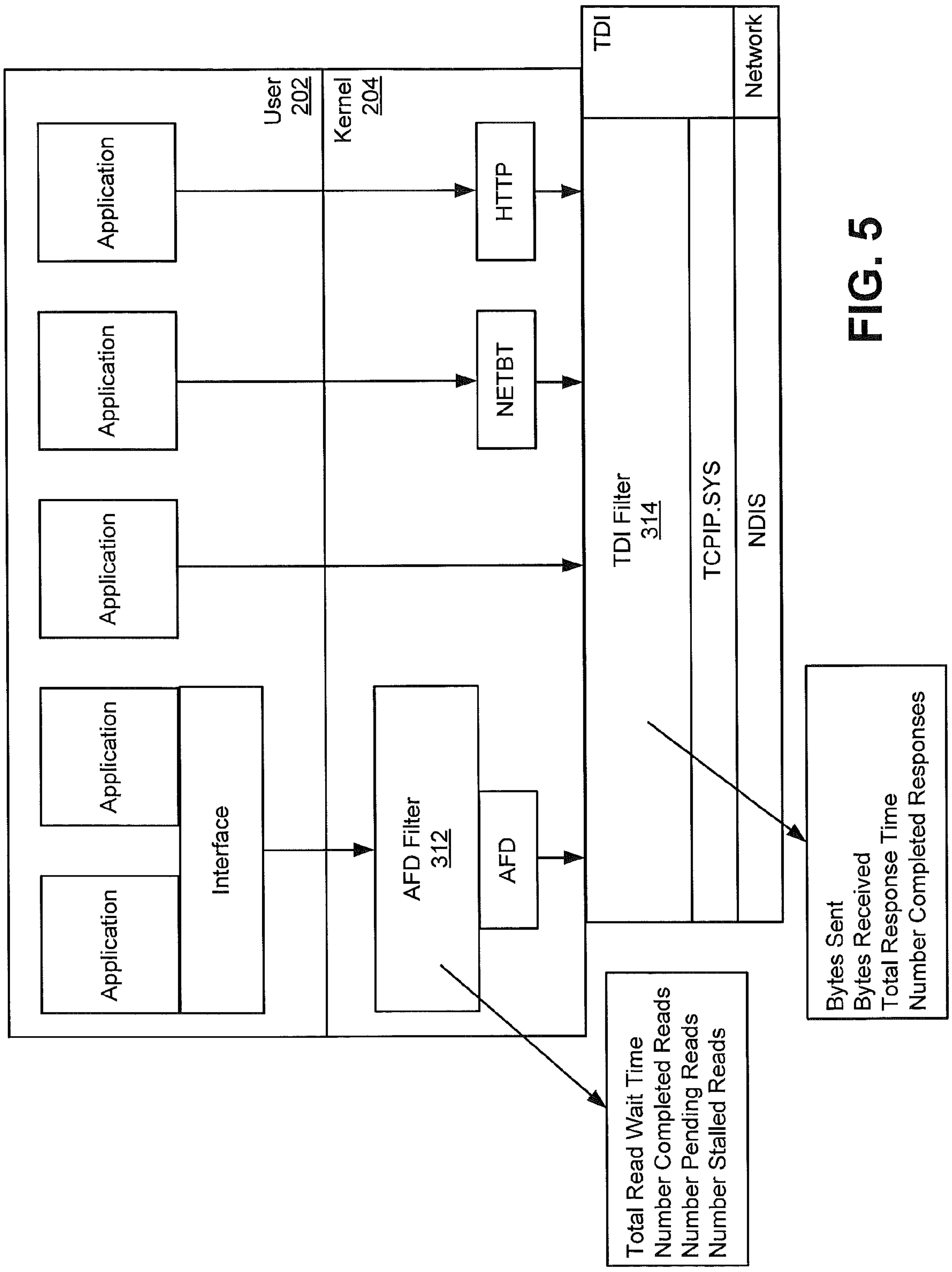

User
202
Kernel
204
Application
Application
Application
Application
Application
Interface
HTTP
NETBT
AFD Filter
312
AFD
TDI
Network
TDI Filter
314
TCPIP.SYS
NDIS
Total Read Wait Time
Number Completed Reads
Number Pending Reads
Number Stalled Reads
Bytes Sent
Bytes Received
Total Response Time
Number Completed Responses

FIG. 5

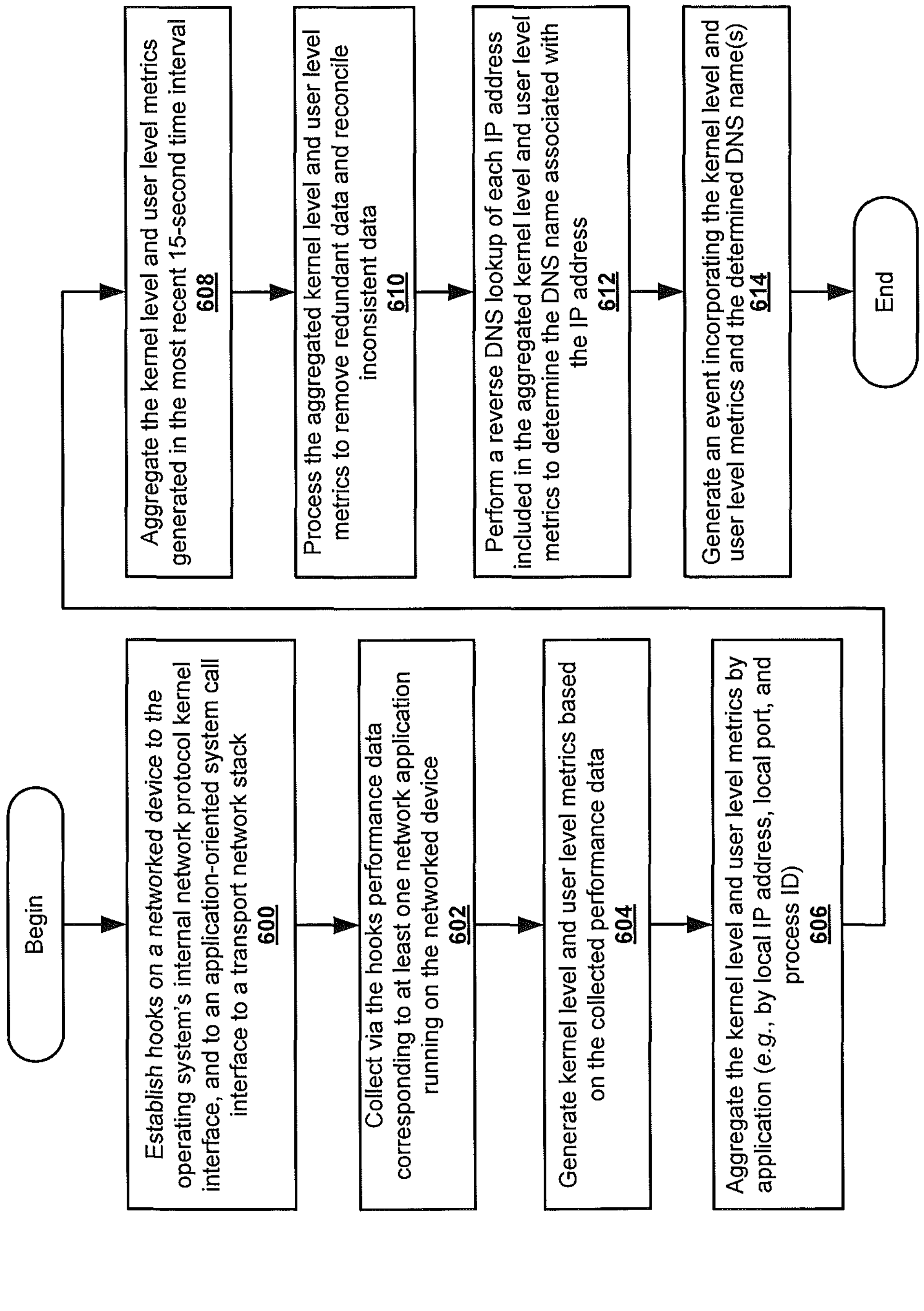

Begin
Establish hooks on a networked device to the operating system's internal network protocol kernel interface, and to an application-oriented system call interface to a transport network stack
600
Collect via the hooks performance data corresponding to at least one network application running on the networked device
602
Generate kernel level and user level metrics based on the collected performance data
604
Aggregate the kernel level and user level metrics by application (e.g., by local IP address, local port, and process ID)
606
Aggregate the kernel level and user level metrics generated in the most recent 15-second time interval
608
Process the aggregated kernel level and user level metrics to remove redundant data and reconcile inconsistent data
610
Perform a reverse DNS lookup of each IP address included in the aggregated kernel level and user level metrics to determine the DNS name associated with the IP address
612
Generate an event incorporating the kernel level and user level metrics and the determined DNS name(s)
614
End

FIG. 6

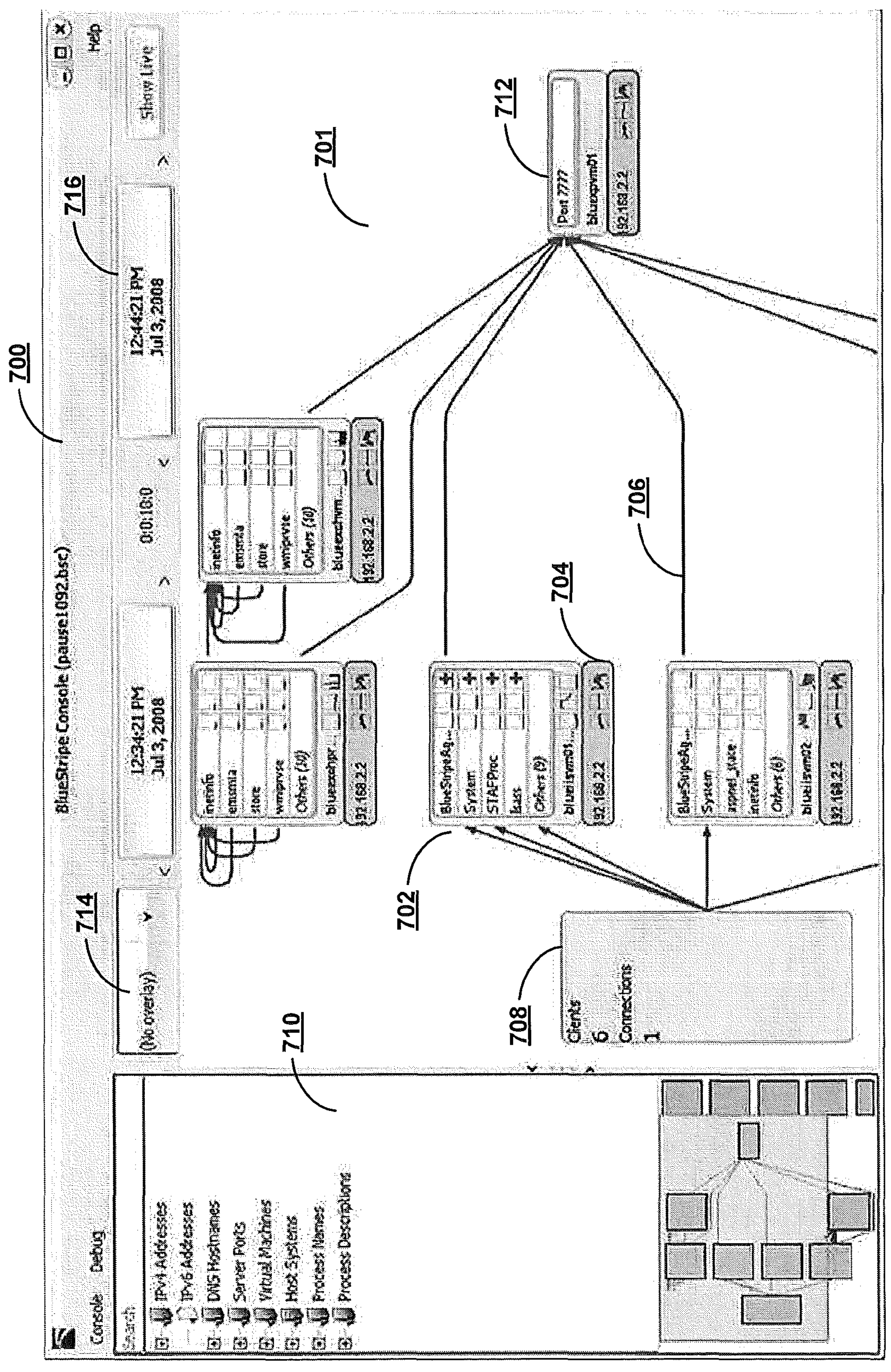

700
BlueStripe Console (pause1092.bsc)
Console
Debug
Help
Search
IPv4 Addresses
IPv6 Addresses
DNS Hostnames
Server Ports
Virtual Machines
Host Systems
Process Names
Process Descriptions
714
(No overlay)
12:34:21 PM
Jul 3, 2008
0:0:16:0
716
12:44:21 PM
Jul 3, 2008
Show Live
701
710
708
Clients
6
Connections
1
702
704
706
712
inetinfo
emsmta
store
wmprvse
Others (10)
blueexchvm...
192.168.2.2
BlueStripeAg...
System
STAFProc
lsass
Others (9)
blueisvm01...
aspnet_state
inetinfo
Others (6)
blueisvm02
Port 7777
blueexpvm01

FIG. 7

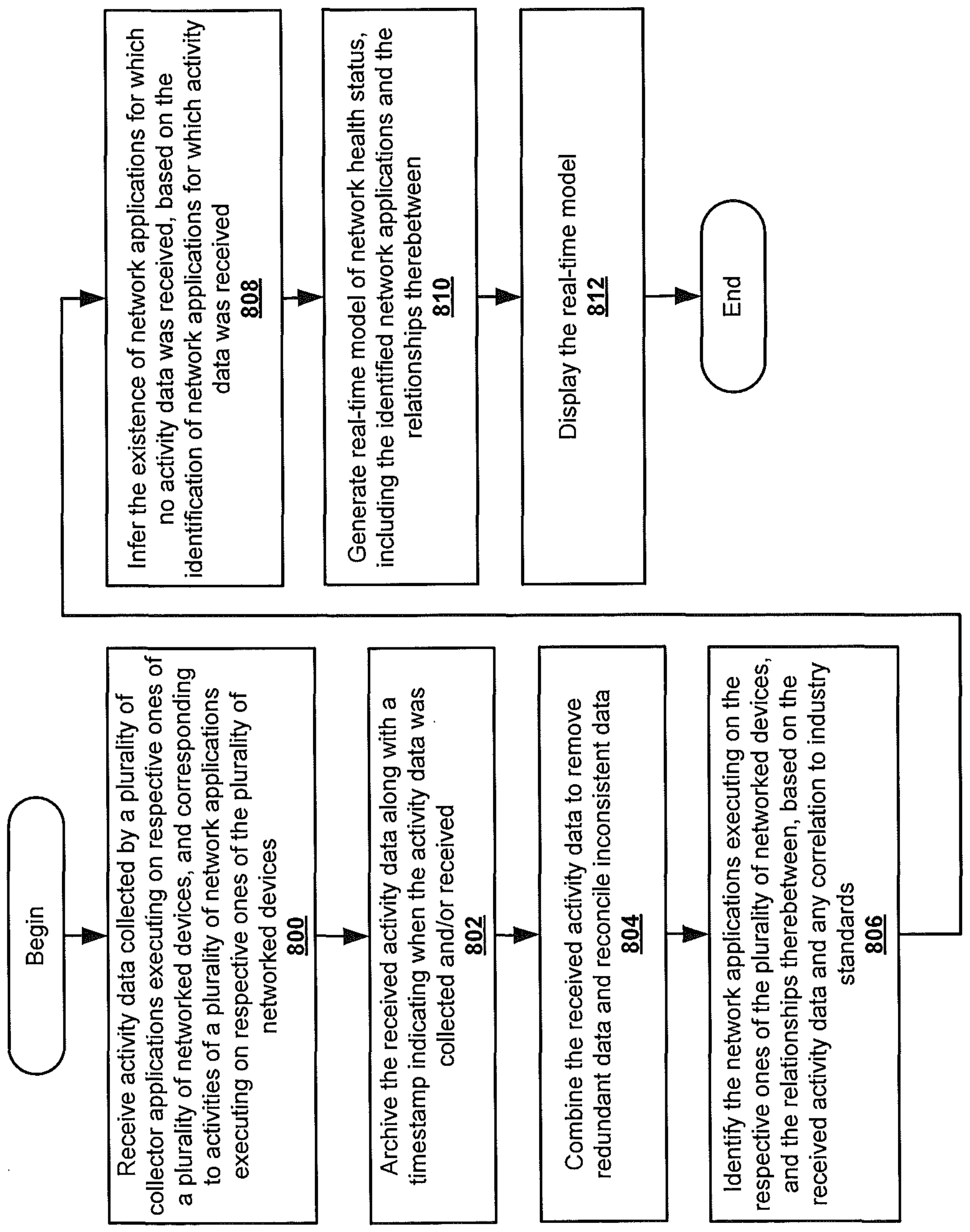

Begin
Receive activity data collected by a plurality of collector applications executing on respective ones of a plurality of networked devices, and corresponding to activities of a plurality of network applications executing on respective ones of the plurality of networked devices
800
Archive the received activity data along with a timestamp indicating when the activity data was collected and/or received
802
Combine the received activity data to remove redundant data and reconcile inconsistent data
804
Identify the network applications executing on the respective ones of the plurality of networked devices, and the relationships therebetween, based on the received activity data and any correlation to industry standards
806
Infer the existence of network applications for which no activity data was received, based on the identification of network applications for which activity data was received
808
Generate real-time model of network health status, including the identified network applications and the relationships therebetween
810
Display the real-time model
812
End

FIG. 8

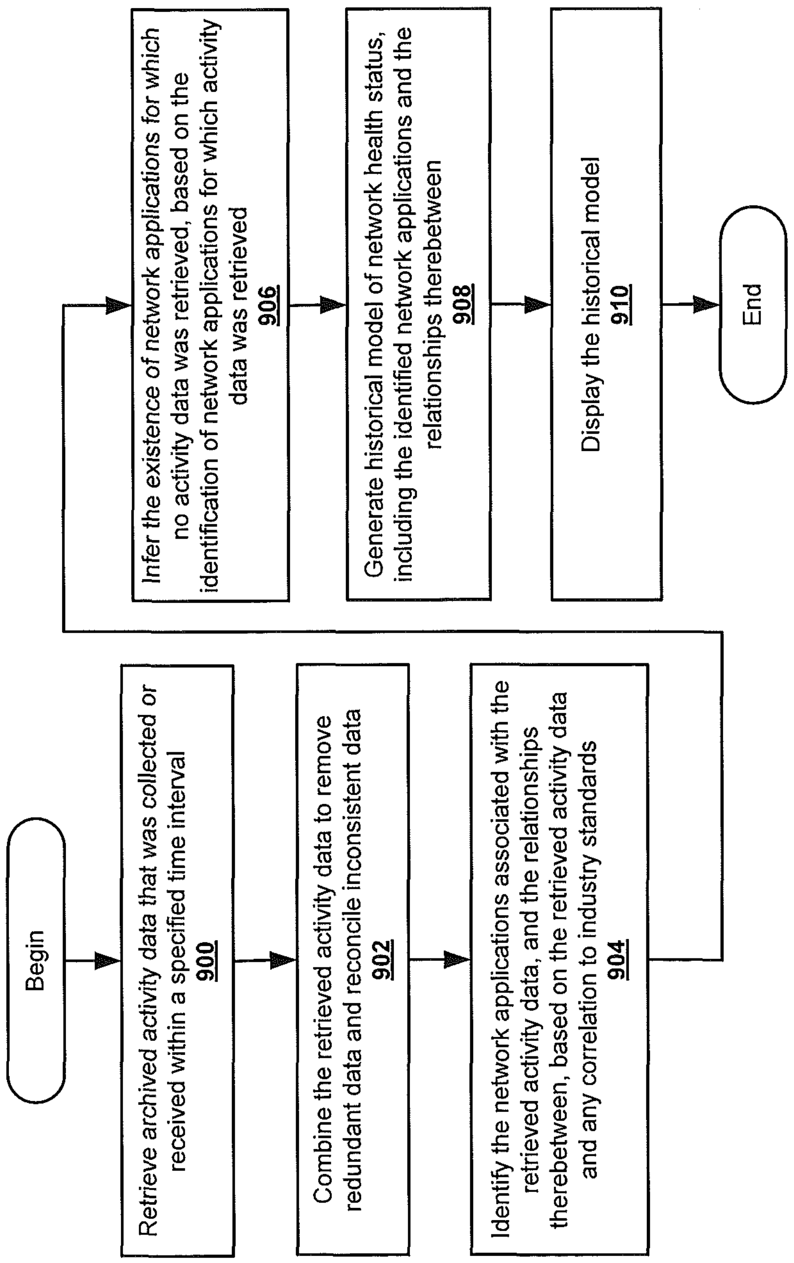
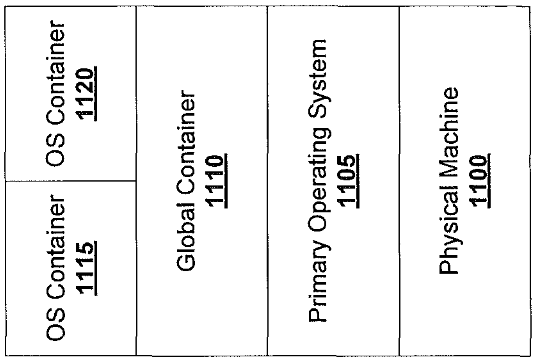
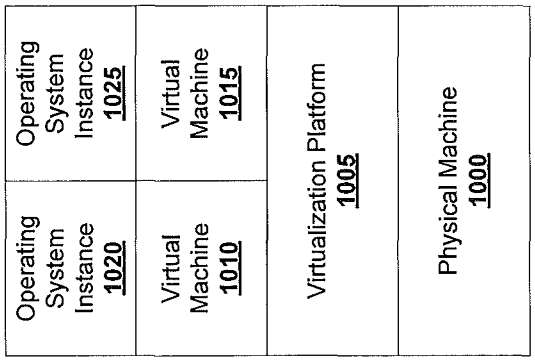

Begin
Retrieve archived activity data that was collected or received within a specified time interval
900
Combine the retrieved activity data to remove redundant data and reconcile inconsistent data
902
Identify the network applications associated with the retrieved activity data, and the relationships therebetween, based on the retrieved activity data and any correlation to industry standards
904
Infer the existence of network applications for which no activity data was retrieved, based on the identification of network applications for which activity data was retrieved
906
Generate historical model of network health status, including the identified network applications and the relationships therebetween
908
Display the historical model
910
End

FIG. 9



Operating System Virtualization Architecture

FIG. 11


Operating System Instance 1020
Operating System Instance 1025
Virtual Machine 1010
Virtual Machine 1015
Virtualization Platform 1005
Physical Machine 1000

Full-Machine Virtualization Architecture

FIG. 10

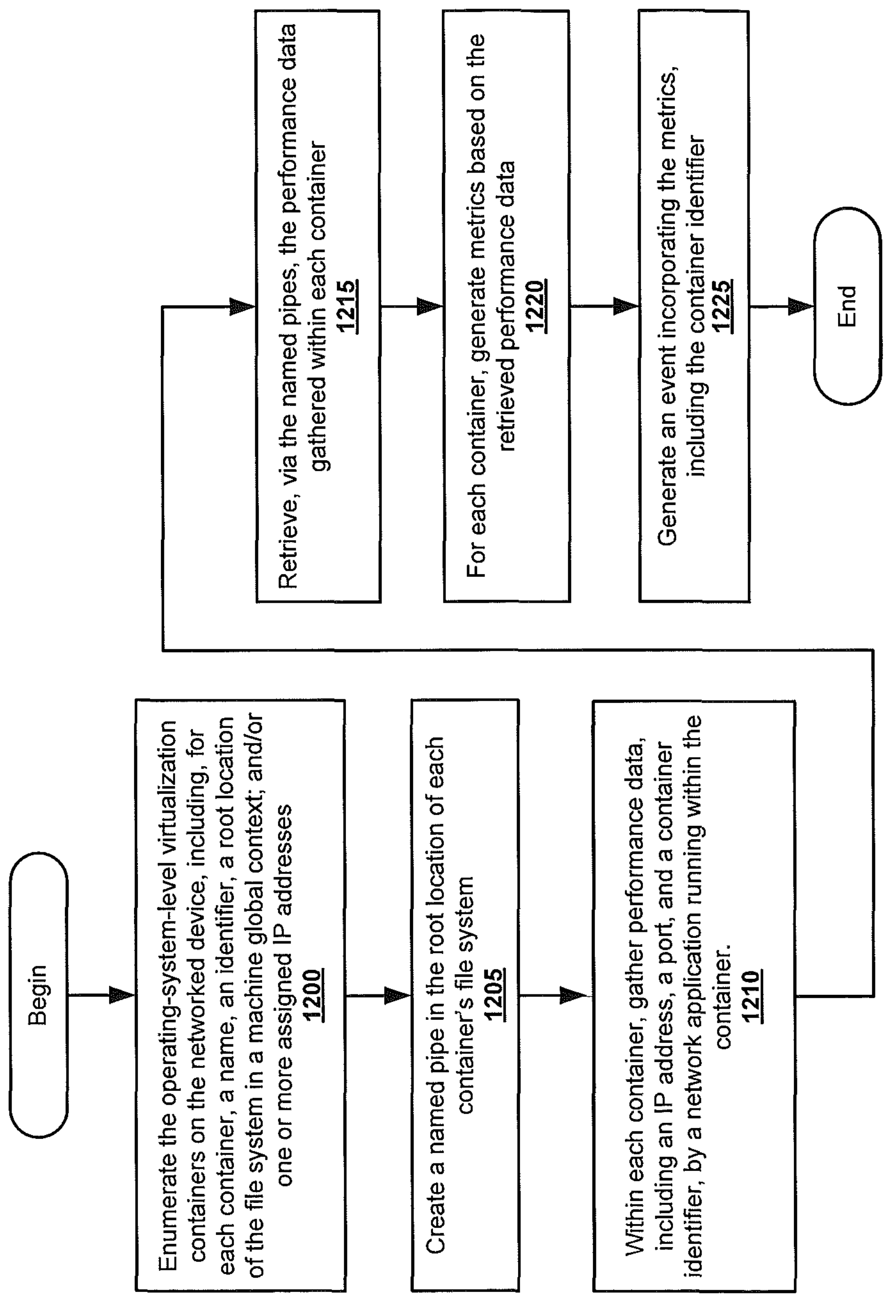

Begin
Enumerate the operating-system-level virtualization containers on the networked device, including, for each container, a name, an identifier, a root location of the file system in a machine global context; and/or one or more assigned IP addresses
1200
Create a named pipe in the root location of each container's file system
1205
Within each container, gather performance data, including an IP address, a port, and a container identifier, by a network application running within the container.
1210
Retrieve, via the named pipes, the performance data gathered within each container
1215
For each container, generate metrics based on the retrieved performance data
1220
Generate an event incorporating the metrics, including the container identifier
1225
End

FIG. 12

METHODS AND COMPUTER PROGRAM PRODUCTS FOR MONITORING AND REPORTING PERFORMANCE OF NETWORK APPLICATIONS EXECUTING IN OPERATING-SYSTEM-LEVEL VIRTUALIZATION CONTAINERS

FIELD OF INVENTION

The present invention relates to computer networks and, more particularly, to network performance monitoring methods, devices, and computer program products.

BACKGROUND

The growing presence of computer networks such as intranets and extranets has brought about the development of applications in e-commerce, education, manufacturing, and other areas. Organizations increasingly rely on such applications to carry out their business, production, or other objectives, and devote considerable resources to ensuring that the applications perform as expected. To this end, various application management, monitoring, and analysis techniques have been developed.

One approach for managing an application involves monitoring the application, generating data regarding application performance, and analyzing the data to determine application health. Some system management products analyze a large number of data streams to try to determine a normal and abnormal application state. Large numbers of data streams are often analyzed because the system management products may not have a semantic understanding of the data being analyzed. Accordingly, when an unhealthy application state occurs, many data streams may have abnormal data values because the data streams are causally related to one another. Because the system management products may lack a semantic understanding of the data, they may not be able to assist the user in determining either the ultimate source or cause of a problem. Additionally, these application management systems may not know whether a change in data indicates an application is actually unhealthy or not.

Current application management approaches may include monitoring techniques such as deep packet inspection (DPI), which may be performed as a packet passes an inspection point and may include collecting statistical information, among others. Such monitoring techniques can be data-intensive and may be ineffective in providing substantively real time health information regarding network applications. Additionally, packet trace information may be lost and application-specific code may be required.

Embodiments of the present invention are, therefore, directed towards solving these and other related problems.

SUMMARY

It should be appreciated that this Summary is provided to introduce a selection of concepts in a simplified form, the concepts being further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of this disclosure, nor is it intended to limit the scope of the invention.

Some embodiments of the present invention are directed to a method for monitoring and reporting the performance of network applications executing in operating-system-level virtualization containers. Methods may include monitoring application performance in a networked device that provides operating-system-level virtualization containers. One or

more operating-system-level virtualization containers on the networked device are enumerated, and named pipes that are accessible by at least one application running in a respective one of the one or more operating-system-level virtualization containers, and that are configured to receive data from within the respective one of the one or more operating-system-level virtualization containers, are created. Performance data, gathered by the at least one application running in the respective one of the one or more operating-system-level virtualization containers and including an identification of the respective one of the one or more operating-system-level virtualization containers, is retrieved via the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers. A plurality of metrics based on the collected performance data is generated, and an event incorporating at least one of the plurality of metrics is generated. Some embodiments may provide that the generated event includes an IP address, a port, and/or a container identifier.

In some embodiments, creating a named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers includes creating a named pipe within a file system for a respective one of the one or more operating-system-level virtualization containers.

Enumerating one or more operating-system-level virtualization containers on the networked device, in some embodiments, includes determining, for a respective one of the one or more operating-system-level virtualization containers, a name, an identifier, a root location of a file system in a machine global context, and/or one or more IP addresses assigned to the respective one of the one or more operating-system-level virtualization containers. In some embodiments, enumerating one or more operating-system-level virtualization containers on the networked device occurs responsive to a system startup. Some embodiments may provide that enumerating one or more operating-system-level virtualization containers occurs responsive to a startup and/or a shutdown of an operating-system-level virtualization container on the networked device.

Methods according to some embodiments may include monitoring, for a respective one of the one or more operating-system-level virtualization containers, a call to a container shutdown function. The named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers is removed responsive to detecting the call to the container shutdown function. In some embodiments, a call to a system shutdown and/or a system reboot function is monitored, and the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers is removed responsive to detecting the call to the system shutdown and/or the system reboot function.

Some embodiments may provide that a write connection to a named pipe that is accessible from within a respective one of the one or more operating-system-level virtualization containers is maintained, the write connection being operative to prevent the named pipe from being automatically closed.

In some embodiments, a computer program product including a non-transitory computer usable storage medium having computer-readable program code embodied in the medium is provided. The computer-readable program code is configured to perform operations corresponding to methods described herein.

Other methods, devices, and/or computer program products according to exemplary embodiments will be or become

apparent to one with skill in the art upon review of the following drawings and detailed description. It is intended that all such additional methods, devices, and/or computer program products be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in more detail in relation to the enclosed drawings, in which:

FIGS. **1***a*-**1***d* are block diagrams illustrating exemplary networks in which operations for monitoring network application performance may be performed according to some embodiments of the present invention,

FIG. **2** is a block diagram illustrating an architecture of a computing device as discussed above regarding FIGS. **1***c* and **1***d*,

FIG. **3** is a block diagram illustrating operations and/or functions of a collector application as described above regarding FIG. **1***a*,

FIG. **4** is a diagram illustrating determining a read wait time corresponding to a user transaction according to some embodiments of the present invention,

FIG. **5** is a block diagram illustrating a kernel level architecture of a collector application to explain kernel level metrics according to some embodiments of the present invention,

FIG. **6** is a flowchart illustrating exemplary operations carried out by a collector application in monitoring and reporting network application performance according to some embodiments of the present invention,

FIG. **7** is a screen shot of a graphical user interface (GUI) including a model generated by a health data processing application according to some embodiments of the present invention,

FIG. **8** is a flowchart illustrating exemplary operations carried out by a health data processing application in generating and displaying a real-time model of network application health according to some embodiments of the present invention, and

FIG. **9** is a flowchart illustrating exemplary operations carried out by a health data processing application in generating and displaying an historical model of network application health according to some embodiments of the present invention.

FIG. **10** is a block diagram illustrating the architecture of a system providing full-machine virtualization according to some embodiments of the present invention.

FIG. **11** is a block diagram illustrating the architecture of a system providing operating-system-level virtualization according to some embodiments of the present invention.

FIG. **12** is a flowchart illustrating exemplary operations carried out a collector application **200** in monitoring the performance of network applications executing within operating-system-level virtualization containers utilizing named pipes according to some embodiments of the present invention.

DETAILED DESCRIPTION

In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed

descriptions of well known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail. While various modifications and alternative forms of the embodiments described herein may be made, specific embodiments are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims. Like reference numbers signify like elements throughout the description of the figures.

As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless expressly stated otherwise. It should be further understood that the terms "comprises" and/or "comprising" when used in this specification are taken to specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof. It will be understood that when an element is referred to as being "connected" or "coupled" to another element, it can be directly connected or coupled to the other element or intervening elements may be present. Furthermore, "connected" or "coupled" as used herein may include wirelessly connected or coupled. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items, and may be abbreviated as "/".

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another.

Exemplary embodiments are described below with reference to block diagrams and/or flowchart illustrations of methods, apparatus (systems and/or devices), and/or computer program products. It is understood that a block of the block diagrams and/or flowchart illustrations, and combinations of blocks in the block diagrams and/or flowchart illustrations, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, and/or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer and/or other programmable data processing apparatus, create means (functionality) and/or structure for implementing the functions/acts specified in the block diagrams and/or flowchart block or blocks.

These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instructions which implement the functions/acts specified in the block diagrams and/or flowchart block or blocks.

The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process, such that the instructions, which execute on the computer or other programmable apparatus, provide steps for implementing the functions/acts specified in the block diagrams and/or flowchart block or blocks.

Accordingly, exemplary embodiments may be implemented in hardware and/or in software (including firmware, resident software, micro-code, etc.). Furthermore, exemplary embodiments may take the form of a computer program product on a non-transitory computer-usable or computer-readable storage medium having computer-usable or computer-readable program code embodied in the medium for use by or in connection with an instruction execution system. In the context of this document, a non-transitory computer-usable or computer-readable medium may be any medium that can contain, store, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The computer-usable or computer-readable medium may be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device. More specific examples (a non-exhaustive list) of the computer-readable medium would include the following: a portable computer diskette, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), and a portable compact disc read-only memory (CD-ROM).

Computer program code for carrying out operations of data processing systems discussed herein may be written in a high-level programming language, such as C, or Java, for development convenience. In addition, computer program code for carrying out operations of exemplary embodiments may also be written in other programming languages, such as, but not limited to, interpreted languages. Some modules or routines may be written in assembly language or even micro-code to enhance performance and/or memory usage. However, embodiments are not limited to a particular programming language. It will be further appreciated that the functionality of any or all of the program modules may also be implemented using discrete hardware components, one or more application specific integrated circuits (ASICs), or a programmed digital signal processor or microcontroller.

It should also be noted that in some alternate implementations, the functions/acts noted in the blocks may occur out of the order noted in the flowcharts. For example, two blocks shown in succession may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the functionality/acts involved. Moreover, the functionality of a given block of the flowcharts and/or block diagrams may be separated into multiple blocks and/or the functionality of two or more blocks of the flowcharts and/or block diagrams may be at least partially integrated.

Reference is made to FIGS. **1***a*-**1***d*, which are block diagrams illustrating exemplary networks in which operations for monitoring and reporting network application performance may be performed according to some embodiments of the present invention.

Computing Network

Referring to FIG. **1***a*, a network **10** according to some embodiments herein may include a health data processing application **100** and a plurality of network devices **20**, **24**, and **26** that may each include respective collector applications **200**. It is to be understood that a "network device" as discussed herein may include physical (as opposed to virtual) machines **20**; host machines **24**, each of which may be a physical machine on which one or more virtual machines may execute; and/or virtual machines **26** executing on host machines **24**. It is to be further understood that an "application" as discussed herein refers to an instance of executable software operable to execute on respective ones of the network devices. The terms "application" and "network application" may be used interchangeably herein, regardless of whether the referenced application is operable to access network resources.

Collector applications **200** may collect data related to the performance of network applications executing on respective network devices. For instance, a collector application executing on a physical machine may collect performance data related to network applications executing on that physical machine. A collector application executing on a host machine and external to any virtual machines hosted by that host machine may collect performance data related to network applications executing on that host machine, while a collector application executing on a virtual machine may collect performance data related to network applications executing within that virtual machine.

The health data processing application **100** may be on a network device that exists within the network **10** or on an external device that is coupled to the network **10**. Accordingly, in some embodiments, the network device on which the health data processing application **100** may reside may be one of the plurality of machines **20** or **24** or virtual machines **26**. Communications between various ones of the network devices may be accomplished using one or more communications and/or network protocols that may provide a set of standard rules for data representation, signaling, authentication and/or error detection that may be used to send information over communications channels therebetween. In some embodiments, exemplary network protocols may include HTTP, TDS, and/or LDAP, among others.

Referring to FIG. **1***b*, an exemplary network **10** may include a web server **12**, one or more application servers **14** and one or more database servers **16**. Although not illustrated, a network **10** as used herein may include directory servers, security servers, and/or transaction monitors, among others. The web server **12** may be a computer and/or a computer program that is responsible for accepting HTTP requests from clients **18** (e.g., user agents such as web browsers) and serving them HTTP responses along with optional data content, which may be, for example, web pages such as HTML documents and linked objects (images, etc.). An application server **14** may include a service, hardware, and/or software framework that may be operable to provide one or more programming applications to clients in a network. Application servers **14** may be coupled to one or more web servers **12**, database servers **16**, and/or other application servers **14**, among others. Some embodiments provide that a database server **16** may include a computer and/or a computer program that provides database services to other computer programs and/or computers as may be defined, for example by a client-server model, among others. In some embodiments, database management systems may provide database server functionality.

Some embodiments provide that the collector applications **200** and the health data processing application **100** described above with respect to FIG. **1***a* may reside on ones of the web server(s) **12**, application servers **14** and/or database servers **16**, among others. In some embodiments, the health data processing application **100** may reside in a dedicated computing device that is coupled to the network **10**. The collector applications **200** may reside on one, some or all of the above listed network devices and provide network application performance data to the health data processing application **100**.

Computing Device

Web server(s) **12**, application servers **14** and/or database servers **16** may be deployed as and/or executed on any type and form of computing device, such as a computer, network device, or appliance capable of communicating on any type and form of network and performing the operations described herein. FIGS. **1***c* and **1***d* depict block diagrams of a computing device **121** useful for practicing some embodiments described herein. Referring to FIGS. **1***c* and **1***d*, a computing device **121** may include a central processing unit **101** and a main memory unit **122**. A computing device **100** may include a visual display device **124**, a keyboard **126**, and/or a pointing device **127**, such as a mouse. Each computing device **121** may also include additional optional elements, such as one or more input/output devices **130***a*-**130***b* (generally referred to using reference numeral **130**), and a cache memory **140** in communication with the central processing unit **101**.

The central processing unit **101** is any logic circuitry that responds to and processes instructions fetched from the main memory unit **122**. In many embodiments, the central processing unit **101** is provided by a microprocessor unit, such as: those manufactured by Intel Corporation of Mountain View, Calif.; those manufactured by Motorola Corporation of Schaumburg, Ill.; the POWER processor, those manufactured by International Business Machines of White Plains, N.Y.; and/or those manufactured by Advanced Micro Devices of Sunnyvale, Calif. The computing device **121** may be based on any of these processors, and/or any other processor capable of operating as described herein.

Main memory unit **122** may be one or more memory chips capable of storing data and allowing any storage location to be directly accessed by the microprocessor **101**, such as Static random access memory (SRAM), Burst SRAM or Synch-Burst SRAM (BSRAM), Dynamic random access memory (DRAM), Fast Page Mode DRAM (FPM DRAM), Enhanced DRAM (EDRAM), Extended Data Output RAM (EDO RAM), Extended Data Output DRAM (EDO DRAM), Burst Extended Data Output DRAM (BEDO DRAM), Enhanced DRAM (EDRAM), synchronous DRAM (SDRAM), JEDEC SRAM, PC100 SDRAM, Double Data Rate SDRAM (DDR SDRAM), Enhanced SDRAM (ESDRAM), SyncLink DRAM (SLDRAM), Direct Rambus DRAM (DRDRAM), or Ferroelectric RAM (FRAM), among others. The main memory **122** may be based on any of the above described memory chips, or any other available memory chips capable of operating as described herein. In some embodiments, the processor **101** communicates with main memory **122** via a system bus **150** (described in more detail below). In some embodiments of a computing device **121**, the processor **101** may communicate directly with main memory **122** via a memory port **103**. Some embodiments provide that the main memory **122** may be DRDRAM.

FIG. **1***d* depicts some embodiments in which the main processor **101** communicates directly with cache memory **140** via a secondary bus, sometimes referred to as a backside bus. In some other embodiments, the main processor **101** may communicate with cache memory **140** using the system bus **150**. Cache memory **140** typically has a faster response time than main memory **122** and may be typically provided by SRAM, BSRAM, or EDRAM. In some embodiments, the processor **101** communicates with various I/O devices **130** via a local system bus **150**. Various busses may be used to connect the central processing unit **101** to any of the I/O devices **130**, including a VESA VL bus, an ISA bus, an EISA bus, a MicroChannel Architecture (MCA) bus, a PCI bus, a PCI-X bus, a PCI-Express bus, and/or a NuBus, among others. For embodiments in which the I/O device is a video display **124**, the processor **101** may use an Advanced Graphics Port (AGP) to communicate with the display **124**. FIG. **1***d* depicts some embodiments of a computer **100** in which the main processor **101** communicates directly with I/O device **130** via HyperTransport, Rapid I/O, or InfiniBand. FIG. **1***d* also depicts some embodiments in which local busses and direct communication are mixed: the processor **101** communicates with I/O device **130***a* using a local interconnect bus while communicating with I/O device **130***b* directly.

The computing device **121** may support any suitable installation device **116**, such as a floppy disk drive for receiving floppy disks such as 3.5-inch, 5.25-inch disks, or ZIP disks, a CD-ROM drive, a CD-R/RW drive, a DVD-ROM drive, tape drives of various formats, USB device, hard disk drive (HDD), solid-state drive (SSD), or any other device suitable for installing software and programs such as any client agent **120**, or portion thereof. The computing device **121** may further comprise a storage device **128**, such as one or more hard disk drives or solid-state drives or redundant arrays of independent disks, for storing an operating system and other related software, and for storing application software programs such as any program related to the client agent **120**. Optionally, any of the installation devices **116** could also be used as the storage device **128**. Additionally, the operating system and the software can be run from a bootable medium, for example, a bootable CD, such as KNOPPIX®, a bootable CD for GNU/Linux that is available as a GNU/Linux distribution from knoppix.net.

Furthermore, the computing device **121** may include a network interface **118** to interface to a Local Area Network (LAN), Wide Area Network (WAN) or the Internet through a variety of connections including, but not limited to, standard telephone lines, LAN or WAN links (e.g., T1, T3, 56 kb, X.25), broadband connections (e.g., ISDN, Frame Relay, ATM), wireless connections (e.g., IEEE 802.11), or some combination of any or all of the above. The network interface **118** may comprise a built-in network adapter, network interface card, PCMCIA network card, card bus network adapter, wireless network adapter, USB network adapter, modem, or any other device suitable for interfacing the computing device **121** to any type of network capable of communication and performing the operations described herein. A wide variety of I/O devices **130***a*-**130***n* may be present in the computing device **121**. Input devices include keyboards, mice, trackpads, trackballs, microphones, and drawing tablets, among others. Output devices include video displays, speakers, inkjet printers, laser printers, and dye-sublimation printers, among others. The I/O devices **130** may be controlled by an I/O controller **123** as shown in FIG. **1***c*. The I/O controller may control one or more I/O devices such as a keyboard **126** and a pointing device **127**, e.g., a mouse or optical pen. Furthermore, an I/O device may also provide storage **128** and/or an installation medium **116** for the computing device **100**. In still other embodiments, the computing device **121** may provide USB connections to receive handheld USB storage devices such USB flash drives.

In some embodiments, the computing device **121** may comprise or be connected to multiple display devices **124***a*-**124***n*, which each may be of the same or different type and/or form. As such, any of the I/O devices **130***a*-**130***n* and/or the I/O controller **123** may comprise any type and/or form of suitable hardware, software, or combination of hardware and software to support, enable, or provide for the connection and use of multiple display devices **124***a*-**124***n* by the computing device **121**. For example, the computing device **121** may include any type and/or form of video adapter, video card, driver, and/or library to interface, communicate, connect or otherwise use the display devices **124***a*-**124***n*. In some embodiments, a video adapter may comprise multiple connectors to interface to multiple display devices **124***a*-**124***n*. In some other embodiments, the computing device **121** may include multiple video adapters, with each video adapter connected to one or more of the display devices **124***a*-**124***n*. In some embodiments, any portion of the operating system of the computing device **100** may be configured for using multiple displays **124***a*-**124***n*. In some embodiments, one or more of the display devices **124***a*-**124***n* may be provided by one or more other computing devices connected to the computing device **121**, for example, via a network. Such embodiments may include any type of software designed and constructed to use another computer's display device as a second display device **124***a* for the computing device **121**. One ordinarily skilled in the art will recognize and appreciate the various ways and embodiments that a computing device **121** may be configured to have multiple display devices **124***a*-**124***n*.

In further embodiments, an I/O device **130** may be a bridge **170** between the system bus **150** and an external communication bus, such as a USB bus, an Apple Desktop Bus, an RS-232 serial connection, a SCSI bus, a FireWire bus, a FireWire 800 bus, an Ethernet bus, an AppleTalk bus, a Gigabit Ethernet bus, an Asynchronous Transfer Mode bus, a HIPPI bus, a Super HIPPI bus, a SerialPlus bus, a SCI/LAMP bus, a FibreChannel bus, and/or a Serial Attached small computer system interface bus, among others.

A computing device **121** of the sort depicted in FIGS. **1***c* and **1***d* may typically operate under the control of operating systems, which control scheduling of tasks and access to system resources. The computing device **121** can be running any operating system such as any of the versions of the Microsoft® Windows operating systems, any of the different releases of the Unix and Linux operating systems, any version of the Mac OS® for Macintosh computers, any embedded operating system, any real-time operating system, any open source operating system, any proprietary operating system, any operating systems for mobile computing devices, and/or any other operating system capable of running on a computing device and performing the operations described herein. Typical operating systems include: WINDOWS 3.x, WINDOWS 95, WINDOWS 98, WINDOWS 2000, WINDOWS NT 3.51, WINDOWS NT 4.0, WINDOWS CE, WINDOWS XP, WINDOWS VISTA, WINDOWS 7.0, WINDOWS SERVER 2003, and/or WINDOWS SERVER 2008, all of which are manufactured by Microsoft Corporation of Redmond, Wash.; MacOS, manufactured by Apple Computer of Cupertino, Calif.; OS/2, manufactured by International Business Machines of Armonk, N.Y.; and Linux, a freely-available operating system distributed by Red Hat of Raleigh, N.C., among others, or any type and/or form of a Unix operating system, among others.

In some embodiments, the computing device **121** may have different processors, operating systems, and input devices consistent with the device. For example, in one embodiment the computing device **121** is a Treo 180, 270, 1060, 600 or 650 smart phone manufactured by Palm, Inc. In this embodiment, the Treo smart phone is operated under the control of the PalmOS operating system and includes a stylus input device as well as a five-way navigator device. Moreover, the computing device **121** can be any workstation, desktop computer, laptop, or notebook computer, server, handheld computer, mobile telephone, any other computer, or other form of computing or telecommunications device that is capable of communication and that has sufficient processor power and memory capacity to perform the operations described herein.

Architecture

Reference is now made to FIG. **2**, which is a block diagram illustrating an architecture of a computing device **121** as discussed above regarding FIGS. **1***c* and **1***d*. The architecture of the computing device **121** is provided by way of illustration only and is not intended to be limiting. The architecture of computing device **121** may include a hardware layer **206** and a software layer divided into a user space **202** and a kernel space **204**.

Hardware layer **206** may provide the hardware elements upon which programs and services within kernel space **204** and user space **202** are executed. Hardware layer **206** also provides the structures and elements that allow programs and services within kernel space **204** and user space **202** to communicate data both internally and externally with respect to computing device **121**. The hardware layer **206** may include a processing unit **262** for executing software programs and services, a memory **264** for storing software and data, and network ports **266** for transmitting and receiving data over a network. Additionally, the hardware layer **206** may include multiple processors for the processing unit **262**. For example, in some embodiments, the computing device **121** may include a first processor **262** and a second processor **262'**. In some embodiments, the processor **262** or **262'** includes a multi-core processor. The processor **262** may include any of the processors **101** described above in connection with FIGS. **1***c* and **1***d*.

Although the hardware layer **206** of computing device **121** is illustrated with certain elements in FIG. **2**, the hardware portions or components of computing device **121** may include any type and form of elements, hardware or software, of a computing device, such as the computing device **121** illustrated and discussed herein in conjunction with FIGS. **1***c* and **1***d*. In some embodiments, the computing device **121** may comprise a server, gateway, router, switch, bridge, or other type of computing or network device, and have any hardware and/or software elements associated therewith.

The operating system of computing device **121** allocates, manages, or otherwise segregates the available system memory into kernel space **204** and user space **202**. As discussed above, in the exemplary software architecture, the operating system may be any type and/or form of various ones of different operating systems capable of running on the computing device **121** and performing the operations described herein.

The kernel space **204** may be reserved for running the kernel **230**, including any device drivers, kernel extensions, and/or other kernel related software. As known to those skilled in the art, the kernel **230** is the core of the operating system, and provides access, control, and management of resources and hardware-related elements of the applications. In accordance with some embodiments of the computing device **121**, the kernel space **204** also includes a number of network services or processes working in conjunction with a cache manager sometimes also referred to as the integrated cache. Additionally, some embodiments of the kernel **230** will depend on embodiments of the operating system installed, configured, or otherwise used by the device **121**.

In some embodiments, the device **121** includes one network stack **267**, such as a TCP/IP based stack, for communicating with a client and/or a server. In other embodiments, the device **121** may include multiple network stacks. In some embodiments, the network stack **267** includes a buffer **243** for queuing one or more network packets for transmission by the computing device **121**.

As shown in FIG. **2**, the kernel space **204** includes a high-speed layer 2-7 integrated packet engine **240** and a policy engine **236**. Running packet engine **240** and/or policy engine **236** in kernel space **204** or kernel mode instead of the user space **202** improves the performance of each of these components, alone and in combination. Kernel operation means that packet engine **240** and/or policy engine **236** run in the core address space of the operating system of the device **121**. For example, data obtained in kernel mode may not need to be passed or copied to a process or thread running in user mode, such as from a kernel level data structure to a user level data structure. In this regard, such data may be difficult to determine for purposes of network application performance monitoring. In another aspect, the number of context switches between kernel mode and user mode are also reduced. Additionally, synchronization of and communications between packet engine **240** and/or policy engine **236** can be performed more efficiently in the kernel space **204**.

In some embodiments, any portion of the packet engine **240** and/or policy engine **236** may run or operate in the kernel space **204**, while other portions of packet engine **240** and/or policy engine **236** may run or operate in user space **202**. In some embodiments, the computing device **121** uses a kernel-level data structure providing access to any portion of one or more network packets, for example, a network packet comprising a request from a client or a response from a server. In some embodiments, the kernel-level data structure may be obtained by the packet engine **240** via a transport layer driver interface (TDI) or filter to the network stack **267**. The kernel-level data structure may include any interface and/or data accessible via the kernel space **204** related to the network stack **267**, network traffic, or packets received or transmitted by the network stack **267**. In some embodiments, the kernel-level data structure may be used by packet engine **240** and/or policy engine **236** to perform the desired operation of the component or process. Some embodiments provide that packet engine **240** and/or policy engine **236** is running in kernel mode **204** when using the kernel-level data structure, while in some other embodiments, the packet engine **240** and/or policy engine **236** is running in user mode when using the kernel-level data structure. In some embodiments, the kernel-level data structure may be copied or passed to a second kernel-level data structure, or any desired user-level data structure.

A policy engine **236** may include, for example, an intelligent statistical engine or other programmable application(s). In some embodiments, the policy engine **236** provides a configuration mechanism to allow a user to identify, specify, define or configure a caching policy. Policy engine **236**, in some embodiments, also has access to memory to support data structures such as lookup tables or hash tables to enable user-selected caching policy decisions. In some embodiments, the policy engine **236** may include any logic, rules, functions or operations to determine and provide access, control and management of objects, data or content being cached by the computing device **121** in addition to access, control and management of security, network traffic, network access, compression, and/or any other function or operation performed by the computing device **121**.

High speed layer 2-7 integrated packet engine **240**, also generally referred to as a packet processing engine or packet engine, is responsible for managing the kernel-level processing of packets received and transmitted by computing device **121** via network ports **266**. The high speed layer 2-7 integrated packet engine **240** may include a buffer for queuing one or more network packets during processing, such as for receipt of a network packet or transmission of a network

packer. Additionally, the high speed layer 2-7 integrated packet engine **240** is in communication with one or more network stacks **267** to send and receive network packets via network ports **266**. The high speed layer 2-7 integrated packet engine **240** may work in conjunction with policy engine **236**. In particular, policy engine **236** is configured to perform functions related to traffic management such as request-level content switching and request-level cache redirection.

The high speed layer 2-7 integrated packet engine **240** includes a packet processing timer **242**. In some embodiments, the packet processing timer **242** provides one or more time intervals to trigger the processing of incoming (i.e., received) or outgoing (i.e., transmitted) network packets. In some embodiments, the high speed layer 2-7 integrated packet engine **240** processes network packets responsive to the timer **242**. The packet processing timer **242** provides any type and form of signal to the packet engine **240** to notify, trigger, or communicate a time related event, interval or occurrence. In many embodiments, the packet processing timer **242** operates in the order of milliseconds, such as for example 100 ms, 50 ms, or ms. For example, in some embodiments, the packet processing timer **242** provides time intervals or otherwise causes a network packet to be processed by the high speed layer 2-7 integrated packet engine **240** at a 10 ms time interval, while in other embodiments, at a 5 ms time interval, and still yet in further embodiments, as short as a 3, 2, or 1 ms time interval. The high speed layer 2-7 integrated packet engine **240** may be interfaced, integrated and/or in communication with the policy engine **236** during operation. As such, any of the logic, functions, or operations of the policy engine **236** may be performed responsive to the packet processing timer **242** and/or the packet engine **240**. Therefore, any of the logic, functions, and/or operations of the policy engine **236** may be performed at the granularity of time intervals provided via the packet processing timer **242**, for example, at a time interval of less than or equal to 10 ms.

In contrast to kernel space **204**, user space **202** is the memory area or portion of the operating system used by user mode applications or programs otherwise running in user mode. Generally, a user mode application may not access kernel space **204** directly, and instead must use service calls in order to access kernel services. As shown in FIG. **2**, user space **202** of computing device **121** includes a graphical user interface (GUI) **210**, a command line interface (CLI) **212**, shell services **214**, and daemon services **218**. Using GUI **210** and/or CLI **212**, a system administrator or other user may interact with and control the operation of computing device **121**. The GUI **210** may be any type and form of graphical user interface and may be presented via text, graphical or otherwise, by any type of program or application, such as a browser. The CLI **212** may be any type and form of command line or text-based interface, such as a command line provided by the operating system. For example, the CLI **212** may comprise a shell, which is a tool to enable users to interact with the operating system. In some embodiments, the CLI **212** may be provided via a bash, csh, tcsh, and/or ksh type shell. The shell services **214** may include the programs, services, tasks, processes and/or executable instructions to support interaction with the computing device **121** or operating system by a user via the GUI **210** and/or CLI **212**.

Daemon services **218** are programs that run continuously or in the background and handle periodic service requests received by computing device **121**. In some embodiments, a daemon service may forward the requests to other programs or processes, such as another daemon service **218** as appropriate. As known to those skilled in the art, a daemon service **218** may run unattended to perform continuous and/or periodic system wide functions, such as network control, or to perform any desired task. In some embodiments, one or more daemon services **218** run in the user space **202**, while in other embodiments, one or more daemon services **218** run in the kernel space.

Collector Application

Reference is now made to FIG. **3**, which is a block diagram illustrating operations and/or functions of a collector application **200** as described above regarding FIG. **1***a*. The collector application **200** includes a kernel space module **310** and a user space module **320**. The kernel space module **310** may generally operate to intercept network activities as they occur. Some embodiments provide that the kernel space module **310** may use a kernel mode interface in the operating system, such as, for example, Microsoft Windows transport data interface (TDI). The kernel space module **310** may include a TDI filter **314** that is configured to monitor and/or intercept interactions between applications. Additionally, some embodiments provide that the kernel space module **310** may include an ancillary functions driver (AFD) filter **312** that is configured to intercept read operations and the time of their duration. Some operating systems may include a kernel mode driver other than the AFD. In this regard, operations described herein may be used with other such kernel mode drivers to intercept application operational data.

The raw data related to the occurrence of and attributes of transactions between network applications may be generally referred to as "performance data." The raw data may have value for diagnosing network application performance issues and/or for identifying and understanding the structure of the network applications. The measurements or aggregations of performance data may be generally referred to as "metrics" or "performance metrics." Performance data and the metrics generated therefrom may be temporally relevant—i.e., the performance data and the metrics may be directly related to and/or indicative of the health of the network at the time the performance data is collected. Performance data may be collected, and metrics based thereon may be generated, on a client side and/or a server side of an interaction. Some embodiments provide that performance data is collected in substantially real-time. In this context, "substantially real-time" means that performance data is collected immediately subsequent to the occurrence of the related network activity, subject to the delays inherent in the operation of the computing device and/or the network and in the method of collection. The performance data collected and/or the metrics generated may correspond to a predefined time interval. For example, a time interval may be defined according to the dynamics of the network and may include exemplary period lengths of less than 1, 1, 5, 10, 15, 20, 30, and/or 60, seconds, among others.

Exemplary client side metrics may be aggregated according to one or more applications or processes. For example, the client side metrics may be aggregated according to destination address, port number, and a local process identifier (PID). A PID may be a number used by some operating system kernels to uniquely identify a process. This number may be used as a parameter in various function calls allowing processes to be manipulated, such as adjusting the process's priority and/or terminating the process. In this manner, multiple connections from the same application or process to the same remote service may be aggregated. As discussed in more detail with respect to FIGS. **10-11**, client side metrics for processes that work together as a single logical unit may also be aggregated into process pools.

Similarly, server side metrics may be aggregated according to the same application or service regardless of the client. For example, some embodiments provide that server side metrics may be aggregated according to local address, port number, and PID. Respective ones of the client side and server side metrics may be collected from the kernel space and/or user space.

The kernel space module **310** may include a kernel events sender **316** that is configured to receive performance data from the AFD filter **312** and/or the TDI filter **314**, and generate metrics based on the performance data for receipt by a kernel events receiver **322** in the user space module **320**. In the user space module **320**, metrics data received by the kernel event receiver **322** may be processed by a reverse domain name system (DNS) resolver **325** to map an observed network address to a more user-friendly DNS name. Additionally, metrics data received by the kernel events receiver **322** may be used by a process resolver **326** to determine the processes and/or applications corresponding to the collected kernel metrics data.

The user space module **320** may include a machine information collector **324** that is operable to determine static machine information, such as, for example, CPU speed, memory capacity, and/or operating system version, among others. As the performance data is collected corresponding to applications and/or processes, the machine information may be non-correlative relative to the applications and/or processes. The user space module **320** may include a process data collector **328** that collects data corresponding to the processes and/or applications determined in the process resolver **326**. A machine performance data collector **330** may collect machine specific performance data. Examples of machine data may include information about resource utilization such as the amount of memory in use and/or the percentage of available CPU time consumed. The user space module **320** may include an event dispatcher **332** that is configured to receive the machine information, resolved DNS information, process identification, process data, and/or machine data, and to generate events incorporating the aggregated metrics data for dispatch to a health data processor application **100** that is operable to receive aggregated metrics data from multiple collectors **200**.

Some embodiments provide that the performance data collected and/or metrics generated may be diagnostically equivalent and, thus, may be aggregated into a single event. The identification process may depend on which application initiates a network connection and which end of the connection is represented by a current collector application host.

Kernel level metrics may generally include data corresponding to read operations that are in progress. For example, reference is now made to FIG. **4**, which is a diagram illustrating determining a read wait time corresponding to a user transaction according to some embodiments of the present invention. A user transaction between a client **401** and a server **402** are initiated when the client **401** sends a write request at time T**1** to the server **402**. The server **402** completes reading the request at time T**2** and responds to the request at time T**3** and the client **401** receives the response from the server **402** at time T**4**. A kernel metric that may be determined is the amount of time spent between beginning a read operation and completing the read operation. In this regard, client measured server response time **410** is the elapsed time between when the request is sent (T**1**) and when a response to the request is read (T**4**) by the client. Accordingly, the client measured server response time **410** may be determined as T**4**−T**1**. The server **402** may determine a server measured server response time **412** that is the elapsed time between when the request is read (T**2**) by the server **402** and when the response to the request is sent (T**3**) by the server **402** to the client **401**. Accordingly, the server measured server response time **412** may be determined as T**3**−T**2**.

As the application response is measured in terms of inbound and outbound packets, the application response time may be determined in an application agnostic manner.

Additionally, another metric that may be determined is the read wait time **414**, which is the elapsed time between when the client **401** is ready to read a response to the request T**5** and when the response to the request is actually read T**4**. In some embodiments, the read wait time may represent a portion of the client measured server response time **410** that may be improved upon by improving performance of the server **402**. Further, the difference between the client measured server response time **410** and the server measured server response time **412** may be used to determine the total transmission time of the data between the client **401** and the server **402**. Some embodiments provide that the values may not be determined until a read completes. In this regard, pending reads may not be included in this metric. Further, as a practical matter, higher and/or increasing read time metrics discussed above may be indicative of a slow and/or poor performing server **402** and/or protocol where at least some messages originate unsolicited at the server **402**.

Other read metrics that may be determined include the number of pending reads. For example, the number of read operations that have begun but are not yet completed may be used to detect high concurrency. In this regard, high and/or increasing numbers of pending read operations may indicate that a server **402** is not keeping up with the workload. Some embodiments provide that the total number of reads may include reads that began at a time before the most recent aggregated time period.

Additionally, some embodiments provide that the number of reads that were completed during the last time period may be determined. An average of read wait time per read may be generated by dividing the total read wait time, corresponding to a sum of all of the T**4**-T**5** values during the time period, by the number of completed reads in that period.

In some embodiments, the number of stalled reads may be determined as the number of pending reads that began earlier than a predefined threshold. For example, a predefined threshold of 60 seconds may provide that the number of pending read operations that began more than 60 seconds ago are identified as stalled read operations. Typically, any value greater than zero may be undesirable and/or may be indicative of a server-initiated protocol. Some embodiments may also determine the number of bytes sent/received on a connection.

The number of completed responses may be estimated as the number of times a client-to-server message (commonly interpreted as a request) was followed by a server-to-client message (commonly interpreted as a response). Some embodiments provide that this may be measured by both the server and the client connections. In some embodiments, this may be the same as the number of completed reads for a given connection. Additionally, a total response time may be estimated as the total time spent in request-to-response pairs.

Reference is now made to FIG. **5**, which is a block diagram illustrating a kernel level architecture of a collector application **200** to explain kernel level metrics according to some embodiments of the present invention. As discussed above, regarding FIG. **3**, the collector may use a TDI filter **314** and an AFD filter **312**. The AFD filter **312** may intercept network activity from user space processes that use a library defined in a standard interface between a client application and an underlying protocol stack in the kernel.

The TDI filter **314** may operate on a lower layer of the kernel and can intercept all network activity. As the amount of

information available at AFD filter **312** and TDI filter **314** is different, the performance data that may be collected and the metrics that may be generated using each may also be different. For example, the AFD filter **312** may collect AFD performance data and generate AFD metrics that include total read wait time, number of completed reads, number of pending reads and number of stalled reads, among others. The TDI filter may collect TDI performance data and generate TDI metrics including total bytes sent, total bytes received, total response time and the number of responses from the server. Depending on the architecture of a target application, the AFD metrics for client-side connections may or may not be available. In this regard, if the application uses the standard interface, the collector may report non-zero AFD metrics. Otherwise, all AFD metrics may not be reported or may be reported as zero.

Some embodiments provide that kernel level metrics may be generated corresponding to specific events. Events may include read wait metrics that may include client side metrics such as total read wait time, number of completed reads, number of pending reads, number of stalled reads, bytes sent, bytes received, total response time, and/or number of responses, among others. Events may further include server response metrics such as bytes sent, bytes received, total response time and/or number of responses, among others.

In addition to the kernel metrics discussed above, the collector **200** may also generate user level metrics. Such user level metrics may include, but are not limited to aggregate CPU percentage (representing the percentage of CPU time across all cores), aggregate memory percentage (i.e., the percentage of physical memory in use by a process and/or all processes), and/or total network bytes sent/received on all network interfaces, among others. User level metrics may include, but are not limited to, the number of page faults (the number of times any process tries to read from or write to a page that was not in its resident in memory), the number of pages input (i.e., the number of times any process tried to read a page that had to be read from disk), and/or the number of pages output (representing the number of pages that were evicted by the operating system memory manager because it was low on physical memory), among others. User level metrics may include, but are not limited to, a queue length (the number of outstanding read or write requests at the time the metric was requested), the number of bytes read from and/or written to a logical disk in the last time period, the number of completed read/write requests on a logical disk in the last time period, and/or total read/write wait times (corresponding to the number of milliseconds spent waiting for read/write requests on a logical disk in the last time interval), among others.

Further, some additional metrics may be generated using data from external application programming interfaces. Such metrics may include, for example: the amount of memory currently in use by a machine memory control driver; CPU usage expressed as a percentage; memory currently used as a percentage of total memory; and/or total network bytes sent/received, among others.

In some embodiments, events may be generated responsive to certain occurrences in the network. For example events may be generated: when a connection, such as a TCP connection, is established from or to a machine; when a connection was established in the past and the collector application **200** first connects to the health data processing application **100**; and/or when a connection originating from the current machine was attempted but failed due to timeout, refusal, or because the network was unreachable. Events may be generated when a connection is terminated; when a local server process is listening on a port; when a local server process began listening on a port in the past and the collector application **200** first connects to the health data processing application **100**; and/or when a local server process ceases to listen on a port. Events may be generated if local network interfaces have changed and/or if a known type of event occurs but some fields are unknown. Events may include a description of the static properties of a machine when a collector application **200** first connects to a health data processing application **100**; process information data when a process generates its first network-related event; and/or information about physical disks and logical disks when a collector application **200** first connects to a health data processing application **100**.

Some embodiments provide that the different link events may include different data types corresponding to the type of information related thereto. For example, data strings may be used for a type description of an event. Other types of data may include integer, bytes and/or Boolean, among others.

In some embodiments, the events generated by collector application **200** for dispatch to heath data processing application **100** may incorporate metrics related to network structure, network health, computational resource health, virtual machine structure, virtual machine health, and/or process identification, among others. Metrics related to network structure may include data identifying the network device on which collector application **200** is executing, or data related to the existence, establishment, or termination of network links, or the existence of bound ports or the binding or unbinding of ports. Metrics pertinent to network health may include data related to pending, completed, and stalled reads, bytes transferred, and response times, from the perspective of the client and/or the server side. Metrics related to computational resource health may include data regarding the performance of the network device on which collector application **200** is executing, such as processing and memory usage. Metrics related to virtual machine structure may include data identifying the physical host machine on which collector application **200** is executing, and/or data identifying the virtual machines executing on the physical host machine. Metrics pertinent to virtual machine health may include regarding the performance of the host machine and/or the virtual machines executing on the host machine, such as processing and memory usage as determined from the perspective of the host machine and/or the virtual machines. Finally, metrics related to process identification may include data identifying individual processes executing on a network device.

Reference is made to FIG. **6**, which illustrates exemplary operations that may be carried out by collector application **200** in monitoring and reporting network application performance according to some embodiments of the present invention. At block **600**, collector application **200** establishes hooks on a networked device to an internal network protocol kernel interface utilized by the operating system of the networked device. In some embodiments, these hooks may include, for instance, a TDI filter. Collector application **200** also establishes hooks to an application oriented system call interface to a transport network stack. The hooks may include, in some embodiments, an AFD filter. Collector application **200** collects, via the established hooks, performance data corresponding to at least one network application running on the networked device (block **602**). At block **604**, kernel level and user level metrics are generated based on the collected performance data. The generated metrics may provide an indication of the occurrence of an interaction (e.g., establishment of a network link), or may provide measurements of, for instance, a count of some attribute of the collected performance data (e.g., number of completed reads) or

a summation of some attribute of the collected performance data (e.g., total read attempts). The kernel level and user level metrics are aggregated by application—e.g., by aggregating metrics associated with the same IP address, local port, and process ID (block **606**). At block **608**, the kernel level and user level metrics generated within a specified time interval are aggregated. For instance, in some embodiments, metrics generated within the most recent 15-second time interval are aggregated.

At block **610**, redundant data is removed from the aggregated metrics, and inconsistent data therein is reconciled. Redundant data may include, for instance, functionally equivalent data received from both the TDI and AFD filters. Collector application **200** performs a reverse DNS lookup to determine the DNS name associated with IP addresses referenced in the generated kernel level and user level metrics (block **612**). Finally, at block **614**, an event is generated, incorporating the kernel level and user level metrics and the determined DNS name(s). The generated event may be subsequently transmitted to health data processing application **100** for incorporation into a model of network health status.

Installation without Interruption

In some embodiments, the collector application **200** may be installed into a machine of interest without requiring a reboot of the machine. This may be particularly useful in the context of a continuously operable system, process and/or operation as may be frequently found in manufacturing environments, among others. As the collector operations interface with the kernel, and more specifically, the protocol stack, installation without rebooting may entail intercepting requests coming in and out of the kernel using the TDI filter. Some embodiments include determining dynamically critical offsets in potentially undocumented data structures. Such offsets may be used in intercepting network activity for ports and connections that exist prior to an installation of the collector application **200**. For example, such previously existing ports and connections may be referred to as the extant state of the machine.

Some embodiments provide that intercepting the stack data may include overwriting the existing stack function tables with pointers and/or memory addresses that redirect the request through the collector filter and then to the intended function. In some embodiments, the existing stack function tables may be overwritten atomically in that the overwriting may occur at the smallest indivisible data level. Each entry in a function table may generally include a function pointer and a corresponding argument. However, only one of these entries (either the function or the argument) can be overwritten at one time. Thus, intercepting function calls may rely on two consecutive overwrites of the stack data corresponding to the function and corresponding argument. In some embodiments, there is no means for protecting from an intervening operation between overwriting one of the function and argument and overwriting the other one of them. In this regard, system stability may be at risk from two attempted consecutive overwrites.

As the consecutive overwrites of intercepting function calls may place the machine at risk of instability, a dynamic overwriting operation may be used. Specifically, a separate data structure is provided that includes a pointer to the original function, its original argument and dynamically generated code to call a filter in the collector application **200**. The address of this data structure may be used to atomically overwrite the original function pointer in a single operation. The collector collects the data and then calls the original function corresponding to the overwritten stack data to perform its intended purpose. In this manner, the original behavior of the machine is preserved and the collector application collects the relevant data without rebooting the machine and/or placing the machine at risk of instability.

Some embodiments may include identifying the potentially undocumented data structures representing bound ports and network connections. For example, TDI objects (connections and bound ports) created prior to the installation of the collector application **200** may be determined by first enumerating all objects identified in a system. Each of the enumerated objects may be tagged with an identifier corresponding to its sub-system. A request corresponding to a known TDI object is created and sent for processing. The type codes of the enumerated objects are compared to those of the known TDI object to determine which of the objects are ports and which of the objects are connections. The enumerated objects may then be filtered as either connections or ports.

In some embodiments, this may be accomplished using an in-kernel thread. The thread may monitor network connections having restricted visibility and may detect when a monitored connection no longer exists. Connections may be added dynamically to the monitored list as needed.

Some embodiments provide that events may be generated to indicate that visibility into network events may be incomplete. For example, information may be missing corresponding to an active process, the state of a known connection, and/or missing information regarding network activity. In this manner, depending on conditions, a custom event can be transmitted to indicate what type of information is missing and what process may be responsible for that information.

Health Data Processing Application

In some embodiments, the health data processing application **100** may be operable to receive, from at least one collector application **200**, network activity data corresponding to network activity of the applications on the network device on which the collector application **200** is installed. The health data processing application **100** may combine the network activity data received from the collector application **200** to remove redundant portions thereof. In some embodiments, the health data processing application **100** may archive the received activity data in a persistent data store along with a timestamp indicating when the activity data was collected and/or received. The health data processing application **100** may generate a model that includes identified network application components and their relatedness and/or links therebetween. The generated model may be displayed via one or more display devices such as, e.g., display devices **124*a*-124*n*** discussed in greater detail above.

In some embodiments, the health data processing application **100** may be operable to combine network activity data reported from multiple collector applications **200** to eliminate redundancy and to address inconsistencies among data reported by different collector applications **200**. For example, network data from multiple collector applications **200** may be stitched together to create a consistent view of the health of the network applications.

Some embodiments provide that the model may be a graphical display of the network including application components (machines, clients, processes, etc.) and the relationships therebetween. In some embodiments, the model may be generated as to reflect the real-time or near-real-time activity of the network. It is to be understood that, in this context, "near-real-time" may refer to activity occurring in the most recent of a specified time interval for which activity data was received. For instance, health data processing application **100** may receive from collector applications **200** aggregated activity data corresponding to the most recent 15-second interval of network operation, and, accordingly, the model of near-real-time activity may reflect the activity of the network as it existed during that most recent 15-second interval.

Some embodiments provide that the model may be generated to reflect an historical view of network activity data corresponding to a specified time interval. The historical view may be generated based on archived activity data retrieved from a persistent data store and having a timestamp indicating that the activity data was collected or received during the specified time interval. In other embodiments, the model may be dynamically updated to reflect new and/or lost network collectors and/or network components. Further, graphs may be provided at each and/or selected network resource indicators to show activity data over part of and/or all of the time interval.

In some embodiments, a model may include sparklines to provide quick access to trends of important metrics, process and application views to provide different levels of system detail, and/or model overlays to provide additional application analysis. For example, visual feedback regarding the contribution of a network link relative to a given criterion may be provided. In this manner, hop by hop transaction data about the health of applications can be provided. Additionally, visual ranking of connections based on that criteria may be provided. Bottleneck analysis based on estimated response times may be provided to identify slow machines, applications, and/or processes, among others.

Some embodiments provide that health data processing application **100** may be operable to infer the existence of network devices and/or network applications for which no activity data was received or on which no collector application **200** is running, based on the identification of other network devices and/or other network applications for which activity data was received. For instance, activity data received by health data processing application **100** may indicate that a network link has been established between a local network device running collector application **200** and a remote network device that is not running collector application **200**. Because the activity data may include identifying information for both the local and remote network devices, health data processing application **100** may infer that the remote network device exists, and incorporate the remote network device into the generated model of network activity.

In other embodiments, health data processing application **100** may be operable to identify a network application based on predefined telecommunications standards, such as, e.g., the port numbers list maintained by the Internet Assigned Numbers Authority (IANA). Health data processing application **100** may, for example, receive activity data indicating that a process on a network device is bound to port **21**. By cross-referencing the indicated port number with the IANA port numbers list, health data processing application **100** may identify the process as an File Transfer Protocol (FTP) server, and may include the identification in the generated model.

Reference is made to FIG. **7**, which is a screen shot of a graphical user interface (GUI) including a model generated by a health data processing application according to some embodiments of the present invention. The GUI **700** includes a model portion **701** that illustrates representations of various network applications and/or application components **702**. Such representations may include identifier fields **704** that are operable to identify application and/or application component addresses, ports, machines and/or networks. Connections **706** between network applications and/or application components may be operable to convey additional information via color, size and/or other graphical and/or text-based information. A summary field **708** may be provided to illustrate summary information corresponding to one or more applications and/or application components, among others. A port identification portion **712** may be operable to show the connections corresponding to and/or through a particular port. The GUI **700** may include a system and/or network navigation field **710**, overlay selection field **714**, and one or more time interval and/or snapshot field(s) **716**.

FIG. **8** is a flowchart illustrating exemplary operations that may be carried out by health data processing application **100** in generating and displaying a real-time model of network application health according to some embodiments of the present invention. At block **800**, health data processing application **100** may receive activity data from a plurality of collector applications **200** executing on respective ones of a plurality of network devices. The received activity data corresponds to activities of a plurality of network applications executing on respective ones of the plurality of networked devices. At block **802**, the received activity data is archived along with a timestamp indicating when the activity data was collected and/or received. As discussed in greater detail with respect to FIG. **9**, this archived data may allow health data processing application **100** to generate and display an historical model of network application health during a specified time interval. At block **804**, the received activity data is combined to remove redundant data and to reconcile inconsistent data. At block **806**, health data processing application **100** identifies the network applications executing on the respective ones of the plurality of networked devices, and ascertains the relationships therebetween. The identification of the network applications and the relationships therebetween may be based on the received activity data, and may further be determined based on a correlation between the received activity data and predefined industry standards, as discussed above. At block **808**, health data processing application **100** may infer the existence of network applications for which no activity data was received, based on the identification of network applications for which activity data was received. At block **810**, a real-time model of network health status, including the identified network applications and the relationships therebetween, is generated, and the model is displayed at block **812**.

FIG. **9** is a flowchart illustrating exemplary operations carried out by a health data processing application **100** in generating and displaying an historical model of network application health according to some embodiments of the present invention. At block **900**, the activity data previously archived at block **802** and corresponding to a specified time interval is retrieved. The retrieved activity data is combined to remove redundant data and reconcile inconsistent data at block **902**. At block **904**, health data processing application **100** identifies the network applications associated with the retrieved activity data, and ascertains the relationships therebetween. The identification of the network applications and the relationships therebetween may be based on the retrieved activity data, and may further be determined based on correlation between the retrieved activity data and industry standards. At block **906**, health data processing application **100** may infer the existence of network applications for which no activity data was retrieved, based on the identification of network applications for which activity data was retrieved. At block **908**, an historical model of network health status in the specified time interval, including the identified network applications and the relationships therebetween, is generated, and the historical model is displayed at block **910**.

Custom Protocol

Some embodiments provide that transferring the activity data between the collector applications **200** and the health data processing application **100** may be performed using a compact, self-describing, linear buffer communications protocol. In some embodiments, the custom protocol uses a common representation for monitoring information, commands and configuration data. As the methods and systems described herein are intended to monitor network performance, the protocol may be operable to minimize the volume of information exchanged between the collector applications **200** and the health data processing application **100**.

In some embodiments, the collector applications **200** are operable to generate events in a streaming data format. Events may be generated corresponding to the predefined monitoring time period. Information provided corresponding to an event may include an event type, network resource identification data including PID, remote identifiers, quantities and/or types of data sent/received, and/or response time information, among others. The protocol may include a banner portion that may be established through a handshaking process that may occur when a collector application **200** initially communicates with the health data processing application **100**. The banner portion may define the data types and formats to be transferred. In this manner, the protocol may be flexible by virtue of the self-descriptive banner portion and may avoid sending unused, unwanted or blank data fields.

Monitoring and Reporting Performance of Network Applications Executing in Operating-System-Level Virtualization Containers

Reference is now made to FIG. **10**, which is a block diagram illustrating the architecture of a system providing full-machine virtualization according to some embodiments of the present invention. As discussed above, collector application **200**, in some embodiments, may be operable to collect performance data and generate metrics for network applications that are executing within a virtual machine environment—i.e., within a virtual machine provided by a full-machine virtualization platform, such as VMware, among others. Such a full-machine virtualization platform may execute on a single physical computer but may provide multiple isolated virtual machines, each of which may execute a separate instance of an operating system, and may be perceived as a separate physical computer by the operating system instance and user applications executing within the virtual machine. For example, as seen in FIG. **10**, physical machine **1000**, which may be a computing device as described above and illustrated in FIGS. **1***c* and **1***d*, may run virtualization platform **1005**, which may be the software that provides full-machine virtualization functionality. Virtualization platform **1005** may provide virtual machines **1010** and **1015**, each of which may execute its own instance of an operating system (such as operating system instances **1020** and **1025**, respectively).

In some embodiments, collector application **200**, when executing within a full-machine virtualization system, may run on physical machine **1000**, or may run within virtual machines **1010** and/or **1015**. In this way, performance data may be gathered and events generated for each physical and/or virtual machine.

In contrast to full-machine virtualization, some operating systems may provide virtualization at the operating system level. Reference is now made to FIG. **11**, which is a block diagram illustrating the architecture of a system providing operating-system-level virtualization according to some embodiments of the present invention. This type of virtualization is distinct from full-machine virtualization in that the kernel of the operating system may allow the creation of multiple isolated user space instances, referred to as virtualization containers. For example, as illustrated by FIG. **11**, physical machine **1100**, which may be a computing device as described above and illustrated in FIGS. **1***c* and **1***d*, may execute primary operating system **1105**, which may provide operating-system-level virtualization functionality. Primary operating system **1105** may provide global virtualization container **1110**, within which multiple operating system virtualization containers **1110** and **1115** may be created. Some examples of virtualization containers, among others, are Workload Partitioning (WPAR) containers provided by the AIX operating system, and Zones provided by the Solaris operating system.

Collector application **200**, when executed within an operating-system-level virtualization system, may run within global virtualization container **1110**, while the network applications to be monitored by collector application **200** may run within operating system virtualization containers **1115** and **1120**. However, because operating system virtualization containers **1115** and **1120** are isolated from global virtualization container **1110** by primary operating system **1105**'s isolation mechanisms, collector application **200** may not be able to collect performance data from the network applications executing within operating system virtualization containers **1115** and **1120**. Moreover, when a process executing within a particular operating system virtualization container binds a port to the ANY (0.0.0.0) or loopback (127.0.0.1) IP addresses within that operating system virtualization container, collector application **200** may not be able to determine in which operating system virtualization container the bind occurred. This could result in the model of network application health generated by health data processing application **100** being unable to provide an accurate depiction of the existing network links.

Accordingly, in some embodiments, collector application **200** may provide a method for monitoring the performance of network applications executing within operating system virtualization containers **1115** and **1120**. Collector application **200** may first enumerate the existing virtualization containers present in the global virtualization container **1110**. In some embodiments, enumerating may include determining the name and identifier of each operating system virtualization container, the root location of each operating system virtualization container's file system in a machine global context, and/or the IP addresses assigned to each operating system virtualization container, among others.

Collector application **200** may then create, for each enumerated operating system virtualization container **1115** and **1120**, a named pipe that is accessible for writing from within each of operating system virtualization containers **1115** and **1120**, and from which collector application **200** may read. It is to be understood that a "named pipe" is a first-in, first-out (FIFO) data conduit that enables the transmission of data between executing processes. In some embodiments, collector application **200** may create the named pipe within the file system for each of operating system virtualization containers **1115** and **1120**, using the root location of each operating system virtualization container's file system as determined during collector application **200**'s enumeration of the existing operating system virtualization containers. Collector application **200** may retrieve, via the named pipe, performance data collected within operating system virtualization containers **1115** and **1120** (for example, performance data gathered by network applications running within operating system virtualization containers **1115** and **1120**), effectively overcoming the isolation between operating system virtualization containers **1115** and **1120** and the global virtualization container **1110**. Collector application **200** may then generate kernel level metrics and/or user level metrics based on the collected performance data, and may generate an event incorporating the kernel level metrics and the user level metrics.

Some embodiments may provide that the generated event includes an IP address, a port, and/or a container identifier, among others. For example, the generated event may include a data block as illustrated below:

IP Address	Port Number	Container Identifier

In some embodiments, health data processing application **100** may use the additional data provided by the generated event to more accurately model network application health, such as, e.g., by providing special modeling of intra-container connections to the ANY and/or loopback IP addresses.

In some embodiments, collector application **200**'s enumeration of the existing virtualization containers occurs on system startup. This allows collector application **200** to obtain a view of the initial state of the virtualization environment immediately after the system begins execution. Some embodiments may provide that enumeration of the existing virtualization containers occurs in response to the startup or shutdown of an individual virtualization container, thus permitting collector application **200** to maintain an accurate list of open virtualization containers.

Collector application **200**, in some embodiments, may execute on operating systems that may not permit a virtualization container to shut down if there exists an active connection to a named pipe within the virtualization container. Accordingly, collector application **200** may monitor a container shutdown function, for instance by "hooking," or intercepting calls to, the container shutdown function. When a call to the container shutdown function is detected for a virtualization container, collector application **200** may remove the named pipe for the virtualization container prior to shutdown to avoid interfering with the container shutdown. Some embodiments may provide that collector application **200** hooks the system shutdown function and/or the system reboot function, and, in response to a call to the system shutdown function and/or the system reboot function, removes all named pipes for existing virtualization containers prior to system shutdown or reboot.

In some embodiments, an operating system that provides named pipe functionality may monitor the number of write connections to a named pipe, and, in order to conserve system resources, may automatically remove the named pipe when all data sources within the operating system virtualization container have released the named pipe. To prevent this automatic removal from occurring, some embodiments may provide that collector application **200** may create and maintain its own write connection to each named pipe that it creates—i.e., collector application **200** may hold both a read connection and a write connection to each named pipe, in addition to any write connections to the named pipes from within operating system virtualization containers **1115** and **1120**. Accordingly, as long as collector application **200** holds a write connection to each named pipe, the operating system will not remove the named pipe should there temporarily be no active connections to the named pipe within operating system virtualization containers **1115** and **1120**.

Reference is now made to FIG. **12**, which a flowchart illustrating exemplary operations carried out by a collector application **200** in monitoring the performance of network applications executing within an operating-system-level virtualization containers utilizing named pipes. At block **1200**, collector application **200** enumerates the operating-system-level virtualization containers on the networked device. In doing so, collector application **200** may determine a name, an identifier, a root location of the file system in a machine global context, and/or one or more assigned IP addresses for each virtualization container. Collector application **200** creates a named pipe in the root location of each virtualization container's file system (block **1205**). Within each container, performance data is gathered by at least one network application running within the container, the performance data including an IP address, a port, and/or a container identifier (block **1210**). At block **1215**, collector application **200** retrieves, via the named pipes, the performance data collected within each container. Collector application **200** generates, for each container, metrics based on the retrieved performance data (block **1220**), and generates an event incorporating the metrics, including the container identifier (block **1225**).

Many variations and modifications can be made to the embodiments without substantially departing from the principles of the present invention. The following claims are provided to ensure that the present application meets all statutory requirements as a priority application in all jurisdictions and shall not be construed as setting forth the scope of the present invention.

That which is claimed:

1. A method for monitoring application performance in a networked device that provides operating-system-level virtualization containers, the method comprising:

enumerating one or more operating-system-level virtualization containers on the networked device;

creating a named pipe that is accessible by at least one application running in a respective one of the one or more operating-system-level virtualization containers and that is configured to receive data from within the respective one of the one or more operating-system-level virtualization containers;

retrieving, via the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, performance data gathered by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, wherein the collected performance data includes an identification of the respective one of the one or more operating-system-level virtualization containers;

maintaining a write connection to the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, wherein the write connection is operative to prevent the named pipe from being automatically closed;

generating a plurality of metrics based on the retrieved performance data; and

generating an event incorporating at least one of the plurality of metrics;

wherein said enumerating one or more operating-system-level virtualization containers, creating a named pipe, retrieving performance data, generating a plurality of metrics, and/or generating an event comprise operations performed using at least one programmed computer processor circuit.

2. The method of claim **1**, wherein creating the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers comprises creating the named pipe within a file system for the respective one of the one or more operating-system-level virtualization containers.

3. The method of claim **1**, wherein the generated event comprises a container identifier associated with the one or more operating-system-level virtualization containers.

4. The method of claim **1**, wherein enumerating one or more operating-system-level virtualization containers on the networked device comprises determining, for a respective one of the one or more operating-system-level virtualization containers

a root location of a file system in a machine global context.

5. The method of claim **1**, wherein enumerating one or more operating-system-level virtualization containers on the networked device occurs responsive to a system startup.

6. The method of claim **5**, wherein enumerating one or more operating-system-level virtualization containers further occurs responsive to a startup and/or a shutdown of an operating-system-level virtualization container on the networked device.

7. The method of claim **1**, the method further comprising:

monitoring, for a respective one of the one or more operating-system-level virtualization containers, a call to a container shutdown function; and

removing the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers responsive to detecting the call to the container shutdown function.

8. The method of claim **1**, the method further comprising:

monitoring a call to a system shutdown and/or a system reboot function; and

removing the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers responsive to detecting the call to the system shutdown and/or the system reboot function.

9. A computer program product comprising:

a non-transitory computer readable storage medium having computer readable program code embodied therein, the computer readable program code executable on a processor, comprising:

computer readable program code configured to enumerate one or more operating-system-level virtualization containers on a networked device;

computer readable program code configured to create a named pipe that is accessible by at least one application running in a respective one of the one or more operating-system-level virtualization containers and that is configured to receive data from within the respective one of the one or more operating-system-level virtualization containers;

computer readable program code configured to retrieve, via the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, performance data gathered by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, wherein the collected performance data includes an identification of the respective one of the one or more operating-system-level virtualization containers;

computer readable program code configured to maintain a write connection to the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, wherein the write connection is operative to prevent the named pipe from being automatically closed;

computer readable program code configured to generate a plurality of metrics based on the retrieved performance data; and computer readable program code configured to generate an event incorporating at least one of the plurality of metrics.

10. The computer program product of claim **9**, wherein the computer readable program code configured to create the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers comprises computer readable program code configured to create the named pipe within a file system for the respective one of the one or more operating-system-level virtualization containers.

11. The computer program product of claim **9**, wherein the generated event comprises a container identifier associated with the one or more operating-system-level virtualization containers.

12. The computer program product of claim **9**, wherein the computer readable program code configured to enumerate one or more operating-system-level virtualization containers on the networked device comprises computer readable program code configured to determine, for a respective one of the one or more operating-system-level virtualization containers a root location of a file system in a machine global context.

13. The computer program product of claim **9**, wherein the computer readable program code configured to enumerate one or more operating-system-level virtualization containers on the networked device is further configured to enumerate one or more operating-system-level virtualization containers on the networked device responsive to a system startup.

14. The computer program product of claim **13**, wherein the computer readable program code configured to enumerate one or more operating-system-level virtualization containers on the networked device is further configured to enumerate one or more operating-system-level virtualization containers on the networked device responsive to a startup and/or a shutdown of an operating-system-level virtualization container on the networked device.

15. The computer program product of claim **9**, the computer readable program code comprising further comprising:

computer readable program code configured to monitor, for a respective one of the one or more operating-system-level virtualization containers, a call to a container shutdown function; and

computer readable program code configured to remove the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers responsive to detecting the call to the container shutdown function.

16. The computer program product of claim **9**, the computer readable program code further comprising:

computer readable program code configured to monitor a call to a system shutdown and/or a system reboot function; and

computer readable program code configured to remove the named pipe that is accessible by the at least one application running in the respective ones of the one or more operating-system-level virtualization containers responsive to detecting the call to the system shutdown and/or the system reboot function.

17. A computer implemented method embodied on a non-transitory computer-readable medium and executable by a processor, the method comprising:

creating a named pipe that is accessible by at least one application running in a respective one of one or more operating-system-level virtualization containers on a networked device, and that is configured to receive data from within the respective one of the one or more operating-system-level virtualization containers on the networked device; and

retrieving, via the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, performance data gathered by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, wherein the collected performance data includes an identification of the respective one of the one or more operating-system-level virtualization containers; and

maintaining a write connection to the named pipe that is accessible by the at least one application running in the respective one of the one or more operating-system-level virtualization containers, wherein the write connection is operative to prevent the named pipe from being automatically closed.

18. The method of claim **17**, further comprising:

generating a plurality of metrics based on the retrieved performance data; and

generating an event incorporating at least one of metrics.

19. The method of claim **1**, wherein the generated event comprises an IP address and/or a port.

20. The method of claim **1**, wherein enumerating one or more operating-system-level virtualization containers on the networked device comprises determining, for a respective one of the one or more operating-system-level virtualization containers:

a name,

an identifier, and/or

one or more IP addresses assigned to the respective one of the one or more operating-system-level virtualization containers.

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